

A MUSE OF FIRE

British Trench Warfare Munitions, their Invention, Manufacture and
Tactical Employment on the Western Front, 1914–18

Submitted by Anthony James Saunders to the University of Exeter as a thesis for the degree of Doctor of Philosophy in History, September 2008.

This thesis is available for library use on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other university.

Anthony Saunders

Abstract

The emergence of static warfare on the Western Front in late 1914 encouraged the reinvention of devices associated with siege warfare and the invention of hitherto unknown munitions. These munitions included hand and rifle grenades and trench mortars and their ammunition. At the outbreak of war, the British effectively possessed none of these devices and lacked an infrastructure by which they could be quickly designed, manufactured and supplied to the British Expeditionary Force (BEF). The British met this challenge with considerable success. The subsequent proliferation of trench warfare munitions had profound consequences for the evolution of British tactics on the Western Front.

This thesis examines the processes by which these devices were invented, developed into manufacturable devices and supplied to the BEF. It considers their novelty in respect to similar devices from the American Civil War and the Russo-Japanese War. It looks at how their technical evolution affected tactical developments. The thesis discusses the relationship between the technical characteristics of these devices and the evolution of their tactical employment. It also considers how the characteristics of certain munitions, such as the Stokes mortar and the Mills grenade, directly affected tactics. It argues that the tactical employment of these munitions was dependent upon their functionality, utility and reliability.

The present thesis provides a different model of trench warfare conducted by the British on the Western Front and, thereby, demonstrates the significance of the novel munitions under discussion and the role they played in changing infantry warfare. This thesis also provides a different view of the Ministry of Munitions from that usually offered. It argues that certain aspects of the Ministry's role in providing the BEF with munitions has been overstated in the standard interpretation of the Ministry's work; the Ministry deliberately underplayed the work of the War Office, while overlooking that conducted by the Royal Engineers in France.

O! for a Muse of fire, that would ascend
The brightest heaven of invention;
A kingdom for a stage, princes to act
And monarchs to behold the swelling scene.
Then should the war-like Harry, like himself,
Assume the port of Mars; and at his heels,
Leash'd in like hounds, should famine, sword, and fire
Crouch for employment.

William Shakespeare, *The Life of Henry the Fifth*, Prologue, lines 1–8

Contents

Abstract	2
List of figures	6
List of tables	8
Acknowledgements	9
1 Object and Scope	11
Technicalities, invention and novelty	15
The politics of invention	19
A question of anticipation	21
Prior publications	22
Sources, breadth and limitations	27
Summary of objects	29
2 Trench Warfare Munitions before 1914	35
Hand grenades <i>c.</i> 1500–1860	36
Innovation in the American Civil War, 1861–5	38
The Russo-Japanese War, 1904–05	41
Innovation in Manchuria	44
Consequences of the Russo-Japanese War	46
Commercial drive, 1905–14	49
Looking forwards	55
3 The Bureaucracy of Invention	63
The problem of novel munitions	64
Inventing a new process – handling novelty	66
Invention and design	70
Evolutions and convolutions of organisation	74
Royal Engineers	78
Towards a common goal	83
4 A Question of Engineering	93
Demand versus supply	93
Evaluating novel munitions	94
Manufacture and inspection	100
A multi-functional approach	104
Output	108
Engineering solutions	112
5 Inventing Grenades	124
Addressing the technical–tactical relationship	125
Grenade types	127
Utility of purpose	129
Lethality	135
Functionality and reliability	138
The impracticalities of percussion-fuzed grenades	145
Technical evolutions	149

6 Inventing the Trench Mortar	160
Types of mortar	161
Ammunition and propellants	163
Utility of purpose	166
Lethality and destructiveness	169
Functionality	171
Second-generation developments	176
The problem of fuzing	177
Evolution	182
7 The Evolution of Grenade Warfare	192
Handling procedures	193
Shooting a rifle grenade	197
Throwing techniques	199
Learning the art of bombing	200
The tactics of grenade warfare	207
The rise and fall of grenade warfare	214
8 The Tactical Employment of Mortars	223
Organisation and Drill	224
Battery positions and emplacements	228
Gunnery	234
Tactical roles of mortars	236
Tactical employment of the Stokes mortar	237
Training	244
Tactical maturity and the light mortar	245
9 Conclusions – Invention, Firepower and Mobility	252
Asking the right question	252
The question of novelty	256
The role of manufacture	260
Organisation and management	262
Inventors and inventions	266
Tactics and technology	268
A new model of infantry warfare	270
Glossary and Abbreviations	276
Sources and Bibliography	283

List of Figures

Fig. 1 British improvised hand grenade from the siege of Mafeking, 1899	37
Fig. 2 Parlour's hand grenade of <i>c.</i> 1834	38
Fig. 3 Ketchum hand grenades	39
Fig. 4 No. 19 hand grenade of 1917	39
Fig. 5 Drawings from Adams's US patent, US45806	41
Fig. 6 Three hand grenades improvised by the Russians at Port Arthur	42
Fig. 7 Japanese soldier in Manchuria with a percussion-fuzed hand grenade	43
Fig. 8 Japanese light mortar used at Port Arthur	45
Fig. 9 No. 1 hand grenade	48
Fig. 10 Detailed drawings of the No. 1	48
Fig. 11 Military and naval attachés pose with Marten Hale at the Faversham works	49
Fig. 12 Leaflet advertising Marten Hale's patented rifle grenade	51
Fig. 13 Marten Hale rifle grenade fitted with its rod	51
Fig. 14 Arming vane which was the cause of prematures	51
Fig. 15 Drawings from GB124837	98
Fig. 16 Engineering drawings of Newton Pippin hand grenade	105
Fig. 17 Captain Todhunter's sketch of three novel devices invented by Newton	105
Fig. 18 3.7-inch Newton mortar, cast from SAA cartridge cases	113
Fig. 19 Output v. demand and cost over time for the Nos 3, 20 & 24 rifle grenades	115
Fig. 20 Output v. demand and cost over time for No. 5 and No. 23 Mills grenades	115
Fig. 21 Percussion-fuzed grenades with short handles	128
Fig. 22 Large fragments from a US hand grenade	136
Fig. 23 X-ray of a grenade wound of the shoulder	136
Fig. 24 Cast-iron body of the Pitcher	136
Fig. 25 Roland hand grenade	139
Fig. 26 Drawings from Roland's Belgian patent of 1912	139
Fig. 27 Mills hand grenade as described in GB2468/15	140
Fig. 28 Differences between the No. 5 and No. 36 grenades	143
Fig. 29 Disassembled No. 5 and No. 36 grenades	143
Fig. 30 Cutaway of a No. 36 and its centrepiece	143
Fig. 31 Humphries, DG and Bellamy grenades	146
Fig. 32 Engineering drawings of experimental Bellamy egg grenade	148
Fig. 33 Evolution of the Hale type of rifle grenade	150
Fig. 34 Newton Pippin rifle grenade	150
Fig. 35 McClintock rifle grenade	151
Fig. 36 Engineering drawing of a stand for firing rifle grenades, 1915	151

Fig. 37 Woolwich 2-inch medium mortar	162
Fig. 38 9.45-inch heavy mortar	164
Fig. 39 6-inch Newton mortar with second-pattern guide rods	165
Fig. 40 3-inch Stokes mortar with second-pattern stand	167
Fig. 41 Bomb for the 3-inch Stokes mortar	174
Fig. 42 Striker and its relationship with the breech in 3-inch Stokes mortar	174
Fig. 43 Time fuze, adapted from the Mills mechanism, for 3-inch Stokes bombs	178
Fig. 44 No. 31 fuze	180
Fig. 45 No. 148 Mk I fuze	180
Fig. 46 No. 110 Mk II fuze derived from the No. 107 Newton fuze	180
Fig. 47 No. 107 fuze	181
Fig. 48 No. 146 fuze	181
Fig. 49 No. 105B fuze, a simple percussion mechanism	181
Fig. 50 No. 147 Vickery fuze with clip instead of tape	181
Fig. 51 Royal Engineer demonstrates correct position for firing cup discharger	198
Fig. 52 Correct stance for firing rodded Mills No. 23	198
Fig. 53 Correct stance for firing a rodded Mills from the shoulder	198
Fig. 54 Starting position for throwing a grenade	199
Fig. 55 Position after throwing a grenade from a deep trench	199
Fig. 56 Throwing a grenade from a kneeling position	199
Fig. 57 Throwing a grenade from a kneeling position	199
Fig. 58 Means of carrying grenades	202
Fig. 59 How to bomb along a trench as taught from early 1915	210
Fig. 60 Variations on the theme; how to negotiate an island traverse	210
Fig. 61 Trench block, 1917	210
Fig. 62 Improvement on the theme	210
Fig. 63 Attacking round traverses with rifle and bayonet	213
Fig. 64 Trench to trench attack, 1917	216
Fig. 65 Platoon tactics when attacking above ground to engage a strongpoint	216
Fig. 66 Australian Stokes mortar detachment demonstrating misfire drill	228
Fig. 67 Trench mortar battery positions	229
Fig. 68 2-inch mortar emplacement in the Middle East	230
Fig. 69 Double emplacement for medium mortars	230
Fig. 70 9.45-inch mortar emplacement	232
Fig. 71 Stokes mortar emplacement, June 1918	233
Fig. 72 Stokes mortar ammunition carriers, Ypres salient, August 1917	241
Fig. 73 Part of Stokes mortar detachment prepare ammunition for a shoot	241
Fig. 74 Stokes mortar detachment carrying the three elements of the mortar	246
Fig. 75 A Stokes mortar detachment ready to advance	246

List of Tables

Table 1. British patents relating to hand grenades, 1905–13	54
Table 2. British patents relating to rifle grenades, 1905–14	54

Acknowledgements

This thesis has its origins in a chance discovery I made in 1978 when working as a Patent Officer in the Principal Directorate of Patents, MoD. While investigating a case concerning Crown use of intellectual property owned by a third-party, I searched the patent abridgements for Class 119, small arms, covering 1915–16. I was surprised to discover patents for grenades and other devices for trench warfare, including the first patents granted to William Mills for the grenade which came to be known as the Mills bomb. In 1997, I set about researching the field of novel munitions invented for trench warfare and, in 1999, *Weapons of the Trench War* was published by Sutton Publishing, followed by its companion, *Dominating the Enemy*, in 2000. My work made it apparent to me that this was an under-researched field and that I had only scratched the surface of the subject. The invention and widespread use of such devices led me to speculate on the nature of their effect on the conduct of trench warfare in the First World War. This ultimately led me to undertake the research which is the subject of this thesis.

Any project of this scale inevitably requires the assistance of others. I would like to thank everyone who has helped me with this project over the years.

Jonathan Falconer, my commissioning editor at Sutton Publishing in the late 1990s, acted as a referee when I applied to Exeter to undertake a PhD. My second referee was Mike Hibberd, formerly of the Firearms and Exhibits Department, Imperial War Museum, who had assisted me with my research for *Weapons of the Trench War* which subsequently formed a foundation for this thesis.

Norman Bonney has been tirelessly helpful. At the time of writing, Norman had recently retired as a lieutenant-colonel in the Royal Army Ordnance Corps, Territorial Army, in which capacity he is an acknowledged authority in the field of First World War munitions, especially grenades. His expertise has led to him assisting the Belgian Army, for example, in identifying unexploded British ordnance from 1914–18. He has an unrivalled collection of grenades and fuzes from the First World War and an impressive document archive, all of which he has acquired over three decades. I am grateful to him for providing me with copies of the papers concerning the court case brought against William Mills in 1917. He also read the drafts of this thesis and suggested amendments.

H A B Newton, the son of the late Henry Newton, was happy to talk to me about his father and his inventions. I was put in touch with him via his sister, a friend of whom told her about a letter I had written to the *Derby Gazette* about Henry Newton and his family. The Newton family came from Derbyshire and had an engineering business in the town at the time of the First World War. The Newton family gave me access to some of Henry's papers. Alas, many more of them had been lost in a house fire in the late 1970s. In connection with the Newton family, I would also like to thank Mrs Jan Baggaley for providing me with a letter

written by her father, Ralph Goodwin, in June 1976. Mr Goodwin had been an employee of Newton Brothers at the time of the First World War.

Professor Ian Beckett, Professor of History at the University of Northampton, very kindly read drafts of my thesis and offered me invaluable advice which I have endeavoured to heed.

Professor Jeremy Black, my supervisor in the Department of History in the School of Humanities and Social Sciences at the University of Exeter, has been a friend as well as my guide for which I am truly grateful. His enthusiasm, insight, knowledge of all things historical, as well as his unwavering faith in me as a researcher, have been expressed with a friendly forthrightness, an approach which is both refreshing and empowering.

I would like to thank the Belgian Patent Office for emailing me a pdf of Roland's original patent and I would like to thank the staff at Leeds City Library for emailing me pdf copies of several British patents. I obtained most of my copies of British patents in the late 1990s when undertaking research for *Weapons of the Trench War* and *Dominating the Enemy*; at that time, a complete set of patents and abridgements were held in the Science Reference Library in Southampton Buildings, Chancery Lane, London. Although somewhat belatedly, perhaps, I would like to thank the staff of that library who were always very helpful in giving me access to the vaults in which the patents were, then, stored. I would also like to thank Phillip Powell, Stock Control Manager in the Department of Printed Books of the Imperial War Museum, London, for photocopying a large number of Stationary Service documents for me. Lisa Anderson of the library of the University of Birmingham very kindly photocopied 'Mr Stokes and Educated Drainpipe' and posted it to me when I was unable to find a copy elsewhere. Finally, I would like to thank the interlibrary loan staff in the library at the University of Exeter for helping me track down copies of *The Sphere*.

1 Object and Scope

No army went to war in 1914 expecting to conduct trench warfare for four years and, consequently, no army was equipped for such an eventuality.¹ Apart from the demands for howitzers, large-calibre guns and huge quantities of high-explosive shells, trench warfare also required other sorts of munitions which the British termed novel or experimental to distinguish them from conventional guns, their ammunition and small arms ammunition (SAA).² The challenge of providing the British Expeditionary Force (BEF) with devices to enable the infantry to conduct trench warfare operations during the First World War has attracted little attention since the 1920s and 1930s when it was discussed during some of the hearings conducted by the Royal Commission on Awards to Inventors.³ Indeed, there has been scant acknowledgment that such a challenge had to be faced. It is not surprising, then, that the question of whether this challenge affected the conduct of BEF operations on the Western Front, large and small, has not been discussed hitherto, whereas the tank, defences in depth, infiltration tactics, and the development of artillery tactics in the evolution of deep battle have all attracted much scholarly analysis.⁴

The First World War was principally an artillery war⁵ and it is not the contention of this thesis that the novel munitions under discussion here were more important to the prosecution of the war on the Western Front than artillery. On the contrary, these munitions assisted in the development of infantry tactics which formed part of the evolution of three-dimensional warfare. Nevertheless, so much attention has been paid to the other aspects of warfare on the Western Front that the novel munitions devised for the infantry have been largely overlooked. Such munitions were principally hand grenades, rifle grenades, trench mortars and their ammunition. It has been assumed that these were incidental to the development of warfare. Indeed, it has been assumed that these munitions were merely copies, or minor developments, of similar devices which had been improvised during the Russo-Japanese War.⁶

It is an object of this thesis to demonstrate that both these assumptions are false and that they ignore the fundamental changes which occurred within the infantry of the British army during the First World War. Such changes were directly related to the adoption of these novel munitions. The nature of infantry, how it was armed and how it fought, was fundamentally changed by them. The infantry of 1918 and thereafter was quite unlike the infantry of 1914.⁷ This was especially true of the BEF but the effect was universal and no army emerged from the First World War unaffected by the introduction of these munitions. Rather than being merely another technological advancement in the engines of war due to the inevitable march of progress, the transformation was brought about by a different process of change from that usually discussed in relation to technology and warfare. This thesis focuses on that process.

In order to undertake an analysis of this process, it is first necessary to set out the means by which it is to be conducted. An understanding of the technical aspects of these devices is essential if insight into the mechanism of change is to be achieved, for reasons which will become apparent within this thesis. A technical examination of the technical aspects of a military technology, rather than a sociological or philosophical examination of it, is not commonly applied in an historical context. However, as will become evident, the technical characteristics of these novel devices played a crucial role in the process of change. The form of analysis adopted here to examine the technical aspects has been borrowed from an entirely different discipline, namely that of the patents profession, specifically, an aspect of prosecuting patent applications, which conveniently may be termed comparative technical analysis. This form of analysis is specifically concerned with function rather than with form, although the two have a direct relationship; thus, the manner in which something is *intended* to function, as defined by its mechanical characteristics, is considered rather than its form or appearance, and such functionality is compared with that of other similar devices and with devices intended to be used for the same purpose. The difference between intention and actuality is important in this context as it highlights the role of failure in the processes of invention and development, an aspect of technology which is rarely considered in relation to change. As will become clear, this form of analysis is especially relevant to a discussion of inventions and the process of invention, both of which are central to this thesis.

At the outbreak of war, the BEF possessed no trench warfare devices because no one had foreseen a need for them; they had to be invented.⁸ The concept of invention as a process and, indeed, the matter of what constitutes an invention, that is, the product of such a process, is essential to the present thesis. It is an object of this thesis to show that the invention of these munitions and their subsequent adoption by the BEF led to operational and tactical changes in infantry warfare on the Western Front and that these changes were directly related to the technical characteristics of the munitions concerned, rather than to a generalised notion of 'new technology' and what might be done with it. Hitherto, the relationship between the technical and the tactical has not been examined from a technical perspective. Indeed, it has hardly been discussed at all in the literature.

Invention was a crucial process in the provision of what the BEF needed. Furthermore, the backgrounds of the inventors helped to determine the nature of their inventions. As will be demonstrated, the inventors were mostly civilian engineers with a different ethos from those usually concerned with developing munitions. Because such munitions did not exist prior to the war, no specification for them existed. This raised questions about the form they ought to take and how they ought to function.⁹ These inventors were not constrained by what may be termed conventional armament design considerations because they had no experience of munitions. Thus, they relied on first principles, that is, basic engineering principles. Conceptualisation of these devices came afterwards. Tactical developments initially followed invention rather than concept.¹⁰ Thus, invention was fundamental to the development of tactical guidelines for the operational use of these munitions. The question of how such munitions should be handled in the field, how soldiers should be trained in

their use, indeed, how the munitions should be used operationally and tactically, could only follow after the devices had been invented and developed, while the technical characteristics defined the tactical limitations. There was no body of knowledge on procedures and tactics prior to their invention.¹¹

In 1914, no infrastructure for the organisation of the manufacture and supply of these munitions existed.¹² Thus, an examination of the organisational and logistical problems, and their solutions, as well as an examination of the processes of evaluation of inventions, form part of the analysis in this thesis. An unusual set of circumstances existed during the First World War which provided fertile ground for the kind of change which occurred. The fact that every aspect of the provision of novel munitions for trench warfare had to be created from scratch has not been fully acknowledged before now.¹³ As will become clear, the manner by which this was achieved played an important role in the evolution of infantry warfare.

Invention was but one of a complex series of processes which made an idea tangible, then took a prototype and turned it into a mass-producible device. The means by which the novel devices could be manufactured by engineering firms unfamiliar with the demands of munitions production had to be organised and the manufacturing monitored by a process known as inspection (in modern parlance, quality assurance).¹⁴ Large-scale manufacture of these munitions created an enormous organisational and logistical challenge but, at the same time, raised engineering standards by increasing the level of skill in the workers involved in the fabrication of these munitions.¹⁵ Innovative solutions to the problem of quick and reliable manufacture had to be found. The mass production of munitions by such firms was a contributory factor in the development in Britain of a fully industrialised approach to the war. These solutions were directly related to the technicalities, in both mechanism and form, of the munitions concerned. Furthermore, some designs were modified to accommodate new mass-production techniques.¹⁶ As will be demonstrated, design and manufacture had a direct bearing on handling procedures in the field and, hence, on tactics and operations, both directly and indirectly.

The problems associated with invention, conceptualisation and manufacture had to be handled concurrently with the problems of operational usage and training, which compounded the difficulties. This unusual circumstance was caused by the urgent need for such munitions.¹⁷ The wartime situation was an inversion of normal peacetime practice and experience.¹⁸ Ideally, such matters should have been handled sequentially, allowing a straightforward feedback loop. However, urgency precluded this, so that the process was neither simple nor smooth. Inevitably, conflicting ideas about the nature of these munitions remained throughout the war.¹⁹ However, by 1918, they had ceased to be regarded as novel and had become standardised equipment. Clearly, a fundamental change had occurred. The wartime circumstances required adept problem-solving skills and ad hoc solutions rather than rigid procedures in order to solve problems quickly. This necessity was especially true of the first twelve to eighteen months of trench warfare when shortages were especially acute. The significance of adopting an adaptable approach was not lost on some of those who were responsible for providing novel munitions,²⁰ whereas it has tended to be missed

by historians. Indeed, this adaptable ad hoc approach has even been criticised for being inefficient, especially in the context of the War Office.²¹ As will be shown, such a conclusion is based on poor understanding of the problems, how they were addressed and, indeed, the process of invention.

Expediency during the first year of trench warfare dominated how all matters pertaining to novel munitions were addressed. The unrelenting demands for such munitions throughout the war ensured that a sequential execution of these processes never fully developed. Before the war, expertise in these areas did not exist in any government department nor in any branch of the British army. Expertise had to be acquired. This, in itself, required men with an open mind and an ability to recognise novelty if the BEF was to be provided with what it needed for trench warfare operations. The only soldiers with any kind of familiarity with unconventional munitions were Royal Engineers but their knowledge was empirical, ad hoc, and far from universal within the service.²² Thus, every aspect of providing novel munitions and the manner of their use, operationally and tactically, had to be learned, and, as quickly as possible.

This, then, was the extent of the challenge which faced not only the BEF but also the British government and British industry at the start of trench warfare on the Western Front in the autumn of 1914. This thesis discusses how this challenge was addressed. It examines the nature of the problems and the manner of their resolution.

There is no single narrative thread which commences at a beginning that coincides with the start of trench warfare in the autumn of 1914 and continues unbroken to an end that coincides with the cessation of trench warfare during 1918. Rather, there are a series of concurrent narratives. These may be defined as: the conceptualisation of novel munitions; the bureaucracy and organisation of the invention, development and supply of novel munitions; the technical evolution of novel munitions; the improvement of operating procedures for the novel munitions and the growth of relevant training; and the advancement of tactics. These narratives were not independent of each other. Indeed, their inter-relationships were complex. The present thesis is organised along these lines for the sake of clarity and analysis rather than because such a demarcation actually existed.

The munitions which are the subject of this thesis were not the only novel devices of the war; inventions also featured in the air war and in the war at sea.²³ Moreover, as far as manufacturing capability and logistical support are concerned, many of the other novel devices competed with the hand grenades, rifle grenades, trench mortars and their ammunition that are the subjects of this thesis. As far as trench warfare is concerned, other novel munitions included body armour, periscopes and hyposcopes, bomb-throwing engines, wire-cutters, flamethrowers and the Livens projector, a form of mortar used in gas warfare.²⁴ These devices are outside the scope of the present thesis; some of them were indispensable to trench warfare. The periscope, in particular, was of vital importance. Periscopes were needed in large numbers by the artillery as well by the infantry. While the artillery took precedence over the latter for good-quality magnifying periscopes, the front-line infantry would have been largely blind without the lower-quality periscopes with which they had to make do.²⁵

The British devised and used more forms of body armour than any other combatant nation during the First World War.²⁶ It was from so-called mobile or wheeled shields that the tank emerged.²⁷ Mechanical bomb-throwing engines and catapults were widely used as substitutes for trench mortars when the latter were in short supply until about the spring of 1916.²⁸

Although gas weapons were conceived for trench warfare, they are outside the scope of this thesis. Gas weapons, including the Livens projector, were operated by members of the Special Brigade,²⁹ Royal Engineers, rather than by the infantry. Gas warfare is too vast a subject to be included here and has been well, if not comprehensively, covered elsewhere.³⁰ The tactical use of gas weapons was unique to such weapons, although similar in some respects to the use of artillery.³¹ The tank is not part of this analysis, although it was conceived to break the deadlock of the trench warfare. The tank did not appear on the Western Front until September 1916 and was operated by a specialist unit, the Tank Corps. The development of the tank and its role during the First World War has been well covered elsewhere.³²

Thus, the devices under discussion in the present thesis may be termed infantry weapons although, initially, they were viewed as specialist munitions and, as far as mortars are concerned, there was an overlap with the artillery.

Technicalities, invention and novelty

It will be shown that the transformation from novelty to standardised munition had its origins in the technical characteristics of the devices concerned. The technicalities of any device define its utility, functionality and reliability. Utility concerns its fitness for the purpose for which the device is intended and the success rate of the device in an operational environment. It also relates to the unit cost of manufacture, unit cost to operate, unit cost to train its operators in its use, and so on. Functionality concerns the form and mechanical arrangement of the device, how these relate to its operation and what it requires for successful operation. Reliability is a measure of the state of readiness of the device to operate as intended, the amount of time required to maintain it in a functionable condition, and the probability of successful operation when used in an operational environment. All these matters are interrelated. Throughout the war, these aspects had to be addressed by those responsible for devising and manufacturing novel munitions for trench warfare, as well as by those responsible for evaluating them. The question of criteria and how these changed as the war progressed with increasing expertise was also a factor in the evolution of these munitions and their usage.

Although, as far as munitions are concerned, these issues are usually discussed in military terms, they are principally technical matters and need to be considered accordingly.³³ It becomes more apparent that this is the case when the utility, functionality and reliability of several similar devices have to be considered. Some characteristics are not measurable in an historical context, however. Whereas, technical evaluations of new devices occurred contemporaneously during the war,³⁴ singly and comparatively, studies of the results of such evaluations are not always possible in an historical context because not all the data are still extant. There is an unspoken assumption that the best devices emerge from an evaluation

process because the least effective devices are discarded.³⁵ This is a false assumption as the present thesis will demonstrate. The failures, that is, the devices which do not function as the inventor intended, tend not to be considered when examining a technology from an historical perspective. As already stated, failure is an essential part of any process of development because it helps to define the requirements which an effective device must satisfy. This is especially applicable to the novel munitions under discussion here for it is evident that short-term failure, fuelled by the pressing need for quick solutions, played a part in the selection of which novel munitions were supplied for front-line use. Short-term failure, no more than initial success, should be taken as a definitive characteristic of any device. Thus, the widespread use of certain novel munitions by 1917 should not be viewed retrospectively as having been inevitable nor as having been attributable to their innate superiority over other similar devices.³⁶ These matters are especially pertinent to the question of novelty.

In the present context, the terms 'novel' and 'novelty' have meanings distinct from 'new' and 'newness'. The latter terms may be applied to anything that has recently come into existence, whether it be of a known pattern or of a hitherto unknown configuration, whereas 'novel' defines that hitherto unknown configuration; hence, novelty is the state of being novel. Thus, a novel munition is a device in a hitherto unknown configuration. This may be extended to include hitherto unknown munitions. Such a distinction helps to clarify the term 'invention'. An invention is novel, not merely something that is new.³⁷ Thus, an invention is a device which does not form part of the state of the art. This is best defined by reference to the Patents Act 1977.

Although this thesis is not solely concerned with patentable inventions, nevertheless, the provisions of the Patents Act 1977, the Act currently in force,³⁸ provide a useful explanation of what constitutes an invention which may be applied in the present context.³⁹ The provisions of this Act and earlier Patents Acts are especially pertinent to the thesis because it relies upon British patents granted during the First World War as a primary source.⁴⁰ According to the 1977 Act, a patentable invention is a device or process that is not only novel but one which has involved an inventive step in its creation.⁴¹ The latter is concerned with obviousness; in other words, whether it would be obvious to a notional expert in that field to take the step that has led to the device or process in question.⁴² If it was obvious, that step was not inventive and, under current law, the invention is not patentable. The Act in force at the time of the First World War, the Patents and Designs Act 1907, did not require the invention to pass the obviousness test; it only had to be new, as opposed to novel, in the United Kingdom.⁴³ Nevertheless, the question of whether an invention was obvious is of particular interest in the present context because obviousness or its absence sheds light on the process of invention and, as such, is especially relevant to the novel munitions of trench warfare.

The difficulty with obviousness is determining exactly what is obvious since this can only ever be a matter of informed opinion, never fact. Did the inventor arrive at his invention by taking the next logical step forward from the state of the art or did he take a leap beyond the next logical step?⁴⁴ This question has to be evaluated from the perspective of a contemporaneous notional expert at some moment prior to the creation of the invention

in question. There is the added complication that in some instances an invention is, in fact, a reinvention.⁴⁵ Any reinvention of a device more than fifty years old could theoretically be patented during the time of the First World War.⁴⁶ A reinvention could take many forms. It might be a copy, made knowingly or unwittingly, of an earlier device with more modern materials or fabrication techniques. The cup discharger, a device attached to a standard rifle to launch a grenade, first appeared in the seventeenth century.⁴⁷ Examples dating from 1743 are almost identical to the cup discharger reinvented during the First World War.⁴⁸ Clearly, the same idea can occur independently to different people in different times and places;⁴⁹ human beings tend to find similar solutions to similar problems.

Furthermore, any invention created outside the geographical confines of the United Kingdom was theoretically patentable in Britain at the time of the First World War.⁵⁰ Thus, patented inventions from that period may, in fact, have been neither novel nor non-obvious. This apparent confusion over what is a patentable invention at that time is why the term 'invention' is used here in the sense described in the 1977 Act. In other words, an invention is something which is novel, has involved an inventive step, and is capable of industrial application. It may seem perverse to take the view that an invention made during the First World War should only be regarded as such if it had involved an inventive step when this requirement was not part of the 1907 Act. At that time, practically no invention relating to any of the unconventional munitions under discussion here could reasonably be described as obvious for the simple reason that no body of knowledge pertaining to such devices existed prior to the First World War. This is an important point. Obviousness can only spring from existing knowledge in a given field specific to the invention in question; it cannot spring from a generalised knowledge of, say, engineering. This highlights a hitherto unremarked significance of the inventions which are discussed in the present thesis: their mechanical novelty.

One other point needs to be emphasised in respect of the terms 'invention' and 'design'. The terms 'invention' and 'design' are not interchangeable. A design is a conceptual creation and the product of this process; it is the form given to something, irrespective of whether that something is non-functioning or functionable, and irrespective of its novelty. An invention is a tangible creation of a novel means for carrying out a specific function. Whereas a design is not an invention, an invention may involve a design element.⁵¹

The process of invention is as much a philosophical matter as it is one of inspiration and practicality. It invariably differs from inventor to inventor and according to circumstance. An invention may be a single step forward from the existing state of knowledge in that field. Such a step tends to be one of many similar-looking steps made independently by different inventors. A leap of inspiration, on the other hand, can be so fantastical that it requires a change of perception to see that it is not some crackpot thing but a significant technical advance.⁵² Put like this, it would seem that any invention would stand out as being clearly novel and that, by definition, it must also demonstrate a clear improvement over what has gone before or satisfy a need that has been wanting.⁵³ In fact, an invention can be very hard to recognise and, consequently, so can its significance, certainly when viewed with hindsight which tends to render obvious all inventions. At the time an invention is created,

there may be no recognition of the need which it is intended to satisfy so that the invention seems unnecessary and pointless.⁵⁴ Indeed, a need may even have to be found to justify its existence. And to make matters more complicated, the invention may consist of no more than changing the shape of a component in a particular way so that it does something different from a similar component in a prior-art device.⁵⁵ Design, or form, is sometimes an essential aspect of invention which can make the difference between a device working and not working, especially when it is mechanical in nature, although, as already pointed out, design alone is not sufficient to be inventive.⁵⁶ Furthermore, inventions which look different may, in fact, be essentially the same.

One approach to resolving this conundrum is to compare the function and purpose of the component parts of inventions rather than look at the form they take in any given embodiment. A patent specification describes an invention according to this principal. The comparative analysis of the technical aspects of devices from a functional perspective can be applied to individual components and to the devices in their entirety. This is a useful analytical tool which allows the importance of weapon systems to be evaluated in a systematic way according to criteria based on aspects of functionality. Correlating the results of such analyses with operational and tactical considerations can provide a clearer view of the effect that novel munitions had on the conduct of trench warfare in the First World War. Without an understanding of an invention from a technical perspective and its relationship to the prior art, it is difficult to form an informed opinion about its usefulness. Without such an approach, some inventions can acquire an importance they do not warrant merely because they look as though they are significant. Moreover, contemporary political backing, or lack of it, can alter how such inventions are viewed.⁵⁷

In an article in *The Royal Engineers Journal* of December 1924,⁵⁸ Captain Giffard Martel, one of the tank pioneers, argued that an invention goes through four stages: pure research, applied research, design, and production.⁵⁹ The idea was that by the time an invention passed to the production stage, all the potential problems had been discovered and resolved. This theory implies that the processes of invention and development occur in discrete and sequential stages.⁶⁰ In reality, they do not. Moreover, the pure research stage is largely absent as far as inventing is concerned. None of the novel munitions under discussion here emerged from pure research. Indeed, pure research is aimed at discovery, not creation, whereas applied research is often stimulated by the need to resolve a specific practical problem. It is applied research which has the potential for invention. Furthermore, the processes are not necessarily sequential; the invention stage overlaps the development stages, linked by a feedback loop. Invention often arises from developmental work. This was certainly true of the novel munitions under discussion here.

This brings us to the question of production. Before any invention can be manufactured as a useable device, the prototype has to pass through a production engineering stage whereby the considerations of manufacture, rather than of novelty, are the principal concerns. Engineers know that, often, a given mechanism is too complex to manufacture quickly, especially on a large scale and to a consistent standard. Thus, the unnecessary complexities

have to be identified and designed out. It is one area where the processes of invention and development overlap. Moreover, in order to solve a production difficulty, an innovative solution may have to be found. In peacetime, production engineering occurs before a device enters service but, during the First World War, this process was rarely completed as far as the munitions under discussion here were concerned. Taking an idea and turning it into a mass-producible device can be a complex and time-consuming process which can delay the introduction of the device on to the battlefield. In peacetime, such delay is less of a concern than in wartime. As far as the munitions under discussion here are concerned, the urgency with which they were needed by the BEF meant that the devices were introduced before the matter of production engineering had been properly addressed. Premature introduction inevitably led to operational difficulties when the device failed to perform as predicted. The premature introduction of munitions to the battlefield is common; they have often been technically underdeveloped when used operationally for the first time because of military or political pressure to get a potentially war-winning munition into service.⁶¹ Neither Martel nor Trebilcock considered production engineering or premature introduction and neither presented a complete picture of the process of invention.⁶² The naïve assumption that new weapons are fully developed when introduced to the battlefield is based on a false premiss and is not supported by the evidence.⁶³

It could be argued that premature introduction is only apparent with hindsight, that it is inevitable because only usage on the battlefield can highlight shortcomings. While there is some truth in this assertion and, of course, it is not possible to anticipate all the problems which might arise in the field, the assertion obscures the fact that, from a technical perspective, devices are often introduced to the battlefield too soon.⁶⁴ Although stasis is never reached, nevertheless, there is an optimal point at which a technology can be said to be sufficiently well developed that it will provide most, if not all, of the advantages it has promised. Political expediency or military urgency may lead to the invention being introduced to the battlefield before it reaches this optimal point as exemplified during the First World War with the tank.⁶⁵

As far as the novel munitions of trench warfare are concerned, it is almost universally true that they were introduced to the battlefield before they were fully developed and, hence, appeared prematurely,⁶⁶ which had several consequences for the sorts of munitions which eventually became standardised. In the present context, premature introduction was partly due to political interference, which arose from the desire to see immediate benefits accruing from the adoption of any given device and from an unwillingness to accept that the developmental process took a length of time which could not be prescribed.

The politics of invention

Political interest played a major role in the provision of novel munitions from the outset and has influenced how this provision was subsequently presented to posterity. The invention, manufacture and supply of novel munitions during the first year of the war under the auspices of the War Office has been overshadowed by that subsequently carried out by the Ministry of Munitions which came into being in June 1915 following the shell scandal of

a few months earlier. The view that the War Office had failed in all respects to supply the munitions needed by the BEF during the first year of the war was deliberately inculcated by the new Ministry and, especially, by David Lloyd George, the first Minister of Munitions (June 1915 – July 1916). The authors of the *History of the Ministry of Munitions*, a multi-volume account of the activities of the new Ministry written before the war ended, underplayed the work carried out by the War Office prior to the creation of the new Ministry.⁶⁷

Unfortunately, much of the work carried out between the autumn of 1914 and the summer of 1915 is not well documented. Neither the work conducted by the FW3 section of the Directorate of Fortifications and Works, which developed hand grenades and introduced trench catapults during the first six months of trench warfare,⁶⁸ nor the work conducted by the Royal Arsenal to develop trench mortars, is recorded in War Office files, although evaluations of some novel munitions are recorded in Ordnance Board minutes.⁶⁹ There are no records of the experimental work and manufacture of novel munitions by the Royal Engineers in France throughout the war. The bias is all the greater because, on the creation of the Ministry of Munitions, War Office staff who were working on trench warfare munitions were transferred to the new Ministry along with their files which were then rejacketed and given new registry codes.⁷⁰ Thus, there is a temptation to view everything in the field of trench warfare devices as the work of the Ministry of Munitions because of the dearth of material jacketed as War Office files.⁷¹

It is a fact that when the British went to war in 1914 there was no War Office department with responsibility for the evaluation of inventions. Although an ad hoc committee had existed to consider submissions, mostly from servicemen, its function had been to assess their usefulness with a view to awarding the ‘inventor’ a financial consideration.⁷² There was a laissez faire attitude to the matter of invention, largely because neither the War Office nor the Admiralty had to concern itself with such arcane matters. Invention was not the business of government departments.⁷³ The consequence of the sudden demand in the autumn of 1914 for novel munitions for trench warfare was an urgent need for a department which could handle the demand and a system for handling all aspects of invention. This was yet another challenge which had to be faced by the British government. The subsequent politicalisation of such matters has tended to obscure the manner in which the challenge was met. Thus, some archival material and some published sources have to be viewed with some caution as they are not unbiased.⁷⁴

The enormity of the technical challenge to provide novel munitions for trench warfare has been obscured by the emphasis that has been placed on inventions that were presented as war winners, both at the time and subsequently.⁷⁵ The concept of war-winning devices is deep-rooted.⁷⁶ In particular, the advocates of the tank, such as Fuller, Liddell Hart and Martel, subsequently presented their favoured device as a technical saviour indispensable for avoiding the horrors of trench warfare in a future war.⁷⁷ Discussions about the validity of their advocacy have hindered a proper analysis of the role of invention in the land war, especially when many of the other, often more important, inventions were not regarded as war-winners. Politics has helped to obscure the importance of the devices under discussion

here because they have always been regarded as insignificant to the prosecution of the war. The technical failures of the tank during the First World War have been discussed elsewhere⁷⁸ and are outside the scope of this thesis. Nevertheless, they return us to the issue of the importance of the technical aspects of an invention and their bearing on the invention's impact on warfare. As will be seen in what follows, political interest could override technical or military considerations, irrespective of the consequences. Thus, an element of chance entered the process of providing munitions for trench warfare.

The First World War forced the British government to reconsider the importance of scientists and engineers in relation to the country's ability to wage a war that became increasingly dependent on the country's industrial, technological and scientific resources.⁷⁹ The direct application of science and engineering to the needs of war was something which the British had hitherto eschewed. Moreover, for half a century, it was the British view that science and engineering were not the business of soldiers.⁸⁰ The First World War changed this attitude and brought about the rise in technical proficiency among British infantry.⁸¹ This was due in no small part to the demands made upon them by the technicalities of the new and novel munitions with which they now fought.

A question of anticipation

An essential question which needs to be addressed is whether the novel munitions under discussion here had precursors from earlier wars, in particular, the American Civil War and the Russo-Japanese War. Did any device prior to the outbreak of war in 1914 anticipate the trench warfare munitions devised during the First World War? To assume that the trench warfare munitions of the First World War were derived from earlier devices is an enormous leap of faith. Firstly, it is an assumption made without recourse to an examination of the engineering evidence; and, secondly, it ignores the matter of obviousness discussed above. One of the arguments of the present thesis is that the novel munitions provided to the BEF during the First World War had no antecedents and were, indeed, novel. It is an object of this thesis to disprove the assumption of anticipation by demonstrating that the engineering aspects of the devices from earlier wars and those of the First World War were unrelated. In other words, not only was an inventive step involved in the creation of the unconventional munitions of the First World War but there was effectively no prior art.

This takes us back to the question of whether technological change occurs as a series of logical next steps or whether it involves inventive leaps. An examination of objections raised by patent office examiners to patent applications provides some insight.⁸² Generally, such objections are of three types: that the invention is entirely anticipated by the prior art; that the prior art anticipates certain aspects of the invention but does not anticipate it in entirety; or that the prior art *seems* to anticipate the invention. In the latter situation, a reasoned argument can be constructed to demonstrate that the prior art does not anticipate the invention. There is, of course, a fourth possibility: that nothing anticipates the invention. It follows, then, that, if technological change occurs as a linear progression of logical next steps, situations three and four cannot arise. Moreover, the question of obviousness would be irrelevant since a

linear progression is, by definition, a series of obvious steps. Previous writers on the subject of technological change, especially in the context of warfare, have tended to follow the logical next step model, viewing inventive leaps as the exception to the rule.⁸³

This brings us to the matter of what has been written about the munitions under discussion in this thesis. In other words, where do they figure in the literature on the First World War? This is not merely a matter of placing this thesis in the context of existing scholarship but it is also a matter of putting the questions which this thesis attempts to address, as discussed above, into the context of what has already been asked about trench warfare. Indeed, it becomes apparent that the questions which this thesis attempts to address have not been posed hitherto, partly because invention, both as a process and as a product of that process, tends to be viewed as the inevitable consequence of the march of progress. The role of failure in this process is often underplayed or ignored in the literature.

Prior publications

Surprisingly little has been published about the novel munitions of trench warfare. Many of those books which have touched upon such munitions have often lacked scholarship and are unreliable. No book, contributed chapter, paper, nor journal article has correlated the technical aspects of any of these devices with operational or tactical usage. *Weapons of the Trench War* and *Dominating the Enemy*⁸⁴ are the only books devoted exclusively to the novel munitions developed for trench warfare during the First World War. The former focuses on grenades and mortars, while the latter is concerned with devices such as body armour and periscopes. Both rely upon archival sources, including British patents. They consider the complexity of the technical challenge which faced the BEF at the start of trench warfare in the autumn of 1914 and discuss how it was addressed. Unfortunately, the brevity of the books precluded a full examination of the subject.

Surviving Trench Warfare, Technology and the Canadian Corps, 1914–1918 is an examination of the role of technology in the conduct of the First World War from the perspective of the Canadian Corps.⁸⁵ It is relevant to the British army experience because weapons, equipment and tactics were largely common to both. It relies upon Canadian primary sources rather than British sources. The main focus is on tanks and artillery but grenades and mortars are discussed more fully than in many other studies. Unfortunately, there is no proper discussion of the technicalities of any of the devices, which gives the impression that all mortars, for example, worked in the same way and with the same degree of reliability and effectiveness; the issues of functionality, utility and reliability are not addressed. Nevertheless, it provides a broad picture of the application of technology to the problems of the Western Front.⁸⁶

There are, of course, many other books which look at technological advances on the Western Front. Terraine's *White Heat, the New Warfare 1914–18* is one but it covers a very broad spectrum, from aircraft to tanks, from gas warfare to naval warfare, and does not discuss the processes of invention or development which led to the devices.⁸⁷ The novel munitions of trench warfare, such as grenades and mortars, receive a brief mention but their significance to infantry warfare is not discussed. *White Heat* exemplifies the assumption that such munitions

were not significant to the prosecution of the war. A useful reference guide to British grenades is *'Grenade', British and Commonwealth Hand and Rifle Grenades*⁸⁸ but it covers the entire twentieth century. It makes extensive use of archival material but includes no analysis and the book lacks footnotes and a proper list of references. There is no similar work which deals with mortars. In 2004, Martin Pegler, Senior Curator, Weapons Department, Royal Armouries, published a brief article on the history of the Mills grenade.⁸⁹ This article, however, contains inaccuracies and lacks a technical appraisal of this important munition.

Hartcup's *The War of Invention*⁹⁰ discusses how science and technology were harnessed to the war effort. While its principal focus is on British endeavours, it also looks at those of other belligerent nations and examines the invention and development of new devices for the land, sea and air wars. *The War of Invention* is only 190 pages of text and its scope is too broad for Hartcup to have devoted much space to the devices of trench warfare. He discusses some of the inventions departments in the War Office and the Ministry of Munitions but he omits a great deal and is not definitive. Unfortunately, the book also lacks clarity and precision; the accounts of how Mills invented his grenade and Stokes his mortar, for example, are imprecise and inaccurate.⁹¹ *The War of Invention* has the advantage of having comprehensive footnotes.

An account of the invention and development of the Stokes mortar may be found in 'Mr Stokes and his educated drain-pipe', published in *The Great War*.⁹² While the article relies on primary sources, the article lacks an analysis of the mortar, a comparative analysis with other mortars, and a discussion of tactics. The author was too trusting of Lloyd George's version of events. Lloyd George's *War Memoirs*⁹³ overemphasised his own role in the adoption of the Stokes mortar⁹⁴ and presented a highly misleading account of the work conducted by the War Office prior to the creation of the Ministry of Munitions.⁹⁵ Much of what Lloyd George wrote concerning the Ministry of Munitions was based on historical accounts of the work conducted by the Ministry which are now in the MUN 5 series of files in the National Archives.⁹⁶

An unpublished PhD thesis from 1980 looked at one of the departments charged with investigating submissions from inventors and with developing new munitions, 'The Munitions Inventions Department. A Case Study in the Management of Military Science 1915–19'.⁹⁷ Its author, Michael Pattison, was too uncritical and failed to acknowledge fully the existence of the many sections, branches, departments and committees that were set up by the War Office, the Ministry of Munitions and GHQ, France, at various times during the war to deal with inventions in all fields of warfare. This omission remained in his subsequent published work on related issues.⁹⁸ Pattison gave the impression that, apart from the Admiralty's Bureau of Invention and Research (BIR) which dealt with inventions relating to naval warfare, also the subject of a doctoral thesis,⁹⁹ the Munitions Inventions Department (MID) was the only significant government organisation that dealt with land warfare inventions.¹⁰⁰ Moreover, Pattison failed to discuss Lloyd George's motives for instigating the MID and did not properly consider whether the MID succeeded in its purpose. He lacked an understanding of the nature of invention as a process and did not properly consider what constitutes an

invention.¹⁰¹ Pattison provided a misleading impression of invention, both from an engineering perspective and from an organisational one, during the First World War, although he did discuss the continual conflict between the MID and other Ministry departments concerned with design and invention.¹⁰² Pattison also discussed briefly the problems faced by the War Office in conducting research into new munitions and the time constraints imposed by the situation but he failed to explore any of this in depth and, hence, provided no insights.¹⁰³

Novel munitions of the sort under discussion in the present thesis tend not to figure in analyses of the tactics of the First World War.¹⁰⁴ Griffith devoted a chapter of *Battle Tactics of the Western Front* to the search by the British for new weapons for trench warfare.¹⁰⁵ He provided an interesting, if limited, summary but there was no correlation between types, logistics and tactics. He devoted more space to the importance of artillery to the conduct of the war, the development of new infantry tactics and tank-infantry-aircraft cooperation. Bidwell's and Graham's *Fire-power* offered little of significance about mortars and grenades. A better discussion of the development of artillery tactics and three-dimensional warfare is Bailey's 'The First World War and the Birth of Modern Warfare' in *The Dynamics of Military Revolution, 1300–2050* which succinctly analyses the developments.¹⁰⁶ These are more fully discussed in his *Field Artillery and Firepower*, especially Chapter 16, although this relied on 'Mr Stokes and his educated drain-pipe' for its information on the Stokes mortar and so provides no useful insights into the tactical use of trench mortars.¹⁰⁷ An earlier book which looked at the development of artillery tactics in the First World War is *History of the Royal Regiment of Artillery, Western Front, 1914–18*.¹⁰⁸ This devoted a mere three-quarters of a page to the tactical organisation of mortars, although they figured in the description of specific battles elsewhere in the book. It offered no insights into the technical evolution of mortars or the development of tactics.

Although Travers examined the tactics of the First World War and considered the role of new technology, such as the tank, in *The Killing Ground*, it is significant that he consulted no Ministry of Munitions papers. The role of novel munitions for trench warfare was not discussed. Similarly, the technology and tactics of 1917–18 were discussed in his *How the War was Won*, this time in terms of the defeat of the German Army in 1918, but Travers did not concern himself with the technicalities of any of the munitions. Neither did he consider how the tactics of infantry warfare absorbed grenade and mortar warfare in an all-arms system.

Since about the mid-1990s, there has been a growing historiography concerned with the influence of training manuals, particularly SS135 and SS143, in the development of tactical systems which integrated all arms and, especially, the coordinated use of grenades, mortars, Lewis guns and artillery. Notable among the more recent books are *Command and Control on the Western Front*, edited by Sheffield and Todman, *Steady the Buffs!*, by Connelly, *Look to Your Front*, edited by Bond, and Simpson's *Directing Operations*.¹⁰⁹ While these consider integration in some depth, none look at small-unit operations within the larger-scale workings of platoons and divisions. Yet, as will be discussed in Chapters 7 and 8 of this thesis, it was at section level, rather than platoon or division level, that the tactics of grenade and mortar warfare

evolved. None of these books examines the grenade and mortar operating procedures set out in the technical manuals, nor, with the exception of McCarthy in 'Queen of the Battlefield' in *Command and Control*, do they glance at the tactical manuals specific to these munitions. Such manuals were the foundations on which SS135 and SS143 and others of their type were constructed. McCarthy devotes less than a page to the evolution of grenades and their use on the Western Front; he is inaccurate and too cursory to be useful.¹¹⁰

The discussion of the tactical use of mortars in these books often lacks depth. Mortars receive no mention at all in the essays in *Command and Control* and, while *Directing Operations* discusses mortars, it fails to mention grenades. Yet, the contents of the SS135 and SS143 manuals, and others like them, are discussed in both works; these manuals discuss mortars and grenades and direct the reader to manuals such as SS182 Instructions on Bombing, Parts I and II, and SS189 Light Mortar Training, for example. *Steady the Buffs!* is, perhaps, more informative. However, while Connelly goes into more detail than many other writers, he does not discuss the means by which the tactics of grenade and trench mortar warfare were created. Nor does he examine how sections functioned within the larger whole, whether as part of a mortar battery or as part of a bombing team. Furthermore, as far as mortars are concerned, Connelly only discusses the 3-inch Stokes.

Among the more significant of earlier works which discuss the evolution of cooperative tactics are the essay collections *Look to Your Front*, *Studies in The First World War* edited by Brian Bond, and *1918, Defining Victory* edited by Dennis and Grey, both published in 1999.¹¹¹ Of particular note in *Look to your Front* are Richard Bryson's 'The Once and Future Army' and John Lee's 'Some Lessons of the Somme: the British Infantry in 1917'. However, while grenades and mortars are mentioned in relation to the development of the all-arms infantry platoon, the tactics of grenade warfare and those of mortar gunnery are not discussed.¹¹² Lee discusses the composition of a platoon in 1917, including its bombers, and goes on to examine how these men were used.¹¹³ The importance of light mortars and rifle grenades by 1918 are mentioned by Sheffield in 'The Indispensable Factor: The Performance of British Troops in 1918' in *1918, Defining Victory*.¹¹⁴ In 'The Black Day of the German Army: Australians and Canadians at Amiens, August 1918' in *Defining Victory*, Wise makes the essential point that the important tactical unit on the battlefield was the section.¹¹⁵ 'Winning the War' by Prior and Wilson illustrates the importance of the infantry mortar and rifle grenades in 1918.¹¹⁶ Unfortunately, none of this constitutes an analysis of grenade or mortar tactics as there is no discussion of procedures. The importance of the section in relation to grenade warfare and mortar warfare is discussed in Chapters 7 and 8 of this thesis. As will be shown, an understanding of procedure is central to an appreciation of grenade and mortar tactics and their changing nature during the war.

Many books have tended to present bombing as an arcane practice in which enthusiasm was the driving force. There is little sense of a process of development or evolution, nor any sense that usage of grenades was related to their technical characteristics. The simplistic view of 'bombing' is, perhaps, epitomized by Andrew Whitmarsh in 'The Development of Infantry Tactics in the British 12th (Eastern) Division, 1915–1918' in *Stand To!*, the journal

of The Western Front Association.¹¹⁷ Here, bombing lacks any sense of systemisation. Moreover, the transition of the bomber from specialist to everyman is not discussed, thereby, reinforcing the notion that the tactical use of grenades was entirely ad hoc.

There are several unpublished theses which consider the evolution of all-arms tactics on the Western Front in the light of manuals of the SS135 and SS143 type. Among these theses are 'A Social and Military History of the 1/8th Battalion, The Royal Warwickshire Regiment, in the Great War', an MPhil thesis from 1999, and 'British 21st Infantry Division on the Western Front, 1914–1918, A Case Study in Tactical Evolution', an MPhil thesis from 2001.¹¹⁸ However, they did not look at the operating procedures and tactical manuals for grenades or mortars and, hence, did not consider tactics at the section level. There was no discussion of the relationship between technology and tactics.

None of the above works discusses the conceptualisation of novel munitions during the First World War. The process of invention is not considered. There is little reference to the effect of reliability of munitions on tactics or operations. Similarly, there is no analysis of the organisation of the developmental processes within the War Office or the Ministry of Munitions and no discussion of the many sections, branches, committees and departments under their respective auspices that dealt with novel munitions for trench warfare.¹¹⁹ The question of manufacture is hardly mentioned, nor the problems that mass production of these munitions presented when the armaments firms were fully occupied in producing shells. The question of how such novel munitions became available in the necessarily large numbers required on the Western Front has not been addressed. There is no comparative technical discussion of the devices nor of their influence on training and small-unit tactics. All of these matters are largely unexplored aspects of the First World War. And yet, such munitions as the hand grenade, the rifle grenade and the trench mortar not only became the sine qua non of trench warfare but eventually became standard equipment for the British army.

While the process by which the British economy was turned over to war production during the First World War is outside the scope of this thesis, nevertheless, certain aspects of the process are pertinent. The means by which small engineering firms, unconnected with munitions work in 1914, became efficient manufacturers of novel trench warfare munitions during the First World War is an aspect of war production that has not been discussed hitherto in the literature but it is of importance to the matters under discussion here. It is tempting to view the process of transition from civilian engineering to munitions production from purely organisational and administrative standpoints. However, as will become apparent, it is the engineering practicalities of this transition which need to be considered if insight into the process of change is to be gained. The problems faced by small engineering firms, the War Office and the Ministry of Munitions were largely engineering in nature and they required engineering solutions rather than purely organisational or administrative changes.

An examination of the theoretical framework proposed for the transition of a peacetime economy to a wartime economy during the Second World War, discussed by E A G Robinson in 'The Overall Allocation of Resources' in *Lessons of the British War Economy*,¹²⁰ provides a counterpoint to how the manufacture of trench warfare munitions was handled in the

First World War. In *Warfare State*, David Edgerton¹²¹ discusses government research facilities and their role in the development of weapons after the First World War in respect to the relationship between technology, the state, industry and the military. He also provides a counterpoint to what is discussed in this thesis, both in terms of manufacture by small firms and in terms of the organisation and restructuring of those departments within the Ministry of Munitions concerned with the provision of trench warfare munitions during the First World War as discussed in the present thesis.

Neither Robinson nor Edgerton raises the issue of engineering or, indeed, invention, with regard to processes of practical problem-solving but consider production of munitions from theoretical and organisational standpoints. As will become apparent in the discussions that follow, the key to the successful production of munitions by small engineering firms, the so-called trade, during the First World War, rested almost entirely with the skills associated with practical problem-solving. This subject is not discussed in the literature. Indeed, the practical issues of engineering as a production process and problem-solving within this process, does not arise in the literature in respect to the munitions of the First World War.

Sources, breadth and limitations

Because the field of novel munitions for trench warfare has been under-researched hitherto, much of the archival material has not been examined in detail before. There are several hundred files in the National Archives pertinent to this field, most of them in the Ministry of Munitions (MUN) series, the majority in the MUN 4 series and MUN 5 (historical record) series but files also fall in the War Office (WO), Treasury (T), Treasury Solicitor (TS), Board of Trade (BT), Cabinet Office (CB), Supply (SUPP), and Directorate of Scientific and Industrial Research (DSIR) series. Of the Treasury files, the most important to this thesis are those in the T 173 series which contain records of the proceedings by the Royal Commission on Awards to Inventors, which sat during the 1920s and 1930s to hear claims submitted by inventors in respect of government use of their inventions in the pursuance of the war. The T 173 series also contains verbatim records of interviews of expert witnesses. There are some 830 files in this series but only twenty-five are pertinent to this study. The T 173 series provide valuable insights into how inventors worked and the importance of their inventions to the conduct of the war. T 173/1 and T 173/26 contain material concerning the procedures adopted by the Royal Commission, and the procedures for appointing members of the Commission.

Private papers provide material which does not appear to be available elsewhere. In particular, material relating to William Mills and to Henry Newton, two inventors of considerable importance, comes from private papers.¹²² Information about the activities of the Royal Engineers in relation to inventions and the manufacture of novel munitions is problematical because there appear to be no extant primary sources. Most information concerning the Royal Engineers and their involvement with novel munitions is in a series of articles published in *The Royal Engineers Journal* between 1924 and 1925. There appears to be no original archival sources extant relating to the Army Workshops or to the Experimental Section, GHQ, all of which played important roles in the processes of invention, evaluation,

and manufacture of novel munitions for trench warfare.¹²³ The war diaries of the Army Workshops during 1915, one of the most important years for the invention and manufacture of novel munitions, appear to be no longer extant. They may have been lost during the war, especially during the German spring offensives of 1918.¹²⁴

A wide range of official documents concerning operating procedures, tactics, training, lessons from recent fighting, and technical developments were published both in Britain and by GHQ as official documents in the Stationery Service (SS) series.¹²⁵ These not only include SS135 and SS143 and other tactical manuals but also technical and procedural manuals concerning grenades and mortars. These all provide essential information about the way in which such munitions were used on the Western Front. They are all the more important because they were derived from the technical characteristics and limitations of the munitions concerned as well as from practical experience. The issue of the relationship between what was printed in the manuals and what occurred in practice is one which is difficult to quantify. The two principal sources of what occurred in practice are war diaries and memoirs. An examination of these might seem to offer insights into tactical and procedural issues. This, however, presupposes that tactical developments in grenade and mortar warfare were from the top down, rather than derived from experience; as will be shown in Chapters 7 and 8, tactical developments arose from experience on the battlefield rather than from theory.¹²⁶ It is an object of this thesis to examine the technical–tactical relationship of these munitions which can only be done by examining the manuals and archival material relating to the invention, development and use of these munitions.

There are, of course, other archives, besides the National Archives at Kew, which contain some relevant material, such as the Vickers Archive at Cambridge University, the Liddell Hart Centre for Military Archives at Kings College, and the House of Lords archive, but the principal papers relevant to this thesis are in the National Archives. Time does not permit examination of all archival matter in every repository that might be pertinent; thus, considered choices have been made.

British patents published between about 1900 and 1925, and the patent abridgements for the period 1855 to 1930, have also been used as primary sources for this thesis. Patents are a valuable resource of historical technical information, both individually and collectively. A patent specification explains how an invention is intended to work and often discusses the problems which the inventor was attempting to solve. By referring to the patent specifications, it is possible to conduct a comparative technical analysis of some of the more important munitions. Collectively, patents also provide information about the inventors and their market position: the more patents an inventor has been granted in a given field, the greater his hold on that field, especially from a commercial perspective.¹²⁷ The patents classification system of the time allowed the abridgements to be grouped according to subject, independent of the patent number.¹²⁸ The Classes at the time of the First World War pertaining to the novel munitions under discussion in this thesis are: 9 (i), ammunition and ammunition receptacles; 9 (ii), torpedoes, explosives and pyrotechnics; 92 (i), ordnance and machine-gun carriages and mountings; 92 (ii), ordnance and machine-guns; and 119, small arms.

Summary of objects

This thesis attempts to fill a gap in the scholarship of the First World War, as discussed in the foregoing. The present thesis has three principal objects: firstly, to examine the processes by which novel munitions were invented and developed into manufacturable devices, then supplied to the BEF; secondly, to examine the relationship between the technical characteristics of these devices and the evolution of tactics for their use on the Western Front; and, thirdly, to consider whether the technical characteristics of specific novel munitions had a direct effect upon operations and tactics. The mechanism by which the latter occurred is discussed and its wider applicability to technological changes in relation to changes in warfare is considered.

The present thesis provides a different model of trench warfare conducted by the British during the First World War and thereby demonstrates the significance of the novel munitions under discussion and the role they played in changing infantry warfare. In so doing, this thesis also provides a different view of the Ministry of Munitions from that usually offered and argues that certain aspects of its role in providing the BEF with munitions have been overstated by virtue of the *History of the Ministry of Munitions* having underplayed the work of the War Office, while overlooking that conducted by the Royal Engineers in France.

Notes

¹ J E Edmonds, *History of the Great War, Military Operations, France and Belgium, 1914*, (London, 1925), vol. 1, pp. 9–10, 11 (hereafter referred as *Military Operations*); see also Chapters 2 and 3 in Tim Travers, *The Killing Ground*, (London, pbk ed., 1990); Lt-Col O F Brothers, 'The Development of Weapons Used in Trench Warfare', p. 1 in MUN 5/383/1600/14.

² See, for example, *History of the Ministry of Munitions*, vol. XI *The Supply of Munitions*, Part I *Trench Warfare Supplies*, pp. 1–2, p. 4 and p. 7. (A complete set of *History of the Ministry of Munitions* is in MUN 5/321A.)

³ The setting up of the Royal Commission on Awards to Inventors was announced in *The Times* on 23 May 1919, while on 16 June 1919 *The Times* ran a short piece informing its readers that anyone who thought they might have a claim could now make a submission to the Royal Commission. The Royal Commission heard submissions on all types of invention and was not restricted to considering novel munitions for trench warfare.

⁴ For artillery tactics see Jonathan Bailey, 'The First World War and the Birth of Modern Warfare' in MacGregor Knox and Williamson Murray (eds), *The dynamics of military revolution, 1300–2050*, (Cambridge, 2001), pp. 132–153.

⁵ In the First World War, 58.51 per cent of BEF casualties were caused by high-explosive (mainly shells and trench mortar bombs), 38.91 per cent were caused by small arms fire (including machine-guns), while only 2.19 per cent were caused by grenades (both hand and rifle). The remaining 0.32 per cent were caused by edged weapons such as bayonets and knives. See Bailey, *Field Artillery and Firepower*, (Annapolis, 2004), p. 240, fn. 2. British casualties amounted to 513,093 killed in action or died of wounds and 1,662,625 wounded, making a total of 2,175,718 casualties (see Field Marshall Lord Carver, *British Army in the 20th Century*, (London, 1998), p. 130). Thus, 1,273,013 were due to high-explosive shells and bombs, and 47,648 were due to grenades.

⁶ Gary Sheffield makes a similar point in 'The Indispensable Factor: Performance of British Troops in 1918' in Peter Dennis & Jeffrey Grey (eds), *1918, Defining Victory*, (Canberra, 1999), p. 75. See also Ian M Brown, 'Feeding Victory: The Logistic Imperative Behind the Hundred Days' in Dennis & Grey, *op cit.* p. 146.

⁷ See, for example, Grenade Training Manual, (Washington), January 1918, p. 10; Brothers, *op cit.* p. 39; *Military Operations, 1914*, vol. 2, p. 399; *Textbook of Small Arms*, (London, 1929), pp. 105–7; Guy Hartcup, *The War of Invention, Scientific Developments, 1914–18*, (London, 1988), p. 62; Bill Rawling, *Surviving Trench Warfare, Technology and the Canadian Corps, 1914–1918*, (Toronto, 1992), p. 24; John Ellis, *Eye-Deep in Hell, The Western Front 1914–18*, (London, 2002), p. 77.

- ⁸ *Military Operations, 1915*, (London, 1927), vol. 2, pp. 7–9 (including footnotes); MUN 5/382/1600/8 Notes on the History of Trench Warfare Research, Aug 1914 – May 1915, draft dictated 11/12/17, p. 1.
- ⁹ See Brothers, *op cit.* p. 42 especially in regard to grenades.
- ¹⁰ Brothers, *op cit.* p. 39.
- ¹¹ Brothers, *op cit.* p. 42; *Trench Warfare Supplies, op cit.* pp. 1–3.
- ¹² *History of the Ministry of Munitions*, vol. IX, *Review of Munitions Supply*, Part II *Design and Inspection*, pp. 48–50 and *Trench Warfare Supplies, op cit.* pp. 1–5.
- ¹³ It is quite explicit in the *History of the Ministry of Munitions* (see, for example, *Trench Warfare Supplies, op cit.* p. 3.
- ¹⁴ *Trench Warfare Supplies, op cit.* p. 12; MUN 5/382/1600/8, *op cit.*
- ¹⁵ MUN 5/382/1600/11 Record of History and Work, Ministry of Munitions, Trench Warfare Supply Department, OEB [Outside Engineering Branch] by Captain Leeming, 20/7/17, pp 12–13, 14–15.
- ¹⁶ *Design and Inspection, op cit.* p. 46; *Trench Warfare Supplies, op cit.* pp. 15–20.
- ¹⁷ See, for example, MUN 5/382/1600/6 The History of Trench Warfare Supplies, Section IV, General Policy & Procedure; this was the first draft of material used in the *History of the Ministry of Munitions*. See also Brothers, *op cit.*; and *Military Operations, 1915*, vol. 1, pp. 6–11.
- ¹⁸ See Brothers, *op cit.* p. 39 and *Trench Warfare Supplies, op cit.* Chapters 1 and 2, pp. 1–33, especially pp. 6 and 16–17. Such change is in contradistinction to that described by Trebilcock who views change as an ordered, sequential, process in which invention is a discrete step. It is doubtful that this has ever been the case, however. See, for example, “‘Spin-Off’ in British Economic History: Armaments and Industry, 1760–1914”, *The Economic History Review*, New Series, vol. 22, no. 3 (December 1969), pp. 474–90; ‘Legends of the British Armaments Industry’, *Journal of Contemporary History*, vol. 5, no. 4 (1970), pp. 3–19; ‘British Armaments and European Industrialization, 1890–1914’, *Economic History Review*, New Series, vol. 26, no. 2, 1973, pp. 254–72.
- ¹⁹ This is discussed in later chapters of this thesis.
- ²⁰ This was especially true of the Royal Engineers in France and of those who worked in close association with them, especially among those who had civilian engineering backgrounds. See, in particular, Chapters 3 and 4 of this thesis. Lieutenant-Colonel Jackson, RE, and Captain Newton, TF, may be singled out as of particular importance in this respect, the contributions of whom are discussed below.
- ²¹ The origins of such criticism lay with the *History of the Ministry of Munitions* and with David Lloyd George’s *War Memoirs*, 6 vols, (London, 1933). For criticism of the War Office’s ‘ad hocism’ see Michael Pattison, ‘Scientists, Inventors and the Military in Britain 1915–19: The Munitions Inventions Department’, *Social Studies of Science*, vol. 13, no. 4, 1983, pp. 521–68, especially pp. 559–60, and ‘The Munitions Inventions Department, A Case Study in the State Management of Military Science, 1915–1919’, unpublished PhD thesis, Teesside Polytechnic, 1981, especially pp. 217–18, 219, 221.
- ²² See, for example, ‘The Work of the Royal Engineers in the European War, 1914–19’, *The Royal Engineers Journal*, September 1924, pp. 449–50; and *Military Operations, 1915*, vol. 2, *op cit.* p. 7 especially footnote 1.
- ²³ See, for example, Hartcup, *op cit.* especially Chapters 7 and 8.
- ²⁴ Few works discuss these devices. The only books devoted exclusively to them are the present author’s *Weapons of the Trench War, 1914–1918*, (Stroud, 1999) and *Dominating the Enemy*, (Stroud, 2000). A hyposcope, also known as a periscope rifle or a sniperscope, is a remote-firing device fitted to a rifle. It was provided with a periscope and, sometimes, a remote trigger and bolt-operating mechanism. Such devices were also fitted to machine guns.
- ²⁵ See *Dominating the Enemy, op cit.* Chapter 5, pp. 73–99.
- ²⁶ Bashford Dean, *Helmets and Body Armor in Modern Warfare*, (New Haven, 1920), p.110. Some armour was supplied through official channels but much was also bought privately in department stores in Britain.
- ²⁷ MUN 5/382/1600/8, *op cit.*
- ²⁸ MUN 5/382/1600/8, *op cit.* p. 3; *Trench Warfare Supplies, op cit.* pp. 91–2.
- ²⁹ See Maj-Gen C H Foulkes, “Gas!” *The Story of the Special Brigade*, (Edinburgh & London, 1934), pp. 111–12, 161–5; WO 142/337 Report on the Activity of the Special Brigade during the War; MUN 5/385/1650/1 Work of Trench Warfare Section 5 on flame projectors, sprayers, etc. from June 1915 to March 1916; MUN 5/385/1650/6 History of the Supply of Flame Projectors, June 1915 – March 1918.
- ³⁰ Foulkes, *op cit.*; L F Haber, *Poisonous Cloud, Chemical Warfare in the First World War*, (Oxford, 1986); William Moore, *Gas Attack: Chemical Warfare 1915 to the Present Day*, (London, 1987); Donald Richter, *Chemical Soldiers, British Gas Warfare in World War One*, (London, 1994).
- ³¹ See Foulkes, *op cit.* for how gas clouds, Livens projectors, and 4-inch Stokes mortars were used operationally. See also WO 142/337 Report on the Activity of the Special Brigade during the War.
- ³² For example: J F C Fuller, *Tanks in the Great War, 1914–1918*, (London, 1936); B H Liddell Hart, *The Tanks*, vol. 1, (London, 1959); Bryan Cooper, *The Ironclads of Cambrai*, (London, 1967); A J Smithers, *A New Excalibur, the Development of the Tank 1909–1939*, (London, 1986); Tim Travers, *How the War was Won*, (London, 1992), especially Chapters 4 and 5; Rawling, *op cit.*
- ³³ This point is also made by Rawling, *op cit.* pp 3–7.
- ³⁴ For example, the preparation of technical reports based on the results of trials, examining, in the case of a trench mortar, for example, construction, range, accuracy, reliability, speed of operation, method of operation,

ease of dealing with misfires, barrel pressure, muzzle flash, rate of burning of propellant, type of propellant. See, for example, Ordnance Board minutes in Supp 6 series and MID reports in MUN 4/426 and MUN 4/3076.

³⁵ This is typified by the tone in many accounts of developmental work. See, for example, *Trench Warfare Supplies*, *op cit.* and Brothers, *op cit.*, although the latter is less self-congratulatory and more sceptical than the former. It is also evident in more recent works such as Hartcup, *op cit.*

³⁶ See, for example, Brothers, *op cit.* which implies that an alternative to the Mills grenade was forestalled by its superiority over the stopgap measures. However, the argument is rather circular since it centres on the time element. Had there been more time, as in peacetime, a superior alternative might have been developed but for the fact that it was the very urgency of the need which led to the Mills being developed in the first place. Had there been more time, it is unlikely that any hand grenade would have been developed to replace the No. 1 percussion grenade.

³⁷ The distinction is made here in order to highlight what defines an invention. In current patent law, the term 'new' means that there has been no prior disclosure of the device or process. Thus, the invention may, indeed, be novel but if the inventor has disclosed information about it before filing a patent application, it is no longer new.

³⁸ Amended by the Copyright Designs and Patents Act 1988, The Patents Act 2004 and other legislation.

³⁹ It should be noted, however, that none of the Patents Acts has ever provided a definition of an invention; on the contrary, they define the requirements which an invention must satisfy for it to be patentable. See also *Manual of Patent Practice*, Part I Patentability, Section 1, especially 1.04 and 1.08. The *Manual* provides a commentary on the provisions of the current Act. A link to downloadable pdfs of all the sections of the *Manual* is on the UK Patent Office website, www.patent.gov.uk/patent/reference/mpp/index.htm. All references in this thesis to the *Manual* relate to the June 2006 version. Because the *Manual* is specifically concerned with interpretation of the Act and takes judicial decisions into account, it is regularly updated and amended.

⁴⁰ For an explanation of the evolution of the British patents system and the structure of a patent see Stephen van Dulken, *British Patents of Invention, 1617–1977, A Guide for Researchers*, (London, 1999).

⁴¹ Sections 1, 2 and 3, Patents Act 1977. Section 1 concerns patentable inventions, Section 2 concerns novelty, while Section 3 concerns the inventive step (obviousness). Apart from novelty and involving an inventive step, the invention must also be capable of industrial application (Section 4). A full discussion of all the provisions of the 1977 Act are available on the Patent Office website www.patent.gov.uk/patent/reference. See also www.ipa.gov.uk/p-law-manual-practice-patent1977.htm for a summary of patentability. (Accessed June 2006.)

⁴² For a discussion of obviousness see *Manual of Patent Practice*, *op cit.* Section 3, especially Objective Test, Sections 3.03–3.05.

⁴³ Patents and Designs Act 1907 as amended by the Patents and Designs Act 1908.

⁴⁴ *Manual of Patent Practice*, *op cit.*

⁴⁵ The percussion-fuzed hand grenade was reinvented at least three times, with gaps of about 250 years, forty years and ten years between each 'invention'. See, for example, *Textbook of Small Arms*, *op cit.* pp. 105–06.

⁴⁶ Patents and Designs Act 1907, *op cit.* Section 7.

⁴⁷ *Textbook of Small Arms*, *op cit.* p. 124.

⁴⁸ *Ibid.*

⁴⁹ Otherwise, patent laws would be largely redundant.

⁵⁰ Patents and Designs Act 1907, *op cit.* Sections 1 and 7. See also van Dulken, *op cit.* p. 23. This is no longer the case and the evidence of the existence of a given invention anywhere in the world voids its patentability in the UK unless it has been patented in its country of origin.

⁵¹ Patents Act 1977, *op cit.* Sections 1–4.

⁵² This is discussed in Chapter 4. The Stokes mortar and its method of loading and firing is a good example. See T 173/453 which contains the proceedings of the Royal Commission on Awards to Inventors concerning the submission of Wilfrid Stokes.

⁵³ This is the problem faced by a patent applicant, and his patent attorney, when a patent office examiner cites prior art which may anticipate the invention described in the application. While it is sometimes a matter of unequivocal fact one way or the other, it is often a matter of reasoned argument.

⁵⁴ Marten Hale's rifle grenade of 1908 is a typical example. No such device had previously existed. See Chapter 2.

⁵⁵ A good example is the centrepiece of the Mills grenade which was the subject of several patents. Its design and construction were codependent. The form of the centrepiece, which housed the working parts and screwed into the base of the grenade body, was important to the manufacturing process and to the functioning of the grenade. This is discussed in Chapter 4. See Brothers, *op cit.*

⁵⁶ See 1907 Act, *op cit.* and 1977 Act, *op cit.*

⁵⁷ See Lloyd George, *op cit.* vol. 2 regarding his political backing for the Stokes mortar, pp. 619–21. His version of events is not entirely accurate, however.

⁵⁸ Captain Martel, 'The Use of Inventions in War' in *The Royal Engineers Journal*, December 1924, pp. 572–8.

⁵⁹ *Op cit.* p. 574. Giffard le Quesne Martel, 1889–1958, was descended from the Martel who fought with William Duke of Normandy at Hasting in 1066.

⁶⁰ This is also Trebilcock's view.

- ⁶¹ See, for example, Sir Albert Stern's comments to Churchill in his *Tanks 1914–1918, The Log-book of a Pioneer*, (London, 1919), p. 210. The lack of reliability and the under-performance of a new device typifies this. Such failings are epitomised by the retrospective fitment of improvements intended to solve the shortcomings of a device. Such retrofits are not usually intended to improve the performance and reliability of the device beyond the performance initially promised but rather to bring it up to specification. The tank is good example of this process.
- ⁶² The author's views on the process of invention are drawn from his experience of working with inventors as a Patent Officer in the Principal Directorate of Patents, MoD, 1978–83.
- ⁶³ Hartcup (*op cit.* p. 67) acknowledges the fact that the Stokes mortar was underdeveloped when it was introduced to the Western Front in 1915 but fails to grasp the significance of this observation.
- ⁶⁴ This, too, can be demonstrated by examining patent abridgements. Any series of patents in which the same or related problems are being addressed by inventors, especially when they tend to be the same inventors, shows that a satisfactory solution to a given problem was still being sought. In this instance, the inventors tend also be in groups which are often related to specific firms, showing the rivalry between the firms. Relating the inventions to specific events provides insights into the technical viability of the devices in question. Such an analysis is only touched upon here. No such analysis of any military device from the 1850s to the present day has been attempted by any researcher. While an analysis of British patents can only go back as far as 1855 (when the abridgements start), an analysis of US patents can go back to 1790.
- ⁶⁵ Indeed, it could be argued that the tank did not achieve its optimal performance until the 1980s. All tanks from 1916 onwards, including those of the Second World War, suffered from serious deficiencies. This continued into the 1980s when composite armour, high-performance engines, high first-shot-kill capability gun systems among other developments started to become the norm.
- ⁶⁶ The reasons for the premature introduction of such munitions is discussed below, especially in Chapter 3.
- ⁶⁷ See, for example, *Design and Inspection, op cit.* pp. 44–67 and *Trench Warfare Supplies, op cit.* pp. 6–8. Both discuss the work carried out under the auspices of the War Office. See also Lloyd George, *op cit.* vol. 1, pp. 139–45, 162–7, 188–213.
- ⁶⁸ MUN 5/382/1600/8, *op cit.*
- ⁶⁹ Ordnance Board proceedings are in the SUPP 6 series; July 1914 to June 1915 are in SUPP 6/184 to SUPP 6/187.
- ⁷⁰ MUN 5/41/263.6/15 contains papers concerning the transfer in June 1915 of General Jackson and FW3 from the War Office to the Ministry of Munitions. See also Dewar, *op cit.* pp. 44–5 which gives a somewhat garbled version of the transfer of responsibilities from the War Office to the Ministry of Munitions. Dewar seems to provide the only contemporary published account of this event.
- ⁷¹ Pattison falls into this trap when he cites the Stokes as one of the MID's successes; he fails to give due significance to the fact that Stokes invented his mortar with no outside assistance and before the creation of the Ministry of Munitions (see Pattison, 'Scientists, Inventors and the Military in Britain', *op cit.* p. 539). The Stokes mortar is discussed in Chapter 6 of the present thesis.
- ⁷² WO 32/5339 Awards for Inventions During the War. See Report of the Departmental Committee on Awards To Inventors, October 1918 pp. 1–2.
- ⁷³ *Design & Inspection, op cit.* p. 45. Pattison makes a similar point. See 'Scientists, Inventors and the Military in Britain', *op cit.* pp. 525 and 560.
- ⁷⁴ For example, *History of the Ministry of Munitions, op cit.* and Lloyd George's *War Memoirs, op cit.* Some degree of caution is also necessary when examining Ministry of Munitions files in the National Archives when the content raises any issue that bears on the War Office.
- ⁷⁵ The emphasis on the war-winning invention is noticeable in writings of Lloyd George, Liddell Hart, Fuller and Dewar and, more recently, in Hartcup, Terraine and Travers, if only because there is undue focus on devices such as the aircraft, the tank and the submarine.
- ⁷⁶ See, for example, preface to Benedict Crowell's *America's Munitions, 1917–1918*, (Washington, 1919) and *Military Operations, 1916*, vol. 2, (London, 1938), pp. 245–9. The latter discusses the tank and the Landship Committee. This part of *Military Operations* came from minutes and proceedings of the Royal Commission on Awards to Inventors in respect of claims submitted by the inventors of the tank. These are in the T 173 series in the National Archives.
- ⁷⁷ Fuller, *op cit.* Liddell Hart, *op cit.* Martel, *op cit.*
- ⁷⁸ See, for example, Cooper, *op cit.*, Bidwell and Graham, *op cit.*, especially pp. 137–9 and pp. 191–2, Smithers, *op cit.* and Terraine, *op cit.* pp. 241–2 and p. 303, and Terraine, *The Smoke and the Fire*, (London, 1980), pp. 148–60.
- ⁷⁹ Hartcup, *op cit.* Chapters 2 and 3. See also Pattison, 'Scientists, Government and Invention: the Experience of the Inventions Boards 1915–1918' in Peter H. Liddle (ed.), *Homes Fires and Foreign Fields, British Social and Military Experience in the First World War*, (London, 1985), pp. 83–4.
- ⁸⁰ The relationship between science, industry, the state and armed forces is discussed in Chapters 7, 8 and 9 of William H. McNeill *The Pursuit of Power*, (Chicago, pbk ed., 1984). See also Hillary Rose and Stephen Rose, *Science and Society*, (London, pbk ed., 1977), Chapter 2.
- ⁸¹ Paddy Griffith, *Battle Tactics of the Western Front, The British Army's Art of Attack 1916–18*, (New Haven, 1994), pp. 186–91. See also Andrew Whitmarsh, 'The Development of Infantry Tactics in the British 12th (Eastern) Division, 1915–1918, *Stand To!*, January 1997, no. 48, p. 31; Sheffield, 'The Indispensable Factor', *op cit.* pp. 84–5.

- ⁸² Based on the author's experience of prosecuting patent applications in the early 1980s.
- ⁸³ See, for example, McNeill, *op cit.* pp. 273 and 278.
- ⁸⁴ *Weapons of the Trench War, op cit.* and *Dominating the Enemy, op cit.*
- ⁸⁵ Rawling, *op cit.*
- ⁸⁶ See also Rawling's 'A Resource not to be Squandered: The Canadian Corps on the 1918 Battlefield' in Dennis & Grey, *op cit.* pp. 43–70; this chapter covers similar ground to *Surviving Trench Warfare, op cit.*
- ⁸⁷ John Terraine, *White Heat, the New Warfare 1914–18*, (London, 1982).
- ⁸⁸ Rick Landers, 'Grenade' *British and Commonwealth Hand and Rifle Grenades*, (Dural, 2001).
- ⁸⁹ Martin Pegler, 'Mr Mills' grenade', *Arms & Armour*, vol. 1, no. 1, 2004, pp. 89–99.
- ⁹⁰ Hartcup, *op cit.*
- ⁹¹ Hartcup, *op cit.* regarding Mills pp. 62–3, regarding Stokes pp. 65–7.
- ⁹² Peter T Scott, 'Mr Stokes and his educated drain-pipe', *The Great War*, vol. 2, no. 3, May 1990.
- ⁹³ Lloyd George, *op cit.*
- ⁹⁴ Lloyd George, *op cit.* vol. 1, pp. 268–9, vol. 2, pp. 619–21.
- ⁹⁵ Lloyd George, *op cit.* vol. 2, pp. 615–17, especially p. 617.
- ⁹⁶ The MUN 5 series in the historical record of the Ministry of Munitions. The notes of what became the *History* are in the MUN 5/382 series, which contains the notes and accounts of work carried out by the various sections within the Ministry of Munitions. Further reports and accounts are in the MUN 5/384 series. Some reports on munitions development are in the MUN 5/385 series. The MUN 5/383 series contains the drafts of the chapters of the *History* which had been prepared from these notes and reports, as well as from other sources. Some of the text in the final version of the *History* does not agree with some of the source material in the MUN 5 files. Some of the other sources used in writing the *History* are not easy to identify because the reference numbers of the original files were changed at some point after the *History* was published. Some of the sources were not Ministry of Munitions papers.
- ⁹⁷ Pattison thesis, *op cit.*
- ⁹⁸ Pattison 'Scientists, Inventors and the Military in Britain', *op cit.* and 'Scientists, Government and Invention', *op cit.*
- ⁹⁹ J K Gusewelle, 'The Board of Invention and Research. A Case Study in the Relations between Academic Science and the Royal Navy in the First World War', (University of California, 1971), unpublished PhD thesis. The BIR is outside the scope of the present thesis. See fn 56 in Pattison 'Scientists, Government and Invention', *op cit.* p. 100 which quotes Gusewelle with regard to science, technology and inventions. Gusewelle's definition of invention is flawed, especially when he claims that it 'is frequently a matter of pure chance and mechanical gadgets may be developed by skilful tinkerers who gave little or no knowledge of either science or applied technology'. This is nonsense.
- ¹⁰⁰ Pattison thesis, *op cit.* cites the existence of nine 'bodies' dealing with inventions (relating to all aspects of warfare) in July 1915. He includes the War Committee of the Royal Society and the Consultative Committee of the Chemical Society, neither of which was actually concerned with inventions, and he fails to include the Experimental Section, GHQ (see his note 94).
- ¹⁰¹ See, for example, Pattison 'Scientists, Government and Invention', *op cit.* pp. 88, 89, 90–91, 96.
- ¹⁰² See, for example, Pattison thesis, *op cit.* pp. 155–65. See Chapter 3 of the present thesis for a further discussion of the issue of areas of responsibilities and conflict between rival departments.
- ¹⁰³ See, for example, Pattison 'Scientists, Government and Invention', *op cit.* pp. 83–4.
- ¹⁰⁴ See, for example, Travers, *The Killing Ground, op cit.* and *How the War was Won, op cit.*; Shelford Bidwell and Dominick Graham, *Fire-Power, British Army Weapons and Theories of War, 1904–45*, (London, 1982); Griffith, *op cit.*
- ¹⁰⁵ Chapter 6, comprising seventeen pages.
- ¹⁰⁶ Knox and Murray, *op cit.*
- ¹⁰⁷ Bailey, *Field Artillery and Firepower, op cit.*
- ¹⁰⁸ General Sir Martin Farndale, KCB, *History of the Royal Regiment of Artillery, Western Front, 1914–18*, (London, 1986).
- ¹⁰⁹ Gary Sheffield and Dan Todman (eds), *Command and Control on the Western Front*, (Staplehurst, 2004); Mark Connelly, *Steady the Buffs, A Regiment, a Region, and the Great War*, (Oxford, 2006); Brian Bond (ed.), *Look to Your Front*, (Staplehurst, 1999); Andy Simpson, *Directing Operations, British Corps Command on the Western Front 1914–18*, (Stroud, 2006).
- ¹¹⁰ Sheffield and Todman, *op cit.* pp. 176–7. McCarthy repeats the common error of referring to the 'Hales' grenade; the correct name is 'Hale' derived from its inventor Frederick Marten Hale (see Chapter 2 of the present thesis).
- ¹¹¹ Bond, *op cit.*; Peter Dennis & Jeffrey Grey, *op cit.*
- ¹¹² See, for example, Richard Bryson, 'The Once and Future Army' in Bond, *op cit.* pp. 33, 49; and John Lee 'Some Lessons of the Somme: the British Infantry in 1917' in Bond, *op cit.* pp. 79–80.
- ¹¹³ Lee, *op cit.* pp. 81–4.
- ¹¹⁴ Sheffield, 'The Indispensable Factor', *op cit.* p. 85.
- ¹¹⁵ S F Wise, 'The Black Day for the German Army: Australians and Canadians at Amiens, August 1918' in Dennis & Grey, *op cit.* p. 26.
- ¹¹⁶ Robin Prior and Trevor Wilson, 'Winning the War' in Dennis and Grey, *op cit.* p. 38.

¹¹⁷ Whitmarsh, *op cit.* p. 29. Whitmarsh includes in his discussion reference to the training manuals SS135 and SS143 without explaining how any of it was put into practice; he includes an interpretation of a diagram from SS143 showing how bombers, rifle grenadiers, Lewis gunners and riflemen cooperated to take a strongpoint (p. 30). It is too simplified to be informative.

¹¹⁸ Robert Williams, 'A Social and Military History of the 1/8th Battalion, The Royal Warwickshire Regiment, in the Great War', unpublished MPhil thesis, Birmingham, 1999; Kathryn Snowden, 'British 21st Infantry Division on the Western Front, 1914–1918, A Case Study in Tactical Evolution', unpublished MPhil thesis, Birmingham, 2001.

¹¹⁹ Hartcup, *op cit.* does discuss some of these issues but only to a very limited extent and fails to establish the relative importance of the departments. Pattison, *op cit.* also mentions some but fails to put them in the context of all the other inventions departments.

¹²⁰ E A G Robinson, 'The Overall Allocation of Resources' in D N Chester (ed.), *Lessons of the British War Economy*, (Cambridge, 1951), pp. 34–57.

¹²¹ David Edgerton, *Warfare State, Britain, 1920–1970*, (Cambridge, 2006).

¹²² Copies of the Mills papers were provided by Norman Bonney. The location of the originals has proved frustratingly elusive as have copies within any archive. The authenticity of the copies is not in doubt.

The Newton papers consist of a dissertation written by one of Henry's grandsons in the late 1970s for a school project. This was largely copied from official papers and *The Royal Engineers Journal* but also includes photocopies of typewritten documents prepared by Henry either during the war or immediately afterwards and are unavailable from other sources. The only other reliable source of information about Henry Newton is T 173/728 which contains a verbatim record of his attendance at a hearing of the Royal Commission on Awards to Inventors. Henry kept many documents relating to his inventions and their development which represented a unique record. Unfortunately, many of the papers were lost in a house fire in the 1970s. It is unclear how many documents survived. Many of the surviving documents are burned round the edges to some degree; in some cases, some of the information has been lost. Some of these documents were reproduced in his grandson's dissertation. Wherever possible, the handwritten part of the dissertation has been cross-checked against documents from other sources, such as those in the National Archives or the *Royal Engineers Journal*.

¹²³ The Royal Engineers library at Chatham appears to contain nothing in this regard.

¹²⁴ The Workshops in the Second Army area, for example, were overrun in spring 1918. See Colonel G H Addison, (ed.), *The Work of the Royal Engineers in the Late European War, 1914–19, Miscellaneous*, (Chatham, 1927), p. 262; Newton papers *op cit.*

¹²⁵ These are available in a variety of repositories, including the Imperial War Museum, London, and the National Archives, Kew. As far as the latter is concerned, there is no easy way to locate such documents as they do not have individual piece numbers and tend to turn up unexpectedly in files. The Imperial War Museum has a large number of such documents but does not have a complete set. Some are available from private sources, especially the manuals and handbooks. A few are in the author's collection.

¹²⁶ Lee, *op cit.* p. 82, makes a similar point about SS143 being based on experience.

¹²⁷ Between June 1906 and March 1914, Frederick Marten Hale applied for ten patents in respect of hand and rifle grenades; all were granted.

¹²⁸ The full set of Classes current during the First World War can be seen in the back of any of the sets of *Abridgements of Specifications* for this period, published in the 1920s by the Patent Office. The current classification system is more complex and is of no help in searching patents granted before 1963 when it was introduced. The full set of abridgements is available at the British Library (but not the Patent Office) and are also held by a few regional and academic libraries. See the British Library website www.bl.uk/collections/patents (accessed February 2005). Each abridgement was intended to be no more than a guide to the full specification and comprised a very brief description of the essential features of the invention, with one or more of the drawings, preceded by a one-word or two-word description of the subject matter to which the invention related. Each abridgement was headed by the patent number, the name(s) of the patentee(s) and the application date. Abridgements were superseded by abstracts, prepared by the patent agent, with the 1977 Act. Each set of abridgements included a Subject-Matter Index and a Name Index at the front. An excellent guide to all British patents and Patents Acts is van Dulken, *op cit.*

2 Trench Warfare Munitions pre-1914

An essential question which needs to be addressed before considering the trench warfare munitions of the Western Front is the matter of prior art. In other words, what kind of munitions relating specifically to trench or siege warfare predated the munitions of the First World War and did any of the former anticipate the latter? The object here is to ascertain the technical nature of the devices relating to trench warfare, specifically grenades and mortars, prior to the First World War and to consider how such devices were used on the battlefield. With this in mind, the present chapter looks at the technological developments which occurred in these fields during the hundred years preceding the First World War. Of particular interest are the inventions of the American Civil War, those of the Russo-Japanese War and those of British inventors during the nineteenth century. The question of whether these wars influenced the design of hand grenades or mortars in Britain prior to the First World War can then be addressed. Of particular relevance is the relationship between the munitions of trench and siege warfare and the surge of innovation in the field of munitions in the hundred years prior to the First World War.

During the nineteenth century, weapon design went through a revolution, resulting in a huge increase in firepower which outpaced tactical developments.¹ Digging in by the infantry of Western armies became common practice following the adoption of the Minié bullet and the rifled musket in the 1850s. It was no longer feasible for infantry to remain in massed formations in the open. The size of the lethal zone increased exponentially as firepower increased. Trenches became a common feature of battles of the last two years of the American Civil War.² The wars of the second half of the nineteenth century made increasing use of trenches and earthwork fortifications because of the technological advances which enabled both small arms and artillery to shoot accurately at ever increasing ranges. At about the time of Waterloo (1815), a musket had a killing range of about 200 yards but was only accurate to about 100 yards.³ The accurate killing range of a rifle increased to about 500 yards by the time of the American Civil War and by 1900 it was in excess of 1000 yards.⁴ However, in Manchuria it was noted that ‘few Japanese dead were ever observed at distances much beyond 700 yards from the Russian positions’.⁵ Over the same period, artillery range increased from about 1000 yards (9 pdr roundshot)⁶ to 3000 yards during the American Civil War,⁷ to 6500 yards by 1900.⁸ Roundshot was replaced by high-explosive shell during this time.

By the 1870s, the pace of change in weapons technology had accelerated to such an extent that innovative new weapons were beginning to appear in quick succession. Obsolescence became a feature of these munitions; what was innovative in 1860 was obsolescent by 1880. This process was repeated several times between about 1870 and 1914. Hitherto, obsolescence had been a process measured in centuries. The invention of such munitions as ogival shells (1850s), fixed metallic centrefire small arms ammunition (1866), recoil and recuperator systems

for artillery (1872), smokeless propellants (1884), high explosives (1885), quick-locking breech mechanisms for both artillery (1880s) and rifles (1839) all fuelled this revolution. These developments were aided by innovations in manufacturing techniques which allowed the cheap and reliable rifling of gun barrels and the reliable mass production of weapon components.⁹ The latter ensured that any given part of a weapon system could be manufactured to a consistent standard thereby allowing the parts to be interchangeable rather than specific to a given weapon which had been the case hitherto. There were more developments in weapons technology in the second half of the nineteenth century than in the previous two hundred years. And there was another factor at work which aided these changes: the rising importance of intellectual property, patents in particular, as a business asset.¹⁰

McNeill has suggested that the Crimean War inspired British inventors to invent weapons and munitions.¹¹ He cites the increase in patent applications at the British Patent Office as evidence of this.¹² There is no question that the British public learned what was happening in the Crimea very much faster than in previous wars thanks to *The Times* and its correspondent, William Russell, and not a little help from the steamship.¹³ Inventors were, thus, theoretically in a position to respond to any perceived need of the British army. While it is true that there was an increase in the number of patents granted for firearms, ammunition and ordnance in Britain during the 1850s,¹⁴ this had little to do with the war in the Crimea. On the contrary, it was largely because of a change in patent law brought about by the Patents Law Amendments Act 1852, Britain's first modern patents act.¹⁵ One of the purposes of the Act was to simplify and rationalise the patenting procedure. After its introduction, there was a five-fold increase in the number of patents granted for inventions. The number of applications increased from 400 to 2000 a year.¹⁶ By 1863, the number of applications had increased to 3000 a year but many were for old ideas. The lack of examination or search procedures during the application process meant that there was no way to check whether the invention was, indeed, new.¹⁷ Such shortcomings were not rectified until the Patents Act 1883, which introduced examination, and the 1902 Act, which required patent examiners to search British patents going back fifty years.¹⁸ Thus, it is misleading to suggest that the increase in patents granted for munitions during the 1850s was due to inventors responding to the impetus of the Crimean War.¹⁹ Indeed, there was not one patent for a hand grenade in the 1850s. Only one inventor submitted a novel hand grenade to the Ordnance Board during the Crimean War.²⁰ There is nothing to suggest that he was inspired by the war although hand grenades were used by the British, French and Russians during the siege of Sevastopol in 1854.²¹

Hand grenades c. 1500–1860

The Chinese invented the hand grenade in about the tenth century.²² It did not appear in Europe until the fifteenth century.²³ Hand grenades have always been associated with siege warfare and trenches. Defenders of fortifications used them to repel attackers, while attackers used them to overcome the defenders. The main benefit of hand grenades was their shock effect. By the eighteenth century, elite regiments of grenadiers had come into being. Their role as throwers of hand grenades was short-lived, however, because they were vulnerable to enemy



Fig. 1 *British improvised hand grenade from the siege of Mafeking, 1899. Note the wooden handle. The grenade is a time-fuzed iron sphere. The metal disk is an identification tag* (Norman Bonney)

musket fire; the throwing range of a grenade was far shorter than the range of a musket ball. The heyday of the grenadier was the first half of the eighteenth century.²⁴ Thereafter, interest in hand grenades waned and continued to decline throughout the nineteenth century, although the British used them as late as 1884–5 in the Sudan.²⁵ There is some evidence that grenades were improvised by the British, fifteen years later, during one of the sieges of the Boer War.²⁶

Until the beginning of the twentieth century, the hand grenade remained essentially unchanged in Europe. It comprised a spherical container of gunpowder into which was inserted a fuze which had to be lit with a naked flame. Although pottery and even glass vessels²⁷ were sometimes used, typically during the sixteenth century, spheres of cast iron were more common. Whereas a sixteenth-century fuze was typically a slow match similar to those used with matchlock muskets, an eighteenth-century fuze usually comprised a tapering wooden tube with a narrow bore filled with slow-burning gunpowder.²⁸ The main problems with these fuzes were their unpredictable rate of burning and their susceptibility to moisture damage which rendered them useless. Thus, lighting and throwing hand grenades always required some trepidation on the part of the grenadier as he could never be certain what was going to happen. The grenade could explode in his face, fizzle out as he threw it, or the fuze might burn for so long that the enemy was able to pick up the grenade and throw it back before it exploded.²⁹ These drawbacks were largely overcome by the invention of the safety fuze by William Bickford in 1831.³⁰ Bickford devised the fuze which subsequently bore his name to overcome the hazards of using unpredictable fuzes in mines but its military applications quickly became apparent; his safety fuze was soon taken up for military purposes. Safety fuze consisted of a jute rope with a core of gunpowder, sealed with a varnish. It burned at a constant rate and was very much more moistureproof than earlier types of fuze. The British declared this type of hand grenade obsolete in 1902.³¹

The unpredictability and unreliability of the time fuze was a serious drawback to the handling and operational use of grenades, although it was the increasing range and accuracy of small arms which rendered hand grenades impractical. These shortcomings exercised the minds of few inventors. A chimera which some pursued was the so-called percussion-fuzed hand grenade.³² A percussion-fuzed device is supposed to have been invented as early as the end of the sixteenth century but its form is unknown.³³ No one made a serious attempt to devise a similar fuze for artillery shells until the middle of the nineteenth century



Fig. 2 ParLOUR's hand grenade of c. 1834. This early percussion-fuzed hand grenade embodies two features which recurred in most subsequent inventions in this field: a safety device and an all-ways functionality. The threaded pin on the left prevented the pin mounted on the neck of the grenade (inside the separate mushroom head) from hitting the percussion cap mounted inside the mushroom head (Author's photograph of specimen in Norman Bonney's collection)

and the advent of the ogival shell.³⁴ The notion of a percussion-fuzed hand grenade re-emerged at about the same time but there was little interest in such things. There was no incentive to produce a workable percussion fuzed hand grenade. Captain Norton of the 34th Regiment submitted a 'detonating hand grenade' to the Ordnance Board in 1828, while William ParLOUR of the East India Military Seminary submitted a similar device

six years later.³⁵ Both were rejected as 'ingenious, but not applicable to His Majesty's Service'.³⁶ In 1852, the Ordnance Board examined and rejected 'models and drawings' of percussion-fuzed hand grenades and shells which had been submitted by William Spencer.³⁷

The Board's indifference to these devices implies that percussion-fuzed hand grenades were faulty in both concept and realisation. However, an examination of ParLOUR's drawings shows it to have had the potential to be a viable device.³⁸ The Ordnance Board clearly regarded the gunpowder-filled, time-fuzed grenade as quite adequate for the purpose and saw no need for anything more sophisticated. In other words, there was no requirement for a 'better' hand grenade.

Innovation in the American Civil War, 1861–5

The Americans seem to have taken a quite different view of hand grenades. At least six patterns of hand grenade were used during the American Civil War, three of which were novel.³⁹ There were at least two other patented hand grenades but it is unclear whether they were used.⁴⁰ A percussion grenade was invented by a New York manufacturer of farm equipment, William Ketchum.⁴¹ Ketchum patented his grenade in 1861 when the Civil War was barely a few months old, so the war is unlikely to have been his inspiration.⁴² The Ketchum was used by the Union Army and Navy;⁴³ some 90,000 Ketchums are supposed to have been ordered by the US government.⁴⁴

The device had an ovoid body to which was attached a wooden tail with cardboard fins. It resembled a dart and had to be thrown like one to ensure that the device functioned as intended. Its fuze and detonator assembly included a percussion cap at the end of a tube



Fig. 3 Ketchum hand grenades of 1861. Note the plunger disc, the metal body and the wood-and-cardboard tail (Smithsonian Institution)

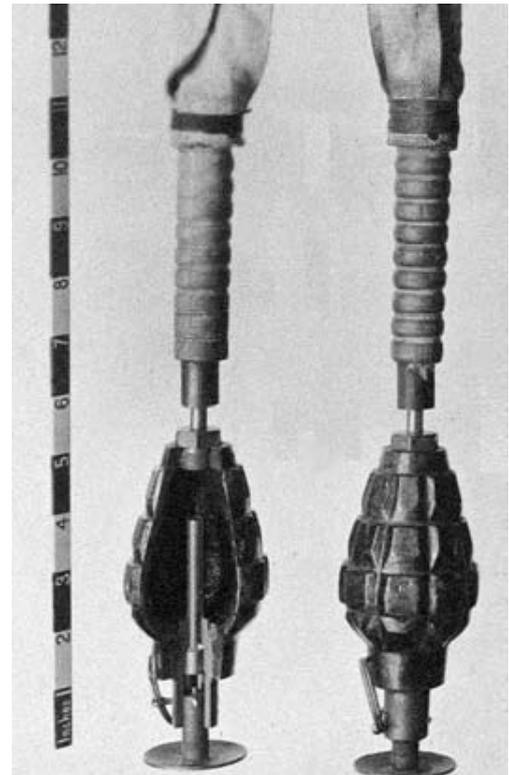


Fig. 4 The No. 19 hand grenade of 1917. Note that it uses a similar disc to the Ketchum and for the same reason, namely to provide a crude 'all ways' facility for the percussion fuze. The 1917 version was no more reliable than the 1861 version (MUN 5/383/1600/14)

which contained a spring-retained striker, the external part of which was surmounted with an external disc.⁴⁵ When the latter hit a hard surface, it forced the striker against the spring into the cap, detonating the grenade. The reliability of the device clearly depended upon the strength of the spring and the fit of the striker inside the tube. It is not known whether Ketchum realised that, in order for his grenade to function, the detonator assembly needed to be manufactured within tight tolerances. The Confederate army copied the Ketchum, renaming it the Raines, after General Gabriel Raines, head of the Confederate Torpedo Bureau.⁴⁶ The Raines sometimes dispensed with the tail and used a paper streamer instead. The purpose of the tail and the streamer was to stabilise the flight of the grenade and ensure that it landed fuze first.

There were some functional similarities with the British Parlour grenade: both used a plunger or striker to hit a percussion cap to ignite the explosive; both used a mushroom extension on the external part of the striker to provide a crude all-ways functionality; and both used a tail to help the head of the grenade hit the ground at such an angle that the detonator functioned as intended. Whereas the Ketchum was used operationally, the Parlour only existed as a lone prototype.⁴⁷ Here was an instance of two inventors finding similar solutions to the same problem, namely that of dispensing with the time fuze for something efficient, only to encounter another problem, that of how to ensure reliable operation of the mechanism. The Ketchum had a reputation for poor functionality; Union troops complained

that it often failed to detonate.⁴⁸ Confederate troops laid out sheets of fabric to prevent the fuze from striking a hard surface, an expedient that was rediscovered by German troops during the First World War in response to British and French percussion-fuzed grenades.

Hand grenades were used in riverine and naval operations as well as in sieges, including the one at Vicksburg in 1863.⁴⁹ Technical deficiencies of Civil War hand grenades aside, the difficulties experienced by Union troops trying to storm the Confederate defences at Vicksburg using hand grenades highlighted the need for a coherent tactical system for their use, one which took account of the technical deficiencies.⁵⁰ However, hand grenades were used on an entirely ad hoc basis during the Civil War. Moreover, a tactical system was inhibited by the fact that more than one type of grenade was in use and each one required a different handling procedure. Thus, technical deficiencies limited operational use.

The deficiencies of the Ketchum highlighted a problem that dogged all subsequent percussion-fuzed grenades; in order for the fuze to function correctly, it needed a reliable all-ways capability which increased the complexity of the fuze. An all-ways capability meant that the device would detonate irrespective of how it hit the ground. In England in the 1830s and in America in the 1860s, there was no incentive to invest time and effort in trying to perfect something which was of little importance to the armies concerned. It is significant that these devices were all invented by individuals unconnected with the munitions industry. In one sense, this gives some credence to the notion of the crackpot inventor pestering wiser men with his harebrained contraptions. What he lacked, however, was not sense, nor, indeed, skill, but the imperative to succeed: the need for such a device was lacking.⁵¹

It is clear that the concept of all-ways functionality was known to be important to the utility of the percussion-fuzed grenade and, indeed, to its reliability. Other American inventors of such grenades tried to tackle the all-ways question with more creative solutions than that attempted by Parlour and Ketchum. Perhaps the most bizarre and the most dangerous was the solution adopted by an inventor called Hanes in 1862.⁵² The Hanes Excelsior grenade had fourteen hollow spikes, each surmounted by a percussion cap, radiating from a sphere which contained the explosive. This assembly was contained in a two-part casing which was intended to act as a striking surface for the caps. The idea was that, irrespective of how the device landed, one of the cap-surmounted spikes would strike the casing; the flash from the exploding cap would travel down the spike into the gunpowder and cause the device to explode. Herein lay its biggest drawback. Without some form of safety mechanism to prevent accidental detonation, percussion fuzes will detonate whenever they strike a hard surface. In the Hanes, this danger was compounded by the large number of percussion fuzes and further heightened by the fact that, unless the active part of the grenade was suspended within the casing, for which there was no provision, at least one of the caps was always touching it. Evidently, there were accidents with the device and it was rarely, if ever, used in action.⁵³ This problem highlighted another essential requirement of percussion-fuzed grenades: a reliable safety mechanism. The device had to be safe to handle so that it only detonated after it had been thrown. This, again, increased the complexity of such a device.

In 1865, John Adams of Massachusetts was granted a US patent for a time-fuzed grenade that used a friction lighter.⁵⁴ The end of the lighter was clipped to a strap which had a loop that went round the wrist of the throwing arm; as the grenade was thrown, a friction wire was pulled out through a match composition, lighting the fuze.⁵⁵ The object of this arrangement, according to the US patent, was to obviate the problems of wet fuzes and accidental ignition. The Adams grenade was a much more sophisticated device than any of the contemporary percussion grenades. It included several novel features: it allowed for the escape of combustion gases from the burning fuze to prevent premature detonation due to flash-through;⁵⁶ it incorporated a safety slot to prevent the igniter being pulled accidentally; and it used a waterproof cap to prevent the ingress of moisture to the fuze prior to use. These refinements suggest that the device had undergone a process of development before being patented and infer a sophisticated evaluation methodology. The Adams amply demonstrated how an inventor could provide a novel solution to a known problem, namely the unreliability of time fuzes. It is significant that the crude and unreliable Ketchum appeared in the opening months of the war, while the technically superior and more reliable Adams appeared towards the end of the war.

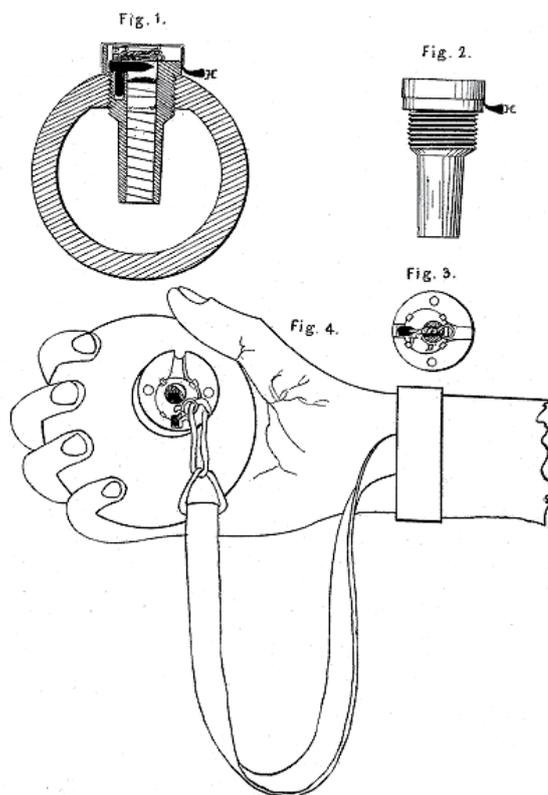


Fig. 5 Drawings from Adams's US patent, US45806. The sophistication of the fuze is evident

There is no evidence to indicate that the British took an interest in the novel hand grenades of the American Civil War although at least one British report described the Ketchum.⁵⁷ The French, on the other hand, adopted the Adams in 1870.⁵⁸ The British ignored hand grenades for the next forty years. There were only nine British patents relating to hand grenades between 1855 and 1904.⁵⁹ All but one of the specifications mentioned grenades so as not to exclude them from the scope of the patent, rather than because the invention was a new type of grenade.⁶⁰ The one British patent which was specifically concerned with hand grenades was granted to an American.⁶¹ The device it described, however, offered little of significance to the technology of hand grenades.

The Russo-Japanese War, 1904–05

Neither the Russians nor the Japanese went to war in 1904 equipped with hand grenades. The Russian defenders of Port Arthur were the first to improvise them.⁶² Initially, the grenades were made using a variety of containers of differing sizes and weights, including artillery shells and spent cases.⁶³ Provided the explosive was black powder, Bickford safety

fuze could be used to ignite the explosive but when high explosive was used, a detonator was needed; a burning fuze cannot generate enough energy to detonate high explosive because it is much more stable than gunpowder. This introduced a new element to grenade design. All of the grenades of the American Civil War had contained black powder and, thus, had not needed a detonator. Nevertheless, the grenades improvised by the Russians did not represent a technological advance; they were no more than extemporised versions of the traditional grenade. The use of high explosive in place of gunpowder was an obvious alternative given its availability.

The Russians had nine designs of grenade, including the traditional spherical iron bomb, while the Japanese had two designs.⁶⁴ The latter used the tin linings from biscuit boxes for the casings which were fashioned to the appropriate shape by Japanese engineers; again, this was extemporisation in the field using the materials that were to hand.⁶⁵ All but one of the Russian grenades used Bickford safety fuze; the exception was a device which used a quill friction lighter which was typically used on obsolete muzzle-loaded artillery.⁶⁶ Initially, the Russians over-estimated the length of fuze needed which enabled the Japanese to either remove the fuze before the device exploded or to pick it up and throw it back at the Russians. The Japanese made sure that their fuzes only burned for about 7 seconds, so that the device

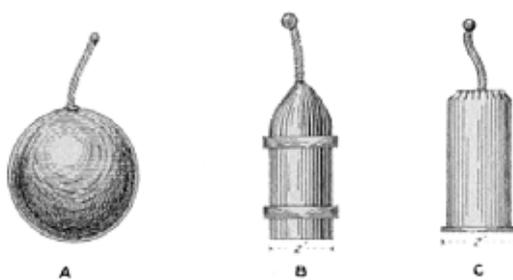


Fig. 6 Three of the hand grenades improvised by the Russians at Port Arthur. Left to right: cast-iron grenade, 4.5 inches in diameter; 2-inch shell with lead driving bands still in place; and cartridge case from a Hotchkiss shell. Whereas the first two could be loaded with the explosive from common shells or with dynamite, the third one was only loaded with dynamite. All were fitted with 3 inches of Bickford fuze which had to be sealed in place to prevent the ingress of moisture (WO 33/1520)

exploded about 1 second after landing. It gave the Russians no time to pick it up and throw it back.⁶⁷ This process of empiricism indicates the general lack of experience with hand grenades of both the Russians and the Japanese. Many of these grenades were too unwieldy or too heavy to throw far, although 20–25 yards seems to have been the average distance.⁶⁸

By the spring of 1905, a new type of grenade had been devised, first by the Russians, then by the Japanese after they captured one of the new Russian devices in March in the area of Mukden following the battle.⁶⁹ The new grenade was percussion-fuzed with a separate detonator and had a long wooden handle to enable it to be thrown further than the time-fuzed grenades. The Russian percussion grenade represented an inventive step forward from the state of the art.⁷⁰ Unlike the Ketchum of forty years earlier, this percussion grenade was thrown overarm. Whereas the Russian grenade may have been used in the battle, the Japanese copy of it was produced too late to see action so remained untried operationally. The Japanese device was supposed to have been invented by the Chief Engineer of the Second Japanese Army.⁷¹ The grenade had a cylindrical body, which contained the explosive, ringed with a lead band segmented for fragmentation.⁷² They were designed to be more lethal by producing more



Fig. 7 Japanese soldier in Manchuria with a percussion-fuzed hand grenade attached to his belt by a clip. It is not armed. Note the streamer wrapped round the end of the throwing handle. The handle is uppermost (WO 33/1524)

fragments on detonation than earlier designs.⁷³ Neither device incorporated a Ketchum-like mushroom extension to the striker but relied on trajectory to ensure that the grenade landed fuze first. This required a particular method of throwing to ensure that the grenade left the hand at a high trajectory so that it described a parabola which ensured that the grenade hit the ground at an angle close to the perpendicular. The incorporation of a handle shows that some thought had gone into throwing range: a handle increased the moment of inertia as it left the thrower's hand and, hence, increased its momentum so that it travelled further.

The Japanese grenade used streamers which played out behind to ensure that the grenade landed fuze first, a refinement that had already been used in the American Civil War, but which must have caused drag so that range was impaired. These grenades were improvised from materials that were readily to hand from the battlefield, including Russian ammunition boxes which were cannibalised by the Japanese.⁷⁴

The Japanese claimed, somewhat implausibly, to have had no accidents with theirs during 'practice'.⁷⁵ Accidental detonations due to carelessness and inexperience after the grenade had been armed were common with percussion-fuzed grenades. However, the grenade might fail to explode because the device had been incorrectly armed in the heat of the moment.⁷⁶ These lessons were learned by the British when they experimented with percussion-fuzed devices following the Russo-Japanese War. The Russians evidently disliked percussion-fuzed grenades because they were so dangerous to handle. This led to their improving the method of ignition of time fuzes to make them more reliable.⁷⁷ That both the Russians and the Japanese inserted the detonators in the percussion-fuzed grenades immediately prior to use, shows that they were well aware of their inherent dangers of armed percussion-fuzes. Once armed, such a grenade will detonate if it strikes a hard surface, irrespective of whether it has been thrown, dropped or casually knocked against something. Yet, detonation was never assured when the grenade was thrown in anger: hence, the need for some kind of all-ways functionality. The diametrically opposed requirements of safety and all-ways functionality could not be met by the simple mechanisms employed in these devices.

It is unclear how many grenades were used during the war but they were almost entirely, if not exclusively, time-fuzed devices. In excess of 44,000 hand grenades of all types were used by five Japanese divisions in the course of the siege of Port Arthur.⁷⁸ This is less than 9000

grenades per division over a period of about six months, July–December 1904; in other words, about fifty grenades a day for a whole division. This was not a high expenditure. In June 1905, the engineers of the Second Japanese Army were reported to be making 4000 percussion grenades.⁷⁹ As in the American Civil War, there seems to have been no tactical system for the use of hand grenades. Certainly, the small numbers involved, as implied by the Japanese expenditure at Port Arthur, suggest that they used on an ad hoc basis. Reports of fighting in Manchuria in which grenades figured indicate that defenders threw grenades out of trenches at their attackers, who were above ground, while attackers threw grenades into trenches but it is unclear whether trench-to-trench throwing or grenade exchanges occurred.⁸⁰

Japanese troops found hand grenades to be very effective in siege operations. However, they discovered that aggressive attacks on Russian positions using grenades were only successful when combined with supporting rifle fire.⁸¹ This was a significant tactical point but no report expanded upon it. There is no clear evidence to indicate whether the effect of grenades was moral or physical, however. One British report emphasised the fact that grenades had a considerable moral effect on troops that were crowded together.⁸² Experiments with the Japanese percussion grenade showed that fragments could travel up to 150 yards but the size and velocity of such fragments were not recorded.⁸³ It is not possible at this remove to make any meaningful comments about lethality without more specific data although it was claimed that the lead band broke up into thirty-six pieces, corresponding to the number of segments in the band, but this is highly unlikely.⁸⁴ The construction of the earlier devices implies a relatively low lethality because they would have produced few fragments of significant size, relying on blast alone for effect. Some of the 6 per cent of miscellaneous casualties that had occurred up to December 1904 were claimed to have been caused by grenades.⁸⁵

Innovation in Manchuria

The mortar has been used in siege warfare since the fifteenth century. It is a high-trajectory weapon capable of dropping projectiles over defensive structures and into trenches; hence, its utility in siege operations. The field gun, on the other hand, fires with a flatter trajectory and was used to batter breeches in defensive positions. Whereas a field gun comprised a barrel mounted on a carriage fitted with wheels, a mortar comprised a short heavy barrel set in a heavy wooden frame which lacked wheels. Once set up in a given position, a mortar was not moved until it had done its job.⁸⁶

A light mortar was introduced by the Japanese in early October 1904.⁸⁷ It was not a variation on the siege mortar but was derived from devices used for firework displays in Japan.⁸⁸ It was a feeble weapon. Its only advantages were cheapness and portability. Like a traditional mortar, it was slow to load and fire but it was sometimes spectacular to watch.⁸⁹ Its effect appears to have been more moral effect than material and it was very inaccurate. One British observer thought that its inaccuracy was, perhaps, an advantage since those on the receiving end did not know where the next bomb was going to land, thus, damning it with faint praise.⁹⁰ Neither he nor any other British observer suggested that the British might like to experiment with light mortars of their own.

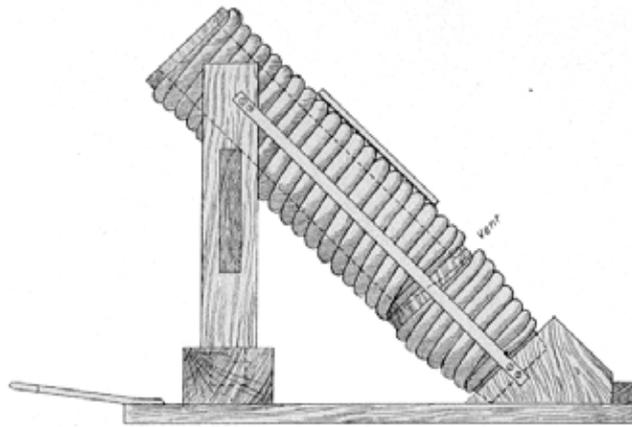


Fig 8 *Japanese light mortar used at Port Arthur. This drawing shows that it had a fixed elevation and no traversing capability* (WO 33/1520)

The barrel was improvised from four strips of fir, wound with bamboo cane.⁹¹ These materials had been chosen for their cheapness and lightness; the barrel and stand only weighed 90 lb, allowing the device a degree of mobility that was impossible with siege mortars.⁹² They were easy to make in the engineer workshops at Port Arthur and the Japanese had skilled coopers accustomed to using these materials.⁹³ The 5-inch mortar fired a 4.5 lb bomb, of which 3.5 lb was explosive,⁹⁴ and had a range of 100–400 yards depending on the size of the bagged propellant charge used. These came in five sizes from 10 g to 50 g.⁹⁵ This method of range adjustment was used with conventional mortars and would have been familiar to the gunners in Marlborough's army. The Japanese sometimes fired incendiary bombs from the mortar to ignite the sandbags of the Russian trenches.⁹⁶

The use of a wooden barrel for a mortar was not new. Wooden-barrelled mortars had been improvised by the Union Army engineers at the siege of Vicksburg in 1863.⁹⁷ Logs of seasoned gumwood were cut to length. Bands of iron were then shrunk on to each end before the logs were bored to the appropriate calibre.⁹⁸ Such devices were quite capable of withstanding repeated firings because only small propellant charges were used, although this restricted the range to about 100–150 yards.⁹⁹ Nevertheless, this was sufficient to reach the Confederate lines at Vicksburg. Some 468 shells of 6 lb and 12 lb were fired from three such mortars into the Confederate positions, over a period of 48 hours, causing more than ninety casualties.¹⁰⁰ Although there was no link between the American and Japanese mortars, nevertheless, it is clear that similar solutions to similar problems had been found: the sudden need for a high-trajectory weapon had been improvised on the spot using a plentiful resource, namely wood. The significance here is that such mortars were low-pressure devices. Guns and traditional siege mortars are high-pressure devices.

The success of the Japanese wooden mortar led to the development of a smaller, more compact, mortar, the Nakamura, named after its designer.¹⁰¹ This was intended to be easily transported so that it could be taken forward with the infantry in an attack.¹⁰² This was an innovation since, hitherto, no mortar had been designed with this in mind. Although steel was used in place of wood, its construction was based on that of the wooden mortar: four steel plates were held together with wide steel bands top and bottom to form a tube. The mortar weighed only 36.44 lb so it would have been entirely feasible to carry the weapon forward in an attack.¹⁰³ Nakamura also developed tactical procedures for the mortar.¹⁰⁴ The mortar was

never used in battle so its performance and Nakamura's tactics remained untested.¹⁰⁵ With the end of the war, interest in the Nakamura faded and nothing more was heard of it. A question which, thus, remained unanswered was how well the device would have withstood operations. The joints between the plates would have been the weakest aspect of the design: dirt could ingress between the plates while propellant gases could egress, unless the seal between them was gastight, otherwise gas leakage would have had an unpredictable effect on range for each shot. The integrity of the design might well have proved sound, since iron guns had been constructed in a similar fashion before the widespread use of forging techniques in the seventeenth century, but no subsequent designer adopted a similar approach to low-pressure barrels. Although absence of evidence is not definitive, it is, nevertheless, significant. Thus, it may be fair to speculate that the Nakamura approach to mortar design was, indeed, a dead-end. It had the advantage of simplicity since it obviated the need for casting and machining operations in the manufacture of the barrels, neither of which would have been feasible for the Japanese in Manchuria.

The Russians also used improvised light mortars.¹⁰⁶ In February 1905, the Russians were reported to be experimenting with a light mortar made of aluminium and 'shaped like a horn'.¹⁰⁷ A firm in St Petersburg had evidently been contracted to make 100 mortars and 10,000 rounds. Each round was supposedly fired by a 12-bore shotgun cartridge inserted into the 'narrow end' of the muzzle-loaded mortar but it is unclear how the cartridge was supposed to have been loaded.¹⁰⁸ Neither is it clear how the device would have been fired. The weapon reportedly had a calibre of 4.5 inches while the bomb only weighed 1 kg.¹⁰⁹ Such a light bomb would have contained very little explosive and, thus, would have caused little damage. There appears to be no evidence that the device was anything more than conjecture or was, perhaps, false intelligence intended to fool the Japanese.

It is difficult to assess the effectiveness of these mortars. Operational accounts tend to be second-hand and anecdotal; there is at least one instance of a Japanese mortar reportedly beating off a Russian attack with a single round.¹¹⁰ The Japanese used 103 5-inch and twenty-three 7-inch mortars at Port Arthur, firing a total of 1090 common shells (the 7-inch mortar only fired twenty of them) and 10,415 specially made bombs (9857 by the 5-inch mortar, 558 by the 7-inch mortar), as well as 519 incendiary rounds.¹¹¹ There appears to be no information about the destructiveness of these weapons but the Japanese evidently believed the mortar to be effective and looked into fielding a mortar corps. The war ended before this could be pursued.¹¹²

Consequences of the Russo-Japanese War

In the 1880s, the British had not quite abandoned the idea of using hand grenades in defence of fortifications. Royal Engineers manuals of the time advised that a store of grenades should be kept for defence.¹¹³ Nevertheless, the British army had little interest in improving the devices. Throughout the nineteenth century, the Ordnance Board had politely resisted the efforts of inventors to persuade it of the utility of their grenades. In 1902, the War Office finally decided that hand grenades had no place in a modern army and declared them obsolete.¹¹⁴ However, barely two years later, in October 1904, following the first reports of

hand grenades in Manchuria, the Chief Superintendent of Ordnance Factories (CSOF) was instructed by the War Office to design a hand grenade.¹¹⁵ Clearly, something had occurred to change British opinion about the utility of hand grenades.

The British decision about grenades was but one of several concerning trench warfare matériel in the early years of the twentieth century. The British experience in South Africa highlighted a need for a number of trench warfare devices. These included armoured trench shields, adopted in 1902, wirebreakers, adopted in 1912, and periscope rifles.¹¹⁶ The latter were not taken up but one inventor, William Youlten, was clearly motivated by the demands of trench warfare in South Africa to experiment with such devices.¹¹⁷ Despite the fact that the British army did not anticipate becoming involved in siege operations, its attitude towards such devices was clearly changed by the Boer War. These devices were not novel; shields, for example, had been a part of siege operations for centuries¹¹⁸ and the Americans had experimented with periscopes in the Civil War.¹¹⁹ Although the British, like the continental armies, tended to emphasise the attack in tactical matters, nevertheless, by the end of the nineteenth century and the beginning of the twentieth, there was a growing awareness that trenches would feature in any future war. Thus, the British experience in South Africa made the War Office more receptive to new ideas concerning trench warfare devices. However, the British viewed such devices as specialist munitions to be handled by specialists, namely Royal Engineers, rather than by infantry. The Royal Engineers were expected to train infantrymen in the use of hand grenades as required.¹²⁰ This approach was followed until about May 1915 when the imperative to organise training on a more systematic basis led to the setting up of bombing schools in Britain and France in which the same methods for handling and using grenades were taught.¹²¹

The first attempts by the Royal Laboratory, Woolwich, to devise a new hand grenade were time-fuzed devices.¹²² They were far from satisfactory. When Lieutenant-Colonel Haldane, one of the British observers attached to the Japanese army in Manchuria, returned to Britain following the end of the Russo-Japanese War, he brought back one of the Japanese percussion-fuzed grenades with him. The Royal Laboratory used this device as the basis of a new pattern. It is unclear why a percussion-fuzed grenade should have excited such interest when there was no body of evidence to suggest that the device was suitable for service use. However, it is significant that inventors in the American Civil War, the Russo-Japanese War and subsequently in Britain, up to and following the outbreak of the First World War, held the percussion-fuzed grenade to be an ideal to which grenade designers should aspire.¹²³ This view seems to have been a reaction to the unpredictability of time fuzes and their susceptibility to moisture damage which could render them useless but it completely ignored the inherent dangers of percussion-fuzed hand grenades. In 1907, the dangers of handling any kind of percussion grenade were specifically raised by an officer who had been attached to the Japanese army during the Russo-Japanese War and had seen the grenades being used. He advised against them.¹²⁴

The British percussion grenade went through three designs, each an improvement on the last, before what was to become the Percussion Grenade No. 1¹²⁵ was presented to the Director of Artillery (DoA) for evaluation in June 1906.¹²⁶ The No. 1, a somewhat over-engineered copy of the Japanese percussion grenade, was adopted by the Army in 1908.¹²⁷

About 420 were manufactured before the outbreak of the First World War.¹²⁸ Considering the numbers of grenades used in Manchuria, this was a paltry figure. Clearly, the device was not considered to be important to the kind of military operations in which the British army envisaged becoming involved. Moreover, the devices had been dismissed by Haldane in his report on Japanese infantry tactics as irrelevant to European warfare: they were weapons of ‘fortress fighting’ and would only be useful if the British army was going to fight the Russians, a reference to old enmities and to the apparent preference of the Russians for fighting from prepared positions.¹²⁹ This raises the question of why so much effort should have been expended on a device which was of little military interest.

Fig. 9 (below left) No. 1 hand grenade. On the left, is a Mk I, introduced in 1908. The short handle of the Mk II was an attempt to solve the problem of throwing the device in a trench. On the far right is a cut-away model of the Mk II. The cast iron ring round the grenade body was supposed to produce lethal fragments on detonation. The wire loop is for hanging the grenade from a belt. Note the transit cap and safety pin (MUN 5/383/1600/14)

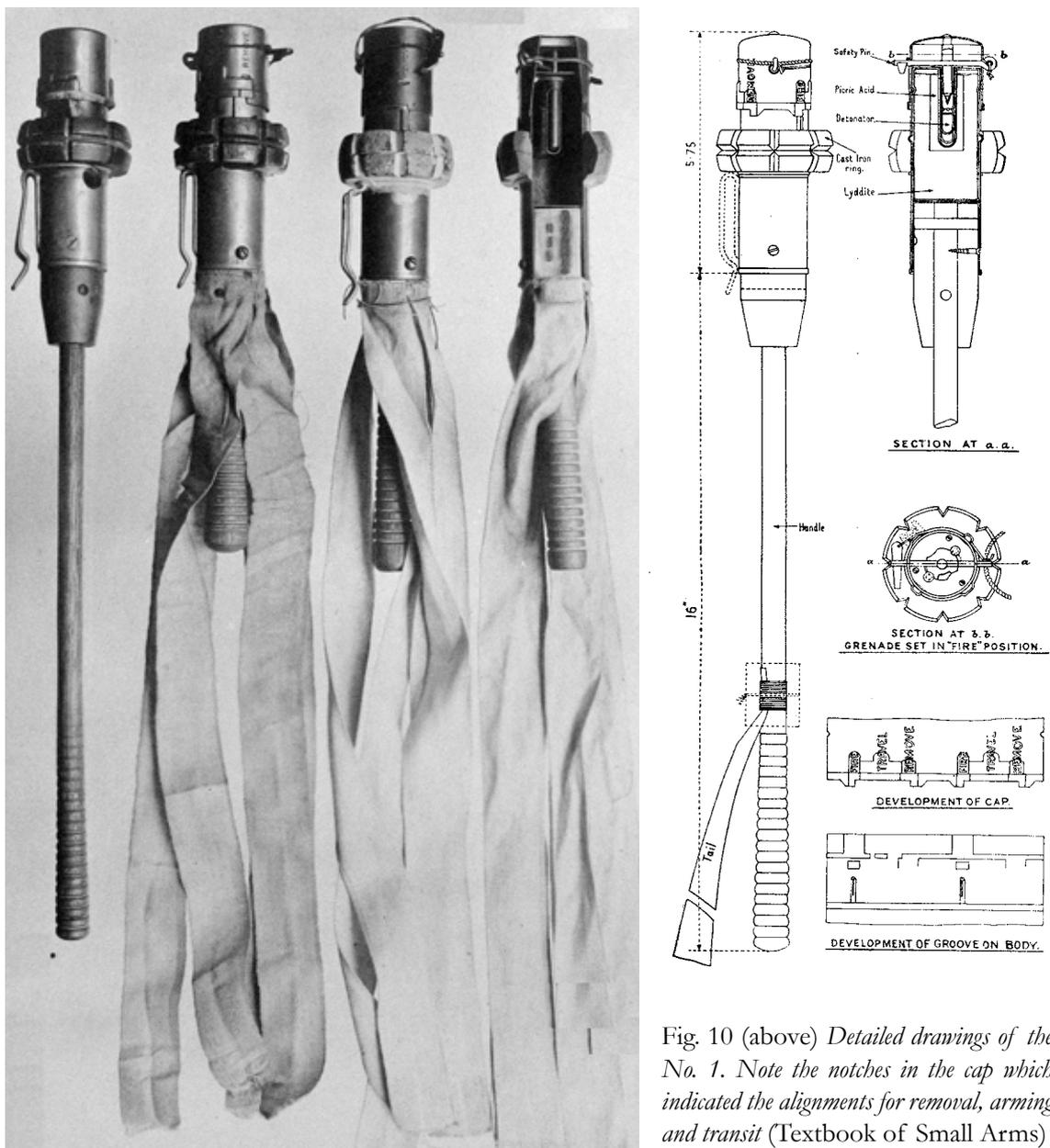


Fig. 10 (above) Detailed drawings of the No. 1. Note the notches in the cap which indicated the alignments for removal, arming and transit (Textbook of Small Arms)

Commercial drive, 1905–14

At the same time that the Royal Laboratory was struggling to develop a hand grenade, Frederick Marten Hale started work on a design of his own. Marten Hale was an inventor with considerable experience with explosives and was a director of the Cotton Powder Company, a commercial manufacturer of explosives for mining and the military.¹³⁰ He did not reveal how he became interested in the percussion-fuzed hand grenade.¹³¹ He might have been inspired by reports of the grenades in Manchuria and he might well have seen the Japanese grenade brought back by Haldane. He certainly discussed grenades with at least one Japanese officer but it is unclear whether this was in 1906 or 1908.¹³² He recognised the commercial potential of such a device and patented his grenade in 1906.¹³³

The War Office did not want Hale's hand grenade.¹³⁴ They considered it inferior to the Royal Laboratory device and claimed that it was liable to misfires.¹³⁵ Whether Marten Hale's grenade was more dangerous and less reliable than the Royal Laboratory design is a moot point since neither was safe or reliable. Even after Hale improved his device and persuaded the CSOF to witness a demonstration of the improved version at the Cotton Powder Company's Faversham works in 1908, it was still declined as unsuitable on the grounds that it was difficult to throw in a trench.¹³⁶ This was a rather fatuous objection given that the Royal Laboratory and the Hale grenades were of similar form and each suffered from the same drawbacks. There was little to choose between them in terms of functionality, utility and reliability. Clearly, these were merely excuses. As far as the War Office was concerned, the Royal Laboratory device scored over Marten Hale's simply by virtue of ownership; adoption of the Hale grenade would have been more expensive because it was not government owned.

In 1908, Marten Hale invented and patented a hitherto unknown device, the rodded rifle grenade.¹³⁷ He claimed the idea came to him when he considered what might happen if a ramrod was shot out of a rifle barrel.¹³⁸ The idea of projecting a grenade further than a man could throw one was not new. Indeed, cup attachments for muskets dated from the seventeenth and eighteenth centuries but the concept had been abandoned because it was unreliable and dangerous for the firer.¹³⁹ Marten Hale's device was the first novel grenade-projecting means to be devised for about 200 years. The concept of projecting a grenade from a rifle barrel by means of a rod inserted into the barrel and fired by a blank round was ingenious and represented an inventive leap.¹⁴⁰ The Cotton Powder Company offered the



Fig. 11 Military and naval attachés of the principal foreign governments pose with Marten Hale (far right holding rifle) at the Faversham works in 1908. This was the first public demonstration of his rifle grenade (T 173/252)

rifle grenade to the War Office in July 1908.¹⁴¹ The Chief Draughtsman at Woolwich referred disparagingly to it as ‘a crazy and audacious monstrosity’ that would burst the barrel when fired from a rifle.¹⁴² Shooting rodded rifle grenades certainly put the barrel under greater stress than it was originally intended to withstand when firing conventional ball ammunition. Moreover, rifles used for firing rodded grenades could not be safely used for firing ball ammunition as well, although this may not have been known at the time. Nevertheless, the objection was based on ignorance rather than on a proper understanding of the device. Commercial concerns aside, it betrayed an unwillingness to embrace unsolicited submissions from ‘crackpot’ inventors.

Improvements in British patent law during the second half of the nineteenth century meant that it had become commonplace to patent and market inventions, so Marten Hale was doing nothing out of the ordinary. In the 1880s, Hiram Maxim had taken a salesman’s approach to persuading potential customers to buy his machine-gun, organising dramatic demonstrations of its power. Nevertheless, Marten Hale was probably first to market a new munition as though it were a bicycle or a bar of soap. He placed advertisements in journals and newspapers, produced glossy leaflets and fliers, gave interviews to journals such as *The Illustrated London News* and to local and national newspapers.¹⁴³ He also sent letters to the War Office as well as to the representatives of foreign governments to persuade those with the authority to procure equipment that his device was not only worthy of attention but better than anything similar which might subsequently be offered to them.¹⁴⁴ At that time, of course, Marten Hale had a monopoly, not merely because of his patents, but because no one else in Britain was making rifle grenades.

Marten Hale was not someone to be easily deterred and he persisted in his attempts to interest the War Office in both his hand grenade and his rifle grenade. Between July 1908 and June 1909, the Cotton Powder Company approached the War Office on four occasions, arguing that the rifle grenade was something which the army ought to have in its arsenal.¹⁴⁵ In 1910, the company managed to persuade the War Office to undertake trials with fifty rifle grenades but the Ordnance Board thought the service hand grenade was a better device and the Hale was turned down in October of that year.¹⁴⁶ This suggests that the War Office saw the rifle grenade as an alternative to the hand grenade rather than as complementary to it. Then, the War Office suddenly became interested in the concept of a grenade fired from a rifle and instructed the Royal Laboratory to develop one. It is not clear why the War Office changed its mind. Someone in the War Office may have realised the potential of the rifle grenade or, more likely, the War Office wanted to counter the growing dominance of Marten Hale in this new field of munitions. The War Office was clearly reluctant to commit itself to buying munitions from a commercially aggressive supplier with a strong portfolio of patents.

In 1911, the Cotton Powder Company tried twice more to interest the War Office in the rifle grenade, pointing out that the device had been improved.¹⁴⁷ Again the grenade was turned down. In the meantime, experiments continued with a CSOF design based on the service hand grenade. By 1913, the improved Hale was deemed superior to the products of

THE
COTTON POWDER COMPANY, LTD.
 JANUARY, 1913. 24, WALBROOK, LONDON, E.C. JANVIER, 1913.

"F. MARTEN HALE'S"
 PATENTS.
 DESIGN "J."

LATEST SAFETY DESIGN.
 RIFLE-PROPELLED
 AND
 HAND-THROWN

**Military
 Shrapnel
 Grenade.**

Maximum Range, 300-500 yards.

The Best Fragmentation.

Sensitive Impact.

Explodes on Water, Soft
 Earth, Snow,
 At any angle of incidence.

Weight of Grenade, 23 ozs.



Fig. 1.

BREVETS
 F. MARTEN HALE.
 MODÈLE "J."

**Grenade
 Militaire
 à
 Shrapnel.**

LANCÉE AU FUSIL
 OU À LA MAIN.
 TYPE DE SURETÉ.
 DERNIER MODÈLE.

Portée Maximum 275 à 460 mètres.

Fragmentation la Meilleure.

Sensible au Choc.

Explosion sur l'Eau, la Terre
 Meuble, la Neige,
 Et sous n'importe quel angle.

Poids de la Grenade, 650 grammes.

Telegrams and Cables:
 "Tanta, London."

WORKS: FAVERSHAM, KENT, and MILLING, LANCS.
 (Established 1872.)

Telephone, P.O.
 Central 7912.



Fig. 12 (above) Leaflet advertising Marten Hale's patented rifle grenade. It is in both English and French to ensure that most potential clients would be able to read it (WO 32/18989)

Fig. 13 (right) The Marten Hale rifle grenade fitted with its rod. Note the muzzle clip which was designed to clasp the muzzle of the SMLE. This unnecessary accessory demonstrated how the device was over-engineered (Author's photograph of specimen in Norman Bonney's collection)

Fig. 14 (left) The arming vane which was the cause of prematures when it failed to work properly. Note the safety pin projecting through the collar below the vane. Air passing through the vane caused it to rotate and thereby release the firing mechanism (Author's photograph of specimen in Norman Bonney's collection)



these experiments and further trials were ordered with another fifty Hale rifle grenades. By October, the Ordnance Board proclaimed Hale's rifle grenade to be acceptable and troop trials were ordered.¹⁴⁸ It had taken five years to get this far; the War Office had failed to establish an independent supply of the new rifle grenade. However, as with the hand grenade, which it had adopted a few years earlier, there was little enthusiasm for the device although the War Office was still trying to develop its own rifle grenade when war broke out. In 1914, the War Office complained that it was practically impossible to develop a rifle grenade of its own without infringing Marten Hale's patents.¹⁴⁹ In 1915, the Ministry of Munitions complained about the same thing.¹⁵⁰ In August 1914, the British army had an unopened box of fifty rifle grenades, the number ordered from the Cotton Powder Company following the army's acceptance of the grenade the previous year.¹⁵¹ These had been supplied only a few months earlier.

Marten Hale's dominance of the field, which he had achieved by dint of commercial acumen, highlighted the shortcomings of the pre-war approach to developing new munitions which allowed arms manufacturers to do most of the work. It demonstrated that a privately funded research and development programme could leave the government in the invidious position of having little control over what was supplied to the army in the field. Marten Hale was granted eleven patents relating to hand and rifle grenades between 1906 and the outbreak of the First World War.¹⁵² He had a monopoly in Britain which he defended vigorously against occasional challenges from other companies and the Ministry of Munitions during the war.¹⁵³ Neither was Marten Hale content merely to pursue the British market; over the period 1908–13, he arranged demonstrations at the Faversham works for representatives of eighteen countries, including France, Germany, Russia, Mexico and Spain.¹⁵⁴

Germany adopted a rifle grenade in 1913.¹⁵⁵ Although the Cotton Powder Company had sold a number of its rifle grenades to Germany for trials in 1911,¹⁵⁶ the German grenade was not a version of the Marten Hale device.¹⁵⁷ Marten Hale probably did more than anyone to promote the hand grenade and the rifle grenade, not only in Britain, but throughout the world and especially in Europe. His aggressive marketing of the rifle grenade led to its adoption by several foreign governments.

It is perhaps significant that the first nations to adopt the rifle grenade and use it were not major European powers who were likely to fight a major European war. The rifle grenade was first used by Spanish forces in Morocco in 1909,¹⁵⁸ in a colonial conflict of no military significance other than for the operational debut of the rifle grenade. This went largely unnoticed or, at least, unremarked. In 1912, the Mexican government ordered 25,000 rifle grenades for suppressing riots.¹⁵⁹ Hale may have been making money from such sales but he was hardly promoting the rifle grenade as a serious munition for professional armies. The British army had little idea of what it was going to do with its rifle grenades and hand grenades; there was a vague notion that they might be useful in trench fighting. Until such time as a large supply of both rifle and hand grenades became available, no tactical or operational system was likely to be developed. Unfortunately, this seems to have become a circular argument: without a clear idea of how they might be used, there was

no demand for such devices; there was no demand because no one knew what to do with them because there were not enough of them.

Marten Hale was not the only entrepreneur to take up the grenade during the first decade of the twentieth century. Indeed, a Norwegian called Niels Aasen was a competitor. He was granted two British patents for grenades in 1907 and another in 1911 (*see* Table 1, p. 54). He was subsequently granted another in 1915.¹⁶⁰ A Danish company, MM Defenseur of Copenhagen,¹⁶¹ tried to persuade the British government to buy Aasen's grenades in early 1914.¹⁶² The DoA scheduled a trial to be conducted at Woolwich but it was postponed after the outbreak of war. In March 1915, trials eventually took place in France, and subsequently at Woolwich, with three types of Aasen grenade.¹⁶³ The DoA disliked the safety device on Aasen's Excelsior grenade. None of Aasen's grenades was taken up by the British despite numerous trials with different explosive fillings. The Directorate considered using one type of Aasen grenade in an early type of trench mortar but nothing came of it.¹⁶⁴ Aasen had better luck with the French who, at the time of the March trials, were producing 1,500 Excelsiors a day which was about to be increased to 10,000 a day.¹⁶⁵ The Germans, it seems, also used Aasen grenades in 1915. British grenade manuals describe it as a German device while there are photographs of French soldiers carrying it.¹⁶⁶ That is not to suggest that the British had been wrong to turn it down, merely that all armies were desperate for grenades in the first year of trench warfare.

Few other inventors turned their minds to grenades in the years between the end of the Russo-Japanese War and the start of the First World War, suggesting that this was an area of little interest to engineers. Before the Russo-Japanese War, there were no British patents relating to 'modern' grenades and there were practically none relating to the traditional type. In 1905, there were two patents which claimed to be concerned with grenades, although this was stretching a point. In 1906, there was only Hale's hand grenade patent. In 1907, there were three patents; two were granted to Aasen and another one was for a percussion fuze which was claimed to be relevant to grenades. In 1908, the only grenade patent was granted to Hale, the first patent for a rifle grenade. He had filed three applications that were subsequently joined, resulting in a single patent¹⁶⁷ (*see* Tables 1 and 2, p. 54). There were no hand grenade patents in 1909 but another three rifle grenade patents were granted to Hale. Aasen was granted a rifle grenade patent in 1911, while Hale was granted three more rifle grenade patents that year, and two other rifle grenade patents were granted. Hale's patents show the development of his rifle grenade as he tried to solve problems of reliability and safety. In 1912, there were two patents, both concerned with rifle grenades. In 1913, there were four patents, two for hand grenades, two for rifle grenades. There were two more rifle grenade patents in 1914, applications for both of which were submitted before the outbreak of war.

Thus, between 1905 and the outbreak of war in August 1914, a total of eight patents were granted in respect of hand grenades and a further eighteen were granted in respect of rifle grenades, making a total of twenty-six, some of them only tenuously connected with grenades. In 1915 alone, twenty-two patents were granted in respect of grenades.¹⁶⁸

Table 1. British patents relating to hand grenades, 1905–13¹⁶⁹

Priority Date	Patent Number	Applicant(s)	Description
9/8/05	GB16192/05	B F S Baden-Powell ¹⁷⁰	Mentions use as a grenade but more like a scatter mine
2/6/06	GB12580/07	N W Aasen	Percussion-fuzed hand grenade with bamboo shaft and fabric wings
2/6/06	GB12926/07	L Diederichs	Percussion fuze for shells that is also claimed for grenades
25/6/06	GB14605/06	F M Hale	Percussion-fuzed hand grenade with rope or stick handle
11/12/06	GB12657/07	N W Aasen	Improvement to GB12580/07
23/4/09	GB9659/10	Siemens Bros & Co C R Riber	Percussion fuze that can be used in a grenade
9/4/13	GB8371/13	F Eichbauer	Hand grenade with percussion fuze
18/8/13	GB18766/13	L Roland	Grenade with automatic igniter for time fuze

Table 2. British patents relating to rifle grenades, 1905–14¹⁷¹

Priority Date	Patent Number	Applicant(s)	Description
6/10/05	GB20238/05	B Pedersen	Possibly broad enough to cover rifle grenades
15/7/08	GB15045/08 (cognate 1776/08, 17960/08)	F M Hale	First rifle grenade patent
11/3/09	GB18425/09	W Berger	Rifle grenade percussion fuze
15/5/09	GB11561/09	F M Hale	Gas-check on rod of rifle grenade
3/12/09	GB10494/09	F M Hale	Illuminating rifle grenade
15/12/09	GB29292/09	F M Hale	Cartridge for reducing flash when firing rifle grenade
6/2/11	GB3007/11	N W Aasen	Percussion fuze and grenade
25/2/11	GB4690/12	R Machenbach	Rifle grenade and fuse which is armed as the rod is inserted into the barrel
27/2/11	GB4925/11	F M Hale	Improvement to GB15045/08; concerned with safety mechanism
8/5/11	GB11096/11	H F Donaldson C C Noot W Charlesworth	Rifle grenade with stops on rod to adjust range
27/7/11	GB21792/11	F M Hale	Improvement to GB15045/08; concerned with safety mechanism
29/11/11	GB26764/11	F M Hale	Improvements to GB15045/08, GB4925/11 and GB21792/11; safety vane
30/12/11	GB29014/12	G Roth Akt-Ges	Rifle grenade with time fuze with safety used on percussion grenades
15/2/12	GB2615/13	R Machenbach	Gas-check on rod
20/6/12	GB14431/12	E Cremonesi	Rifle grenade with bearing between rod and head to prevent head rotating in flight
30/4/13	GB10219/13	F M Hale	Improvement to GB15045/08; safety
23/6/13	GB13688/14	Carbonit Sprengstoff Akt-Ges	Gas-check for rod; void, published under Section 21 of 1907 Act; may have been used on German M1914 rifle grenade
28/3/14	GB7935/14	F M Hale	Improvement to GB15045/08 and GB26764/11; preventing movement of safety vane until gun fired

Between 1905 and August 1914, a number of German nationals were granted British patents in respect of grenades. The DoA, which had responsibility for grenades, took no interest in the German devices until after the outbreak of war, an apparently curious lapse of intelligence.¹⁷² At least one German grenade, the *Diskusgrenate*, was the subject of two US patents.¹⁷³ Again, it seems to have occurred to no one to scrutinise US patents to gain intelligence on enemy munitions, even after the outbreak of war. Yet, this was perhaps unsurprising given the lack of interest in Britain in grenades prior to the First World War. About a year after the outbreak of the war, someone at last realised that patents were, indeed, a source of intelligence and steps were taken to prevent the publication of any British patent that might prove helpful to the enemy but no effort was made to look at existing patents held by enemy nationals in Britain or elsewhere. On 14 October 1915, the Comptroller-General of Patents was empowered to withhold publication of any specification, deemed by representatives of the Army Council, the Admiralty and, from May 1918, the Air Ministry, likely to aid the enemy. It was accomplished by the simple expedient of suspending acceptance of the patent application in question until the end of hostilities.¹⁷⁴

Looking forwards

Despite attempts by various British inventors to ‘improve’ the hand grenade throughout the nineteenth century, the British army showed no interest until the Russo-Japanese War when military observers wrote of its potential for trench fighting. The growing importance of entrenchments during the nineteenth century and the British experience of trenches in South Africa brought about a restrained interest in some of the devices of trench warfare. Thus, at the beginning of the twentieth century, the British were prepared to develop a hand grenade of the ‘new’ type from Manchuria on the principal that it might prove useful in the hands of the specialists, namely, Royal Engineers. There was no intention of training infantry to use hand grenades except on an impromptu basis.¹⁷⁵ Thus, the British army was ambivalent about such munitions. Even after it had adopted a service hand grenade and subsequently adopted the Marten Hale rifle grenade, it had no tactical doctrine for grenades. Neither was there an imperative to secure large stores of such munitions prior to a war. The utility of such munitions was seen as limited and confined to special circumstances which would require the services of the Royal Engineers.

The American grenade inventions of the Civil War period made no impact on British military thinking. Although the French adopted the time-fuzed Adams grenade, which was still in service in 1914, this was a ‘fortress grenade’ not a general service munition. It is significant that no one took up percussion-fuzed devices. Indeed, it would appear that, in America, they had been abandoned by the end of the Civil War.¹⁷⁶ Hand grenades did not figure significantly in the wars of the second half of the nineteenth century. However, the ‘success’ of such devices in the Russo-Japanese War led to all the major European powers re-adopting them over the next few years. The grenades developed in Britain in the years before the First World War bore only a superficial resemblance to the devices used in Manchuria and there was no technical link with the American devices of forty years

earlier.¹⁷⁷ Nevertheless, the No. 1 hand grenade represented only a minor step forwards in technological terms and it did not solve any of the inherent problems of percussion-fuzed hand grenades which had become apparent in America and in Manchuria.

Perhaps the greatest effect of the Russo-Japanese War grenades was to inspire some inventors, men such as Marten Hale, who saw the grenade as a business opportunity. Thus, in Britain, grenade development was largely an entrepreneurial endeavour. The grenade was not taken up by the established armaments firms. The Royal Laboratory, the government's armaments research facility, laboured to develop a workable device. The impetus of commercial interest was more persuasive than military need in convincing governments that they ought to arm their troops with these munitions, which was not helped by the fact that, being new, there was no tactical doctrine for their use. This was most pronounced with the rifle grenade, a novel device quite unconnected with the Russo-Japanese War. It was the militarily weaker nations which first took up the rifle grenade rather than the dominant military powers.

The light mortar, introduced by the Japanese in Manchuria, was novel but a technological dead end. The British had no interest in such a device and no doubt believed that, should a need arise for plunging fire, conventional howitzers would be better suited to the job.¹⁷⁸ No British inventor tried to invent a mortar before the First World War. Only the Germans seem to have been impressed by the concept of a mortar that could be brought up to the front line in order to bombard the enemy sheltering in trenches. It is significant that it was established armaments firms which developed small mortars, rather than entrepreneurial individuals. In this context, the word 'small' is apposite since the devices were not 'light'; rather, they were scaled-down, less sophisticated, versions of howitzers,¹⁷⁹ albeit muzzle-loaded, and lacking carriages and wheels; the wheeled carriage was a detachable component. Nevertheless, in 1908 and 1910, Krupp patented a projectile unlike conventional ammunition for a muzzle-loaded mortar.¹⁸⁰ This had a steel stem or tail which fitted inside the barrel while the approximately spherical payload projected from the muzzle. The German army adopted mortars in 1910 and 1911 but they fired ammunition of a more conventional design.¹⁸¹

The attitude of the War Office to grenades and light mortars has to be viewed within the context of its attitude to the machine-gun, a novel device of the second half of the nineteenth century and, thus, contemporaneous with grenade and mortar developments. Prior to the First World War, the War Office saw no reason to assume that any of these munitions would make a difference to how the British army fought a future war as they were viewed as no more than ancillaries to conventional munitions. The British army had not been slow to adopt machine-guns, unlike the German army; the British took them up in 1891, the Germans in 1899.¹⁸² In Britain, financial considerations dictated that preference be given to conventional munitions and relatively few machine-guns were bought.¹⁸³ The utility of the machine-gun was always questioned. This argument applied equally to the light mortar, the hand grenade and the rifle grenade in the ten years leading up to the First World War. Moreover, the power of such devices seemed limited in the context of the sort of tactics in which the British army trained and the kind of war which it expected to fight. The

Russo-Japanese War demonstrated what these munitions might be capable of inflicting on an enemy but the evidence from Manchuria was equivocal which only served to reinforce the views already held by the War Office.¹⁸⁴ Indeed, the machine-gun, the hand grenade and the rifle grenade were viewed as defensive munitions rather than as munitions of the offensive, while the light mortar was clearly a poor substitute for a howitzer.¹⁸⁵ As with the machine-gun prior to about 1915, there was no consensus on tactical systems for the use of grenades. No one had a clear idea how to use these munitions.

Notes

¹ This has been discussed in many books; for example, see William H. McNeill *The Pursuit of Power*, (Chicago, pbk ed. 1984), Steven T Ross, *From Flintlock to Rifle*, (London, 1996), B P Hughes, *Firepower*, (Staplehurst, 1997), Dennis E Showalter, 'The Prusso-German RMA, 1840–1871' in MacGregor Knox and Williamson Murray, *The dynamics of military revolutions 1300–2050*, (Cambridge, 2001), Maj-Gen J B A Bailey, *Field Artillery and Firepower*, (Annapolis, 2004).

² American Civil War tactics are discussed by Paddy Griffith in *Rally Once Again*, (Marlborough, 1987).

³ Hughes, *op cit.* pp. 26–9. Effective range of muskets depended on whether a single weapon was being fired at a single target or a volley was being fired at a massed target: approximately 100 yards for a single target for a marksman, approximately 200 yards for a volley at a massed target. Griffith, *op cit.* cites effective range of a Napoleonic musket as 50–60 yards (p. 73).

⁴ For lethal range in the American Civil War see Griffith, *op cit.* p. 74. A Minié bullet was accurate to about 500 yards but it was lethal to about 1000 yards. Hughes, *op cit.* also cites 1000 yards (p. 182). For c. 1900, see Donald Featherstone, *Weapons and Equipment of the Victorian Soldier*, (Poole, 1978), pp. 30 and 32. The 1909 Field Service Regulations Part I Operations p. 17 gives 2800 yards as a distant target for rifle fire and 600–1400 yards as the effective range.

⁵ WO 33/1526, *The Russo-Japanese War, Reports from Officers Attached to the Japanese Forces in the Field*, vol. 5 (London, 1906), p. 297.

⁶ Hughes, *op cit.* pp. 29 and 33.

⁷ Griffith, *op cit.* pp. 167, 169, 170. Battle ranges were often less than 1000 yards.

⁸ British 15 pdr field guns of 1901 had a range of 6400 yards; the 18 pdr Mk I of 1904 had a range of 6525 yards. See I V Hogg and L F Thurston, *British Artillery Weapons and Ammunition 1914–1918*, (London, 1972), pp. 73 and 81.

⁹ McNeill, *op cit.* pp. 233–4.

¹⁰ Stephen van Dulken's *British Patents of Invention, 1617–1977, A Guide for Researchers*, (London, 1999), pp. 3–5. Intellectual property includes patents, trademarks, registered designs and industrial know-how; intellectual property rights (IPR) concern ownership and use of such intellectual property.

¹¹ McNeill, *op cit.* p. 223. The same claim is made by Pattison in 'Scientists, Inventors and the Military in Britain 1915–19: The Munitions Inventions Department', *Social Studies of Science*, vol. 13, no. 4, 1983, pp. 521–68, (see especially p. 524).

¹² See also William Reid, *The Lore of Arms*, (Abingdon, 1976), p. 210, which also cites an increase in patent applications.

¹³ Russell was neither the first nor the only war correspondent in the Crimea. The steamship meant that his dispatches quickly arrived in London. His report of Balaklava, for example, appeared in *The Times* only three weeks after the event. See first chapter of Philip Knightley, *The First Casualty*, (London, pbk ed, 1987).

¹⁴ Between 1617 and 1852, 300 British patents relating to firearms were granted, whereas, between 1852 and 1858, 600 were granted (quoted in Reid, *op cit.* p. 210).

¹⁵ 'History of Patents and the Patent Office' (The Patent Office, undated). See van Dulken, *op cit.* pp. 3–4.

¹⁶ 'History of Patents and the Patent Office', *op cit.* p. 3.

¹⁷ *Op cit.* p. 4.

¹⁸ *Op cit.* pp. 4–5; van Dulken, *op cit.* p. 5.

¹⁹ There were, of course, patents granted for inventions prior to 1852 but there was no properly regulated or systemised procedure for getting one. Moreover, not all inventors were literate. In the early eighteenth century, descriptions of the inventions were only beginning to be recognised as necessary and were not obligatory, so a patent could be granted without one. This hardly changed until the end of the century. There was no

easy way to protect intellectual property since a patent was difficult to police and the term of the monopoly was uncertain. Many preferred to keep their inventions secret. By the early nineteenth century, the patenting procedures had become expensive and convoluted which further discouraged many from patenting. Prior to the 1852 Act, some people, Brunel among them, were opposed to patents because of their uncertainty and complexity. See 'History of Patents and the Patent Office' and van Dulken *op cit.* p. 62.

²⁰ Bucknill in 1854. Private communication from Norman Bonney, email dated 7 April 2005.

²¹ *The Sphere*, 4 August 1917, 'Hand-Grenades', p. 94. The French were supposed to have used 3200 grenades at Sevastopol. See also *Textbook of Small Arms*, (London, 1929), p. 105.

²² Rick Landers, 'Grenade' *British and Commonwealth Hand and Rifle Grenades*, (Dural, 2001), p. 1.

²³ *Textbook of Small Arms, op cit.*

²⁴ *Ibid.*

²⁵ *Ibid.*

²⁶ The School of Infantry, Wiltshire, has a single example of such a device from the siege of Mafeking, 1900. Private communication with Norman Bonney, email dated 13 June 2005.

²⁷ British patent No. 303, dated 1692, for a glass hand-grenade. This is probably the first patent granted for a hand grenade of any description. Examples of glass hand-grenades have survived to the present day. See also Anthony Kemp, *Weapons and Equipment of the Marlborough Wars*, (Poole, 1980), p. 37.

²⁸ Kemp, *op cit.* p. 85; Landers, *op cit.* p. 2.

²⁹ *Textbook of Small Arms, op cit.*

³⁰ Usually referred to as Bickford safety fuze; GB6159 [1831].

³¹ Landers, *op cit.* p. 10.

³² In its simplest form, a percussion fuze functions by means of impact with a hard surface which forces a firing pin into a percussion cap.

³³ *The Textbook of Small Arms, op cit.* This is only reference to it. The device may have used a fulminate as a detonating composition; fulminates did not see widespread use until the advent of percussion-lock firearms in the 1820s which used a cap containing a fulminate. Fulminates are extremely sensitive explosives and will detonate when struck.

³⁴ For example, the Hotchkiss shell and fuze of 1862. See GB1798 [1862] granted to J H Johnson who assigned his rights to Hotchkiss. This was used in the American Civil War. The first British shells to use percussion fuzes were developed in 1845 but were less reliable than the new Boxer time fuze. The British did not adopt a percussion fuze until 1861 (invented by Pettman, a foreman at Woolwich). See p. 14 of 'The Development of Artillery Ammunition' a paper presented by Major (Retired) R J Reid MBE at the Winter Meeting of the Royal Artillery Historical Society, 19 January 2005, at Larkhill.

³⁵ WO 44/631 Ordnance Board papers.

³⁶ *Op cit.* letter dated 2 December 1834.

³⁷ WO 44/634 Ordnance Board papers, letters dated 30 January 1852 and 20 February 1852. In fact, Spencer was not the inventor. His father had devised a percussion fuze in about 1842, at the age of seventy-nine, when the issue of whether the artillery should adopt a percussion-fuzed shell, rather than continue using roundshot, had occupied the minds of the public and the members of the Ordnance Board.

³⁸ The most serious of these was the use of a throwing rope fixed to the grenade by means of an eyelet. This had the potential for accidents (WO 44/361 *op cit.*). See Chapter 6 where the Roland grenade of 1912, which also used such a rope, is discussed.

³⁹ Jack Coggins, *Arms and Equipment of the Civil War*, (Mineola, pbk ed, 2004), pp. 97–8.

⁴⁰ US41615 and US42082 granted to George Ganster and Isaac Schuyler in 1864, and US42262 granted to George Ganster the same year. US42082 related to percussion fuzes which were also applicable to shells. The other two were for percussion-fuzed hand grenades. The inventors were from New York.

⁴¹ http://inventors.about.com/cs/astartinventions/a/HollandThompson_4.htm. Inventors, The Agricultural Revolution (accessed June 2008). Ketchum patented a mowing machine in 1844.

⁴² US33089 dated 20 August 1861.

⁴³ 1lb, 2lb and 3lb; see Smithsonian website, www.civilwar.si.edu/weapons_grenades.html (accessed June 2008).

⁴⁴ Coggins, *op cit.*

⁴⁵ US33089, *op cit.*

⁴⁶ Coggins, *op cit.*

⁴⁷ Now in the possession of Norman Bonney. It was previously in the Royal Arsenal, Woolwich, where it had remained, unidentified, since the 1840s.

⁴⁸ www.infernal-machines.com/_sgg/m1m4_1.htm (accessed June 2008).

⁴⁹ www-cgsc.army.mil/carl/resources/csi/gabel5/gabel5.asp concerning the siege of Vicksburg in 1863 in which hand grenades were used; the report of Captain Andrew Hickenlooper, Chief Engineer Seventeenth Army Corp, and the Reports of Colonel O P Lyles, Twenty-third Arkansas Infantry at Fort Hudson; see also Anon, *Battles and Leaders of the Civil War*, (Edison, nd), p. 443.

⁵⁰ F Stansbury Haydon, 'Grant's Wooden Mortars and some Incidents of the Siege of Vicksburg', *The Journal of the American Military Institute*, vol. 4, no. 1, p. 33.

⁵¹ The prolific American inventor, Thomas Edison, said at a press conference in 1929: 'None of my inventions came by accident. I see a worthwhile need to be met and I make trial after trial until it comes. What it boils down to is one per cent inspiration and ninety-nine per cent perspiration.' This quote is often rendered as 'Genius is 1 per cent inspiration, 99 per cent perspiration'. It is likely that he made both statements at different times in response to questions from the press.

⁵² Hanes (or Haynes; it is unclear which is the correct spelling) patented his device according to Coggins *op cit.* p. 98 but it does not appear in the US Patent Office database. The concept was reinvented by A M Flack and patented in 1915 (GB14904/15) and again by J R Hamilton the same year (GB17494/15).

⁵³ http://ehistory.osu.edu/uscw/features/Articles_New/display.cfm?NationId=62 Civil War Newsletter, Issue 19 June 2002; www.infernal-machines.com/_sgg/m1m4_1.htm (both accessed June 2008).

⁵⁴ US45806, granted 10 January 1865.

⁵⁵ The friction igniter works on the same principal as a match head on a rough surface. The igniter's primer is a similar composition to that on a non-safety match. A friction wire is pulled through the composition to ignite it.

⁵⁶ Flash-through occurred when the fuze burned almost instantaneously due to the high temperature and pressure of the combustion gases. See Chapter 5 for a discussion of flash-through in relation to the Mills grenade.

⁵⁷ WO 33/14 Lieutenant-Colonel T L Gallwey and Captain H J Anderson, 'Report upon the Military Affairs of the United States of America', 1864. In *The Military Legacy of the Civil War*, (Lawrence, 1988) Luvaas mentions this report and reproduces a sketch of the Ketchum contained in the report (p. 40). The sketch is very inaccurate.

⁵⁸ The French M1870 bracelet grenade (also known as a fortress grenade) is almost identical to the Adams. According to the *Textbook of Small Arms, op cit.* p. 106 the French improvised grenades in Morocco and on the basis of that experience they developed the M1870 grenade. However, its similarity to the Adams suggests that this explanation is incorrect.

⁵⁹ See *Abridgements of Specifications*, Class 9 ammunition, torpedoes, explosives and pyrotechnics, 1855–1905, published by HMSO between 1898 and 1910. The abridgements were published retrospectively and out of chronological sequence. Thus, the 1855–66 abridgements were published in 1905, while the 1867–76 abridgements were published in 1904.

⁶⁰ Mentioning a possible use of an invention in the specification is a common ploy of patent agents when drafting a specification in order to make the scope of the patent as broad as possible. It does not mean that the inventor has, in fact, put the invention to that use nor, indeed, that such a use is practicable.

⁶¹ GB19365 [1895] granted to G M Hathaway. The invention concerned the container for the explosive, not the fuze.

⁶² WO 33/1520 *The Russo-Japanese War, Selection of Reports from Officers attached to the Japanese Forces*, vol. 2, 'Russian and Japanese Hand Grenades', Report by Captain Sir A Bannerman, Bart., Royal Engineers, Port Arthur, 28 December 1904, (London, 1906), pp. 508–9 and plate 37. Captain Alexander Bannerman, RE, was attached to the Japanese army at Port Arthur between August 1904 and March 1905, the duration of the siege, and wrote twenty-five reports on his observations. On the strength of these, he was promoted major in 1906. He retired in 1912 but returned to duty with the outbreak of war in 1914, served with the 37th Division in France in 1915 and, promoted lieutenant-colonel, commanded the 2/5 North Staffordshire Regiment in 1917. He retired for a second time in 1919. He died in 1934 aged sixty-three.

⁶³ *Op cit.* p. 508.

⁶⁴ *Op cit.* pp. 509–10.

⁶⁵ *Ibid.*

⁶⁶ *Op cit.* p. 508.

⁶⁷ *Op cit.* p. 509.

⁶⁸ *Ibid.*

⁶⁹ WO 33/1524 *The Russo-Japanese War, Selection of Reports from Officers attached to the Japanese Forces*, 'Russian Hand Grenades' description by Lt-Col Haldane, p. 360. The first report of the Russian percussion-fuzed grenade was when some Chinese children found one; it detonated when they were playing with it. The Japanese subsequently improved the design of their percussion grenade and produced a new model but it was probably no safer than the previous design or the Russian pattern. Lt-Col James Aylmer Lowthorpe Haldane, a general staff officer, was attached to the Japanese army in Manchuria from July 1904 to September 1905 and wrote thirty-eight reports based on his observations. He had previously served in South Africa, 1899–1900. As a brigadier, he was GOC 3rd Division of the BEF 1914–16 and GOC VI Corps, 1916–19. He retired in 1926 and died in 1950, aged eighty-eight.

⁷⁰ It is unlikely that the Russians were aware of the existence of the Ketchum.

⁷¹ Major Joseph E Kuhn, *Reports of Military Observers attached to the Armies in Manchuria during the Russo-Japanese War*, Part III, (Washington, 1906), p. 193.

⁷² Again, the body was made from materials available on the battlefield, such as the zinc from Russian ammunition boxes (see WO 33/1524, *op cit.* 'Japanese Hand Grenades', Three Reports by Lieut-Colonel A L Haldane, DSO, General Staff, Manchuria 13 June, 15 July, 3 August 1905, p. 355).

⁷³ WO 33/1524, *op cit.* 'Japanese Hand Grenades', pp. 354, 357, and 'Russian Hand Grenades', p. 360.

- ⁷⁴ Kuhn, *op cit.*
- ⁷⁵ WO 33/1524, *op cit.* 'Japanese Hand Grenades', p. 357.
- ⁷⁶ Major Bannerman, RE, in Ordnance Committee Minute 63369 of 4 December 1907 quoted in Landers, *op cit.* p. 9.
- ⁷⁷ *Op cit.*
- ⁷⁸ WO 33/1526, *op cit.* Table V Special Supplementary Stores, p. 330.
- ⁷⁹ WO 33/1524, *op cit.* 'Japanese Hand-Grenades', p. 355.
- ⁸⁰ See reports of fighting in WO 33/1524 *The Russo-Japanese War, op cit.* pp. 129, 130, 176, 186; WO 33/1526 *The Russo-Japanese War, op cit.* pp. 259, 311.
- ⁸¹ See reports on fighting in WO 33/1524, *op cit.* WO 33/1526, *op cit.*
- ⁸² Kuhn, *op cit.* makes a similar comment on pp. 194–5.
- ⁸³ WO 33/1524, *op cit.* 'Japanese Hand-Grenades', p. 354.
- ⁸⁴ The question of fragmentation is discussed in Chapter 5 of this thesis.
- ⁸⁵ WO 33/1520, *op cit.* p. 509.
- ⁸⁶ For a brief history of field artillery and siege mortars see, for example, Leonid Tarassuk and Claude Blair (eds), *The Complete Encyclopaedia of Arms & Weapons*, (London, 1982), pp. 48–67 and 346–7; and Bailey, *op cit.* pp. 139–501.
- ⁸⁷ WO 33/1520, *op cit.* 'Japanese Wooden Mortar', Report by Captain Sir A Bannerman, Bart, Royal Engineers, Port Arthur, 20 December 1904, p. 511.
- ⁸⁸ WO 33/1524, *op cit.* 'Japanese Bomb Mortars', Report by Lieut-Colonel A L Haldane, DSO, General Staff, Head-Quarters, Second Army, 17 August 1905, p. 361.
- ⁸⁹ WO 33/1520, *op cit.* p. 513.
- ⁹⁰ *Op cit.* The observer in question was Captain Bannerman.
- ⁹¹ WO 33/1520, *op cit.* p. 511.
- ⁹² *Ibid.*
- ⁹³ In the First World War, the Germans used an improvised wooden mortar called an Albrecht, 'a makeshift mortar put together by sappers . . . a wooden tube wrapped-around with thick coils of wire or steel bands . . . a low rate of fire but with all the more terrible effect'. From Otto Lais, *Experiences of Baden Soldiers at the Front, vol. 1, Machine-guns in the Iron Regiment (8th Baden Infantry Regiment No.169)*, (Karlsruhe, 1935), translation by Andrew Jackson (1998) on www.pals.org.uk/lais_e.htm (accessed June 2008). See also Major James E Hicks, *Notes on German Ordnance 1841–1918*, (New York, 1937), p. 82 and Anthony Saunders, *Weapons of the Trench War*, (Stroud, 1999), p. 33.
- ⁹⁴ WO 33/1520, *op cit.* 'Japanese Wooden Mortar', pp. 511–13.
- ⁹⁵ WO 33/1520, *op cit.* p. 512.
- ⁹⁶ *Ibid.*
- ⁹⁷ Haydon, *op cit.* pp. 34–8.
- ⁹⁸ Haydon, *op cit.* pp. 34 and 37.
- ⁹⁹ Haydon, *op cit.* p. 36.
- ¹⁰⁰ Haydon, *op cit.* pp. 35–7.
- ¹⁰¹ WO 33/1524, *op cit.* p. 362.
- ¹⁰² WO 33/1524, *op cit.* Appendix A 'Bomb Mortars', p. 364.
- ¹⁰³ WO 33/1524, *op cit.* 'Japanese Bomb Mortars', p. 363.
- ¹⁰⁴ WO 33/1524, *op cit.* Appendix A 'Bomb Mortars', pp. 364–8.
- ¹⁰⁵ WO 33/1524, *op cit.* pp. 362–4 where the experimental nature of the Nakamura is implicit but see also WO 33/1526, *op cit.* p. 259 where metal mortars are cited as having replaced wooden mortars.
- ¹⁰⁶ Kuhn, *op cit.* pp. 192–3 and plate XXXIV.
- ¹⁰⁷ WO 106/5551, Journal of the Principal Events connected with the Russo-Japanese War, February 1905, p. 58.
- ¹⁰⁸ *Ibid.*
- ¹⁰⁹ *Ibid.* The bomb was reported to weigh 1 kg, while the calibre was quoted in inches.
- ¹¹⁰ The Battle of Mukden, February–March 1905. WO 33/1526, *op cit.* reports of fighting, p. 42.
- ¹¹¹ WO 33/1526, *op cit.* Table V Special Supplementary Stores, p. 330. The common shell was so-called because it was the type most commonly used.
- ¹¹² WO 33/1524, *op cit.* 'Japanese Bomb Mortars', p. 362 and Appendix A, p. 365.
- ¹¹³ Private communication from Norman Bonney, August 2006.
- ¹¹⁴ Landers, *op cit.* p. 10.
- ¹¹⁵ Landers, *op cit.* p. 9.
- ¹¹⁶ List of Changes in War Matériel and of Patterns of Military Stores (LoC) §11663, 30 September 1902, Plate, loop-holed (Mark I). The LoC were published on the first day of each month by the War Office from 1860 onwards. Each entry was given a number and a date. This was not always the date of first usage, however. During the First World War, it was not uncommon for a munition to appear in the LoC many months after its first use on the Western Front.

- ¹¹⁷ Youlten was granted three patents: GB15273/00, GB24814/01 and GB5791/03 all relating to periscopic sights for machine-guns and rifles to enable them to be fired from below cover.
- ¹¹⁸ A shield called a pavise was used by archers from the fourteenth century to the sixteenth century. See Tarassuk and Blair, *op cit.* pp. 362–3. Eighteenth-century siege engineers used gambions, fascines and mantlets. See Kemp, *op cit.* pp. 112, 113 (Fig. 75) and 114 (Fig. 76).
- ¹¹⁹ Griffith, *op cit.* p. 26.
- ¹²⁰ Musketry Regulations Part I, 1909, Appendix VII, pp. 283–7, especially p. 287. Field Service Regulations Part I Operations, 1909, pp. 174 and 181. See also MUN 5/321A *History of the Ministry of Munitions*, vol. IX, *Review of Munitions Supply*, Part II *Design and Inspection*, p. 72.
- ¹²¹ MUN 5/383/1600/14 Lt-Col O F Brothers, *The Development of Weapons Used in Trench Warfare*, p. 40. Training is discussed in Chapter 7 of the present thesis.
- ¹²² Landers, *op cit.* p. 9.
- ¹²³ See, for example, Brothers, *op cit.* pp. 50, 51 and 74; and *Textbook of Small Arms*, *op cit.* p. 117.
- ¹²⁴ Major Bannerman in Ordnance Committee Minute 63369 of 4 December 1907.
- ¹²⁵ Grenade nomenclature was altered at various times but for convenience and to avoid ambiguity all grenades described here are referred to by number (Arabic numeral) and, where relevant, mark (Roman numeral). This system remained in use until 1944 when Arabic numerals were also adopted for the mark number.
- ¹²⁶ Landers, *op cit.* The design number was RL14751.
- ¹²⁷ LoC §14424 Grenade, hand (Mark I) L, 6 July 1908; see also Landers, *op cit.* p. 10 which reproduces §14424.
- ¹²⁸ The No. 1 was manufactured at Woolwich. The figures from the Annual Accounts of the Ordnance Factories are: 1909–10, 18 grenades; 1910–11, 108 grenades; 1911–12, 198 grenades; 1912–13, wanting; 1913–14, 93 grenades. I am grateful to Norman Bonney for providing the data from the Annual Accounts.
- ¹²⁹ WO 33/1526, *op cit.* reports on fighting, p. 259.
- ¹³⁰ Around the time of the Boer War, Marten Hale was closely involved in persuading the British to adopt high explosives for shell fillings. He claimed this was altruism but it was also a business opportunity. By about the 1920s, he had been granted 270 patents, the first of them in 1886, but not all related to munitions. See pp. 5, 10–11, 12 of *Great War “Souvenir” 1914–1918* in T 173/252. This was a glossy compilation of journal and newspaper articles, all uncritical and laudatory, about Marten Hale’s inventions. It was prepared as a promotional booklet in 1921.
- ¹³¹ In contemporary documents, Marten Hale’s grenades, especially his rifle grenade, were called Hales grenades.
- ¹³² *Great War “Souvenir”*, *op cit.* p. 11.
- ¹³³ GB14605/06. The technicalities of the device are discussed in Chapter 5.
- ¹³⁴ WO 32/18989, Hales Rifle Grenade.
- ¹³⁵ Landers, *op cit.* p. 9.
- ¹³⁶ *Ibid.* Hale’s grenade could be fitted with a long wooden handle like the devices used in Manchuria or it could be fitted with a rope handle. The latter required a throwing technique similar to that for a bolas which hardly recommended itself to trench fighting.
- ¹³⁷ GB15045/08. *The Great War “Souvenir”*, *op cit.* p. 7 erroneously gives 1906 as the year of invention.
- ¹³⁸ *The Great War “Souvenir”*, *op cit.* p. 11.
- ¹³⁹ *Textbook of Small Arms*, *op cit.* p. 124 and Figs 12a and 12b. Reid, *op cit.* pp. 116–18. Such devices were often referred to as hand mortars.
- ¹⁴⁰ The technicalities of Marten Hale’s rifle grenade are discussed in Chapter 5.
- ¹⁴¹ WO 32/18989, *op cit.*
- ¹⁴² Landers, *op cit.* p. 19.
- ¹⁴³ WO 32/18989, *op cit.* for promotional material. *Great War “Souvenir”*, *op cit.* pp. 14–15 for reprint of article from *The Evening Standard*, 13 September 1909, p. 17 for reprint from *The Illustrated London News*, 13 September 1913.
- ¹⁴⁴ *Great War “Souvenir”*, *op cit.* pp. 5 and 11 in T 173/252; WO 32/18989, *op cit.* which contains correspondence from the Cotton Powder Company regarding the rifle grenade going back to December 1911. There is also a summary of earlier correspondence going back to July 1908.
- ¹⁴⁵ WO 32/18989, *op cit.*
- ¹⁴⁶ *Ibid.*
- ¹⁴⁷ *Ibid.*
- ¹⁴⁸ *Ibid.*
- ¹⁴⁹ *History of the Ministry of Munitions*, vol. XI, *The Supply of Munitions*, Part I *Trench Warfare Supplies* p. 74. MUN 5/382/1600/10 History of Production of Trench Warfare Stores by the Trade, p. 1.
- ¹⁵⁰ *Trench Warfare Supplies*, *op cit.* p. 75. MUN 5/197/1640/5 Production of grenades.
- ¹⁵¹ WO 32/18989, *op cit.*
- ¹⁵² *Abridgements of Specifications*, Class 9 (i), *op cit.* 1906–14, (London, 1910 and 1921).
- ¹⁵³ T 173/110 claim by Beaton and Sons before the Royal Commission on Awards to Inventors. Beaton produced the No. 39 Steuart rifle grenade, with the agreement of the Ministry of Munitions, which infringed Marten Hale’s patents.

- ¹⁵⁴ According to the *Great War "Souvenir"*, *op cit.* p. 11 the full list is Argentina, Austria, Belgium (two), Brazil, Britain (three), Bulgaria, Denmark, France (two), Germany (three), Greece, Holland, Italy, Norway, Rumania, Russia (two), Spain, Turkey (two), USA (two).
- ¹⁵⁵ The German army went to war in 1914 equipped with hand grenades and rifle grenades (adopted in 1913); see *Textbook of Small Arms*, *op cit.* pp. 106–7. See also Brothers, *op cit.* p. 39. According to *Military Operations, 1915*, vol. 1, (London, 1927), footnote p. 9, the German army went to war with 160 trench mortars.
- ¹⁵⁶ Unfortunately, this is outside the scope of this thesis. It would be an informative exercise which might shed light on Marten Hale's monopoly.
- ¹⁵⁷ From a comparison of the description and drawings of the German rifle grenades of 1913 and 1914 in CDS74 The Training and Employment of Grenadiers, Oct 1915, with Marten Hale's rifle grenade patents.
- ¹⁵⁸ *The Army and Navy Gazette*, supplement, 26 July 1913, p. IV in WO 32/18989.
- ¹⁵⁹ *Ibid.*
- ¹⁶⁰ GB8755/15.
- ¹⁶¹ Aasen is supposed to have had his own company but it is unclear whether it was this one.
- ¹⁶² SUPP 28/40. This comprises typewritten summaries, on index cards, of minutes of the Ordnance Board and its successors relating to grenades between about 1908 and 1945. The Aasen minutes are OB9916, OB10019, OB11184, OB12325, OB12966, OB13169/16, OB13752, OB13835, OB13907, OB14134, OB14522.
- ¹⁶³ SUPP 28/40, *op cit.*
- ¹⁶⁴ *Ibid.*
- ¹⁶⁵ *Ibid.*
- ¹⁶⁶ See, for example, Training and Employment of Grenadiers, *op cit.* p. 41 and plate 32; for photographs of French soldiers armed with Aasen grenades see, for example, *The Illustrated War News*, 25 August 1915, p. 43, and *The Sphere*, 4 August 1917, p. 91.
- ¹⁶⁷ The combination of two or more patent applications into a single patent is signified by the term cognate.
- ¹⁶⁸ *Abridgements of Specifications*, Class 9 (i), *op cit.* 1909–15.
- ¹⁶⁹ *Abridgements of Specifications*, Class 9, *op cit.*; Class 9 (i), *op cit.*
- ¹⁷⁰ B F S Baden-Powell was the younger brother of Robert Baden-Powell, founder of the Scout movement. He was enthusiastic about kites for military reconnaissance. B F S was a major in the Scots Guards when he was granted the patent cited here. He was also President of the Royal Aeronautical Society which he had founded in 1900.
- ¹⁷¹ *Abridgements of Specifications*, Class 9, *op cit.*; Class 9 (i), *op cit.*
- ¹⁷² Captured German munitions were evaluated. See, for example, OB16549 and OB14675 which, respectively, dealt with a German percussion fuze for trench mortar ammunition and a rifle grenade, in the *Annual Report of the President, Ordnance Board for the year 1915*, (London, 1917), pp. 84–6, in MUN 5/120/810/6.
- ¹⁷³ US1035486 and US1041894 both granted to Ernst Sokolowski in 1912. Sokolowski assigned his US rights to the DuPont company. There were no equivalent British patents.
- ¹⁷⁴ MUN 7/310, letter from Admiral Bacon, Controller of Munitions Inventions, dated 12 September 1918. See also MUN 4/766 which contains a note dated 17 January 1917 which states that no patented invention which had been accepted by the Trench Warfare Supply Department could be published as this would be deemed as aiding the enemy. Evidence of late acceptance can be seen by looking at patents granted in the early 1920s. Those granted to Henry Newton are a case in point.
- ¹⁷⁵ Field Service Regulations, *op cit.* Brothers, *op cit.* pp. 39–40.
- ¹⁷⁶ This is a case of absence of evidence to show that grenades were retained in service.
- ¹⁷⁷ This also held true for German hand grenades of the same period when compared with Russian, Japanese and American devices.
- ¹⁷⁸ WO 33/1520, *op cit.* 'Japanese Wooden Mortar' p. 513.
- ¹⁷⁹ This was the view held by British artillery officers at the start of the First World War. See *Trench Warfare Supplies*, *op cit.* p. 4.
- ¹⁸⁰ GB19345/08 and GB19397/10. Krupp also patented them in the USA: US932214 (1909) and US1003079 (1911).
- ¹⁸¹ *Textbook of Small Arms*, *op cit.* p. 153.
- ¹⁸² Wolfgang Fleischer, *German Trench Mortars and Infantry Mortars, 1914–45* (Atglen, 1996), p. 4.
- ¹⁸³ Eleven a year between August 1904 and August 1914. See J D Scott, *Vickers, A History*, (London, 1963), p. 99.
- ¹⁸⁴ See, for example, the general tenor of The Russo-Japanese War up to 15 August 1905, A Report by Major J M Home, 2nd PWO Gurkhas lately attached to the Russian Army in Manchuria, 1905 in WO 33/337. See especially the section on tactics, pp. 10–21.
- ¹⁸⁵ Opinion was divided over the utility of trench mortars and whether they were merely cheap alternatives to howitzers. See Memorandum on the Functions of the Trench Warfare Supply Department, p. 5, in MUN 5/382/1600/7 History and Work Ministry of Munitions Trench Warfare Supply Department June 1915 to September 1917 by the Deputy Director-General, Mr E V Haigh.

3 The Bureaucracy of Invention

The War Office began receiving official and unofficial requests from France for trench warfare stores of all kinds as soon as stalemate developed along the Aisne in September and October 1914.¹ The unofficial requests mostly came from officers returned from France, bypassing the chain of command. Such requests were often for trench mortars and grenades for specific battalions or divisions rather than for the BEF as a whole. Inevitably, some of these unofficial requests were granted, complicating logistics, since it always left doubt about what had been supplied to the BEF. In some instances, officers bought equipment for their men from department stores without referring to the War Office.² Body armour, trench knives, periscopes and wire-cutters were all provided in this way.³ In one instance, the commanding officer of a New Army battalion not only bought trench knives but had them designed and manufactured at his own expense.⁴ Such enterprise could not address the urgent need for explosive munitions, however. There were instances where British troops were forced out of recently captured trenches because they had no hand grenades with which to respond to counter-attacking German bombers.⁵

Irrespective of whether the requests came through official channels or via some other route, demand far outstripped supply. The numbers of hand and rifle grenades delivered to the BEF during the first months of trench warfare were insignificant in comparison to the numbers demanded.⁶ The requests from GHQ were initially vague because no one knew what to ask for or in what numbers they were needed, which was one reason why unofficial requests were made by officers on leave. In October 1914, Sir John French did not state that he needed trench mortars but asked for some sort of artillery that could be used at close range against trenches.⁷ The War Office had to untangle all this, determine what was needed and set about supplying it. Thus, in the autumn and winter of 1914, the War Office was faced with two problems: how to increase rapidly the production of existing hand and rifle grenades; and how to design and produce entirely new devices to satisfy demand.

There was no infrastructure in Britain to address these matters in the autumn of 1914. Indeed, not only had no one envisaged a circumstance where the army might be in sudden need of large numbers of munitions it did not possess but no one had foreseen that there might come a time when an organisational framework might have to be created from scratch in a matter of months in order to address the unimagined nightmare of supplying munitions that did not exist. It is the organisational aspects of this predicament which is the subject of this chapter and the next.

The focus here is on organisation and management, rather than on the processes of evaluation and manufacture which are discussed more fully in the next chapter. This differentiation is adopted here as a convenience for the sake of clarity rather than because it was an actuality. All these elements were intimately connected in the process of providing

novel munitions for trench warfare, in contradistinction to conventional munitions where experimentation was quite separate from manufacture.⁸ The relationship between research and manufacture of novel munitions for trench warfare was fundamental to the process of providing the BEF with what it needed, especially during the first twelve months of trench warfare. This interdependence was an unusual situation⁹ which, rather unexpectedly, had a beneficial effect on the process of development as it allowed a direct feedback loop to operate.¹⁰ However, this arose because of the sudden demand for such munitions rather than from intention. It was encouraged by a flexible approach to problem-solving within the War Office before the Ministry of Munitions tried to impose a more rational system. In the context of unconventional munitions, the pre-war ad hoc method of dealing with problems¹¹ served the BEF well during the first year of war, whereas the bureaucratic system¹² fostered by the Ministry of Munitions after June 1915 was fraught with difficulties and was, in some respects, less successful.

This chapter and the next discuss the development and evolution of those organisations which existed prior to the outbreak of war and those which were created during the war to deal with novel munitions. It looks at the roles played by the various sections and departments concerned with the development and supply of novel munitions and considers their interrelationships.¹³ The roles played by particular individuals are highlighted to show that individuals sometimes had a greater impact on which novel munitions were provided to the BEF than the organisational framework in which they worked. This was especially true of the first year of war. Indeed, as will be discussed below, the effectiveness of any given section or department in the development and evaluation of novel munitions depended more upon the skills and dynamism of particular individuals than on bureaucratic working practices set up to systemise development, evaluation, manufacture and supply. At the same time, of course, the reverse was also true; the actions of individuals could have a detrimental effect on these processes.¹⁴ There were instances where political decisions were taken with little regard to the technical implications.¹⁵ Fortunately, for the most part, the decisions turned out to be the right ones. However, any analysis of their consequences needs a technical understanding of the munitions concerned, otherwise it becomes a ‘what if . . .’ peregrination through political speculations rather than an appraisal of the military consequences. The serendipitous outcome of some of the political interventions should not be taken as evidence of clear thinking from a technical or a military perspective.¹⁶

The problem of novel munitions

At the start of the First World War, the Master General of Ordnance (MGO) had overall control and responsibility for all matters relating to munitions, including hand grenades, rifle grenades, trench mortars and their ammunition.¹⁷ The DoA defined the requirements of the army and had the authority to adopt new equipment for service use. The Chief Inspector Woolwich (CIW) advised on matters of design, while the Chief Superintendent Ordnance Factories (CSOF) advised on production.¹⁸ In practice, neither was usually consulted because the armaments firms dealt with such matters;¹⁹ peacetime research and development of

munitions was mostly conducted by the armaments firms, such as Vickers, Armstrong-Whitworth, Elswick Ordnance²⁰ and Coventry Ordnance.²¹ Some additional work was carried out by the Royal Laboratory and the small Research Department of the Royal Ordnance Factory at Woolwich.²² The Ordnance Board²³ carried out evaluations of new munitions using the experimental grounds at Shoeburyness (ordnance) and Hythe (small arms) and advised the DoA accordingly.²⁴ Inspection of munitions was solely the responsibility of the Inspection Department of the Royal Ordnance Factory.²⁵ At the start of the war, the system for placing contracts for the manufacture of munitions was simple. The War Office stated what it wanted and by which date, irrespective of the deadline's feasibility and without regard to formulating an organised munitions programme.²⁶ Before the creation of the Ministry of Munitions in June 1915, no such programme had ever existed for any kind of munition and there was little organised cooperation between design, manufacture and supply.²⁷ A need for such cooperation had not arisen prior to the outbreak of the First World War and it was not merely a matter of scale.

Major-General Sir Stanley von Donop, the MGO,²⁸ felt that the war would be over before the process of design and development could be completed and that the question of new munitions, conventional or unconventional, would not arise.²⁹ This view fitted the general belief among officers involved in weapons procurement that design and research of new munitions would be abandoned once war broke out. The war would be brief and the current types of munitions would fulfil their intended roles without problem. The armaments firms would be fully occupied with meeting the demands of the army for conventional munitions; they would have no time to develop unnecessary new equipment. This was a circular argument. The false premise on which it was based did not become apparent until the advent of trench warfare in the autumn of 1914. Thus, in August 1914, the Ordnance Board turned down a proposal to develop a trench mortar based on a pre-war German design.³⁰ At that time, the army had no need of such a mortar and there was no evidence to suggest that it might need one in the near future.

Nevertheless, this was a selective view of previous experience. In the Boer War, only fourteen years earlier, the army had found itself deficient in large-calibre field guns and had been forced to improvise them.³¹ The War Office then realised that it needed new guns to fill this gap in the army's artillery capability, so designs were initiated while the war was still in progress. The new guns did not enter service until several years after the Boer War had ended.³² The experience of the Boer War suggested that a more open-minded approach to the capabilities and usefulness of the army's equipment might be advisable. The Russo-Japanese War indicated that a hand grenade might be useful but it took the Royal Laboratory four years to develop one and the resulting device had little to recommend it. The Royal Laboratory failed to develop a rifle grenade to compete with the Marten Hale rifle grenade, despite several designs, some of which included novel features.³³ Unconventional munitions, insofar as they were considered at all, were viewed as unimportant to the conduct of operations. Indeed, the view that hand grenades and rifle grenades were a 'side issue' persisted well into 1915.³⁴

Thus, in the autumn of 1914, the idea that unconventional munitions could be designed, manufactured and supplied to the BEF in a matter of months was inconceivable to the MGO. Nevertheless, such munitions were increasingly demanded by the BEF. The logistical and technological problems which it faced in 1915 concerned all types of munition, conventional and unconventional, of course. The shortage of artillery shells in 1915 and, in particular, high-explosive shells of large calibre, which were essential for the destruction of the German defences, was a major problem that persisted well into 1916.³⁵ The shell crisis had serious military consequences for the BEF³⁶ and acute political consequences for the government. The crisis led to the formation of the Ministry of Munitions.³⁷ The shortage of artillery ammunition occupied the minds of soldiers, politicians and bureaucrats almost to the exclusion of all other concerns during 1915. Although the question of unconventional munitions was a separate issue from that of shells and guns, the shell crisis inevitably had an effect on the provision of novel munitions, if only because it ensured that only one of the armaments firms, Vickers, became involved with trench warfare munitions, and its contribution was limited. The crisis also contributed to the public debate on the government's use of the scientific resources of the country for the prosecution of the war.

Inventing a new process – handling novelty

There is a temptation to divide the narrative of the research, manufacture and supply of novel munitions for trench warfare into what happened before and after the creation of the Ministry of Munitions: simplistically, the inefficient versus the efficient. Such a differentiation was emphasised by the Ministry of Munitions for political reasons. This view was embodied in the *History of the Ministry of Munitions* and reinforced by Lloyd George in his *War Memoirs*. It has been perpetuated thereafter, implicitly, if not explicitly, in many studies that have looked at the First World War and have relied on Lloyd George's version of events.³⁸ The shell scandal established the impression that the War Office and the MGO had failed in their duty to the BEF in every respect of logistics, while the Ministry of Munitions promoted itself as the BEF's saviour. As will be seen in the discussion that follows in this chapter and the next, this impression was not only disingenuous but a distortion of a much more complex truth. Whereas there is no doubt of the failure of the War Office in the supply of conventional munitions, the same is not true of unconventional munitions, if only because the starting points were different in each case.

Hostility between the War Office and the Ministry of Munitions flared throughout the war. Inevitably, it affected the development, manufacture and supply of novel munitions. The decision to provide the BEF with the Stokes mortar, for example, was a political act by Lloyd George rather than a military decision or, indeed, a bureaucratic one, and was intended to show up the War Office as reactionary and ineffectual.³⁹ This hostility introduced an element of chance into the process of developing suitable munitions and affected how the work conducted by the War Office and the Ministry of Munitions was perceived after the war. It also helps to explain why the Royal Engineers received little recognition after the war for their contribution to the provision of novel munitions for trench warfare: they were

outside the political arguments because they were part of the military structure of the BEF. The role played by the Royal Engineers in providing these munitions seems to have been largely overlooked, except for an offhand acknowledgement that the Engineers 'improvised' what the army needed, thus damning them with faint praise;⁴⁰ they hardly figure in the *History of the Ministry of Munitions*.⁴¹ However, an acknowledgement by the *History* would inevitably have undermined the impression that its authors wished to promote of the Ministry's record in the field of novel munitions. Thus, the *History* should be viewed with some caution as it is partisan, although it is the only record of its type and it is encyclopaedic.

Rather than discuss the organisation and management of the provision of novel munitions from a chronological perspective, which inevitably leads to a before and after differentiation, it is more revealing to consider how the various functions involved in providing the munitions were addressed. These may be defined as invention and design, research and development, evaluation and trial, manufacture and inspection, and supply (or distribution). The organisation and management of these functions went through several major changes during the course of the war.⁴² Such changes were not necessarily the result of considered improvements for the sake of efficiency but sometimes came about for bureaucratic or political reasons. One of the complexities of the management of the development and supply of novel munitions was the creation, amalgamation, dissolution and regeneration of various sections, committees, departments and branches that were responsible for the diverse aspects of providing these munitions. Indeed, so complex were these changes that even the *History of the Ministry of Munitions* cannot be relied upon as an entirely accurate record in this respect, even though these changes all occurred after the creation of the Ministry which subsequently controlled the functions under discussion here.

The numerous inventions departments that existed at various times during the war were never in a state of stability, although snapshot views taken retrospectively of any given moment during the war might suggest otherwise. On the contrary, they were often in a state of flux. Cooperation and coordination between these invention and evaluation departments was a constant problem.⁴³ Even within the Ministry of Munitions, there was often rivalry between them. There were disagreements over areas of responsibility. The Trench Warfare Section of the Ordnance Committee complained that Woolwich failed to tell its members when trials of trench mortars were scheduled and that they went ahead without them. Even when the date and time were forthcoming, the Committee would turn up at the right time and place only to find that the test firings had been conducted ten minutes before they arrived.⁴⁴ The impression that the *History of the Ministry of Munitions* wished to promote after the war was that of efficiency derived from a well-structured organisational framework in which working practices were not only defined but followed in a cooperative and coordinated manner, although it does concede that this was sometimes hard to achieve.⁴⁵

The question of whether the ad hoc methods of the War Office were inferior to the bureaucracy of the Ministry of Munitions pertains to whether the Ministry was more effective than the War Office in providing appropriate novel munitions in appropriate numbers. However, any discussion about which of them was the more efficient is somewhat

specious as the circumstances under which they worked were not the same. The War Office had to start from scratch, whereas the Ministry of Munitions had a much clearer idea of what sort of munitions were needed and how to go about providing them precisely because of the work which had already been done by the War Office and, indeed, Royal Engineers in France. The War Office laid the foundations on which the Ministry of Munitions built a development and supply system that out-produced demand. Moreover, some of those people responsible for this achievement had worked in the War Office before being transferred to the Ministry. The work of the Royal Engineers provides a counterpoint to that of the War Office and the Ministry of Munitions. Indeed, there is a case for arguing that the Royal Engineers were more efficient than either the War Office or the Ministry of Munitions and achieved more in a shorter time than the government departments. Some Royal Engineers, along with other officers who had worked with inventions in France, were also transferred to the Ministry of Munitions. Thus, the new Ministry was hardly 'new' as it relied heavily on the experience and knowledge of others upon whom the subsequent achievements of the Ministry largely depended.

Since the War Office was the only government department concerned with the army and its munitions at the start of the war, it was inevitable that the War Office would receive unsolicited suggestions and submissions from the public following the outbreak of war.⁴⁶ The War Office had always been unenthusiastic about unsolicited submissions from civilians and military personnel alike.⁴⁷ Sir Arthur Conan Doyle wrote to *The Times* in 1900 complaining about the lack of response from the War Office in relation to an invention submitted by a friend.⁴⁸ Nevertheless, there was a well-established procedure within the War Office for rewarding inventors from the services which dated back to before the turn of the century. Non-technical evaluations of servicemen's inventions were made by an ad hoc committee, rather than their being the responsibility of a specific section within the War Office. By the winter of 1914, the War Office was forced to change its mind about unsolicited submissions because of the dire need for trench warfare munitions. Even so, the War Office remained sceptical of their usefulness.⁴⁹ It is hard to imagine that the Ministry of Munitions, had it existed in 1914, could have behaved differently.

Many of these submissions were directed to FW3 Section⁵⁰ of the Directorate of Fortification and Works (DoFW) while others went to the DoA or the Inspection Department of the Royal Ordnance Factory at Woolwich.⁵¹ The submissions had to be evaluated, trials of the more promising devices had to be conducted and development work instigated to turn any potentially useful device into a practical munition. The scale of this work, which was not well publicised in the press nor well known outside the sections concerned with these matters, grew rapidly as it became apparent that trench warfare was not a temporary setback but a feature of war on the Western Front.⁵² On Christmas Day 1914, Sir John French, Commander-in-Chief (C-in-C) of the BEF, wrote to Lord Kitchener, requesting that someone of an inventive turn of mind be given the task of devising the novel munitions that the army urgently needed.⁵³ French was apparently unaware that such matters were in hand. This suggests that the results of the work had yet to have a significant impact on operations on the Western Front.

In October 1914, FW3 was responsible for non-explosive devices for trench warfare. Its head, Lieutenant-Colonel Louis Jackson, one of the so-called 'dug-outs', was a leading authority on military engineering.⁵⁴ The War Office sent requests and submissions to his section unless they related to explosive munitions which were the responsibility of the MGO. Submissions from commercial engineering firms 'the trade'⁵⁵ were passed directly to the Inspection Department at Woolwich for evaluation.⁵⁶ This demarcation of responsibilities quickly became blurred, however. Von Donop, was not dogmatic about the division of work along traditional lines and was quite prepared to listen to new ideas. Thus, he allowed Jackson to develop hand grenades when the latter offered his assistance after overhearing the MGO bemoan the BEF's shortage of these devices.⁵⁷

In the context of trench warfare, the War Office had three tasks: to increase production of existing munitions; to devise new munitions; and to evaluate submissions for novel devices. The first of these was easily separated from the other two, but, ideally, all three should have been focused in one branch. However, there was no single branch which could take on all three tasks. Hitherto, the need for such a branch had not arisen, so none was structured in such a way that would enable it to perform all three tasks. Thus, the work was spread across several branches.⁵⁸ There was little coordination of the efforts to address these issues by the various sections that found themselves having to deal with them. This reflected the absence of a guiding authority rather than a lack of cooperation. It was made more complicated by the ad hoc way in which the supply and design functions were initially treated in the War Office, although this was not due to lack of organisational skills but to the fact that development and supply occurred concurrently rather than sequentially. This was an unavoidable consequence of meeting the urgent need for devices that did not exist.

For some munitions, both functions were handled by the FW3 Section, while, for some types of explosive munition, the functions were handled by other branches. Until June 1915, the design and development of new explosive munitions was the responsibility of the Royal Laboratory and CSOF, while their supply to the BEF was handled by the supply authorities that handled conventional munitions. With the creation of the Ministry of Munitions in June 1915, these functions were reorganised in the expectation that it would make the processes more efficient.⁵⁹ Supply and research were, therefore, separated and handled independently by two sections. This was a bureaucratic change, not a practical one, and the fact that research, manufacture and supply were inextricably linked was missed by those who brought about the change.⁶⁰ This was partly due to a lack of understanding of problems and partly due to an unhealthy disregard for what the War Office had hitherto achieved in the supply of unconventional munitions.

Three lines of research and development arose during late 1914 and early 1915: firstly, work to devise from scratch novel munitions to meet recognised requirements, most of which came initially from GHQ; secondly, work to improve imperfect devices already in use at the front; and thirdly, work to develop promising inventions submitted from members of the public and servicemen but which were unsuitable for front-line use in their prototype form.⁶¹ In reality, these distinctions were not so clear cut, however, because of the need

to provide these munitions as quickly as possible, which brought such work into direct contact with the question of manufacture. The design element of the inventions had to be considered from the perspective of their mass production.⁶² This can be viewed as a panic response and poor management but it can also be viewed as creative and, indeed, innovative. Perhaps the best known example of the first process, that is, inventing from scratch, was the tank, which grew from a requirement in 1915 for a device to cross barbed-wire obstacles and incorporated work on mobile armoured shields conducted by FW3.⁶³ The third category was more important during the first twelve months of the trench warfare than it became subsequently. This was because the shortage of suitable munitions during the first twelve months meant that very little could be turned down; substandard munitions were better than none at all.⁶⁴ Later, when the crisis period was over, a more critical approach could be applied to the selection of munitions worthy of development. This coincided with the transfer of responsibilities from the War Office to the Ministry of Munitions. Thus, less of this type of work was conducted under the auspices of the Ministry of Munitions than had been the case with the War Office.

Invention and design

Before the First World War, inventing was not an activity in which government departments often engaged;⁶⁵ inventing was largely the job of the armaments firms.⁶⁶ Similarly, designing a new munition was primarily the responsibility of the armaments firms. The War Office tended to wait until an armaments firm had developed a new munition before placing an order. The sudden demand for novel munitions in late 1914 turned this system on its head. The only pre-war department with experience of munitions design work was the Royal Laboratory at Woolwich, while the small Research Department, also at Woolwich, dealt with munitions research. Because of the pressing need for guns and ammunition, the research facilities at Woolwich were largely turned over to production.⁶⁷

When the MGO asked the CSOF for a trench mortar in late 1914, Woolwich was unable to invent one.⁶⁸ Woolwich produced three designs: the 2-inch mortar, a workaday design, was an adaptation of a patented Krupp device;⁶⁹ the 3.7-inch and 4-inch mortars were improvisations of conventional form with design flaws which could not then be engineered out.⁷⁰ In 1915, the Royal Laboratory designed two of the many stopgap hand grenades to appear that year, the No. 6 and No. 7.⁷¹ The grenades were no more inventive than the No. 1 had been nine years earlier. Indeed, they were less innovative than some of the improvisations that had been devised in France, from which they were derived. They were, however, engineered to be capable of quick manufacture. The Royal Laboratory fared little better with rifle grenades; the No. 17 of late 1915 was obsolescent even before it was issued.⁷² The inability of Woolwich to devise novel munitions for the BEF was indicative of two related difficulties which faced any government department attempting invention: bureaucracy and lack of incentive.

That the War Office should adopt a bureaucratic approach to invention was hardly surprising since the organisational structure of the War Office was bureaucratic, formal and hierarchical.⁷³ Despite the willingness to adopt an impromptu approach to the question of

novel munitions, nevertheless, the system was inevitably constrained by bureaucratic custom, although the exigencies of the war overcame this to some extent. Such an environment was not conducive to the process of invention, however. Inventing required an intellectually freer environment. Moreover, inventing is not only a creative process but a commercial one; hence, the growth of patenting systems in most of the industrialised nations during the nineteenth century. Thus, expertise in inventing was to be found in commercial firms, not government departments. The Ministry of Munitions was no better than the War Office in this respect. There was little incentive for any government department to adopt a commercial approach to inventing, even after the outbreak of trench warfare, because of the surfeit of civilian engineers, both talented and harebrained, who turned to inventing, unbidden, and submitted their creations to War Office and, subsequently, to the Ministry of Munitions.⁷⁴ Some have dismissed the efforts of civilian inventors as Victorian amateurishness,⁷⁵ quite overlooking the fact that, until the decades after the Second World War, invention was an activity practised by individuals rather than large institutions.⁷⁶

In 1913, H G Wells wrote a series of articles for *The Daily Mail* in which he predicted that science and engineering would be essential to the winning of the next war.⁷⁷ The war was going to be more mechanised than any war hitherto and victory would go to whichever side 'applied the best brains to the problem of war'.⁷⁸ The War Office did not set up a department for inventing these nebulous devices of mechanised warfare, however, and no such department existed at the outbreak of war. Only a small section in the DoA, known as A4, dealt with submissions, which mostly came from servicemen. Mechanisation was not a new concern. Not only had popular fiction put such ideas into the imaginations of ordinary people but engineers and scientists had been discussing the increasing mechanisation of warfare since at least the 1870s.⁷⁹ The topic continued to resurface occasionally in *The Times* until the outbreak of war. The First World War was only a few months old when it was being described as an industrialised war which would be 'fought and ultimately decided in the workshop and the laboratory'.⁸⁰ In November 1914, an artillery officer described the war as one of 'mechanical appliances'.⁸¹ This sort of view, published in the press, helped to shape public opinion.

In the spring of 1915, letters began to appear in *The Times* calling for scientists to devote their energies to providing Britain with whatever warlike tools it needed to defeat Germany, although there was no consensus about how this effort should be coordinated.⁸² Wells was one of several prominent men who wrote to *The Times* on the subject. A major in the Department of the Superintendent of Design believed that the Germans had entered the war better prepared for static warfare than had the British, arguing that British science should now be harnessed to inventing new ways to kill the enemy.⁸³ The Royal Society set up a War Committee.⁸⁴ In the press, the War Office was perceived as dragging its feet in dealing with the need for novel munitions. No one seemed to be aware that civilian inventors had responded to the needs of the moment before the start of this debate. Such men submitted their inventions to the War Office rather than writing to *The Times* about it. Neither were these correspondents aware of the work being conducted by FW3 and the DoA which were dealing with many of these submissions.⁸⁵

There was a general belief that Germany was technologically superior to Britain in 1914 largely because Germany had institutionalised scientific research long before the end of the nineteenth century, whereas Britain had done little in this direction, despite the creation of the National Physical Laboratory (NPL) in 1900 specifically to bring together science and industry.⁸⁶ Significantly, the NPL was independent of the War Office so that there was no link between science, industry and the military. One researcher has described Britain as having been ‘scientifically in arrears’ at the outbreak of war, a somewhat jaundiced view based on the assumption that German science was better than British science.⁸⁷ Nevertheless, science, engineering and warfare were almost mutually exclusive terms in Britain. This did not mean, of course, that British engineering was inferior to German engineering although this is often inferred by the absence of a strong link in Britain between science, engineering and the state at the time of the First World War.⁸⁸ It was in this climate that the Ministry of Munitions was created.

The War Office had a much more pragmatic approach to the problem of providing novel munitions than that suggested by the *History of the Ministry of Munitions*.⁸⁹ Jackson was not given an explicit instruction for his section to assume the functions of inventing and designing: he used his initiative.⁹⁰ The MGO gave Jackson the latitude to invent and design hand grenades, although such devices were outside the scope of FW3. The MGO, thus, showed that his department was flexible enough to take up Jackson’s offer, rather than being hidebound by bureaucracy. The *History of the Ministry of Munitions* implied that this evolution was the result of happenchance caused by bad management. On the contrary, it demonstrated an adaptability that was surprisingly absent in the new Ministry.⁹¹ The responsibilities of FW3 expanded in December 1914 to include gas warfare at the behest of the Engineer-in-Chief, Brigadier-General George Fowke;⁹² once again, this was due to Jackson’s initiative. During the spring of 1915, Jackson’s section took on civilian staff⁹³ and became FW3a,⁹⁴ Engineer Munitions Branch. On the creation of the new Ministry, Jackson and his section were transferred from the War Office to the Ministry of Munitions where it was transformed into the Trench Warfare Department (TWD).⁹⁵ In this new guise, Jackson’s section continued to work in much the same vein as before, albeit with a larger budget.

In June 1915, a General Staff major in the Department of the Superintendent of Design at the War Office expressed the view that only the C-in-C at GHQ could decide what the army required.⁹⁶ The idea was that the C-in-C produced a shopping list which was passed to the War Office who then engaged inventors to devise what was needed and contracted manufacturers to produce the devices in large numbers which were then supplied to the army in France. This kind of linear thinking betrayed a lack of understanding of all the processes involved in taking an idea, turning it into a tangible device that worked, then manufacturing it quickly. It also assumed that the higher authorities in the shape of the MGO and C-in-C were capable of identifying all such needs and, moreover, that if such authority did not identify a need it did not exist.⁹⁷ While this view reflected the pre-war system of design and development, it is significant that it was expressed in June 1915 just as the Ministry of Munitions came into being. The War Office wanted to retain its control over decisions concerning which new munitions would be sent to

France. The major invoked King's Regulations (KR) to argue that the Chief of the Imperial General Staff (CIGS) should make recommendations to the Army Council, via the appropriate member of the Council, about the choice and manufacture of new munitions.⁹⁸ This was a contentious issue which continued to cause discord between the War Office and the Ministry of Munitions until the matter was settled later that year in the new Ministry's favour.

The lack of flexibility in the Ministry was a curious inversion of what might have been expected, given Lloyd George's avowed intention for the Ministry of Munitions to be more efficient than the War Office.⁹⁹ He made a point of eschewing the War Office practice of staffing its departments with military officers and had persuaded civilian engineers and scientists to join the new Ministry in order to bring commercial engineering and business skills to the tasks which the new Ministry had to undertake.¹⁰⁰ Indeed, the Munitions Inventions Department (MID) even co-opted five Patent Office examiners to help assess inventions submitted for evaluation to help prevent time being wasted on worthless devices.¹⁰¹ And yet, the bureaucracy of the new Ministry was more complex and less flexible than that of the War Office. This was partly due to its newness and having to assert itself but also partly because of the high proportion of civilian staff.¹⁰² There were sharp demarcations of responsibility and bureaucratic procedures, all supposedly in the interests of efficiency, and none of the lines was supposed to be crossed.¹⁰³ This inevitably led to bickering and a territorial mentality. It was hardly efficient, or, indeed, sensible.

Neither the War Office nor the Ministry of Munitions succeeded in resolving the problems of institutionalised inventing. Indeed, neither made a serious attempt to invent what the BEF needed and spent more time on evaluation and development than on inventing. None of the revolutionary inventions of the war, such as the Mills grenade, the shrapnel helmet,¹⁰⁴ the Stokes mortar, and the Livens projector, for example, was invented by anyone working in the War Office or the Ministry of Munitions.¹⁰⁵ With the exception of the Livens projector, a type of mortar, which was invented while Captain Livens, RE, was serving in the Royal Engineers Special Brigade, these devices were the creations of civilian engineers who had no previous experience of munitions and no experience of the military. Even Livens had been an engineer in civilian life before he was commissioned into the Royal Engineers in 1914.¹⁰⁶ Captain Henry Newton, perhaps the most prolific inventor in military service during 1915–16, was a Territorial and a civilian electrical and mechanical engineer.¹⁰⁷ Moreover, many of the engineers who submitted inventions to the War Office, and subsequently to the Ministry of Munitions, during 1914, 1915 and 1916 were already inventors when they turned their attention to munitions.¹⁰⁸ These civilian engineers invented munitions unbidden by government, without prompting from letters in *The Times* and at their own expense.¹⁰⁹

In contrast to the War Office and the Ministry of Munitions, the Royal Engineer Workshops, which were set up behind the front during 1915, and the Experimental Section at GHQ, set up in 1914,¹¹⁰ were productive inventions factories at which a wide range of novel munitions were devised from scratch. Some were groundbreaking and arguably superior to much of what was developed by government departments.

Evolutions and convolutions of organisation

By late 1914, there were at least five different sections of the War Office dealing with inventions: the A4 Inventions Department of the DoA;¹¹¹ FW3 section of the DoFW; the Ordnance Board; the Experimental Section at the School of Musketry; and the Inspection Department at Woolwich.¹¹² There was also the Experimental Section at GHQ, France, which acted independently of the War Office. Although GHQ relied heavily on its Experimental Section, the War Office and the Ministry of Munitions seemed oblivious to its influence. Indeed, the *History of the Ministry of Munitions* only refers to the Experiments Committee at GHQ,¹¹³ formed by Sir John French in June 1915.¹¹⁴ The Ministry of Munitions failed to realise that this Committee relied totally upon the recommendations of the Experimental Section, GHQ, which predated it by ten months. The Experiments Committee was no more than a discussion forum and a means of liaison with the Ministry of Munitions and the War Office; the Experimental Section, GHQ, did the work, designed and conducted the experiments, gathered data and analysed it before making recommendations to the Experiments Committee. It also invented and designed novel munitions.¹¹⁵

By July 1915, all this had changed. The Ordnance Board was replaced by the Ordnance Committee.¹¹⁶ FW3a was transferred to the newly created Ministry of Munitions where it became the TWD.¹¹⁷ Its function was to assess rather than create novel munitions.¹¹⁸ Woolwich passed to the new Ministry and ceased evaluations. The MGO was not happy about this arrangement. He complained that ‘the trade’ would take advantage of the inexperience of the Ministry’s civilian staff in munitions design and manufacture by trying to lower the standards to which they had to work because they found meeting the tolerances too difficult.¹¹⁹ The Ordnance Board had been there to act as the MGO’s scientific evaluation arm and to offer appropriate advice. The MGO felt that manufacturing difficulties should not be the overriding factor in production, which he feared would now happen. Previously, the MGO had balanced manufacturing constraints with the needs of the army. He believed that only the army could decide what was suitable for its requirements, not a civilian organisation. It is probable that the General Staff major in the Department of the Superintendent of Design at the War Office had merely expressed the MGO’s views on this issue.

In July 1915, the Admiralty set up the Board of Invention and Research (BIR) to evaluate naval inventions and to conduct its own research.¹²⁰ Its inception was announced in the press¹²¹ which, inevitably, led to correspondence in *The Times* about the need for a similar department to serve the needs of the army.¹²² None of the correspondents was aware of the work already being conducted by Jackson’s section, Woolwich or the DoA. Lloyd George, the Minister of Munitions, seized upon this public debate, conveniently overlooking the fact that the Admiralty, unlike the army, had no department for research and development, and created the MID in August 1915.¹²³ The MID was charged with conducting all evaluations of submitted inventions and with carrying out research and development in the fields of land warfare and aerial warfare.¹²⁴ The creation of the MID was opportunistic and played to the gallery of public opinion.¹²⁵ What land warfare research lacked was coordination from a guiding authority, not another department made up of people who had little connection with the work that had been conducted hitherto.

The War Office was only diplomatically cooperative with the MID; it was less so in practical terms. A4 was supposed to be dissolved on the MID's creation but, in fact, it expanded, much to the annoyance of Lloyd George and Sir Ernest Moir, Comptroller of the newly formed MID.¹²⁶ Moreover, the Army Council retained control of which munitions were to be adopted by the army.¹²⁷ This unhelpful division of responsibilities was not resolved until the end of the year when the MID at last gained control of munitions procurement from the Army Council.¹²⁸ The MID was now supposed to be the sole department responsible for inventions concerning land warfare and aerial warfare. This brought it into conflict with the TWD which dealt with inventions relating to trench warfare. The TWD was expected to hand over all its inventions work to the MID, a less than practical notion since the definition of what constituted an invention was not addressed.¹²⁹ Nor did the proposal address the issue of the close relationship between design, invention and manufacture where trench warfare munitions were concerned. Moir complained that the TWD, and Jackson in particular, was reluctant to comply with the instruction and seemed less interested in the peculiar relationship of research with manufacture in the field of novel munitions than he was in establishing a monopoly on inventions within the Ministry of Munitions.¹³⁰

The TWD had responsibility for every aspect of devising and supplying all types of munition for trench warfare, including trench mortars and their ammunition, which had been passed to the TWD by Woolwich upon the former's creation, as well as having responsibility for training schools for grenades and mortars at Clapham.¹³¹ By July 1915, the TWD no longer initiated original research into novel munitions and restricted itself to the evaluation of submissions of inventions related to trench warfare, although it was also concerned with developing gas warfare.¹³² There was an uneasy relationship with the MID. The Experimental Section at Hythe, however, retained its evaluation role unchanged but was now under the control of the MID rather than the War Office. An interdepartmental conference on the coordination of inventions work was chaired by Lloyd George in July 1915, while a second was held in August 1915.¹³³ In reality, the conferences were intended to enable the new Ministry to exert its authority. They were surprisingly inconclusive and it would appear that monthly meetings of this sort were not continued. Lloyd George argued that all munitions design work should be transferred to the new Ministry as it was impractical for the War Office to retain its control of design while the Ministry was responsible for supply. Thus, in November 1915, responsibility for design and, hence, by association, invention, was finally transferred from the War Office.¹³⁴ The staff of A4 were now transferred to the MID.¹³⁵

It was at this point that the MID took over the responsibilities previously handled by the War Office concerning government use of third-party-owned patents and the payment of royalties to the owners of the patent rights.¹³⁶ It also took on the task of patenting government-owned inventions, as well as responsibility for the internal awards scheme, previously handled by the War Office.¹³⁷ These changes had only come about because of the resolution of a legal anomaly concerning the transfer of details of unpatented inventions from the War Office to the new Ministry. Section 30 (12) of the 1907 Patents and Designs Act allowed inventors to disclose details of an invention to the War Office or the Admiralty without prejudicing their

right to apply subsequently for a patent in respect of that invention.¹³⁸ Section 29 allowed the War Office and the Admiralty to use third-party owned inventions without prior consent if it was deemed to be in the national interest to do so.¹³⁹ Since the Ministry of Munitions had been created after the Act had been passed, the Ministry was not included in these provisions; indeed, some in the War Office argued that the new Ministry was, therefore, specifically excluded.¹⁴⁰ This was one of the reasons for the refusal of the War Office to hand over responsibility for dealing with inventions to the Ministry of Munitions, and to the MID in particular. Permission for the Ministry to use third-party owned intellectual property without prior consent of the owners was vested in the Minister in July 1915¹⁴¹ but, until the transfer of the design authority to the Ministry of Munitions, the Ministry was not specifically covered by Section 30 (12).

At the end of 1915, the TWD was split into the Trench Warfare Research Department (TWRD), under General Jackson, and the Trench Warfare Supply Department (TWSD), under Jackson's former deputy and financial adviser, Alexander Roger, a civilian with no prior experience of munitions or the military.¹⁴² This separated development from manufacture and supply, thereby breaking the close relationship between research, supply and operational use that had been fostered by Jackson. The interdependency had always been perceived as a weakness in the system; the Ministry of Munitions took the view that efficiency was better served by separating research from manufacture and supply.¹⁴³ This was a bureaucratic choice rather than a practical solution and it did not meet with universal approval.¹⁴⁴ Roger lobbied for the split because he believed that the supply function was hindered by its close association with research. From a bureaucratic perspective, he had a point but, from a practical perspective, the evidence was less certain. E V Haig who worked in the TWSD thought that it was 'a great step forward. The combination of Research and Supply proved thoroughly unsatisfactory probably from both the Research and Supply point of view but certainly from the latter'.¹⁴⁵ Like Roger, Haig was a civilian.¹⁴⁶

After the split, the research function no longer had a direct link with the BEF via GHQ. Prior to the split, there was direct feedback on the functionality and reliability of novel munitions. Until mid-1916, all hand grenades were experimental munitions and feedback had a direct bearing on their manufacture and supply. Although design changes inevitably caused disruptions to manufacture and, hence, supply, nevertheless, the system ensured that the lead time between demand and supply of improved munitions was kept to a minimum. Such improvements were not mere whims but essential modifications to imperfect munitions to improve functionality, reliability or manufacturability. Until late 1915, quantity could not be compromised for quality but by mid-1916 the trade-off was about equal so there was a stronger temptation to opt for consistency of manufacture to maintain output of acceptable, if imperfect, munitions at a high level. This temptation was born of a belief that munitions design had reached a stasis at an acceptable level of trade-off. Disruptions to manufacture now could only be tolerated if a major advance in design came about; there was a reluctance to interrupt manufacture for the sake of minor alterations. The separation of Research from Supply of novel munitions both reinforced this belief and was a consequence of it.

Within six months of the split, the TWRD had been absorbed into the Munitions Design Department (MDD), which had been created in November 1915 with General Du Cane as its director-general (DGMD).¹⁴⁷ Previously, he had been head of the Experiments Committee at GHQ. The newly formed Ordnance Committee acted as his advisors, performing the same role for the DGMD as the Ordnance Board had performed for the MGO. Thus, the Ministry of Munitions had control over all aspects of munitions procurement. The War Office now had none. Kitchener wanted to retain the post of MGO, which, unlike the DGMD, had a place on the Army Council, but the MGO's influence had been usurped by that of the DGMD so there was little point.¹⁴⁸ The DGMD became military advisor to the Minister of Munitions in early 1916.¹⁴⁹ There was a problem finding suitable staff who had an understanding of the relationship between design and manufacture, a problem that extended to the newly formed Ordnance Committee.¹⁵⁰ It was the very problem which the MGO had anticipated. Fortunately, the MDD included officers with commercial engineering experience, as well as officers from the trench mortar schools.¹⁵¹ It became immediately apparent that such expertise was essential if good designs were to be engineered from prototype into production model. A Munitions Design Committee was also created to advise the DGMD on matters relating to small arms, grenades and other trench warfare devices. This Committee was made up of a number of sections each of which dealt with one type of munition.¹⁵²

While TWRD was being absorbed into the MDD, there were effectively three design sections. This caused considerable overlap of responsibilities as far as the devices of trench warfare were concerned.¹⁵³ The situation was made unmanageable by a lack of cooperation between these sections which did not liaise with each other or with GHQ. In August 1917, the Ministry was reorganised again and a Design Group was created, which included the MDD, MID and a department dealing with inspection and research of trench warfare devices. By October 1917, the TWRD had ceased to exist and Jackson had gone. He had resigned in late 1916 following a criticism by Du Cane who questioned his approach to research.¹⁵⁴ In September 1916, Du Cane was himself replaced as DGMD by Major-General Bingham.¹⁵⁵ The DoA transferred its design and evaluation responsibilities, the latter via the TWRD, to the MDD. Hence, the latter became responsible for the design of trench mortars and their ammunition, as well for the design of hand and rifle grenades. It was also responsible for approving designs for the BEF, although this brought it into conflict with the MID which had similar responsibilities relating to inventions.¹⁵⁶ The problem here was in the definition of invention and when an invention became a design matter, a question which was never satisfactorily answered during the war.

The lack of liaison between research, manufacture, supply and the BEF proved to be a serious deficiency in the management of the provision of novel munitions for trench warfare. The Trench Warfare Committee (TWC) was created in 1917 in an attempt to redress the matter.¹⁵⁷ Its focus was on trench mortars and their ammunition, hand and rifle grenades, and body armour. The TWC was intended to act as a bridge between design and operational experience, thereby remedying the absence of feedback on design. It was not entirely successful, however. A Superintendent of Trench Warfare Design was created at the same time.¹⁵⁸ He

was located in the Supply Department but reported to the DGMD. Six months later, a new department was set up, the Trench Warfare (Design) Department (TW(D)D), replacing the TWC. This, too, was supposed to maintain a close liaison with Supply. As with the TWC before it, the new Department was located in the same building as Supply and liaison officers from Supply were appointed as ex-officio members of the TW(D)D's advisory committee.¹⁵⁹ By mid-1917, supply had superseded design in importance because design issues were now less concerned with novelty than with refinements to existing munitions; novel munitions were in the process of becoming standardised.¹⁶⁰ The conceptualisation of such munitions as hand grenades and trench mortars meant that these munitions were no longer vague ideas but were defined by precise requirements based on functionality, utility and reliability.

Those departments which dealt with inventions and trench warfare research were regrouped in July 1918 as the Warfare Group.¹⁶¹ In August 1918, a subcommittee of the TW(D)D was charged with investigating whether any trench warfare stores could be improved beyond their present state of development. Such investigations continued until the end of the war. By the time that trench warfare was giving way to more mobile warfare in June 1918, the supply function was finally reunited with design, whereby a supply section was added to the TW(D)D.¹⁶² However, this section was very different from what had been the TWSD of 1915 and it did not perform the same function.¹⁶³ By then, the novel munitions of trench warfare had ceased to be regarded as unconventional.

It would be unwise to ascribe such changes to a series of planned developments as there was no blueprint from which the Ministry of Munitions could be constructed, especially when it came to matters concerning novel munitions. Indeed, the very fact of the changes, their type and frequency implies that there was no plan. Empiricism with a feedback loop which took account of growing experience as the war progressed and as circumstances changed accounts for the convolutions of these departments. By the time of the Second World War, of course, a planned process of development was made feasible in order to best use the available resources because of the experience of the First World War.¹⁶⁴

Royal Engineers

While the War Office was struggling to provide the BEF with the novel munitions it needed for trench warfare, the Royal Engineers set about improvising a wide range of devices using locally available materials. They devised and produced hand grenades as well as ammunition for improvised trench mortars.¹⁶⁵ Not only did the Royal Engineers provide large numbers of such devices when quite inadequate quantities were being supplied from Britain but their work became the foundation of significant development work and industrial manufacture in France that out-produced the commercial engineering firms in Britain during the first eighteen months of trench warfare.¹⁶⁶ Moreover, the Royal Engineers continued to provide an unequalled evaluation service, via the Experimental Section at GHQ, that was of particular significance in the investigation of failures of novel munitions under operational conditions.

There were several crucial differences between the Royal Engineers and government departments. Unlike the War Office or the Ministry of Munitions, the Royal Engineers were

directly involved in production and organised manufacture on an industrial scale, while maintaining an intimate link with research and development at the same facility. In this respect, each facility was self-contained. The Army Workshops were, in effect, factories with research departments, while the Experimental Section at GHQ was the principal research facility in France.¹⁶⁷ Royal Engineers were not supposed to work on anything which was the province of the Ordnance workshops such as fuzes and grenades so that special dispensation had to be granted to allow the Army Workshops to invent and develop any munition that involved fuzes.¹⁶⁸

The manner in which the Royal Engineer facilities grew was more analogous to the growth of a commercial business than it was similar to the evolution of the departments and sections in the Ministry of Munitions. They had greater experience with engineering munitions than the commercial engineering firms in Britain, although, like them, the Royal Engineers had to use civilian workforces which had no munitions experience. There was less bureaucracy, no political interference and a much simpler organisational structure based on commercial workshop principals rather than a military chain of command.¹⁶⁹ No Workshops operated according to a standard system of administration, research, production or distribution: each developed its own working practices. This was largely because they arose independently of each other. Each Workshop was answerable to the Chief Engineer in each Army, while the Experimental Section at GHQ was answerable to the Engineer-in-Chief of the BEF.¹⁷⁰ Each facility had the authority to make technical changes without reference to higher authority. In essence, on technical matters, they were the highest authority and provided technical expertise to the Chief Engineers and ultimately to the C-in-C. This arrangement allowed for a greater flexibility than was possible in Britain.

In October 1914, Brigadier-General Fowke instructed the commander of the 2nd Bridging Train, RE (attached to GHQ Reserve), to find a suitable officer to oversee the manufacture of hand grenades and ammunition for several improvised 90 mm mortars. The mortars had been constructed by Royal Engineers in a small paper mill near St Omer, where GHQ was located.¹⁷¹ Lieutenant E S R Adams, Special Reserve, RE, who had peacetime experience of engineering workshops and had improvised jam-tin grenades on the Aisne, was given the task. Although the post had no official designation, Adams quickly became known as the Experimental Officer to the Chief Engineer and his small command became known as the Experimental Section.¹⁷² It was initially located in a barn at Tilques not far from St Omer, moving into Tilques château a few months later. At this stage, the Section comprised Adams and eight sappers but by March 1915 this had increased to sixteen sappers plus an NCO. In August 1915, the Section was relocated to a canal barge in St Omer which was better equipped with engineering tools, including two lathes.¹⁷³

When GHQ moved to Montreuil-sur-Mer in March 1916, the Experimental Section moved with it to 'the back shed of a private house by the South Gate near the main Montreuil-Abbeville road'.¹⁷⁴ The 'shed' housed two lathes, a drilling machine, a blacksmith's forge, an acetylene welding plant and numerous bench tools. In March 1917, Adams was transferred to the TW(D)D, a posting which was intended to enable the views of GHQ to be represented;

Lieutenant Bellamy, RE, took over command of the Experimental Section. In June 1917, with a reorganisation of the Engineer-in-Chief's Office, the post of Experimental Officer was graded as staff captain thereby making the post official. The Section was expanded in late 1917 and another officer, Lieutenant J McAllister, RE, was posted to it. He had served in the infantry for two and a half years and was 'a trained mechanical engineer'. Experimental work now increased in both scope and extent. New equipment was brought in, including a capstan lathe and a press, to increase the output of percussion mechanisms and to cope with repetitious work, while a second workshop was built for a carpenter, tinsmith and second blacksmith. In addition, a store was built for explosives and grenades. By mid-1918, the hazards to the local French population necessitated the removal of the Section to a field outside Montreuil-sur-Mer and the Experimental Officer moved with it, thereby making the Section independent of GHQ and other Royal Engineer units. In September 1918, the Section consisted of a major, a lieutenant, a quartermaster sergeant, two corporals, ten sappers (these twelve being classed as artisans), a clerk and three draughtsmen.¹⁷⁵ The Experimental Section was dissolved in April 1919.

The scope of the Section's work was extensive and embraced all aspects of research, development and evaluation of novel munitions:¹⁷⁶ experimental work; evaluation of new types; preparation of reports on their suitability for trench warfare; improvement of existing types; comparative trials of British, French and German devices;¹⁷⁷ writing technical sections for manuals and handbooks;¹⁷⁸ investigation of accidents with all types of trench warfare munition; and the provision of general advice on trench warfare munitions. This was a broader range of responsibilities than those of any single department in the Ministry of Munitions. Typically, the work encompassed the gamut of devices used in trench warfare, including hand grenades, rifle grenades, rifle grenade (cup) dischargers, grenade guns, pyrotechnic signals for all branches – including the Royal Flying Corps (RFC) – light machine-gun mechanisms and mountings, small arms ammunition (SAA) including penetration tests of all types, loophole (sniper's) plates, parapet shields, body armour, periscopes, hyposcopes (remote-firing devices), smoke generators, illuminating devices, message-carrying projectiles, land mines, and light mortars and their mountings.¹⁷⁹

Nearly every trench warfare device invented in Britain and in France during the course of the war was evaluated by the Experimental Section. Significant exceptions included the Livens projector and other gas warfare devices which were all dealt with by the Special Brigade. This gave the Section an unrivalled continuity of expertise which no government department could match. It was responsible for initiating the development of many devices that ended up in regular and widespread use along the Western Front.¹⁸⁰ The influence of the Experimental Section was considerable; its findings were disseminated across the BEF to Royal Engineer units and to fighting units, and was probably more influential in weapons procurement than any department in Britain, despite the efforts of the Ministry of Munitions to be solely responsible.

During the first twelve months of trench warfare, accidents with novel explosive munitions were commonplace.¹⁸¹ Many were fatal or resulted in the loss of a limb, typically the

lower arm, hand or fingers.¹⁸² It was essential to determine their causes in order to ascertain which of them were due to design flaws in the munitions, which were due to carelessness, and which were due to procedural deficiencies in the handling of the munitions. Once the causes were known, possible corrective measures could be explored. Such investigations were best conducted in the field and, inevitably, it fell to the Experimental Section to conduct them.¹⁸³ During 1915, these investigations led to GHQ changing its mind about the munitions it wanted from Britain, thereby disrupting demand which annoyed the Ministry of Munitions. The Section provided solutions wherever possible which sometimes resulted in the MID and the MDD being cut out of the loop.¹⁸⁴ Although the Experimental Section could not implement design changes to munitions manufactured in Britain, it made recommendations via GHQ. This, too, led to criticisms. In theory, design matters were the responsibility of the MID and MDD. The validity of such criticisms is moot, however, especially when design matters were not always handled well by the Ministry.¹⁸⁵

One of the most important functions of the Section was that of advising the Engineer-in-Chief on novel munitions to help the General Staff make decisions concerning the tactical and operational use of such devices. In this respect, the Experimental Section, and the Experimental Officer in particular, was influential in the establishment of schools in France during 1915 to train the infantry in the use of grenades and trench mortars, as well as being influential in the evolution of tactics.¹⁸⁶ It is clear that the functionality and reliability of the munitions provided the basis of the advice which the Section provided from its inception in late 1914. Throughout its four-and-a-half-year existence, the Experimental Section was never an official part of the Royal Engineer Establishment at GHQ because it was regarded as a temporary expedient which would become redundant when the war ended. Temporary or not, the Section played an important role in the invention and evaluation of trench warfare munitions throughout the war.¹⁸⁷ The post of Experimental Officer was one of the most important in the BEF as he had considerable influence over policy matters concerning novel munitions.¹⁸⁸ Yet, the Experimental Section seems to have been largely unknown.¹⁸⁹

In June 1915, French formed the Experiments Committee at GHQ.¹⁹⁰ It comprised the Experimental Officer and officers appointed by the General Staff, the Artillery Adviser and the Chief Engineer, with General Du Cane as its chairman.¹⁹¹ It has been suggested that French did this because he recognised a need for experimentation to develop new devices¹⁹² but this is highly unlikely as GHQ's Experimental Section had been in existence for the past ten months. The Committee's supposed function was to evaluate, at staff level, inventions submitted to GHQ by the officers and men of the BEF.¹⁹³ It is no coincidence that the Experiments Committee was created at the same time as the Ministry of Munitions came into being. The Experiments Committee ensured that GHQ retained its veto over which novel devices it adopted for trial and operational use, thereby preventing the Ministry from imposing on the BEF untried munitions devised in Britain. Ranked no higher than a staff captain, the Experimental Officer lacked sufficient authority to stand up to the Ministry, whereas the Committee, as the voice of the C-in-C, was of a far higher status. All the Committee had to do was exist; the real work was undertaken by the Experimental Officer.¹⁹⁴ The Experiments

Committee did not last long, however.¹⁹⁵ Any question relating to inventions was dealt with the Experimental Officer, sometimes under the loose supervision of the General Staff at GHQ.¹⁹⁶

The Ministry of Munitions tried to insist that all submissions be sent to the MID. The idea was that a centralised system of evaluation, research and development could be implemented to avoid duplication of effort and wasted resources. Although a laudable aim, this was never achieved, largely because it was impractical. It was undermined by the ad hoc manner in which departments developed and changed within the Ministry as the war progressed and the MID found itself in conflict with the Design Department. This process of evolution ran counter to the avowed aims of Lloyd George but was inevitable because of the nature of the work in which the Ministry was engaged.¹⁹⁷ It is likely that a similar process would have occurred within the War Office had the Ministry of Munitions not been created.

The MID's desire for centralisation, with itself at the hub, was more to do with bureaucracy and politics than with efficiency of effort, however. There were shortcomings with the manner in which evaluation, development, manufacture and supply had evolved under War Office control during the first ten months of war but the lack of a guiding authority was never satisfactorily addressed by the Ministry of Munitions. The diversity of departments and sections with responsibility for inventions, novel munitions, research, development, manufacture and supply needed the efficiency of organisation and management which Lloyd George had promised. There was an inevitable overlap of interests but the willingness to resolve the inevitable conflicts was sometimes absent. Relations between the War Office, GHQ and the Ministry of Munitions were not improved by General Sir Douglas Haig's Routine Order of June 1917 which stated that no officer in Britain on leave should communicate information about new inventions to MID staff and that all suggestions about inventions should be submitted in writing via GHQ.¹⁹⁸ The Minister of Munitions was obliged to communicate his unease about this order to the Army Council, suggesting that Haig appoint an inventions liaison officer to his staff, preferably one who was familiar with the inventions work in the Ministry.¹⁹⁹

Haig's order had to be 'clarified' to the Minister to avoid any suggestion that GHQ, and Haig in particular, was trying to undermine him, the MID or the Ministry.²⁰⁰ The order was intended to ensure that a proper procedure for dealing with proposals was maintained to avoid wasting time on ill-conceived ideas that may have already been turned down at GHQ. The MID, however, interpreted it as a deliberate attempt to undermine its authority since it relied on informal communication with GHQ and divisional officers to provide it with information about what the BEF needed and how well some devices were performing under battle conditions. No doubt, Haig saw his order as nothing more than a formalisation of procedure to preserve the normal chain of command by reminding his officers that they were governed by KR. It was intended to put a stop to officers making unofficial requests and making unofficial submissions. Moreover, the order had been issued to comply with a request from the MDD to ensure that design matters were channelled directly to it rather than haphazardly as had been the case hitherto.²⁰¹ The incident illustrates the lack

of communication between the Ministry's own departments and the petty bureaucratic arguments that arose from time to time. It is doubtful that the order made the slightest difference to which devices ended up at the front.

Towards a common goal

It is easy to view the different ways in which the War Office and the Ministry of Munitions organised the provision of trench warfare munitions as ineptitude versus efficiency. Such a view belies the complexity of the problems that had to be addressed in order to provide the BEF with what it required. Moreover, the problems of 1915 were not the problems of 1916 nor those of 1917. This was reflected in the organisational changes within the Ministry of Munitions. An organisational framework had to be instigated, then developed and adapted in order to meet the challenge of setting up, then running, what was, in effect, a vast production engineering business in Britain. There is a tendency to view the Ministry of Munitions as the epitome of organisation and efficiency. This is largely because the historical perspective of the Ministry is based on the *History of the Ministry of Munitions* and Lloyd George's *War Memoirs*, neither of which presented views contrary to the notion of organisational efficiency. But there were contrary views.²⁰² What tends to be overlooked is that the War Office laid the foundations of the success subsequently achieved by the Ministry of Munitions. Although the former had a less systemised regime than the latter, this is no reason to condemn it as inefficient. Indeed, the opposite was the case. It allowed men such as Jackson the creative freedom to develop both munitions and an organisational framework. On its creation, the new Ministry appropriated the man and his methods.

There is also another point that needs to be stressed in relation to government departments. The bureaucracy of the paper organisation did not necessarily reflect how such departments functioned in practice. One of the reasons why the War Office was able to work effectively with ad hoc organisational changes was familiarity with how the War Office and the army functioned; many of its staff were army officers. Such a familiarity was lacking in the Ministry of Munitions. Not only was it a new organisation without established practices but its staff included many outsiders from business and industry with little understanding of how things got done in a bureaucratic system. This inevitably caused frictions. It is noticeable that certain individuals, such as Jackson, Adams and Newton, are prominent in the achievements of the departments under discussion here and that they were all army officers, the very influence which Lloyd George had wanted to dilute with civilian incomers. It is far from clear whether the Ministry of Munitions functioned more efficiently with these incomers or whether it would have performed as well or better had it been staffed in the same way in which the War Office was staffed.

This chapter presents only part of the story, however. The measure of success is not the efficiency of the administrative framework but the output of effective munitions. The first steps in this process included identification of potentially useful munitions for trench warfare from those submitted, followed by development and production. Evaluation and manufacture are discussed in the next chapter; they had direct bearing on the success or

failure of government departments in providing what the BEF needed for trench warfare. Thus, before drawing any conclusion about the effectiveness of the organisational effort, it is necessary to consider evaluation and manufacture, which were inexorably linked to research in the field of novel munitions.

The work of the Royal Engineers Workshops, and that of the Experimental Section, was unlike anything conducted in Britain in the provision of trench warfare munitions. Although, for the sake of convenience, discussion of their work is split between the present chapter and the next, the work more closely linked research and development to manufacture than was possible in Britain. The Experimental Section was the means by which GHQ decided which novel munitions it would adopt, whether for trials or for service use. If the Experimental Section gave a munition a bad report, it was much less likely to be adopted than if the Section gave it a favourable one. Thus, although the Ministry liked to imagine that it was responsible for design decisions, the Experimental Section was the final arbiter. No one at the Ministry seems to have grasped this, although many in the Ministry were aware of the veto held by GHQ.

Nevertheless, despite the disagreements and arguments over who controlled which aspects of the provision of novel trench warfare munitions, everyone was working towards a common goal: mass production of effective munitions for the BEF.

The number of departments dealing with trench warfare munitions, and their changing organisation and function during the war, was indicative of the changing nature of the requirement of such munitions as the war progressed. These departments did not outlast the Ministry of Munitions, whereas most of the permanent research establishments not only predated the First World War but continued to operate after the war ended. The trench warfare departments were staffed differently from the permanent establishments and permanent departments, drawing heavily on service personnel, civilian engineers and civilian business people. Thus, the structure and organisation of the trench warfare departments reflected their transience and the expediency of their existence; as such, they were unlike the permanent government research establishments.²⁰³

Notes

¹ The first recorded instance of German troops throwing grenades into British trenches occurred on the Aisne on 27 September 1914. See J E Edmonds, *History of the Great War, Military Operations, France and Belgium, 1914*, (London, 1925), vol. 1, p. 399. See also MUN 5/382/1600/8 Notes on the History of Trench Warfare Research, Aug 1914 – May 1915 dictated by General Louis Jackson, December 1917. The account in this Ministry of Munitions file refers to Jackson's work at the War Office before his transfer to the new Ministry.

² Such as Gamage's, the Army & Navy Stores and the Civil Service Stores. For the private purchase of knives see *The Times* correspondence, 30 November 1915 and 1 December 1915.

³ Because such devices were available for private purchase, many newspapers and journals carried advertisements for them. See, for example, *The Times*, 21 January 1915 for the Oik-Oie periscope, 22 March 1915 for the Duerr periscope; and *The Sphere*, 29 September 1917 for the Dayfield Body Shield.

⁴ This was the eighth Lord Howard de Walden who commanded the 9th (Service) Battalion Royal Welch Fusiliers. The so-called Welsh sword was designed by Félix Joubert, an antiques dealer, who based it on the

Bronze Age Welsh *cledd*. He devised a folding hilt to enable the weapon to be worn comfortably on the hip, which he patented in 1916 (GB108741).

⁵ MUN 5/321A *History of the Ministry of Munitions*, vol. XI, *The Supply of Munitions*, Part 1 *Trench Warfare Supplies*, p. 73.

⁶ According to *Trench Warfare Supplies*, *op cit.* p. 1 'about a dozen only had been made before the outbreak of war'. But see note 126 in Chapter 2 of this thesis. The number of No. 1 grenades at the outbreak of war was confused with the smaller number of rifle grenades that were available, although this was more than 'about a dozen'. This estimate is also contradicted on p. 7.

⁷ *Trench Warfare Supplies*, *op cit.* p. 34. At the time, trench mortars did not exist in Britain. Thus, French was unlikely to ask specifically for them. However, by December, he was specifically requesting trench mortars (*op cit.* p. 38).

⁸ *Trench Warfare Supplies*, *op cit.* pp. 6–22 and *History of the Ministry of Munitions*, vol. IX, *Review of Munitions Supply*, Part II *Design and Inspection*, pp. 45–8. Lt-Col O F Brothers, *The Development of Weapons Used in Trench Warfare*, pp. 5 and 39 (in MUN 5/383/1600/14).

⁹ This was recognised at the time, especially in the context of grenades. See, for example, Brothers. *op cit.* pp. 39 and 41; see also *Design and Inspection*, *op cit.* pp. 45–8 and *Trench Warfare Supplies*, *op cit.* pp. 4–5.

¹⁰ MUN 5/382/1600/8 Notes on the History of Trench Warfare Research, Aug 1914 – May 1915.

¹¹ It was customary, as is still the case, for governments to form ad hoc committees to deal with particular issues. This approach was used by the War Office. On the one hand, this can be interpreted as disorganised but it is a very flexible method of dealing with specific issues. Pattison condemns the ad hoc approach of the War Office as inefficient but this is a misunderstanding of how the process works. See 'The Munitions Inventions Department, a Case Study in the State Management of Military Science 1915–19', unpublished PhD thesis, 1981, and 'Scientists, Inventors and the Military in Britain 1915–19: The Munitions Inventions Department', *Social Studies of Science*, 13, No. 4, 1983.

¹² MUN 5/375/700/1 contains an account of the formation and organisation of the MID.

¹³ Although supply and manufacture are discussed as distinct and separate functions, the term 'supply' was used during the war to denote the combined function of manufacture and distribution. In the present thesis, 'supply' is used solely to denote the distribution aspect.

¹⁴ For example, the person who turned down finned mortar bombs; after two years of struggling with finless projectiles, it was realised that fins were necessary to stabilise the round in flight. See Newton's section in Brothers, *op cit.*; and Stokes's booklet based on his lecture to The Junior Institution of Engineers, 'The Stokes Gun and Shell and their Development', 24 June 1918 in T 173/453.

¹⁵ Lloyd George's instruction to manufacture the Stokes mortar, for example. See David Lloyd George, *War Memoirs*, 6 vols, (London, 1933), vol. 2, pp. 619–20. John Terraine is mistaken when he states that it was Haig's intervention, while he was First Army commander, which rescued the Stokes mortar from oblivion (see John Terraine, *White Heat, The New Warfare, 1914–18*, (London, 1982), p. 145. The Stokes is discussed in Chapter 6 of this thesis.

¹⁶ It is not the purpose of this thesis to enter into such 'what if' discussions about political decisions, although some of their technical implications are discussed.

¹⁷ While trench mortars did not exist in the British arsenal at the start of the First World War, with the recognition in late 1914 of a need for them, they were viewed as artillery and, hence, the responsibility of the MGO. See, for example, *Trench Warfare Supplies*, *op cit.* pp. 34–5, and *Design and Inspection*, *op cit.* p. 45.

¹⁸ The post of Chief Superintendent of Ordnance Factories was created in 1880s to oversee the work of the five Ordnance Factories (Royal Gunpowder Factory at Waltham Abbey, Royal Small Arms Factory at Enfield, and Royal Laboratory (ammunition), Royal Gun Factory (gun barrels) and Royal Carriage Factory (mountings) at Woolwich). In 1909, the CSOF's responsibilities were limited to the Factories at Woolwich and another Chief Superintendent was appointed to look after Enfield and Waltham Abbey. Woolwich Arsenal was also home to the Ordnance Board, the Research Department (part of the Royal Laboratory), the Inspection Department, the Naval Ordnance Inspection Department, and a very large Ordnance Depot. I am indebted to Norman Bonney for this summary.

¹⁹ MUN 5/120/810/6 Notes on Design, Prepared in Historical Records Branch, 18 January 1919. This comprises three pages of typescript.

²⁰ J D Scott, *Vickers, A History*, (London, 1963), p. 31. The Elswick Ordnance Works was a part of Armstrong Whitworth. The Elswick Ordnance Company was founded in 1859 and merged with Armstrong in 1864.

²¹ The armaments firms are listed in George Dewar, *The Great Munitions Feat, 1914–1918* (London, 1921) p. 13 as Vickers, Armstrong Whitworth, Birmingham Small Arms Company (BSA), Coventry Ordnance Works, Beardmore, Firth, Hadfield, and Cammell Laird. Three government factories are listed: the Royal Ordnance Factory at Woolwich, the Royal Small Arms Factory at Enfield, and the Royal Gunpowder Factory at Waltham Abbey. See also *Military Operations, 1914*, vol. 1, *op cit.* p. 12 for government factories. They were the responsibility of the MGO.

²² CAB 1/16/23, p. 3 of minute DGMD/Genl/023 by General Du Cane, DGMD, 4 March 1916, to Lloyd George, Minister of Munitions. This suggests that more design work was carried out by the Ordnance Factories than by the armaments firms.

- ²³ A Small Arms Committee advised on anything relating the service rifle.
- ²⁴ MUN 5/120/810/6 Notes on Design, *op cit.*
- ²⁵ *Ibid.* Inspection in engineering terms means checking that the component parts of a given device have been manufactured within specified tolerances. It is carried out by engineers using gauges, to measure, for example, the dimensions of the components concerned.
- ²⁶ Scott, *op cit.* pp. 98–9. The problem was made worse by the fact that Vickers, which had little experience of supplying the War Office, as opposed to the Admiralty, was suddenly swamped with War Office orders. This epitomised the chaos prior to the creation of the Ministry of Munitions.
- ²⁷ *Ibid.*
- ²⁸ Major-General Sir Stanley Brenton von Donop was MGO from 1913 to 1916 when he was replaced by Lieutenant-General Sir William Thomas Furse. Von Donop had to preside over the shell scandal and the shortage of heavy howitzers, although he was responsible for the fact that the BEF had any howitzers at all.
- ²⁹ *Design & Inspection, op cit.* p. 45; MUN 5/120/810/6 Notes on Design, *op cit.* Lloyd George makes the same comment about the MGO (Lloyd George, *op cit.* vol. 2, p. 617) but only because he was using these Ministry of Munitions files when he wrote his memoirs.
- ³⁰ *Trench Warfare Supplies, op cit.* p. 34. See also OB11520(II). However, in 1915, a Krupp design was used as the basis of the 2-inch toffee apple mortar. See Chapter 5. This also implies that entrenchments were a feature of the fighting right from the outset, rather than appearing some three months after the outbreak of war, but mobility dominated until the armies were exhausted.
- ³¹ Namely, 4.7-inch naval guns removed from ships and mounted on improvised field carriages; Woolwich then engineered better carriages and in 1900 the gun became the 4.7-inch Quick-firing (QF) field gun. Similarly, some 6-inch naval guns were also converted for land use in South Africa. I V Hogg & L F Thurston, *British Artillery Weapons & Ammunition 1914–1918*, (London, 1972), pp. 110 and 140.
- ³² For example, the 13 pdr horse artillery gun did not enter service until 1904 and the 18 pdr field gun, which entered service at the same time, was modified in 1906 to become the Mk 2, then the gun, its recuperator system and carriage were modified still further during the war, illustrating not only the length of time involved in developing new equipment but also that the notion of engineering stasis is false. See Hogg & Thurston, *op cit.* pp. 58 and 80–3.
- ³³ Rick Landers, 'Grenade' *British and Commonwealth Hand and Rifle Grenades*, (Dural, 2001), pp. 6–7. See WO 32/18989 for Ordnance Board (OB) minute OB7460 from 1912 concerning the development and trials of Royal Laboratory rifle grenades. Previous minutes from 1911 were OB5913 and OB5982 I. The design numbers were RL17940, RL17770, RL17840, RL17870A. OB minute OB8126 from 1913 shows that development was still underway but with different designs, RL20424, RL20431. Work on the RL designs ended later that year.
- ³⁴ Brothers, *op cit.* p. 40.
- ³⁵ *Military Operations, 1916*, vol. 1, (London, 1932), p. 119. The building of National Factories for the production of ammunition began to have an effect on the supply of shells during 1916. *History of the Ministry of Munitions*, vol. VIII *Control of Industrial Capacity and Equipment*, Part I *Review of State Manufacture*, pp. 40–4.
- ³⁶ WO 32/5152, Shortage of artillery ammunition in the field 1914–1915.
- ³⁷ The artillery and shell questions are outside the scope of the present thesis and is well covered elsewhere.
- ³⁸ See, for example, Pattison thesis, *op cit.*, Guy Hartcup, *The War of Invention*, (London, 1988). But also see Scott, *op cit.* pp. 100–03.
- ³⁹ Lloyd George, *op cit.* vol. 2, pp. 619–20.
- ⁴⁰ For example, *Military Operations, 1915*, vol. 2, (London, 1927), p. 23; Richard Holmes, *Tommy, The British Soldier on the Western Front 1914–1918*, (London, 2004), pp. 385–9; but see Paddy Griffith, *Battle Tactics of the Western Front*, (New Haven, 1996), p. 103 where the 'key role' of the Royal Engineers in developing technologies is acknowledged.
- ⁴¹ Indeed, the fact that some of those described as 'Engineers' were not, in fact, Royal Engineers but servicemen from a variety of branches of the army was not usually mentioned at all.
- ⁴² *Trench Warfare Supplies, op cit.* pp. 6–31; *Design and Inspection, op cit.* pp. 44–107.
- ⁴³ *Trench Warfare Supplies, op cit.* p. 22; *Design and Inspection, op cit.* p. 76.
- ⁴⁴ SUPP 6/509 Report of the Proceedings of the Ordnance Committee, Trench Warfare Section, 11 December 1915 to 23 April 1917, pp. 36–7.
- ⁴⁵ See, for example, *Trench Warfare Supplies, op cit.* pp. 8–13. See also MUN 4/4520 Co-ordination of Invention, Research and Design, 14 September 1918; MUN 9/21 coordination of Ministry of Munitions and War Office activities; MUN 5/41/263.6/20 regarding lack of cooperation between the Trench Warfare Supply Department and Trench Warfare Research Department in 1917.
- ⁴⁶ The Admiralty also received submissions.
- ⁴⁷ Parlour *et al* in the nineteenth century (see previous chapter of this thesis). See also Hartcup, *op cit.* pp. 4–5; Hillary Rose and Stephen Rose, *Science and Society*, (London, pbk ed. 1977), pp. 21–8.
- ⁴⁸ *The Times*, 22 February 1900.

⁴⁹ It is, of course, difficult to differentiate between scepticism and practicality since inventors tended to believe their devices to be brilliantly conceived and peerless. Although it is something of a cliché, nevertheless, the unsolicited invention tends to be crackpot rather than sober.

⁵⁰ *Ibid.* FW3 was concerned with coastal defence at the start of the war but its remit changed to that of dealing with devices for trench warfare in the autumn of 1914.

⁵¹ *Design and Inspection, op cit.* pp. 29–30.

⁵² And, indeed, in other theatres of war.

⁵³ Hartcup, *op cit.* p. 61; PRO 30/57/49 letter of 25/12/14 from French to Kitchener asking for ‘an inventive expert’ to be appointed to invent trench warfare devices because the Germans had the tactical and technological edge over the BEF in the trenches.

⁵⁴ Lieutenant-Colonel Loius Jackson was born on 7 March 1856, attended Somerset College, Bath, and the Royal Military Academy, Woolwich. He served in Afghanistan in 1879 and was ADC to the Governor of the Leeward Islands in 1883. From 1895 to 1902, he was an instructor in fortifications and military engineering at the School of Military Engineering, Chatham. He was the Commissioner for the Anglo-German Boundary of Northern Nigeria, 1902–04; he was Commander Royal Engineers in Dublin 1904–06 and was the Assistant Director of Fortifications and Works from 1907 to 1910 before becoming the Chief Engineer of the London District in 1910. He retired in 1913. On the outbreak of war, he was reappointed as an assistant director at the War Office. In 1915, he became a director-general in the Ministry of Munitions; 1916–17, he was Controller of Trench Warfare Research in the Ministry. He visited the Russian front in July 1916 and was sent to Canada by the War Office on special duty in 1918. He retired as an honorary major-general in November 1918. He was appointed CMG in 1906, CB in 1917 and KBE in 1918. He was also made a Commander of the Legion of Honour in 1917 and a Knight of St Stanislas (1st Class) in 1918. He died on 8 October 1946 at the age of 90. See *Who Was Who, 1941–50*, (London, 1967), p. 593 summarised in *Weapons of the Trench War, 1914–1918*, (Stroud, 1999), pp. 8–9. See also Hartcup, *The War of Invention*, pp. 23, 25, 25, 61–2. Unfortunately, Hartcup is imprecise about Jackson’s role at the War Office, 1914–15, especially when it comes to how Jackson became involved with inventions, development and supply.

⁵⁵ ‘The trade’ was a contemporaneous term used to denote all commercial engineering firms not customarily engaged in the armaments industry. Edgerton refers to such firms as ‘civilian industry’ to distinguish them from armaments manufacturers (see David Edgerton, *Warfare State, Britain, 1920–1970*, (Cambridge, 2006), pp. 13, 37).

⁵⁶ According to *Design and Inspection, op cit.* p. 45, trade designs of hand and rifle grenades were submitted directly to the Inspection Department, Woolwich, for evaluation.

⁵⁷ MUN 5/382/1600/8, *op cit.*

⁵⁸ This point was noted in *Trench Warfare Supplies, op cit.* p. 7.

⁵⁹ The history of how the War Office dealt with these matters was written by the authors of the *History of the Ministry of Munitions*. There is an ambivalence to the account concerning the work conducted by the War Office before the creation of the Ministry of Munitions. The *History* cannot avoid acknowledging what the War Office achieved because Jackson, the chief architect of the achievements, was transferred to the new Ministry on its creation and subsequently played an important role in the Trench Warfare Department of the new Ministry. Moreover, his notes on his work at the War Office were used in writing the Ministry’s *History*.

⁶⁰ This is discussed in the next chapter.

⁶¹ Brothers, *op cit.* p. 6; *Trench Warfare Supplies, op cit.* p. 39; MUN 5/118/700/27, Collection of Papers re Inventions, 1915–1916.

⁶² *Design and Inspection, op cit.* p. 51 and *Trench Warfare Supplies, op cit.* pp. 15–16; MUN 5/118/700/27, *op cit.*

⁶³ MUN 5/382/1600/8, *op cit.* See also Bashford Dean, *Helmets and Body Armor in Modern Warfare* (New Haven, 1920), pp. 190–2.

⁶⁴ Brothers, *op cit.* p. 16.

⁶⁵ It should be noted that the spherical case, or shrapnel shell, of 1784 (invented by Lieutenant Henry Shrapnel, an artillery officer), the Hale rocket of 1867 (Hale was a technician at Woolwich) and the Boxer cartridge in 1866 (invented by Colonel Boxer who was Superintendent of the Royal Laboratory) were exceptions to the rule. Boxer invented and patented a number of devices relating to shells, fuzes and cartridges in the 1860s.

⁶⁶ *Design and Inspection, op cit.* p. 45; William H. McNeill *The Pursuit of Power*, (Chicago, pbk ed. 1984), p. 272.

⁶⁷ *Trench Warfare Supplies, op cit.* p. 14. The Royal Laboratory became the Design Department in 1921.

⁶⁸ For MGO request see *Trench Warfare Supplies, op cit.* pp. 2, 34–5; for problems inventing a mortar see p. 35. See also *Annual Report of the President, Ordnance Board for the year 1915*, (London, 1917), pp. 305–8, 317–20, 321–3, 324–6 (MUN 5/120/810/6).

⁶⁹ *Trench Warfare Supplies, op cit.* pp. 34–7. The Krupp patents were GB19345/08 and GB19397/10. These do not appear to have been examined, however. *Trench Warfare Supplies* refers to a ‘German technical magazine’ (p. 37).

⁷⁰ *Trench Warfare Supplies, op cit.* pp. 35–7. See also *Annual Report, op cit.* The technical deficiencies of the first mortars are discussed in Chapter 6 of this thesis.

⁷¹ The No. 6 and the No. 7 hand grenades were essentially the same device; the latter was slightly heavier as it contained shrapnel balls whereas the former relied on the power of the explosive alone for its effect. They were re-engineered jam-tin grenades.

- ⁷² List of Changes in War Matériel and of Patterns of Military Stores §18689, 17 March 1916.
- ⁷³ Lloyd George alluded to the inventor's dislike of bureaucracy but in so doing reinforced the notion of inventors as eccentrics (see Lloyd George, *op cit.* p. 595).
- ⁷⁴ *Design & Inspection, op cit.* pp. 47–8, 61. See also Pattison in *Social Studies of Science, op cit.* pp. 538–9 regarding 'eccentric' inventions.
- ⁷⁵ See, for example, Pattison thesis, *op cit.* p. 212.
- ⁷⁶ In the decades following the Second World War, the process of invention became increasingly expensive, especially in certain fields of endeavour, such as electronics and aviation, so that ever bigger research budgets were needed and thus the resources of large corporations. Hence, the 'amateur' was priced out of the market. However, there is a case for arguing that innovation makes its greatest leaps when individuals are allowed to pursue their own lines of enquiry without having to conform to the expectations of the firm which employs them. The great Victorian inventors, all of whom were 'amateurs', gave us the telephone, the aeroplane, the gas turbine, the internal combustion engine, the suspension bridge and the electric filament bulb. This was not institutionalised inventing. Even within large modern corporations, inventions are created by individuals rather than committees.
- ⁷⁷ *The Times*, 18 April 1913, report of the annual dinner of the Institution of Mechanical Engineers. Colonel Seely, the Secretary of State for War, emphasised that victory would depend on mechanical engineers advancing the technology of war. He referred to a recent series of articles written by H G Wells for *The Daily Mail*. Indeed, Wells had written a number of prescient stories about technological warfare, going back to 1903.
- ⁷⁸ *Ibid.*
- ⁷⁹ *The Times*, 18 May 1877.
- ⁸⁰ Lloyd George, *op cit.* vol. 2, p. 615.
- ⁸¹ *The Times*, 23 November 1914.
- ⁸² *The Times*, correspondence, May, June and July 1915. See also MUN 5/118/700/27, *op cit.* regarding the mobilisation of science with respect to the correspondence in *The Times*.
- ⁸³ WO 32/9281 Inventions Departments of the War Office, top minute addressed to the Deputy Superintendent of Design, June 1915.
- ⁸⁴ Hartcup, *op cit.* pp. 22–3.
- ⁸⁵ Pattison is of the opinion that such correspondence was 'a politically embarrassing debate' (Pattison *Social Studies of Science, op cit.* p. 527) but this overstates the case in favour of Lloyd George who capitalised on the notion of an incompetent War Office.
- ⁸⁶ See Rose *op cit.* pp. 29, 35–6; Pattison thesis, *op cit.* p. 3; WO 32/9281, *op cit.* The perception that German technology was superior to British engineering and that the British were reactionary ran deep. However, this unfounded view was not borne out by reality. The relationship between state, science and the military was institutionalised in Germany because it was a militarist state.
- ⁸⁷ Pattison thesis, *op cit.* pp. 6–7.
- ⁸⁸ Edgerton suggests that there was a stronger link than historians have generally appreciated; see Edgerton, *op cit.* pp. 11, 272, 277, 313, for example. It is outside the scope of this thesis to debate this issue but sadly the assumption is widespread and seems to be based on the notion that German engineering produced the most technically advanced weapons during the nineteenth and twentieth centuries, a notion which does not stand up to scrutiny.
- ⁸⁹ See, for example, *Design and Inspection, op cit.* pp. 44–53 and *Trench Warfare Supplies, op cit.* pp. 7–8.
- ⁹⁰ MUN 5/382/1600/8, *op cit.* draft dictated 10/12/17.
- ⁹¹ *Design and Inspection, op cit.* p. 47.
- ⁹² Subsequently Lieutenant-General Sir G H Fowke. Fowke was Chief Engineer of the BEF in January 1915. In July, he was appointed Engineer-in-Chief. Major-General Spring R Rice took over the post in 1916 who was replaced by Major-General M Heath in 1917. When the post of Engineer-in-Chief was created in July 1915, the post of Chief Engineer in each Army and Corps was created at the same time (www.remuseum.org.uk/corpshistory/rem_corps_part14.htm accessed July 2008).
- ⁹³ *Design and Inspection, op cit.* p. 50. In January 1915, Jackson had two staff captains and a personal assistant (see MUN 5/382/1600/8, *op cit.* draft dictated 10/12/17, pp. 4–5). It would appear that he was assigned two more captains about a month later (*op cit.* p. 3). By June 1915, Jackson had at least one other officer, a major, working in his section (see MUN 5/382/1600/11 Record of History and Work, Ministry of Munitions, Trench Warfare Supply Department, OEB, p. 1). See also MUN 5/382/1600/6 The History of Trench Warfare Supply, Departmental Organization for the Production of Trench Warfare Stores, Evolution of Trench Warfare Department, pp. 1–2.
- ⁹⁴ It is unclear at which date the designation changed to FW3a and it would appear to have been a short-lived designation due to the transfer of the branch to the Ministry of Munitions in June 1915.
- ⁹⁵ MUN 5/41/263.6/15 Transfer of Jackson from War Office to Ministry of Munitions. At the same time, Jackson was promoted brigadier-general. The transfer occurred on 23 June 1915.

- ⁹⁶ WO 32/9281, *op cit.* pp. 1–2.
- ⁹⁷ GHQ, France, set up a committee to address this matter.
- ⁹⁸ Kings Regulations Appendix IV, p. 409 regarding making recommendations ‘affecting the fighting efficiency of the military forces’. WO 32/9281, *op cit.*
- ⁹⁹ Lloyd George, *op cit.* vol. 1, pp. 124–5, 126, 134, 136, 243.
- ¹⁰⁰ *Op cit.* p. 245.
- ¹⁰¹ MUN 5/357/700/1 Formation and Organisation of the Munitions Inventions Department, p. 3. The transfer was with the full cooperation of the Comptroller of Patents, Mr Temple Franks.
- ¹⁰² Pattison ascribes its success and its legacy to the civilian staff but he overlooks the military personnel who also staffed the Ministry, many of whom had engineering backgrounds.
- ¹⁰³ *Trench Warfare Supplies, op cit.* p. 33. See also MUN 5/41/263.6/20, *op cit.*
- ¹⁰⁴ An inventive part of the British shrapnel helmet was the liner which prevented the manganese-steel bowl (the use of Hadfield manganese steel was also inventive) from sitting directly on the head. The British helmet was invented by an engineer called John Brodie. He applied for a patent on 16 August 1915 (GB11803/15) and another on 9 November 1917 (GB120606).
- ¹⁰⁵ Such a list of ‘important’ inventions is highly subjective, of course. Nevertheless, it is a truism that ‘important’ inventions did not generally originate in government departments.
- ¹⁰⁶ Letter to *The Times*, 5 February 1964, concerning the death of Livens.
- ¹⁰⁷ T 173/728 Minutes of the Proceedings before The Royal Commission on Awards to Inventors held on Monday 17 November 1924, Claim of Colonel Newton, p. 29. Newton was a Captain in the 1st/5th Sherwood Foresters when he went to France in 1915.
- ¹⁰⁸ From a reading of the top sheets of patent specifications relating to devices submitted to the War Office for evaluation.
- ¹⁰⁹ One of Stokes’s complaints after the war was that he was not reimbursed the £3000 he had spent on developing the mortar. See T 173/453.
- ¹¹⁰ ‘The Work of the Royal Engineers in the European War, 1914–19’, *The Royal Engineers Journal*, September 1924, pp. 449–50; Colonel G H Addison, (ed.), *The Work of the Royal Engineers in the European War, Miscellaneous*, (Chatham, 1927), pp. 255, 258.
- ¹¹¹ See MUN 5/357/700/1/B for a description, from the perspective of the Munitions Inventions Department, of the work and responsibilities of A4 which is erroneously referred to as A4I, an error repeated by Pattison in *Social Studies of Science, op cit.* (pp. 526, 535). According to this, A4 could assess submissions and advise but could not initiate research.
- ¹¹² While there are various documents, such as conference reports in CAB 17/120, which list such departments, no list is definitive. Neither is the *History of the Ministry of Munitions* to be relied upon. The matter is made more difficult by the lack of consensus about the naming of such departments. Thus, lists in the present thesis are made up from various sources including CAB 17/120, WO 32/9281, *Trench Warfare Supplies, op cit.* and *Design and Inspection, op cit.*
- ¹¹³ *Trench Warfare Supplies, op cit.* p. 20.
- ¹¹⁴ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 451.
- ¹¹⁵ Hartcup is mistaken when he states (Hartcup *op cit.* p. 26) that the ‘Inventions Committee’ passed favourable submissions to Jackson in FW3. The Experimental Section, GHQ, was independent of FW3 and conducted its work without reference to the War Office. There was no policy for sending ‘good’ inventions to FW3 or any other section in Britain.
- ¹¹⁶ *Annual Report, op cit.* p. xvii.
- ¹¹⁷ MUN 5/41/263.6/15, *op cit.*
- ¹¹⁸ MUN 5/357/700/1, *op cit.* p. 4.
- ¹¹⁹ *Design and Inspection, op cit.* p. 54; see also MUN 5/43/263.8/3 Memoranda etc concerning the transfer of responsibility from the War Office to the Ministry of Munitions Nov 1915 – Jan 1916.
- ¹²⁰ CAB 17/120, *op cit. Design and Inspection, op cit.* p. 48.
- ¹²¹ *The Times*, 19 July 1915.
- ¹²² *The Times*, May–August 1915.
- ¹²³ Lloyd George, *op cit.* vol. 1, p. 540; *Design and Inspection, op cit.* pp. 48, 49, 61. It was announced in *The Times* on 12 August 1915. See also MUN 5/118/700/27, *op cit.*
- ¹²⁴ MUN 5/357/700/17; *Design and Inspection, op cit.* p. 32. The Royal Flying Corps was a branch of the army from its formation in 1912 until its amalgamation with the Royal Naval Air Service in 1918 to form the Royal Air Force.
- ¹²⁵ *Design and Inspection, op cit.* p. 49.
- ¹²⁶ MUN 5/357/700/1, *op cit.* For appointment of Moir as head of MID see p. 2. For expansion of A4 see p. 5. See also MUN 9/21 regarding lack of cooperation between A4 and the MID. See also Lloyd George, *op cit.* vol. 2 pp. 622–3 for Moir’s appointment.
- ¹²⁷ *Design and Inspection, op cit.* p. 49. MUN 5/43/263.8/3, *op cit.*

- ¹²⁸ *Design and Inspection, op cit.* pp. 53–4. MUN 5/43/263.8/3, *op cit.*
- ¹²⁹ The MID subsequently discussed the matter of what constituted an invention with the Design Department to try to resolve an ambiguity over areas of responsibility but the discussion was inconclusive (see MUN 5/357/700/1, *op cit.* p. 23).
- ¹³⁰ Indeed, Moir even suggested that Jackson was not up the task of running a big department with diverse interests. Politicking was, thus, not confined to MPs. See letter to Colonel Arthur Lee, MP, Military Secretary to the Minister of Munitions, dated 18 November 1915 in MUN 5/43/263.8/13.
- ¹³¹ *Trench Warfare Supplies, op cit.* p. 30.
- ¹³² MUN 5/382/1600/8, *op cit.* *Trench Warfare Supplies, op cit.* pp. 8–9.
- ¹³³ MUN 5/118/700/27, *op cit.* CAB 17/120, *op cit.* for July conference on coordination and cooperation between inventions departments; WO 32/9281, *op cit.* for August conference. See also *History of the Ministry of Munitions, Design and Inspection, op cit.* pp. 44–55.
- ¹³⁴ MUN 5/43/263.8/3, *op cit.* MUN 5/357/700/1, *op cit.* pp. 4–7; *Design and Inspection, op cit.* pp. 53–5.
- ¹³⁵ MUN 5/357/700/1, *op cit.* pp. 9–10.
- ¹³⁶ MUN 5/357/700/1, *op cit.* pp. 7–8. *Design and Inspection, op cit.* pp. 61–2. McNeil is mistaken when he claims that in the 1880s ‘the law did not permit Woolwich to infringe patents’ (*op cit.* p. 272) since the Patents Acts have always permitted Crown use of third-party owned patents without consent which obviates infringement but, since the 1883 Act, the Crown has then to compensate the patentee. See Van Dulken, *British Patents of Invention, 1617–1977*, (London, 1999), p. 38.
- ¹³⁷ See WO 32/9285, Patents, Rewards and Royalties, Transfer of Responsibility to Ministry of Munitions., especially p. 4 of a minuted Conference on Patents, Royalties and Rewards held on 27 March 1916. See van Dulken, *op cit.* for government committees dealing with inventions and awards. Until at least the 1980s, the MoD had a Committee on Awards to Inventors. A section within the Principal Directorate of Patents, MoD, and its predecessors, which dealt with all matters pertaining to intellectual property rights concerning the Crown, investigated claims for the Committee and made recommendations.
- ¹³⁸ *Design and Inspection, op cit.* p. 61; MUN 5/357/700/1 *op cit.* p. 7 where Section 30 (2) is erroneously cited. See also Patents and Designs Act 1907, Section 30 (12). In other words, disclosure was deemed to be in confidence.
- ¹³⁹ Patents and Designs Act 1907, Sections 29 and 30. See also BT 209/482 which contains a copy of the 1907 Act with proposed amendments. See also MUN 5/357/700/2/10 which deals with Kings Regulations in respect of patent applications filed by servicemen and MUN 5/ 357/700/2/11 which deals with applications filed by members of the Ministry of Munitions. See also WO 33/387 which deals with servicemen filing patent applications, covering the period 1905–06, and WO 55/3044 which deals with War Office use of third-party owned patents, covering the period 1898–1904. Sections 29 and 30 of the 1907 Act were drafted to clarify the system and thereby establish the nature of the rights involved.
- ¹⁴⁰ MUN 5/357/700/1 *op cit.* p. 7; *Design and Inspection, op cit.* pp. 61–2.
- ¹⁴¹ *Design and Inspection, op cit.* p. 61.
- ¹⁴² *Trench Warfare Supplies, op cit.* p. 10. See also MUN 4/6870 History of the Trench Warfare Supply Department, provisional notes by Sir Alexander Roger; and MUN 5/382/1600/6 History of Trench Warfare Supply, Part I, Departmental Organisation for the Production of Trench Warfare Stores, first draft, p. 4.
- ¹⁴³ Brothers, *op cit.* pp. 39, 41.
- ¹⁴⁴ *Trench Warfare Supplies*, pp. 11–12.
- ¹⁴⁵ MUN 5/382/1600/7 History and Work Ministry of Munitions Trench Warfare Supply Department June 1915 to September 1917 by the Deputy Director-General, Mr E V Haigh, p. 6.
- ¹⁴⁶ Haigh was recruited to the Department by Captain Leeming in June 1915 (MUN 5/382/1600/7, *op cit.* p. 1; see also MUN 5/382/1600/11 Record of History and Work, Ministry of Munitions, Trench Warfare Supply Department, OEB by Captain Leeming, 20/7/17, p. 11). Haigh became Deputy Director-General (DDG) in September 1916 (MUN 5/382/1600/7, *op cit.* p. 8). He later became Controller of the TWSD (*Trench Warfare Supplies, op cit.* p. 13).
- ¹⁴⁷ Du Cane was appointed on 3 December 1915. See *Trench Warfare Supplies, op cit.* p. 10; see also *Design and Inspection, op cit.* pp. 54–5.
- ¹⁴⁸ *Design and Inspection, op cit.* p. 55.
- ¹⁴⁹ This was not without its problems. See CAB 1/16/23, *op cit.*
- ¹⁵⁰ *Op cit.* pp. 57, 59.
- ¹⁵¹ *Trench Warfare Supplies, op cit.* p. 11.
- ¹⁵² *Design and Inspection, op cit.* p. 58.
- ¹⁵³ *Op cit.* pp. 58–60.
- ¹⁵⁴ Addison papers D2/5 Department of Trench Warfare, and gas warfare, 1915–17, (fols 251–348) MS Addison dep. c. 74 (Department of Special Collections and Western Manuscripts, Bodleian Library).
- ¹⁵⁵ *Design and Inspection, op cit.* p. 59.
- ¹⁵⁶ MUN 5/357/700/1 *op cit.* pp. 20–4.
- ¹⁵⁷ *Trench Warfare Supplies, op cit.* p. 11. Brothers, *op cit.* p. 8.
- ¹⁵⁸ *Trench Warfare Supplies, op cit.* p. 11.

- ¹⁵⁹ *Ibid.* See also *Design and Inspection, op cit.* p. 63. See also Brothers, *op cit.* p. 3 where the department is referred to as the Trench Warfare Department. For a description of the organisation of the TW(D)D see Brothers, *op cit.* pp. 5–7.
- ¹⁶⁰ *Trench Warfare Supplies, op cit.* pp. 13, 31; *Design and Inspection, op cit.* pp. 59, 94–9.
- ¹⁶¹ *Design and Inspection, op cit.* p. 59.
- ¹⁶² *Trench Warfare Supplies, op cit.* pp. 13; Brothers, *op cit.* p. 4.
- ¹⁶³ The Trench Warfare Supply Department had been broken up in the autumn of 1917. See *Trench Warfare Supplies, op cit.* p. 12.
- ¹⁶⁴ E A G Robinson, ‘The Overall Allocation of Resources’ in D N Chester (ed.), *Lessons of the British War Economy*, (Cambridge, 1951), pp. 34–57.
- ¹⁶⁵ *Military Operations, 1915*, vol. 2, *op cit.* p. 9.
- ¹⁶⁶ See, for example, ‘The Work of the Royal Engineers’, September 1924, *op cit.* pp. 456–8, and March 1925, pp. 76–80.
- ¹⁶⁷ ‘The Work of the Royal Engineers’, September 1924, *op cit.* pp. 449–65.
- ¹⁶⁸ T 173/728, *op cit.* p. 31.
- ¹⁶⁹ Addison, *op cit.* pp. 255–6, 258, 260.
- ¹⁷⁰ T 173/728, *op cit.* pp. 451–2.
- ¹⁷¹ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 455.
- ¹⁷² The work of the Experimental Section is discussed in Chapter 5 in relation to the technical development of trench warfare devices, comparing it with that of other inventions agencies such as the FW3 Section of the War Office, the Trench Warfare Department and MID.
- ¹⁷³ The significance of the lathes is that metal turning was now possible which permitted a higher degree precision than had been possible hitherto. Although precision engineering was necessarily avoided for ease of mass manufacture, some components needed the resources of a well-equipped workshop to make them to a high enough standard to be consistently reliable.
- ¹⁷⁴ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 452.
- ¹⁷⁵ *Op cit.* pp. 452–4.
- ¹⁷⁶ *Op cit.* pp. 454–5.
- ¹⁷⁷ This provided GHQ with technical intelligence on enemy munitions.
- ¹⁷⁸ This began in 1914 with handbooks such as Notes from the Front and Notes on Field Defences.
- ¹⁷⁹ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 461.
- ¹⁸⁰ Many of these devices are outside the scope of this thesis; those which fall within its remit are discussed in Chapters 5 and 6.
- ¹⁸¹ See, for example, *Trench Warfare Supplies, op cit.* pp. 36–7, 38–9, 67, 77, 79, 81. See also letter, dated 8 September 1915, from Lieutenant-General Maxwell, GHQ, in MUN 4/2557 Pitcher grenades. Accidents and defects of grenades, especially the No. 5 are discussed in T 173/802 Minutes of Proceedings before the Royal Commission on Awards to Inventors, evidence of Major Beddoes in respect of Mr Vickery’s claim (27 January 1920). The technical causes are discussed in Chapters 5 and 6 of the present thesis.
- ¹⁸² See, for example, Dunlap Pearce Penhallow, *Military Surgery*, (London, 1916), Fig. 60, p. 143; also MUN 4/2557, *op cit.*
- ¹⁸³ The Experimental Section investigated accidents with all types of munition throughout the war. See ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 455. See also *Military Operations, 1915*, vol. 1, (London, 1927), p. 90.
- ¹⁸⁴ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 459.
- ¹⁸⁵ The slotted striker of the Mills grenade is a case in point. This is discussed in Chapter 5.
- ¹⁸⁶ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 455; *Military Operations, 1915*, vol. 1, *op cit.* p. 91.
- ¹⁸⁷ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 449.
- ¹⁸⁸ This point went unremarked in the *History of the Ministry of Munitions*.
- ¹⁸⁹ This was not helped by its unofficial status. There are appear to no contemporaneous documents relating to the work of the Experimental Section, GHQ. It was mentioned in the Official History, however. See *Military Operations, 1915*, vol. 1, *op cit.* p. 90.
- ¹⁹⁰ *Military Operations, 1915*, vol. 1, *op cit.* p. 90; ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 455. The ‘Experimental Committee’ is mentioned in *Design and Inspection, op cit.* pp. 48, 49 but is correctly identified on p. 55. This misnaming may have been due to poor proofreading, although it was also typical of the casual way in which departments were misnamed. It is also subtly patronising as it implies that GHQ were bunglers. The whole point of the *History* was to present a rosy picture of the Ministry’s achievements and was written in the full knowledge that it would cease to exist when the war ended.
- ¹⁹¹ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 451; Terraine is mistaken when he says in *White Heat, op cit.* p. 230, that the Experimental Section grew out of the Experiments Committee. Griffith makes the same error (*op cit.* p. 110). The error is assisted by a misdated pamphlet, Notes Compiled by the Experiments Committee, which, according to the cover, was issued in August 1914. This is plainly wrong since the Notes refer to trench warfare which had yet to develop. Moreover, none of the devices discussed in the Notes existed in August 1914. The year ‘1914’ is clearly a misprint for ‘1915’.
- ¹⁹² Pattison, thesis, *op cit.* p. 16.
- ¹⁹³ ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 451.
- ¹⁹⁴ *Op cit.* p. 452.

¹⁹⁵ There appears to be no explanation for its short life. Presumably, it proved to be unnecessary.

¹⁹⁶ 'The Work of the Royal Engineers', September 1924, *op cit.* pp. 451–2.

¹⁹⁷ No one, including Lloyd George, chose to comment on this process of change. Neither is it discussed explicitly in the *History of the Ministry of Munitions*. Indeed, the authors of the *History* were at pains to avoid such an unfortunate comparison with the War Office.

¹⁹⁸ MUN 4/3047 and *Design and Inspection, op cit.* p. 100.

¹⁹⁹ MUN 4/3047, *op cit.* Liaison was maintained by MID officers visiting GHQ. See MUN 5/43/263.8/19 Memorandum on the Function and Organisation of the Munitions Inventions Department, p. 3; and MUN 5/117/700/4 Munitions Inventions Department, Report of the Departmental Committee on Reconstruction, July 1917, p. 3, Reply part IV to D2. It is likely that there was, by necessity, if for no other reason, a good relationship between these officers and the Experimental Officer at GHQ.

²⁰⁰ MUN 4/3047, *op cit.*

²⁰¹ MUN 4/3047, *op cit. Design and Inspection, op cit.* pp. 62, 100.

²⁰² According to a former member of the Grenade Section of the TWD, the Department was no more than 'a collection of Sections' which went their own ways without a guiding authority and was a department in name only. See MUN 5/385/1640/1 History of the Grenade Section, Trench Warfare Supply Department. For 'collection of Sections' see letter dated 5 May 1917 to Dr Addison, the then Minister of Munitions, from Lieutenant Richmond, RNVR, who had worked in the Grenade Section until illness forced him to withdraw. In his letter, he explained that, during his convalescence, he had written an 'unvarnished' history of the Section, covering the period February 1915 to January 1917. For 'going their own way' see p. 9 of the History of the Grenade Section. Richmond had a jaundiced view of the Ministry of Munitions and regarded the civilians brought in to staff the Ministry as interlopers who caused more problems than they solved. His rather colourful account provides a different perspective from that presented in the *History of the Ministry of Munitions*. Such views were diametrically opposed to those of Lloyd George which may explain why nothing of Richmond's account appears in the *History of the Ministry of Munitions*.

²⁰³ In this respect, their history is peculiar to them and does not inform the nature of the permanent research establishments in which the 'state research corps' worked; see Edgerton, *op cit.* pp. 113–16.

4 A Question of Engineering

The supply of grenades and mortars was entirely dependant upon the processes of evaluation and manufacture, which were at opposite ends of a complex process. If the evaluation of new munitions failed to identify well-conceived devices which were capable of fulfilling the needs of the BEF, and if the selected devices were not subsequently manufactured on a large enough scale to satisfy demand, the BEF would suffer a crisis similar to the one inflicted upon it by the shell scandal. This was a matter of supply and demand. This chapter discusses how these processes were developed to overcome the problems which arose when dealing with novel munitions and highlights how their outcome all came down to a matter of engineering.

Supply and demand of grenades and mortars regulated not their price, as in commerce, but the operational proficiency of the BEF. Moreover, in Britain, supply and demand were regulated by the manufacturing proficiency of the contracted firms which had a major impact on price.¹ Inspection, or quality assurance, is often overlooked when considering manufacture. It is an essential part of the process. It was especially critical in the manufacture of novel munitions during the First World War because of the involvement of commercial industry which had no experience of munitions work.² These firms had to apply tighter engineering tolerances than they were generally accustomed to meeting. Inspection ensured that the munitions and their components met the required standards and ensured that the BEF was supplied with reliable munitions.³ However, the inspectors had to be recruited and trained, and their precision instruments had to be manufactured.⁴ These were all engineering problems. This chapter discusses how these issues were addressed.

Demand versus supply

During the first year of the war, GHQ's demands for trench warfare devices fluctuated as GHQ and the BEF reacted to situations that arose on some part of the British-held front or according to preparations for an impending operation.⁵ The BEF was also expanding rapidly. The number of infantry divisions in France rose from five in August 1914 to ten plus the Indian Corps in October 1914, to twenty-six a year later and to fifty-eight by the end of 1916.⁶ Its length of the front increased from 24 miles in November 1914 to 36 miles by April 1915 and to 75 miles by the end of the year.⁷ Demand rose as the BEF grew and its responsibilities increased and changed according to the performance of the devices that were being sent to France. Those devices which performed badly were rejected while those which performed well were demanded in larger numbers. It was difficult for the supply authorities and GHQ to stay abreast of improvements, especially when improvements in one device leapfrogged developments in a similar one, with both devices being demanded by GHQ.⁸ This was an inevitable consequence of the dominance of time as a factor.

The number of patterns of hand grenades caused both logistical and operational problems during much of 1915. By the late spring, there were fourteen approved patterns of high-explosive hand grenade with about nine different operating procedures.⁹ Most grenades were stopgap patterns or improvisations. Some came from Britain but the majority came from Royal Engineer Workshop facilities in France. The No. 5 Mills grenade could only be produced in small numbers until about the following October because of manufacturing problems that were largely caused by the contractors' inexperience with munitions.¹⁰ Some redesigning of components eased production difficulties but a radically different approach to the mass production of hand grenades was necessary. The idea that production could be increased by altering the design of some components gradually gained acceptance during 1915.

The Ministry of Munitions was less tolerant of the inconsistency of GHQ's demands than the War Office had been. The Ministry wanted demand to be uniform and regular. In October 1915, GHQ was asked to set its requirements on a systematic basis.¹¹ Although it then attempted to estimate monthly demand by division, matters remained unresolved in June 1916.¹² The Minister complained to the Army Council that it was unreasonable to expect armaments workers to work long hours to achieve a high weekly output to meet a given demand from GHQ only for that demand to be suddenly reduced so that the work rate had to be rapidly curtailed.¹³ The Army Council pointed out that such fluctuations were only to be expected since it was impossible to be accurate when trying to predict consumption.¹⁴ This was especially true when the munitions concerned were unproven. The solution proposed by the War Office was to persuade manufacturers to build up excess capacity which could be used at short notice whenever a sudden demand arose. This would avoid the need to take on extra labour, of which there was little to be found, and without raising costs with overtime and Sunday working.¹⁵ The drawback was that few firms were prepared to expand only for that expansion to be idle capacity, which adopting such a proposal would require, until demand rose to such a level that the excess capacity absorbed it.

Evaluating novel munitions

Until about the end of 1915, evaluations were carried out by the Ordnance Board, the CIW¹⁶ and the DoA on the experimental grounds at Shoeburyness and Hythe. Explosive munitions, such as mortars, their ammunition and rifle grenades, were evaluated at Shoeburyness, while munitions related to small arms were evaluated at Hythe, which made for some duplication as this included rifle grenades and, rather curiously, bomb-throwing devices, such as the Leach catapult and the West Spring Gun.¹⁷ Hand grenades were also evaluated at Woolwich by the CIW. This woolly arrangement reflected the unconventional nature of such devices and the lack of an established procedure for evaluating them. Once the Ministry of Munitions assumed responsibility for evaluation, the grounds came under its control but the duplication remained, although Woolwich no longer conducted evaluations.¹⁸ Because of the rise in the number of munitions that had to be evaluated, the TWD acquired additional experimental grounds at Wembley, Clapham Common, Claremont Park and Porton.¹⁹ These were used

to evaluate grenades, flamethrowers, chemical munitions, mobile shields, steel plates, body armour and other munitions related to trench warfare.

The process of submission and evaluation was relatively straightforward and remained so throughout the war, irrespective of which section was involved or where the evaluation took place. Although it is tempting to generalise the process, no two instances were, in fact, the same as there was no regularised system for submission and evaluation. Indeed, despite efforts to systemise the process, especially by the MID from about 1916, it remained essentially an ad hoc affair.²⁰ The Mills grenade is a case in point.

In early January 1915, a British engineer, William Mills, arranged with Major Banks of the War Office for the CIW to evaluate a Belgian hand grenade, the Roland.²¹ Mills and a Belgian engineer, Albert Dewandre, who was familiar with the Roland grenade, attended a trial on 26 January.²² Dewandre armed and threw four Roland grenades which Mills had fabricated for the trial.²³ The trial went badly and the CIW evaluator, Major Denn, flatly rejected the Roland as unsafe and unreliable.²⁴ This ought to have been the end of the matter but, the next day, Mills discussed the rejection with Major Banks. The major offered several, if vague, suggestions about how the device might be improved.²⁵ Although inventors often tried to plead their case following rejection, Mills was not the inventor of the Roland but, aware of the dire need of the BEF for grenades, he believed an improved Roland might be the answer. By the beginning of February, Mills had devised a new hand grenade, derived from the Roland. This was successfully tested at Shoeburyness on 20 February.²⁶

From this several points emerge: firstly, tests of similar devices were not conducted under identical conditions; secondly, the testing authority was different each time;²⁷ and, thirdly, constructive feedback on trials was not mandatory but could be garnered if pursued. Furthermore, it is clear that the personal opinion of the evaluator played a role in the outcome of the trial. This was certainly the case at the School of Musketry at Hythe in Kent. The Experimental Section at Hythe was essentially one man, the Experimental Officer, Captain Todhunter.²⁸ He evaluated a broad range of devices: armoured shields, night sights, automatic rifles, machine-guns, sniper scopes, hyposcopes and rifle grenades.²⁹ He was rigorous in his evaluations, if somewhat sceptical of the value of some inventions. Todhunter often made unsolicited recommendations to an inventor if he believed that the device could be improved. On occasion, he even suggested that an inventor should contact another when he thought they would benefit from collaborating. Unfortunately, he tended to have preconceived ideas about the usefulness of certain inventions. Automatic rifles were a case in point; he always rejected them.³⁰ Preconceptions were a problem for any evaluator.

There is the question of whether, in 1915, anyone knew what to look for in novel devices such as grenades and mortars. Certainly, Dewandre felt that Denn did not know what he was talking about but, as Mills later realised, Dewandre knew a great deal less about grenades, and the Roland in particular, than he had given Mills to believe.³¹ In January 1915, Mills was far from expert himself in the field of munitions; he had never handled or examined a hand grenade before the Roland. A set of standards had yet to be established against which evaluators might measure novel devices. Indeed, there was not even a set of criteria

which novel devices had to satisfy. It was all rule of thumb and the evaluator had to make a judgement on the viability of the munition based on his experience of conventional munitions and rely on first principals: does it work, is it safe, is it reliable. There was, of course, a fourth question: does it do what it is claimed to do. Many submissions were decidedly unworkable, while others were too bizarre to be taken seriously.³² Serviceable inventions were rejected due to a surfeit of similar submissions, some of them already in production or development but sometimes it was just plain oversight. It was a monumental task to evaluate every submission and unfailingly sort the good from the bad.

Some novel devices required a conceptual leap by evaluators, something which could not be prescribed. Much as Todhunter failed to make that leap with automatic rifles, so the evaluators of the Stokes mortar during the spring of 1915 failed to make a similar leap. The Stokes mortar performed adequately during trials at Shoeburyness but was rejected.³³ The DoA felt that the BEF had enough types of mortar and did not need another, imperfect, device.³⁴ However, following a trial in France,³⁵ the DoA reconsidered the Stokes in July. This led to further trials³⁶ in August.³⁷ Trials were still being conducted in November.³⁸ The ammunition was a major problem. Although the mortar was impressively accurate, the range was poor and the ammunition was prone to prematures, blinds and misfires.³⁹ These defects were typical of all mortars and their ammunition at that time. Thus, there was no incentive to adopt the Stokes. Moreover, the innovative features of the Stokes⁴⁰ were disliked. Not until the objections to these features were overcome could the advantages of the Stokes be realised. Political interference by Lloyd George led to its adoption before its defects had been resolved, however.

The engineering solutions to the defects in hand grenades were perceived as easier to resolve than the defects in mortars. This was based on the classification of mortars as artillery and, hence, complex pieces of engineering, whereas grenades were seen as uncomplicated. This view of grenades was supported by the fact that the armaments firms had never been involved in their manufacture. Stokes was a civilian engineer with no armaments experience; the mortars with which his device was competing were engineered by Vickers and Woolwich both of whom had long experience of guns. Thus, there was a predisposition to regard the Stokes as inferior to conventional designs.

Inevitably, many more inventors had their inventions rejected than had them accepted. One of the complaints made at the end of the war about the MID was the small number of inventions it approved. It evaluated 47,987 submissions during its lifetime⁴¹ of which only 226 were deemed worthy of further development.⁴² Such figures need to be treated with some caution, however, as they do not reflect the true number of inventions that were submitted to the MID. It is impossible to determine what percentage of the 47,987 were, in fact, first submissions of inventions because many of the MID evaluation reports have been lost.⁴³ Some of these submissions were, in fact, re-submissions of devices that were in development over the course of which they might have been evaluated several times. In February 1918, 982 inventions were submitted to the MID and 880 were examined or forwarded to other departments if they were outside the scope of the MID.⁴⁴ In addition,

another 1059 inventions were undergoing evaluations by the committees of the Munitions Inventions Panels. Some 124 inventions were reported to be worth further investigation that month. Concealed within these figures is the number of resubmissions. Only some of these devices would have been pertinent to trench warfare, of course⁴⁵ but the figures give an idea of the amount of evaluation work that was undertaken each month by the MID, although the monthly numbers were not constant.⁴⁶ Some evaluations were of devices which originated within the MID and the MDD, while some came from the Experimental Section at GHQ.⁴⁷

Thus, such an apparent level of rejection is misleading. Moreover, it implies an unwillingness within the MID to accept innovation while also suggesting that inventors were harebrained. There were, of course, a fair number of crackpot ideas.⁴⁸ It would be a mistake, however, to think that most inventions fell into this category. Indeed, very few inventions were from the Heath Robinson school of engineering, although some devices, by their very nature, appeared to have come from this source. Sniperscopes and hyposcopes are prime examples.⁴⁹ Indeed, some percussion-fuzed hand grenades appeared to be from the same school.⁵⁰ The apparently high percentage of rejections also implies that the MID wasted its time on pointless investigations of unworkable munitions, although such a conclusion relies on hindsight.⁵¹ The evaluations were conducted impartially, scientifically and diligently. Indeed, for all the bureaucracy of the Ministry of Munitions, the MID was very efficient when it came to evaluating munitions as demonstrated by the surviving reports. Despite the large number of evaluations of all types of munition, conventional as well as unconventional, the experimental grounds were never so overwhelmed that short-cuts were taken. Trials were scrupulous. The MID had a number of small subcommittees each of which examined specific types of device. The members of these subcommittees became experts in their fields so that a high degree of proficiency and know-how was developed. That is not to suggest that the MID was any more efficient than had been the CIW, DoA or FW3 before it; the MID merely had the benefit of greater experience than its predecessors because it dealt with novel munitions for longer.

Rejection could occur at any stage in the process: initially on submission, after trials, after development following trials. It could be for a wide variety of reasons: unworkability, complexity, cost, unreliability, poor performance, unwanted munition, no improvement over existing service munitions. From few or no criteria at the start of trench warfare, the criteria against which the submissions were measured increased in number and changed as the circumstances of trench warfare changed.⁵² As the shortages of 1915 gave way to the relative plenty of 1916, so the criteria of stopgap solutions gave way to more stringent requirements for reliability, utility and safety. By 1917, the criteria became standardised as the conceptualisation of the novel munitions led to the establishment of specifications in terms of utility, functionality and reliability. Thus, what might have been accepted in 1915 would have been rejected in 1916. Solutions to much more specific problems were being sought from 1916 onwards, rather than the generalised response of 1915 to the need for munitions for trench warfare. Hence, by 1917, technically specific solutions were being sought to such

matters as how to fire 6000 Livens projectors simultaneously⁵³ and how to achieve correct alignment of the flange holes in the body of the Mills hand grenade during manufacture.⁵⁴

More submissions were likely to be rejected as the war progressed simply because the need for certain types of munition no longer pertained. The hand grenade became standardised as the Mills, for example, while the light mortar became standardised as the 3-inch Stokes. The willingness of the Ministry of Munitions and the BEF to abandon a reasonably successful munition for an entirely new one decreased as the war progressed because of the disruption to manufacture, supply and training that this would cause with a consequent effect on operations.⁵⁵ There is a tendency to view the proliferation of the Mills grenade as evidence of its superiority over other hand grenades but it had more to do with avoidance of disruption. Moreover, there was little point in trying to replace the Mills with an entirely different device when the timescale of development, evaluation and mass production would have prevented the new device from playing a significant role in the war.

Rejection was not always taken well.⁵⁶ Some went beyond moaning in private and wrote letters of complaint. When a patented shoulder-fired grenade gun was turned down by the MID in mid-1917, the inventor's patent agent even wrote to the Parliamentary Secretary for the Ministry of Munitions, Sir Laming Worthington-Evans MP, to protest at the MID's short-sightedness.⁵⁷ In at least one instance, accusations of chicanery were made against the MID, although not by the inventors or their patent agent but by a third party, an MP.⁵⁸ This was another instance of political interference in matters about which the prime mover was ill-informed. The Right Honourable William O'Malley had witnessed a trial of

a grenade called the DG⁵⁹ and had become the grenade's champion although he knew nothing about grenades. Indeed, he clearly had no understanding of the technical issues involved. On 30 November 1916, O'Malley wrote to Major-General Bingham, the Deputy Director of Artillery (DDA),⁶⁰ about what he believed were irregularities in the manner in which the DG had been tested.⁶¹ Bingham informed him that the device had been rejected because it had failed to satisfy service requirements.⁶² In early 1917, O'Malley wrote

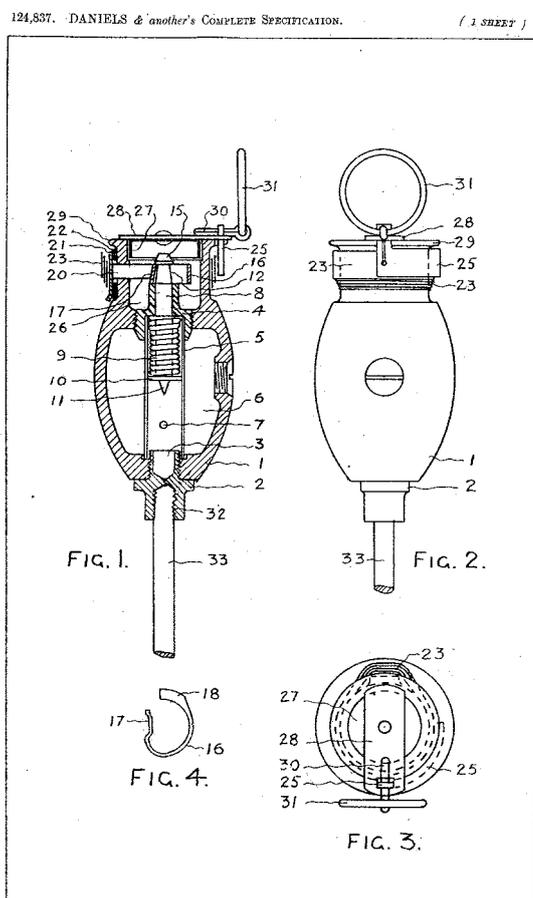


Fig. 15 Drawings of the DG grenade from GB124837. All percussion mechanisms tended to be more complex than time-fuzze mechanisms, partly because of the necessity of incorporating safety devices. In the drawing, 23 is a tape that unwinds when the grenade is in flight to release the safety bolt; the striker falls when the bolt is extracted

to Dr Christopher Addison, the Minister of Munitions,⁶³ to complain about the evaluation process and the decision not to take up the DG grenade, which O'Malley believed was a good design and just what GHQ was looking for. In response, O'Malley received what he described as 'one of those stereotyped replies which are so characteristic of Government Departments' in which Addison explained that 'he saw no reason . . . to interfere with the decision of the Designs Department [sic]'.⁶⁴ O'Malley then wrote to Worthington-Evans to complain about Addison's reply and demanded that the evaluation procedures be changed. He was particularly aggrieved by the way in which the MID and the DoA seemed to defer to the MDD when it came to the decisions on which devices should be adopted. Political interference of this sort was not unusual. When Lloyd George intervened in the matter of the Stokes mortar, the evaluator's rejections were overruled despite the poor functionality of the mortar and which needed to be improved before it could be used operationally.⁶⁵

Whereas the trials of the Stokes, although conducted over a long period, were lengthy because of the difficulties with its ammunition, the DG grenade became involved in a lengthy evaluation process because the criteria were changed so that the device had to be altered not only to resolve imperfections but also to satisfy the new requirements. The competitive trials in which it took part were very different from the simple tests to which the Roland and Mills grenades and the Stokes mortar had been subjected. Evaluation had become more exacting with growing expertise which, in turn, helped to develop more stringent criteria beyond mere workability. The inventors of the DG first submitted their device to the MID in February 1916.⁶⁶ Captain Goodwin Smith, who had been seconded to the MID as an experimental officer in March 1916, tested the grenade between May 1916 and June 1917, during which time, 6730 DG grenades were thrown successfully without accident. Smith wrote several favourable reports. However, trials at Clapham in November 1916 showed the DG to be seriously flawed and prone to prematures, while blinds would be dangerous to anyone charged with disposing of the unexploded grenades. Nevertheless, trials at the Lyndhurst Bombing School in January 1917 evidently led Addison, as Minister of Munitions, to state that the device was 'perfect'.⁶⁷ At some point, Smith passed the grenade to the MDD where it was tested again, this time by 2nd Lieutenant Palmer, who rejected it. Palmer apparently only threw two grenades before reaching this decision. Smith was highly critical of Palmer's methods. O'Malley accused Captain Ley, who was Palmer's superior and the MID's grenade expert, of abandoning the DG in favour of a patented device of his own.⁶⁸

The DG continued to be tested in the ongoing competitive trials with percussion-fuzed grenades although an order for 25,000 DG grenades was not endorsed. Trials with the DG continued until July 1917 when it was rejected again. This was not the end of the matter, however, as tests continued until the end of the year. By then, the requirements of percussion grenades had changed to include a capability for being fired from a cup discharger. A report in December 1917 stated that experiments with the Mk VIII DG had proved satisfactory in preventing prematures in flight when using a new ballistite blank cartridge.⁶⁹ A further 1000 DG grenades⁷⁰ underwent trials in France in early 1918 at the end of which it was rejected for the final time.

The cost of the DG trials up to about spring 1917 was around £3000; the total cost was probably double that figure. In August 1918, there was an unusual twist in the tale: Smith and Daniels, one of the inventors, were prosecuted for corruption at the Central Criminal Court in London.⁷¹ Smith was alleged to have taken a bribe from Daniels to promote the DG grenade. Money certainly changed hands but, according to the defence, not in a corrupt manner.⁷²

The saga of the DG grenade illustrates how lengthy the process of evaluation became as well as its close relationship with developmental work. It also shows the lack of agreement over whether the army wanted a percussion-fuzed hand grenade; Bingham said that the army did not want one, whereas the CIGS, Sir William Robertson, said that it did.⁷³ The MID was later criticised for such expense and time spent with no useful result. However, failure is not the same as not having tried since it adds to the sum of practical knowledge. Knowing what does not work is as valuable as knowing what does. Moreover, as the persistence with the Stokes was to prove, what appears to be unpromising can turn out to be revolutionary; it is unwise to give up too soon. The difficulty is in achieving the right balance.

Manufacture and inspection

Until about mid-1916, the inability of anyone in government departments to reconcile the conflicting desiderata of high output, utility of design and reliability of novel explosive munitions was the greatest obstacle to providing the BEF with what it needed. Throughout 1915, the task was complicated by sudden changes in demand from GHQ, many of which were due to the inutility of the many stopgap designs being sent out from Britain. The enormity of this problem has been concealed by the fact that, despite shortfalls and setbacks, the BEF did, indeed, receive what it needed, albeit inadequately during 1915. The key to the resolution of the problem lay in mass producing fewer designs. Firstly, the appropriate designs had to be selected. Secondly, new production methods had to be devised. And thirdly, commercial firms had to be engaged. By mid-1916, the BEF was receiving some trench warfare munitions in excess of what it required so that production was cut back. To go from a situation where there were no devices for trench warfare, no means of making them and no infrastructure for supplying them, to mass production of such devices in about twelve months is one of the understated triumphs of the war. From one government factory at Woolwich and one commercial firm, the Cotton Powder Company, producing novel munitions in 1914, by mid-1915 there were about 200 contractors,⁷⁴ most of them small firms of no more than twenty workers, producing trench warfare munitions in large numbers.⁷⁵

The firms contracted to manufacture novel munitions came from a wide range of backgrounds. During the first six months of 1915, contracts to make the Woolwich 2-inch trench mortar were given to engineering firms which, in peacetime, produced agricultural machinery and to railway repair shops, while iron foundries were contracted to make the cast-iron bombs.⁷⁶ Makers of cotton-making machinery and small engineering firms were contracted to make grenade bodies.⁷⁷ In July 1915, firework makers in Yorkshire were contracted to fill the bodies with explosive, thereby helping to relieve Woolwich of the task.⁷⁸ Whereas commercial firms became involved in filling grenades with explosive, the

job of filling and assembling mortar ammunition was initially restricted to Woolwich and Vickers, which filled their own bombs, and to the firm of Roburite & Ammonal which manufactured explosives.⁷⁹ Because of the lack of filling capacity, several new factories were built for filling trench mortar bombs.⁸⁰ Before the Stokes mortar was adopted, Ransomes & Rapier of Ipswich was the sole manufacturer.⁸¹ Subsequently, the barrels were produced by the Mannesmann Tube Company of Swansea which later supplied tubes for the Livens projector.⁸² The Stokes barrels were produced by a process of passing a steel bar through two eccentrically mounted rollers which rotated the bar and forced it over a mandrel to produce a seamless tube of even thickness. This cost 75 per cent less than producing barrels by traditional gun forging methods.⁸³ The ammunition was made by small workshops such as garages.

Learning to work to tighter tolerances was not merely a matter of degree but required a different level of skill. This had to be acquired on the job which resulted in an alarmingly high rejection rate of grenade components and mortar ammunition during the second half 1915⁸⁴ which raised costs and slowed output.⁸⁵ Some firms charged a premium to compensate for their low output because income was based on output and there was a real possibility of their going out of business. Inevitably, there was friction.⁸⁶ Eventually, the premium was stopped but it took up to a year to abolish it entirely and only after rejection rates fell. The design of some components was modified to accommodate mass production methods which had been designed to obviate the use of specialist machinery which most commercial firms lacked.⁸⁷ Problems with the production of the first Mills grenades led to changes in manufacture.⁸⁸

As with all munitions, irrespective of who manufactured them, the output by commercial contractors had to be inspected to ensure that it was within tolerances. The inspectors initially rejected far more than these firms thought reasonable because they were unable to solve production difficulties or meet tolerances. The Inspection Department at Woolwich was viewed by some in the TWSD as officious and obstructive, even in 1917, because it did not understand commercial engineering and rejected components too readily.⁸⁹ Woolwich was a bottleneck because all explosive munitions and anything classified as a gun, such as a mortar, had to be inspected by CIW before being sent to France. Woolwich lacked the capacity to cope with the increasing number of such devices.⁹⁰ In June 1915, Jackson persuaded the Director of Ordnance Stores EF and the Deputy Director of Equipment and Ordnance Stores to agree to inspection being carried out on premises other than Woolwich; that is, the Ordnance Officer at the port of embarkation for the munitions to France carried out inspections.⁹¹

In June 1915 Captain Leeming was appointed to organise these outside engineers.⁹² Initially, this was a one-man section but by July the new section had a staff of ten and by end of the year there were ninety-two inspectors.⁹³ They became the Outside Engineers Branch (OEB). Following FW3a's transfer to the Ministry of Munitions at the end of June, the OEB was formed as part of the TWD.⁹⁴ The inspectors, who had to be recruited, were technical experts, mostly civilians, who could advise contractors on engineering and production problems.⁹⁵ They also acted as liaison officers for the Supply Department. In addition, they sought out raw materials and new engineering firms which could take on

the production of grenades or mortar bombs.⁹⁶ There was, however, conflict between the Inspection Department and the OEB over who had responsibility for inspecting munitions produced by commercial contractors. The OEB could not state that a firm's output would be passed by the Inspection Department but it could advise firms what would definitely fail inspection by Woolwich.⁹⁷ It is evident that the OEB were not officially authorised to pass munitions but did so when it was the only inspection authority involved. During 1915, there was a high rejection rate which had an adverse effect on prices but the OEB inspectors helped to reduce unnecessary wastage.⁹⁸ As contractors became more skilled, the work of the inspectors changed so that they became involved in placing contracts and finding raw materials. With the creation in December 1915 of local Boards of Management for the production of munitions, the inspectors placed most of their contracts through the Boards.⁹⁹ By about mid-1916, the inspectors' roles had completely changed as there was no longer any need for them to supervise commercial firms engaged in manufacturing munitions.¹⁰⁰

The OEB's efforts increased output which reduced prices. By the summer of 1916, the unit price of the No. 5 grenade fell to nearly half its price of a year earlier.¹⁰¹ The unit price of rifle grenades fell by two-thirds of their initial price between autumn 1915 and autumn 1916 because of more efficient production methods and greater cooperation by the principal contractors, the Cotton Powder Company and Roburite & Ammonal, both of which were controlled by Marten Hale. On the other hand, the unit price of the far simpler No. 15 Ball grenade remained constant over the same period; there was no complex engineering involved in its manufacture.¹⁰²

The question of mass production was complicated by the need to change patterns, especially in the case of hand grenades. This occurred frequently during 1915, although less often thereafter, due to the prevalence of stopgap measures. Every time a new pattern was introduced, or components had to be modified, new tools and jigs had to be manufactured, and new procedures learned by both workers and inspectors.¹⁰³ Not surprisingly, this interfered with output. It was not popular with contractors, who were generally kept in the dark about the reasons for such changes, or with the supply authorities who were more concerned with maintaining supplies than with the BEF receiving improved munitions.¹⁰⁴ There were other ways to improve output. A demand in August 1915 by GHQ for 500 1.57-inch Vickers mortars and 500 2-inch Woolwich mortars was interpreted by the Ministry of Munitions as one for 1000 medium mortars. It placed contracts for only 200 Vickers mortars because these were more complex and took longer to produce than the Woolwich mortars.¹⁰⁵ The performance of the mortars was essentially the same so their ratio made little difference to operations.¹⁰⁶

Cooperative group manufacturing was developed by the OEB during 1915 and 1916 to maximise the facilities offered by different firms and thereby speed up output of novel munitions.¹⁰⁷ A munition was broken down into groups of components and each contracted firm manufactured one group rather than the entire munition. The groups were finally assembled by another firm on whose premises inspection was carried out. The process was coordinated by the OEB. It became a crucial aspect of the inspectors' work from 1916 and greatly increased the output of grenades, mortars and their ammunition.¹⁰⁸

Group manufacture was first tried in Birmingham with two firms making grenades in 1915.¹⁰⁹ In February 1916, following the decision to supply the BEF with the Stokes mortar, group manufacture was taken a stage further when the mounting for the mortar was broken down into groups of components for the firms contracted to make the mortar following the decision to supply to the BEF.¹¹⁰ Group manufacture allowed the production of 1000 mountings to be carried out much more speedily and smoothly than had each firm made complete mountings. The same firms, car manufacturers, were already making other parts of the mortar. Production was also eased by introducing standard bolt sizes. Hitherto, each firm making a munition had used bolt sizes according to its usual practice but this led to difficulties with repairs and maintenance in the field. Standardising bolt sizes increased interchangeability of standard components, a concept which was sixty years old.¹¹¹ The success of group manufacture increased the output of unconventional munitions which led to its employment by commercial firms engaged in the production of conventional munitions.¹¹²

By spring 1916, the quantity of mortars and mortar ammunition being produced led to the establishment of a new proving ground in Buxton, Derbyshire. Hitherto, proving had been carried out solely by Woolwich and Vickers, the principal manufacturers before the introduction of the Stokes, although the output of other mortars by commercial contractors had increased significantly during the second half of 1915.

There was, however, one major obstacle that was made worse by group manufacture: the increase in the number of engineering drawings that were needed. By the middle of the war, it was common for 3000 approved changes in design to be made each week.¹¹³ The Ministry of Munitions drawing office was often overloaded with work. Of course, not all of these drawings related to trench warfare munitions; many related to conventional munitions, especially artillery fuzes. Nevertheless, all munitions work was affected by the overload. The drawing office supplied factories and workshops with the engineering drawings for manufacturing new munitions and for implementing changes to munitions already in production. Each modification required a new engineering drawing which took between three days and a month to prepare depending on its complexity. During the summer of 1915, changes were being made to some types of mortar ammunition on a daily basis which led to confusion, increased costs and slower output. This was a direct consequence of concurrent development, manufacture and operational use.

Until early 1916, delays in production were caused by shortages of essential components which could not be made fast enough.¹¹⁴ Fuzes for mortar ammunition, detonators for mortar ammunition, hand grenades and rifle grenades, ignition systems for trench mortars, all delayed the completion of manufacture.¹¹⁵ The delay led to the adoption of simpler fuzes, commercial detonators and alternative ignition systems, all of which had to be evaluated prior to adoption.¹¹⁶ Thus, by the summer of 1916, output reached a level whereby the needs of the BEF could be exceeded. Output of mortar ammunition had gone from 42,753 rounds in the three months April–June 1915 to 1,502,990 for the corresponding period in 1916.¹¹⁷ This represented a triumph of mass production for commercial firms, which produced 1,138,558 rounds of 3-inch Stokes bombs.¹¹⁸ Such numbers allowed the unreliable 3.7-inch mortar

of 1915 to be phased out of operational use which had important tactical and operational consequences for the BEF. By the autumn of 1916, stocks of ammunition were such that production could be reduced.¹¹⁹

During 1917 and 1918, changes were made to some munitions and production methods in order to reduce costs and improve production efficiency. Where possible, scarce metals, such as steel and copper, were replaced with less-scarce materials, such as cast iron and zinc, for some components.¹²⁰ When steel became scarce in 1917, production of novel munitions suffered but to a lesser extent than the production of artillery shells because of the switch to alternative materials.¹²¹ Where possible, casting replaced fabrication processes that involved joining several separate precision-engineered pieces to make a component but sometimes joining several non-precision parts might replace casting of a single component.¹²² Altering the shape of a component could simplify casting and assembly.¹²³ Such changes to the engineering of these munitions was possible because of a far greater understanding of such devices which had been gained since early 1915.

Perversely, the very success of group manufacture and improved fabrication techniques adversely hindered the development of new devices because of the disruption to these processes that their adoption would cause. Thus, the Mills grenade remained the mainstay of the BEF, a point that was recognised at the time.¹²⁴

By 1917, it had become common practice to set up national factories for munitions production but these took time to build and to come on stream.¹²⁵

A multi-functional approach

At the start of trench warfare, Royal Engineers Field Companies improvised munitions for trench warfare to meet local demand but, in order to manufacture such devices in large numbers, the Engineers had to organise workshop facilities.¹²⁶ That the Royal Engineers were supposed to provide engineering support to the BEF has tended to obscure the magnitude of the undertaking and, indeed, their success in tackling problems which, in Britain, were causing considerable difficulties.¹²⁷ The Royal Engineer Army Workshops¹²⁸ became highly successful factories, with research and development sections, and turned out large numbers of novel munitions.¹²⁹ Only three Army Workshops were established: First Army, Second Army and subsequently Third Army Workshops.¹³⁰ Although they were the only large-scale permanent Royal Engineer facilities within the BEF,¹³¹ many smaller, temporary, workshops were set up by Royal Engineer units to make trench warfare matériel; these were, to some extent, miniature versions of the Army Workshops but lacked the lathes and specialist tools of the larger workshops.¹³² The Army Workshops were the pinnacle of improvisation. The facilities in each differed according to the machinery available in the locality and according to how its army personnel were allocated. All of the devices produced in the Workshops were made according to engineering drawings prepared at the Experimental Section, GHQ, from devices invented and designed at the Workshops.¹³³ Thus, not only did Royal Engineer facilities invent, evaluate and manufacture to meet demand but they also established a centralised distribution network whereby novel ideas from one Army were shared with other Armies within the BEF.

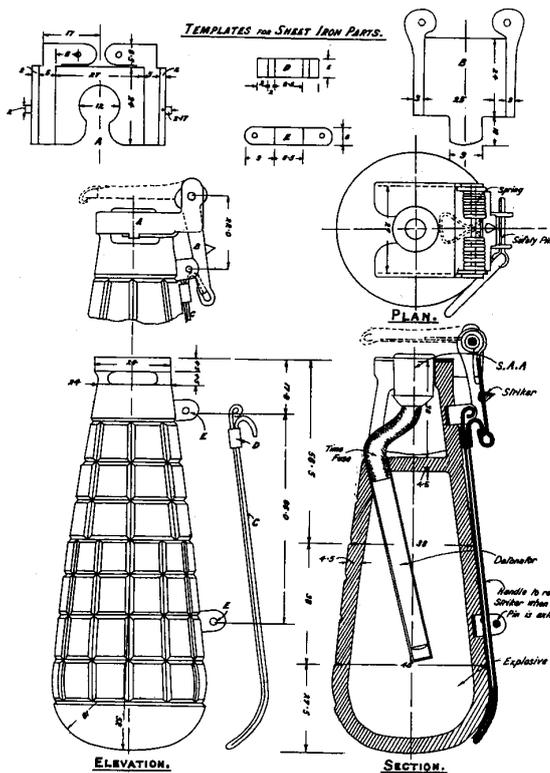
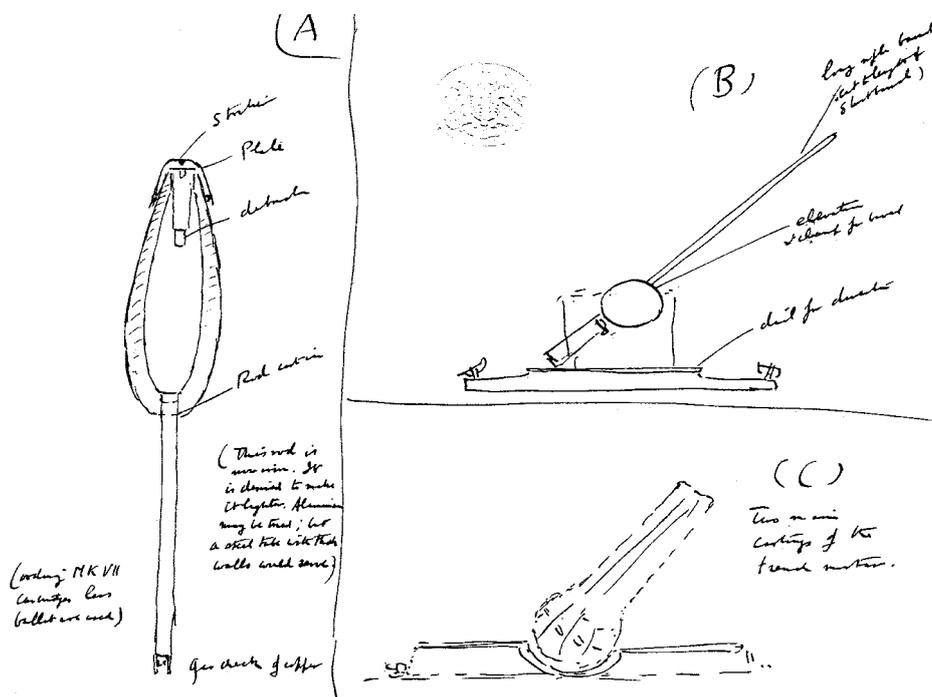


Fig. 16 (left) Engineering drawings of Newton Pippin hand grenade prepared by the Engineer-in-Chief, GHQ for distribution among other Engineer Workshops. Note the use of sheet metal for the mechanism (Articles Manufactured by RE Workshops in France, undated folio)

Fig. 17 (below) Captain Todhunter's sketch of three novel devices invented by Henry Newton at the Second Army Workshops. A is the Newton Pippin rifle grenade, B is a rifle grenade launcher which used the cut-down barrels of long Lee Enfield rifles, C is the cast brass mortar in Fig. 18 (WO 140/14)

The first Workshops was the so-called Béthune Bomb Factory, located in a Béthune workshop owned by Piteux and Flament.¹³⁴ Here, in November 1914, bombs for a locally designed mortar¹³⁵ were manufactured, initially by its French workforce, for the 3rd Company Bengal Sappers and Miners.¹³⁶ It also manufactured the improvised mortar which fired them and a variety of improvised hand grenades to meet the demands of the troops of the Indian Corps stationed along the La Bassée part of the front. One of these grenades was the Battye bomb, named after its inventor, Captain Basil Battye of the 21st Company Bombay Sappers and Miners.¹³⁷ The device was based on one designed by Major R L McClintock, RE, in India in 1913.¹³⁸ Royal Engineers under McClintock's command had experience of improvising hand



grenades in India before the war. It is likely that they were the primary source of knowledge on improvising and handling hand grenades on the Western Front in 1914 and that they were the originators of the so-called jam-tin and hairbrush grenades that were extensively improvised throughout much of 1915.¹³⁹ When the First British Corps took over the La Bassée sector in December, the Bomb Factory was taken over by a detachment of the 26th Field Company RE, commanded by Lieutenant H H Bateman. The French workforce remained but they were now under the supervision of Bateman and his sappers. The workshop evolved into the First Army Royal Engineers Workshop¹⁴⁰ at the end of 1915 when its administration became the responsibility of the Chief Engineer of the First Army.¹⁴¹

The Workshop did not have its own established personnel until July 1917 when the Royal Engineers Army Workshop Companies were formed in order to provide a core of Royal Engineer staff. Hitherto, personnel were posted to and from the Workshop according to the arrival and departure of divisions in the First Army area. Consequently, the size and composition of the workforce were always in a state of flux. From time to time, additional personnel were detailed to assist at the Workshop but these were usually infantrymen, mostly unskilled and thus unable to operate specialist machinery such as lathes. In June 1916, there were about 250 personnel in the First Army Workshop. Its workforce was still much the same size a year later.¹⁴² The apparent impermanence of the Workshop had other drawbacks, not the least being the difficulty in acquiring necessary plant. Usually, it had to be bought or hired from local French firms which often charged high prices. Similar manpower and machinery problems bedevilled the Second Army Workshops.

The Second Army Workshops dated from about April 1915.¹⁴³ Captain Henry Newton of the 1st/5th Sherwood Foresters, a Territorial battalion which arrived in France in February 1915,¹⁴⁴ designed a rifle grenade aiming rest¹⁴⁵ and constructed it, with the help from some of the men of his battalion, in an abandoned blacksmith's shop at Kemmel¹⁴⁶ when he was out of the line.¹⁴⁷ This was for the sole benefit of his battalion. Newton was one of five brothers,¹⁴⁸ with two of whom Henry owned an engineering business in Derby, Newton Brothers,¹⁴⁹ and some of the men serving in the battalion came from the Newton Brothers works.¹⁵⁰ Henry Newton's enterprise came to the attention of Brigadier-General Sir William Furse, who was on the General Staff of II Corps. Furse instructed Newton to establish a workshop in more suitable premises so that he could produce larger quantities of trench warfare stores for II Corps. That Newton was given the opportunity to put his expertise as an engineer to good use went against the trend at that time for skilled men from industry to be taken into the army as infantrymen with no regard to whether their skills could be better employed.¹⁵¹ Indeed, it would appear that this was a sufficiently unusual occurrence for it to be remarked upon ten years after the end of the war.¹⁵²

What was to become the Second Army Workshops was established in the *École Nationale* in Armentières, an abandoned engineering school; the *École* was unoccupied because it was within range of the German guns. It was very well equipped: facilities included a machine shop and shops for working wood, sheet metal and hot metal. Importantly, it had its own steam power plant.¹⁵³ In the spring of 1915, the technical school was taken

over by the Chief Engineer of the Second Army.¹⁵⁴ This was perhaps the best-equipped Royal Engineer workshop of any kind throughout the whole of the BEF.¹⁵⁵ When Newton took over the Workshops in May 1915, which he commanded until September 1917, the personnel detailed to work at the *École Nationale* comprised forty-five tradesmen from the 46th Division. Some time later, small detachments of tradesmen from Territorial units in the Second Army and two additional officers were posted there. It was at around this time that it was designated the Second Army Workshops. As with the First Army Workshop, it did not have an official establishment and fluctuations in the composition and size of the workforce remained a problem until the advent of the Workshop Companies in 1917. About twenty French workers from the locality were employed in the Workshops in May 1915. Their numbers increased as the workload increased and by about the end of June there were 200 French workers.¹⁵⁶

The shortage of rifle grenades in mid-1915 was such that a mere six grenades were issued to each platoon for a front-line trench tour of between five and ten days.¹⁵⁷ It was not surprising, therefore, that the First and Second Army Workshops should be asked to devise and manufacture rifle grenades to make up the considerable shortfall of supplies of Marten Hale rifle grenades from Britain.¹⁵⁸ The Workshops had an advantage over the War Office and the Ministry of Munitions in that they were able to keep the process of invention closely linked to manufacture. Indeed, the novel munitions invented in the Workshops were devised around the materials and the methods of fabrication that were available. Cast iron was used rather than steel, brass instead of aluminium; steel was unavailable and aluminium scarce. Wherever possible, scrap was used rather than virgin metal. Semi-skilled and unskilled fabrication methods were used in preference to precision engineering which required specialised tools and skilled workers.¹⁵⁹ This was especially important because of the fluctuations in the workforces.

Men such as Newton were accustomed to solving engineering problems. Thus, invention was approached differently in the Workshops from how it was tackled in the War Office or the Ministry of Munitions which lacked men of similar experience. Inevitably, the Workshops' munitions were designed and produced at a much lower cost than many of the trench warfare devices being devised and manufactured in Britain.¹⁶⁰ The Newton Pippin rifle grenade could be made more quickly than the Hale type, it was cheaper and used no scarce materials; it used cast iron instead of steel and brass. The Hale cost 25 shillings (£1.25) whereas the Newton Pippin cost 2 shillings (£0.10).¹⁶¹

In the early summer of 1915, the Germans discovered the location of the Workshops and began to shell the site.¹⁶² Consequently, Newton transferred them and the technical school's machinery ten miles further back to a location at Hazebrouck, well beyond the range of all but the biggest-calibre guns. The scope of the facilities was increased as new buildings were built for a foundry and a forge, while existing buildings were converted into shops for tinsmiths, carpenters and fitters, in addition to a machine shop and an assembly shop that were already on the new site. More machinery, equipment and petrol engines were acquired in the town. So large was the Workshops now that the workforce reached a peak of 950, the size of a substantial factory.¹⁶³ Local French women were recruited and trained for some of the repetitive work involved in the

manufacture of munitions.¹⁶⁴ Experimental work increased, leading to improvements in trench mortars and their ammunition as well as to the development of other trench warfare devices.

In July 1917, the Royal Engineer contingent of the Army Workshops was made less peripatetic by the introduction of the Workshop Companies with fixed establishments of 131 officers and other ranks.¹⁶⁵ Five Companies were formed, one for each Army. This did not completely solve the problem of periodic fluctuations in personnel, however, because each Chief Engineer tended to assign personnel to the Companies according to his own ideas.¹⁶⁶ Each Company could still be augmented by attached troops. The matter was complicated by the Companies being split into three sections, one for each Corps in the Army.¹⁶⁷ This meant that the sections tended to be dispersed rather than kept together in one place. It is clear from this that GHQ viewed the Workshops of 1917 and 1918 differently from those of 1915 and 1916. The emphasis in 1915 and 1916 was on devising and producing hand and rifle grenades and mortars and their ammunition rapidly and large numbers. By the end of 1917, the Workshops were no longer producing munitions except on an experimental basis because production had been taken over completely by the Ministry of Munitions as a result of the success of the methods that had been adopted in Britain.¹⁶⁸

Output¹⁶⁹

The statistics for the production of trench warfare munitions should be treated with caution because they are incomplete, especially before mid-1915. Production figures show a rapid rise in output in Britain from mid-1915 onwards when capacity began to increase. However, the figures conceal more than they reveal since it was sometimes the production of specific components, such as detonators, which restricted output. Moreover, certain aspects of some munitions involved unavoidable precision engineering which also hindered output. Nevertheless, no discussion of manufacture is complete without an examination of output.¹⁷⁰

In November 1914, the average monthly supply of hand grenades from Britain was a mere 280.¹⁷¹ Sir John French wanted at least 4000 a month.¹⁷² During the last quarter of 1914, only 2164 hand and rifle grenades were produced in Britain; most of these were the No. 1 percussion grenade and the No. 3 rifle grenade. Throughout much of 1915, the supply of detonators¹⁷³ was the weak link in the production of all hand and rifle grenades, irrespective of design. Indeed, it remained a problem into 1916.¹⁷⁴ FW3 experimented with commercial detonators to find alternatives to military detonators, experimentation which continued after it became the TWD. Commercial detonators were made for commercial explosives used in, for example, mining. There was no guarantee that they would work well with military explosives, such as TNT and lyddite.¹⁷⁵ At the same time, an alternative to military explosives was needed by the Royal Engineers because the entire production of military explosives was needed for shell fillings.

One of the first tasks Jackson undertook in autumn 1914 was that of finding a suitable commercial explosive. He chose ammonal which was available in large quantities and had a similar performance to that of military explosives.¹⁷⁶ Moreover, ammonal did not need a military detonator to fire it; a commercial detonator could be used. The Roburite & Ammonal Company manufactured the explosive for mining and made containers from tin to hold the charge.¹⁷⁷ Jackson adapted the process for the manufacture of hand grenades. Rather than

spend time trying to invent new devices, he based his designs on the jam tin and hairbrush (or racket) grenade being improvised by the Royal Engineers in France. The results were the Nos 8 and 9 (jam-tin type) patterns and the No. 12 (hairbrush type) pattern.¹⁷⁸ Jackson's use of commercial materials and production processes ensured that his hand grenade designs placed no pressure on existing manufacturing capacity.

The supply of detonators was especially problematical for the No. 1 hand grenade and the Hale rifle grenade because both required 'special' detonators that were slow to make and output could not easily be increased because Woolwich had neither the capacity nor the trained workers to do so.¹⁷⁹ In early 1915, the only large commercial producer of detonators in Britain, Nobel, was encouraged by the War Office to manufacture the 'special' detonators but it could only do so if it sacrificed production of other detonators, such as those used in mining. All detonators were made on the same machinery and, while Nobel could produce 90,000 commercial detonators and 50,000 military detonators for hand grenades, the same plant could only make 5000 special detonators in a comparable period.¹⁸⁰

The Cotton Powder Company also made some special detonators. The firm was asked to increase production of its grenades but it lacked suitable machinery to make more.¹⁸¹ Roburite & Ammonal undertook the manufacture of more of the Hale rifle grenades but could not make the detonators which had to come from Nobel.¹⁸² In September 1915, production of Nobel detonators was still only 5000 a week.¹⁸³ A compromise was eventually reached so that Nobel increased its production of special detonators to 20,000 a week in October but at the expense of commercial detonators.¹⁸⁴ The conflict was only resolved when Nobel increased its manufacturing capacity in 1916 by which time the No. 1 grenade had been superseded by the No. 5 Mills grenade. Kynoch, the manufacturer of small arms ammunition, built a factory to produce 40,000 detonators a week but this did not come on stream until early 1916.¹⁸⁵

The shortages led to a number of desperate measures. In late 1914, the British begged some M1870 bracelet grenades from the French. Major-General Rawlinson requested 5000 M1870 grenades per division to be manufactured in Britain.¹⁸⁶ His request was turned down, partly because the grenades were no better than British devices but also because it would have taken too long to construct a factory for their production. More than once, GHQ asked the War Office to organise the manufacture of French grenades in Britain. Lieutenant-General Maxwell, QMG at GHQ, wanted the French P1 grenade and thought it quite good.¹⁸⁷ The Ordnance Board evaluated it and other French types but was unimpressed.¹⁸⁸

During the first six months of 1915, production increased in Britain but was still meagre in comparison to demand; only 65,315 hand and rifle grenades were produced. In the early part of 1915, the War Office placed orders for 5,000,000 No. 5 Mills grenades with contractors but, by the end of June, only 16,000 had been delivered because of production difficulties.¹⁸⁹ By end of August 1915, the monthly demand for hand grenades rose to 172,800 percussion grenades alone; it could not be met even though contracts had been placed for 570,000.¹⁹⁰ By the beginning of September, fewer than 10 per cent of the No. 5s that were supposed to have been delivered by that date had been supplied by contractors.¹⁹¹ It was not until October

that the output of the No. 5 met demand when it exceeded 300,000 a week and was about to increase to 400,000 a week.¹⁹² This compares with between 1000 and 1500 Battye bombs produced daily by the Béthune Bomb Factory in early 1915.¹⁹³ The Factory could not cope with the demand for its grenades during the battle of Festubert in May 1915, however, so, capacity was increased, enabling it to supply 80,000 grenades during the Battle of Loos a few months later.¹⁹⁴ By October, hand grenade production at the Bomb Factory had ceased entirely, production being given over to rifle grenades of which it was producing daily 1000 Newton Pippin rifle grenades,¹⁹⁵ an output it maintained until July 1916.¹⁹⁶ Between about July and December 1915, the Second Army Workshops produced approximately 80,000 Newton Pippin hand grenades,¹⁹⁷ while the output of the rifle grenade increased to 5000 a day. The total output of the rifle grenade by the Second Army Workshops was 700,000.¹⁹⁸ Still more were produced in a facility at Merville.¹⁹⁹ The No. 22 rifle grenade, an improved Newton Pippin rifle grenade, was manufactured in Britain and supplied to the BEF throughout much of 1916.²⁰⁰ About 5,000,000 were eventually produced before it was withdrawn in mid-1917 due to the high incidence of prematures.²⁰¹

From about July to December 1915, most hand grenades manufactured in Britain were the No. 15 Ball type of which 1,670,332 were produced during the three months July to September (an average of approximately 140,000 a week) and a further 4,237,188 (an average of approximately 350,000 a week) were produced during the last quarter of the year after which production was drastically reduced; production ceased in the third quarter of 1916.²⁰² Following the disastrous failure of the Ball grenades at Loos, they were shipped to the Middle East and to Russia. Between September 1915 and September 1916, 3,831,575 No. 16 Oval pattern²⁰³ grenades were produced in Britain. The total number of hand grenades of all types produced in Britain during the third quarter of 1915 was 2,208,676, which increased to 9,489,765 in the fourth, making a grand total of 11,698,441 for the second half of the year.²⁰⁴ During 1916, the output of hand grenades was more than doubled to 28,956,513, the majority of which were No. 5s. By then, the stopgap grenades such the Ball and Oval patterns had been withdrawn. Production was switched to the No. 23 Mills in 1917.²⁰⁵

It was a similar story with trench mortars. At the end of December 1914, only twelve mortars with 545 rounds were sent out from Britain.²⁰⁶ These were the first mortars to come from Britain. In the first quarter of 1915, output of light mortars was fifty-eight which increased to ninety-one in the second quarter, while eighteen mediums were produced. It was not until the advent of the 3-inch Stokes that output of light mortars increased substantially; in the last quarter of 1915, 364 light mortars were produced in Britain, of which 304 were Stokes mortars. Only 104 of these reached the front, however, the remainder being sent to training schools. The greater simplicity of the Stokes compared with the 3.7-inch and 4-inch mortars, the other light mortars in service until replaced by the Stokes, allowed for faster production. The output of Stokes mortars increased to 391 and 1415 over the next two quarters, then dipped to 885 in the third quarter of 1916 and to 432 in the last quarter. Thereafter, it slowly rose to 748 in the third quarter of 1917, reaching 1247 in the next quarter and a high of 1931 in the first quarter of 1918. Thereafter, output remained high

until the end of the war. In 1918 alone, 4985 3-inch Stokes mortars were produced. In all, 11,331 3-inch Stokes mortars were manufactured in Britain.²⁰⁷ Output of no other mortar was on a similar scale. Indeed, the output of most other mortars declined in 1916, rose again for the first nine months of 1917, then fell substantially during 1918.²⁰⁸

The only other mortar produced in relatively large numbers was the 2-inch medium, introduced in early 1915.²⁰⁹ Over the next twelve months, 172 were produced. Quarterly output increased in the first three months of 1916, reaching a peak of 540, but the average was only 168 a quarter between spring 1916 and the end of 1917. It was replaced by the 6-inch Newton mortar in the second quarter of 1917. Output of the Newton was higher than that of the 2-inch mortar. During 1917, 1929 Newtons were produced but thereafter average output fell to only fifty-four a quarter, apart from the second quarter of 1918 when 448 were produced.²¹⁰

The utility of mortars was, of course, dependent on the ammunition supply, principally high-explosive bombs.²¹¹ When the Stokes was introduced in late 1915, only 35,000 rounds had been produced which amounted to only 115 per mortar.²¹² By the end of the first quarter of 1916, output had increased to 805,975 rounds.²¹³ In the second quarter, output almost doubled to 1,458,285 and remained more than a million each quarter for the next twelve months, only dipping to 648,58 in the second quarter of 1917 before rising to 1,337,320 in the third quarter before dipping again. It fluctuated thereafter between about half a million and a million each quarter until the end of the war. In total, 11,621,424 high explosive bombs for the 3-inch Stokes were produced between late 1915 and the end of the war, far more than for any other mortar used by the BEF.²¹⁴ The fluctuations in output from about spring 1917 were largely due to large stockpiles created by surplus capacity. Output thereafter was rarely at capacity, an achievement which would have been impossible in 1915. Had not the design of the bomb been simple and had not cast iron been used for its body, the output would have been much lower.

The output of 2-inch bombs for 1915 was only 40,146 but in 1916 it rose to 1,081,519, then fell to 502,115 in 1917 when production ceased, amounting to 1,623,780 in total. Production of bombs for the Newton started in the first quarter of 1917 and continued until the end of the war. Output increased throughout 1917 and totalled 239,471 bombs. Output continued to rise in 1918 and, by the end of the war, 1,374,264 had been produced over approximately twenty-one months of production, only 249,516 fewer than the output of 2-inch bombs over thirty-six months. It is clear that the output of 6-inch rounds was faster than the output of 2-inch rounds. This was indicative of how commercial firms became more skilled but also of the greater difficulty in making the 2-inch bomb which comprised a spherical cast iron head attached to a 2-inch diameter steel tail.²¹⁵ Finding steel tubing strong enough to withstand the shock of firing was initially problematical. The joint between the tail and the head was prone to porosity which weakened it, causing serious problems for contractors; rejections were 75–80 per cent between August and December 1915 so that the BEF had to rely on the output from Woolwich.²¹⁶ The problem was almost completely eliminated by the beginning of 1917, by which time, the 2-inch was about to be replaced by the 6-inch Newton.

The huge output of 3-inch mortar rounds epitomised the success achieved by commercial engineering firms in producing trench warfare munitions. Their output exceeded demand and allowed reserves to be stockpiled, which led to a cut-back of production. The higher rate of fire of the Stokes mortar encouraged a higher expenditure of ammunition than was possible with the medium mortars so that output of 3-inch ammunition had to be high in order to cope with demand. While a comparison of the number of rounds produced for the 3-inch Stokes with the number of rounds produced for the medium mortars is somewhat misleading because of differences in technical characteristics and operational use, nevertheless, it is instructive as it highlights the success of the Stokes mortar and of munitions production. Thus, it is not only an indicator of successful engineering but also of effective organisation and management.

Engineering solutions

The close association between design and manufacture in the Army Workshops was one reason they were able to produce munitions at a high rate at short notice during 1915. The Workshops were limited by a lack of appropriate machinery and skilled workers. An apparent disadvantage was turned into an asset, however; simplicity of design and avoidance of materials that needed to be precision-engineered allowed mass production techniques to be used. This process was helped by the fact that engineers with light-industry backgrounds tended to run the Workshops. The inventors and designers working in these Workshops devised munitions according to the availability of materials and fabrication techniques. They relied on first principals and combined an understanding of the conditions on the Western Front with an appreciation of what criteria the new devices had to satisfy to devise effective munitions. The inventors and designers in Britain were less fortunate and were further hampered by lack of direct experience of how such munitions would be used.

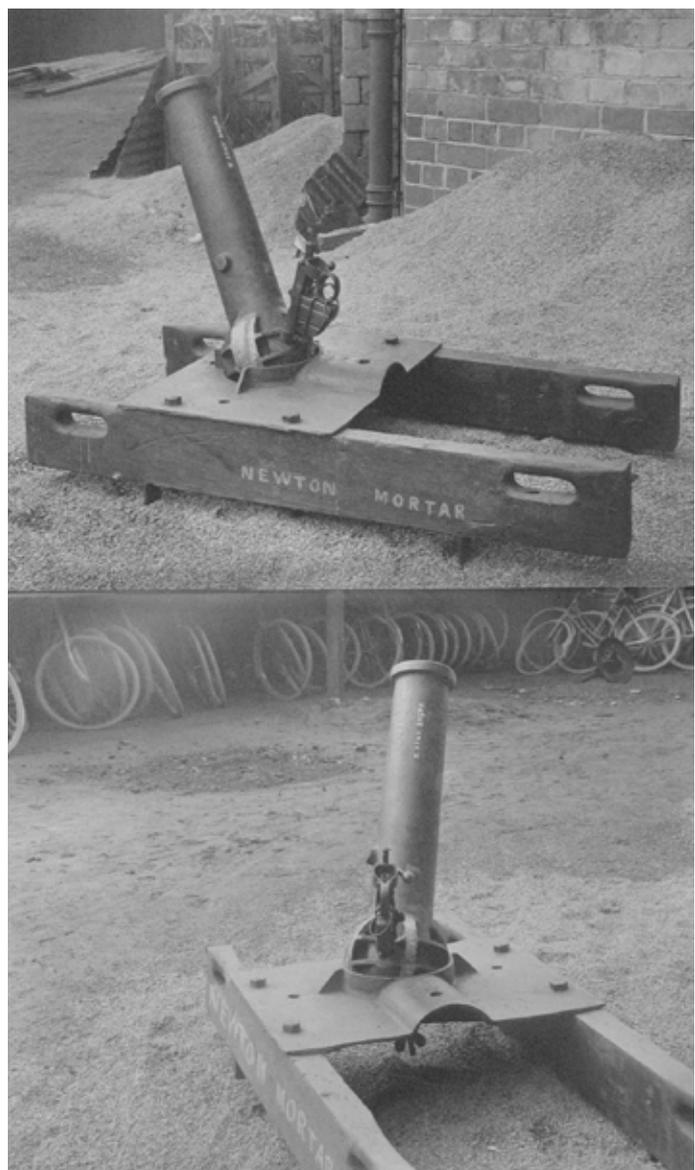
The circumstances under which the War Office operated during the first ten months of the war were not the same as those under which the Ministry of Munitions subsequently worked. Hence, different sets of criteria are necessary to gauge their relative effectiveness in providing trench warfare munitions. In some respects, the success of the Ministry can be attributed to the work previously carried out by the War Office since this laid the foundation on which the Ministry built. However, it is unrealistic to consider the work of the War Office and that of the Ministry of Munitions in purely chronological terms since the development of munitions did not occur in discreet stages which coincided with before and after the creation of the Ministry of Munitions. The needs of the BEF, the capabilities of contractors, nor the utility of the munitions supplied to the BEF on the Western Front can be viewed according to an arbitrary line of demarcation that signifies before and after the creation of the new Ministry.

The production of trench warfare munitions in Britain was made possible by contracting commercial firms to manufacture the munitions. Prior to the First World War, no circumstance had arisen whereby such a recourse had been necessary for the production of any sort of munition. Hence, there was no scheme for such an eventuality. Some firms

were set up for the sole purpose of manufacturing trench warfare munitions, such as Pall Mall Grenades, Mills Munitions Ltd and The Trenchscope Company.²¹⁷ The process of selecting suitable firms initially relied upon the expertise and experience of the inspectors of the OEB. While the allocation of contracts to specific firms for the manufacture of trench warfare munitions became more systemised during the war, especially when contracts were placed through the local Boards of Management, nevertheless, this was still extemporisation rather than a plan.

In a very broad sense, the process of engaging commercial firms in the manufacture of trench warfare munitions and the subsequent massive output by these firms resembled the four-phase process described by Robinson.²¹⁸ However, the resemblance is superficial, partly because his process relates to an entire economy rather than to one aspect of it, as under discussion here. Robinson derived his four-phase process from his experience of the British war economy in the Second World War and it may be argued that the process is specific to the Second World War. Two major factors pertained in 1914 which were quite absent in 1939: the munitions under discussion in this thesis did not exist in 1914 and had to be invented and, hence, there was no body of knowledge about methods of production. At the start of the

Fig. 18 *Two shots of the 3.7-inch Newton mortar, cast from SAA cartridge cases, sketched by Todhunter. The skeleton ball-and-socket joint (for traverse and elevation) is clearly visible. The breach is fitted with a firing mechanism from a scrap SMLE rifle. A lanyard would have been fitted to the trigger. Note the carrying handles in the wooden supports. This photograph was taken at the Second Army Workshops (MUN 5/383/1600/14)*



Second World War, such problems as these did not exist; there was no sudden requirement to invent then manufacture novel munitions in order to allow the army or, indeed, the RAF or the Navy to conduct operations. Moreover, the number of firms engaged in the manufacture of trench warfare munitions during the First World War represented only some of the firms that were engaged in the production of munitions, many of which produced conventional munitions. Here, we are only concerned with the manufacture of trench warfare munitions. Finally, the processes of invention, development, manufacture and operational use occurred concurrently, rather than sequentially, during the First World War and this had an effect on manufacture which was not factored into Robinson's four-phase process.

That between autumn 1914 and summer 1915, research, invention and evaluation took place concurrently with manufacture and operational use was not a matter of choice for the War Office nor a question of incompetence. Time, much taken for granted in both peacetime and retrospectively, was the determinant in this equation. Processes which took years in peacetime had to be completed in months or even weeks. That the demands of the BEF were met was a considerable achievement of both organisation and engineering which was underplayed by the authors of the *History of the Ministry of Munitions* and by Lloyd George. Instead, the drawbacks of concurrent, rather than sequential, processes was emphasised without a discussion of the context. Thus, the many substandard, underdeveloped, unreliable and unsafe munitions which inevitably found their way to the BEF during 1914 and 1915 were highlighted along with the paucity of supply, rather than the development of processes by which the BEF's demands could be met. The fact that, under less critical circumstances, such munitions would have been rejected by the Ordnance Board as unsuitable for service use was sidestepped.

One unexpected benefit of this unavoidable approach to munitions development went unnoticed: the brainstorming which it encouraged. Had a purely bureaucratic or a highly systemised approach to providing novel munitions been adopted in autumn 1914, as the Ministry of Muniton subsequently tried to implement, it is unlikely that the BEF would have received what it needed from Britain. Thus, the products of this brainstorming process, many of them derided for their inutility and their unreliability, not only addressed demand but also provided the basis for future development. This last point is significant since for technological advances to be made, there has to be something upon which to improve.²¹⁹ This begs the question of whether the devices of the First World War were, indeed, first generation or, in fact, derived from early devices such as those improvised during the Russo-Japanese War.

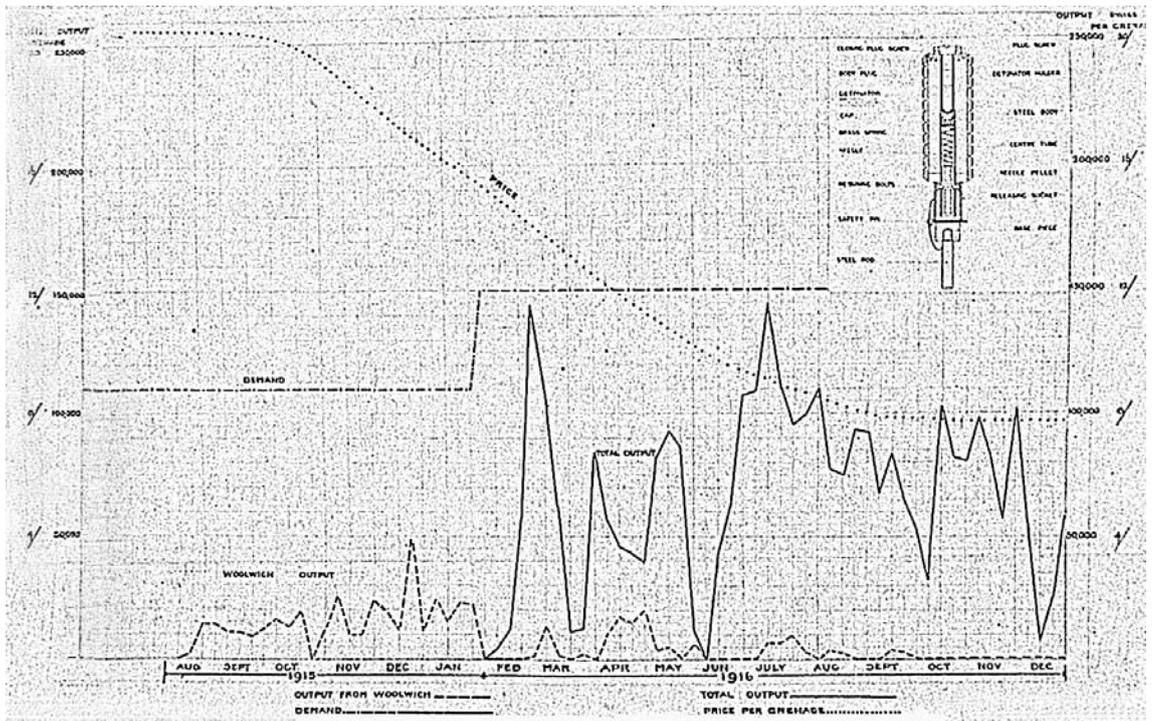


Fig. 19 A graph of output versus demand and cost over time for the Nos 3, 20 and 24 rifle grenades (Hale type) between August 1915 and December 1916. Output is never steady but fluctuates from month to month. Cost falls as average output rises but output never catches up with demand (MUN 5/385/1640/1)

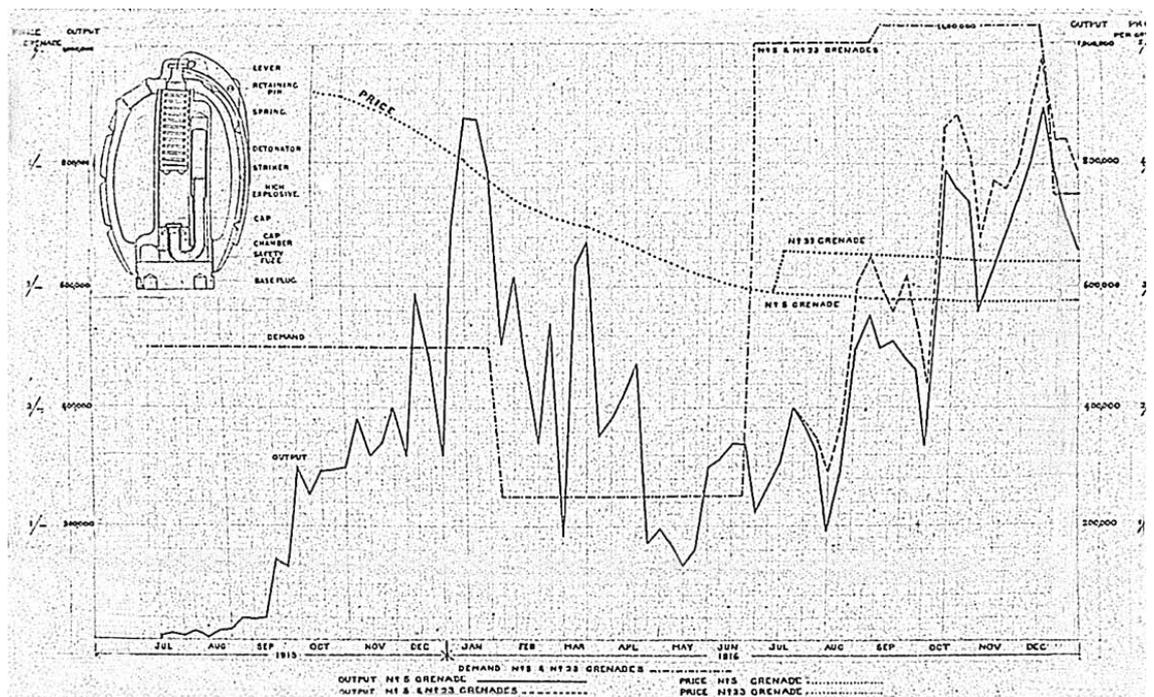


Fig. 20 A graph of output versus demand and cost over time for the No. 5 and No. 23 Mills grenades. Output is never steady, fluctuating from month to month. Output sometimes exceeds demand. Cost falls as average output rises (MUN 5/385/1640/1)

Notes

¹ MUN 5/382/1600/7, History and Work Ministry of Munitions Trench Warfare Supply Department, June 1915 to September 1917 by the Deputy Director-General, Mr E V Haigh, p. 14.

² *Op cit.* p. 35. George Dewar estimated that 90–95 per cent of firms producing munitions during 1916 and 1917 had no prior experience of such work. See George Dewar, *The Great Munitions Feat 1914–1918*, (London, 1921), p. 59.

³ If any of the components of a munition are outside tolerance, they may not fit together correctly so that the munition fails to function correctly.

⁴ MUN 5/321A *History of the Ministry of Munitions*, vol. XI, *The Supply of Munitions*, Part 1 *Trench Warfare Supplies*, p. 41. See also vol. VIII *Control of Industrial Capacity and Equipment*, Part I *Review of State Manufacture*, p. 25 regarding the established by the Ministry of Munitions of the Gauge Department for the supply of gauges which had to be manufactured to the correct standards. Lack of gauges for inspection sometimes slowed output which affected the initial output of bombs for the 3-inch Stokes mortar (see *Trench Warfare Supplies*, *op cit.* p. 50).

⁵ *Trench Warfare Supplies*, *op cit.* pp. 1–4, 105–6.

⁶ J E Edmonds, *History of the Great War, Military Operations, France and Belgium, 1914*, vol. 1, (London, 1925), Appendix I Order of Battle of the British Expeditionary Force, August 1914, 415–28; vol. 2, Appendix I Order of Battle of the British Expeditionary Force, October 1914, pp. 473–86. *History of the Ministry of Munitions*, vol. IX *Review of Munitions Supply*, Part I *Munitions Programmes*, pp. 2–3. Paddy Griffith, *Battle Tactics of the Western Front, The British Army's Art of Attack 1916–18*, (New Haven, 1996), p. 218.

⁷ *Military Operations*, 1914, vol. 2, *op cit.*, 1915, vol. 2. For a graphical representation of the increase in strength of the BEF see Benedict Crowell, *America's Munitions 1917–1918*, (Washington, 1919), p. 17.

⁸ MUN 5/382/1600/6 The History of Trench Warfare Supply, pp. 1–3, especially p. 3. See also *Trench Warfare Supplies*, *op cit.* p. 3.

⁹ No. 1, No. 2 (both percussion-fuzed), Battye and Newton Pippin (both made in France), No. 5 Mills, No. 6 and No. 7 Lemon grenades (jam-tin grenade re-engineered by Woolwich), No. 8 and No. 9 double-cylinder grenades (jam-tin grenade re-engineered by Jackson), No. 12 Hairbrush (re-engineered from improvised hairbrush grenades), No. 13 and No. 14 Pitcher grenades (patented), No 15 Ball grenade, No. 16 Oval grenade. There were also a variety of locally improvised grenades. In November 1915 improvised and stopgap grenades were withdrawn because of the increasing availability of the No. 5 Mills (see *Trench Warfare Supplies*, *op cit.* p. 79). These grenades are discussed in the next chapter.

¹⁰ *Trench Warfare Supplies*, *op cit.* pp. 78–9.

¹¹ *Op cit.* p. 2.

¹² *Op cit.* pp. 1–4. MUN 4/2615 Trench Mortar & Ammunition Requirements, letter dated 8 June 1916.

¹³ MUN 4/2615, *op cit.*

¹⁴ *Op cit.* letter dated 23 June 1916.

¹⁵ *Op cit.* minute dated 29 September 1916.

¹⁶ Also referred to as the Inspection Department which, with the creation of the Ministry of Munitions came under the control of the new Ministry (see *History of the Ministry of Munitions*, vol. IX, *Review of Munitions Supply*, Part II *Design and Inspection*, *op cit.* p. 73). The Inspection Department came into being in April 1916.

¹⁷ The Leach catapult and the West Spring Gun were temporary expedients to make up for the lack of mortars. The Leach catapult, also known as the Gamage catapult, was invented by Claude Pemberton Leach and was initially manufactured by the Gamage's department store but was also made by Royal Engineers in France and the Dardanelles from drawings (which may also have been used by Gamage's). Leach patented his device (GB7710/15). The West Spring Gun was invented by a Captain West and was, in effect, a mechanical catapult powered by springs rather than rubber. See Anthony Saunders, *Weapons of the Trench War, 1914–1918*, (Stroud, 1999), pp. 51–66; 'The Work of the Royal Engineers in the European War, 1914–19', *The Royal Engineers Journal*, vol. XXXIX, no. 1, March 1925, pp. 78–80; Lt-Col O F Brothers, The Development of Weapons Used in Trench Warfare, pp. 5 and 39 (in MUN 5/383/1600/14) pp. 79–79A (West Spring Gun) and p. 80 (Leach catapult).

¹⁸ A list of experimental grounds is in Appendix IV (pp. 114–15) of *Design and Inspection* but the list is incomplete and does not include proving grounds set up to test the mortars produced by commercial contractors.

¹⁹ There were at least eight experimental grounds in Britain at which trench warfare munitions were developed and evaluated under the auspices of the Ministry of Munitions. Some were initially controlled by the TWD and some by the MID.

²⁰ The MID used subcommittees to evaluate devices, each subcommittee specialising in one type of munition. This allowed the development of expertise within the MID. See, for example, MUN 4/426 which contains MID monthly reports from 1918; MUN 5/375/700/1 (especially p. 3 of top report and pp. 3–4 of report dated 19 November 1919; the two reports are different versions of the same thing) which contains an account of the formation and organisation of the MID.

- ²¹ Entries from Diary of Defendant William Mills (enclosure No. 3 of case papers of Roland & Others *v.* Mills & Another, King's Bench Division, 1917 R No. 45), January 1915 entries. See also draft of Proof of Evidence of Mr William Mills, p. 22.
- ²² Mills Diary, *op cit.* and Proof of Evidence, *op cit.* p. 23. The grenades were filled by Roburite & Ammonal.
- ²³ Proof of Evidence, *op cit.* p. 23.
- ²⁴ Proof of Evidence, *op cit.* pp. 23–4.
- ²⁵ Mills Diary, *op cit.* and Proof of Evidence, *op cit.* pp. 26–7.
- ²⁶ Mills Diary, *op cit.* February 1915.
- ²⁷ There appear to be no Ordnance Board minutes relating to the evaluation of the first Mills grenade at Shoeburyness although there are minutes dating from about August 1915 onwards relating to investigations of faults with the Mills. This implies that the testing authority in February was neither the DoA nor Woolwich.
- ²⁸ He was a pre-war regular who had held the post for some time before the war. Promoted to major during the war, he was still in the post at the end of 1916.
- ²⁹ WO 140/13, WO 140/14, WO 140/15 contain Todhunter's Reports of Trials covering January 1913 to December 1916. The WO 140 series contains reports going back to 1853 but there is nothing after December 1916. Reports after this date ought to be in one of the MUN series as Hythe would have come under the Ministry of Munitions but nothing has come to light.
- ³⁰ Todhunter evaluated all the automatic rifles of the period. He rejected them partly because they were technically flawed but partly because he perceived the automatic rifle as no more than a conventional rifle from which the burden of manual loading and ejection had been replaced by a mechanical system. He always wanted to aim and shoot an automatic rifle in the same way as the manually operated service rifle, thereby negating one of the benefits of automatic loading and ejection, namely, volume of fire.
- ³¹ There is a definite impression that Dewandre knew very well that the Roland did not work properly and that he was trying to kid Mills to the contrary. Dewandre was not entirely straight with Mills over other matters; for example, Dewandre did not reveal that he had already approached other British firms to make the Roland. See Proof of Evidence, *op cit.*, especially pp. 6–9, 23–7, 29–31, 39–40.
- ³² Yet some very unusual devices were used in the trenches, including padded mattress-like constructions for throwing across barbed wire entanglements to enable troops to cross. Known as barbed wire traverser mats, their manufacture was organised by FW3a (MUN 5/382/1600/10 History of the Production of Trench Warfare Stores by the Trade, July 1915 – December 1917, p. 5). The French even used ancient cannon to fire grapnels into barbed wire entanglements; the grapnel was then pulled back through the wire to drag the wire out of the way (*The Illustrated War News*, 4 August 1915, p. 10).
- ³³ *Annual Report of the President, Ordnance Board for the year 1915*, (London, 1917), pp. 308–12. See also booklet of a lecture by Stokes on 24 June 1918 to The Junior Institution of Engineers, 'The Stokes Gun and Shell and their Development' in T 173/453. Lloyd George condemned the Ordnance Board for failing to take up the Stokes (see David Lloyd George, *War Memoirs*, (London, 1933), vol. 1, pp. 268–9). The history of the Stokes, its invention and subsequent trials are in MUN 5/384/1610/4 Notes on the early history of the Stokes gun 8 January 1915 – 30 October 1915 by Capt E F Atkinson (Trench Warfare Research).
- ³⁴ *Annual Report, op cit.* p. 312.
- ³⁵ Financed by Stokes. See p 3 of claim submitted by Stokes on 5 June 1919 to the Royal Commission on Awards to Inventors, and pp. 2 and 3 of claim resubmitted on 3 May 1921 in T 173/453. In all, Stokes and Ransomes & Rapier spent £3,000 developing the mortar and its ammunition and providing mortars and bombs for trials both in Britain and in France. Stokes was the managing director of Ransomes & Rapier.
- ³⁶ Proofing trials appear to have been conducted at Wembley Park (see *Annual Report, op cit.* p. 314).
- ³⁷ *Annual Report, op cit.* pp. 312–13.
- ³⁸ *Op cit.* p. 314.
- ³⁹ Premature detonation occurs when the munition explodes in the barrel or soon after leaving it; a misfire occurs when the propelling charge fails to ignite properly, so that it only burns partially or not at all, and the live munition is left in the barrel or travels only a very short distance; a blind occurs when the munition fails to explode because the fuze has malfunctioned. Misfires of mortar rounds were sometimes called fizzles. Blinds could occur with any type of munition fitted with a fuze.
- ⁴⁰ Discussed in Chapter 6.
- ⁴¹ August 1915 to March 1919. See *Design and Inspection, op cit.* p. 61.
- ⁴² MUN 4/426, *op cit.* MUN 5/357/700/2/13 has a breakdown of the MID-approved inventions.
- ⁴³ Mostly, through enemy action in the Second World War.
- ⁴⁴ MUN 4/426, *op cit.*
- ⁴⁵ In order to breakdown the types of invention and their relevance to trench warfare it would be necessary to analyse each of the MID's monthly reports.
- ⁴⁶ There are no reliable figures for submissions to all departments and sections concerned with novel munitions.
- ⁴⁷ For example, the No. 34 egg grenade was originally devised at the Experimental Section in late 1916. See 'The Work of the Royal Engineers in the European War, 1914–19', *The Royal Engineers Journal*, September 1924,

- p. 454; and Rick Landers, *'Grenade' British and Commonwealth Hand and Rifle Grenades*, (Dural, 2001), pp. 104–08. Eventually, four types of egg grenade entered competitive trials in Britain, two of which were devised at the Experimental Section and two by the TW(D)D.
- ⁴⁸ A helmet fitted with a pistol, a vacuum gun (see MUN 5/199/1660/17) and death rays (MUN 7/305) were all suggested. The helmet gun was even patented, invented by a man called Pratt (GB100891 and GB106461).
- ⁴⁹ These are outside the scope of the present thesis; see Anthony Saunders, *Dominating the Enemy*, (Stroud, 2000), Chapter 6, pp. 100–127.
- ⁵⁰ These are discussed in the next chapter.
- ⁵¹ Pattison jumps to this conclusion.
- ⁵² See, for example, Proceedings of the Trench Warfare Department for 1917 and 1918 in WO 142/206, WO 142/207 and WO 142/208.
- ⁵³ Brothers, *op cit.* pp. 95–6, 98; Maj-Gen C H Foulkes, *"Gas!" The Story of the Special Brigade*, (Edinburgh & London, 1934), p. 99.
- ⁵⁴ Discussed more fully in Chapter 5.
- ⁵⁵ *Military Operations, 1915*, vol. 2, *op cit.* p. 10; *Trench Warfare Supplies, op cit.* p. 33.
- ⁵⁶ Inventors tend to believe that their invention is the equivalent in importance to the wheel and tend to ascribe rejection to factors other than poor functionality.
- ⁵⁷ Thring's grenade gun GB124469 and GB124478 discussed in MID report for July 1917 in MUN 4/426, *op cit.* It was not the patent agent's job to promote or sell the invention; writing such a letter was unusual.
- ⁵⁸ MUN 4/426, *op cit.*
- ⁵⁹ The DG grenade, a percussion-fuzed device, was invented by Leslie Daniels and Charles Gardiner, directors of Trench Warfare and Armaments (Limited) which had been set up during the war to make grenades. They were granted two patents in respect of the device: GB124837 (3 May 1916), GB129042 (4 October 1917).
- ⁶⁰ Major-General Francis Bingham became DGMD in 1916. He had been DDA since 1913.
- ⁶¹ Liddell Hart Centre, Robertson: 8/5/80, 30 November 1916.
- ⁶² Liddell Hart Centre, Robertson: 8/5/81, 1 December 1916.
- ⁶³ Dr Christopher Addison replaced Lloyd George as Minister of Munitions in December 1916 but only remained in office until 1917 when he became Minister of Reconstruction. He was replaced by Winston Churchill.
- ⁶⁴ MUN 4/426, O'Malley letter dated 21 May 1917.
- ⁶⁵ It was a shrewd political act which gave the impression of perspicacity and that he had swept aside the obstructionism of the War Office. At that time, no mortar stood out as exceptional so that had the Stokes turned out to be a failure no one would have been surprised and no blame would have attached to Lloyd George. That it was a success reflected well on him.
- ⁶⁶ They probably resubmitted it to the MID in April after making some modifications which may have been recommended prior to trial. See report of court case in *The Times* 5 November 1918. The inventors filed a patent application on 3 May. See also O'Malley's correspondence in MUN 4/426.
- ⁶⁷ O'Malley's letter, *op cit.* in MUN 4/426.
- ⁶⁸ The only patent granted to Ley was GB160881 but he did not file a patent application until 26 November 1919.
- ⁶⁹ MUN 4/426, *op cit.*
- ⁷⁰ These were Mk VIIIs. The high mark number is an indication of the number of modifications that had been made to the device since its inception in May 1916.
- ⁷¹ *The Times*, 5 August 1918.
- ⁷² It was claimed to be a loan. The case was heard before Mr Justice Avory who reluctantly acquitted the accused when, three days into the trial, the jury indicated that it would not find them guilty. Avory implied that they were not entirely innocent of the charges which had initially been brought under the Prevention of Corruption Act 1916. The evidence did not point to the firm trying to obtain a contract so was outside the scope of the 1916 Act; the case had then proceeded under the 1906 Act. See *The Times*, 5 August, 7 November and 8 November 1918.
- ⁷³ O'Malley letter, *op cit.* The development of a reliable percussion-fuzed hand grenade was not completed until after the war.
- ⁷⁴ Vickers was also producing small numbers of trench mortars. From October 1914 to June 1915, the Ordnance Factory at Woolwich and Vickers were the only manufacturers of mortars. See *Review of State Manufacture, op cit.* p. 28.
- ⁷⁵ Such figures provide only a snapshot, of course. There are no contemporary statistics for the total number of such firms contracted during the course of the war, either expressed as an absolute figure or as a percentage of the total number of commercial firms operating in Britain at the time so it is difficult to gauge how much of the industrial capacity of Britain was engaged in the manufacture of trench warfare munitions.
- ⁷⁶ MUN 5/384/1610/2 Trench Warfare Supply, History and Work of TW3(B), p. 1. TW3(B) was a subsection of the Trench Warfare Department, dealing with medium mortars.
- ⁷⁷ *Trench Warfare Supplies, op cit.* p. 14; MUN 5/382/1600/11, *op cit.* p. 12.
- ⁷⁸ Hitherto, Woolwich and the Cotton Powder Company works at Faversham were the only sites where grenade and mortar bomb could be filled with explosive. Roburite & Ammonal also had facilities that were subsequently used.

- ⁷⁹ *Trench Warfare Supplies, op cit.* p. 23. Roburite & Ammonal took on the job in January 1915.
- ⁸⁰ The National Bomb-filling Factories are discussed in *Review of State Manufacture*, pp. 23–31. See also *History of the Ministry of Munitions*, vol. VIII *Control of Industrial Capacity and Equipment*, Part II *The National Factories*, pp. 155–6.
- ⁸¹ The company manufactured cranes, excavators, railway plant and river sluices, among other things.
- ⁸² *Trench Warfare Supplies, op cit.* p. 15. The Mannesmann Tube Company of Swansea produced, among other things, seamless tubing which was ideal for a low-pressure gun with a smooth-bore barrel.
- ⁸³ *Ibid.* MUN 5/5/382/1600/11, *op cit.* p. 12.
- ⁸⁴ Contractors did not become heavily involved in manufacturing grenades, mortars and mortar ammunition until about the middle of the year. Prior to that, production was restricted to Woolwich and Vickers for mortars, Woolwich for mortar ammunition and grenades, and the Cotton Powder Company for rifle grenades.
- ⁸⁵ *Trench Warfare Supplies, op cit.* pp. 49, 51; *Design and Inspection, op cit.* pp. 87, 90–1. MUN 5/5/382/1600/11, *op cit.* MUN 5/384/1610/2, *op cit.* p. 4.
- ⁸⁶ *Trench Warfare Supplies, op cit.* pp. 20–3, 64–5, 78, 107.
- ⁸⁷ *Op cit.* pp. 15–16.
- ⁸⁸ *Annual Report, op cit.* p. 377. OB15600 (9 September 1915).
- ⁸⁹ See MUN 5/384/1610/2, *op cit.* p. 5 where the inspection of 2-inch mortar ammunition produced by contractors was viewed as ‘too exacting’ to the extent that ‘thousands of feet of thoroughly sound tubing has been condemned as scrap’ due to excessive caution by the Inspection Department at Woolwich. See also MUN 5/384/1610/9, Personal Notes on the Work and History of TW3 by A P Stockings (dated 9 June 1917), pp. 6–7 regarding the relationship of TW3 with the Inspection Department. TW3 was a section of the Trench Warfare Department.
- ⁹⁰ *Trench Warfare Supplies, op cit.* p. 8; *Design and Inspection, op cit.* p. 50.
- ⁹¹ MUN 5/382/1600/10, *op cit.* p. 3.
- ⁹² Leeming was on sick leave from France, having been gassed. He had an engineering background. See MUN 5/382/1600/1, *op cit.* p. 1. According to Hartcup, Alexander Roger, a civilian who joined the TWD on its creation and became Jackson’s deputy and subsequently ran the Trench Warfare Supply Department, devised the OEB (see Hartcup *op cit.*, p. 61). Roger may have overseen expansion of the OEB but he did not originate it (see MUN 5/383/1600/11 *op cit.*, p. 4). It is quite clear from the *History of Ministry of Munitions* that it originated in Jackson’s FW3a section (see *Trench Warfare Supplies, op cit.* p. 12).
- ⁹³ MUN 5/382/1600/11, *op cit.* p. 7. The number of staff continued to increase throughout 1916 and reached 156 by the end of the year. Thereafter, the number of staff fell slightly but was in the region of 130 in mid-1917.
- ⁹⁴ The Outside Engineers Branch became part of the Trench Warfare Supply Department when the Trench Warfare Department was split in two.
- ⁹⁵ MUN 5/382/1600/11 *op cit.* p. 16. See also MUN 5/382/1600/6 History of Trench Warfare Supply, Part I, Departmental Organisation for the Production of Trench Warfare Stores, first draft, pp. 5, 11 and 23. The OEB inspectors were paid a flat rate, whereas Woolwich inspectors were less specialised and were paid a lower rate with overtime. It was argued that the OEB inspectors were better qualified to inspect novel munitions and worked to a higher standard than the Woolwich inspectors. It is difficult to ascertain the validity of this claim because it was made at a time when the OEB was having to justify its role. However, while the author of the Personal Notes on the Work and History of TW3, *op cit.* (p. 7) in MUN 5/384/1610/9 conceded that the OEB was of considerable help to the Supply Offices of the department, he thought that the inspectors had too little experience and lacked the necessary standing to negotiate effectively with contractors and complained that they lacked the ability to write clear reports of the supply requirements of the contractor.
- ⁹⁶ *Trench Warfare Supplies, op cit.* pp. 14, 17–18. MUN 5/382/1600/11 *op cit.* pp. 1–2, 4, 8.
- ⁹⁷ MUN 5/382/1600/11, *op cit.* pp. 2, 5–6.
- ⁹⁸ MUN 5/382/1600/11, *op cit.* p. 5.
- ⁹⁹ *Trench Warfare Supplies, op cit.* pp. 12, 18. MUN 5/384/1610/6 Record of History and Work Ministry of Munitions Trench Warfare Supply Department TW7(B) Supply of 3-inch Stokes bombs by Mr J Alexander, 16 June 1917 p. 4. The contracts placed through the Boards were not without their problems. See MUN 5/384/1610/16 Record of History and Work Ministry of Munitions Trench Warfare Supply Department TW3(D) Trench Howitzers and Ammunition by Mr W A Tanner, 11 June 1917, pp. 9–10.
- ¹⁰⁰ Inspection was remained a part of production and the Inspection Department at Woolwich still functioned as such.
- ¹⁰¹ MUN 5/385/1640/1 History of the Grenade Section, Trench Warfare Supply Department. See also MUN 5/382/1600/11, *op cit.* pp. 7–8.
- ¹⁰² The same was also true of the No. 16 Oval grenade. See graphs in MUN 5/385/1640/1, *op cit.*
- ¹⁰³ *Design and Inspection, op cit.* p. 95.
- ¹⁰⁴ *Op cit.* pp. 95–6.
- ¹⁰⁵ *Op cit.* p. 99.
- ¹⁰⁶ This raises the question of how GHQ had arrived at its ratio of the two mortars. A simpler demand would have been for 1000 medium mortars of unspecified pattern. However, the BEF was still feeling its way with mortars and no one knew which of the two would prove the superior design.

- ¹⁰⁷ *Trench Warfare Supplies, op cit.* p. 19. MUN 5/382/1600/10, *op cit.* p. 22.
- ¹⁰⁸ *Trench Warfare Supplies, op cit.* p. 19. MUN 5/382/1600/11, *op cit.* pp. 14–15.
- ¹⁰⁹ The bodies were cast by one firm while the centrepiece and mechanism were made by a second firm which also loaded the grenades. See *History of the Ministry of Munitions, Trench Warfare Supplies, op cit.* p. 19 and MUN 5/382/1600/10, *op cit.* p. 10.
- ¹¹⁰ *Trench Warfare Supplies, op cit.* MUN 5/382/1600/10, *op cit.* pp. 22–3.
- ¹¹¹ William H. McNeill *The Pursuit of Power*, (Chicago, pbk ed. 1984), p. 233. Interchangeability was not a given even when parts were seemingly identical. The levers of No. 5 Mills grenades were specific to individual grenades, once the grenades had been assembled in the factory. See contemporary precautions listed in Landers, *op cit.* p. 42.
- ¹¹² Commercial engineering firms became increasingly involved in munitions work of all kinds from about mid-1915.
- ¹¹³ *Design and Inspection, op cit.* p. 98.
- ¹¹⁴ MUN 4/2604 Memorandum on Grenades by General Jackson dated 14 September 1915 and his minute of 22 October 1915. *Trench Warfare Supplies, op cit.* pp. 48–9, 52–6, 74–6. MUN 5/385/1640/1, *op cit.* pp. 3, 11, 14, 15, 18, 21–2.
- ¹¹⁵ *Trench Warfare Supplies, op cit.* pp. 70, 79.
- ¹¹⁶ FW3 laid the foundation for use of commercial detonators and simpler systems. See MUN 4/2604, *op cit.*
- ¹¹⁷ *Trench Warfare Supplies, op cit.* Appendix XI pp. 130–1.
- ¹¹⁸ *Ibid.*
- ¹¹⁹ Such increases in output of munitions also applied to shells, of course; from 500,000 in 1914 to 76.2 million in 1917. See Ian F W Becket, *The First World War, The Essential Guide to Sources in the UK National Archives*, (London, 2002), p. 187.
- ¹²⁰ *Trench Warfare Supplies, op cit.* pp. 64, 81. Brothers, *op cit.* pp. 46–7. Landers, *op cit.* p. 78 regarding centrepieces for Mills No. 23.
- ¹²¹ As far as the bodies of grenades and mortar rounds were concerned, cast iron was superior to steel because of its better fragmentation characteristics. There was even experimentation with thermosetting plastics for some components. A thermosetting plastics is one which cannot be melted or dissolved in a solvent once it has been processed to make an object, eg, Bakelite, a phenolic resin that is heat and chemical resistant. Thermoplastics can be remelted and dissolved in solvents after they have been processed into an object. There were a few patented grenades in which plastics components were used. The term ‘plastics’ with the ‘s’ differentiates a synthetic polymeric material from plastic behaviour which can be exhibited by metals as described by Hooke’s Law.
- ¹²² The centrepiece of the Mills grenades is a case in point.
- ¹²³ For example, the centrepiece of the Mills No. 23 was made by several quite different processes, from casting as a single piece to fabricating from three separate but simplified components. The shape was also modified to simplify casting. There were many variations of manufacture. The variations related to attempts to solve a recurring problem of prematures caused by faulty centrepieces. See Landers, *op cit.* p. 78.
- ¹²⁴ Brothers, *op cit.* pp. 49–50.
- ¹²⁵ This worked well because of the simplicity of the devices. More complex devices presented a problem. The Farquhar-Hill automatic rifle, for example, was taken up in late spring 1918. It was planned to make the components in various new factories which would then be assembled in national workshops. However, the rifle was dropped before the scheme was implemented because the war was going to end before enough rifles could be produced for them to have an impact on operations. See *Review of State Manufacture, op cit.* p. 55.
- ¹²⁶ *Military Operations, 1915*, vol. 2, *op cit.* p. 7–9, including footnotes. Brothers, *op cit.* p. 40. ‘The Work of the Royal Engineers’, September 1924, *op cit.* pp. 449–50, and March 1925, *op cit.* p. 76. Colonel G H Addison, (ed.), *The Work of the Royal Engineers in the European War, Miscellaneous*, (Chatham, 1927), p. 255.
- ¹²⁷ It is worth noting that the BEF was provided with far superior technical support in the theatre of operations than either the French or Belgian armies, although the technical support available to the German army was comparable to that of the BEF. See Addison, *op cit.* p. 251.
- ¹²⁸ Few records of the First and Second Army Workshops survived the war. There are no records of what was produced and in what quantities before 1918.
- ¹²⁹ Addison, *op cit.* pp. 261–2.
- ¹³⁰ *Op cit.* pp. 261–2.
- ¹³¹ There were factories in base areas, such as at Merville, but these did not conduct research. They were French engineering firms taken over by the Royal Engineers. There were also Ordnance Workshops and Engineer Stores Workshops but these were not concerned with trench warfare munitions of the sort under discussion here.
- ¹³² Addison, *op cit.* pp. 261–2.
- ¹³³ ‘The Work of the Royal Engineers’, September 1924, *op cit.* pp. 454–5, 457.
- ¹³⁴ *Military Operations, 1915*, vol. 2, *op cit.* p. 7 footnote. Addison, *op cit.* p. 255.
- ¹³⁵ The so-called Indian pattern.

¹³⁶ *Military Operations, 1915*, vol. 2, *op cit.* p. 7 footnote. Addison, *op cit.* p. 255.

¹³⁷ Landers, *op cit.* p. 27.

¹³⁸ Display in Royal Engineers Museum, Chatham (2000). *Military Operations, 1915*, *op cit.* vol. 2, p. 7 footnote 1. McClintock was a firm advocate of the hand grenade and the rifle grenade. See Major R L McClintock, 'An Extemporised Hand Grenade', *The Royal Engineers Journal*, April 1913, pp. 193–200 and 'An Extemporised Rifle Grenade, The Bangalore "Universal" Grenade', *The Royal Engineers Journal*, November 1914, pp. 281–294. Both articles include details of materials, labour and costs. The hand grenade predated publication of the first article by at least a year and the rifle grenade, based on the hand grenade, predated the second article by some months.

¹³⁹ These are discussed in the next chapter.

¹⁴⁰ There was no consistency in the use of the singular or plural of 'Workshop'. Thus, that in the First Army area was a 'Workshop' while that in the Second Army area was a 'Workshops'.

¹⁴¹ Addison, *op cit.* p. 258.

¹⁴² *Ibid.*

¹⁴³ *Ibid.*

¹⁴⁴ L W de Grave, *The War History of the Fifth Battalion The Sherwood Foresters, Notts and Derby Regiment, 1914–1918*, (London, 1930), p. xiii. The publisher, Bemrose, was a former commanding officer of the battalion. The battalion entered the trenches at Ploegsteert in March and stayed in the Ypres salient until the end of September.

¹⁴⁵ According to the Addison, *op cit.* p. 258 the device was a rifle grenade aiming rest. The engineering drawings that were subsequently prepared by Sapper T Bazley in the Engineer-in-Chief's Office have drawing numbers which indicate that they were prepared after production of the devices had started and thus provide no clue about the chronology. However, Henry Newton wrote that it was a rifle battery (see Brothers, *op cit.* p. 28 in MUN 5/383/1600/14).

¹⁴⁶ In the Ypres sector.

¹⁴⁷ Brothers, *op cit.* p. 28 where Kimmel is misspelled as Kimmel. Addison, *op cit.* p. 258.

¹⁴⁸ At least one of Henry's brothers became an inventor; Frederick Newton invented a voltage regulator used in British aircraft during the Second World War. *The Derbyshire Advertiser*, 6 November 1959, p. 8, Frederick Newton's obituary.

¹⁴⁹ Henry Newton was a director of the company, an electrical engineering firm, which became a limited company in March 1915. He specialised in the non-electrical side of the engineering and the production side of the business, although he described himself as an electrical engineer (History of the Derby and Derbyshire Chamber of Commerce and Industry 1864–1995 at www.sdchamber.co.uk, accessed May 2005). See also BT 31/32204/139711 Newton Brothers Ltd. According to the recollection of Henry's son, H A B Newton, in 1999, Henry played no part in the running of the business during the war (H A B Newton, telephone conversation with the author, May 2000).

¹⁵⁰ Letter written by Ralph Goodwin, a former employee of Newton Brothers, dated June 1976 (courtesy of his daughter, Mrs Jan Baggaley).

¹⁵¹ *Military Operations, 1915*, vol. 2, *op cit.* p. 39.

¹⁵² The perspicacity of General Furse was applauded by former Brigadier-General A M Asquith in a letter to Newton in December 1927. Asquith had been briefly Controller of the Trench Warfare Department when Newton was a deputy controller (Newton dissertation). He was subsequently regarded in the USA as the most important British inventor of the war. In 1920, he was awarded the CBE for his 'inventive genius'. In May 1915, Henry Newton was 35. He was evidently energetic, helpful and accessible. See 'Trench Mortars in the Second Army' by Lieutenant-Colonel Sir John Keane, *The Ypres Times*, date unknown, p. 69 reproduced in part in the Newton dissertation. *The Ypres Times*, first published by the Ypres League in October 1921, is not to be confused with the *Wipers Times*, the trench magazine produced between 1916 and 1918.

¹⁵³ Captain Todhunter visited the Second Army Workshops at Armentières in June 1915 and was impressed with what he saw, especially the methods for manufacturing hand and rifle grenades, trench mortars and rifle grenade firing stands. He recommended to the School's commandant that similar workshops be established in Britain. Nothing came of this, however.

¹⁵⁴ Addison, *op cit.* p. 258. Brothers, *op cit.* p. 28.

¹⁵⁵ A typical day's output during the early summer of 1915 included: 200 single-mirror periscopes; fifty box periscopes; forty sniperscopes; rifle batteries; rifle rests; trench club heads; and machine-gun pivot mountings (Addison, *op cit.* p. 259). Most of these were of novel designs which originated in the Second Army Workshops. The bayonet periscope (not a true periscope as it had only one mirror) was a copy of a design called the Vigilant that had been patented in France in November 1914 (or at least, an application of that date was filed at the French patent office). This became the No. 18 periscope and remained in service throughout the war. It is questionable whether trench club heads or rifle rests would have been manufactured in Britain. Other devices produced by the Workshops included anti-aircraft mountings for machine-guns, anti-aircraft sights, sub-beds for trench mortars, beds for 2-inch mortars (devised by Newton), and a wide variety of stores unrelated to munitions but essential to life in the trenches.

- ¹⁵⁶ WO 140/14 Minute by Captain Todhunter, Experimental Officer at the School of Musketry, Hythe, dated 25 June 1915, following a visit to the Second Army Workshops.
- ¹⁵⁷ Newton dissertation, *op cit.* Brothers, *op cit.* p. 55.
- ¹⁵⁸ Addison, *op cit.* p. 259. ‘The Work of the Royal Engineers’, September 1924, *op cit.* p. 451. Brothers, *op cit.* pp. 41, 55.
- ¹⁵⁹ Addison, *op cit.* pp. 257, 259.
- ¹⁶⁰ Newton dissertation, *op cit.* This includes copies of comparative lists prepared either during the war or immediately afterwards, possibly in support of his claim before the Royal Commission on Awards to Inventors. See T 173/728 Minutes of the Proceedings before the Royal Commission on Awards to Inventors held on Monday 17 November 1924, Claim of Colonel Newton.
- ¹⁶¹ T 173/728, *op cit.* p. 10.
- ¹⁶² Addison, *op cit.* p. 260.
- ¹⁶³ It is not known when this peak occurred.
- ¹⁶⁴ Addison, *op cit.* p. 260.
- ¹⁶⁵ Addison, *op cit.* p. 261. This includes seven officers, a warrant officer, eleven sergeants and 112 other ranks. A further eighteen other ranks were also attached.
- ¹⁶⁶ Addison, *op cit.* p. 261.
- ¹⁶⁷ The existence of the Workshop Companies was brief, as the German spring offensives of 1918 disrupted them, forcing three to retreat without their heavy machinery. All but one of the Companies managed to regenerate themselves but, by spring 1918, their importance had declined.
- ¹⁶⁸ Output focused on wooden beds for medium and heavy trench mortars, machine-gun pivots and mountings but by far the greatest output was trench boards, panels and frames; mining timbers; and related metalwork. Demands for such items remained high throughout the war. See Addison, *op cit.* pp. 266–8.
- ¹⁶⁹ Strictly speaking, output is the number produced, including rejections. If the rejection rate was 100 per cent, nothing would be delivered. Since, in the present context, deliveries of acceptable munitions are of interest rather than the percentage of production that was delivered, output is used here to mean deliveries rather than production. The data which is available in contemporary files was usually compiled from deliveries.
- ¹⁷⁰ Production and output of novel munitions during the First World War has not been discussed hitherto. The subject can only be touched upon here but it deserves a much more detailed examination.
- ¹⁷¹ *Military Operations, 1915*, vol. 2, *op cit.* p. 7. These would have been No. 1s.
- ¹⁷² *Ibid.*
- ¹⁷³ High explosives are useless without a suitable detonator and different types of detonator are required according to the characteristics of the explosive.
- ¹⁷⁴ MUN 4/2604, *op cit.*
- ¹⁷⁵ TNT is 2,4,6-trinitrotoluene $C_6H_2(CH_3)(NO_2)_3$; lyddite (named after Lydd in Kent where it was tested) is compressed picric acid, 2,4,6-trinitrophenol, $C_6H_2(NO_2)_3OH$ (toluene and its precursor benzene have ring-like structures of six carbon atoms; the numbers refer to the positions on the ring where the nitro groups $-NO_2$ are attached, which affects chemistry).
- ¹⁷⁶ Ammonal is a mixture of powdered aluminium and ammonium nitrate NH_4NO_3 (hence its name) used commercially for mining and pyrotechnics. Military ammonal consisted of 65% ammonium nitrate, 15% TNT, 17% aluminium, 3% charcoal. Its use in munitions paved the way for the widespread military use of other ammonium nitrate explosives during the war. These included amatol, a 50 : 50 mixture of ammonium nitrate and TNT; and Roburite, a mixture of ammonium nitrate and dinitrochlorobenzene or dinitrobenzene.
- ¹⁷⁷ MUN 5/382/1600/8 Notes on the History of Trench Warfare Research, Aug 1914 – May 1915 dictated by General Louis Jackson, December 1917.
- ¹⁷⁸ *Trench Warfare Supplies*, *op cit.* pp. 76–7.
- ¹⁷⁹ *Op cit.* p. 74–5.
- ¹⁸⁰ MUN 4/2604, *op cit.* *Trench Warfare Supplies*, *op cit.* p. 74. See also MUN 5/197/1640/5 Production of Grenades.
- ¹⁸¹ MUN 4/2604, *op cit.*
- ¹⁸² *Ibid.*
- ¹⁸³ *Ibid.*
- ¹⁸⁴ *Ibid.*
- ¹⁸⁵ *Ibid.*
- ¹⁸⁶ MUN 5/197/1640/9 Copy of Ordnance Board minutes relating to hand grenades.
- ¹⁸⁷ MUN 4/2604 letter from Maxwell to Army Council, 4 September 1915. This was a percussion grenade made by a Paris firm and used by the French army.
- ¹⁸⁸ *Trench Warfare Supplies*, *op cit.* p. 3. SUPP 28/40 Card index of Ordnance Board minutes relating to grenades. See OB12966 (4 March 1915).
- ¹⁸⁹ MUN 4/2604 Memorandum on Grenades, *op cit.*
- ¹⁹⁰ MUN 4/2604 calculated from figures in letter from Maxwell dated 27 August 1915 (120 percussion-fuzed grenades per day per division; 48 divisions for 30 days); Memorandum on Grenades for 570,000.

- ¹⁹¹ MUN 4/2604, Memorandum on Grenades, *op cit.*
- ¹⁹² MUN 4/2604, Minute *op cit.*
- ¹⁹³ Addison, *op cit.* p. 255.
- ¹⁹⁴ *Op cit.* p. 256.
- ¹⁹⁵ These were Newton Pippin rifle grenades, invented by Henry Newton.
- ¹⁹⁶ Addison, *op cit.* pp. 256–7.
- ¹⁹⁷ The impact-mechanism version of Newton’s hand grenade was similar to his rifle grenade. However, the mousetrap-mechanism version of his hand grenade was quite different. All were called Newton Pippins.
- ¹⁹⁸ Addison, *op cit.* p. 261.
- ¹⁹⁹ *Ibid.*
- ²⁰⁰ Brothers, *op cit.* p. 56. *Trench Warfare Supplies, op cit.* p. 82.
- ²⁰¹ Newton dissertation, *op cit.* See also *Textbook of Small Arms*, (London, 1929), p. 107.
- ²⁰² MUN 5/385/1640/1 graph of Ball grenade production. *Trench Warfare Supplies, op cit.* Appendix XIII The Output of Grenades, pp. 134–5.
- ²⁰³ Like the No. 15, it was a stopgap. It used the same No. 8 Mk VII igniter as the Ball grenade and suffered from the same problems as the Ball.
- ²⁰⁴ *Trench Warfare Supplies*, Appendix XIII, *op cit.*
- ²⁰⁵ Brothers, *op cit.* p. 48.
- ²⁰⁶ *Trench Warfare Supplies, op cit.* Appendix X The Output of Trench Mortars and Special Weapons and Appendix XI The Output of Trench Mortar, and Special, Ammunition, pp. 130–1. *Military Operations, 1915*, vol. 2, *op cit.* p. 8. There appear to be no figures for the output by Royal Engineer sources in France for this period, although, according to the ‘The Work of the Royal Engineers’, March 1925, *op cit.* p. 76, no mortars were received from Britain until March 1915. This does not include the improvised 4-inch mortars devised at Woolwich in late 1914.
- ²⁰⁷ *Trench Warfare Supplies*, Appendix X, *op cit.*; see also a less precise figure of 11,000 cited on p. 2 of Stokes’s claim submitted to the Royal Commission on Awards to Inventors on 3 May 1921, *op cit.* in T 173/453.
- ²⁰⁸ *Trench Warfare Supplies*, Appendix X, *op cit.*
- ²⁰⁹ *Ibid.*
- ²¹⁰ *Ibid.* all figures.
- ²¹¹ A round of mortar ammunition is conventionally called a bomb rather than a shell.
- ²¹² *Trench Warfare Supplies*, Appendix X and Appendix XI, *op cit.*
- ²¹³ *Trench Warfare Supplies*, Appendix XI, *op cit.*
- ²¹⁴ *Ibid.* all figures.
- ²¹⁵ The spherical head was 9.25 inches in diameter and contained 12.25 lb of explosive. The tail was made from weldless solid-drawn steel tubing. See MUN 3/384/1610/2, *op cit.* p. 4.
- ²¹⁶ *Ibid.*
- ²¹⁷ *Weapons of the Trench War, op cit.*, p. 82; *Dominating the Enemy, op cit.*, p. 88; BT 31/22958/141366.
- ²¹⁸ E A G Robinson, ‘The Overall Allocation of Resources’ in D N Chester, *Lessons of the British War Economy*, (Cambridge, 1951), pp. 34–57.
- ²¹⁹ The question of technical advancement is discussed in the next two chapters.

5 Inventing Grenades

Although the novel devices that are the subject of this thesis have been put into an historical context with respect to the American Civil War and the Russo-Japanese War, their effectiveness as munitions in the First World War has yet to be discussed. While invention, both as a process and as a product of that process, has figured in the preceding chapters, these munitions have yet to be considered from what is, perhaps, the most important perspective, namely, how they worked. In other words, the matters of functionality, utility and reliability of these munitions have yet to be considered in respect of what might be termed the real world, namely the Western Front. They not only had to work but they had to do so in the conditions of the Western Front when handled by soldiers under fire. Such practical considerations are often overlooked in discussions about military technology. This chapter and the next address these matters by considering the technical features of these munitions in the context of the soldiers who had to handle them. The present chapter is concerned with grenades while the following chapter considers mortars.

The object of this chapter is not to provide a comprehensive technical history of all grenades used by the BEF. Rather, it has two objects: firstly, to highlight specific technical aspects of selected munitions to illustrate the complexity of the processes of invention and development; and, secondly, to highlight the advantages that specific technical features conferred on a device.

Although it has been implicit in all the preceding discussion that such munitions were effective and that they did, indeed, satisfy the BEF's requirements, it cannot be assumed that the novel munitions provided to the BEF performed adequately merely because they were supplied in large numbers. Such an assumption fails to acknowledge the fact that all of them were imperfect when initially supplied, that many troop trials were undertaken with munitions which, ultimately, were not adopted for service, and that failure played a significant role in the process of selection.

This, of course, raises the question of why this was the case. The situation was certainly exacerbated by the necessity of development and operational use occurring concurrently rather than sequentially but that was not the sole reason.¹ There is a tendency to attribute blame when imperfect munitions first appear on the battlefield because it is presumed that someone must have been at fault for the failure to provide better ones. This is partly because the processes of invention and development are not examined, thereby allowing the assumption that perfected munitions are routinely introduced to the battlefield to remain unchallenged.² This may be termed the perfected weapon principal.

In this context, introduction means first appearance, which may be taken as covering a period of time rather than being a specific date. The length of such a period is, of course, open to argument. It may be a matter of days, weeks, months or even years. Indeed, it

might even be decades. It serves no purpose to attempt to arrive at an arbitrary definition of 'a period of time' since its length varies according to what is being discussed. It can be argued, for example, that the manually operated bolt-action rifle had an introductory period of about sixty years, that the tank had an introductory period of several months, while cylinder-released poison gas was introduced in a single day.

Geography plays a part in such a definition since a weapon may be introduced in one part of the world yet be unknown somewhere else. The hand grenade is a good example. It appeared in Europe 600 years after its invention in China.³ It can be argued that poison gas was first used on the Eastern Front in January 1915.⁴ However, lethal gas was first released from cylinders against the French at Ypres in April 1915.⁵ To a large extent, the definition is dependent on the criteria being applied as well as on the nature of the technology concerned. As far as the devices under discussion here are concerned, introduction can be taken to mean a period that varied between a few weeks and about a year. This is complicated by the fact that, during 1915, the operational life of the stopgap patterns of hand grenade was brief, lasting no more than months, so that the introductory period coincided with the service lifespan.⁶ On the other hand, the Mills No. 5 hand grenade was introduced over a period of almost a year from about April 1915 to about March 1916 but was declared obsolete at the end of 1916.⁷ The year-long introductory period was almost entirely due to manufacturing problems.

It can be argued that no perfected weapon, irrespective of how simple or complex it might be, has ever been introduced to the battlefield. It is the imperfection of weapons which encourages their improvement and development. Many of the shortcomings of new munitions do not become apparent until they have been used operationally for some period of time, partly because soldiers do things which designers and inventors have not anticipated and it takes time for a body of evidence to accumulate. It is unreasonable, then, to assume that, at any given time, the weapons in use by armies are perfected since development is a continuous process and stasis does not occur. Slowness of change should not be mistaken for lack of change any more than rapid change should be mistaken for technological failure.

Addressing the technical–tactical relationship

Irrespective of political interference, no munition was adopted by the BEF during the First World War purely on the basis of unqualified approval of it by a politician. Had the Stokes mortar proved to be inefficient, it would have been abandoned, irrespective of Lloyd George's intervention. The previous chapter has already demonstrated that evaluations of munitions were conducted scrupulously by those charged with the task. Ultimately, neither corruption nor political interference affected which munitions entered service. The outcome of operations depended on the usefulness of the munitions employed; it was in no one's interest to accept substandard munitions if something better was available. Although, as far as novel munitions were concerned, compromises were often necessary even as late as 1916, these were made for expediency and were only ever viewed as such by all concerned.⁸ The intention was to provide the BEF with sufficient numbers of stopgaps to allow time for the development

and manufacture of better munitions. As discussed in Chapter 4, it took time to set up the mass production of new munitions and, if production problems had to be solved, it could be many months before a significant number of the new munition became available to the BEF. Hence, the improvisations of 1914 and 1915 should be viewed in this light, rather than as a consequence of someone having failed to do his job of providing better munitions. This did not mean, however, that the awaited munitions would be flawless when they went into service. Neither is it appropriate to suggest that hasty development led to flawed munitions. On the contrary, hasty development led to the premature introduction of underdeveloped munitions.

Operational failures due to the inutility and unreliability of munitions should neither be disregarded nor attributed to other factors, however. The question of how much blame should be attached to the use of imperfect munitions in what proved to be unsuccessful operations is unanswerable and ultimately uninformative; it is not the purpose of this thesis to attempt to provide an answer. Indeed, it would be a simplistic approach to a complex matter. Moreover, imperfection is not synonymous with faultiness which is an entirely different issue, although sometimes there is but a fine line between them. Nevertheless, the lack of a definitive quantifiable answer to the matter of blame should not obscure that fact that inadequate munitions did cause serious operational difficulties. The failure of the No. 15 Ball grenades at Loos in September and October 1915 was an equipment failure not a human failure on the part of the soldiers using them.⁹

All this raises the question of the relationship between the technical characteristics of munitions and the development of tactical systems for their use and, indeed, the issue of whether inutility and unreliability hindered the operational usage of novel munitions by the BEF in the First World War. In the American Civil War and again during the Russo-Japanese War, this was certainly the case as far as hand grenades were concerned. They were only ever used piecemeal because they were unreliable. This scenario was repeated on the Western Front during the opening stages of trench warfare with every prospect that it would continue so long as trench warfare continued. Thus, not only did the BEF have no tactical system for about a year but there was no sense that one was needed.¹⁰ From this, it is clear that novel munitions did not figure prominently in the minds of either tacticians or operational planners until about mid-1915. The question is, then, what changed? Why did grenades and mortars become important, tactically and operationally? The simple answer is that technical improvements allowed these munitions to be used in ways that no one had envisaged hitherto.

The question of whether there was a direct relationship between the engineering design of such munitions and how they were handled, the proficiency users achieved in handling them under operational conditions and the development of tactics, can only be addressed by first examining the technical characteristics of the munitions. The assumption that all similar-looking munitions worked in the same way with the same level of utility and reliability does not stand up to scrutiny. The technical characteristics of a munition define its utility, functionality and reliability.¹¹ These characteristics, in turn, define efficiency, a measure of military usefulness, which affects operational experience and the development of tactical

systems. Efficiency is a nebulous concept and needs clarification. Clearly, the higher the utility, functionality and reliability of a device, measured either qualitatively or quantitatively, the more efficient it is. These characteristics do not necessarily work cooperatively, however, but can work competitively because of practical considerations relating to manufacturability and to cost-effectiveness, measured both in terms of cost per unit and in terms of lethality per unit. Lethality is an important concept in relation to munitions and has operational, tactical and technical components. While these characteristics inform efficiency, at the same time, efficiency also informs utility, functionality and reliability in a feedback loop. This is a complex relationship which, if it were presented graphically, would show an area bounded by the curves representing these characteristics rather than a single point of intersection by the curves. It follows, then, that efficiency is not a fixed value but a range of values. Thus, efficiency may be defined as an optimum compromise between utility, functionality, reliability and manufacturability, wherein a device performs what is required of it within a range of operational conditions.

Grenade types

It is useful at this point to discuss briefly the different types of hand grenade and rifle grenade used by the BEF on the Western Front during the First World War. Hand grenades may be categorised according to their operating mechanisms: time-fuzed and percussion-fuzed. Time-fuzed mechanisms may be subdivided according to the method of ignition, namely, match-lit¹², friction-lit and mechanically lit devices. Mechanical ignition was known as automatic ignition because the bomber did not have to do anything to light the fuze other than remove a safety pin and throw the grenade, whereas match-lit fuzes were ignited by a flame, while friction-lit fuzes worked on the same principal as a vesta. At the time of the First World War, mechanically lit devices were innovative, whereas match-lit devices were well known and friction ignition was known to artillerymen. The novelty of mechanical ignition is at the heart of this discussion.

Mechanically lit devices may be further subdivided according to the type of mechanism: striker and lever, of which the Mills type was a typical example; impact, whereby the bomber struck the head of the grenade on a hard surface, such as the sole of his boot, to ignite the fuze; rotary or mousetrap; and miscellaneous.¹³ A hybrid type, which could be thrown by hand and fired from a rifle, was developed from the end of 1915. These could be percussion-fuzed or time-fuzed devices. Hand grenades can also be categorised according to whether they had a high-explosive or chemical filling. Chemical fillings varied from lachrymatory compounds for clearing dugouts to white phosphorus to produce smoke.¹⁴ Only high-explosive hand grenades are discussed here.

The functional difference between a time-fuzed device and a percussion-fuzed device relates to what happens when the mechanism is activated. Thus, the former has a fuze ignited by a striker hitting a percussion cap which detonates and lights a length of safety fuze which burns for a specific length of time before firing the detonator, while the latter has no such safety fuze so that the detonator is fired immediately the cap is hit by the striker.¹⁵ The lack of a time delay with

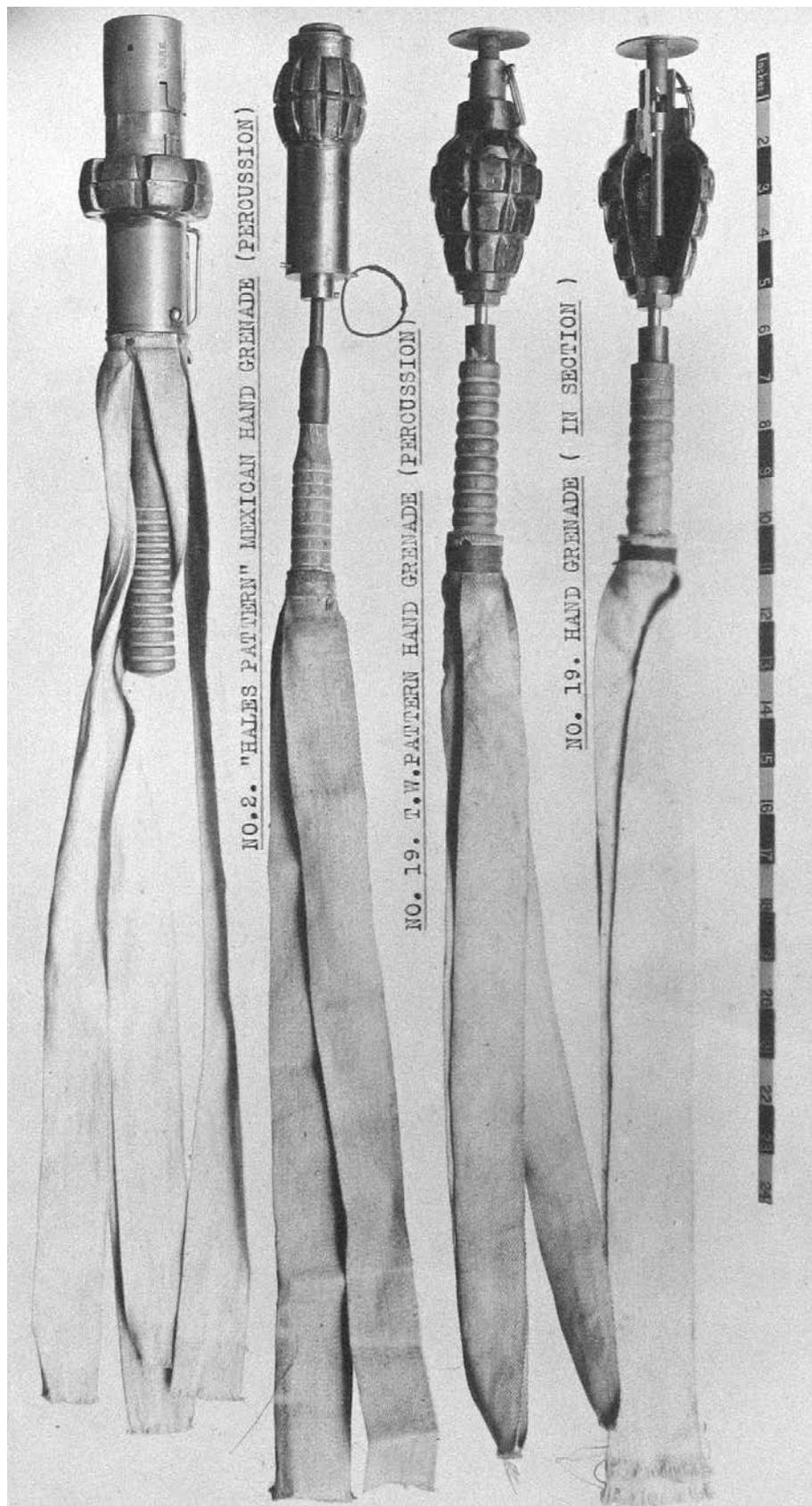


Fig. 21 Percussion-fuzed grenades with short handles. The shorter handles were supposed to make them safer to handle in a trench. Left to right: No. 1 Mk III, No. 2, No. 19 and sectional view of a No. 19. Note the length of the webbing tails which were intended to act as drags on the grenade so that it landed headfirst (MUN 5/383/1600/14)

percussion-fuzed mechanisms means that safety features have to be incorporated in order to prevent accidental detonation. A percussion-fuzed mechanism also requires a means to arm it automatically, independently of the bomber and only after it has left his hand. Percussion-fuzed grenades are inherently more dangerous than time-fuzed grenades and consequently require more complex mechanisms to render them safe yet efficient. Such mechanisms were innovative at the time of the First World War.

Rifle grenades may be categorised as three types: those fitted with a rod, which was inserted into the rifle barrel in order to launch the grenade; those without a rod and fired from a cup discharger attached to the rifle muzzle; and a transitional type which was fired from a cup attachment¹⁶ with the aid of a rod. The cup attachment grew out of the need to retain the lever of a rodded Mills grenade prior to launch. Rifle grenades may also be subdivided into time-fuzed and percussion-fuzed devices. They may also be classified according to their content: explosive grenades and signal grenades. The latter carried a pyrotechnic composition in a container fitted with a parachute. They were designed to explode in the air and therefore had to fulfil quite different engineering requirements from those of explosive-filled grenades. Only the latter are discussed here.¹⁷ Like the hand grenade, the explosive rifle grenade was an anti-personnel weapon, although an anti-tank version was devised towards the end of the war.¹⁸ The first workable rifle grenade, invented by Marten Hale in 1908,¹⁹ was a rodded grenade with a graze fuze²⁰ and included, from 1911, a rotatable-vane safety device.²¹ The majority of rodded rifle grenades used by the BEF throughout the war were of the Hale type; its complicated safety mechanisms were greatly simplified in successive patterns.²²

The cup discharger used by the BEF was invented in 1916 by a New Zealander of the Mechanical Transport Workshops, Lieutenant Robert Burn, who patented it in Britain in February 1917, although it was arguably a re-invention of a device that dated from the seventeenth century.²³ It was in use on the Western Front by the autumn of 1917 but did not see widespread use until the spring of 1918. The device fired the No. 36 Mills, fitted with a gas-check disc and without the need for a rod. Approximately 256,000 were supplied to the BEF before the end of the war.²⁴

Utility of purpose

As discussed in Chapter 1 of this thesis, utility concerns the fitness of a device for the purpose for which it is intended. Utility is, of course, conceptual, rather than an absolute; there is no thing and no process that is the definitive embodiment of utility. Variables such as the success rate of the device in an operational environment may be related to the unit cost of manufacture, unit cost to operate, and unit cost to train its operators in its use; it is dependent upon the criteria pertaining. All inform utility. Here, we are principally concerned with fitness for purpose: did the device do the job required of it? Although functionality and reliability will be discussed later, these characteristics are, of course, interdependent. However, for the sake of clarity, it is simpler to deal with them separately rather than together.²⁵

There is no definitive method by which utility may be quantified since it is a ratio of practicality with respect to an arbitrary specification which is, in effect, no more than a

list of desiderata and may be changed according to different criteria which are themselves dependent upon circumstances. Moreover, it is related to perception. What seems useful to one person may seem useless to another. Utility of a given device has to be related to the criteria pertaining at the time, not to some arbitrary re-evaluation based on hindsight. Determining what those criteria were at any given time during the First World War is complicated by the fact that, for much of the war, there was no consensus of opinion on grenades.²⁶ Thus, the percussion-fuzed hand grenade was viewed as the ideal type because time-fuzed grenades did not explode until the time delay fuze had been consumed.²⁷ Although the British were forced to abandon percussion grenades in May 1916 because production could not keep up with demand and because of difficulties in handling them in trenches, development of such devices continued throughout the war. Troop trials were conducted with several promising devices but the British army did not re-adopt a percussion-fuzed hand grenade until 1923.²⁸

Despite the dominance of time-fuzed hand grenades during the war, by 1918, an extensive specification had been drawn up for percussion-fuzed grenades.²⁹ No similar specification was ever created for time-fuzed devices. This was partly because a great deal of thought had gone into the means by which a percussion-fuzed grenade could be made as reliable and safe as the Mills patterns. The latter were viewed as interim measures until a safe and reliable percussion-fuzed device could be introduced, despite the fact that, by mid-1916, the time-fuzed Mills grenade had become the standard British hand grenade. However, the proliferation of the Mills effectively stifled development of anything that might be better simply because of the disruption the adoption of a replacement would cause.³⁰ Before the Mills, time-fuzed grenades with manual ignition were renowned for poor performance.³¹ The friction lighter devised by the Royal Laboratory in early 1915 for the Nos 6 and 7 grenades was a case in point.³² A friction bar was pulled, by means of a wire loop, through a tube coated with a match composition. Bombers found that the grenade had to be gripped between their knees so that they could pull the loop with both hands which meant that the wire cut into their fingers.³³ The poor view of time-fuzed grenades was reinforced by the fact that the early mechanical systems were no better than the match-lit and friction-lit systems they were intended to supersede. Typical of these was Arthur Roodhouse's grenade, the subject of British patent GB4392/15. It had a striker and lever mechanism in which the lever was pivotally attached to the end of the striker so that it did not fly off when released, unlike the lever of the Mills grenade and, indeed, all successful striker and lever mechanisms.³⁴ It was tested but rejected by the DoA in early 1915 because it was too flimsy and prone to failure.³⁵

There was an inherent flaw with the early percussion-fuzed grenades: in order for the fuze to operate, the mechanism had to hit a hard surface and this required, among other things, a very sensitive fuze. The fuze of the No. 2 percussion grenade was so sensitive that any sudden movement could detonate the grenade after it had been armed.³⁶ On the other hand, if the ground was soft and muddy, a direct-action impact fuze often failed to function. Moreover, without some form of all-ways functionality, a percussion mechanism was likely to fail because of the infinite variety of ways in which a grenade might land; there was no guarantee that it would land in such a way that the fuze would function. This led to

the development of a crude all-ways mechanism by the TWD which was used in a stopgap percussion-fuzed hand grenade, the No. 19.³⁷ It saw limited use with ANZAC troops in France during the spring and summer of 1916 but it was not a success.³⁸ A mushroom-shaped extension to the striker tail provided the all-ways functionality.³⁹ The No. 19 resembled the percussion grenades of the nineteenth century and its utility was no improvement on them. By 1917, percussion-fuzed grenades had to be capable of being fired from a cup discharger.⁴⁰ Thus, the criteria of 1914 were not those of 1916 nor, indeed, those of 1917.

During 1915, nine patents were granted in respect of percussion-fuzed hand grenades⁴¹ but these were often quirky inventions and included wheel-like grenades which could be rolled along the ground, doubled-walled grenades that resembled the Haynes Excelsior of 1864, and devices with eccentric weights arranged to provide an all-ways functionality but without adequate safety means. During 1916, the number of patents relating to percussion-fuzed hand grenades rose to twenty-nine.⁴² The majority had complex mechanisms which mitigated against reliability. In 1917, the number of patents fell to ten while in 1918 there were only five. Throughout the war, more patents were granted in respect of percussion fuzes for hand grenades than were granted for time-fuzed hand grenades.⁴³ This reflected the greater complexity of percussion-fuzed devices which allowed a wider range of engineering approaches to tackling the problems of reliability and safety, compared to time-fuzed devices which were simpler with a more limited range of engineering options regarding functionality; the mechanisms of most time-fuzed hand grenades devised since the First World War are derived from those invented between 1915 and 1917.⁴⁴ This also reflected the fact that no one managed to devise a reliable and safe percussion mechanism for a hand grenade.

Not all inventors were British nationals, of course. During the course of the war, British patents in respect of hand grenades were also granted to Belgian, Danish, French, Italian and American inventors and most, if not all, were evaluated.⁴⁵ However, all grenades used by the BEF were British inventions.⁴⁶ It would be disingenuous to ascribe this to British superiority in matters of engineering, especially when the general view among the public at the time was of German engineering superiority.⁴⁷ Whenever foreign inventors came up with something that no British inventor had devised, the devices were evaluated and sometimes adopted. The hydraulic interrupter gear, invented in 1916 by George Constantinesco, a Romanian engineer, for firing machine-guns through propeller blades is a case in point; it saw widespread use by the RFC and RAF by the end of the war.⁴⁸ The adaptation of a French 240 mm heavy mortar for British service in 1916 was another prominent example.⁴⁹ However, no grenade invention by foreign nationals proved to be superior to what British inventors devised.

Many inventors of grenades, British and foreign, failed to grasp the fact that any device that was going to be handled by soldiers in stressful situations needed to be robust so that it did not detonate accidentally because of mishandling. It was the failure to satisfy this requirement that resulted in many inventions being rejected.

In reality, the time-fuzed hand grenade was the dominant type during the First World War because effective safety mechanisms were easier to devise for them than for percussion devices. The utility of any grenade was dependent on its safety mechanism. The utility of the

Mills No. 36 of 1918 was significantly higher than that of the Mills No. 5 of 1915 while that of all percussion-fuzed grenades remained unacceptably low throughout the war. Indeed, the utility of the No. 36 was such that it remained in British service until the early 1970s, essentially unchanged since 1917.⁵⁰ The No. 36 did what was required of it, producing a lot of lethal fragments on detonation. This grenade was probably one of the most lethal hand grenades ever devised.⁵¹ It suffered few blinks and was safe to handle under operational conditions.⁵² Even the No. 34, designed at the request of GHQ to counter the threat posed by the German egg grenade⁵³ which could be thrown further than the heavier Mills, could not match the Mills because it was less lethal.⁵⁴

The stopgap grenades of 1915 only had to satisfy simple requirements, namely, that they were easy to manufacture and that they exploded more frequently than they were blind. In essence, the overriding criterion was availability; safety was a secondary consideration. Thus, the improvised match-lit grenades, and their re-engineered alternatives of late 1914 and early 1915, were unsophisticated and little different from the improvised grenades of the Russo-Japanese War. Indeed, all of the stopgap grenades of 1915 were of low utility. Bombers were generally pitied by the rest of the infantry because these grenades were as likely to kill or injure the bomber as they were to incapacitate the enemy, a situation made worse by the fact that each pattern required a different handling procedure which increased the opportunity for mistakes and consequent accidents. The Nos 13 and 14 Pitcher grenades⁵⁵ were so dangerous that the bombers armed with them acquired the unenviable sobriquet of the Suicide Club.⁵⁶ If its fuze assembly had not been properly secured in place by the bomber, it was jerked out of the grenade when he pulled the friction-ignition strip.⁵⁷ Inevitably, the fuze was fired when this happened so that the thrower's hand was severely injured by the exploding detonator. Alternatively, the strip might not tear away as intended, leaving the thrower uncertain as to whether the grenade had been fired.⁵⁸ Under these circumstances, the bomber often failed to throw the grenade which then detonated in his hand. The third possibility was that the strip tore away but failed to ignite the grenade, leaving it blind but still dangerous. These deficiencies led to a lot of accidents,⁵⁹ some of them fatal.⁶⁰ The Pitcher had such a low utility that it was quickly withdrawn by GHQ.⁶¹

The situation was little different with rifle grenades. A rifle grenade effectively turned an infantry rifle into a small artillery piece, albeit of limited range, accuracy and power,⁶² and thereby provided the infantry with what in a later age would be termed a close-support weapon, the first time that the infantry was so equipped. The rifle grenade was an inherently imperfect system, however. Accuracy decreased with increasing range, partly because of the angular error⁶³ but also because it was intrinsically inaccurate because of its unstable flight characteristics and its susceptibility to the effects of wind, while the payload was small in comparison with that of an artillery shell. A Newton Pippin rifle grenade was charged with 2.25 oz of explosive,⁶⁴ while the No. 24, an improved Hale type, was charged with as little as 1.5 oz;⁶⁵ an 18-pounder HE shell was charged with 13 oz.⁶⁶ Whereas the rifle grenade could be directed by infantry at local targets of opportunity, the rods were heavy and awkward to carry so that they were a considerable burden for rifle grenadiers during any kind of advance,

whether as part of an offensive or during a raid.⁶⁷ Moreover, any rifle used for firing grenades could not then be used to fire ball ammunition.⁶⁸ Thus, specific rifles had to be allocated for firing rifle grenades, rather than any handy rifle being used as the need arose. This meant that rifle grenadiers were unable to defend themselves in a raid, for example, and relied on conventionally armed infantry for support.

The rod of the Hale type of rifle grenade served two purposes: it enabled a grenade to be fired from a rifle and it acted as a tail when the grenade was in flight. Paradoxically, while it was essential to the utility of a rifle grenade, it was also detrimental to it. The rods contributed nothing to the destructive effect⁶⁹ but consumed a great deal of steel. A longer rod increased the range of the grenade because the propellant gases acted on it for longer than on a short rod, thereby increasing the velocity of the grenade. The length of rod was originally determined according to the amount of recoil the shooter could withstand when firing from the shoulder.⁷⁰ The longer the rod, the greater the recoil; 10 inches was found to be the longest that was comfortable.⁷¹ However, rods were usually 11 inches or 15 inches because of range considerations although grenades fitted with rods of these lengths were rarely fired from the shoulder.

When the gases hit the tail of the rod, a pressure wave was reflected back towards the breech. This substantially increased the pressure in the barrel as the wave travelling down the barrel was additive; the barrel bulged momentarily under the excess pressure. The shorter the rod, the greater the strength of the reflected wave and the greater the excess pressure.⁷² Thus, in general, the shorter the rod, the shorter the lifespan of the barrel. This was a good reason for not firing ball ammunition from a rifle which had been used to shoot grenades. It was proved that a rodded rifle grenade could be fired with a bulletted round but it was risky. The principal was subsequently used with a 2.5-inch discharger fitted to a rifle breech mechanism in which form it was known as the MID Grenade gun. This was fitted to the tail of Handley-Page bombers and in some tanks.⁷³ Firing rifle grenades put much more stress on the whole rifle than it was intended to withstand. The consequence was that it became unsafe after a finite number of shots. If the barrel did not burst, the heavy recoil of discharging a grenade eventually shook the rifle to pieces.⁷⁴ The effect of recoil on the rifle was accentuated when the grenade was launched with the rifle's butt pressed firmly against the ground since the shock was reflected from the ground back into the rifle.

The rod was a poor flight stabiliser.⁷⁵ In flight, the grenade was usually aligned tangentially to its trajectory, head first. However, it often slewed due to the rod whipping as it left the barrel.⁷⁶ Although the oscillations diminished into the flight, they adversely affected range.⁷⁷ Sometimes, the grenade tumbled in flight so that it landed rod-first which prevented the grenade's mechanism from working.⁷⁸ The capability of a grenade to land head first was dependent on the weight distribution in the body: the further forward it was, the greater the likelihood of the grenade landing on its striker mechanism.⁷⁹ If the rod was not mounted axially on the body, the rod became bent as it left the barrel which adversely affected flight and range. The rod was problematical in other ways. It had to fit the bore of the barrel such that it was neither too tight nor too loose: too tight and it might jam; too loose and propellant

gases escaped past it.⁸⁰ The fit of a rod in the barrel always had to be checked before screwing it into the grenade; if it was adjudged to be incorrect, the rod was discarded, which meant that spares had to be carried.⁸¹ Range was dependent on three factors: obturation, angle of fire, and the propellant. Poor obturation and excessive windage could reduce the range of a rifle grenade by as much 62 per cent.⁸² The aerodynamics of the grenade had little effect on range.⁸³ Range varied considerably; approximately 100–400 yards. Typically, the maximum range of the No. 3 was 200 yards, while that of the No. 22 was 350 yards.⁸⁴ A firing angle of 45° gave the greatest range for any given grenade, rod length and cartridge. These variables were only partially understood before the war.

In 1915, the requirements of a rifle grenade were that it not explode prematurely on launch, that it travel a reasonable distance and that it detonate when it arrived at the target. Unfortunately, the Hale type often failed all these requirements despite the fact that it had been in existence since 1908. Hitherto, improvement of the device had lacked the impetus of war and, thus, had been at the mercy of Marten Hale and his patent portfolio which now hindered development by anyone else.⁸⁵ Its complex manufacture and its special detonator ensured that only relatively small numbers were available in 1915, all of which adversely affected its utility. It was prone to prematures and blinds, and it lacked an all-ways functionality.⁸⁶ Many of these defects were overcome by the Newton Pippin rifle grenade, a far simpler device. The Pippin's body was cast iron, rather than the machined steel of the Hale, while its detonator was a modified SAA cartridge, rather than one which had to be manufactured specially.⁸⁷ The Newton Pippin's fuze mechanism had only one moving part, the functionality of which enabled it to act as both a striker and, in cooperation with lugs on the body exterior, as a safety device.⁸⁸ Its blunt-headed shape pushed the centre of gravity closer to the head than the centre of gravity of the Hale; this ensured that the grenade landed head-first.⁸⁹

The striker plate extended over the entire face of the head and was turned over its edge, thereby allowing the plate to have the maximum strength for the minimum thickness; the turned-over part acted as a stiffener.⁹⁰ It also ensured that the plate was forced downwards irrespective of the angle of impact, even on soft ground, although this required that the plate was a loose fit. Thus, the shape of the grenade and the design of the striker plate provided an all-ways functionality. The Pippin's striker was short whereas that in most percussion-fuzed grenades was long.⁹¹ The short striker meant that the angular force acting on it when the grenade hit a surface at any angle was, in effect, a normal force. This was aided by the tip of the striker being conical which made the striker self-centring.⁹² The thickness of the plate and, hence, its weight were also crucial to the efficient functioning of the mechanism: too thin and it was deformed on impact so that it failed to deliver a sharp blow to the cap to detonate it; too heavy and the plate set back on launch and caused a premature.⁹³ It is unclear whether Newton calculated the size and thickness of the plate prior to making a prototype or whether he arrived at its dimensions empirically. Failures from all causes with Newton Pippin rifle grenade ran at 2–5 per cent.⁹⁴

The utility of the Newton Pippin led to it being re-engineered in Britain for mass production in which form it became the No. 22 rifle grenade. The Munitions Design

Committee insisted on the addition of a safety pin which necessitated a heavier plate and, in so doing, reduced the reliability of the grenade. The prevalence of prematures with the Hale type of rifle grenade persuaded the Committee of the ubiquity of prematures with all types of rifle grenade. Hitherto, the Newton Pippin had lacked a conventional safety mechanism because it did not need one. The excessive caution of the Committee created a problem where none existed. The higher incidence of prematures with the No. 22 than with the original Newton Pippin was investigated by the TWD. It speculated that that there were two possible causes: either, the rod was being forced through the base of the grenade into the detonator on discharge, or the heavier striker plate of the No. 22 was being set back on launch so that it hit the cap.⁹⁵ The former was likely to have been due to poor casting during manufacture, made worse by badly fitting rods. Newton favoured the second explanation due to the increased weight of the plate of the No. 22 and this led to the development of the Mk II with a lighter plate. The cause remained undetermined, however. Prematures became such a problem with the No. 22 that it was withdrawn from service in 1917.⁹⁶

One measure of utility of any grenade is the amount of mishandling it can tolerate before it kills the grenadier. Once armed, a grenade is live but it may be kept safe so long as the firing mechanism is prevented from activating. Hence, the need for a safety mechanism. In the case of time-fuzed grenades, the bomber manually arms the device by inserting the fuze assembly, while the firing and safety mechanisms are one and the same, the time fuze acting as an additional safety. In the case of percussion-fuzed devices, there was no time delay and, although the grenadier inserted the detonator by hand, the grenade had to remain unarmed in this state because of the dangers of accidental detonation. The Nos 1 and 2 grenades became armed when the detonator was inserted and this led to accidents.⁹⁷ Hence, arming had to be achieved independently of the grenadier and a separate safety mechanism was needed. This inevitably led to percussion-fuzed devices being more complex than time-fuzed grenades and, as a consequence, the utility of percussion-fuzed mechanisms was reduced with an increased risk of failure. The problems were accentuated with percussion-fuzed rifle grenades because the firing, arming and safety mechanisms had to withstand the shock of discharge. The risk of a premature was greatly reduced if the rifle grenade was time-fuzed, however, such as the No. 23 Mk III and No. 36 Mills patterns. One reason for the adoption of the Mills as a rifle grenade was the reduced risk of a premature compared to percussion-fuzed rifle grenades. A temporary solution to the risk of a premature was to remove the grenadier from the rifle discharging the grenade by fixing the rifle to a stand sited in a bay or a part of a trench that had been evacuated.⁹⁸ But this did little to improve the utility of the rifle grenade.

Lethality

For a grenade to be useful, it has to have a high lethality. In terms of utility, lethality has three components: the manner in which a munition causes injury; the nature of that injury; and the mortality rate among casualties caused by that munition. Lethality is affected by functionality and reliability: if it works in a simple manner and does so most of the time, its lethality will be

higher than if it has a complex mechanism which fails to work. In operational terms, lethality is affected by the tactical use of the weapon and how it is handled in combat. One measure of operational lethality is the number of fatal casualties caused by that weapon,⁹⁹ especially when this is expressed as a percentage of all fatalities.¹⁰⁰

Lethality of an explosive anti-personnel munition is largely dependent upon its fragmentation characteristics.¹⁰¹ The position of the detonator relative to the grenade's major axis,¹⁰² the material from which the body is made, the thickness of the body and its shape,¹⁰³ the nature of the fragmentation component when this is not the body,¹⁰⁴ the type of explosive and the size of the charge all affect the fragmentation characteristics of a given device.¹⁰⁵ In 1916, Captain Ley of the MID conducted fragmentation experiments and found that a centrally located detonator in a spherical grenade gave better fragmentation than an eccentrically located detonator or a barrel-shaped grenade.¹⁰⁶ The belief that segmenting the body aided the formation of uniformly sized fragments on detonation led to most grenade bodies of the

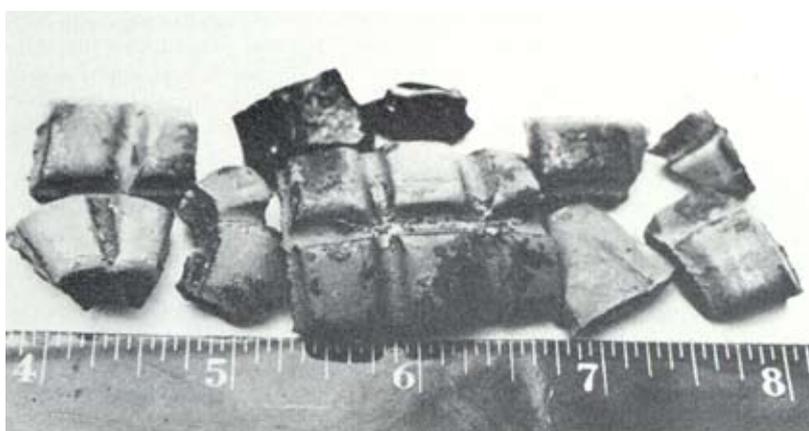
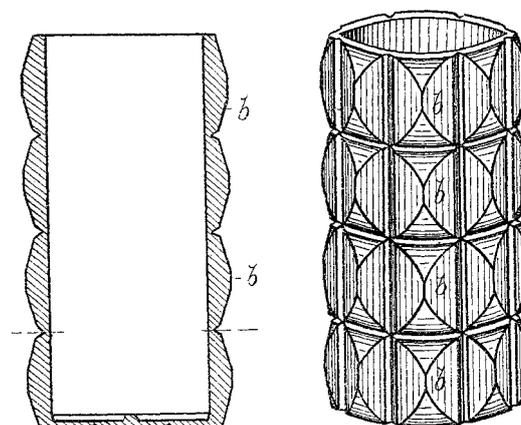


Fig. 22 (left) Large fragments from a US hand grenade. This illustrates how segmentation has little effect on how the body of the grenade breaks up on detonation (Coates)

Fig. 23 (below left) An X-ray of a grenade wound of the shoulder showing many small fragments. The curved structures are drainage tubes (Penhallow)



Fig. 24 (below right) The cast-iron body of the Pitcher, showing Sangster's patented segmentation which was supposed to aid fragmentation. The labels *b* indicate pyramidal raised areas set between grooves (drawings from GB5900/15)



First World War being segmented.¹⁰⁷ Thus, it was stated with a certainty that was not supported by experimental evidence that the body of the No. 14 Pitcher grenade produced thirty-five fragments on detonation.¹⁰⁸ Grenades with smooth exteriors were segmented on the inner face of the body. As early as January 1915, Mills observed that many more fragments than anticipated were produced from a segmented cast-iron body, some of which was reduced to dust on detonation.¹⁰⁹ Research in the early 1970s showed that the Mills No. 36 body produced fragments that ranged in size from about 0.1 g to greater than 5 g. Two-thirds were between 0.1 g and 1 g.¹¹⁰ These were the most dangerous.¹¹¹ The No. 36 body produced, on average, more than 770 fragments.¹¹² This is indicative of the number of fragments that would have been produced by all segmented cast-iron grenade bodies irrespective of the pattern of grenade. The best that could be claimed for segmentation of the exterior is that it allowed the thrower to grasp the grenade more firmly than might otherwise have been possible, especially in cold and wet conditions.

When a device explodes, the detonation wave expands through the explosive from the major axis of the detonator.¹¹³ If the detonator is misaligned due to a manufacturing fault, the shape and force of the explosion are affected adversely. The detonation wave from a non-spherical hand grenade is essentially cylindrical but is complicated by the fact that grenades such as the Mills are asymmetrical.¹¹⁴ The fuze assembly and the base-plug, being more solid than the body of the grenade, effectively constrict the wave, while the curvature of the body acts as a wave former. The fuze assembly may survive detonation almost intact, while the base-plug is effectively fired outwards along the major axis of the grenade as a projectile.¹¹⁵ Thus, the orientation of the grenade when it explodes is a factor in its lethality since its orientation effects how much of the blast and how many of the fragments are directed towards potential targets.¹¹⁶ This was especially true in the confines of a trench since the blast might be directed into the sides rather than along it. It was less of an issue when the grenade detonated inside an enclosed space, such as a dugout, since the walls, floor and ceiling contained and reflected the blast wave.¹¹⁷

The magnitude of the explosion, determined by the type and amount of explosive for a given grenade, affects the number of fragments produced. There are several theories relating to the formation of fragments but it is likely that their size is a function of the rate of expansion of the explosion and the rate of the tensile relief (rarefaction) wave in the grenade body away from a fracture.¹¹⁸ A fracture occurs when the tensile strength of the metal is exceeded in that locality. In this theory, devised by N F Mott in the 1940s, the location of the fractures, their number and, hence, the size of the fragments, are determined by the balance between the rate of increasing strain in the unrelieved areas and the rate of the relief wave.¹¹⁹ Clearly it is unaffected by segmentation. The number of fragments determines the blast pattern: the smaller the fragments, the greater their number and the closer the pattern. A smaller number of large fragments produces an open pattern.¹²⁰ The smaller the fragments, the lower their lethality¹²¹ but the greater the chances of their hitting a target because of the close pattern, whereas, the larger the fragments, the higher their lethality but the lower the chances of their hitting a target because of the open pattern. Larger fragments are more lethal than smaller ones because

of their higher kinetic energies: more energy can be imparted to the target on impact.¹²² In September 1915, GHQ noted that the No. 15 Ball grenade was more lethal when it was partly filled with sand instead of being completely filled with explosive because this produced bigger fragments.¹²³ In July 1917, it was noted that, weight for weight, the No. 34 hand grenade produced 30 per cent more fragments than the Mills, the larger of the two grenades.¹²⁴ A larger charge produced fewer fragments because the blast turned a larger proportion of the body into dust, as previously noted by Mills.¹²⁵ Fragments from the Mills were lethal at 75 yards from the explosion, while the base-plug was lethal at 200 yards.¹²⁶ Fragments from the French F1 were lethal at only 30 yards.¹²⁷ Without fragmentation, the lethal radius was about 7 yards, depending on the size of the charge.¹²⁸

The fuze of percussion devices also effected lethality. The Newton Pippin had a distinct advantage over the Hale type: its instantaneous fuze meant that, when the grenade struck the ground, the explosive force was mostly directed above ground rather than in making a crater.¹²⁹ The Hale penetrated the ground before exploding because the fuze reacted more slowly. The Newton Pippin's crater was approximately 18 inches wide by 6 inches deep in 'stiffish clay' but the detonation wave was effective to a radius of 3–4 feet, while pea-sized fragments were dangerous at 50 yards.¹³⁰ The Hale expended most of its explosive force in producing a crater into which 80–90 per cent of the fragments were blasted.¹³¹ Thus, the Newton Pippin rifle grenade was more lethal than the Hale types.

Functionality and reliability

Functionality is concerned with the form of a device, its shape and mechanical arrangement, and how it works. Reliability is a measure of the state of readiness of the device to work as intended, the amount of time required to maintain it in a functional condition, and the probability of successful operation when used in an operational environment. Reliability is dependent upon functionality. Clearly, functionality and reliability inform utility. As will become clear in what follows, it is necessary to discuss the engineering detail in order to understand why one device works while another, similar, device does not, and why one munition was a practical proposition for the conditions of the Western Front, while another was impractical. An examination of functionality can provide insight into the process of invention in the context of the novel munitions under discussion here.

In December 1914, GHQ requested a 'self-igniting' grenade to obviate the problems associated with manual ignition.¹³² The Royal Laboratory tried to devise one but abandoned work in January 1915.¹³³ It is unclear whether the invention of the Mills grenade was the reason the Royal Laboratory stopped working on its own device. The grenade devised by William Mills was developed from a device invented and patented in 1912 by Léon Roland, a Belgian soldier.¹³⁴ The combination of a spring-loaded striker, with a central spike, retained by three successive safety devices, including an external lever which engaged the tail of the striker, as well as the internal arrangement of the components, together formed a patentable invention.¹³⁵ Indeed, there had been no device like it. Whereas the Roland represented an imaginative leap, it did not represent a technological one. Any Victorian engineer could have devised its

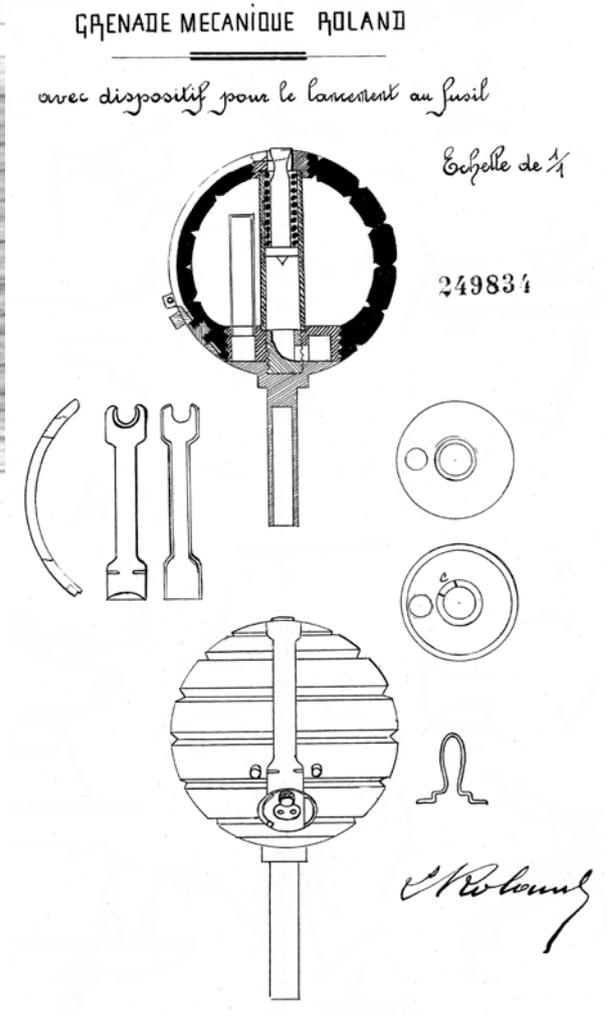


Fig. 25 (left) *The Roland hand grenade. The centrepiece, striker and base-plug can be seen clearly in the top photograph, while the lever and safety pin can be seen in the bottom photograph. The forked head of the lever engages the tail of the striker. Note that the grenade is spherical and that the cast body is provided internally and externally with grooves to assist fragmentation. The cutaway is an aluminium demonstration example in which the centrepiece has been cast in one piece for convenience (Author's photographs of specimens in Norman Bonney's collection)*

Fig. 26 (right) *Drawings from Roland's Belgian patent of 1912 (Courtesy of the Belgian Patent Office)*

mechanism but the focus of those who wanted to improve on the archaic hand grenade had always been on percussion mechanisms rather than on automatic time mechanisms. This highlights the difficulties in determining what is obvious, from an inventive standpoint, and demonstrates that ingenuity and inventiveness need not involve new technology.¹³⁶

While the Roland represented an advance in the field of time-fuzed grenades it was not an advance in terms of engineering. Indeed, the Roland was an unnecessarily complex grenade which did not work reliably due to its safety mechanisms. They were the major reason for the grenade's rejection by Woolwich in January 1915.¹³⁷ Too many of its components had to be precisely engineered and the mechanism had to be assembled precisely. The fuze assembly was difficult to insert while every screw required in the assembly of the mechanism was non-standard.¹³⁸ All of this suggested that the Roland grenade would be difficult to manufacture and awkward to use operationally. It also implied that the device had not been through the process of production engineering to address such matters. When Mills examined the Roland prototype

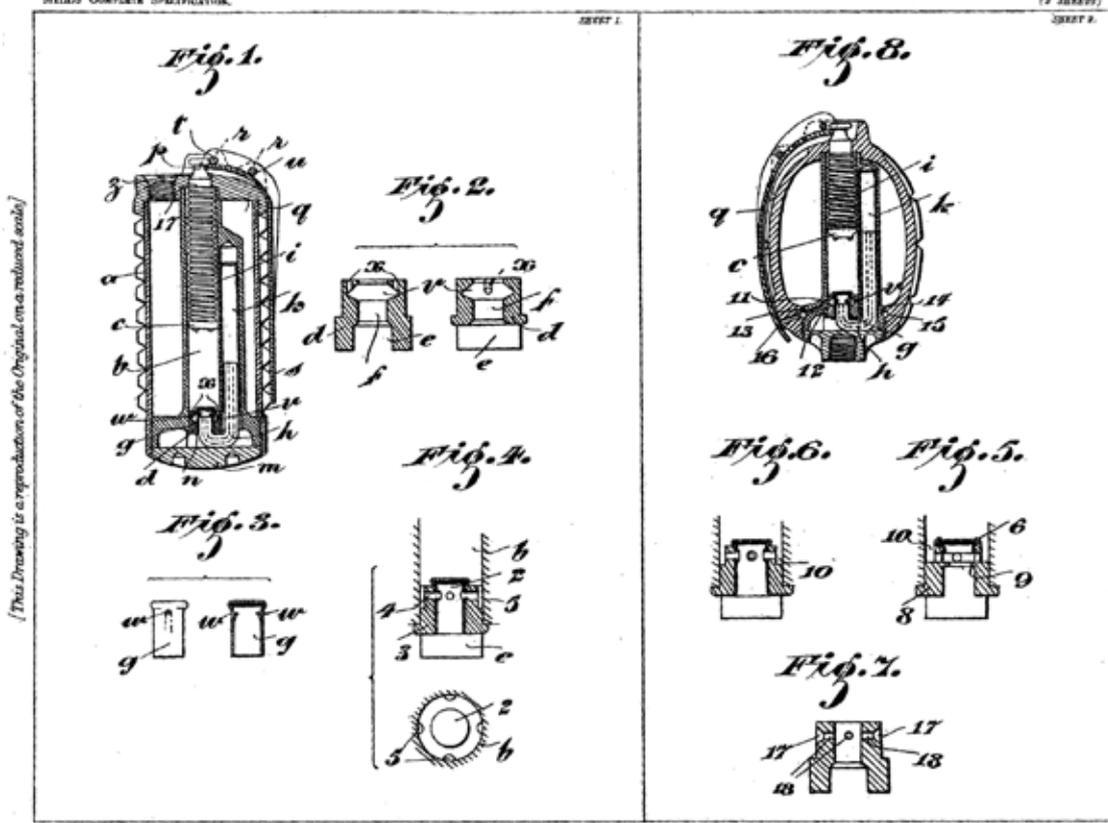


Fig. 27 The Mills hand grenade as described in GB2468/15. This shows all the features of the No. 5 and variations on the matter of venting the percussion cap. The top righthand figure shows a base-plug with a screw thread for a rod but when the application was filed in February 1915 there was no thought of using the No. 5 as a rifle grenade

on 2 January 1915, he realised that some components could be simplified to ease manufacture and reduce costs.¹³⁹ In implementing this process of change, Mills was doing no more than what should have done by Roland and his collaborators but which they had manifestly not done.

The grenade eventually developed by Mills differed substantially from the Roland.¹⁴⁰ Mills applied his engineering experience to the poor functionality of the Roland and turned a good idea into a workable device. This was no less inventive than Roland's original work. Unlike the Roland lever, the upper part of the Mills lever was formed as a channel-section¹⁴¹ and was provided with trunnions just below its head. These engaged slots in a pair of flanges located on the upper surface of the grenade body. The use of trunnions allowed the lever to pivot at a fulcrum that was not the point of contact with the striker, as was the case with the Roland, thereby allowing freer movement with a considerably reduced risk of the components jamming or slipping back, which could occur with the Roland arrangement.¹⁴² The lever was held in a safe position by a removable pin which engaged holes in the sides of the channel-section adjacent to holes in a second pair of flanges, between which the channel-section passed, to retain the lever against the body of the grenade.¹⁴³ This was a far simpler method than the three co-operating safety mechanisms of the Roland and required no precision engineering. Moreover, it worked.

Nevertheless, the No. 5 Mills suffered from a number of design faults which were not immediately apparent. These came to light because of an unacceptably high number of

accidents in training and in the front line during 1915 and 1916.¹⁴⁴ This was at a time when the No. 5 was not as plentiful as it was to become after about the spring of 1916, due to production difficulties which meant that it was supplied to divisions on a piecemeal basis until 1916. Thus, the BEF as a whole took many months to become familiar with it. As a consequence, accidents caused by design flaws were not immediately obvious since accidents were also being caused by lack of familiarity with the grenade, a common occurrence with grenades during this period of the war.¹⁴⁵ The accidents had many causes,¹⁴⁶ including premature detonation, early detonation after the pin had been pulled but before the grenade had been released from the thrower's grip,¹⁴⁷ and pins being pulled out accidentally when several live grenades were being carried in a canvas bucket; the bucket had been designed for transporting additional grenades up support trenches to resupply bombing parties.¹⁴⁸ The fuzing of the Roland and the Mills included a length of Bickford safety fuze to which was attached a percussion cap at one end and a detonator at the other. Premature detonation of the No. 5 was caused by flash-through due to poor venting of the combustion gases from the detonation of the cap. This occurred when the striker head made a gastight seal with the top of the cap as it struck so that the resultant hot gases were directed into the Bickford fuze.¹⁴⁹ The hot gases exerted pressure on the gunpowder core which caused a rapid increase in the rate of burning. Early detonation was caused by premature release of the striker by the lever before the bomber released the lever.¹⁵⁰ The bucket problem was caused by the lever of one grenade engaging the ring of the pin of another and, due to jolting about in the bucket as it was carried, the lever pulled out the pin with predictable results.¹⁵¹ These flaws were of the kind that would be expected in a first-generation device when no expertise existed. Although it was sometimes possible to mitigate problems by adopting better handling procedures, such as splaying the ends of the cotter pins so that they were less easily pulled out accidentally, the basic problems remained because they were design flaws.

An undated report of about October 1917 suggested that GHQ believed that the defects in the Mills grenades supplied during the autumn and winter of 1916 were due to deficiencies in supply and inspection rather than defects in the design.¹⁵² It is important to see this document in the context of its disclosure. It was part of the Crown's evidence at a hearing of the Royal Commission on Awards to Inventors which was sitting to examine claims made before it by Vickery and Gibbons, two inventors who provided solutions to the flaws in the No. 5 grenade, which led to the development of the No. 36. The document was just one of many reports on grenades written during the war and, out of context, it is misleading. Defective supply and inspection were responsible for defective grenades reaching France during 1915 when the commercial contractors and the inspectors were learning and gaining experience. As already discussed in the previous chapter, inspection was an essential part of the process of manufacture and experience was initially lacking. Moreover, 1915 was the time of the stopgap grenades which were notorious for their lack of reliability and poor utility. The War Office selected the report to support its case against making an award to Vickery or Gibbons, not because the report was representative of the state of knowledge at the time. By 1917, the causes of the accidents were known and remedial action was being

taken. The fruits of this were not seen in France until 1918 because of the large numbers of Mills grenades that had already been produced, far too many simply to discard them, especially when some of the faults could be remedied by changing handling procedures.¹⁵³

In order to understand the nature of these problems, it necessary to examine the arrangement of the fuze assembly, for it was here that some of the solutions had to be found. Essentially, the assembly comprised two parallel tubes, known as the centrepiece, the larger tube housing the spring-loaded striker, the smaller one housing the detonator,¹⁵⁴ a cone-shaped cap holder, which sat at the base of the striker tube and acted as a means by which the cap was joined to the Bickford fuze, this being guided from the detonator to the cap via the holder.¹⁵⁵ The holder, cap, fuze and detonator were assembled by the firms which manufactured these components.¹⁵⁶ Thus, this assembly was a single entity¹⁵⁷ which was easily inserted in the grenade in the field¹⁵⁸ immediately prior to use. A base-plug¹⁵⁹ was then screwed into the grenade body to retain it. The correct positioning of the socket, and of the fuze in relation to the cap, were critical to the proper functioning of the grenade. If the cap was not correctly mounted, the striker hit it eccentrically causing a misfire.¹⁶⁰ If the fuze pressed tightly against the cap, there was no space to allow the combustion gases from the detonating cap to escape; this caused flash-through. Thus, vents were provided in the upper face of the socket to allow the combustion gases to escape into the striker tube.¹⁶¹ Although the Roland incorporated vents, these were to the exterior of the device, that is, facing in the opposite direction from the Mills vents, and were solely for exhausting the combustion gases from the fuze, rather than from the cap to prevent flash-through. This was a fundamental difference between the Roland and the Mills and went to the heart of the functionality of the two grenades.

Because of the huge number of Mills grenades that were available by mid-1916, the number of accidents in training schools rose to ten a month, causing twenty to thirty casualties a month.¹⁶² The number of accidents in action was doubtless far higher but the number went unrecorded although GHQ complained about a high incidence.¹⁶³ GHQ investigated the accidents, then wrote to London in August 1916 to suggest a technical solution.¹⁶⁴ This apparently originated from evaluations conducted by the Experimental Section.¹⁶⁵ In Britain, Major Ley evaluated the suggestion and concluded that it did, indeed, prevent flash-through. The solution was to cut a diagonal slot in the face of the head of the striker to a depth of 0.5 inch which allowed the gases from the cap to vent past the head into the tube and escape through the small space between the tail of the striker and the aperture in the body of the grenade through which it protruded.¹⁶⁶ The slot meant that, when the striker was in contact with the cap, a gastight seal was prevented. Mills had come to the same conclusion a year earlier and had told the TWD by at least November 1915 to cut such a slot.¹⁶⁷ In October 1916, the Inspector of Grenades at Woolwich wanted to know why the slotted striker had not been adopted following Mills's recommendation.¹⁶⁸ He wrote to Mills to find out if the TWD had simply let the matter drop due to lack of enthusiasm, inefficiency or failure to recognise its utility. Thus, the slotted striker was known eighteen months before it was adopted.¹⁶⁹ The huge stocks of the Mills meant that few grenades incorporating the new striker reached France before early 1918.



Fig. 28 (above) This illustrates the differences between the No. 5 (left) and No. 36 (right) hand grenades. The tops of the strikers, the flanges which engage the lever trunnions, and the filler holes are all noticeably different. It is clear from this photograph that the notched striker of the No. 36 allows the lever to make a firmer engagement (inert-ord.net)

Fig. 29 (below) Disassembled No. 5 (left) and No. 36 (right) grenades. Note the different strikers. The No. 5 has two projections on the striker face and a recessed top, while the face of the No. 36 striker is slotted and the top is notched. Note also the channel-section lever of the No. 5 and stamped lever with integral trunnions of the No. 36. The baseplug of the No. 36 has a threaded hole for a rod (inert-ord.net)

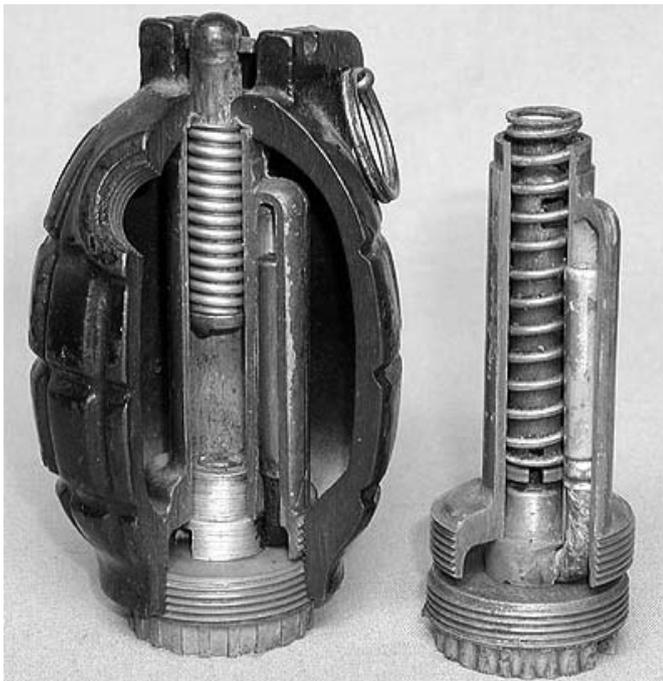
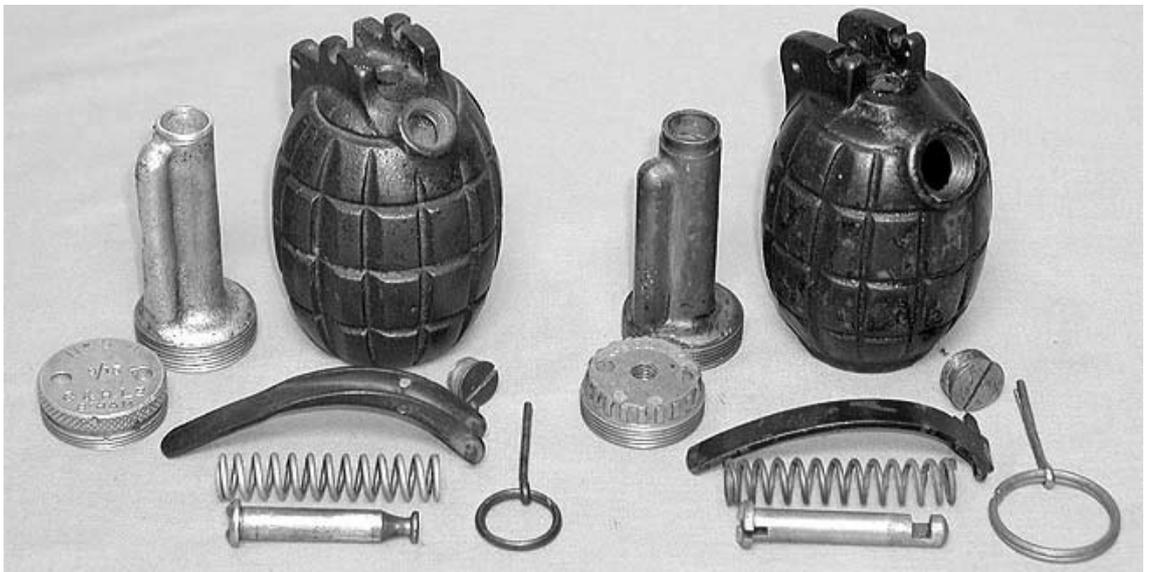


Fig. 30 (left) A cutaway of a No. 36 and its centrepiece. The cap holder at the bottom of the centrepiece with the fuze attached to the detonator are clearly visible. Note that the fuze exits the cap holder via a slot and immediately enters the tube holding the detonator to which it is attached. This arrangement was common to all versions of the Mills grenade. There is no cap in the holder (inert-ord.net)

Mills was granted a patent in respect of the slotted striker, GB11223/15.¹⁷⁰ It is possible that the Experimental Section had tested a slotted striker made by Mills or had seen the patent specification before it made its recommendation to the MID. Curiously, Ley never saw Mills's modified striker and was unaware of the patent until 1920 when he gave evidence at a hearing of the Royal Commission on Awards to Inventors in respect of Mills's claim.¹⁷¹ GB11223/15 also described a means to prevent the fuze from being pushed in too far into the cap holder from below,¹⁷² which was a contributory factor in flash-through, and described the cap as being provided with a central vent and flanges to prevent it from being pushed into the holder too far from above. This arrangement ensured that there was always space between the cap and the fuze to prevent flash-through. The head of the striker, as described in GB11223/15 was also modified to penetrate the central vent in the cap¹⁷³ yet allow the gases of combustion to escape into the striker tube. Ley estimated that the risk of premature detonation of the No. 5 was between 1 in 3,000 to 1 in 100,000. The risks fell to between 1 in 200,000 and 1 in 300,000 with grenades fitted with the modified striker.¹⁷⁴ The striker head of GB11223/15 was not taken up. Instead, to prevent misfires, the two-pronged head of the original striker was replaced with one which had a sharp-edged circular-ridge to ensure that enough of the rim of the cap was always struck to ensure detonation.¹⁷⁵ There had been problems due to poor manufacture and inadequate inspection so that a wide range of sizes of prong were produced, leading to prematures and blinds.¹⁷⁶ The new shape obviated such problems.

Premature release of the striker was down to simple mechanics, governed by the laws of levers, although it had been far from obvious that the original positioning of the striker–lever fulcrum would cause problems. The solution was threefold: the position of the lever's fulcrum was dropped to below the point of engagement of the lever and striker;¹⁷⁷ a deep slot was cut into the tail of the striker instead of providing it with an annular recess which had been used hitherto; and the forked head of the lever was replaced with a squared head to ensure that the engagement between the lever and the slot was firm.¹⁷⁸ The question of who invented these features was raised during a hearing of the Royal Commission on Awards to Inventors in 1921.¹⁷⁹ Two people claimed to have been the inventor, Francis Gibbons,¹⁸⁰ who filed a patent application on 21 December 1916 which described the notch and the square-ended lever,¹⁸¹ and Vickery who did not file a patent application. Vickery's counsel successfully argued that the repositioning of the fulcrum and a number of other modifications to the Mills grenade were Vickery's invention.¹⁸² Accidents due to unintentional release of the striker fell markedly after the introduction of the square-ended lever, combined with the lowered fulcrum.¹⁸³ The trunnions of the original Mills lever consisted of a pin which was inserted through holes in the lever's channel section. Poor manufacture could cause the trunnions to be too short or to rotate in lever's the holes. Vickery proposed a stamped lever in which the trunnions were integral, thereby obviating the earlier difficulties.¹⁸⁴

To prevent the lever of one grenade catching the pin of another, the body of the grenade was reshaped to form a recess where the tail of the lever contacted the body so that no part of the tail now protruded.¹⁸⁵ At the same time, the manner in which the body of the grenade was cast was changed.¹⁸⁶ Each part of the two-piece mould of the

No. 5 contained one of the flanges which carried the holes for the trunnions. When the body halves were joined, the trunnion holes did not always match up which led to many rejections. Vickery proposed that the mould should be redesigned so that both flanges were cast in the same half-mould, thereby removing the possibility of misalignment.¹⁸⁷ Vickery made several other changes to the body which made manufacturing easier and improved fragmentation.¹⁸⁸

By late-1916, the No. 5 had evolved into a hybrid hand and rifle grenade, the No. 23 Mk I, by the substitution of the original base-plug for a steel one provided with a threaded hole into which a rod could be screwed so that it could be fired from a rifle. The Mk II had a slightly modified lever and a number of other minor changes. However, the modifications discussed above resulted in a major redesign of the Mills grenade. The new pattern appeared in mid-1917 as the No. 23 Mk III¹⁸⁹ but, as already pointed out, this did not make an impact on the BEF until 1918. The Mk III was vastly superior to its predecessors.¹⁹⁰ It was safer to handle and far more reliable than earlier Mills grenades. Inspection of the Mk III was much easier than with earlier patterns.¹⁹¹ Rejections fell by half to about 2 per cent of those manufactured.¹⁹² When William Mills was shown all the proposed modifications prior to their implementation, he was opposed to them on the grounds that they would diminish the safety and functionality rather than improve them.¹⁹³ It is unclear why he should have objected to the proposed modifications. All his objections were systematically addressed and, by experimentation, his fears were shown to be groundless.

The impracticalities of percussion-fuzed grenades

In 1915, the Royal Laboratory developed a percussion-fuzed hand grenade from the No. 15 Ball grenade in an effort to overcome the deficiencies of the Nos 1 and 2 grenades.¹⁹⁴ Its all-ways fuze was adapted from a German trench mortar bomb fuze,¹⁹⁵ made more sensitive to allow for the slower speed at which a grenade strikes the ground compared to a mortar bomb. A suitable safety device had to be devised to cope with its greater sensitivity. Trials of the grenade were undertaken in March 1916 but it was rejected because it was unreliable and unsafe.¹⁹⁶ This typified the war-time problems with the development of percussion-fuzed grenades.

Several patented devices were entered in competitive trials during 1916–18, including the DG and the Chamier grenades,¹⁹⁷ along with a CSOF device, called the Humphries,¹⁹⁸ named after its designer. This had been developed from the failed Ball percussion grenade. Most, if not all, of them were evaluated by the Experimental Section¹⁹⁹ at GHQ, as well as by the Ministry of Munitions and some underwent troop trials. The Experimental Section also undertook developmental work to improve the functionality of some of the mechanisms²⁰⁰ and devised a percussion-fuzed egg grenade, called the Bellamy,²⁰¹ with an all-ways functionality.²⁰² The Bellamy was sent to Britain in January 1918 so that 1000 could be manufactured for trials. By mid-1917, all experimental percussion-fuzed grenades had not only to satisfy the requirements of safety and functionality but they also had to be capable of being fired from a cup discharger.²⁰³



Fig 31 (left) *Humphries* (above) *DG* (right) *Bellamy A*. The weighted tape is clearly visible in each case. The *Humphries* and *DG* could be fitted with a rod to turn them into rifle grenades. The circumferential bands were to enable them to be fired from a 2-inch cup discharger (Left, MUN 5/383/1600/14; above & right, Author's photographs of specimens in Norman Bonney's collection)

The mechanisms of percussion-fuzed grenades all worked in much the same way. There were three elements: an arming device, a safety device and an impact device. These worked cooperatively and sequentially to minimise the risk of premature or accidental detonation, not only while the grenade was being handled, but also while it was in flight, yet ensure that the device always detonated on impact irrespective of the angle at which it struck a surface. The requirement that the grenades was capable of withstanding the inertia of being fired from a discharger increased the difficulty of providing mechanisms which functioned reliably and safely but which were simple enough for easy manufacture. Typically, the percussion mechanism comprised a spring-activated striker which was held in an armed position²⁰⁴ by a displaceable member which itself was held by a restraining means which was only released in flight. A cotter pin prevented the second safety means from being released. The striker could not fall under the action of a compressed spring until the displaceable member had released it; the mechanism could not operate even if the armed grenade was dropped. The complexity of the mechanical arrangements needed to embody all this led to a trade off between reliability, ease of manufacture and utility.

The displaceable member was typically a retractable bolt which engaged the striker, preventing the latter from moving until the bolt was removed. The *DG* and the *Humphries* both incorporated such a bolt which was extracted by a tape, attached to the tail of the bolt; the opposite end of the tape was weighted. With the bolt in place, the tape was coiled round the body of the grenade and prevented from unwinding by a cotter pin.²⁰⁵ In flight, the weighted end pulled out the tape so that it unwound. When the tape reached its full extent,

it pulled out the bolt and thereby armed the grenade. For this to work efficiently, the tape had to be of a minimum length, otherwise the force exerted on the bolt was insufficient to extract it cleanly.²⁰⁶ Moreover, it was essential that the grenade did not become armed too soon after it had left the thrower's hand; this also placed a minimum length requirement on the tape.²⁰⁷ In order for the tape to unwind, it was necessary for the thrower to impart spin on the grenade; the direction of spin had to be such that the tape unwound. Failure to unwind sufficiently or inconsistently would result in the tape failing to extract the bolt. In a trial conducted by the Experimental Section in September 1916, up to 50 per cent of an early version of the Humphries failed because the tape did not unwind correctly.²⁰⁸ There was also a concern that the tape would be frozen to the grenade in low temperatures, thereby rendering the grenade inoperable.

The striker mechanism of a percussion-fuzed hand grenade was far more complex than that of a time-fuzed grenade. A two-element or three-element mechanism was not untypical. The early Humphries used a two-element mechanism comprising a striker pellet and a cap pellet,²⁰⁹ both slidably mounted in the centrepiece²¹⁰ and arranged to act cooperatively.²¹¹ The extractable bolt and a weak coil spring separated the two elements. Once the bolt had been extracted, only the spring kept them apart and was easily compressed by the inertia of the grenade when its flight was halted by an impact. An all-ways functionality was provided by making cooperating hemispherical surfaces on the tail of the striker pellet and the base of the tube in which it acted, while the top of the cap pellet and the lower face of the fuze holder were provided with similar surfaces.²¹² When the grenade struck a surface at an angle which was approximately normal to its principal axis, the pellets were forced together by inertia. At any other angle, the curved faces ensured that an equal and opposite angular force acted on each pellet and thereby impelled them together. The Humphries was rejected by GHQ following troop trials; it was unreliable and suffered from too many blinds.²¹³

A common alternative to the cooperating surfaces and tape was a dislodgable ball. The Chamier was a typical example of such a system.²¹⁴ It was more complex than the Humphries and used a three-element striker mechanism. Two spring-activated plungers were arranged to act in opposition, separated by a ball held by a cage slidably mounted between them. The top of the centrepiece was open to allow the upper plunger, or striker, to slide upwards and out of the top of the grenade but was prevented from doing so by an external lever secured by a cotter pin. So long as the pin remained in place, the lever remained flush with the body of the grenade and prevented the striker from moving.²¹⁵ In this respect, it was similar to the mechanism of the Mills grenade. As soon as the lever was allowed to pivot away from the body, the striker moved upwards, taking the cage with it, thereby freeing the ball which rolled into a bulbous region of the centrepiece and allowed the lower plunger, which contained the cap, to move upwards. The ball then engaged a recess in this plunger and prevented it from hitting the striker. On impact, the ball was dislodged and the two plungers, impelled by their respective springs, were free to engage and detonate the grenade.²¹⁶ The Chamier was rejected by GHQ following troop trials²¹⁷ and by the MID because it was unsafe and unreliable.²¹⁸ The mechanism was far too complex.

Technical evolutions

The question of whether the hand grenades used by the BEF owed anything from an engineering standpoint to those of the Russo-Japanese War, or to those of the American Civil War, may be settled with certainty. It is clear from the technical characteristics of the grenades discussed in this chapter that they owed nothing to any earlier device. Only the pre-war percussion-fuzed grenades had a direct link with the percussion-fuzed grenades of the Russo-Japanese War. There was also a direct link between the pre-war improvisations of the Royal Engineers of the Indian Army and the improvisations of 1914 and 1915, through to the Nos 6, 7, 8, and 9 patterns. This was because the improvisations on the Western Front were made by Royal Engineers who derived their knowledge from the pre-war Indian Army.²¹⁹ The Mills grenade was derived from a pre-war Belgian invention which owed nothing to the devices of the Russo-Japanese War nor to the improvisations on the Western Front, while a practical rifle grenade did not exist until 1908.²²⁰ Thus, it is misleading to describe the grenades of the First World War as the direct descendants of the so-called 'revived' grenades of the Russo-Japanese War.²²¹

The evolution of the Mills grenade illustrates how an idea is turned into a practical embodiment. There were several distinct phases. During the preliminary phase, Roland conceived an automatically lit time-fuzed grenade. His conception was quite different from any grenade devised hitherto. Unfortunately, what inspired him is unknown. There is no question that had the Roland not existed, the Mills would not have been invented since the latter depended on the existence of the former. The first phase of the evolution of what was to become the Mills grenade began when William Mills was asked by Albert Dewandre to make several Rolands for evaluation by Woolwich.²²² When the Roland was rejected, Mills applied his engineering skills to solving the problems highlighted by the trial. By so doing, he turned an impractical device into a workable grenade. This was inventive in the modern sense as discussed in Chapter 1 of this thesis, since none of his solutions was obvious. The next phase involved alteration to the grenade as it went into mass production and in order to allow it to be discharged from a rifle. The third phase was analytical, during which the causes of prematures, blinds and misfires were investigated. The fourth phase involved the development of engineering solutions in response to the findings of these investigations. The fifth phase was the redesigning of the Mills which led to the No. 23 Mk III and No. 36 grenades. The whole process had taken about two and a half years, from January 1915 to about July 1917, while the role of inventor had moved from Roland to Mills to Vickery, Gibbons and others. The result was a grenade which remained in service for fifty-five years.

The No. 5 Mills hand grenade and the rodded rifle grenade both demonstrate that the perfected weapon principal is false. Neither entered service in a fully developed form and both suffered from serious technical problems which had to be resolved. Although rodded rifle grenades were used extensively throughout the First World War, it was a technical dead end. Much time and effort went into simplifying the Hale type and in making it safer and more reliable. It went through several incarnations: the No. 3 was replaced by the No. 20 from March

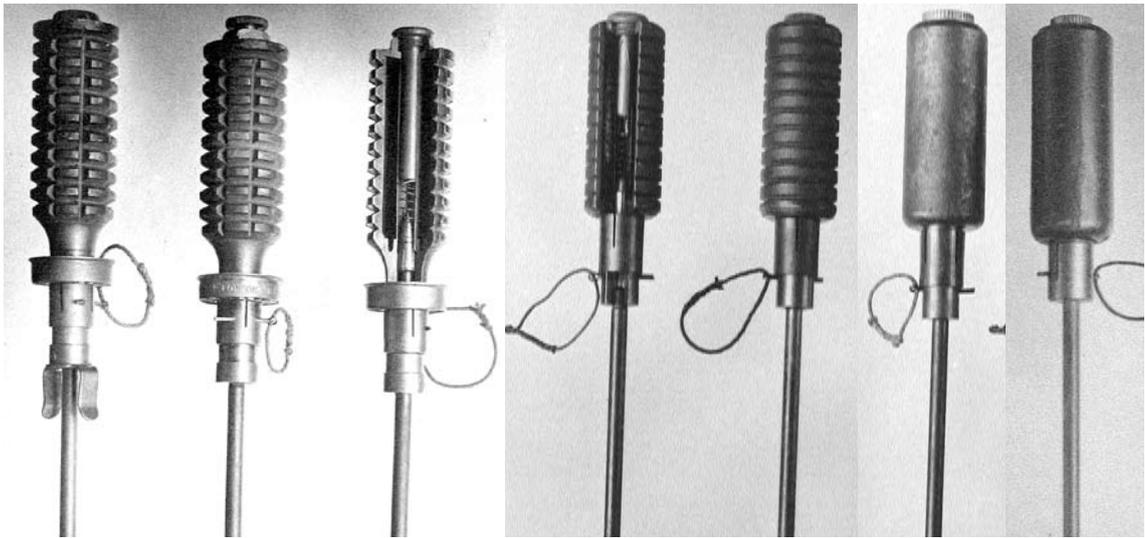


Fig. 33 *The evolution of the Hale type of rifle grenade. From left to right: No. 3 Mk I; No. 3 Mk 1* (no muzzle clip); No. 3 Mk 1* instructional showing the internal components; No. 24 Mk I instructional; No. 24 Mk I; No. 24 Mk II; No. 35 Mk I. Note how the complex machining of the exterior was eventually eliminated and how the mechanism was simplified (MUN 5/383/1600/14)*

1916; the No. 20 was replaced by the No. 24 about a year later; and the No. 24 was replaced by the No. 35 in early 1918.²²³ Each successive pattern was simpler than its predecessor and, hence, was safer and more reliable. The increasing simplicity arose largely from the need for reduce the number of machining operations during manufacture. This also reduced costs because in each successive pattern less brass was needed.

The development of hand and rifle grenades for the BEF was a chaotic process which proceeded independently of each other without coordination for much of the time due to the pressing need to provide the BEF with suitable munitions.²²⁴ The necessity for development to proceed concurrently with operational use exacerbated the problem so that the BEF had to contend with imperfect grenades until about the spring of 1916. This led to a choice of munitions on a least-failures principle rather than according to which munitions fulfilled specific requirements. Indeed, these requirements changed as the war progressed. At the start of trench warfare, there was no clear idea of what form a hand grenade should take. Failure to design a reliable and safe percussion-fuzed device meant that time-fuzed grenades dominated. Because the Mills grenade was the only effective time-fuzed hand grenade in

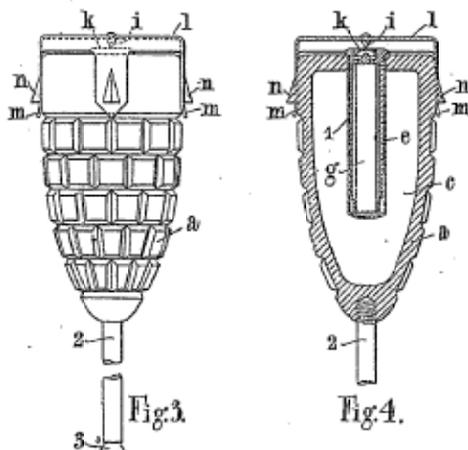


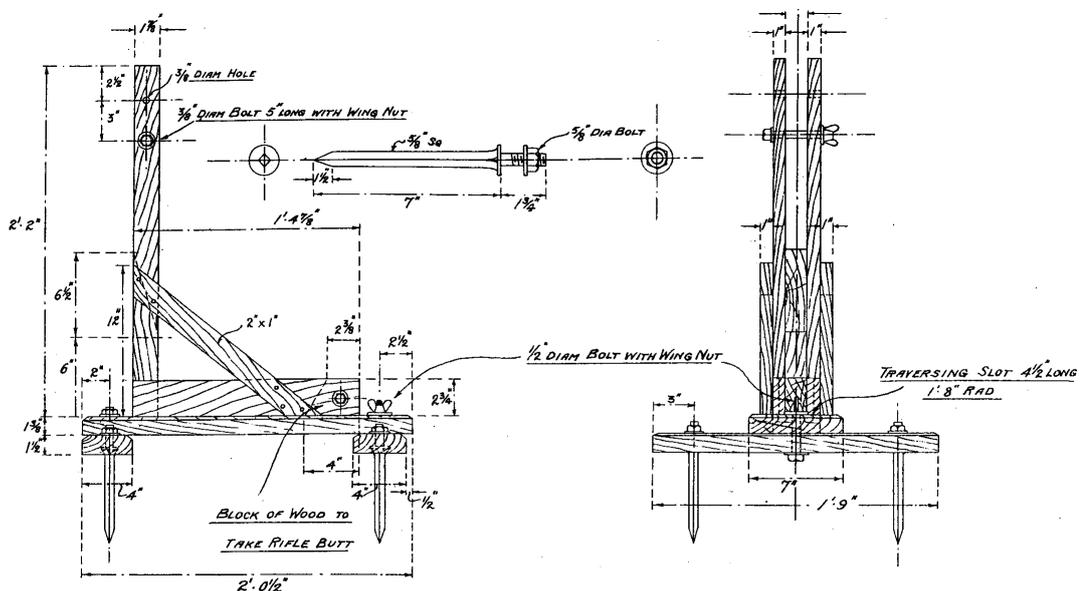
Fig. 34 *Newton Pippin rifle grenade. Note the obturator (3) on the tail of the rod in the left-hand figure. The right-hand figure demonstrates the simplicity of the mechanism compared to that of the Hale types (GB166563)*

1915, it became by default the standard British hand grenade. It was not necessarily the best. Indeed, several grenades with mousetrap mechanisms were invented after the Mills had been adopted and any one of them might well have proved less troublesome to develop than the Mills.²²⁵ Many modern hand grenades use such a mechanism, not a striker/lever mechanism of the Mills type; indeed, none uses the Mills type.²²⁶ The greater utility and reliability of a mousetrap mechanism was not appreciated by the British during the First World War. The dominance of the Mills type meant that there was no incentive to consider alternatives. The Americans, on the other hand, were not so constrained and adopted a grenade with mousetrap mechanisms.²²⁷ It is entirely possible that the British would have done likewise had not Mills developed a workable grenade from the Roland.



Fig 35 (above) *The McClintock rifle grenade, India, 1912. The wooden stand is provided with a butt stop and a movable muzzle rest (pegs in holes) which is positioned according to the aim set by the plumb sight (hanging from the rifle stock). The quiver is for carrying the grenades; its top contains a range table (Royal Engineers Journal)*

Fig. 36 (below) *Engineering drawing of stand for firing rifle grenades produced by First Army Workshops in 1915. Note its similarity to the Indian Army stand (Articles manufactured by RE Workshops in France)*



The search for a safe percussion-fuzed grenade embodied the conflict between utility, functionality and reliability. The difficulties ‘provided much food for thought’.²²⁸ The need to arm the grenade after it left the thrower’s hand or was fired from a discharger presented designers and inventors with a problem that was not successfully overcome during the war. The Humphries evolved into the No. 30 hand/rifle grenade in 1918.²²⁹ This, in turn, was developed into the No. 54 grenade which was adopted by the British army in 1923.²³⁰ It had taken about eight years to reach this point. The No. 54 remained in service for about ten years but was hardly used in anger so its utility was never tested. It had only taken about two and a half years to develop the original Mills grenade into the No. 36 which not only saw service at the end of the First World War but was used in nearly every theatre of operations during the Second World War and in all wars fought by British and Commonwealth forces until the 1970s. It is probably the most widely used of all hand grenades. It can still be found in some armies and guerrilla groups.²³¹ Although the No. 36 was not perfect, it was a deadly weapon and popular with troops. By the Second World War, it was termed a defensive grenade because it was deemed unsuitable for operations in which friendly troops might be within its lethal zone. A so-called offensive grenade produced fewer fragments and relied on blast for its effect which meant that it had smaller lethal zone so that friendly troops were less likely to be within it. In practical terms, a defensive grenade meant that troops had to take cover when one was thrown in the open whereas this precaution was thought unnecessary with an offensive grenade. Such tactical thinking came out of the First World War as will be discussed in Chapter 8.

Notes

¹ MUN 5/383/1600/14 Lt-Col O F Brothers, *The Development of Weapons Used in Trench Warfare*, pp. 39, 41.

² It was recognised at the time that there was not time to perfect hand grenades, for example, before their use by the BEF. See Brothers, *op cit.* p. 41. See also MUN 5/321A *History of the Ministry of Munitions*, vol. IX *Review of Munitions Supply*, Part II *Design and Inspection*, pp. 45–6 with regard to hasty design and supply.

³ Rick Landers, *‘Grenade’ British and Commonwealth Hand and Rifle Grenades*, (Dural, 2001), p. 1.

⁴ Maj-Gen C H Foulkes, *“Gas!” The Story of the Special Brigade*, (Edinburgh & London, 1934), p. 305. This was an artillery bombardment.

⁵ *Op cit.* p. 306.

⁶ For example, the Nos 13 and 14 Pitcher grenades were introduced in May 1915 and withdrawn by GHQ in September. See Landers, *op cit.* pp. 56, 57 which cite List of Changes in War Matériel and of Patterns of Military Stores (LoC) §17252; MUN 4/2557 letter from General Maxwell dated 8 September 1915; and MUN 4/2604 Memorandum on Grenades by Louis Jackson, dated 14 September 1915.

⁷ See Brothers, *op cit.* pp. 46–7. It is difficult to give precise dates because of the lengthy period of introduction, at the end of which, the No. 5 was replaced by the No. 23 Mk I and this was little different from the No. 5. The No. 23 Mk III was quite different from the previous Mills grenades and appeared in mid-1917. The Mills is discussed below.

⁸ Brothers, *op cit.* pp. 40, 42–3.

⁹ Brothers, *op cit.* p. 40. The Ball grenade had been devised in response to the need for grenades in the Dardanelles where rain was less of a problem. See MUN 4/2604 Memorandum on Grenades.

¹⁰ Brothers, *op cit.* pp. 40–2.

¹¹ See Chapter 1.

¹² Strictly speaking, lighting by match is not a mechanism because there are no moving parts but for the sake of convenience it is simpler here to use the term ‘mechanism’.

¹³ Miscellaneous types include a transverse spring/striker, devised by L L Billant in October 1916 (GB127279). Billant's system formed the basis of the French 1916 Model B fuze assembly which was used in the F1 and OF hand grenades.

¹⁴ White phosphorus is also an incendiary agent.

¹⁵ It is unfortunate that the term 'fuze' is applied to mechanisms, such as those discussed here, to Bickford safety fuze and to gunpowder trails.

¹⁶ Such as an attachment was different from a cup discharger. See note 23 below regarding cup dischargers.

¹⁷ Two types of rodded rifle signal grenade were used from about the end of 1916, the No. 31 and the No. 32. The latter was for use at night and carried two or three illuminating stars which could be white, yellow, red or green. The No. 31 was a day signal grenade and carried a coloured smoke candle which could be red, blue or purple. Each grenade used a quick match to ignite both a bursting charge and the candle or stars at a predetermined height. In early 1918, another rodded rifle night signal grenade, the No. 38, was introduced. It was essentially the same as the No. 32 but incorporated some improvements. Experiments were conducted with signal grenades which could be fired from a discharger but these did not appear until the closing stages of the war. See Brothers, *op cit.* pp. 60–1, 64–5.

¹⁸ Brothers, *op cit.* p. 62.

¹⁹ Although Hale is credited with the invention of the rifle grenade, there was at least one earlier patent, GB20238/05, granted to B Pedersen in 1905, which clearly describes such a device. However, Hale did not claim in his patent to have invented the rodded rifle grenade although he clearly did make such a claim in interviews (see *Great War "Souvenir" 1914–1918* in T 173/252). It is possible that he was unaware of Pedersen's patent but, equally, it is possible that he bought the patent rights from Pedersen. It is clear that Hale did not infringe the Pedersen patent. Pedersen only relates to a rodded device without describing the fuze mechanism or any safety devices.

²⁰ A graze fuze has an all-ways functionality by virtue of its sensitivity but is slower than an instantaneous direct-action fuze because it is operated by the deceleration or inertia so that the explosion results a crater.

²¹ The Royal Laboratory devised a similar mechanism at about the same time but the Laboratory was forestalled by Marten Hale's patent application. I am grateful to Norman Bonney for this information.

²² These were the No. 3, No. 20, No. 24 and No. 35 rifle grenades. In Britain, a total of 12,527,779 of these were produced while of the other three types of rodded rifle grenade, excluding the Mills, only 208,201 were produced.

²³ Burn's patent is GB126692. The discharger was re-invented in 1916 by two French engineers called Viven and Bessiere (VB). They were granted several patents in Britain, including GB100700 and GB104836. The VB discharger (known to the French as a *tromblon* or blunderbuss) fired a special grenade with a conventional ball round passing through an axial bore in the grenade; later, a blank cartridge was used. The French used them widely from 1916 onwards. The BEF experimented with VB dischargers in 1917 and they were adopted by the American Expeditionary Force in 1918. The MID experimented with bullet-through grenades but they remained experimental. See SS190 Rifle Grenade Discharger No. 1, Mark I, Description and Instructions for Use, October 1917. See also T 173/578 for Burn's claim before the Royal Commission on Awards to Inventors, 19 May 1919; and MUN 4/3589, SS171 Notes on Inventions and New Stores, No. 1.

²⁴ T 173/146, *op cit.* Crown counter-statement of May 1919 in respect of Burn's claim before the Royal Commission on Awards to Inventors.

²⁵ Functionality, utility and reliability as used here are derived from engineering principals.

²⁶ Brothers, *op cit.* pp. 41, 42.

²⁷ Brothers, *op cit.* pp. 50–1.

²⁸ The No. 54. See Landers, *op cit.* p. 138. See also 'Work of the Royal Engineers in the European War', *The Royal Engineers Journal*, September 1924, p. 455, and June 1925, p. 251; and *History of the Ministry of Munitions*, vol. XI, *The Supply of Munitions*, Part 1 *Trench Warfare Supplies*, p. 84.

²⁹ Brothers, *op cit.* pp. 74–5.

³⁰ Brothers, *op cit.* pp. 69–70.

³¹ MUN 4/426 Inventions and Suggestions: Reports by the Munitions Invention Department.

³² Royal Laboratory drawings RL21991 dated 1 January 1915, RL21992 dated 25 January 1915, RL22131 and RL22132 both dated 27 January 1915.

³³ MUN 4/2604, letter from Lieutenant-General Maxwell dated 20 May 1915. This also stated that the lighter grenade, the No. 6, was preferred to the heavier one, the No. 7, because it could be thrown further and bombers could carry more of them.

³⁴ GB4392/15.

³⁵ According to Mike Hibberd, formerly of the Department of Exhibits and Firearms, Imperial War Museum, in a letter to the author dated 17 March 1998, Roodhouse's grenade underwent trials before being rejected. There appear to be no documents in the National Archives at Kew to substantiate this, however. It is very probable that all the patented devices were submitted for evaluation in the hope that such devices would be adopted by the army and put into mass production. There would have been little point in patenting such devices if the inventor had not cherished hopes of success.

- ³⁶ CDS74 The Training and Employment of Grenadiers, October 1915, p. 27.
- ³⁷ The No. 19 was devised in January 1916. *History of the Ministry of Munitions*, Trench Warfare Supplies, *op cit.* p. 80.
- ³⁸ Landers, *op cit.* pp. 62–3.
- ³⁹ ‘The Work of the Royal Engineers’, *op cit.* p. 463. This describes the No. 19 as having better fragmentation characteristics than the No. 1 but lacking an all-ways capability.
- ⁴⁰ Brothers, *op cit.* p. 66.
- ⁴¹ *Abridgements of Specifications*, Class 9 (i) Ammunition and Ammunition Receptacles, 1915–18. Some patents related to bombs which were probably intended to be dropped from aircraft and the specifications may have included hand grenades merely to increase the scope of the patents rather than because they related specifically to hand grenades.
- ⁴² *Abridgements of Specifications*, *op cit.* Not all of these would have been specific to hand grenades; some would have included them in the specification so as not to limit the scope of the patent. Nevertheless, most were directly concerned with hand grenades. The number does not imply a similar number of individual devices, however; in some cases, several patents related to the same device; eg the three patents relating to the DG grenade (although these date from 1917).
- ⁴³ *Ibid.*
- ⁴⁴ The mechanism most commonly used in current service hand grenades worldwide is the rotary striker.
- ⁴⁵ *Abridgements of Specifications*, *op cit.*
- ⁴⁶ They were not evaluated by the Ordnance Board as there are no minutes which refer to them. It is likely that the devices were examined by the Inspection Department of the Directorate of Artillery and found to be unsuitable for testing, let alone trials. Unfortunately, there are only vague hints about such devices in some of the documents concerning the departments discussed in Chapter 4.
- ⁴⁷ See, for example, correspondence in *The Times* for 1915. See also WO 32/9281, top minute addressed to the Deputy Superintendent of Design, June 1915.
- ⁴⁸ Guy Hartcup, *The War of Invention, Scientific Developments, 1914–18*, (London, 1988), p. 147. See GB129299, filed 14 July 1916 and GB129362, filed 1 November 1917. Constantinesco was not the sole inventor, however. Major L V Blacker, of the RFC also contributed to the development of the gear. See T 173/120 and T 173/564 relating to Blacker’s submission to the Royal Commission on Awards to Inventors.
- ⁴⁹ See Chapter 6.
- ⁵⁰ Landers, *op cit.* p. 116. Production ceased in 1972.
- ⁵¹ See J Wilkes, Fragmentation Data for Eight Grenades, RARDE report TR1/12/72 dated October 1972 (via Norman Bonney).
- ⁵² T 173/477 Deposition, dated 9 August 1920, of Major Ley to the Royal Commission in respect of Mills’s claim. T 173/802 Minutes of Proceedings before the Royal Commission on Awards to Inventors, claim of Mr Vickery (Mills Grenades) Evidence of Major C E W Beddoes, Thursday, 27th January 1920, pp. 4–7. Brothers, *op cit.* pp. 47–9.
- ⁵³ *Trench Warfare Supplies*, *op cit.* p. 83; and *Textbook of Small Arms*, (London, 1929), pp. 107, 136.
- ⁵⁴ Indeed, the German egg was less lethal than the stick grenades because the charge was smaller and the body casing thinner. See Manual for Hand Bombers and Rifle Grenadiers, GHQ AEF, February 1918, pp. 100, 103.
- ⁵⁵ It is unclear why these acquired the name ‘Pitcher’. Sangster’s two British patents relating to these grenades, GB5900/15, *op cit.* and GB5901/15, *op cit.* both refer to ‘military hand or pitcher grenades’ which suggests that the name derives from the pitching action used to throw a hand grenade but this does not explain why his grenades should have been singled out for the name. The No. 13 and No. 14 were identical except for the material used for the body: steel (No. 13) and cast iron (No. 14).
- ⁵⁶ Brothers, *op cit.* p. 40. The name became associated with bombers in general during 1915.
- ⁵⁷ MUN 4/2557, report from 1 Division, dated 1 August 1915.
- ⁵⁸ MUN 4/2557, *op cit.*
- ⁵⁹ The Training and Employment of Grenadiers, *op cit.* p. 34 gave specific warnings about securing the fuze assembly and for bombers to throw the grenade irrespective of whether the strip tore away from the friction tube. To make matters worse, an unexploded Pitcher presented a serious hazard as only specially trained Royal Engineers could extract the fuze assembly.
- ⁶⁰ MUN 4/2557. See letters of 7 July 1915 and 8 September 1915 from Maxwell to the Army Council, stating that GHQ did not want any more Pitchers because of the accidents.
- ⁶¹ MUN 4/2557, *op cit.*
- ⁶² See WO 140/14, Todhunter’s report on Hale rifle grenades, dated 25 May 1915, for ranges with angles of fire for different lengths of rod.
- ⁶³ In other words, the angle of deviation from the line between the shooter and the target. For a given angle, the deviation will increase with increasing range. Hence, an increase in angle will increase the aiming error with increasing distance.
- ⁶⁴ Brothers, *op cit.* p. 56.
- ⁶⁵ Landers, *op cit.* p. 85.

- ⁶⁶ I V Hogg & L F Thurston, *British Artillery Weapons and Ammunition 1914–1918*, (London, 1972), p. 240.
- ⁶⁷ A rifle grenadier carrying sixteen rifle grenades complete with rods was burdened with about 20 lb.
- ⁶⁸ Conventional bullet round are referred to as ball rounds because, until the advent of the Minié bullet in the middle of the nineteenth century, bullets were spherical.
- ⁶⁹ Experiments in 1915 with the Newton Pippin showed that the rod remained intact after the grenade detonated. Notes on Pippin Grenade, a report prepared by the TWD, in MUN 5/197/1640/7.
- ⁷⁰ This came from a requirement in 1912 by the Naval Wing of the RFC (this became the RNAS in July 1914) for a man to be able to shoot a rifle grenade at an enemy balloon or airship. The No. 4 Hale rifle grenade was subsequently developed and adopted for this purpose. See Landers, *op cit.* pp. 23–4. Early promotional material featured photographs of shooters preparing to fire rifle grenades in a variety of poses, including prone, kneeling and standing with the rifle shouldered. See *Great War “Souvenir”* in T 173/252. See also SS182 Instructions on Bombing, Part II, Training and Employment of Bombers, November 1917 for photograph of a soldier shooting a rodded Mills from the shoulder (Plate X, p. 69). This is discussed in Chapter 8.
- ⁷¹ Private communication from Norman Bonney, summer 2006. See also Todhunter’s report on trails with the Hale rifle grenade fired from the long Lee Enfield in May 1915 in WO 140/14.
- ⁷² Brothers, *op cit.* p. 65. See also ‘Work of the Royal Engineers’, *op cit.* p. 460.
- ⁷³ MUN 4/426, *op cit.* Brothers, *op cit.* p. 63.
- ⁷⁴ Artillery made use of recoil and recuperator systems to overcome this problem.
- ⁷⁵ A hollow tail might have been more stable, a technique used since the 1970s on some helicopters.
- ⁷⁶ This was analogous with the archer’s paradox concerning the whipping of an arrow fired from a longbow. See Robert Hardy, *Longbow, A Social and Military History*, (Cambridge, 1976), pp. 199–200.
- ⁷⁷ Notes on Pippin Grenade *op cit.* The observations applied to all rodded rifle grenades.
- ⁷⁸ There was a similar problem with mortar ammunition that used a steel tail, such as that for the 2-inch Woolwich mortar. This had serious implications for effectiveness and is discussed below.
- ⁷⁹ Brothers, *op cit.* p. 56.
- ⁸⁰ Known as windage.
- ⁸¹ And the unsuitable rods had then to be labelled in some way so that the rods would not be used inadvertently.
- ⁸² Notes on Pippin Grenade *op cit.*
- ⁸³ T 173/728, *op cit.* p. 14. Newton claimed at the Commission hearing that the range was slightly increased by streamlining.
- ⁸⁴ Newton dissertation. This is from a list of novel features of the Newton Pippin compared to the Hale, compiled by Henry Newton in respect of his claim before the Royal Commission on Awards to Inventors in 1924.
- ⁸⁵ *Trench Warfare Supplies*, *op cit.* p. 74, 75. MUN 5/382/1600/10 History of Production of Trench Warfare Stores by the Trade, p. 1. MUN 5/197/1640/5 Production of grenades.
- ⁸⁶ Brothers, *op cit.* p. 53.
- ⁸⁷ Newton papers. Newton Pippin list, *op cit.*
- ⁸⁸ GB166563.
- ⁸⁹ Brothers, *op cit.* p. 56.
- ⁹⁰ T 173/728 Minutes of the Proceedings before The Royal Commission on Awards to Inventors held on Monday 17 November 1924, Claim of Colonel Newton, p. 11.
- ⁹¹ See, for example, the No. 3 in Plate 18, p. 51 of *The Training and Employment of Grenadiers*, 1915, *op cit.* and compare this to the Newton Pippin shown on p. 114 of *Textbook of Small Arms*, *op cit.*
- ⁹² T 173/728. This matter was discussed several times during Newton’s hearing before the Commission. See, for example, pp. 69–72. The significance of a short and conical-tipped striker as opposed to a long pointed-tip striker was not readily grasped by the panel.
- ⁹³ T 173/728, *op cit.* p. 11.
- ⁹⁴ T 173/728, *op cit.* p. 12. Notes on Pippin Grenade, *op cit.*
- ⁹⁵ Notes on Pippin Grenade, *op cit.*
- ⁹⁶ See T 173/728, *op cit.* pp. 73 and 74.
- ⁹⁷ *Training and Employment of Grenadiers*, 1915, *op cit.* pp. 25, 27.
- ⁹⁸ For examples of rifle stands, see *Trench Warfare, Articles Manufactured by RE Workshops in France*, E-in-C, GHQ, undated, pp. 1, 21 and Plates 5, 201; see also Anthony Saunders, *Weapons of the Trench War, 1914–1918*, (Stroud, 1999), pp. 116–18.
- ⁹⁹ Although the point is made by Richard Holmes on p. 210 in *Firing Line*, (London, 1985), this aspect of lethality generally goes unremarked when weapons are discussed.
- ¹⁰⁰ There appear to be no such comparative figures relating to the British Army in the First World War. A survey of 360 US casualties in the Bougainville campaign in the Second World War showed that fifty-two (14.4 per cent) were due to grenades, of whom six died which represented 11.5 per cent of all fatal casualties. See Coates jr, Colonel James Boyd (ed.), *Wound Ballistics*, (Washington, 1962), 2nd ed., Table 44, p. 266.

- ¹⁰¹ This is because the fragments travel further than the blast wave. These characteristics include size and energy of the fragments which determine the distance they travel and the lethal radius of the device. Lethal radius is the radius of a sphere centred on the point of detonation inside which the probability that all casualties are fatal approaches 100 per cent. In reality, the blast wave is a distorted cylinder rather than spherical.
- ¹⁰² That is, the axis that runs through the greatest dimension.
- ¹⁰³ Although some grenades of the period were spherical, most were ovoid or barrel-shaped, with the exception of stick grenades which tended to have cylindrical bodies.
- ¹⁰⁴ Such as the steel balls set in resin of the Nos 8 and 9 Double Cylinder patterns of grenade. See *The Training and Employment of Grenadiers*, *op cit.* p. 31; and LoC §17252, *op cit.*
- ¹⁰⁵ Modern expertise derives from experimentation conducted during the First World War.
- ¹⁰⁶ SUPP 28/40, DGMD/Misc/32 and OB 33/2A/15. See also T 173/802 Evidence of Major Beddoes, *op cit.* pp. 19–21. According to Beddoes's recollection in 1920, about twelve No. 36s were tested for fragmentation characteristics and compared with a similar number of No. 5s. The No. 36 gave slightly better fragmentation. The tests were conducted under the supervision of Major Cargill who was Ley's superior.
- ¹⁰⁷ It was thought that, because the channels between the segments were thinner and therefore weaker than the rest of the body, the grenade would break up along these lines of weakness.
- ¹⁰⁸ LoC §17252, *op cit.* The inventor of the Pitcher, Charles Sangster, patented the segmented body on the basis that this was the case. See GB5900/15. Sangster was an engineer more familiar with the motor trade than munitions.
- ¹⁰⁹ King's Bench Division, 1917 R No. 45, *Roland & Others v Mills & Another*. Proof of Evidence of Mr William Mills, p. 24. See also Entries from Diary of Defendant William Mills for January 1915.
- ¹¹⁰ Wilkes, *op cit.* p. 4.
- ¹¹¹ In modern hand grenades, a notched wire is spirally wound inside the body. Alternatively, steel balls are set in a plastics resin cast in the cavity between the double walls of the body which is usually made of a plastics material. See Denis H R Archer (ed.), *Jane's Infantry Weapons*, 4th ed., (London, 1978), pp. 402, 414, 423, 432, 443. Casting steel balls in a resin between two walls was first used in the Nos 8 and 9 hand grenades, the so-called Double Cylinder patterns devised by Louis Jackson from the improvised jam tin grenades. Grenades with notched steel wire are designed to produce 100 per cent fragments from the wire, each within the weight range of either 0.1–0.5 g or 0.5–1.0 g (Wilkes, *ibid.*).
- ¹¹² Wilkes, *op cit.* Table 1.
- ¹¹³ Paul W Cooper, *Explosives Engineering*, (London, 1996) pp. 251 and 254.
- ¹¹⁴ Archer, *op cit.* pp. 398–90.
- ¹¹⁵ *Ibid.* See also letter from Mills to Captain Cargill, TWD, dated 1 July 1915 regarding the survival of a steel base-plug (in papers related to *Roland & Others v Mills & Another*, *op cit.*).
- ¹¹⁶ Orientation also effected the destructiveness of trench mortar ammunition and rifle grenades.
- ¹¹⁷ Cooper, *op cit.* pp. 203–222. This contains a mathematical analysis.
- ¹¹⁸ Cooper, *op cit.* pp. 223–50, 394–6.
- ¹¹⁹ Cooper, *op cit.* pp. 395–6.
- ¹²⁰ Archer, *op cit.* p. 398. For modern examples (1976) see DEFE 15/2290 Estimation of velocity and lethality for secondary fragments recovered from strawboard.
- ¹²¹ See Dunlap Pearce Penhallow, *Military Surgery*, (London, 1916), pp. 54–6.
- ¹²² *Textbook of Small Arms*, *op cit.* p. 116. The readiness of projectiles to transfer their kinetic energy to a target determines their lethality; large grenade fragments are very good at giving up their energy to the target because of their irregular shape which aids tumbling.
- ¹²³ This reduced the charge from 5.5 oz to about 2.5–3 oz. See letter dated 1 September 1915 from Lieutenant-General Maxwell in MUN 4/2604 and *The Training and Employment of Grenadiers*, October 1915, *op cit.* p. 35.
- ¹²⁴ MUN 4/3590 SS171/2 Notes on Inventions and New Stores No. 2.
- ¹²⁵ King's Bench Division, 1917 R No. 45, *op cit.* p. 24.
- ¹²⁶ Archer, *op cit.* p. 398. The Mills No. 36 remained one of the most lethal hand grenades ever produced because of the number of lethal fragments it produced. The Nos 13 and 14 Pitcher grenades (see note 32) also produced large fragments that were lethal up to 200 yards from the point of detonation. See letter from Lieutenant-General Maxwell dated 8 September 1915 in MUN 4/2557.
- ¹²⁷ Grenade Training Manual, US War Department, January 1918, p. 23.
- ¹²⁸ *Ibid.* This is with reference to the French OF grenade which relied upon blast for its effect, as did the German egg grenade.
- ¹²⁹ Newton papers, Newton Pippin list, *op cit.*
- ¹³⁰ Notes on Pippin Grenade, *op cit.* Brothers, *op cit.* p. 56. Although the crater produced by the Newton Pippin was cited contemporaneously as being much smaller than that produced by the Hale type, there appears to be no record of the size of crater produced by the Hale.
- ¹³¹ Newton papers, *op cit.* See also T 173/728, *op cit.* p. 10.
- ¹³² T 173/477 Crown counter-statement to Mills's claim to the Royal Commission on Awards to Inventors, 10 August 1920.

- ¹³³ *Ibid.* It is unclear what form the device took or how far they progressed with it before abandoning development.
- ¹³⁴ Roland filed patent applications and was subsequently granted patents in Belgium in 1912 (BE249834), Britain in 1913 (GB18766/13), France in 1913 (FR461447), USA in 1913 (US1126871), Germany in 1913 (DE275186), Romania in 1914 (2322/3885), and in Russia. It is noteworthy that the grenade was, in fact, never manufactured in any country and only in Britain was there a successful development of the Roland.
- ¹³⁵ This description is based on the US patent (US1126871). Although the wording of the US patent is different in some respects from the British patent, the claimed invention is the same.
- ¹³⁶ T 173/728, *op cit.* p. 48 where the question of inventiveness was raised.
- ¹³⁷ T 173/791, *op cit.* p. 9. Especially the wire catch and cord arrangement which, if it failed to function correctly, could pull the grenade back on to the thrower.
- ¹³⁸ Mills Proof of Evidence, *op cit.* p. 7.
- ¹³⁹ *Ibid.*
- ¹⁴⁰ This was well understood at the time. See Brothers, *op cit.* p. 44.
- ¹⁴¹ GB7636/15. Training and Employment of Grenadiers, *op cit.* Fig. 2, Plate 18, p. 51.
- ¹⁴² T 173/791 *op cit.* p. 8.
- ¹⁴³ GB7636/15 *op cit.*
- ¹⁴⁴ T 173/802 Evidence of Major Beddoes, *op cit.* pp. 3–8. ‘Work of the Royal Engineers’, *op cit.* p. 461. In *Surviving Trench Warfare, Technology and the Canadian Corps, 1914–1918*, (Toronto, 1992), Bill Rawling’s account of how the mechanism of the Mills No. 5 worked and accidents with the grenade is inaccurate (p. 58).
- ¹⁴⁵ ‘Work of the Royal Engineers’, *op cit.* pp. 452, 459, 460, 461. See also MUN4/2557, *op cit.*
- ¹⁴⁶ T 173/802 Evidence of Major Beddoes, *op cit.* p. 3.
- ¹⁴⁷ *Op cit.* pp. 7 and 9.
- ¹⁴⁸ *Op cit.* pp. 3–5. For canvas bucket see SS398 The Training and Employment of Bombers, March 1916, pp. 37–8.
- ¹⁴⁹ T 173/802 Evidence of Major Cuthbert Hillyar Ley, Wednesday 21 July 1920, pp. 5–7.
- ¹⁵⁰ T 173/802 Evidence of Major Beddoes, *op cit.* pp. 3, 4, 7. See also Evidence of Major Ley, *op cit.* p. 4. Brothers, *op cit.* p. 47.
- ¹⁵¹ *Op cit.* the whole document is relevant but especially pp. 3–7. Brothers, *op cit.* p. 47.
- ¹⁵² T 173/802 Part 4 Minutes of Proceedings before the Royal Commission on Awards to Inventors, 21 February 1921, Claims of F W Vickery, evidence of Colonel Henry Newton, pp. 5–6.
- ¹⁵³ Discussed in Chapter 7.
- ¹⁵⁴ Following the placement of contracts for the mass production of the Mills grenade, different approaches to the manufacture of the centrepiece were tried and some of these led to patents for different centrepieces, including GB10515/15 (Mills), GB16083/15 (Parkes; this was the first patent specification to use the term ‘centre-piece’), GB16327/15 (Adshead), GB17397/15 (Findlay), GB17898/15 (Parkes), GB102173 (Walker), GB102364 (Salsbury), GB106555 (Oritor Manufacturing Co & Starkey), GB114122 (Gibbons). The majority of applications were filed between July 1915 and July 1916 which reflects the development of processes for the mass production of the Mills grenade.
- ¹⁵⁵ GB7636/15, *op cit.*
- ¹⁵⁶ For example, A W & Co, and Kynoch, the manufacturer of small arms ammunition. See T 173/697 Minutes of the Proceedings of the Royal Commission on Awards to Inventors, Re: W H Mills grenades, Evidence of Major Cuthbert Hillyar Ley, Monday 21 July 1920, p. 4.
- ¹⁵⁷ T 173/477 The counter-statement claimed that Mills was informed of this requirement following the failure of the Roland grenade at the Woolwich tests. However, Mills makes no reference to this in either his diary or his deposition in respect of the 1917 court action and he stated at his Royal Commission hearing in 1920 that he was given no suggestion from anyone at the War Office or Woolwich how to improve the Roland (T 173/791 *op cit.* p. 27).
- ¹⁵⁸ T 173/697, *op cit.* p. 3.
- ¹⁵⁹ Initially made of aluminium, brass or a soft alloy. Later, steel was used but eventually the base-plug was made of cast iron for the sake of economy and because, apart from steel, it was the only material that could withstand the shock of the rodded grenade being fired from a rifle. By then, late 1916, the Mills had been developed into the No. 23 Mk II, a hybrid hand and rifle grenade.
- ¹⁶⁰ The Mills striker hit the cap with a force of 30lb, while the lever only required a force of 2lb to hold it against the grenade body after the pin had been removed. This was due to the force-magnifying effect of having the fulcrum close to the load (the spring) (T 173/791 *op cit.* p. 13 and Brothers, *op cit.* p. 44).
- ¹⁶¹ GB2468/15.
- ¹⁶² T 173/477, *op cit.* (see also T 173/697, *op cit.* p. 5) Ley, a Royal Engineer, was in command of the Grenade Section of the Design Department from August 1916. He had previously been Superintendent of Experiments in the TWD.
- ¹⁶³ T 173/477 Ley, *op cit.*
- ¹⁶⁴ T 173/697, *op cit.*

- ¹⁶⁵ *Op cit.* p. 12 makes it clear that the suggestion came from GHQ.
- ¹⁶⁶ Brothers, *op cit.* p. 47.
- ¹⁶⁷ T 173/697 *op cit.* pp. 15–17.
- ¹⁶⁸ T 173/697 *op cit.* pp. 15–16.
- ¹⁶⁹ The relevant inspection drawing, CIW2157, was not amended to show the modified striker until September 1916 (DGMD/G/429 dated 7 September 1916).
- ¹⁷⁰ The application filed on 3 August, cognate with patent application 12629/15. The patent was an addition to GB2468/15, his original grenade patent. The Crown counter-statement in T 173/477 wrongly puts the date as 13 August.
- ¹⁷¹ T 173/477 Ley, *op cit.*
- ¹⁷² The opening of the axial hole in the plug was provided with stops.
- ¹⁷³ Initially, caps had been provided with two holes in the rim, diametrically opposite each other.
- ¹⁷⁴ T 173/477 Ley, *op cit.*
- ¹⁷⁵ Rimfire caps and cartridges contained the initiating primer in the rim; hence the term rimfire.
- ¹⁷⁶ T 173/791 *op cit.* p. 12.
- ¹⁷⁷ T 173/802 Minutes of Proceedings, Claims of Mr Gibbons and Mr T W Vickery (Improvements in Mills Grenade), Monday 14th February 1921, pp. 3–5 (note: folios are those typed not the pencilled amendments).
- ¹⁷⁸ T 173/477. Major Ley stated in 1920 that the original arrangement of an annular recess and a fork-headed lever was a bad design but his opinion was based on hindsight (see also T 173/697 *op cit.* p. 7).
- ¹⁷⁹ T 173/802 Minutes of Proceedings, Claims of Mr Gibbons and Mr T W Vickery, *op cit.*
- ¹⁸⁰ T 173/802 Evidence of Major Beddoes; and Claims of Mr Gibbons and Mr T W Vickery, especially pp. 3–7.
- ¹⁸¹ Granted as GB110068.
- ¹⁸² T 173/802 Claims of Gibbons and Vickery, *op cit.* The whole document is pertinent but see especially pp. 3–10, 20–43.
- ¹⁸³ T 173/802 Beddoes *op cit.* pp. 18–19.
- ¹⁸⁴ T 173/802 Claims of Gibbons and Vickery, *op cit.* pp. 9–10.
- ¹⁸⁵ *Ibid.*
- ¹⁸⁶ T 173/802 Claims of Gibbons and Vickery, *op cit.* pp. 6–9.
- ¹⁸⁷ *Ibid.*
- ¹⁸⁸ T 173/802 Claims of Gibbons and Vickery, *op cit.* p. 12.
- ¹⁸⁹ With some minor changes, this became the No. 36 Mk I.
- ¹⁹⁰ This view was expressed by Henry Newton in 1921 at a hearing of the Royal Commission. See T 173/802 Part 4 *op cit.* p. 2.
- ¹⁹¹ *Op cit.* p. 5.
- ¹⁹² *Op cit.* p. 13.
- ¹⁹³ *Op cit.* p. 3. When Mills became aware of the problems with the No. 5, he engaged Francis Gibbons, a watchmaker, and Professor Morgan, an engineer, to find solutions because Mills had become heavily involved with production of the grenade and no longer had time to do the investigation and research himself.
- ¹⁹⁴ Brothers, *op cit.* p. 66.
- ¹⁹⁵ It is unclear which fuze. The German AZ16 is a possibility.
- ¹⁹⁶ ‘The Work of the Royal Engineers’, *op cit.* p. 462.
- ¹⁹⁷ Brothers, *op cit.* p. 67. DG grenade patents GB124837 and GB129042. Frederick William Chamier grenade patents GB125100 and GB125436.
- ¹⁹⁸ Not to be confused with an inventor called Humphris, who patented a percussion-fuzed grenade, GB129005, and a time-fuzed hand grenade with a similar mechanism (GB129004). Both patents had the same priority date, 18 September 1917.
- ¹⁹⁹ ‘Work of the Royal Engineers’, *op cit.* p. 453.
- ²⁰⁰ *Ibid.* Including one by an inventor called Nissen but it is unclear whether this was the same Nissen who invented the hut.
- ²⁰¹ He was the Experimental Officer at the time.
- ²⁰² ‘Work of the Royal Engineers’, *op cit.* p. 463.
- ²⁰³ Brothers, *op cit.* p. 68.
- ²⁰⁴ What may be likened to a cocked hammer of a firearm.
- ²⁰⁵ GB124837, *op cit.* and GB129042, *op cit.* Landers, *op cit.* p. 95.
- ²⁰⁶ Landers, *op cit.* p. 95. The Humphries’s tape was 31 inches long.
- ²⁰⁷ The tape on early version of the Humphries extracted the bolt after the grenade had travelled about 7 yards.
- ²⁰⁸ Landers, *op cit.* p. 96.
- ²⁰⁹ This held the percussion cap.
- ²¹⁰ The centrepiece was similar to that used in a Mills grenade except that it incorporated a third tube set at right angles to the two axial tubes which held the striker mechanism and detonator.
- ²¹¹ Landers, *op cit.* p. 95.

- ²¹² MUN 4/3589 SS171 Notes on Inventions and New Stores No. 1. See also cutaway diagram of Humphries on Landers, *op cit.* p. 95.
- ²¹³ MUN 4/3589 Notes on Inventions and New Stores No. 1, *op cit.*
- ²¹⁴ GB125100 in the names of F W Charmier and W Curtis, filed 15 May 1916 (from *Abridgements of Specifications, op cit.*). ‘Charmier’ is a misspelling of Chamier. See US1303163. The US patent has been relied upon here for the information regarding the mechanism.
- ²¹⁵ US1303163, *op cit.*
- ²¹⁶ *Ibid.*
- ²¹⁷ MUN 4/3590 Notes on Inventions and New Stores No. 2, *op cit.*
- ²¹⁸ ‘The Work of the Royal Engineers’, *op cit.* p. 464.
- ²¹⁹ J E Edmonds, *History of the Great War, Military Operations, France and Belgium, 1915*, (London, 1927), vol. 2, p. 7, fn 1.
- ²²⁰ It is not known whether Pedersen built a grenade as described in his patent and subsequently fired it.
- ²²¹ Alluded to in, for example, Brothers, *op cit.* p. 39. *Trench Warfare Supplies, op cit.* p. 72.
- ²²² Entries from Diary of Defendant William Mills (enclosure No. 3 of case papers of Roland & Others *v.* Mills & Another, King’s Bench Division, 1917 R No. 45), January 1915 entries. See also draft of Proof of Evidence of Mr William Mills, pp. 22, 23. See Chapter 4.
- ²²³ Brothers, *op cit.* pp. 51–5.
- ²²⁴ *Op cit.* pp. 39, 41.
- ²²⁵ In general, mousetrap mechanisms are more reliable.
- ²²⁶ See, for example, Archer, *op cit.* pp. 402, 414–15, 423, 425, 429, 432, 442, 445.
- ²²⁷ Manual for Hand Bombers and Rifle Grenadiers, GHQ AEF, pp. 70–1. This was the Mark 1.
- ²²⁸ ‘The Work of the Royal Engineers’, *op cit.* p. 462.
- ²²⁹ Landers, *op cit.* p. 97.
- ²³⁰ *Op cit.* p. 138.
- ²³¹ It has continued to see widespread use in other armies. It was manufactured under licence in India and Pakistan until the 1980s. In the 1960s, it was copied by the Viet Cong.

6 Inventing the Trench Mortar

This chapter addresses the question of novelty with regard to trench mortars:¹ were trench mortars of the First World War, indeed, novel, or were they merely the next logical development of the siege mortar? The chapter discusses, from a technical perspective, how the trench mortar was transformed from a cumbersome substitute artillery piece into a mobile infantry-support weapon which was as effective in open warfare as it was in the static warfare that inspired it. The purpose here is not to discuss every trench mortar used by the BEF on the Western Front but rather to highlight specific features of certain mortars in order to consider the advantages or disadvantages conferred by these features and thereby show how the transformation occurred. As in the previous chapter on grenades, utility, functionality and reliability form the basis of the discussion. This necessitates an examination of some of the technical details since the mortars did not all work in the same way and it is often the detail, rather than the more obvious differences, which distinguishes them. A mortar and its ammunition constitute a weapon system: to be effective, both elements have to work. Hence, it is necessary to discuss the invention and development of the ammunition, especially fuzes, as well as the means by which it was fired.

Although the British army continued to make limited use of siege mortars after the Crimean War, it lost interest in them during the second half of the nineteenth century because it did not see itself becoming involved in siege operations in a future European war,² unlike the German army which foresaw a need to destroy Belgian and Russian forts.³ Encouraged by their observations in Manchuria in 1905, the Germans set about equipping their army with high-angle-fire weapons of large calibre capable of destroying strong fortifications.⁴ These were the modern equivalents of the siege mortar. The Germans also developed smaller mortars for engaging entrenched defenders and these may be regarded as the first trench mortars, the Japanese improvisations of the Russo-Japanese War notwithstanding.⁵ Significantly, the first German trench mortars were, in effect, scaled-down artillery pieces with rifled barrels.⁶

In 1914 and early 1915, the German army was only marginally better equipped with trench mortars than the BEF despite the complete absence of such weapons in the British arsenal in August 1914.⁷ The British soon caught up, both numerically and technologically; indeed, the British surpassed the Germans in trench mortar technology. By 1917, British mortars such as the 3-inch Stokes and the 6-inch Newton were superior to German mortars in every respect.⁸ Curiously, the Germans never devised an equivalent of the Stokes nor, indeed, copied it. Nevertheless, the myth of German superiority in matters technological is persistent. Yet, the evidence shows that British ingenuity surpassed that of the Germans in many respects during the First World War, especially when it came to trench warfare munitions.⁹ One reason for the poor appreciation of what British engineers and inventors achieved is a lack of understanding of the significance of the inventive leaps they made. This chapter addresses these issues.

In late 1914, the French gave the BEF some small Coehorn mortars¹⁰ that dated from the 1840s.¹¹ The BEF then had to improvise ammunition for them. Such were the straits in which the BEF found itself that, until the end of 1915, bomb throwers powered by springs or rubber had to make up for its lack of mortars.¹² The need for trench mortars was so urgent that the form they took was determined by what could be improvised quickly without putting demands on an already hard-pressed armaments industry.¹³ Although these weapons were inaccurate, dangerous, and prone to misfire, with only a short range, the urgency encouraged a more innovative approach to design than might otherwise have been the case in more relaxed times. That they were slow and cumbersome to load and fire did nothing to diminish their Heath Robinson image. It was not until early 1916 that the BEF had sufficient mortars to be able to dispense with bomb throwers.¹⁴

At no stage during the First World War was a perfected mortar system introduced on the Western Front. All patterns of trench mortar operated by the BEF suffered from major problems when they were first used. Unlike grenades, mortars were the province of the armament firms and the Royal Gun Factory at Woolwich because mortars were classified as guns, so it was inevitable that it was to the armaments firms and Woolwich that the War Office initially turned for such devices. As far as the BEF was concerned, the trench mortar was little more than a cheap substitute for the howitzer,¹⁵ a weapon it also lacked in sufficient numbers. It was from this perspective that mortars were improvised by Royal Engineers in France and designed by the armaments firms and by Woolwich during 1914 and 1915.¹⁶ This situation was to change, however, and solutions radically different from the conventional were to emerge during 1915.

At the end of 1915, the BEF was using eight patterns of mortar on the Western Front, not including the Coehorns.¹⁷ By necessity, if only because of the logistical problems this presented, the number was reduced to three by May 1916.¹⁸ These mortars became the mainstays of the BEF's mortar establishment, made possible by the technical advances in mortars, propellants and ammunition derived from the experience and technical know-how gained over the first eighteen months of trench warfare.

Types of mortar

A trench mortar is a high-trajectory,¹⁹ low-pressure gun in which the recoil is dissipated through a baseplate into the ground.²⁰ Typically, chamber pressures for First World War mortars were 1.7–6.5 ton in⁻² depending on the type of mortar.²¹ In general, pressures varied according to the propellant, both in terms of type and in terms of quantity, while higher pressures produced longer ranges. Such pressures compare with the 16 ton in⁻² of an 18-pounder which was nearly three times that of the 9.45-inch mortar, the biggest used by the BEF.²² All trench mortars essentially comprised four components: a barrel; a baseplate; a mounting; and a sight. The breech engaged the baseplate while the barrel was supported at an angle between about 40° and 80° by a mounting provided with elevating gear and usually with traversing gear. Changing the angle of elevation, altered the range. Thus, a higher elevation resulted in a shorter range because the vertical component of the bomb's trajectory was increased while the horizontal

component was decreased.²³ An elevation of 45° gave the greatest range because the two components were equal.²⁴ The mounting had to be sufficiently robust to withstand repeated firings and, indeed, transportation. One of the complaints made about the first 3-inch Stokes mortars was that the mounting was prone to bending.²⁵ A similar problem was experienced with the first type of mounting for the 6-inch mortar.²⁶

Siege mortars were high-pressure systems. The mounting or bed, in the form of a truncated wheelless carriage, was massive enough to absorb the recoil so had no need of a baseplate. The barrel was pivoted on the mounting by means of trunnions which allowed the barrel to be elevated. A siege mortar had a stubby barrel the wall of which could be thicker than its calibre because the iron or bronze from which it was made would otherwise burst due to the high pressures, whereas a trench mortar had a long thin barrel made of steel which was not produced by traditional gun-forging techniques and generally lacked trunnions.²⁷ At the time of the Crimean War, a 5.5-inch brass Coehorn mortar had a range of 1600 yards, while a 13-inch iron mortar had a range of 2700 yards.²⁸ Thus, there were more differences between trench and siege mortars than there were similarities in form and functionality.

During the First World War, trench mortars were categorised according to the weight of the bomb they fired but tended to be described according to the size of the bore. Thus, the 2-inch mortar was classed as a medium mortar, while the 3-inch mortar was classed as a light mortar²⁹ because the former fired a heavier bomb; a 2-inch bomb weighed 50 lb of which 16 lb was explosive, whereas the 3-inch Stokes bomb weighed 10.7 lb of which 3 lb was explosive.³⁰ The 2-inch mortar fired a super-calibre projectile fitted with a 11.3-inch stem or tail³¹ which went inside the barrel while the body of the bomb remained outside; the 3-inch mortar fired a 3-inch diameter bomb that went inside the barrel. Super-calibre bombs were informally termed toffee-apples, footballs or plum-puddings because of their appearance. Thus, an alternative way of categorising mortars is according to whether they were normal calibre or super-calibre. However, none of these categorisations is very helpful because they say nothing about functionality.

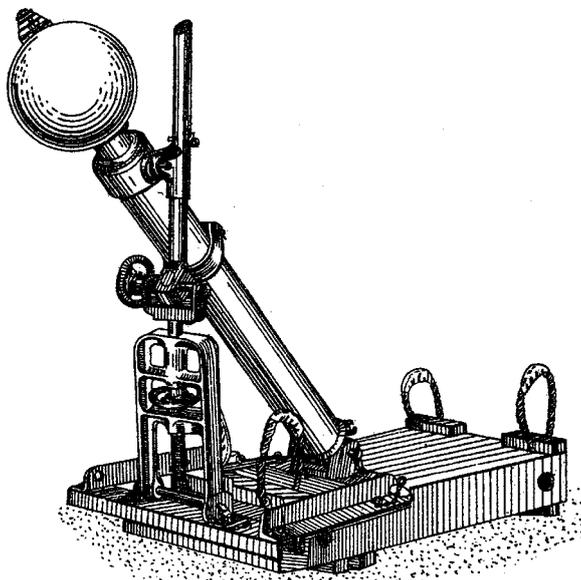


Fig. 37 *The Woolwich 2-inch medium mortar, fitted with a periscope. It is loaded with a stemmed bomb. Note the adjustable stand and steel baseplate on the wooden bed (Handbook of ML 2-inch Trench Mortar)*

Trench mortars may also be categorised as muzzle-loading (ML) and breech-loading (BL). Although several breech-loaders were offered for evaluation during the war by firms such as Vickers and Armstrong Whitworth, none was seriously considered for British service because they were too complex for quick manufacture and their complexity made them unsuitable for the conditions of the Western Front.³² One of the biggest trench mortars evaluated was a 11-inch BL mortar designed by Lieutenant Sutton and built by Armstrong Whitworth, described as a 'miniature heavy howitzer' with a rifled barrel.³³ Fifty of these underwent trials during the second half of 1916 but it was rejected.³⁴ It fired a howitzer-type shell that weighed 200 lb, by far the largest bomb of any mortar in British service, and needed copper driving bands like an artillery shell.³⁵

A few rifled mortars were supplied to the BEF from Britain in December 1914 but these were only stopgap improvisations and thereafter the BEF was equipped exclusively with smooth-bore weapons.³⁶ Rifled mortars tended to be more complex than smooth-bore mortars and were slow to load and fire. The key to trench mortar design was simplicity, a requirement that was reinforced by the urgency of demand, although the armaments firms were unable to resist trying to design scaled-down artillery pieces similar to German trench mortars. Wilfrid Stokes complained in 1918 that the Ministry of Munitions tended to make things more complicated rather than simpler. He recognised that there was a 'tendency to complication' by those skilled in the field of armaments design.³⁷

Ammunition and propellants

There were other types of mortar which dispensed with conventional explosive propellants. These included hydraulic mortars, which used the expansion of a liquid to propel a round, and pneumatic mortars³⁸ which used a gas, typically compressed air. Some were evaluated but none was adopted by the BEF,³⁹ although the French made limited use of a 105 mm pneumatic mortar which the Germans then copied.⁴⁰ Such mortars were largely silent and produced no muzzle flash so that they were difficult to detect but they were more complex than conventional mortars and had slow rates of fire.

Noise and flash were the tell-tale signatures of a trench mortar which, once detected, often prompted a retaliatory artillery bombardment. Almost from the outset, inventors began experimenting with attachments to suppress muzzle flash, smoke and noise⁴¹ but only one, the Temple silencer, was adopted.⁴² This was invented for the 2-inch medium mortar which was particularly loud and produced a considerable muzzle flash⁴³ and a limited number of silencers were available from spring 1916.⁴⁴ It comprised two elements: a muzzle attachment in the form of a chuck, with spring-loaded cones, which restricted the bore at the muzzle to 1.5 inches; and an obturator at the base of the stem. The bomb now had to be fitted with a stem of 1.5 inches diameter, rather than 2 inches, but which widened where it joined the body of the bomb to allow existing bombs to be used with the silencer.⁴⁵ The obturator served to centre the stem in the bore and to prevent the propellant gas escaping from the muzzle. It was an imperfect solution, however, as it caused the barrel to overheat which severely reduced the rate of fire.⁴⁶ An overheated barrel could cause misfires and prematures. Prematures were a

constant problem with trench mortars. Up to fourteen casualties a week could be attributed to prematures with the 2-inch mortar.⁴⁷ No more than six rounds could be fired at the rate of one round a minute before the barrel had to be cooled.⁴⁸ Thus, silenced mortars tended to be used only for night firings when muzzle flash was especially noticeable. The silencer could be fitted and removed quite easily so that dedicated silenced mortars were unnecessary. To load and operate a mortar fitted with the silencer was a rigmarole, especially after having discharged a round. The silencer worked by trapping most of the propellant gases in the barrel which then had to be released by opening the chuck. At the same time, the obturator, which had been stripped from the stem on firing, was ejected from the muzzle. Trapping the gas caused condensation in the bore which had to be sponged out after each round.⁴⁹ It was a far from ideal solution although it did perform the job it was intended to do.

The ammunition fired by a trench mortar could be both time-fuzed and percussion-fuzed. The first improvised mortars fired what were essentially jam-tin grenades, while the bombs fired from the 3-inch Stokes mortars mostly used a fuze adapted from the Mills grenade⁵⁰ because of the difficulties designing a reliable all-ways percussion fuze. The ammunition fired by all trench mortars was high-explosive. Smoke and chemical rounds were fired from some mortars but these were mostly 4-inch Stokes mortars and Livens projectors both of which were operated by the Special Brigade, Royal Engineers, and, hence, outside the scope of this thesis.⁵¹ A mortar bomb usually comprised a cast-iron body to which a steel rod-like stem or fins might be welded.



Fig. 38 9.45-inch heavy mortar. Note the substantial wooden bed and the stack of finned bombs (MUN 5/383/1600/14)

The 9.45-inch mortar, introduced in June 1916, fired finned bombs, popularly known as flying pigs, as did the Newton 6-inch mortar, which began replacing the 2-inch medium mortar from about mid-1917.⁵² Fins did not become standard for Stokes bombs until after the end of the war when a pear-shaped bomb replaced the cylindrical bomb, although Stokes had originally proposed a bomb with fins to stabilise its flight.⁵³ Although long stems were essential to the functionality of some mortars, including the 2-inch, the stems were problematical. They wasted steel and could cause casualties among friendly troops because they were projected back in the direction from whence they came when the bomb detonated.⁵⁴

Unlike other British mortars, the 9.45-inch mortar had a separate combustion chamber below the breech to allow the pressure of the combustion gases of the propellant to reach a particular level before they acted on the projectile and thereby maximised the range for a given charge.⁵⁵ It was discovered that if the chamber was not completely filled with propellant, a short round tended to be the result, although filling the chamber did not entirely eliminate the problem.⁵⁶ Such a chamber made the 9.45-inch more complex than other mortars and when some devices employing the same principal were offered for evaluation they were rejected. It is evident that Newton experimented with improving this mortar⁵⁷ but none of his proposals was adopted although he was granted two patents, GB166149 and GB166162, which relate to mortars with separate combustion chambers.⁵⁸

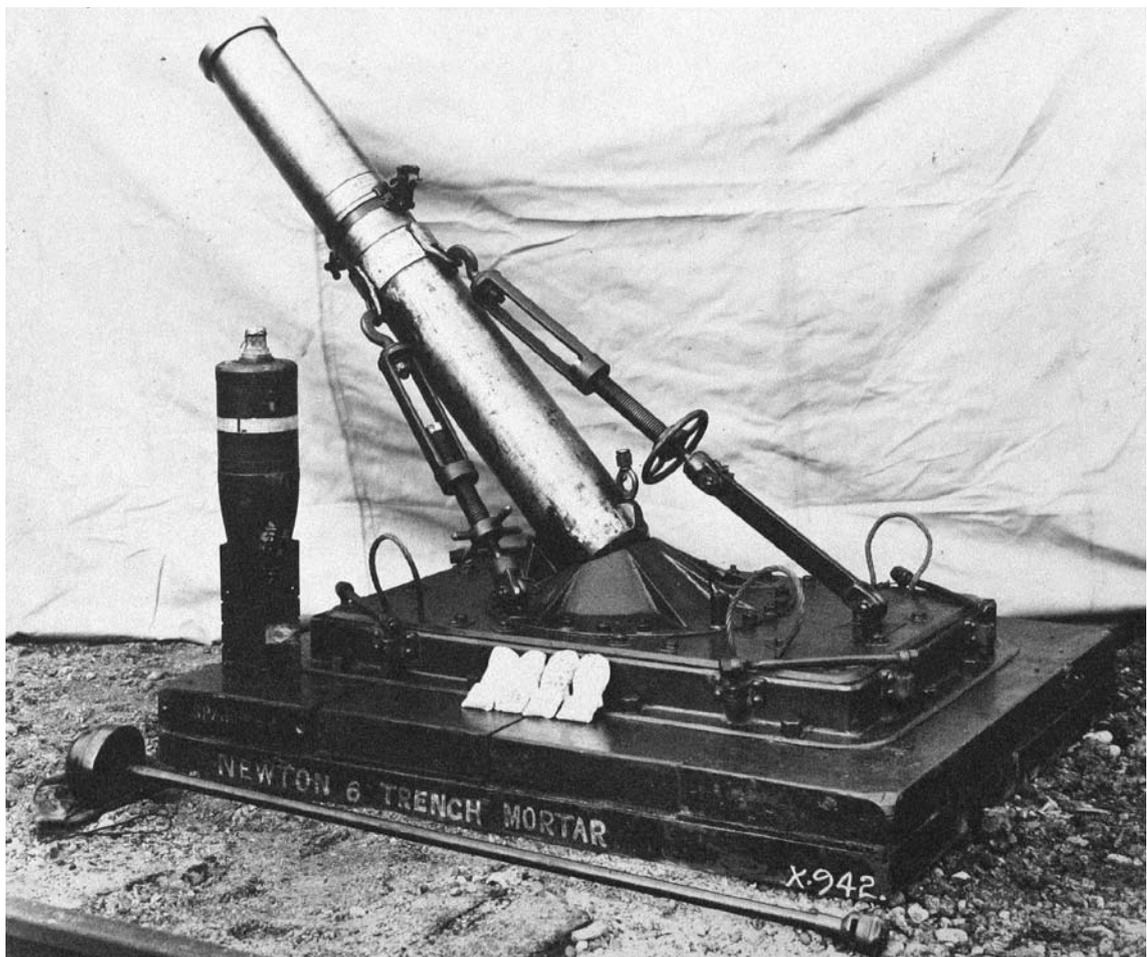


Fig. 39 6-inch Newton mortar with second-pattern guide rods. Note baseplate and bed. The ring-like object on the breech is the misfire plug. Note the finned bomb, fitted with a Newton fuze, and the bagged charges which were fixed between the fins prior to operations. The ramrod is a gas ejector tool (MUN 5/383/1600/14)

Utility of purpose

Whereas light mortars were primarily anti-personnel weapons and relied upon fragmentation of the bomb casing for effect, medium mortars could be used to destroy barbed wire entanglements, provided the bomb was fitted with an appropriate fuze, and to destroy earthworks, which required another type of fuze. However, the bomb of the 2-inch mortar was less than ideal for demolition work since it could not easily bury itself before detonating because of its spherical body. For a mortar bomb to penetrate the ground, it needed an elongated body with a pointed nose. Moreover, such a bomb had to land nose-first which, because the mortars were smooth-bore, required that it was provided with fins to stabilise its flight. Bombs without fins, or a stem to act as a tail, tended to tumble in flight. Such bombs could land in an infinite variety of attitudes. Heavy mortars were only ever used for demolition of enemy trenches and dugouts. Its bomb was finned and had a pointed nose, while its weight ensured that it penetrated the ground. Thus, trench mortars had three functions, depending on the size and shape of the bomb and the type of fuze: anti-personnel, anti-matériel and demolition.⁵⁹

Herein lay two of the limiting factors of any trench mortar: its utility was dependent upon the functionality of the fuze as well as upon the ballistic characteristics of the bomb. The fuze did not have to withstand the high pressures which artillery shells had to tolerate, so a mortar bomb fuze could be much simpler than a shell fuze. The fact that it needed an all-ways functionality, and should only become armed after the bomb had travelled some distance, mitigated against simplicity. Until about mid-1916, no fuze existed which would allow trench mortar bombs, or, indeed, artillery shells, to destroy wire entanglements without severely cratering the ground in the process, thus replacing one obstacle to the infantry with another.

A trench mortar had to satisfy a number of criteria which became more specific as experience with these weapons grew and the drawbacks of certain features became apparent. These criteria related to range, accuracy, rate of fire, reliability, ease of use, noise, muzzle flash, ease of manufacture, the ease with which misfires could be removed, and destructive power. In autumn 1914, GHQ merely wanted some form of trench artillery that was mobile, accurate at short range and destructive.⁶⁰ There is no question that the first mortars improvised by the Indian Corps were very poor in every respect and were little better than the drainpipes they resembled.⁶¹ Their range was no more than about 150 yards, while the jam-tin bombs they fired had little destructive power. They were slow to load and fire and were highly inaccurate. The 3.7-inch and the 4-inch mortars sent out from Britain in late 1914 and early 1915 were little better. Mortars which satisfied GHQ's requirements were far less easy to improvise or re-engineer than hand grenades because a simple smooth-bore tube conferred neither accuracy nor long range on the projectiles fired from it.⁶²

That trench mortars had shorter ranges than artillery was due to the lower chamber pressures of mortars compared to guns: the lower the pressure, the lower the energy acting on the projectile and, hence, the shorter the distance it travelled. Short ranges restricted which targets could be engaged, especially when no-man's-land was wider than the effective range of the mortars, a situation that was worsened by the development of defences in depth from late

1915 onwards.⁶³ Ranges for mortars were typically in the order of 100–250 yards in early 1915 and 300–500 yards in mid-1916. By about mid-1917, ranges had been extended to 800–1200 yards and, by the end of the war, the maximum range had been increased to about 1500–2500 yards, depending on the type of mortar. The heavy 9.45-inch mortar had a range of 1100 yards in 1916. By 1917, this had been extended to 2400 yards. Such ranges compared with 6500 yards for a Mk 1 18-pounder of 1914 and 9300 yards for a Mk 4 of 1918.⁶⁴ An 18-pounder had a 3.3-inch bore which was comparable to that of the Stokes mortar, the maximum range of which was 750 yards in 1917. In 1916, an 8-inch howitzer had a range of 10,500 yards, ten times that of 9.45-inch mortar.⁶⁵ Mortars also had minimum ranges, determined by the size of the propelling charge. The 2-inch and 3-inch mortars both had minimum ranges of 100 yards, while that of the 9.45-inch mortar was six times greater at 600 yards. Clearly, mortars could not engage the same sort of targets as the artillery despite the fact that medium and heavy mortars were looked upon as cheap alternatives to howitzers.

Increases in the range of trench mortars were achieved by a variety of solutions, such as the adoption of improved patterns of mortar, lengthening the barrel, alterations to the design of the bombs, changing the propellant, making the propellant grains uniform in size and shape, and using larger propellant charges. Such measures were not necessarily applied to all patterns of mortar; some were specific to particular weapons. Thus, the 9.45-inch was the only mortar to have its barrel increased in length in order to increase its range: the barrel of the Mk III 9.45-inch was 18 inches longer than that of the Mk I, which more than doubled its range.⁶⁶



Fig. 40 3-inch Stokes mortar with second-pattern stand. Note the small baseplate compared to those of other mortars and the lack of a bed, indicating its suitability for open warfare (MUN 5/383/1600/14)

Increasing the size of the charge in order to extend range was potentially dangerous; the bigger the charge, the greater the pressure in the barrel with a consequently greater risk of the barrel rupturing. The lower pressures in a trench mortar barrel allowed it to be much thinner than a gun barrel but a thin barrel reduced its tolerance for more powerful charges than it was intended to withstand.⁶⁷ Pressure was also dependent on the rate at which the propellant burned; the faster it burned, the faster the rate of increase in pressure in the breech. A slower-burning propellant needed time for the pressure to reach the required level. This led to the use of shearing pins in the barrel which prevented the projectile from moving until the required pressure had been reached at which point the pins were sheared by the bomb as it was propelled up the bore. The pins were intended to improve range and accuracy by ensuring that all the propellant was burned.⁶⁸ In 1915, shearing pins were used, for example, with the 3.7-inch mortar sent out from Britain and the 3.7-inch mortar devised by Newton at the Second Army Workshops. Unfortunately, the pins slowed the rate of fire and the system was dependent upon all the pins having the same shear strength. Inconsistently burning propellants also caused misfires and shorts with consequent dangers to the operators and to friendly troops in front of the mortar position.

The first improvised mortars were fired by lighting a length of safety fuze inserted in a breech vent in the manner of a cannon. This only worked when the propellant was black powder which could be ignited by a flame but black powder had the considerable disadvantage of producing a lot of smoke which gave away the presence of the mortar. When cellulose nitrate propellants, such as guncotton, were substituted for black powder the propellant was ignited by the same friction tubes that were used to fire artillery pieces but the demand by the latter was so great that an alternative had to be found.⁶⁹ Thus, the firing mechanisms of Lee Enfield rifles were fitted to mortar breeches and the magazines were loaded with blanks; a blank released sufficient energy to ignite smokeless propellants. The time it took to load the propellant, which had to be rammed home in the manner of a muzzle-loaded cannon, followed by the bomb, then fire it meant that the best rate of fire which could be achieved was two or three rounds a minute for a 2-inch mortar. The Stokes, on the other hand, could easily fire twenty or thirty rounds a minute.⁷⁰

Mortar bombs fly at subsonic speeds and the time for one bomb to travel a given distance depended on the angle of fire as well as on the weather conditions. A 3-inch Stokes bomb, fired at 45° took 7.1 seconds to travel 240 yards, while it took 15 seconds to travel 800 yards at the same angle of fire.⁷¹ Thus, at a rate of fire of twenty rounds a minute, it was possible for a single mortar to shoot two rounds at the 240-yard target before the first one landed, while five could be fired at the longer-range target. If one Stokes half-battery⁷² of four mortars fired on the 240-yard target, eight rounds would land on it in about 7 seconds, while at twenty rounds a minute, a total of sixty rounds would hit the target area.

Trench mortars were often fitted with periscopes to allow them to be layed without anyone raising his head above the parapet. However, the usefulness of periscopes is doubtful due to their small field of view. Clinometers and dial sights were more efficient and less prone to error.⁷³ Due to the fact that mortars tended to be in permanent positions, it became

common practice to mount the mortar on a large wooden sub-bed so that it did not sink into the ground with repeated firings. A sub-bed could almost double the range of a mortar by providing a more stable platform.⁷⁴ This was a constant problem made worse when the ground was wet. Such beds could be substantial platforms that weighed as much as the mortar itself. The necessity of the beds tended to render mortars immobile. Indeed, only the 3-inch Stokes mortar was truly mobile, although it, too, used a wooden bed when the mortar was located in a fixed emplacement. The bed had to be left behind during a rapid advance. However, the modular construction of the mortar allowed it to be easily broken down into its four constituent parts, each of which could be carried by one man.

Lethality and destructiveness

The lower barrel pressures of a trench mortar had the advantage that the wall of the bomb it fired could be much thinner than that of an artillery shell. Thus, a mortar bomb of a given weight carried a larger explosive charge than an equivalent artillery shell. As discussed in relation to hand grenades, a bigger explosion did not necessarily mean a larger number of fragments, however, but fragmentation was only a factor in anti-personnel bombs and bombs intended to destroy barbed wire. Rounds intended for destroying trenches and dugouts did not need to produce any lethal fragments since their effect lay entirely in the explosive force.

The utility of any mortar bomb depended on its flight characteristics for this determined the likely attitude of the bomb when it landed. Unlike an artillery shell where the rifling of the barrel imparts spin on the projectile to stabilise it, a mortar bomb fired from a smooth-bore tube does not spin. Hence, the bomb is unstable unless some other means is used to provide stability. A bomb with stable characteristics is aligned with its trajectory. During the First World War, such a bomb was cylindrical with a pointed nose and a finned tail or it was spherical with a long cylindrical tail. A bomb with unstable characteristics tended to tumble in flight so that it might land in any one of an infinite variety of attitudes. Such a bomb was typically a cylinder with no tail. The Stokes mortar bomb was of the tumbling type. Despite having a stubby tail, its length in comparison to the length of the bomb was insufficient for it to act as a stabiliser. In 1918, a French pear-shaped finned bomb was evaluated and eventually adopted, after some modification, for the Stokes but it did not enter service until after the war.⁷⁵ The Stokes bomb tended to lie on the ground before it detonated because of its unstable flight characteristics which prevented the bomb from landing nose-first like an artillery shell. Inevitably, this had an effect on its lethality.

One of the first people to investigate the effect of orientation on lethality and destructiveness was Henry Newton. In 1916, he concluded that an ogival bomb stabilised by fins which landed at a steep angle nose-first was the most lethal of the bombs then in service.⁷⁶ Most of the blast of such a bomb was directed forwards from the major axis of the bomb and, hence, most of the blast and fragments from the body were directed towards the enemy.⁷⁷ Thus, the detonation wave did not expand cylindrically but asymmetrically according to the shape of the bomb, its orientation relative to the ground when it detonated and the direction of flight.

The spherical bombs fired by the 2-inch mortar were much less effective than experiments conducted with spherical hand grenades might have suggested,⁷⁸ especially when the mortar bombs were used to destroy barbed wire. Newton concluded that only about 10 per cent of the fragments produced by 2-inch bomb had any effect.⁷⁹ This corresponded to a narrow disc of the spherical detonation wave from the bomb. Essentially anything below the disc would go into the ground and anything above it would go over the target. Ley, who conducted the fragmentation experiments with hand grenades, concluded that a spherical bomb produced better fragmentation than a non-spherical grenade because the detonation wave was spherical but he made no comment on the directionality of the fragments or on the percentage that might be effective.⁸⁰ Newton also concluded that the 3-inch bomb was less effective than the 2-inch bomb for destroying barbed wire because of how the former was likely to be orientated when it exploded. He made the point that neither the fuze nor the end of the 3-inch bomb broke up on detonation. Most of the fragments would go upwards at angles which would carry them over the top of targets. Thus, cylindrical bombs were highly inefficient and their lethality was low compared to streamlined fin-stabilised bombs which landed nose first. The bomb of the 6-inch Newton mortar was comparable in size to that of the 2-inch which it superseded; it weighed 52lb of which 10lb was explosive. However, it was more lethal because its shape meant that more of its fragments were directed at potential targets.⁸¹

A measure of destructiveness of a bomb fired by any mortar was the size of the crater it produced, although this inevitably varied according to the nature of the ground and the prevailing weather conditions. A 9.45-inch bomb weighing 152lb, of which 56lb was high explosive, produced a crater 10 ft deep and 24 ft across, whereas a 2-inch mortar bomb weighing 51 lb, of which 12.5lb was high explosive, produced a crater about half that size, while a 3-inch Stokes bomb produced a crater only 2 ft by 4 ft with its 2.25 lb of explosive.⁸² Clearly, the Stokes was less useful in destroying trenches and dugouts than the 9.45-inch. The discussion about the percentage of effective fragments notwithstanding, the size of the crater produced by the Stokes bomb shows that it was, indeed, very destructive because the effect of the blast would have been lethal some distance beyond the crater rim.⁸³

Not surprisingly, the size of the bomb effected the rate of fire. It took 6 minutes to load and fire a 9.45-inch bomb, while it took 2 minutes to load and fire a 2-inch mortar.⁸⁴ This compared with twenty or thirty rounds a minute for the Stokes mortar. An aspect of lethality or destructiveness that bears on the utility of a mortar is the number of rounds that need to be fired in order to destroy or incapacitate a target. This could be calculated using the laws of probability, a branch of mathematics. The formula used seven variables, including the depth and size of the target, probable errors in range and direction, as well as the destructive area⁸⁵ of the bomb.⁸⁶ From this it is clear that lethality was an important quantifiable datum which had a bearing on logistics. Although figures could be calculated to provide a logistical plan prior to an operation, such figures could not guarantee that a target would, indeed, be destroyed or incapacitated because the figures were expressions of probability not certainty. Nevertheless, the greater the accuracy of the mortar, and the greater the destructive power of its bombs, the fewer that would be needed to destroy a given a target. From this, it was

possible to calculate what might be termed the trade-off point beyond which an increase in the number of bombs fired produced no discernable advantage; when presented graphically, the curve of the plot of number of bombs against destruction tended towards infinity. Hence, there was a maximum number of bombs that could be usefully expended on a given target beyond which rounds were being wasted. This became especially pertinent to the Stokes mortar because of its high rate of fire which meant that far more bombs could be expended on a target than would have been possible hitherto.

Functionality

The functionality of a trench mortar had five aspects, namely, that of the mortar and its mounting, the firing mechanism, the bomb it fired, the bomb's fuze, and the composition and quantity of the propellant. Not surprisingly, these were co-dependent.

The barrel was essentially the same for all mortars in British service only differing in length and calibre, although they were not all made by the same process. Indeed, a variety of processes were used to make the barrels, the most efficient of which was that employed by the Mannesmann Tube Company which supplied Stokes mortar barrels and Livens projector tubes from about mid-1917 onwards.⁸⁷ The barrel of a mortar acted as no more than a smooth-bore tube of a length sufficient to impart directionality on the projectile and allow the propellant gases sufficient time to act on the projectile to accelerate it to a velocity that would propel it far enough to hit a target at a given distance. Without a barrel, neither velocity nor directionality would have been possible. This was one reason why bomb-throwers and, indeed, cup dischargers, were less accurate and had shorter ranges than trench mortars. Rifling would have imparted spin on the mortar bomb, thereby stabilising its flight which would have increased its range and accuracy but rifling was too costly and too complex a process which would have negated two of the chief benefits of trench mortars, namely, cheapness and simplicity.

In all other respects, trench mortar patterns differed quite substantially so that they were more dissimilar than they were alike. The mountings, for example, were all different. That of the 2-inch mortar was fairly crude in comparison to later mortars such as the Stokes and the Newton, while the mounting of the 9.45-inch was more gun-like in that it engaged its mounting via self-locking gears, invented by a Mr W Heap,⁸⁸ by which the barrel was lowered for loading and elevated for range but which locked when the mortar was fired, and lacked separate limbs to support the barrel. The 2-inch mortar had one such limb, in the form of a non-adjustable bipod provided with a simple gear arrangement for elevating the barrel, while the Stokes mortar had an adjustable bipod surmounted by a traversing mechanism which engaged the barrel by means of a ring clamp.⁸⁹ The barrel could be elevated or lowered via a threaded bar that ran vertically from the traversing gear through a horizontal cross stay between the legs of the bipod. Thus, each acted independently of the other so that traversing the barrel did not alter its elevation. The legs on the first 2000 3-inch Stokes mortars were inverted A-frames but these were found to be too flimsy and stronger tubular steel legs were fitted to later Stokes mortars.⁹⁰ The 6-inch Newton used three adjustable rigid guy rods, similar

to those used to tension suspension bridges. Unfortunately, such an arrangement meant that any adjustment for elevation caused the mortar to traverse; at ranges beyond 1000 yards the angular error became significant so that the bombs missed their target.⁹¹

Firing mechanisms of trench mortars were far simpler than those on artillery pieces, largely because mortars did not require quick-locking breech mechanisms which had to be made gastight. Although mortars such as the 2-inch and the 9.45-inch used Lee Enfield rifle mechanisms to fire blanks to ignite the propellant, such an approach was merely an adaptation of the methods that had been used to fire siege mortars, whereby a flame was applied to a fuze inserted into a breech vent. Indeed, before the use of rifle mechanisms, artillery friction lighters had been used on the 3.7-inch and 2-inch mortars. These were practical solutions to the problem of firing a muzzle-loaded weapon. Friction lighters were discontinued because their use with mortars conflicted with their use with artillery. None of these approaches to mortar firing mechanisms was novel. The system devised by Wilfrid Stokes was not only novel but represented an inventive leap.

Stokes had no knowledge of guns but was encouraged to address the BEF's shortage of mortars by H A Gwynn, the editor of *The Morning Post*, following the latter's visit to the Western Front in late 1914.⁹² The approach taken by Stokes was very different from that taken by Woolwich and the armaments firms. Indeed, Stokes approached the problem of how to provide the BEF with what it needed from an entirely different direction, one which, initially, looked to be not only Heath Robinson but quite without promise. The role of failure in the process by which Stokes eventually invented the mortar which subsequently bore his name has tended to be understated or overlooked in accounts of the invention of the Stokes mortar.⁹³ Stokes himself fully appreciated its importance and was more than happy to say so. Rather than trying to devise what was in essence a gun, about which he knew nothing, he decided that he would first invent a bomb, although he knew nothing about bombs, either. This was his 'bouncing cracker bomb', a novel concept but, as it turned out, quite unworkable.⁹⁴

The bomb was a multiple-chambered cylinder, the lethality of which relied upon its entire mass striking a target in the manner of roundshot.⁹⁵ Each of its interconnected chambers contained an explosive charge which, when successively detonated, was supposed to propel the bomb forwards again so that it 'bounced'.⁹⁶ His expectation of what the bomb ought to do was not borne out by experiment and Stokes was unable to produce a workable device. He eventually abandoned the bouncing bomb in favour of a more conventional projectile.⁹⁷ In the process, Stokes invented a novel means of launching the bomb almost by accident. Had he not conceived a bouncing bomb with multiple chambers, it is unlikely that Stokes would have invented a novel way of launching it.⁹⁸ With hindsight, it is easy to condemn the bouncing bomb concept as ludicrous, especially as Stokes failed to make it work.⁹⁹ Nevertheless, it was an important step in the process of inventing the Stokes mortar system.

The bouncing bomb had an internal axial chamber for the propellant charge for which Stokes selected a 12-bore shotgun cartridge minus the shot.¹⁰⁰ Stokes had initially used black powder as the propellant but this proved to be problematical so he experimented with alternatives and chose a propellant used in sport shooting. This was innovative but it posed a

difficulty he had not anticipated; the pressure was too great for the bomb so that it burst in the breech.¹⁰¹ When Stokes developed a conventional projectile, to obviate this problem, he placed the cartridge in an external cylindrical housing provided with radial holes, the number of which and their spacing he determined by trial and error.¹⁰² The holes prevented the housing from rupturing yet allowed sufficient pressure to develop to propel the bomb out of the barrel. The breech of the mortar was provided with an integral striker to engage the primer cap of the propellant cartridge in the tail of a bomb when the latter was dropped down the barrel. The bomb fell on to the striker under the effect of gravity alone due to the angle of the barrel and the windage between the bomb and the bore which prevented friction but reduced the range.¹⁰³ When the cartridge hit the striker, the propellant was ignited and the bomb was propelled up the bore.

Because of the subsequent ubiquity of this system, it now seems obvious to put the propellant cartridge in the tail of the bomb and to load and fire a mortar in such a manner but in December 1914, when Stokes first thought of this system, it was not only novel but it also represented a substantial inventive leap. Indeed, Stokes patented both the mortar and its bomb.¹⁰⁴ However, the mortar and bomb as adopted by the BEF had been developed beyond what was described in the patents so that the service equipment differed in several crucial respects. No previous gun or mortar had been provided with a firing system of this sort and, as a consequence, evaluators insisted that the weapon be provided with a safety mechanism to prevent a bomb from sliding down the barrel and being fired. Clearly, a conceptual leap was required before the advantages of such a system could be realised. It was ingenious in its simplicity because the system contained no moving parts and the rate of fire was solely dependent upon the skill of the loader and the quantity of bombs available to him. Nevertheless, its simplicity concealed difficulties which did not arise with other types of mortar nor came to light until Stokes tried to solve other problems with the mortar. Until these problems were solved, the Stokes was no better than any other mortar and its adoption merely substituted one set of problems for a different set.

Many of these problems related to the firing system, the very aspect of the mortar that made it unique. The mere provision of a spike-like projection in the breech to fire the cartridge in the bomb was not enough to make the concept workable.¹⁰⁵ Indeed, an important part of the inventive process was devising a striker which ensured reliable ignition and avoided a pressure overload in the breech which would cause the barrel to burst. A crucial aspect of the cartridge housing and striker arrangement was that they cooperated in the formation of an expansion chamber when they engaged.¹⁰⁶ The volume of the chamber determined the pressure in the breech for a given charge of propellant which burned entirely inside the cartridge located in the housing, thereby ensuring that fouling was kept to a minimum and that the pressure was consistent. This would not have been the case if burning propellant was expelled into the expansion chamber through the apertures in the housing. It was prevented by the strength of the cartridge wall and consistently sized propellant grains which all burned at the same rate. Thus, the length of the striker and the length of the housing determined the minimum thickness of the breech wall for a given charge and determined the maximum

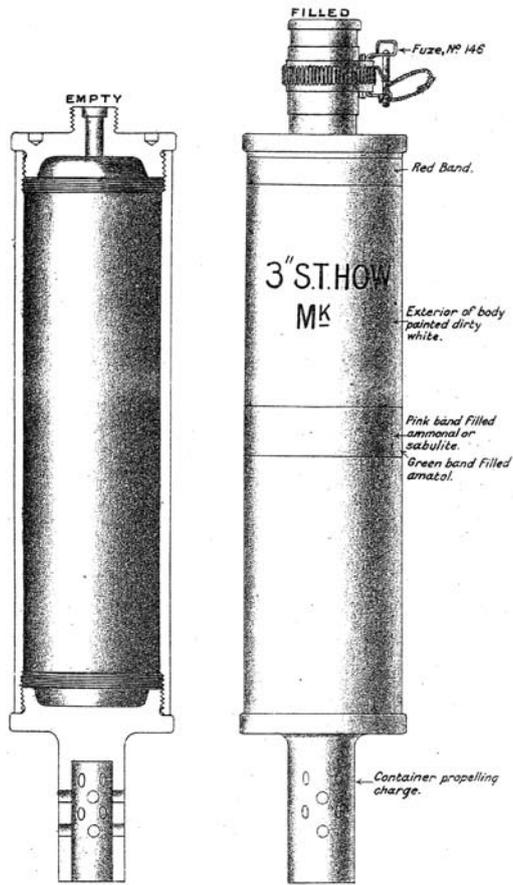
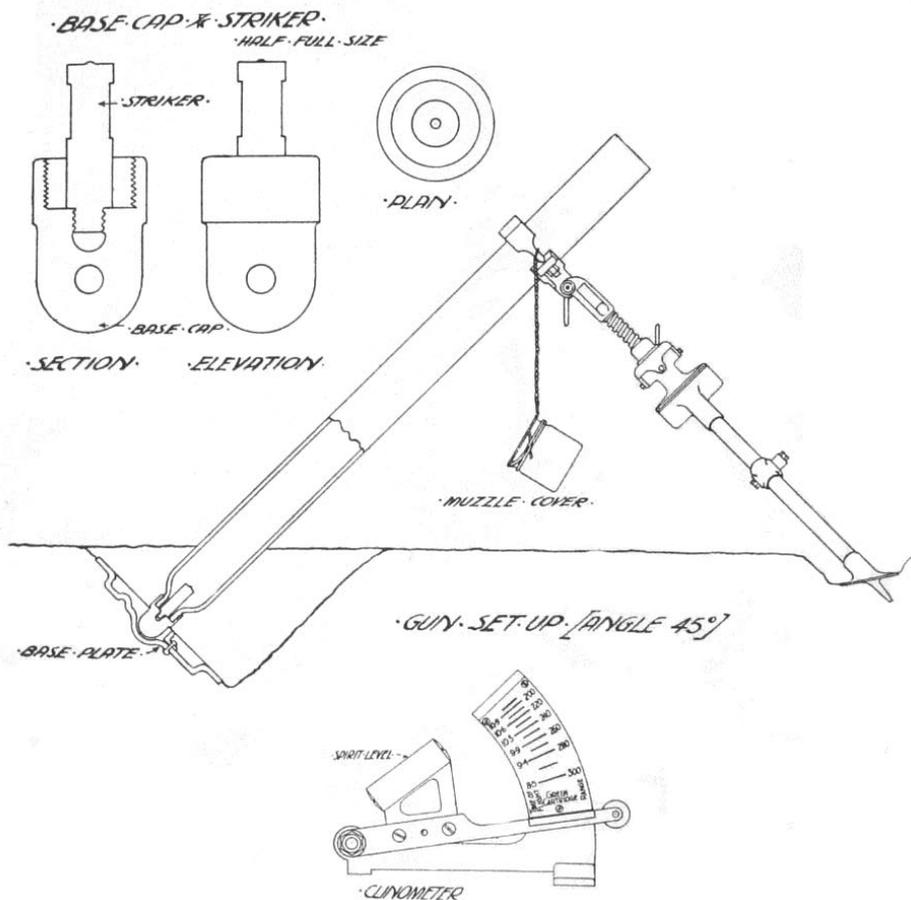


Fig. 41 (left) Bomb for the 3-inch Stokes mortar. Note the cartridge housing and the No. 146 fuze (Handbook of the ML Stokes 3-inch Trench Mortar Equipments)

Fig. 42 (below) This diagram shows the striker and its relationship with the breech. The striker does not enter the cartridge housing. Note the clinometer (WO142/221)



range that could be achieved when the mortar was set at 45°, the optimum angle of elevation. This was an important difference between the Stokes and other mortars then in service.

The size and shape of the striker were fundamental to the correct functioning of the system if misfires and prematures were to be prevented. The striker had to be robust enough to resist bending and dislodgement from repeated use and from being hit by cartridges in misaligned housings. The diameter of the striker was greater than the inner diameter of the housing to prevent the striker from entering and thereby reducing the size of the expansion chamber which might cause the barrel to burst because of the excess pressure. It also ensured that the primer of the cartridge was always struck cleanly. In order to aid this, the upper face of the striker was made slightly convex and the centre was provided with a small projection which acted as a firing pin. The shape of this projection affected how the primer was struck; it was possible for the projection to deform the primer cap and partially close the flash hole into the body of the cartridge which caused a misfire or a short round due to incomplete combustion of the propellant. Stokes originally provided the striker with a conical projection but this proved to be problematical as it often miss-hit the primer. This was replaced by a smaller hemispherical button to prevent miss-hits.¹⁰⁷

Stokes conceived of three strengths of cartridge for three ranges at a given angle of elevation, from 50 yards to 450 yards, each being colour-coded and touch-coded with raised areas for easy identification. This, too, was innovative. The most powerful of these, the red cartridge, caused prematures so it had to be withdrawn in late 1916.¹⁰⁸ A novel approach to increasing the range was devised by Henry Newton while he was still in command of the Second Army Workshops and subsequently became standardised for the 3-inch Stokes in March 1917.¹⁰⁹ His invention became known as the incremental ring charge and extended the range of the bomb without raising the pressure in the chamber. Extending the range of a mortar by increasing the propellant charge was not novel as this was common practice with siege mortars although the powder had always been loaded loose.¹¹⁰ A similar system was devised for larger mortars using bags of propellant.¹¹¹ Up to four rings of additional propellant could be used. At the time of their introduction, the ring charges were seen as an interim measure to make up for the loss of range caused by the withdrawal of the most powerful cartridge. Within a few months, however, they had become standard.¹¹² The maximum range with three rings was 740 yards; without the rings the range was only 420 yards.¹¹³ The increase in range was not an arithmetical progression but a geometrical one. Thus, while two rings offered an increase of 155 yards, the addition of a third increased the range by a further 165 yards. Ring charges allowed a greater flexibility of use of the mortar. They offered the possibility of four or five different ranges with the same cartridge at the same angle of elevation, thereby obviating the need to re-lay the mortar in order to engage different targets, assuming them to be on the same line of sight.

The ring charges were so-called because of their shape and were designed so that they could be slipped around the cartridge holder and were originally made of cambric.¹¹⁴ The hot gases from the primary propellant ignited these secondary charges. The ring propellant burned more slowly than that in the cartridge and thereby prevented the pressure in the barrel exceeding its tolerance. It is curious that Newton does not appear to have patented

the ring charge for it was certainly patentable as evidenced by the fact that Stokes patented a variation on this theme at the beginning of 1918.¹¹⁵

Normally, as a projectile travels up the bore, the pressure reaches a maximum at a certain distance but decreases thereafter because the volume which the gases fill is increasing. By using additional charges of propellant to augment the charge in the cartridge the rate of decrease in pressure was slowed or entirely inhibited so that the maximum pressure acted on the projectile for longer, thereby increasing its velocity which increased its range. A cellulose nitrate propellant called Ballistite, patented by Nobel in 1887, was initially selected for the ring charges but was soon replaced by cordite which increased the range to more than 800 yards.¹¹⁶ Unfortunately, cordite also increased the muzzle flash and the muzzle blast. Moreover, it was difficult to obtain cordite of the right thickness; its rate of burning was dependent on the thickness of the cordite.¹¹⁷ Although a flashless alternative to cordite was eventually found, the newest ring charges were too late to see operational use.¹¹⁸ There was a problem finding a suitable material from which to make the rings. It had to be completely burned in order to prevent fouling of the bore. Celluloid, a flammable synthetic polymer based on cellulose nitrate, was tried but it did not always burn uniformly so that not only were unburned pieces left in the barrel but the propellant in the ring also burned inconsistently because the unburned celluloid acted as an inhibitor.¹¹⁹ It also tended to absorb moisture which altered its burning characteristics.¹²⁰

Second-generation developments

When Newton devised the 6-inch mortar in 1916, he adapted the Stokes firing system because it was efficient and had a high rate of fire.¹²¹ It was inevitable that the Newton mortar would be slower than the Stokes purely because the Newton bomb was heavier than the Stokes bomb so that the 6-inch mortar took longer to load. Nevertheless, the Newton had a far higher rate of fire than its predecessor, the 2-inch mortar, which made it more effective because of the number of rounds that could now be put on to the target in a given period of time.

The Newton mortar used a simple stud, instead of a striker of the form employed in the Stokes, and a cartridge which incorporated its own striker.¹²² This overcame the necessity of an accurately positioned and undisturbed striker in the breech for correct detonation of the cartridge. The Newton cartridge had a spring-mounted striker that clipped on to the brass rim of the cartridge, the striker facing the cartridge primer cap.¹²³ A cup-shaped guide plate was attached to the opposite face of the clip. The clip acted as a spring which, in its unflexed state, kept the striker away from the primer cap. The guide plate, being wider than the diameter of the cartridge, ensured that, under the weight of the bomb, the stud always forced the striker, against the spring, into the primer cap, thereby reducing the possibility of a misfire or a short round. The adapted cartridge became known as the striker clip. This system was so successful that the striker clip was adapted in late 1917 for the 3-inch Stokes mortar.¹²⁴ Rather than the spring clip of the Newton cartridge, the new Stokes cartridge had a striker disc in which the striker was riveted to the end of an arm in the form of a segment of the disc. The disc was held in place by four nicks in the guide plate.¹²⁵ This simple arrangement

increased the utility of the Stokes mortar by reducing the incidence of misfires. Although the bombs of the 9.45-inch mortar were too heavy to be loaded and fired like Stokes bombs, the clip system simplified and speeded up loading and firing the heavy mortar, thereby making it more efficient. Thus, the system, devised by Newton, became universal to all mortars in BEF service although its form varied according to the type of mortar. It formed the basis of second-generation firing systems.

In 1919, Newton made it clear that he had chosen the Stokes system in preference to any other so as to reduce the number of moving parts to a minimum.¹²⁶ He explained that one reason for devising the cartridge clip for the 6-inch mortar was to eliminate the necessity of machining steel for a holder which was a feature of the 3-inch Stokes bombs. Not only was this costly to make but also wasteful of steel because the holder played no part in the destructive effect of the bomb. Indeed, it was a potential hazard to friendly troops nearby since it was projected backwards when the bomb detonated, a problem that was well known with the stemmed 2-inch bombs.¹²⁷ The 6-inch Newton included another innovation in the form of a means for dealing with misfires which were always hazardous to remove. It was typical to have to disassemble the mortar in order to gain access to the misfired round with all the attendant dangers this presented. The 6-inch Newton included a removable breech plug via which a small charge attached to a length of Bickford safety fuze could be inserted so that the round could be removed by firing it from the barrel.¹²⁸

The Newton's bombs were fitted with fins to stabilise them in flight. Unfortunately, the largest propellant charges deformed the fins which resulted in shorts. Various solutions were tried including bracing struts and corrugations to strengthen the fins but using thicker steel solved the problem.¹²⁹ A similar problem occurred with the fins of the 9.45-inch bombs, caused by the use of inferior steel but when better quality steel was used the problem was resolved. Despite fins, the 9.45-inch projectiles were still unstable so longer fins were tried which resulted in only a slight improvement. The solution was to twist the backs of the fins to impart rotation on the projectile.¹³⁰

The problem of fuzing

The need for percussion fuzes which would allow mortar bombs to perform specific functions, such as destroying dugouts or barbed wire, rather than simply detonate on arrival, itself a difficult object to achieve, led to much developmental work being conducted both in Britain and in France. Work on fuzes of all types, including those for artillery shells and anti-aircraft shells, probably occupied more man-hours than any other field of development during the war.¹³¹ Irrespective of the merits or disadvantages of any one pattern of mortar, its utility was ultimately dependent upon the utility of the fuzes fitted to the bombs it fired.

As in the case of percussion-fuzed hand and rifle grenades, the solution to the problem of efficient fuzing was far from obvious nor easy to resolve. The difficulties of arming a fuze at a safe distance from the mortar and ensuring that it would detonate as required and irrespective of how it struck the ground, while obviating blinds and prematures, were many and complex. This was especially so because fuzes for mortar bombs often had to

be devised from scratch since none existed at the outbreak of the war. The solution was not merely a matter of fitting a fuze designed for an artillery shell to a mortar bomb or of adapting such a fuze for fitment to a bomb, although both approaches were tried. Because of the difficulties of devising workable and reliable impact fuzes for mortar bombs, the first fuzes were time action. The problem with an impact or direct action fuze was the difficulty of using the shock of discharge from the mortar to arm it by means of a mechanism that was set back by inertia because the muzzle velocity of a mortar bomb was much lower than that of an artillery shell.¹³² Typical muzzle velocities for a mortar were 372 ft s^{-1} for the 3-inch Stokes and 489 ft s^{-1} for the 6-inch Newton,¹³³ compared to 1615 ft s^{-1} for an 18-pounder and 2525 ft s^{-1} for a 6-inch field gun.¹³⁴

Before the availability of effective and reliable direct-action fuzes for mortar bombs, time fuzes had to be used. However, this meant that the time of flight of the bomb had to be taken into account.¹³⁵ Two of the first time fuzes were no more than more modern equivalents of the wooden fuzes used on eighteenth-century mortar bombs but these were only used on the early improvised mortars.¹³⁶ The 3-inch Stokes bombs were fitted with what was called a pistol head, an adaptation of the Mills grenade mechanism.¹³⁷ The adapted mechanism incorporated a feature which the Mills grenade lacked, namely, a means of retaining the lever after the pin had been removed. This was a practical necessity since the bomb had to be loaded with the pin removed; with the unadapted Mills mechanism, the lever would have flown off before the bomb could be loaded. Therefore, the pistol head incorporated a safety bolt to retain the lever; it set back on launch, releasing the lever which was now only kept in position by the barrel wall and, when the bomb left the barrel, the lever flew off.¹³⁸

The bomb's fuze used 12.5–13.75 seconds of Bickford safety fuze although it was marked up as 14 seconds in length, lines for seconds and dots for half seconds.¹³⁹ It had to be cut by the fuze setter according to range using these marks. Thus, the effectiveness of the bomb



Fig. 43 The time fuze, adapted from the Mills mechanism, used on 3-inch Stokes bombs throughout the war. Note the two safety pins. The left-hand pin prevents the striker from falling, while the right-hand pin prevents a spring-loaded plunger from falling and freeing the lever (author's photograph of example in Norman Bonney's collection)

was dependent upon the accuracy with which the Bickford fuze had been marked up and subsequently cut.¹⁴⁰ In other words, the error in marking up could be multiplied by an error in cutting so that the bomb might burst in the air or lay on the ground for a few moments before exploding.¹⁴¹ Whereas, in practical terms, the latter situation was unlikely to matter, if the bomb exploded before it reached its target, the effectiveness of the bomb was very much reduced unless, by chance, it exploded directly over exposed troops. Stokes devised a new time fuze and a machine to cut the Bickford fuze to the required length but this was not taken up because of the development of an all-ways impact fuze.¹⁴² Nevertheless, the time fuzes fitted to 3-inch Stokes bombs were far from perfect as they were prone to prematures and blinds.¹⁴³ Other mortars, such as the 2-inch medium, used adaptations of time and percussion (T and P) fuzes designed for shrapnel shells. When the mortar fuze was an adapted artillery fuze, the time delay was often a gunpowder trail within the fuze body.¹⁴⁴

The No. 27¹⁴⁵ time fuze, which had been designated the No. 65A T and P fuze when it had been used on pre-war 2.95-inch and 4-inch shrapnel shells,¹⁴⁶ was fitted to 4-inch mortar bombs and later to the bombs fired by the 2-inch mortar.¹⁴⁷ The percussion element of the No. 65A was disabled in the No. 27.¹⁴⁸ In September 1915, following an investigation of blinds with this fuze, the Ordnance Board told the DoA that the fuze was not sufficiently sensitive for use with the 2-inch mortar and suggested that a conversion of the No. 80, a pre-war T and P fuze used on 18-pounder shrapnel shells,¹⁴⁹ might be more effective.¹⁵⁰ The converted No. 80 used only its time components and as such became the No. 31 but was expensive and slow to manufacture.¹⁵¹ It also had a tendency for blinds.¹⁵² Nevertheless, the No. 31 was used with both the 9.45-inch and 2-inch mortars.¹⁵³

The irony is that the No. 80 was originally a Krupp design which had been shared with Vickers under a pre-war commercial agreement dating from 1902 whereby Vickers was licensed to manufacture and sell Krupp-designed fuzes.¹⁵⁴ After the war, Vickers was sued by Krupp for a royalty on every fuze covered by that agreement that had been manufactured by Vickers between 1914 and 1917, including the No. 80 fuzes.¹⁵⁵ Had another firm made a Krupp-patented fuze during the war, the Trading with the Enemy Act would have precluded subsequent compensation. In the 1920s, Krupp filed a claim for lost royalties on the basis that the agreement had not been nullified under the terms of the 1919 Peace Treaty. Because of the provisions of the Patents Act 1907, Vickers were indemnified by the government in respect of its use of third-party owned patents but the proceedings before the Anglo-German Mixed Arbitral Tribunal were complex and, in 1926, Vickers paid Krupp £40,000 although this was considerably less than the sum claimed.¹⁵⁶ The No. 31 was a Woolwich design, so was outside the scope of the agreement.¹⁵⁷ At least one fuze adopted by the BEF was French but caused no difficulties over rights. This was the No. 134 which was used with the 9.45-inch mortar.¹⁵⁸ It was a clever but complicated design which, although known about in May 1916, did not become available until early 1917 due to manufacturing problems.

One of the first attempts to devise a new time fuze for trench mortars was the No. 28, invented by Lieutenant Francis Sutton¹⁵⁹ in late 1915.¹⁶⁰ The device was intended to be a cheap and simple alternative to the much more expensive adaptations of artillery shell fuzes. Trials

led to modifications to the design after which it was deemed to be satisfactory. Although it was adopted in February 1916¹⁶¹ and orders were placed the same month, delays in the preparation and supply of drawings and in the manufacture and supply of inspection gauges meant that it was June 1917 before the first of the ordered 250,000 No. 28 fuzes were ready for supply to the BEF.¹⁶²

The first successful percussion fuze for a trench mortar bomb was the No. 107, an adaptation of the fuze devised by Newton for the Newton Pippin rifle grenade.¹⁶³ This was the first wire-cutting fuze of any sort to be used by the BEF and was much cheaper to make than other fuzes.¹⁶⁴ Although Newton experimented with his fuze during 1915, it was not

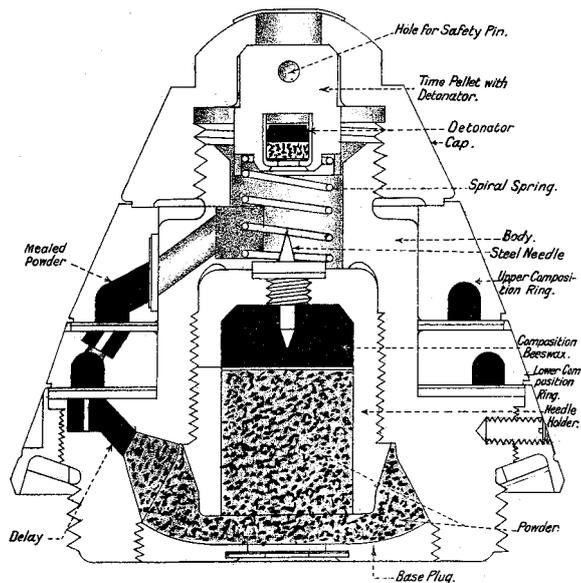


Fig. 44 (left) No. 31 fuze. Its origin was the No. 80 artillery fuze. Note the powder train. Compare with the two fuzes illustrated in Figs 45 and 46 which were devised specifically for trench mortars (Handbook of the ML 9.45-inch Trench Mortars)

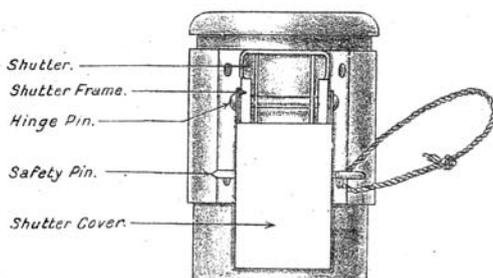
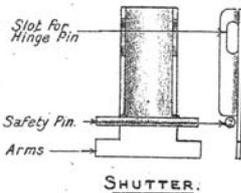
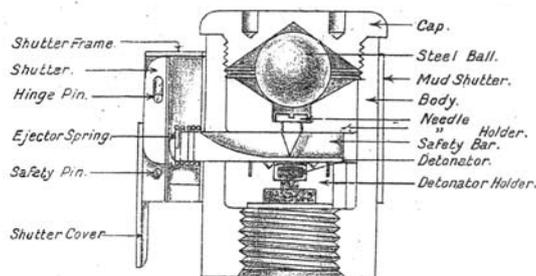
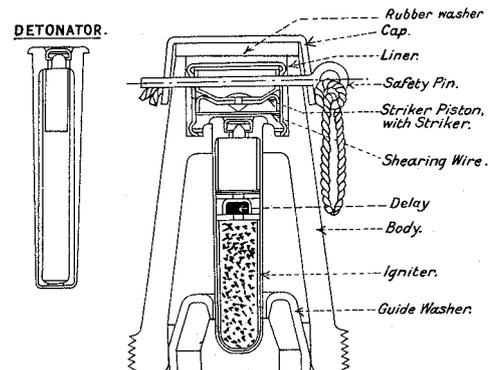
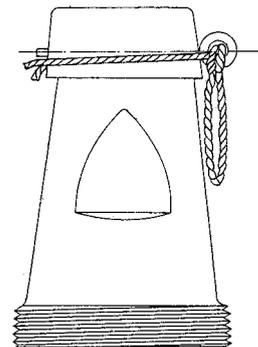


Fig. 45 (below left) No. 148 Mk I fuze. Note its similarity to percussion fuzes for hand and rifle grenades in that it uses a retractable bolt (Handbook of the ML Stokes 3-inch Trench Mortar Equipments)

Fig. 46 (below) No. 110 Mk II fuze derived from the No. 107 Newton fuze (Handbook of the ML 9.45-inch Trench Mortars)



approved for manufacture in Britain until February 1916 and supplies did not reach France until the end of March, by which time, 20,000 a month were being dispatched.¹⁶⁵ However, it did not see widespread use until the opening of the Battle of the Somme for fear of giving away a technological advantage to the Germans; its use would have told them that the British had an efficient means of cutting barbed wire without cratering the ground in the process.¹⁶⁶ Thus, trench mortars had been in operational use on the Western Front for about twenty months before an effective percussion fuze became available and this was only in limited use. By June 1917, the No. 107 had entirely replaced time fuzes on 2-inch mortar bombs.¹⁶⁷ At the same time that the No. 107 began to see widespread use, another percussion fuze, the No. 105, a Royal Laboratory design, began to become available. This was more complex than the No. 107 and more akin to traditional artillery fuzes in concept.¹⁶⁸

The No. 107 was developed into the No. 110 fuze to allow for the larger propellant charge of the 6-inch Newton compared with the 2-inch mortar; the margin of safety with the No. 107 was too low for use with the bigger charge and higher rate of fire of the Newton.¹⁶⁹ Thus, the No. 110 was made less sensitive than the No. 107.¹⁷⁰ Unlike other fuzes, the No. 110 could be set for instantaneous or delayed action¹⁷¹ because it was provided with two types of fuze cartridge, one containing a percussion cap and a detonator, for instantaneous action, and one containing Bickford safety fuze, for delayed action.¹⁷² Thus, the No. 110 followed the principal of adaptability which Newton applied to his other inventions. In essence, all of Newton's fuzes worked in the same way, in that a striker plate impacted the primer cap of a cut-down SAA cartridge which ignited the



Fig. 47 (left) No. 107 fuze

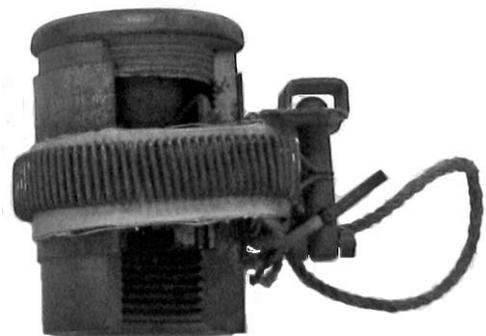


Fig. 48 (right) Cuttaway No. 146 fuze. Note the tape spring which was similar to the tapes used on percussion fuzes for hand and rifle grenades



Fig. 49 (left) No. 105B, a simple percussion mechanism

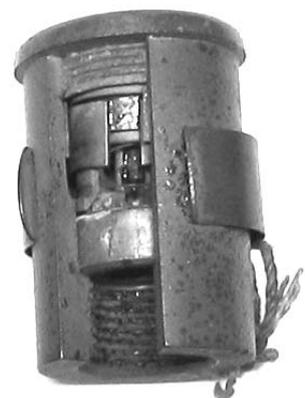


Fig. 50 (right) Cuttaway No. 147 Vickers fuze with clip instead of tape

(author's photographs of examples in Norman Bonney's collection)

detonator or time delay,¹⁷³ although the form of the striker plate differed in each fuze. Unlike the No. 105, they were all simple direct-action fuzes.

During second half of 1917, an all-ways fuze, the No. 146, began to replace the time fuze on 3-inch Stokes bombs. Much time was spent on developing this fuze during 1916 and when it entered service it was still, in effect, experimental.¹⁷⁴ It resembled the percussion mechanisms being developed for hand grenades in that it was a two-element striker system which incorporated a retractable bolt attached to a short tape and a long spring, in the form of flattened helix, which unwound and extracted the bolt thereby arming the fuze. The bolt kept the aluminium needle carrier and the brass detonator holder apart; when it had been extracted, these two elements remained apart but were free to engage under an impact when the inertia of a heavy steel ball, located above the needle carrier, was pushed against the funnel-shaped upper face of the needle holder so that it was urged into the detonator holder, thereby causing the striker to hit the detonator. The inner face of the nose plug was also funnel-shaped or conical so that, together, the faces translated any lateral movement into a perpendicular one. Unfortunately, the mechanism was rather too sensitive making it dangerous to handle and it was prone to prematures, yet it was also prone to blinds.¹⁷⁵ The fuze was patented in 1916.¹⁷⁶ Because the aperture in the fuze body through which the retractable bolt was withdrawn also acted as an access point for dirt when the bomb hit the ground and before the device exploded, an external sliding shutter was later added to close the hole.¹⁷⁷

After much experimentation to improve the fuze,¹⁷⁸ the No. 146 became the No. 148¹⁷⁹ which did away with the tape and spring, using instead an ejector spring retained by a metal safety shutter, which was essentially a pivoted flanged sheet of metal; once released, it swung out of the way to release the bolt.¹⁸⁰ The war ended before this fuze could enter service. Another all-ways fuze, the No. 147, invented by Vickery,¹⁸¹ was developed during 1917 and 1918¹⁸² but was too late to see operational service.¹⁸³ Vickery's mechanism did away with the safety shutter and relied on an internal collar which set back on launch, in a manner similar to the external collar on the Marten Hale rifle grenade, to release the two-element striker pellet.¹⁸⁴ The mud shutter was now located inside the fuze body to prevent ingress of dirt through the hole vacated by the safety pin. Because these fuzes were not used in action, it is uncertain how they would have performed under operational conditions.

Evolution

In the process of developing these impact fuzes for the high-explosive 3-inch Stokes bomb, some thirteen patents were granted over a period of about two years, an indication of the amount of time that was spent on trying to devise reliable all-ways impact fuzes. They were all problematical. Between about the beginning of 1915 and end of the war, excluding the Bickford fuzes of jam-tin bombs fired from the first improvised drainpipe mortars, at least seventeen fuzes were adopted for high-explosive bombs fired by the various patterns of trench mortar used by the BEF. Most of these underwent two or three modifications after having been adopted in attempts to rectify faults or deficiencies in the designs.¹⁸⁵ Of these

fuzes, most were used on the bombs fired by the four mainstays of the BEF's trench mortars, namely the 2-inch medium mortar, its replacement the 6-inch Newton, the 3-inch Stokes light mortar and the 9.45-inch heavy mortar. More fuzes were devised for the high-explosive 3-inch Stokes bombs than for any other, most of these between 1916 and 1918, indicating the increasing importance of this mortar to BEF operations.¹⁸⁶ Yet, this also demonstrates the inability of engineers to develop a reliable all-ways impact fuze, a difficulty that was mirrored by a similar problem with percussion-fuzed hand grenades.

In 1914, the trench mortar was perceived as a cheap alternative to conventional howitzers, although it was acknowledged that mortars lacked the range and reliability of howitzers.¹⁸⁷ The mortar was no more than a stopgap intended to counter the mortars being used by the German army. The lack of range and reliability of the first mortars operated by the BEF did not suggest that such weapons might play a significant role in trench warfare. Indeed, the BEF had far too few of them and only small amounts of ammunition to use mortars as anything other than nuisance weapons. Although the numbers of mortars and the amount of ammunition increased during 1915 and 1916, and although the older less effective mortars were superseded during this period by superior weapons, nevertheless, the trench mortar remained a weapon system in limbo. This was due to their short range and the lack of reliable fuzes. Ultimately, the utility of a trench mortar depended upon the utility of the fuze fitted to the bomb it fired. If the fuze failed because it was blind or too sensitive and caused a premature the utility of the mortar itself was irrelevant. Such a relationship was, of course, well known to manufacturers of ordnance and to artillerymen but it had to be re-learned and applied to a new class of weapons, namely, trench mortars.

The problems with trench mortars were not the same as those with artillery or with hand and rifle grenades, although there were similarities. Percussion fuzes for grenades presented the same problems of prematures, blinds and safety and, inevitably perhaps, because of the low velocities of grenades and mortar bombs, some of the approaches were common to grenades and mortar bombs. Indeed, the lower muzzle velocities of mortars compared with guns was both an advantage and a nuisance. While it allowed bombs to carry a bigger explosive charge than an equivalent artillery shell, the range, accuracy and rate of fire mitigated against utility. Although mortars were simple in comparison to guns, they were much less effective as a consequence of that simplicity and, although several sections within the Ministry of Munitions dealt exclusively with the development, manufacture and supply of mortars and their ammunition, it took the efforts of particular engineers outside the War Office and the Ministry of Munitions and within the army to address the problems.

By 1917, the situation had changed. No longer was the BEF having to make do with unreliable and inaccurate mortars that were slow to shoot. The accuracy of the 2-inch mortar was fairly typical: at a range of 520 yards, the mean error was 8 yards,¹⁸⁸ while its successor, the 6-inch Newton, had a mean error of 14.6 yards at 1050 yards range,¹⁸⁹ the rate of fire of the 2-inch was about one round every 2 minutes while the Newton's was twelve rounds a minute.¹⁹⁰ Thus, while it took the 2-inch mortar 20 minutes to fire ten rounds to destroy 100 square yards of barbed wire, it took the Newton only 1 minute.¹⁹¹ The error for a 3-inch

Stokes at 385 yards was 3.5 yards.¹⁹² The technical sophistication of the next generation of mortars was a considerable leap forward from the first generation stopgaps. Newton's incremental ring charges combined with a second-generation propellant cartridge of the Stokes type meant that range could be doubled and even trebled without compromising the integrity of the barrel. The 6-inch Newton's bombs were designed from the outset to use the incremental charge system although the supplementary charges were contained in cambric bags rather than celluloid rings because the tail of the bomb was not configured like that of the Stokes bomb. The rate of fire of a Stokes mortar and that of a Newton mortar were such that the weight of a barrage from a battery of four mortars was now capable of rivalling an artillery barrage of the same duration.¹⁹³ This was primarily a technical feat brought about by engineers who had no previous experience of ordnance. Such mortars as these were powerful and effective.

The problems of inventing and developing mortars, their bombs and the fuzes for the bombs was not one of mere scale nor one of simply adapting conventional ordnance and its ammunition. Trench mortars were low-pressure systems which meant that the bombs were subsonic. Thus, all the knowledge and expertise in ballistics that had been acquired over the last fifty or sixty years in respect of artillery was not directly applicable to trench mortars. The problems of trench mortars were not necessarily those of artillery. Indeed, when it came to impact fuzes, the requirements were quite different for artillery shells and mortar bombs. The problems were, in fact, more akin to those of percussion fuzes for hand and rifle grenades. Similar solutions to the question of safety were applied to percussion-fuzed grenades and to impact fuzes for mortar bombs, namely the retractable bolt and tape. In neither case, however, was a successful fuze introduced before the end of the war. Nevertheless, while percussion-fuzed hand grenades failed to replace time-fuzed grenades after the war, the converse was true when it came to impact fuzes for mortar bombs.

The light trench mortar, in the form of the 3-inch Stokes, became the standard infantry mortar of post-war armies. Its rate of fire made it a formidable weapon. Once the tumbling bomb had been replaced by a fin-stabilised bomb, authority for which had been approved before the war ended,¹⁹⁴ the lethality of this weapon system turned it into one of the most feared of the Second World War. The incremental ring charge was a major contributory factor in this. Indeed, as with the Mills grenade, the success of the Stokes mortar was due to technical improvements which were brought about by several inventors and engineers working independently to overcome specific difficulties with the first-generation weapon. Thus, not only did the BEF end the war equipped with a weapon system which had not existed in 1914, but the weapon system of 1918 was already second generation. Most of these developments occurred within relatively short periods of activity during which one inventor addressed a technical issue while other inventors addressed different technical difficulties. The success of the Stokes mortar was due to at least five different inventions, namely, the mortar itself, its bomb, the fuzes, the striker clip, and the incremental ring charge. Thus, it is misleading to view the 'Stokes mortar' as a single invention. Without all of the contributory inventions, the Stokes would have been far less effective than it proved to be.

The invention and subsequent resolution of deficiencies of mortars, as indeed, with grenades, occurred very much more quickly than the MGO had envisaged in 1914 as being possible.¹⁹⁵ This was largely because unconventional approaches to the resolution of problems were adopted by engineers who were not constrained by accepted practice in the field of ordnance design. As in the case of grenades, the significant advances in mortar technology were made by people unconnected with the pre-war armaments industry. Thus, pre-war expertise in matters relating to ordnance had little effect on the invention and evolution of the trench mortar and its ammunition. These munitions were created entirely from the ingenuity of particular individuals who applied their engineering skills to the problem of providing the BEF with a cheap form of trench artillery that would be easy to operate yet be highly destructive. It is quite clear that the solutions were much harder to find than the problem was to define.

It is clear from the foregoing that the trench mortars invented and developed during the First World War for the BEF had no relationship with the improvised mortars of the Russo-Japanese War. Even the least sophisticated of the BEF's improvised mortars, the so-called drainpipe mortar, was quite different from the Japanese mortars in every respect. Mortars such as the Stokes and the Newton were not even derived from the improvised mortars of 1914 and 1915. The evolution of British mortars had two strands: traditional ordnance-based developments of which the early 3.7-inch and 4-inch mortars and the later 2-inch mortar were examples; and unconventional innovations of which the 3-inch Stokes and the 6-inch Newton were examples. The future of mortars lay with the latter not the former. Indeed, the Stokes mortar represented an inventive and conceptual leap which introduced an entirely new type of ordnance to the battlefield. The Japanese weapons may be seen as curiosities rather than as serious weapons. However, they did inspire the Germans to develop small mortars for trench use prior to the First World War and these were a direct inspiration for the development of British mortars, especially the Stokes.¹⁹⁶

It is quite possible that, had the Germans not entered the war with trench mortars, neither the French nor the British would have devised similar weapons because the incentive would have been lacking. However, inventors such as Stokes and Newton might well have devised such a weapon without the impetus of retaliation because they, like so many other British inventors, recognised a need and set about satisfying it. Wilfrid Stokes epitomised this. Thus, by 1918, mortars could be classed on a functional basis as Stokes and non-Stokes types. By the mid-1920s, the Stokes type predominated and most mortars of the Second World War were of the Stokes type.¹⁹⁷ The Stokes type became the archetypal infantry mortar, a type of weapon which had no relationship with the siege mortars of sixty years earlier. One of its assets, indeed, an advantage not shared by any other mortar in BEF service, was its modular construction which allowed it to be disassembled by the team operating it in the field who could then carry the disassembled weapon with its ammunition forward with the advancing infantry so as to provide support for the infantry from a new position. No army entered the First World War with such a weapon system.

Notes

¹ The terms 'trench mortar' and 'trench howitzer' were used throughout the war although, by mid-1917, the official term was 'trench mortar'. The reason 'trench howitzer' continued to be used was one of practicality. To have dispensed with it would have meant amending a great many engineering drawings to show the change and it was thought to be rather pointless to do this. See MUN 5/196/1610/1 Minute on Nomenclature dated 1 August 1917.

² They were also used at the siege of Delhi in the Indian mutiny, 1857, and against the Maori in New Zealand in 1864.

³ Guy Hartcup, *The War of Invention, Scientific Developments, 1914–18*, (London, 1988), pp. 63–4. Eric Dorn Brose, *The Kaiser's Army, The Politics of Technology in Germany during the Machine Age, 1870–1918*, (Oxford, 2001), pp. 168, 169, 188.

⁴ Wolfgang Fleischer, *German Trench Mortars and Infantry Mortars, 1914–1945*, (Atglen, 1996), pp. 3–4. Hartcup, *op cit.* p. 63–4.

⁵ Fleischer, *op cit.* pp. 3–4. Hartcup, *op cit.* p. 64. MUN 5/321A *History of the Ministry of Munitions*, vol. XI *The Supply of Munitions*, Part I *Trench Warfare Supplies*, p. 34. It is significant that in his discussion of technology and the German army, Brose makes no mention of trench mortars, only heavy mortars intended for the destruction of concrete and steel.

⁶ For German mortars see Fleischer, *op cit.* and Major James E Hicks, *Notes on German Ordnance 1841–1918*, (New York, 1937), pp. 45–98. Later in the war, they used smooth-bore mortars as well.

⁷ J E Edmonds, *History of the Great War, Military Operations, France and Belgium, 1915*, (London, 1927), vol. 2, pp. 8–9, fn 2. MUN 5/382/1600/8 Notes on the History of Trench Warfare Research, Aug 1914 – May 1915. *Trench Warfare Supplies*, *op cit.* p. 34.

⁸ It is outside the scope of this thesis to provide a comparative analysis of British and German mortars. However, an examination of the data in Hicks, for example, shows that German mortars, although well-engineered, were technologically less advanced than the Stokes. That is not to suggest that German mortars were insignificant in their effect. On the contrary, they were generally accurate and powerful but none had the flexibility and firepower of the Stokes.

⁹ This was discussed briefly in Chapter 3 of this thesis. The institutionalisation of scientific research and its close association with the military in Germany was not replicated in Britain because Britain was not a militarist state.

¹⁰ Named after the seventeenth-century Dutch inventor of this type of mortar, Menno van Coehorn.

¹¹ *Military Operations, 1915*, *op cit.* p. 8. *Trench Warfare Supplies*, *op cit.* p. 36.

¹² The West Spring Gun and the Leach, or Gamage, catapult being principal among them. See 'The Work of the Royal Engineers in the European War', *The Royal Engineers Journal*, vol. XXXIX, no. 1, March 1925, pp. 78-9; MUN 5/383/1600/14 Lt-Col O F Brothers, 'The Development of Weapons Used in Trench Warfare', pp. 79–80. See also Anthony Saunders, *Weapons of the Trench War 1914–1918*, (Stroud, 1999), pp. 55–66.

¹³ *Trench Warfare Supplies*, *op cit.* pp. 6–8.

¹⁴ It should be noted that the Germans were also forced to use similar devices as were the French.

¹⁵ The French also viewed mortars as poor substitutes for guns, especially in light of their experience at Verdun. See *Trench Warfare Supplies*, *op cit.* p. 63.

¹⁶ *Trench Warfare Supplies*, *op cit.* p. 4.

¹⁷ MUN 5/196/1610/18 memo dated 24 November 1915 from Chief Ordnance Office, Portsmouth to General Jackson, DG of TWSD. The mortars in service with the BEF at that time included 4-inch Royal Gun Factory (RGF) mortar, 3.7-inch RGF mortar derived from the improvised Indian pattern, 2-inch RGF medium mortar, 1.57-inch Vickers stemmed-bomb mortar (similar to the 2-inch RGF model), 3-inch Stokes, 4-inch Stokes (operated by the Special Brigade), 240 mm French mortar (from which was developed the 9.45-inch mortar), and 58 mm French mortar which fired stemmed finned projectiles.

¹⁸ *Trench Warfare Supplies*, *op cit.* p. 61. The mortars were the 2-inch, the 3-inch Stokes and the 9.45-inch; the Special Brigade continued to use the 4-inch Stokes.

¹⁹ One definition of a mortar is a weapon which shoots at angles of at least 45°.

²⁰ Denis H R Archer (ed.), *Jane's Infantry Weapons*, 4th ed., (London, 1978), p. 495. *Trench Warfare Supplies*, *op cit.* p. 4.

²¹ Typical working pressures were 0.6–1.7 ton in⁻² for the 3-inch Stokes, 3.5 ton in⁻² for a 6-inch Newton mortar, 5 ton in⁻² for a 2-inch mortar and 6.5 ton in⁻² for a 9.45-inch mortar. See Brothers, *op cit.* pp. 35, 36. T 173/453 Sir Wilfrid Stokes, KBE, 'The Stokes Gun and Shell and their Development', Third Gustave Canet Lecture, 24 June 1918, offprint from the *Junior Institution of Engineers*, vol. XXVIII, Part 10, p. 7 quotes 1.75 ton in⁻². CSOF recommended less than 1.7 ton in⁻². See SUPP 6/509 Report of Proceedings of Ordnance Committee, Trench Warfare Section, 11 December 1915 to 23 April 1917, p. 42.

²² *Handbook of Artillery*, (Washington, 1925), p. 273.

²³ This is governed by ballistics of which there are two elements: internal and external. The former is concerned with what happens to a projectile inside a barrel, while the latter is concerned with what happens to it outside a barrel.

²⁴ This is not true of field guns because of their flatter trajectories. The velocity of the projectile is a major factor in the flatness of the trajectory; the greater the velocity, the flatter the trajectory. A factor in velocity is chamber pressure.

- ²⁵ Brothers, *op cit.* p. 8; *Trench Warfare Supplies, op cit.* pp. 44, 64.
- ²⁶ Brothers, *op cit.* p. 16. The Newton's legs tended to break because they were not sufficiently robust.
- ²⁷ For methods of making mortar barrels see *Trench Warfare Supplies, op cit.* pp. 15, 43, 44, 45, 47, 57–8.
- ²⁸ Donald Featherstone, *Weapons and Equipment of the Victorian Soldier*, (Poole, 1978), p. 72.
- ²⁹ Hartcup, *op cit.* pp. 64–5, is mistaken when he describes the 4-inch and 3.7-inch mortars as 'heavy' and the 2-inch mortar as 'light'. The latter was a medium mortar, while the 4-inch and 3.7-inch were light mortars. The British only used one heavy mortar, the 9.45-inch.
- ³⁰ Handbook for Stokes Trench Mortar, 3", Mark I, 1916, p. 13. Handbook of the ML Stokes 3-inch Trench Mortar Equipments, Land Service 1919, 1920, ammunition table on p. 13. Artillery Notes No. 6 – Trench Mortars, GHQ, March 1916, Appendix E, p. 20 but also see Handbook of the ML 2-inch Trench Mortar Mark I Land Service 1917, p. 13 which gives different sizes of bomb from 39lb 14oz to 42lb 6oz.
- ³¹ Handbook of the ML 2-inch Trench Mortar, *op cit.* p. 13. The tail was removable and fitted into a socket on the body of the bomb, it was fixed by a pin which passed through corresponding holes in the socket and the tail. For transportation, the bombs were fixed to wooden carriers to prevent them rolling about.
- ³² Brothers, *op cit.* pp. 24–6.
- ³³ Brothers, *op cit.* p. 25.
- ³⁴ *Trench Warfare Supplies, op cit.* pp. 60–61.
- ³⁵ Brothers, *op cit.* p. 25.
- ³⁶ The first rifled mortars were converted 5-inch howitzers from Elswick Ordnance. GHQ did not like them. Woolwich improvised 4-inch mortars by boring out 6-inch Naval shells, then rifled the bores, the first of which reached France by the end of 1914. *Trench Warfare Supplies, op cit.* pp. 34–6. See also *Annual Report of the President, Ordnance Board for the year 1915*, (London, 1917), pp. 306–7, in MUN 5/120/810/6.
- ³⁷ Stokes, *op cit.* p. 1.
- ³⁸ Hartcup, *op cit.* p. 65, mistakenly terms a mortar fired by carbonic acid as pneumatic; it was a form of hydraulic mortar.
- ³⁹ *Annual Report, op cit.* pp. 331, 335.
- ⁴⁰ Fleischer, *op cit.* pp. 4, 22. Hicks, *op cit.* p. 78. *Weapons of the Trench War, op cit.* pp. 139, 140.
- ⁴¹ *Annual Report, op cit.* pp. 307–8. The proposal of Captain Leefe, RGA, for a device to suppress the noise and muzzle flash from the 4-inch mortar, was tested over a period of about five months but rejected.
- ⁴² The Temple silencer is described in *History of the Ministry of Munitions, Trench Warfare Supplies, op cit.* p. 65 as patented but a search of Class 9 (i) Ammunition and Ammunition Receptacles and Class 92 (ii) Ordnance and Machine Guns for the period 1915–22 shows only a patent granted to Armstrong Whitworth for a similar device at about the time that Temple approached the MID. See GB13445/15. This may, in fact, be the Temple device. Without examining the specification, it is not possible to determine that this is, indeed, the case since the abridgment provides insufficient information for such a determination.
- ⁴³ MUN 5/384/1610/2 Trench Warfare Supply History, TW3(B), Medium Trench Mortars and their Ammunition, pp. 2–3.
- ⁴⁴ SUPP 6/509 Report of Proceedings of Ordnance Committee, Trench Warfare Section, 11 December 1915 to 23 April 1917, pp. 36–9; *Trench Warfare Supplies, op cit.* p. 65.
- ⁴⁵ Handbook of the ML 2-inch Trench Mortar, Mark I, Land Service, 1917, p. 2.
- ⁴⁶ MUN 5/384/1610/2, *op cit.* p. 3. MUN 4/2638 6" Newton Trench Mortar, minute dated 12 October 1916, p. 3.
- ⁴⁷ Newton dissertation, *op cit.* page comparing 6-inch Newton mortar with 2-inch Woolwich mortar.
- ⁴⁸ Handbook of the ML 2-inch Trench Mortar, *op cit.* pp. 3–4.
- ⁴⁹ *Ibid.*
- ⁵⁰ Stokes, *op cit.* pp. 13–14; *Trench Warfare Supplies, op cit.* pp. 42, 55.
- ⁵¹ See Maj-Gen C H Foulkes, "Gas!" *The Story of the Special Brigade*, (Edinburgh & London, 1934), for example, pp. 69, 94–5, 99, 109–111, 168–173.
- ⁵² Brothers, *op cit.* pp. 18, 22. Newton papers, *op cit.* Novel Features of Newton Bomb. Handbook of the ML 9.45-inch Trench Mortar, *op cit.* p. 20 and Plates XVI and XVII.
- ⁵³ Stokes, *op cit.* p. 10. No finned bombs were fired operationally by the 3-inch Stokes. See Brothers, *op cit.* pp. 11–12.
- ⁵⁴ Newton papers, mortar comparison page *op cit.* The stems of the latter were solid-drawn steel tubing and each one weighed about 10 lb. Newton claimed that in the course of a week 100 ton of steel could be expended which equates to about 220,000 2-inch bombs.
- ⁵⁵ Adapted from an invention patented by the French firm Société de Construction des Batignolles. See GB16869/15. The British government had to pay for a licence to make the adapted mortar. See MUN5/196/1610/17 Treasury letter dated 30 December 1915 giving instructions to pay Société de Construction de Batignolles patent royalties of £15,000.
- ⁵⁶ Known as fizzles. Brothers, *op cit.* p. 23.
- ⁵⁷ Brothers, *op cit.* pp. 36–7. 'The Work of the Royal Engineers', *op cit.* p. 77.

- ⁵⁸ GB166149 is supposedly concerned with the 6-inch mortar but the specification also concerns a separate combustion chamber, so the specification has elements of the 6-inch and a modification to the 9.45-inch. GB166162 is solely concerned with a combustion chamber with an adjustable volume.
- ⁵⁹ T 173/728 Minutes of the Proceedings before The Royal Commission on Awards to Inventors held on Monday 17 November 1924, Claim of Colonel Newton, pp. 21–2.
- ⁶⁰ *Trench Warfare Supplies*, *op cit.* p. 34.
- ⁶¹ *Trench Warfare Supplies*, *op cit.* p. 36.
- ⁶² A truth rediscovered by the Provisional IRA in the 1980s and 1990s.
- ⁶³ Discussed more fully in the Chapter 8.
- ⁶⁴ I V Hogg & L F Thurston, *British Artillery Weapons and Ammunition 1914–1918*, (London, 1972), pp. 80–3.
- ⁶⁵ Hogg & Thurston, *op cit.* p. 153.
- ⁶⁶ Brothers, *op cit.* p. 21. Handbook of the ML 9.45-inch Trench Mortars, Marks I, II and III, 1918, p. 5.
- ⁶⁷ The barrels of artillery guns had a degree of safety built into their thickness.
- ⁶⁸ Brothers, *op cit.* p. 29.
- ⁶⁹ MUN 5/384/1630/2 Record of History and Work, Ministry of Munitions, Trench Warfare Supply Department, TW3(F), p. 10. TW3(F) was a subsection set up in January 1916 to organise the manufacture and supply of the Sutton No. 28 fuze but it eventually expanded its activities to include propellants, friction tubes and experimental fuzes.
- ⁷⁰ The record was evidently forty-three rounds a minute. Stokes, *op cit.* p. 8 in T 173/453.
- ⁷¹ Range Table for 3-inch Stokes Mortar (Provisional), issued September 1917.
- ⁷² The composition of mortar batteries is discussed in Chapter 8.
- ⁷³ Although sights were important, they are not discussed here due to lack of space. In general, sights were either periscopes or clinometers, the latter being more accurate and more reliable. All trench mortars were provided with periscopes of which there were several patterns. The problems of periscopes are discussed in Saunders, *Dominating the Enemy, War in the Trenches*, (Stroud, 2000), pp. 73–99, especially pp. 97–9 with regard to trench mortars.
- ⁷⁴ Brothers, *op cit.* p. 16.
- ⁷⁵ The Brandt Maurice bomb. This is possibly GB131288 but only Brandt is named as an inventor. See Brothers, *op cit.* p. 12.
- ⁷⁶ Brothers, *op cit.* pp. 29–31.
- ⁷⁷ Brothers, *op cit.* pp. 30–1.
- ⁷⁸ See previous chapter.
- ⁷⁹ Brothers, *op cit.* p. 30.
- ⁸⁰ SUPP 28/40, DGMD/Misc/32 and OB 33/2A/15. See also T 173/802 Minutes of Proceedings before the Royal Commission on Awards to Inventors, claim of Mr Vickery (Mills Grenades) Evidence of Major C E W Beddoes, Thursday, 27th January 1920, pp. 19–21.
- ⁸¹ After the First World War, they were all streamlined and fin-stabilised so that they hit the ground nose-first at a high angle, thereby allowing a high percentage of fragments to be directed at potential targets. Indeed, during the Second World War, when infantry mortars were widely used, the lethality of the bombs was much higher than in the First World War as a direct result of the knowledge that had been gained on the Western Front.
- ⁸² Unfortunately, the ground conditions are not recorded.
- ⁸³ It is unclear how far this might have been but it would have been in order of several feet.
- ⁸⁴ Artillery Notes, No. 6 – Trench Mortars, March 1917, Appendices D and E.
- ⁸⁵ This was not the same as the lethal radius as it referred to the size of the crater.
- ⁸⁶ Manual for Trench Artillery, *op cit.* pp. 75–8.
- ⁸⁷ HO 213/618, Claim in Respect of Stokes Mortar and Shell, The Schedule, p. 4. This was the claim made by Stokes before the Royal Commission on Awards to Inventors in 1919. Brothers, *op cit.* p. 127. *Trench Warfare Supplies*, *op cit.* p. 100.
- ⁸⁸ GB126324, 12 December 1916.
- ⁸⁹ Handbook of the ML 2-inch Trench Mortar, *op cit.* pp. 2–3 and Plate I. Handbook for Stokes Trench Mortar, *op cit.* pp. 5–6, Figs 6 and 7 on pp. 14–15.
- ⁹⁰ For first-pattern mounting see Stokes, *op cit.* Fig. 6; and Handbook for Stokes Trench Mortar, *op cit.* Fig. 1, p. 6. For second-pattern mounting see Stokes, *op cit.* Fig. 11, and Handbook for Stokes Trench Mortar, *op cit.* Figs 6 and 7.
- ⁹¹ Brothers, *op cit.* pp. 16–17.
- ⁹² Stokes, *op cit.* p. 4. Peter T Scott, ‘Mr Stokes and his Educated Drainpipe’, *The Great War*, vol. 2, No. 3, May 1990, p. 81.
- ⁹³ See for example Hartcup, *op cit.* p. 65, and Peter T Scott, *op cit.* pp. 81–5, although Scott does discuss the difficulties faced by Stokes.
- ⁹⁴ Stokes admitted this. See Stokes, *op cit.* pp. 7 and 10.
- ⁹⁵ Stokes, *op cit.* p. 4.

⁹⁶ Each chamber had its own time fuze, of different lengths so that the time interval between bounces was unequal.

⁹⁷ Stokes, *op cit.* p. 10.

⁹⁸ It is, of course, impossible to prove a negative but the impetus to devise a method of launching the bouncing projectile would have been absent.

⁹⁹ The concept was resurrected in 1918 by the MID when it was discovered that the Germans were using a bouncing mortar bomb, although very different in its form and functionality from what Stokes had conceived. It was a development of a spigot mortar which the Germans had been using since 1916. The bomb was supposed to hit the ground and detonate a charge which relaunched the bomb to about head height before exploding to spray fragments downwards in the manner of a shrapnel shell. See MUN 4/3590 New Type of Bomb for "Granatwerfer" (or Stick Bomb-Thrower), dated 11 April 1918; MUN 4/426 MID reports; and Saunders, *Weapons, op cit.* pp. 50 and 123.

¹⁰⁰ Stokes, *op cit.* pp. 11–12. Brothers, *op cit.* p. 10.

¹⁰¹ Stokes, *op cit.* p. 7.

¹⁰² Stokes, *op cit.* p. 11. HO 213/618, *op cit.* p. 5.

¹⁰³ Stokes, *op cit.* p. 12. HO 213/618, *op cit.* p. 4. The windage was 0.025 inch. The reduction in range was only slight.

¹⁰⁴ GB10882/15 (mortar) and GB10883/15 (bomb).

¹⁰⁵ Stokes, *op cit.* p. 4.

¹⁰⁶ Stokes, *op cit.* p. 7. HO 213/618, *op cit.* p. 4. Although Stokes only referred to the length of the striker as determining the size of the chamber, it is clear that the cartridge housing played a similar and complementary role because together they defined the distance between the base of the bomb and the bottom of the chamber which were its upper and lower limits.

¹⁰⁷ Stokes, *op cit.* p. 7. HO 213/618, *op cit.* p. 4.

¹⁰⁸ Brothers, *op cit.* p. 10. SUPP 6/509, *op cit.* pp. 42–5.

¹⁰⁹ Description and Use of Ring Charges in 3-inch Stokes Trench Howitzers, issued by the Ministry of Munitions. See also WO 142/221 for engineering drawing of ring charge, dated 3 July 1917, following a change of propellant and ring material.

¹¹⁰ Featherstone, *op cit.* p. 88.

¹¹¹ Brothers, *op cit.* pp. 19, 23–4. *Trench Warfare Supplies, op cit.* p. 68. Handbook of the ML 9.45-inch Trench Mortar, *op cit.* p. 20 and Plates XIV and XV.

¹¹² Range Table of 3-inch Stokes' Mortar issued in July 1917.

¹¹³ *Ibid.*

¹¹⁴ Cambric is a cotton fabric.

¹¹⁵ The Stokes patent is GB122509, filed at the Patent Office on 8 February 1918. A search of the patent abridgements for Class 9 (i) Ammunition and Ammunition Receptacles for the period 1915–30 shows only one other patent for a ring charge, E J Lane's patent GB125447 of 1916 which describes a similar but more complex system that is rather self-defeating since the advantage of Newton's ring charges lay in their simplicity.

¹¹⁶ Brothers, *op cit.* p. 10.

¹¹⁷ Stokes, *op cit.* p. 12. Brothers, *op cit.* p. 10. Cordite was originally produced in the form of cords, hence its name, but at the time of the First World War, it was mostly produced in a tubular form called cordite MDT.

¹¹⁸ Brothers, *op cit.* pp. 10–11.

¹¹⁹ Brothers, *op cit.* p. 11. The celluloid was that used for photographic negatives. Celluloid was a trade name for a thermoplastic invented in 1856 and made from cellulose nitrate and camphor. It was the first synthetic plastics material.

¹²⁰ *Trench Warfare Supplies, op cit.* p. 67.

¹²¹ Newton filed a patent application on 30 August 1916 but the patent, GB166149, was not granted until 11 July 1921. Although Newton cited this patent as being specific to the 6-inch mortar, this is not quite the case since the specification omits an essential feature of the mortar, namely the Stokes firing system. Indeed, the patent specification refers to a quite different system, namely a rifle mechanism and a separate combustion chamber. Although the accompanying drawings clearly show many aspects of the 6-inch mortar, it is hard to see how Newton could legitimately cite this patent as pertaining directly to the 6-inch mortar. A possible explanation for the omission is that the scope of the Stokes patent, GB10882/15, prevented Newton including a similar, although modified, system in his specification. See Newton papers, *op cit.* page comparing the 6-inch mortar with the 2-inch mortar, contemporaneous with the patent application. However, in MUN 5/383/1600/14 there is a photograph of a blueprint of a breech for the 6-inch Newton which clearly shows an expansion chamber and means for a rifle mechanism to fire the mortar. There is no clear evidence to determine whether this was merely experimental or whether any such mortar ever saw action. Newton makes no reference to it except in his British patent; his corresponding US patents. however, show the 6-inch mortar.

¹²² Newton papers, *op cit.* p. 17, Novel Features of 6" Newton Trench Mortar, undated but circa 1919. It is claimed in *Trench Warfare Supplies, op cit.* p. 66 that the striker clip was adapted from a system already in use on 4-inch Stokes smoke bombs but this is an error. See Brothers, *op cit.*, p. 19. Brothers was one of the sources used to write the *History*.

- ¹²³ Manual for Trench Artillery, United States Army, Part III The Newton 6-inch Trench Mortar, (Washington, July 1918), p. 10 and Fig. 2, p. 34.
- ¹²⁴ WO 142/221, *op cit.* engineering drawing of the striker clip, dated 25 November 1917. See also Handbook of the ML Stokes 3-inch Trench Mortar Equipments, *op cit.* p. 14 and Plate XIV; and Brothers, *op cit.* p. 19.
- ¹²⁵ Handbook of the ML Stokes 3-inch, *op cit.* p. 14 and Plate XIV.
- ¹²⁶ Brothers, *op cit.* p. 33.
- ¹²⁷ Brothers, *op cit.* pp. 33, 34. Newton papers, comparison of 6-inch and 2-inch mortars, *op cit.*
- ¹²⁸ For engineering drawing of Igniter, Emergency, Propelling Charge see WO 142/221, *op cit.*
- ¹²⁹ Brothers, *op cit.* pp. 18–19. Newton papers, Novel Features of Newton Bomb, *op cit.*
- ¹³⁰ Brothers, *op cit.* pp. 22–3. See WO 142/221, *op cit.* for engineering drawings of Mk IV bombs showing this feature.
- ¹³¹ *Annual Report*, *op cit.* pp. 90–195 for work with all types of fuze for 1915. See also Hartcup, *op cit.* pp. 57–60. All shells depended on efficient fuzes in order to function. Fuzes for anti-aircraft shells was a novel area as was the field of trench mortar fuzes. At the same time, fuzes for artillery shells had to be improved and new ones devised. Far more fuzes were developed and manufactured during the war than grenades or mortars. For an indication of the number of artillery fuzes, including anti-aircraft fuzes, used by the British see Hogg & Thurston, *op cit.* table of fuzes over pp. 247–54 which lists 128 fuzes, not including trench mortar fuzes.
- ¹³² MUN 5/196/1610/21 Memorandum on French Trench Howitzers.
- ¹³³ *Handbook of Artillery*, *op cit.* pp. 62 and 194.
- ¹³⁴ Hogg & Thurston, *op cit.* pp. 81 and 145.
- ¹³⁵ See, for example, Handbook for Stokes Trench Mortar, 3", *op cit.* p. 13, Appendix.
- ¹³⁶ MUN 5/196/1610/3, copy of List of Changes in War Matériel and of Patterns of Military Stores (LoC) relating to trench mortars and ammunition, covering approximately January 1915 to November 1916, pp. 16 and 25.
- ¹³⁷ Handbook of Stokes Trench Mortar, 3", *op cit.* pp. 7–8, 12. Stokes, *op cit.* p. 14.
- ¹³⁸ Stokes, *op cit.* p. 14.
- ¹³⁹ *Op cit.* pp. 7–8. Bickford fuze burned at a rate of 2.5–2.75 seconds per inch. See MUN 5/196/1611/4 memo from Captain Lister to General Jackson, dated 14 April 1916. Stokes confirmed that it burned at the rate of about $\frac{3}{8}$ inch per second. See Stokes, *op cit.* p. 13.
- ¹⁴⁰ MUN 5/196/1611/4, *op cit.*
- ¹⁴¹ *Ibid.*
- ¹⁴² The adjustable time fuze and its setting machine were described in GB124809 of April 1916.
- ¹⁴³ Brothers, *op cit.* p. 12.
- ¹⁴⁴ See Hogg & Thurston, *op cit.* p. 217–20; and Handbook of the ML 2-inch Trench Mortar, *op cit.* p. 14 and Plate IV.
- ¹⁴⁵ The numbering of fuzes was not sequential due to the pre-war practice of allocating blocks of numbers to types of fuze.
- ¹⁴⁶ Hogg & Thurston, *op cit.* p. 249.
- ¹⁴⁷ *Annual Report*, *op cit.* pp. 150–1.
- ¹⁴⁸ MUN 5/196/1610/3, *op cit.* pp. 10–11.
- ¹⁴⁹ Hogg & Thurston, *op cit.* p. 250.
- ¹⁵⁰ *Annual Report*, *op cit.* p. 151.
- ¹⁵¹ MUN 5/384/1630/2, *op cit.* p. 2.
- ¹⁵² T 173/728, *op cit.* p. 18.
- ¹⁵³ *Annual Report*, *op cit.* pp. 151–2. Handbook of the ML 2-inch Trench Mortar, *op cit.* Handbook of the ML 9.45-inch Trench Mortars, *op cit.* p. 21 and Plates XIX and XX.
- ¹⁵⁴ J D Scott, *Vickers, A History*, (London, 1963), pp. 87–8.
- ¹⁵⁵ J D Scott *op cit.* pp. 88 and 151. Hogg & Thurston *op cit.* p. 219.
- ¹⁵⁶ J D Scott, *op cit.* p. 151.
- ¹⁵⁷ MUN 5/384/1630/2, *op cit.* pp. 3–4.
- ¹⁵⁸ *Op cit.* pp. 4–5.
- ¹⁵⁹ GB13095/15 shows the fuze in question. Sutton also invented an 11-inch mortar. It was rejected by the Ordnance Committee but was adopted by the American Expeditionary Force (AEF) in 1917. Captain F A Sutton was a civil engineer by profession. He served in the Dardanelles where he was wounded. He returned to Britain and subsequently joined the Trench Warfare Department. He championed the Stokes mortar. He was partly responsible for Lloyd George and Winston Churchill taking an interest in the Stokes. See MUN 5/196/1610/12 Extracts from Lieut F A Sutton's Diary Relating to the Early History of the Stokes Gun, 12 June 1915 – 31 October 1915. He played a more important role than Hartcup gives credit for. See also Peter T Scott, *op cit.* pp. 84, 86, 87.
- ¹⁶⁰ MUN 5/384/1630/2, *op cit.* p. 1.
- ¹⁶¹ MUN 5/196/1610/3, *op cit.* p. 11.

- ¹⁶² *Op cit.* p. 2.
- ¹⁶³ As described in GB166563. Newton papers, *op cit.* page listing advantages of No. 107 fuze. Brothers, *op cit.* p. 29.
- ¹⁶⁴ Newton papers, No. 107 advantages *op cit.* Brothers, *op cit.* p. 29.
- ¹⁶⁵ MUN 5/384/1630/2, *op cit.* p. 3. See T 173/728, *op cit.* pp. 19–20 where Newton states that the fuze was available from late 1915 but on p. 26 he cites 3 June 1915. This was presumably the date of its invention rather than of its availability.
- ¹⁶⁶ Newton papers, No. 107 advantages, *op cit.* T 173/728, *op cit.* pp. 24–5.
- ¹⁶⁷ MUN 5/384/1630/2, *op cit.* p. 3.
- ¹⁶⁸ *Ibid.*
- ¹⁶⁹ Brothers, *op cit.* p. 32. T 173/728, *op cit.* pp. 25–6.
- ¹⁷⁰ T 173/728, *op cit.* pp. 26–8.
- ¹⁷¹ Brothers, *op cit.* pp. 19–20.
- ¹⁷² Newton 6-inch Trench Mortar, *op cit.* pp. 10–11.
- ¹⁷³ See previous chapter for discussion of the functionality of the Newton fuze as used in the Newton Pippin rifle grenade.
- ¹⁷⁴ MUN 5/384/1630/2, *op cit.* p. 5.
- ¹⁷⁵ Brothers, *op cit.* p. 12.
- ¹⁷⁶ GB112633. The application was filed on 10 August 1916 in the names of A H Midgley and C A Vandervell. The tape and spring arrangement was covered by GB126335, the application for which was filed on 20 December 1916. See also SS189 Light Mortar Training, June 1918, pp. 5–6 for a description of the fuze mechanism.
- ¹⁷⁷ Handbook of the ML Stokes 3-inch, *op cit.* p. 16 and Plate XVII. GB127626 in the name of P H Wilson (filed 2 May 1917).
- ¹⁷⁸ The subject of several patents in the names of Midgley and Vandervell. See GB119329 and GB119761, applications for which were filed in 1917, GB125399 and GB125649, applications for which were filed in 1916. See also S W Cole, GB130017, 18 December 1917.
- ¹⁷⁹ GB130629 in the name of D Kennedy, filed on 25 February 1918. Kennedy was also granted GB131025 for an improvement, filed on 25 March 1918.
- ¹⁸⁰ GB130629, *op cit.* and Brothers, *op cit.* p. 12. For reasons that are not clear, the shutter is referred to as the Umney safety shutter. There are no patents in the name of Umney; the only shutter patent is in the name of Wilson (see note 177, above).
- ¹⁸¹ GB131374, 29 May 1918. See also GB130091, 19 January 1918 and GB130389, 12 February 1918.
- ¹⁸² See, for example, GB130389, 12 February 1918.
- ¹⁸³ Brothers, *op cit.* p. 12.
- ¹⁸⁴ Handbook of the ML Stokes 3-inch, *op cit.* p. 17 and Plate XIX. GB131374, *op cit.*
- ¹⁸⁵ See LoC, *op cit.* pp. 10–16. The Nos 107 and 110, for example, were both developed into Mk IIs, while the No. 146 went to a Mk V. See Handbook of the ML 2-inch Trench Mortar, *op cit.* pp. 15–16 and Plate VI; Handbook of the ML 9.45-inch Trench Mortar, *op cit.* p. 22 and Plate XXI; and Handbook of the ML Stokes 3-inch Trench Mortar, *op cit.* p. 16 and Plate XVIII.
- ¹⁸⁶ Brothers, *op cit.* p. 12; *Trench Warfare Supplies*, *op cit.* p. 68.
- ¹⁸⁷ *Trench Warfare Supplies*, *op cit.* p. 63.
- ¹⁸⁸ MUN 4/2638, *op cit.* p. 2.
- ¹⁸⁹ *Op cit.* memo dated 6 March 1917, p. 2.
- ¹⁹⁰ *Ibid.*
- ¹⁹¹ MUN 4/2638, *op cit.* letter to the War Office from GHQ, dated 9 October 1916. The letter mistakenly states that the Newton would take 2 minutes to fire the ten at nine rounds a minute. In two minutes, it would fire eighteen rounds. Ten rounds was the number calculated as necessary to destroy 100 square yards of barbed wire.
- ¹⁹² Calculated from four range and error figures in the *Annual Report*, *op cit.* p. 313.
- ¹⁹³ This is discussed in Chapter 7.
- ¹⁹⁴ Brothers, *op cit.* p. 12.
- ¹⁹⁵ *Design & Inspection*, *op cit.* p. 45.
- ¹⁹⁶ Stokes, *op cit.* p. 4.
- ¹⁹⁷ In the 1920s, the Stokes mortar was married with the Brandt bomb so that it became known as the Stokes-Brandt mortar.

7 The Evolution of Grenade Warfare

Grenade fighting was an essential feature of trench warfare on the Western Front. For the BEF, grenade fighting began as soon as stalemate developed along the River Aisne in September 1914 when the British first experienced the effects of German grenades.¹ By the beginning of 1916, when grenades had become plentiful, the daily expenditure was huge, running into tens of thousands a day. It is difficult to arrive at meaningful figures because the numbers varied from one part of the line to another according to the level of aggression exhibited by the battalion holding that part of the line.² In mid-1915, a figure of 4500 rifle grenades and 14,000 hand grenades was the estimated daily expenditure per division.³ By 1916, the infantry had become so reliant upon grenades that GHQ issued a directive against their use as a universal weapon for all circumstances.⁴ It was concerned about the loss of musketry skills and the abandonment of the bayonet that the dominance of the grenade was apparently engendering. Yet, this perception of grenade fighting is not entirely borne out by the evidence. Indeed, as will become clear in what follows, far from suppressing musketry and bayonet-fighting skills, grenade warfare encouraged them.

Until recently, the nature of grenade warfare on the Western Front has tended to be overlooked by historians who have focused on the large-scale tactics of the offensive, defence in depth and the artillery. Thus, the tactical employment of the hand and rifle grenade, especially at section level, has been given little consideration hitherto. Tactics of grenade warfare have tended to be lumped together with platoon tactics, especially with regard to all-arms cooperative action. Thus, the tactics specific to grenade fighting are often been reduced to generalisations, or comments about the ‘cult of the bomb’,⁵ which provide little insight into the tactical use of grenades.⁶ This chapter considers the tactics of grenade warfare, and examines their evolution, with particular focus on the section.

Grenade warfare was an integral part of how the BEF conducted operations. From the outset, GHQ wanted all infantrymen to be familiar with grenades and their use. Indeed, General Sir John French wanted every infantryman to become a trained bomber.⁷ Conversely, GHQ believed that only some infantrymen would ‘possess the temperament or the qualifications necessary to make a really efficient grenadier’ and expected such men to be an elite within a platoon, chosen from among the best men.⁸ Reality was somewhat different from both these ideals. During 1915, it was not uncommon for anyone to be told off as bombers. Not surprisingly, some men volunteered to become bombers, relishing the prospect of getting close to the enemy.⁹ A bomber had to be cool under fire. The perception of bombers as hotheads is unfounded.¹⁰ Bombers needed to be fit. They were expected to exercise every day to maintain strength, stamina and suppleness.¹¹ Clearly, the ideal bomber had the physical attributes of an athlete. Indeed, those who were good at games at school or university were initially considered to be the best candidates.¹²

With hindsight, it seems inevitable that tactics for bombing should have evolved during the First World War, given the evolution of infantry tactics, the development of three-dimensional warfare and the proliferation of grenades. But this becomes a circular argument which fails to address how and, indeed, why the transformation occurred. After all, grenades had been used in the eighteenth-century and in the Russo-Japanese War, yet, tactically, little had changed between 1705 and 1905. As was discussed in Chapter 5, the technical evolution of hand and rifle grenades during the First World War was complex and a far from certain process. It was not a foregone conclusion that safe and effective grenades could be devised at all, let alone quickly. Moreover, it was unclear in 1915 that grenades would be anything other than stopgaps and expedients. Hence, there was little incentive to develop tactics for grenade warfare during the first ten or eleven months of the war.

The proliferation of grenade types and the brevity of their service life in 1915 mitigated against the development of a tactical system because each type required a different handling procedure. Suitable handling procedures were crucial to the safe and effective use of grenades. They were the foundation on which tactics were built. Such procedures concerned the arming of grenades, precautions the bomber had to observe with an armed grenade, and how he threw or discharged it. Not surprisingly, the development of training regimes mirrored the rise in importance of grenades which was itself related to the utility and reliability of the devices. Despite GHQ's demand for grenades from late 1914 onwards, it viewed the grenade as no more than a 'side-show' until mid-1915.¹³ Training in grenade fighting was initially an ad hoc affair.¹⁴ Indeed, until May 1915, no specialist bombing schools existed in France or in Britain.¹⁵ This reflected the poor utility of grenades and the lack of training schools in general at this time.

This chapter discusses the development of tactics for grenade fighting and shows that they were not an inevitable consequence of trench warfare but depended upon the development of reliable grenades and a recognition by GHQ that the BEF would benefit from a systemised training programme. Tactics were ultimately dependent upon the technicalities of the grenades since their functionality and reliability determined how they were handled. Hence, this chapter also discusses handling procedures. Inevitably, the chapter mostly concerns the Mills and Hale types of grenade because these were the most widely used by the BEF on the Western Front.

Handling procedures

The term 'drill', which was usually applied to the handling procedures associated with weapons used by the British army, does not seem to have been applied to the handling procedures for grenades at any time during the war. This is indicative of how grenades were perceived by GHQ which was responsible, through its Experimental Section, for such matters as weapons drill for novel munitions. In other words, the grenade was a temporary expedient. It is also indicative of the transience of many of the grenades. Grenade handling procedures were derived from direct experience with the munitions, not from theory.

The diversity of arming procedures for the many grenades that came and went during 1915 placed the bomber in an unenviable position because he could find himself having to use a type he not seen before. Even at the end of 1917, when the number of patterns

had long since been reduced and there was considerable reluctance to introduce new ones, the bomber was still faced with a considerable challenge. He had to be familiar with three patterns of Mills grenade, the No. 34 egg grenade, three patterns of smoke grenade, the No. 28 gas grenade, five patterns of explosive rifle grenade and three patterns of signal rifle grenade, as well as three patterns of rifle grenade cartridge, and various cup attachments for the rifle and the cup discharger. He also had to be familiar with seven patterns of German grenade and two patterns of German bomb-thrower and their bombs.¹⁶ The bomber had to be aware of the lethal radius of all these grenades to avoid injury to himself and to those nearby. In December 1917, bombers and bombing instructors were warned that 'Alterations in design and manufacture of bombs occur so frequently that it is impossible to include descriptions of all types which have, in the various stages of the war, been issued to troops'.¹⁷ Nevertheless, it was impressed upon them that it was essential that they kept up to date with all modifications.¹⁸ It is clear that bombers had to be technicians as well as specialist infantrymen.

Arming the No. 1 percussion grenade was a far from simple process, an indication of the impracticality of the device which was a consequence of the lack of understanding of the functional requirements of grenades when it was designed in 1906. This was a six-step two-stage process.¹⁹ The head cap²⁰ was turned to the 'remove' mark and taken off, the detonator was inserted, then locked in place with a left-hand turn, the cap was replaced and turned back to the 'travel' mark. The second stage entailed releasing the tails so that they hung freely, turning the cap to the 'fire' mark', pulling out a leather strip from the safety pin and releasing a string looped round the cap so that the pin could be extracted. When handling the cap, the bomber had to ensure that the pin stayed in place because it passed through the striker, which was riveted to the inside of the cap, and prevented it from hitting the detonator.²¹ This was far too complicated to ensure that it would be completed unfailingly in the heat of battle.

The stopgap grenades of 1915 were little better. The arming procedure for the Nos 13 and 14 Pitcher grenades required the bomber to cut Bickford safety fuze to the required length, fit one end to the detonator and the other to the lighter, then crimp the joints.²² He had to insert, then fix this assembly in the grenade by means of the cooperating collars on the body and the lighter.²³ This procedure was so fiddly that it was often executed incorrectly, which led to accidents. Finally, there was the firing procedure which, although simpler, was uncertain since the bomber could not always be sure that he had, indeed, fired the grenade.²⁴ The whole process of arming and firing the Pitcher was so fraught with danger that it is hardly surprising that its users became known as the Suicide Club. The Nos 8 and 9 Double Cylinder patterns also required the bomber to cut and fit Bickford fuze.²⁵ The fuze assembly was fixed in place by twisting wires around studs on the exterior of the grenade. In comparison, arming the Nos 6 and 7 grenades was somewhat easier. The flanges on the lighter were clipped between studs on the exterior.²⁶ None of these procedures was simple; there was plenty of scope for error, especially when the bomber had to execute them under fire.

One of the advantages of the No. 5 Mills grenade was the simplicity of its arming procedure, made possible because the fuze assembly was supplied already made up. The

base-plug was unscrewed, the assembly inserted and the base-plug screwed back.²⁷ By the end of 1917, a key was provided for unscrewing the base-plug.²⁸ Unfortunately, it was possible for the bomber to force home the fuze assembly so that the Bickford fuze was pressed into the cap which was likely to cause flash-through.²⁹ Warnings to this effect had to be issued. From about early 1916, safety pins were splayed open so that the pin of one grenade could not be extracted accidentally by the end of the lever of another Mills when the grenades were carried in a canvas bucket.³⁰ All safety pins were split pins (cotter pins) with an eyelet in which was a large-diameter metal ring into which the bomber put one or two fingers to extract the pin; a lever could easily engage this ring. Curiously, while the manuals stressed that 'care should be taken that the safety-pins are not bent when grenades are carried in a bucket', there was no mention of splaying the pins.³¹ To throw a No. 5, the bomber gripped the grenade in his right hand, ensuring that he pressed the lever against the grenade body, removed the pin, and immediately threw the grenade.³²

The myth of the bomber letting the lever fly off and counting to three before throwing the Mills arose during the war.³³ With a 5-second fuze, this was a potentially suicidal act. Indeed, bombers were expressly told not to release the lever before throwing the grenade.³⁴ The origin of the myth was probably the military preference for teaching drill by numbers.³⁵ In 1915, bombers were instructed to press the lever against the body of the grenade with the fingers or thumb of the hand gripping the grenade. By September 1916, they were trained to hold the lever against the grenade using the second joints of their fingers to engage the lever³⁶ but subsequently they were merely instructed to use their fingers.³⁷ The important point here is that experience had shown that neither thumb pressure nor holding the grenade so that the lever was against the palm provided sufficient force to ensure that the lever remained in contact with the body. A design flaw in the No. 5 allowed the striker to fall before the lever was fully released which could occur when the lever was allowed to move slightly from contact with the body of the grenade.³⁸ The refinement in handling procedure largely eliminated the problem of accidental ignition from this cause; bombers were now warned of the risk associated with relaxing their grip on the lever.³⁹ At the same time, they were instructed to check that the pin had not corroded and could be extracted easily.⁴⁰ In fact, the bomber was now supposed to inspect all components to ensure the absence of corrosion and damage, both of which could cause the grenade to premature or could make it blind.

Sometime in the spring of 1916, so-called bomber's hooks, also known as pin pullers, began to be used.⁴¹ The problem was not so much having to extract one pin from a single grenade but having to remove a large number of pins from a lot of grenades during a bombing operation. The fingers became numb or injured and lost their strength when extraction had to be repeated many times over. Such pullers were designed and manufactured by the Royal Engineer Workshops. Although Royal Engineer Workshops referred to them as pullers for No. 23 rifle grenades, training manuals referred to them in relation to the No. 5 which was purely a hand grenade.⁴² A First Army Workshop puller comprised a length of round-section iron bar twisted into the shape of a T, the base of the upright being hammered into a hook which engaged the ring of the pin. It was tied to the wrist so that the crosspiece of the T lay

in the palm, allowing the hand to close round it.⁴³ Another type of puller, manufactured by the Second Army Workshops, was tied to the leg just below the knee by means of a garter. This had the advantage of leaving one hand free to hold the rifle.⁴⁴ The option of using a puller was included in the manual in autumn 1916.⁴⁵

Handling a rifle grenade was rather different from handling a hand grenade. The bomber had to check that the rod was not bent and, although rods were given an anti-rust finish, he still had to check for corrosion.⁴⁶ Any rod that was not pristine was discarded. Inevitably, this meant that extra rods had to be carried which increased the burden on the rifle grenadier. He was initially instructed to oil the rod lightly before inserting it in the barrel⁴⁷ but the instruction was later cancelled. Indeed, the bomber was warned to make sure that there was no oil on the rod because it burned when the cartridge was fired and caused smoke, thereby giving away his position, and fouled the bore.⁴⁸ Arming the No. 3 rifle grenade was no simpler than arming the No. 1 hand grenade. Its transit plug was removed and the grenade pointed downwards to check that the needle pellet was not free.⁴⁹ The detonator was only screwed in place if the needle was secure. If it were free to move, the armed grenade was liable to detonate with only a slight movement. The bomber was cautioned to tap the grenade against the palm of his hand to check that the needle pellet was securely retained by the retractable bolts before inserting the detonator.⁵⁰ Unfortunately, the detonator for the No. 2 hand grenade was very similar to that of the No. 3 rifle grenade and care had to be taken not to confuse them since neither grenade would function if the wrong detonator was inserted.⁵¹ The bomber had to check that the No. 3's arming vane moved freely.⁵²

By the autumn of 1916, the bomber had a checklist of at least seven points to ensure that the No. 3 would function correctly. This was a direct consequence of the complexity of the grenade and its use of precision-engineered components. The slightly simpler Nos 20 and 24 grenades required the same arming and firing procedures as the No. 3⁵³ and, importantly, as many checks.⁵⁴ The No. 35, the simplest of the Hale types, was no better.⁵⁵ During 1916, inspection of the components by the bomber had become standard practice for all patterns and types of grenade. The use of the No. 23 Mills as a rifle grenade produced its own problems. The bomber had to check that the base-plug was steel or cast iron, rather than brass or a soft alloy, because the rod would penetrate the softer metals when the grenade was fired and cause a premature.⁵⁶ Unfortunately, base-plugs were made in a variety of metals and in slightly different designs. The bomber had to be able to recognise them all. Nevertheless, inspections reduced the number of accidents caused by faulty, corroded or incorrect components but it meant that the bomber needed greater technical expertise than had been the case a year earlier.

The No. 23 was armed in the same way as the No. 5. Indeed, the arming procedure for all patterns of Mills grenade was the same. The No. 23 required a cup attachment on the rifle muzzle to ensure that, after the pin was removed, the lever did not fly off until the grenade was discharged.⁵⁷ The attachment was fitted over the bayonet hilt and the bayonet was then fixed. The bomber was wise to check that the fit of the grenade in the cup was such that the lever could not move after the pin was extracted.⁵⁸ By March 1918, specific attention was

drawn to applying the rifle's safety catch before inserting any rifle grenade and to the necessity of the lever of the Mills being held by the ring of the cup attachment. When the bomber was ready to fire the grenade, he withdrew the pin, released the safety catch and immediately fired the grenade.⁵⁹ It is likely that experience had taught instructors and bombers the necessity of applying the safety catch before 1918. That specific attention was drawn to use of the safety catch implies that accidents had occurred when bombers or trainees had failed to apply it.

Although a manual for the cup discharger first appeared in October 1917, the discharger did not feature in a training manual until December 1917.⁶⁰ The handling procedures for fitting it to the rifle and firing a No. 23 Mk III or No. 36 grenade from it were more complicated than the procedures relating to rodded grenades. Fitting the discharger had to be done in a precise way to avoid prying off the nose cap of the rifle.⁶¹ In 1918, rifle grenadiers were advised to fit the discharger to a rifle in which the barrel protruded slightly from the nose cap as this made secure fitment easier and allowed the adjustment screw to make a firmer engagement with the barrel. However, the screw could damage the end of the barrel with repeated firings. Thus, it was inadvisable to fire bulletted rounds from the rifle.⁶² From this it is clear that the discharger did not otherwise preclude the rifle from being used to fire ball ammunition, something which was inadvisable with a rifle used to fire rodded grenades. Nevertheless, the discharger had to be removed at regular intervals to clean away any fouling around the adjustment screw since this could cause it to become permanently attached.⁶³

Shooting a rifle grenade

The manuals cautioned the bomber to discharge a rifle grenade with the designated blank cartridge, rather than with a bulletted round which might cause the barrel to burst.⁶⁴ He was also warned not to lower the muzzle once the grenade had been loaded because it would fall out of the barrel. Whereas the early version of the No. 3 included a muzzle clip, or clutch, to prevent the grenade from sliding out, later versions and the Nos 20, 24, 35 grenades had no clip. The caveat also applied to the No. 23 and the No. 36 Mills patterns. The danger with any Mills rifle grenade if it fell out of the muzzle cup was that the lever would fly off and release the striker. Thus, rifle grenadiers were taught to fire the grenade quickly.

Although during 1914 and 1915, rifles were often set in rests, or stands, in order to fire rifle grenades, bombers were taught to shoot from the shoulder and the hip, while standing, kneeling and prone.⁶⁵ In November 1918, bombers were taught to fire rodded Mills grenades from a standing position, their left leg forward, with the rifle either shouldered or with the butt beside, but not on, the hip.⁶⁶ This style of shooting was largely unchanged since March 1916⁶⁷ and was a refinement of the technique demonstrated by Marten Hale in 1909.⁶⁸ The only drawback to any of these methods was the possibility of a premature but the risk was relatively low by mid-1916, especially when firing No. 23 Mills grenades.

The recoil from firing a Mills from the cup discharger was 'considerable' which meant that the only safe way to do so was to rest the butt of the rifle on the ground so that the recoil went into the ground not the bomber. The grenadier knelt on one knee, holding the rifle in the left

hand.⁶⁹ He loaded a special cartridge in the breech, closed the bolt and applied the safety catch. He adjusted the gas port on the discharger according to the required range, then turned over the rifle so that the magazine and trigger were uppermost. For firing from the discharger, the No. 36 was fitted with 7-second fuze, rather than the 5-second fuze fitted to hand grenades, so it was essential that the bomber inserted the correct fuze assembly. After replacing the base-plug, he screwed a gas-check disc into it. He dropped the grenade into the cup, disc first, until the safety pin was level with the rim of the discharger. He then removed the pin and pushed the grenade to the bottom of the cup. The rifle was then held at 45°, the heel of the butt in a small hole which the bomber had made previously with the heel of his boot. He released the safety catch and immediately pulled the trigger with the index finger of his right hand.⁷⁰

This method of holding and firing the rifle reduced the torque on the bolt which secured the stock to the rifle and, hence, prevented it from breaking.⁷¹ It was a procedure which required practice in order to develop precision in its execution. A different procedure could be followed when rifle grenadiers worked in pairs; the first bomber held, loaded and fired the rifle, while the second bomber handled the grenade.⁷²



Fig. 51 (left) *A Royal Engineer demonstrates the correct position for firing the cup discharger. Note the box respirator, the rifle butt in a small hole beside his knee and the orientation of the rifle. This photograph was included in Instructions on Bombing, Part II of November 1917 (IWM)*

Fig. 52 (below left) *The correct stance for firing a rod-ded Mills No. 23, the butt of the rifle resting beside the right hip (Amendment of SS182 "Instructions on Bombing" Part II, November 1918)*

Fig. 53 (below) *The correct stance for rifing a rod-ded Mills from the shoulder (Instructions on Bombing, Part II, November 1917)*



Throwing techniques

Throughout the war, bombers were trained to throw grenades from standing, kneeling and prone positions. In 1915, bombers were trained to lob grenades in the manner of a shot-putter but this method seems to have been quickly abandoned in favour of the more usual bowling action.⁷³ By the beginning of 1916, bombers were being trained to impart spin on their grenades.⁷⁴ Spin allowed greater distance and accuracy. The grenade was supposed to 'leave the hand at the highest point of the swing'.⁷⁵ This resembled the action of a bowler in cricket and was described as such in the manual issued in March 1916. Indeed, the manual went into



Fig. 54 (above left) *Starting position for throwing a grenade* (The Training and Employment of Bombers, March 1916)



Fig. 55 (right) *Position after throwing a grenade from a deep trench* (The Training and Employment of Bombers, March 1916)

Figs 56 & 57 (below) *Throwing a grenade from a kneeling position* (Instructions on Bombing, Part II, November 1917)



considerable detail about the throwing action, where to place the feet, the weight distribution of the body and the arc followed by the throwing arm.⁷⁶ It is interesting to note that the manual assumed that all bombers were right-handed; they were trained as such irrespective of their natural handedness. The manual also emphasised that, if the bomber dropped a time-fuzed grenade in the act of throwing, he had plenty of time to pick it up and throw it out of the trench before it exploded.⁷⁷

A similar technique was initially applied to percussion grenades fitted with handles to ensure that they landed head-first. The handle increased the moment of inertia during the act of throwing so that, in theory, the grenade travelled further. However, because of the dangers of hitting the side of the trench, the throwing technique for the Nos 1 and 2 grenades was completely changed in late 1914 or early 1915. Now, the bomber grasped and threw the grenade like a dart.⁷⁸ This resembled the technique adopted by Union soldiers with the Ketchum hand grenade during the American Civil War. It is unclear how far a grenade would travel when thrown in this way but it cannot have been far.

The simplest of all grenades in respect of handling procedures was the No. 34 egg grenade.⁷⁹ The bomber withdrew the pin and struck the head of its impact mechanism against the heel of his boot or some other hard surface and immediately threw the grenade. Unlike the Mills, which was generally tossed with a straight arm, the No. 34 was thrown with a bent arm. This technique was also advised for throwing any type of grenade from a deep trench.⁸⁰ It is unclear why a bent-arm technique should have been taught specifically in respect of the No. 34 grenade.

A novice bomber was expected to be able to throw a grenade at least 20 yards, while 30–40 yards and beyond was expected of an expert.⁸¹ That a 50 per cent increase in distance was expected demonstrates that throwing a grenade was a skill which had to be learned and practised. The weight of the grenade affected the distance to which it could be thrown. In general, the heavier the grenade, the shorter the throwing range. Thus, the light No. 34 could be thrown 50–60 yards by an expert.⁸² The bomber had to be able to throw accurately at night and in smoke. He had to acquire skill at throwing grenades not only as far as possible but also to any distance within his maximum range. The byword for bombers was accuracy.⁸³

It is worth noting that night bombing did not become a feasible proposition until the widespread use of the Mills grenade; the ignition of a match-lit or friction-lit grenade would have been clearly visible to the enemy.

Learning the art of bombing

The first reference to what might be described as training in grenade warfare was in *Notes on Field Defences* in 1914, which was based on experience in the front line.⁸⁴ In it, cavalry and infantry were encouraged to become expert in the improvisation of bombs through careful experimentation. Ideas for dummy grenades and dummy detonators were suggested. The booklet stated that the men should practice throwing the dummies ‘from one trench into another, without exposing themselves. They must be alert, and throw immediately the fuze is lit’.⁸⁵ This remained the essence of bombing throughout the war, although it became rather

more sophisticated over the next few years. Bombing was advised as one of several tactical means for countering an enemy sap.⁸⁶ Precautions against enemy bombers, in the form of trench barriers to prevent bombs landing or rolling into a trench, were borrowed from the French, although GHQ was not overly keen on them.⁸⁷

By February 1915, little had changed. A GHQ booklet issued that month, contained nothing new apart from some additional information about the French fortress grenade which was thrown with the aid of a leather wrist strap.⁸⁸ It was emphasised that grenades were the responsibility of Royal Engineers, as laid down in the 1909 Musketry Regulations and Field Service Regulations.⁸⁹ Indeed, the reference to hand grenades and their use in the 1914 Notes on Field Defences did little more than reiterate what scant information there was in the Regulations. Such booklets were meant to supplement existing training manuals, rather than substitute for them. It is unclear how widely these booklets were distributed, although the February 1915 booklet was intended to be issued to all officers.⁹⁰ Nevertheless, it is apparent from the lack of information in these booklets that grenades played an insignificant role at this stage in the conduct of trench warfare. These booklets emphasised the rifle, machine-guns, the bayonet and artillery.⁹¹

Training invariably involved throwing dummies before moving on to live grenades. Dummy grenades and dummy detonators were used in lectures since it was extremely dangerous to bring live grenades into a building where the confined space would make an explosion even more deadly than one in the open.⁹² Practice grenades that were not specifically manufactured as dummies could, theoretically, be charged with explosive and armed but bombers were warned against doing this.⁹³ The mechanisms of Mills grenades tended to be damaged by repeated use and would behave unpredictably. The problem with live grenades was the possibility of blunts so trainees had to know how to deal with them. They were also made aware of the sensitivity of detonators and were taught that they should be held carefully between a thumb and forefinger. Apart from the obvious caveat against dropping one, it emphasised that it was extremely dangerous to attempt to force a detonator into a grenade as this was likely to make it explode.⁹⁴ The dangers of detonators and correct handling of them occupied two pages in the September 1916 manual.⁹⁵ During live practice, the instructor and one trainee occupied the throwing position, the other trainees being under cover.⁹⁶ The danger area corresponded to the lethal radius of the Mills grenade. This was 200 yards, centred on the point of detonation, not the location of the thrower. In 1916, the trainee threw a grenade from behind a wall 4 feet high into a pit 4 feet deep and 10 feet square.⁹⁷ In 1915, no such precautions had been taken.⁹⁸ The precautions were most likely because of the lethality of the Mills grenade which had become the BEF's standard hand grenade by the beginning of 1916.

The attitude to bombing and training began to change during the spring of 1915, as demonstrated by the Memorandum on the Training and Employment of Grenadiers, issued by GHQ, France. This was included in Notes from the Front, Part IV, issued in May of that year.⁹⁹ These were the first formal instructions regarding grenade warfare to be issued by GHQ and were derived from experience at the Front. At this stage, bombing was more an arcane

art than a science. Nevertheless, it was the beginning of the development of a systemised method of grenade fighting in which the requirements of an organised programme of training, which covered all aspects of handling grenades and their tactical use, were seriously considered for the first time. Although ad hoc training had existed ever since grenades began to be used on the Western Front, what was taught and the thoroughness of that training was unregulated and entirely dependent upon individual battalion bombing instructors until about the summer of 1915. These instructors were selected for the task and sent off to attend a bombing course conducted over a few days by a variety of equally randomly chosen individuals, many of whom were probably little better acquainted with the devices than those attending the courses. Some courses were run by Royal Engineers with experience of grenades. During 1915, the responsibility for training men in the art of bombing rested with battalion and company commanders.¹⁰⁰ Indeed, they were usually responsible for organising the training of those men who were to become the battalion's bombing instructors. The battalion bombing officer was assisted by an NCO in each company whose job it was to oversee the supply and storage of the grenades.

The first bombing manuals did not appear until the autumn of 1915, issued by GHQ. A technical manual on British, German and French grenades was issued in September.¹⁰¹ The following month, the same technical information was reprinted with some information on tactics and training.¹⁰² Manual CDS74 *The Training and Employment of Grenadiers* was the first on grenade warfare to be issued to the BEF, the Memorandum of a few months earlier notwithstanding. The publication of such manuals coincided with the much greater availability of Mills and Hale rifle grenades and the realisation of the importance of grenade warfare. The topics covered in the October manual included the composition of a bombing

Fig. 58 *Means of carrying grenades. Top is a bomber's waistcoat, c.1915 which held ten grenades. Below it are two canvas grenade buckets (MUN 5/383/1600/14)*



party and its use in attack and defence, the manner of supplying additional bombs to the party, and the special equipment worn by bombers to carry live grenades during an operation. Importantly, syllabi for elementary and advanced training were set out but these were 'suggestions' rather than mandatory, indicating that bombing instructors had latitude in what they taught and the manner in which they conveyed it to their pupils. Nevertheless, the level of proficiency which bombers were expected to attain raised them from dangerous amateurs of the early part of the war to specialists. Anyone working as a bomber was not expected to perform the usual duties of an infantryman in the line because he was too busy maintaining his bombing skills.¹⁰³ This special status eventually disappeared and, by autumn 1917, bombers were expected to perform all the duties of an infantryman.¹⁰⁴

In March 1916, a superseding manual was issued.¹⁰⁵ By now the term grenadier had been dropped and bomber had become the standard term to avoid confusion with the Grenadier Guards.¹⁰⁶ This manual contained substantially different material from its predecessor. Some of this related to firing rodded Mills grenades with the cup attachment. The manual omitted everything concerned with the stopgap grenades of 1915; these had been declared obsolete at the of 1915 and their use banned.¹⁰⁷ As far as hand grenades were concerned, the bomber was now expected to deal almost exclusively with the Mills type, which, at this time, was the No. 5, although he was still supposed to be trained in the use of the percussion-fuzed No. 1. By far the greatest changes in the manual were to training and the tactics of grenade fighting. Training was becoming more sophisticated with greater emphasis being placed on the development of teamwork so that hand bombers, rifle grenadiers, and bayonet men within a bombing party and its support troops operated as a coordinated team. Teamwork had been the focus of bombing work since the previous autumn but its importance over random bombing by individuals was now emphasised. The rise of teamwork is indicative of the increasing importance of grenades. It also demonstrates the increasing reliability of grenades and their greater availability. Without reliable grenades, bombing was inevitably haphazard and uncertain.

The composition of a bombing squad was left to the bombing officer. The number of such squads in a battalion was not prescribed. The manual only provided guidelines. However, the number of trained bombers was not supposed to exceed between forty or fifty in a battalion, divided into four squads of eight men which constituted the battalion bombing platoon.¹⁰⁸ It recommended that a squad should comprise two throwers, two bayonet men, two carriers of additional grenades and two 'spare' men who acted as carriers, the squad being led by an NCO. Every man was supposed to know how to perform each task so that any one of them could take the place of a casualty. Alternatively, a squad could comprise four men, two men acting as throwers, the other two as bayonet men, with each thrower carrying a canvas bucket of additional grenades which had to be put down before throwing the grenades. The number of grenades carried in a bucket varied according to circumstances but, clearly, the greater the number of grenades, the heavier the bucket and the greater its impediment to the carrier-cum-thrower.¹⁰⁹ There was a trade off between numbers carried and efficient throwing. In addition to these men, a squad could also include

two rifle grenadiers as required.¹¹⁰ Finally, in addition to the battalion bombing officer, there was now also a brigade bombing officer who was given the task of organising training.¹¹¹ It is noteworthy that there was no mention of bombing schools and that training was conducted by individual brigades.

Bombers were expected to maintain their musketry skills in addition to their bombing skills. The trained bombers in a battalion had to practise forming ad hoc bombing parties at a moment's notice in order to deal with emergencies.¹¹² Bombing skills could be widely dispersed throughout a battalion with a large number of trained men having returned to their platoons as riflemen. Although this went some way towards making every infantryman familiar with grenades, it is probable that many of these men did not maintain a high level of proficiency or keep up to date with the latest patterns of grenade simply because they were too busy with other duties. This contrasts starkly with 1915 when men could find themselves using grenades without any training or having only watched a demonstration of bombs and bombing.¹¹³

In September 1916, the grenade manual was rewritten to reflect the changes in grenades and the greater sophistication of the tactics. Every infantryman and every machine-gunner was now expected to have thrown at least one live Mills grenade in practice, although the belief persisted that some men were better suited to be bombers because they had the right temperament for calmness in a crisis and fortitude in the face of danger.¹¹⁴ Even at the end of 1916, it was not unknown for an infantryman to be faced with having to throw grenades in action when he had not thrown a live one in training.¹¹⁵ By November 1917, every infantry recruit had to have thrown at least three live Mills grenades in practice and 50 per cent of recruits had to be trained to fire rifle grenades.¹¹⁵ Although the idea that men who were good at games were likely to be good bombers persisted, the notion of what had been termed a 'bomber's temperament' had now been abandoned. Whether this was because the idea was proved to have been based on a false premise or whether it was indicative of the manpower shortage in the BEF is unclear. Nevertheless, this was another step towards the abandonment of the bomber as specialist and the development of the infantryman as a technician skilled in the use of a variety of weapons, including the Lewis gun, hand grenade and rifle grenade.

By now, of course, the BEF was a mixture of men from a wide variety of backgrounds, the pre-war regulars having been reduced in number through attrition and the survivors diluted by the huge influx of citizen soldiers. Moreover, officers included many more men from the ranks than had ever been the case in the pre-war army, as well as pre-war regulars, territorials and New Army recruits. The pre-war idea that infantrymen were generally unsuited to learning skills other than those traditionally taught to them was laid to rest in the trenches of the Western Front, largely by force of experience. Infantrymen had no choice but to acquire new skills, including those of the bomber, because trench warfare demanded it. GHQ might have taken a little longer to appreciate this reality than had been the case with brigade and battalion commanders, who were closer to the problems thrown up by trench warfare at the lowest level, but that is not to suggest that GHQ opposed the idea of grenade warfare as an adjunct to more traditional forms of infantry warfare. After all, it had

set up the Experimental Section in October 1914 to develop trench warfare devices.¹¹⁶ It is significant that, although there was certainly a general prejudice against grenades in 1915 and 1916, because of their unreliability and the contradictory belief that infantrymen relied too much on them, by late 1917, this attitude had changed. The grenades of 1917 were technically superior to the stopgaps of 1915, handling procedures had been improved and the usefulness of grenades had been proven. Thus, the perception of grenades was different in 1917 from what it had been in 1915. In addition, there was a far better understanding of German tactics with regard to grenades. The March 1916 issue of the bombing manual had included two pages on German bombing tactics, derived from the translation of a German document on the subject.¹¹⁷ The September 1916 issue included twelve pages on the subject.¹¹⁸ Unfortunately, such information was out of date by at least six months.

The manual issued in November 1917 was the first to be separated into two parts. Part I dealt with the technicalities of all British hand and rifle grenades then in service, details of their mechanisms and their arming procedures, which merely updated and expanded similar information presented in the earlier manuals.¹¹⁹ It also provided similar information about German grenades. The idea had always been that bombers should be able to use captured grenades and, as important, deal with unexploded German grenades.¹²⁰ Indeed, part of the work of a bomber involved dealing with unexploded British grenades. Part II covered training and tactics.¹²¹ There were now twenty-six pages devoted to training, including a detailed syllabus for advanced training.¹²² This compares with seven pages in October 1915, ten in March 1916 and thirteen in September 1916.¹²³

Proficiency tests for bombers had become standard practice by the beginning of 1916. When a bomber passed, he was classified as a trained bomber and wore an appropriate badge on his uniform to signify this.¹²⁴ There were five tests. By the end of 1917, their form had changed and, if anything, the tests had become more searching than in 1916, although their purpose remained the same. In 1916, the tests were divided in two parts and a bomber had to pass Part I before he could move on to Part II. Part II involved throwing live grenades.¹²⁵ In 1917, the first test was designed to test accuracy and distance. It was no easy task as it also tested the endurance of the bomber. He had to throw fifteen dummies from a wire cage 6 feet high, or from a trench of the same depth, into three target cages 3 feet high, 4 feet wide and 30 feet long, one set 25 yards directly in front of his position, the other two either side of it at angles of 45° and 20 yards from the throwing position.¹²⁶ In 1916, the bomber had to throw only ten, although he also had to throw ten more when standing in the open and a further ten when kneeling.¹²⁷ He also had to throw five grenades into a trench from a traverse and another three into the trench from two traverses back.¹²⁸ The bomber had to throw his grenades without looking directly at the target. In 1917, the bomber had to get three grenades into the first target cage and at least two into each of the angled cages.¹²⁹ He had to achieve this with no more than the fifteen dummies allowed for the test, otherwise he failed.

For the second test, the bomber had to throw three live grenades at a target. Whether he passed or failed was determined by the supervising officer. The third test evaluated the bomber's proficiency with rifle grenades. He had to shoot dummy grenades, again without

looking directly at the target, into similar cages to those used in the first test, from a distance of 70–90 yards. To pass the test, the bomber had to get three out of five grenades into the target. Since rifle grenadiers often worked in pairs, the bomber under test could be assisted by an observer. The fourth test was concerned with tactics, while the fifth was an oral test in which the bomber was questioned on the technicalities of British and German grenades. The officer conducting these tests had to be fully qualified and hold ‘a Command or Army Bombing School certificate’.¹³⁰

Major Beddoes established the first Bombing School in about May 1915, located at Clapham.¹³¹ From the beginning of 1916, each Command in Britain and each of the Armies in France had its own bombing school, coordinated by Major Beddoes who was appointed as the Inspector of Bombing Schools.¹³² Each month, eight officers from the Home Command schools, one from each school, were sent out to France and their places taken by officers from schools in France or from the line.¹³³ This allowed the Home Command schools to keep up to date with the latest bombing practices in France. The main purpose of the schools was to train instructors but bombing schools also trained personnel to replace bombers who had become casualties.¹³⁴ Brigades still held bombing classes in order to train instructors in accordance with the provisions of SS152, section 4, paragraph 8.¹³⁵ There was a distinction between a School and a Class. The former was larger, permanent and established by GHQ, Army or Corps, while a Class was formed by divisional or brigade commanders at their own discretion.¹³⁶ Major Beddoes stated in 1921 that each battalion had its own bombing school but if this was the case it was not stipulated in the manual.¹³⁷ However, this is probably no more than a question of semantics and that he was, in fact, referring to Classes. According to SS152, a combined Bombing and Light Mortar School was affiliated to each Corps Infantry School and located on the same site.¹³⁸ Each battalion was now supposed to have one sergeant instructor who had been trained at the Bombing and Light Mortar School.¹³⁹ By late 1917, bombing Classes at divisional, brigade and battalion levels were commonplace.

Typically, the syllabus of an Army Infantry School for 150 company commanders and 150 senior NCOs included bombing work at night but not, it seems, bombing in daytime.¹⁴⁰ Presumably, it was thought to be an unnecessary duplication of effort for the Infantry School to run a bombing course which was covered by the Bombing School. The Corps Infantry School for eighty officers and eighty NCOs included work on the co-operation of different arms, including not only artillery, trench mortars and aircraft but also machine-guns, Lewis guns and hand and rifle grenades, both within a battalion and more widely.¹⁴¹ A course in bombing at the Bombing and Light Mortar School for six officers and 72 other ranks lasted fifteen working days; a similar course in trench mortars was run for six officers and fifteen other ranks.¹⁴² The School’s establishment included two officer bombing instructors and six sergeant bombing instructors. In addition to the chief instructor, there was a company sergeant-major, two officer instructors and two sergeant instructors for mortars, eight privates to deal with the stores and ranges, and five batmen for the messes, making a total establishment of twenty-seven.¹⁴³ This may be compared with the Corps Lewis Gun School which catered for a similar number of officers and NCOs for the same length of time, and

had an establishment of twenty-four.¹⁴⁴ The Bombing and Light Mortar Schools turned out approximately three officer instructors and thirty-six NCO instructors in bombing per battalion over a twelve-month period.¹⁴⁵ This compares with the same numbers for Lewis gun instructors per battalion. During the course of the war, the bombing schools in France trained 74,000 officer and NCO instructors with only ten fatalities.¹⁴⁶

The tactics of grenade warfare

A distinction was always made between offensive and defensive bombing operations.¹⁴⁷ The main difference between them was the amount of preparation that was possible, both in terms of reconnaissance and in terms of numbers of grenades that were available.¹⁴⁸ In any operation, it was essential to scout the ground, study aerial photographs, understand the objective, and organise the supply and replenishment of grenades.¹⁴⁹ The preparation and storage of the grenades was fundamental. Out of the line, grenades were kept in an unarmed state in a brigade bomb store but as soon as they were moved into the line they had to be armed, ready for use. Clearly, the simpler the arming process and the safer the grenades when armed, the better. Mills grenades were easy to arm and make safe. Armed grenades were kept in battalion and company bomb stores located in the support or reserve line near junctions with communication trenches, in clearly marked boxes so that there could be no doubt about what they contained. The bomb store was a vital position within a trench system and the rules for its construction and usage became more stringent between 1915 and 1917.¹⁵⁰ Typically, in the spring of 1916, the bomb store for a two-battalion brigade held 3000 grenades, while each battalion store held 1000 and the company stores held another 1000 grenades between them.¹⁵¹ This made a total of 6000 grenades available to the two battalions of a brigade. The stores had to be well sited, bomb-proof and clearly identified.

Parties of bombers were dispersed along the front in the support trenches, close enough to communication trenches that they could go forward to counter-attack in the event of a German incursion.¹⁵² Bombing posts were also established in mine craters and in or near sapheads. Saps were constructed in such a way that grenades could be thrown at the enemy from the saphead while the enemy would be unable to bomb the British fire trench from the same position, should it be captured; the sap was covered to achieve this end. Sometimes, a bombing trench was dug behind the fire trench but within throwing distance of it, again to counter any German incursion.¹⁵³ Defensive blocks in trenches had been used since 1914.¹⁵⁴ Bombing stops and defensive trident trenches designed for bombers to break up enemy encroachments into the British line were developed during 1915.¹⁵⁵ It was acknowledged that, in a counter-attack, it might be necessary for bombers to proceed both left and right along a fire trench as they emerged from the connecting communication trench, so it was essential that everyone knew beforehand which way they were going.¹⁵⁶ By the beginning of 1916, defensive tactics had not developed much beyond this.

Defensive tactics were practised by bombing parties in the section of the front in which they were located. A counter-attack by a bombing party had to be so well rehearsed that it could be executed at a moment's notice. The remainder of the platoon to which the party

belonged supported the counter-attack which developed from the support trenches.¹⁵⁷ By the end of 1917, the only significant addition was the rifle grenadier who had begun to figure in defensive tactics by the autumn of 1916. Rifle grenadiers now fired ranging shots with dummies from a carefully selected reserve position into the British front line so that, in the event of the Germans occupying it, rifle grenades could be immediately fired on them.¹⁵⁸

The standard bombing party of eight men led by an NCO went through a gradual transformation as the war progressed. By spring 1916, each platoon had a bombing squad led by a sergeant, with only one spare man acting as an extra carrier while the eighth was now a rifle grenadier.¹⁵⁹ Within the next six months, the spare man became a sniper or additional rifle grenadier and the carriers became reserve throwers as well as carriers. Although everyone in a squad was expected to be able to act in whatever capacity was required according to the circumstances, that the carriers were now designated reserve throwers is indicative of the attrition on bombing squads during bombing operations. The organisation and composition of bombing squads was changed during 1917. By the autumn of that year, they were referred to as sections, rather than parties or squads, and there was now a section of hand bombers and a section of rifle grenadiers in a platoon of four sections.¹⁶⁰ Separate rifle grenadier sections had existed from at least the beginning of 1917.¹⁶¹ The hand bombers section had the same composition as a year earlier and, thus, included at least one rifle grenadier.

There was a gradual change in emphasis on the purpose of bombing, from a tentative warning that grenades were short-range weapons for trench work and for use against the occupants of dugouts, to a definite statement that bombing operations rarely succeeded without the cooperation of riflemen or Lewis gunners.¹⁶² This was derived from experience. Thus, by 1917, the object of a bombing operation was to force the enemy out into the open where they would present targets for small arms fire. The issue of cooperation between bombers, riflemen and Lewis gunners alters the concept of grenade effectiveness since lethality of a grenade can no longer be the sole criterion. Unfortunately, the number of the enemy who became casualties due to bombing operations on this basis is not quantifiable; it is highly subjective because of the many variables involved. The only measure that might be applied is rate of success of bombing operations but there is no definition of success on such a small scale. Nevertheless, the change in objective from killing the enemy with grenades to forcing him into the killing zone of other weapons shows how grenade warfare had become more sophisticated than merely trying to out-bomb the enemy which had been the sole object until about mid-1915.

Such changes influenced tactical thinking about bombers in major offensives. In 1915, bombers were supposed to position themselves in front of the main infantry attack so that they could 'cover the bayonet assault with a shower of grenades'.¹⁶³ The optimism of this somewhat unrealistic scenario did not escape the author of the manual, however, and he conceded that the bombers were better off following the main assault to mop up. Nevertheless, it was noted in June 1915 that bombers throwing grenades into the enemy fire trench could effectively suppress enemy riflemen to allow other infantrymen to cut intact

barbed wire by hand.¹⁶⁴ When the bombers reached an enemy trench, they worked along it for at least 50 yards to clear it, then erected bomb-stops to prevent enemy bombers from getting within range of the captured part of the trench. Alternatively, they kept on working outwards from the point at which they penetrated the German line until they made contact with adjacent battalions taking part in the attack.¹⁶⁵ Another party of bombers guarded trench junctions, where communication trenches joined the fire trenches, in order to prevent enemy reinforcements from getting through, and to break up counter-attacks.¹⁶⁵

The squad learned to work up the traverses of a trench in a specific routine in single file with the two bayonet men leading, followed by the first thrower, the first carrier, the commander, the second thrower and the second carrier with the two spare men at the back. In this formation, the squad occupied three traverses, arranged two in the front traverse, three in the second, and four in the third.¹⁶⁶ The rest of the platoon followed the bombing squad. Even in 1915, bombers were expected to act in cooperation with riflemen rather than independently because lone bombers and bombing parties were vulnerable. The job of the bayonet men was to protect the rest of the squad. On entering an enemy trench, the first thrower tossed several grenades as quickly as possible into the two traverses beyond the bayonet men. Then, the first bayonet man went forward to check if the bombed traverses were clear. If so, the whole squad advanced to the furthestmost of the bombed traverses and the process was repeated. By spreading the squad between three traverses, the effects of enemy action were minimised. The bayonet men had to be skilled at snap shooting¹⁶⁷ as well as being proficient with the bayonet. Their job was not only to protect the rest of the squad and the lightly armed throwers but also to prevent a grenade duel from developing. Indeed, the bayonet men had to actively pursue the enemy and prevent him from taking up a new position further along the trench. By summer 1916, the emphasis had changed from the bomb to the bayonet; grenades were now only to be a resort when the bayonet men could not deal with the enemy alone.¹⁶⁸ The NCO controlled the progress of the team, while the carriers ensured that their respective throwers did not run out of grenades. The spare man acting as a carrier resupplied the other two carriers. When he had none left, he had to find his way to the nearest bomb store to replenish. When a rifle grenadier was part of the squad, his job was to prevent enemy bombers or reinforcements from holding up the bombing attack.¹⁶⁹ Clearly, for a bombing operation to succeed, teamwork was essential and crowding had to be avoided. Preferably, each man stood at a corner of a traverse so that he could retreat behind it when an enemy grenade landed in front of him.¹⁷⁰

This remained the standard tactic for advancing along an enemy trench, although refinements were made to take account of the changed composition of the squad during 1916. The presence of two rifle grenadiers altered the arrangement of men behind the NCO. Now, he was followed by the first rifle grenadier, the second thrower, the second carrier and, finally, the second rifle grenadier.¹⁷¹ Each rifle grenadier had to carry his own stock of rods, grenades and cartridges. In addition to the explosive grenades, smoke grenades¹⁷² were also carried to throw into dugouts and force out their occupants. It was recommended that two were thrown into each dugout.¹⁷³ The composition of a squad was varied according to the

Fig. 59 (below) *How to bomb along a trench as taught from early 1915. Sandbag men build trench blocks to prevent a counter-attack by enemy bombers. Key: B bayonet man T thrower L leader C carrier S spare man (The Training and Employment of Bombers, March 1916)*

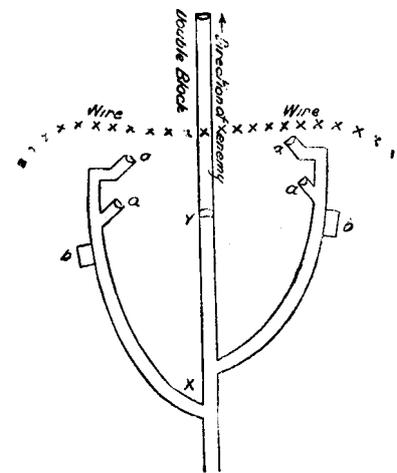
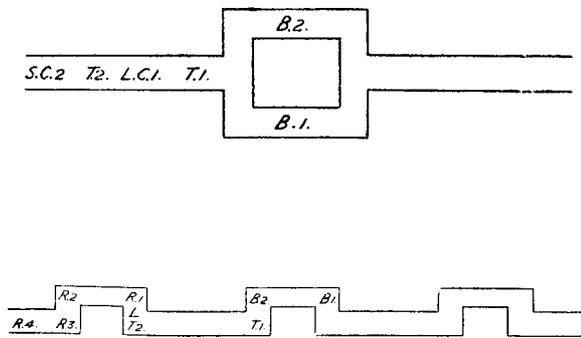
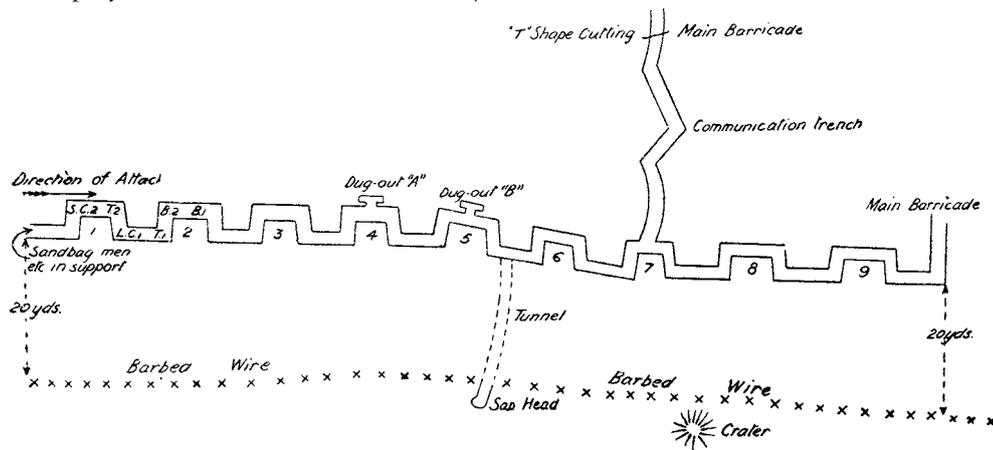


Fig. 60 (above) *Variations on the theme*

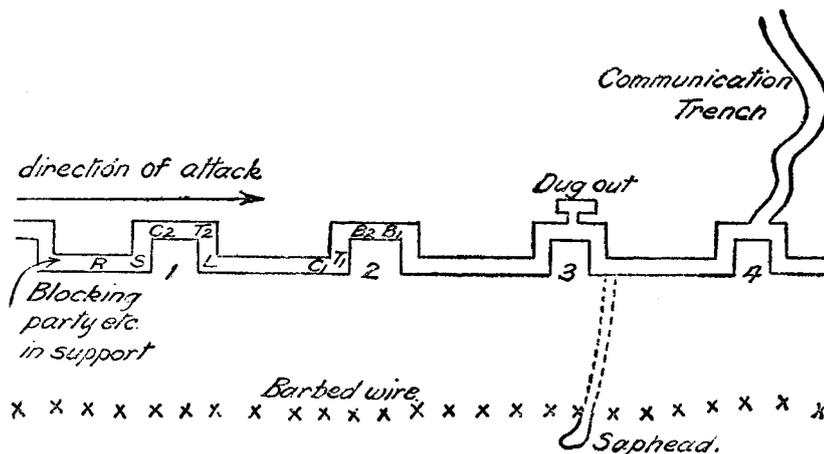
Top *How to negotiate an island traverse. The bombers throw grenades over the island, while the bayonet men wait at the sides*

Bottom *An alternative approach to that shown in Fig. 59 when the squad was split into two groups of four (The Training and Employment of Bombers, March 1916)*

Fig. 61 (above) *Trench block, 1917. This involved digging a sap each side of the blocked trench, and providing the saps with bombing posts which had to be within range of blocked-off section. In 1915, when this trident was first used, bombing posts did not feature.*

Key: a bombing post b bomb store y block (Instructions on Bombing, Part II, November 1917)

Fig. 62 (below) *Improvement on the theme. Note the slightly different positioning of the bombing section in late 1917 and the inclusion of a rifle grenadier R and only one spare man (Instructions on Bombing, Part II, November 1917)*



dictates of a given operation but it was essential that every member of the team, whatever its composition, knew precisely the objective of the operation, knew his own task in it and worked in a disciplined manner.¹⁷⁴ During 1916, Lewis gunners and Stokes mortars began to be part of a support team co-operating with a bombing squad, especially in an assault on an enemy machine-gun.¹⁷⁵ The support could even include 4-inch Stokes mortars,¹⁷⁶ operated by the Special Brigade, Royal Engineers, which provided a smoke screen, particularly when attacking a machine-gun or to conceal the return of a party of bombers from a raid.¹⁷⁷

The question of how bombers ought to be armed was not addressed until 1916. Such matters had been the subject of correspondence in *The Times* in late 1915 and early 1916.¹⁷⁸ By September 1916, the manuals made it clear that throwers were expected to be armed as lightly as possible and were discouraged from taking their rifles on an operation; revolvers, knives and knobkerries as side arms were suggested in their stead.¹⁷⁹ This advice shows that bombing operations were, indeed, close-combat affairs in which hand-to-hand fighting was likely to develop. Nevertheless, the manuals also made it clear that bombers had to be able to throw grenades with their 'rifle slung over their left shoulder'. By mid-1916, they were expected to wear the steel helmet which had become standard equipment during the spring, which hindered them further.¹⁸⁰ Indeed, they had to be able to throw bombs irrespective of how they were encumbered by equipment, despite being advised to be lightly armed. Being weighed down or inconvenienced by all manner of equipment was regarded as typical of trench conditions. Bombers had to be able to work in a gasmask and wearing the box respirator, introduced in about mid-1916.¹⁸¹ Pragmatism rather than theory dictated procedure and practice.

The main offensive functions of a bombing squad were raids, especially when the object was attrition, and small enterprises in cooperation with riflemen to take a limited objective, such as a trench or a crater.¹⁸² Even in early 1916, emphasis was placed on every member of a raiding party being practised in grenade throwing and being familiar with German grenades.¹⁸³ Indeed, every man taking part in the raid was expected to carry two grenades, in addition to those carried by the bombers¹⁸⁴ and this was extended to any size of operation.¹⁸⁵ Company-sized operations had one bombing squad at the point of the attack, with another squad in support to replace casualties and deal with dugouts after the point had moved on, and side parties of bombers for blocking communications trenches to prevent counter-attacks.¹⁸⁶ The support team of riflemen and Lewis gunners could also block trenches until a side party arrived to take over. Men relieved from the point joined the main body of the attacking force. Success depended on the momentum of the attack. Whenever possible, two or three throwers threw their grenades simultaneously, the man with the greatest range throwing to the furthest traverse, the man with the shortest, throwing to the nearest. Rifle grenadiers supported the point using No. 23 Mills grenades.¹⁸⁷

In any large-scale attack, such as a major offensive, the role of the bomber was slightly different. The main tasks were to clear trenches that the assaulting infantry had passed beyond and to protect the flanks of their respective companies once the objective had been taken.¹⁸⁸ They were also meant to counter enemy bombers who might have been bypassed in

the attack. It was noted after the opening battles of the Somme offensive that bombers were well suited to mopping up but that an infantry assault across open ground to take a trench, when possible, was less costly than a bombing attack up the same trench, provided the infantry assault was preceded by 'adequate preparation'.¹⁸⁹ Ironically, GHQ now complained that bombers threw more grenades than was necessary, exhausting the bombers and wasting grenades.¹⁹⁰ It blamed poor throwing discipline. A bombing squad was now expected to be armed with no more than 120 grenades. The two grenades carried by every infantryman was their reserve supply. One of the most important tasks for rifle grenadiers was the suppression of fire from enemy machine-guns and strongpoints during the attack.¹⁹¹ With the introduction of steel-reinforced pillboxes during 1916, hand grenades were often more effective than shell fire when it came to silencing their occupants. A Mills tossed through an aperture killed or wounded the occupants, whereas shells only chipped at the concrete.¹⁹² This could be achieved by digging a sap towards the pillbox and the cooperation of riflemen, Lewis gunners and rifle grenadiers to allow the bombers to reach the pillbox.

In 1917, these tactics and the role of bombers were consolidated, although open warfare now figured more strongly in the manual than had been the case a year earlier.¹⁹³ Flexibility was emphasised even more than in 1916. The tactics of a bombing raid were laid out in more detail than hitherto and the role of the rifle grenadier was given greater prominence in the suppression of enemy counter-attacks and machine-guns.¹⁹⁴ Indeed, while the use of rifle grenades to suppress enemy machine guns was practised in 1915, the fire-suppression role of rifle grenades became much more important in 1916, with the rifle grenadier section providing a barrage of grenades 30–40 yards ahead of the bombing section.¹⁹⁵ Mopping up by bombing sections was made more explicit as a distinct operation and a couple of riflemen and sometimes a Lewis gunner were now included in the mopping-up team.¹⁹⁶ Emphasis was placed on coordination and organisation to ensure that all the captured trenches and their dugouts were dealt with systematically. The use of grenades to repel a counter-attack was now discouraged as they had no effect.¹⁹⁷ This was the opposite of what had been taught in 1915.

By early 1917, bombers could be used in the van of an assault in combination with rifleman, protected by a skirmish line.¹⁹⁸ This was a development of the tactic advocated in 1915 and followed the linear mode of assault, whereas the mode of assault on pillboxes and machine gun positions was more of a process of encirclement to enable bombers to approach from the flanks or rear. A significant development during 1917 was the use of men above ground in coordination with those working along the trench. The moral effect of grenades being thrown into a trench from above ground, simultaneously from both sides, was emphasised. Men working above ground had a better view of their target and enemy movements than was afforded from within the confines of the trench.¹⁹⁸ The team of bombers and their support now totalled more than thirty personnel, most of whom were above ground, on both sides of the trench.¹⁹⁹ Only four of the team advanced along the trench: a bayonet man, followed by a thrower, his carrier and, further back, a rifle grenadier. The speed of advance was regulated by the rapidity of the second bombing group working above ground. This comprised one thrower and his carrier, with two bayonet men or one bayonet man and a rifle

grenadier on the flank to give covering fire when needed. The thrower above ground tossed a grenade into the trench and immediately took cover. His carrier ran several yards beyond him, before also taking cover. The process was repeated until the trench was cleared.²⁰⁰ The lethal radius of the Mills grenade and the number of lethal fragments it produced meant that taking cover was essential. This tactical system was mostly applied to large-scale attacks in which the assault infantry had passed beyond the first lines of the German defences and were pressing further ahead, leaving the bombers to mop up. It was described as an attack in the open and may be seen as the development of semi-open warfare.²⁰¹

The technique of working along traverses had changed. No grenades were thrown until the advance of the bayonet men was checked by the enemy.²⁰² The technique of attacking round a traverse by a bayonet man was refined according to whether it was a left or right traverse.²⁰³ One of the oddities of bombing was the skill required of the bayonet men who needed to be able to manipulate the rifle and bayonet deftly and swiftly irrespective of their position relative to an enemy. Far from rendering the fixed bayonet redundant, the grenade made it more important than ever in trench work. Despite the protestations of some in 1915 that trenches were too confined to wield a rifle and bayonet and that knives, clubs and pistols were better suited to such close work, the skills developed by the bayonet men in a bombing section proved otherwise.²⁰⁴ A man skilled with a rifle and bayonet was a match for anyone in a trench.

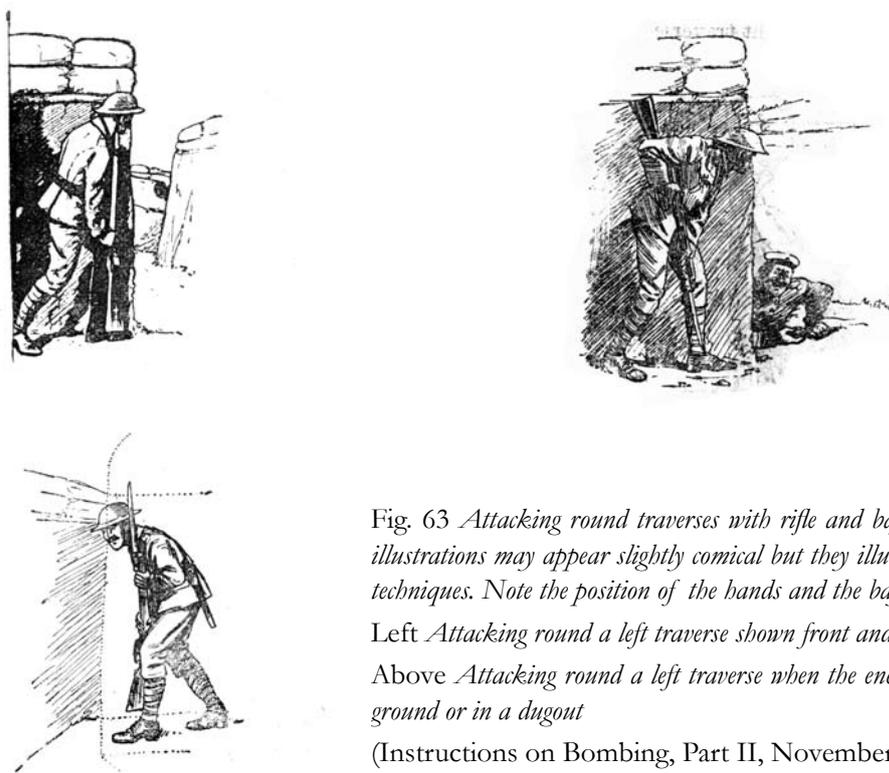


Fig. 63 *Attacking round traverses with rifle and bayonet. These illustrations may appear slightly comical but they illustrate specific techniques. Note the position of the hands and the bayonet point*
 Left *Attacking round a left traverse shown front and back*
 Above *Attacking round a left traverse when the enemy is on the ground or in a dugout*
 (Instructions on Bombing, Part II, November 1917)

In 1917, rifle grenadiers worked in pairs in an eight-man section, led by an NCO. The second man in the pair observed the fall of shot and loaded the rifle with the No. 23 and withdrew the pin, after which the firer loaded the cartridge. Volley, rapid or individual fire was ordered by the section leader according to circumstances. Individual fire was one grenade per

pair, with a specified interval between the shots. Rapid fire required each pair to load and fire as quickly as they could until the requisite number of grenades had been fired. In each case, the NCO specified the range and target.²⁰⁵

Mid-1917 saw the transition between specialist bombers in sections and every rifleman being a bomber, so that, for a while, the rifleman/bomber co-existed with the specialist bombing section.²⁰⁶ By the end of the year, the bombers were reorganised to take account of their changing role.²⁰⁷ The sections lost their role description and became merely numbers. Thus, the bombing section became No. 2 Section, while No. 3 Section were trained as rifle grenadiers.²⁰⁸ This was consolidated at the beginning of 1918. The platoon, comprising between twenty-four and forty men, divided into four sections plus a headquarters, had now become an all-weapons unit, its members familiar with rifle, bayonet, hand and rifle grenades, and the Lewis gun.²⁰⁹ There were three rifle sections and one Lewis gun section. Significantly, there was now no bombing section, although one of the rifle sections could be trained as a bombing team.²¹⁰ By 1918, each member of the team carried up to seven grenades while the carriers had up to fourteen.²¹¹ This made a maximum of eighty-four hand grenades for a ten-man section, a 30 per cent reduction on an eight-man bombing squad of mid-1916 but was similar to the nine-man squad of mid-1917 in which ninety grenades were carried, five by the throwers and at least ten by each of the rest of the section.²¹²

In 1918, the same team could act as rifle grenadiers, in which case, they each carried seven grenades including some smoke grenades.²¹³ A rifle grenadier section of a year earlier carried a similar number.²¹⁴ That the hand grenade was only a temporary expedient made necessary by the dictates of trench warfare was reiterated, although the statement was out of touch with reality, while the rifle grenade was described as ‘the “howitzer” of the platoon’ for giving fire support at up to 100 yards to enable the riflemen to get to close quarters.²¹⁵ Barrages of rifle grenades were directed at machine-guns and points of resistance, with smoke grenades being used to provide cover. Typically, rifle grenades were used in combination with Lewis gunners. An important tactical change for infantry platoons was the abandonment of the notion of mopping up. Now, each section had an objective which had to be taken, leaving no pockets of resistance or areas in enemy hands.²¹⁶ Thus, the idea of bombing sections mopping up was no longer viable. Indeed, the very concept of trench warfare as practised in 1915 and 1916 was no longer valid. A bombing team only worked up a trench when it was unavoidable and only with the support of an attack by riflemen and Lewis gunners above ground.²¹⁷

The rise and fall of grenade warfare

The biggest problem with grenade fighting was its pace. It was slow and very tiring.²¹⁸ As soon as grenade fighting developed during an advance, the advance, in effect, ended. Bombing did not move along the line of attack; rather, it spread outwards, sideways, along trenches that faced the line of attack. This was inevitable because the latter rarely coincided with the line of the trenches under assault; to engage the enemy, the bombers had to move along the trenches, rather than along the line of attack. A similar problem occurred when a strongpoint was the focus of a bombing attack; again, the bombers had to move along the trenches

irrespective of the line of attack. This inability to maintain momentum was one reason for GHQ's concern about infantrymen abandoning the rifle and bayonet in favour of grenades.

The so-called 'cult of the bomb', has been discussed by some writers.²¹⁹ Although bombing was rather indiscriminate in 1915 and 1916, this was a consequence of the dearth of grenades followed by a sudden plenty. There was a certain novelty in having an abundance of reliable and effective grenades when before there had been so few. Inevitably, when they became more plentiful, they were used more often. However, the idea that grenades might supersede the rifle and bayonet was ill-founded and, indeed, it never occurred. In June 1915, Sir John French wrote to the War Office about the greater expenditure of hand grenades in recent heavy fighting²²⁰ than had been anticipated which he blamed on the inability of the infantry to use their rifle and bayonet in the confined space of the trenches, resulting in a profligate use of grenades.²²¹ Ultimately, the fault lay with a lack of a tactical system for bombing, made worse by a lack of training. The notion that the rifle and bayonet could not be used in the confined space of a trench was subsequently proved to be quite false.

In the way that musketry and bayonet fighting required skills which had to be learned and practiced, the skills and technical expertise in handling grenades had to be learned. In that respect, there was no reason to favour grenades over the rifle and bayonet, since learning one set of skills was no easier than learning a different set. The claim that men lurked fearfully behind traverses with grenades rather than advance with their rifles is a misunderstanding of the tactics of grenade warfare.²²² Although during the first half of 1915, some men used grenades without formal training, this was not the norm thereafter. The idea that men used grenades in preference to their rifles, particularly in 1915 and 1916, is difficult to substantiate. Indeed, the fear that it occurred seems to have been largely of GHQ's own making during 1915 and was derived from having little idea of how many grenades ought to be used on an operation, reinforced by the deep-rooted idea that grenades were mere expedients which would become redundant once open warfare resumed. There is also the fact that the grenades were unreliable in 1915. The fear never quite went away and was shared by many, from privates to battalion and brigade commanders.

With greater throwing discipline, aided by safer and more reliable grenades, the numbers of grenades carried and used on a bombing operation went down during 1917 and 1918. This is reflected in the monthly demands made by GHQ to the Ministry of Munitions for grenades and the effect this had on output.²²³ Nevertheless, GHQ continually stressed the importance of the rifle and bayonet and worried about the rise of the grenade.²²⁴ Thus, the 'cult of the bomb' was not an actuality but, rather, it was a phobia. The real problem was that bombing operations moved sideways rather than forwards, not that infantrymen resorted to grenades when they ought have been using their rifles.

Much of the tactical developments in grenade fighting can be related to this concern although the increase in availability and the greater reliability of grenades was also crucial to tactical evolution. It is highly probable, although impossible to prove, that there would have been few, if any, tactical developments in grenade warfare had the BEF been forced to continue using the stopgap grenades of 1915 or, indeed, the pre-war percussion-fuzed grenades. If

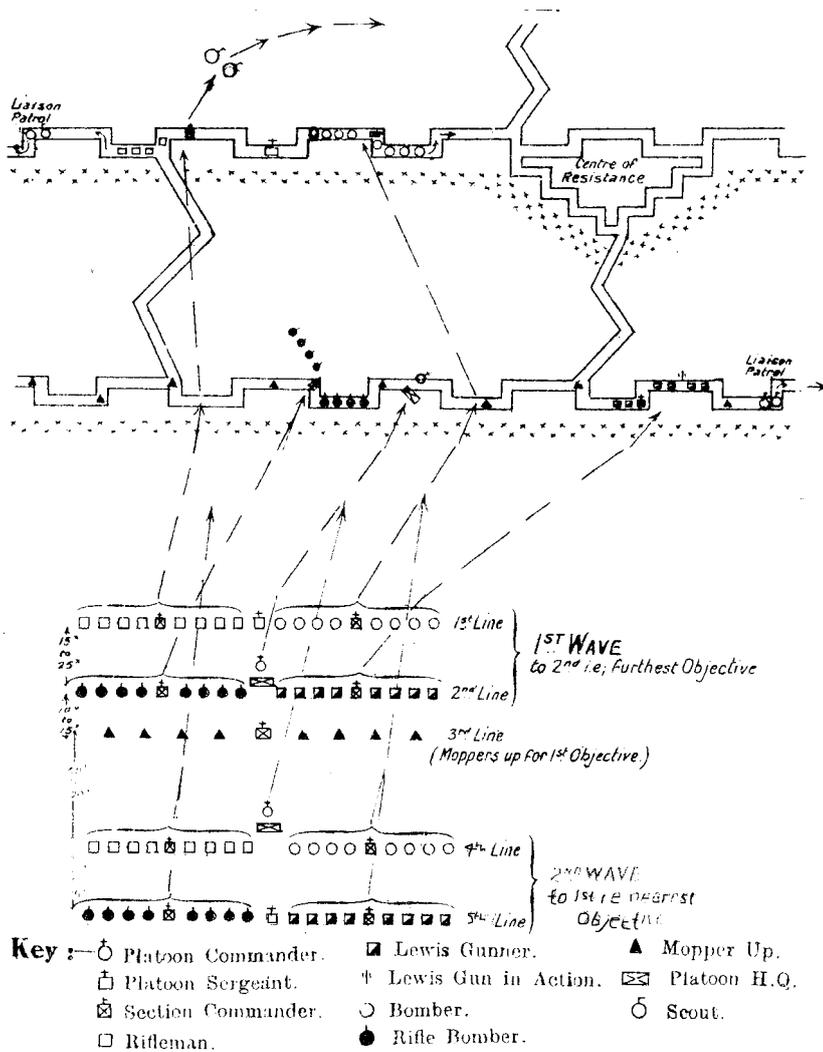


Fig. 64 Trench to trench attack, 1917. This illustrates cooperative tactics employed by a platoon when it encounters a strongpoint. Rifle grenadiers and Lewis gunners obtain superiority of fire over the enemy, while bombers and riflemen advance above ground to turn the enemy flank. Moppers-up guard dugouts and communication trenches. The second wave advances above ground and along the communication trenches to help the first wave. This clearly shows that a platoon attack is, in fact, a series of section attacks (Instructions for the Training of Platoons for Offensive Action, February 1917)

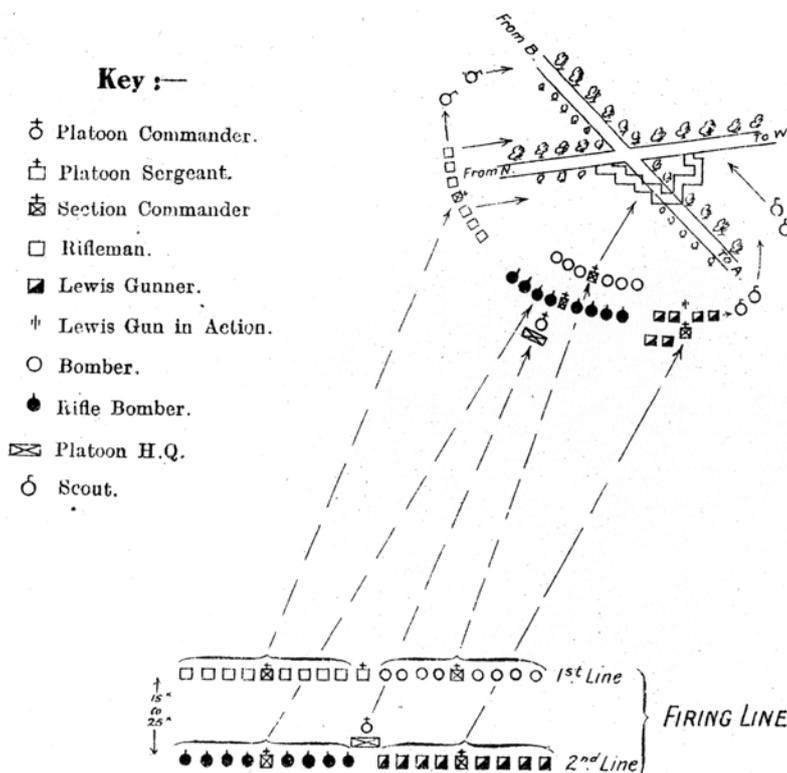


Fig. 65 Platoon tactics when attacking above ground to engage a strongpoint. The riflemen, bombers, Lewis gunners and rifle grenadiers work cooperatively to suppress enemy fire, so that his flank can be turned. Note again that this is a series of cooperative section attacks (Instructions for the Training of Platoons for Offensive Action, February 1917)

the Russo-Japanese War may be cited as an example of extemporised grenade warfare, then it is indicative of the unlikelihood of tactics developing under such circumstances. The advantages of the Mills grenade were its imperviousness to weather conditions, the ease with which it could be armed, its adaptability, its lethality and its reliability. These characteristics allowed the development of tactics. When the tactics of 1917 and 1918 are considered, it is hard to imagine them being feasible with No. 1 or No. 13 hand grenades, for example. The tactics of bombing were the tactics of the Mills grenade.

The tactics of the rifle grenade were essentially fire support and suppression. In 1917, GHQ complained that more practice firing rifle grenades was needed because accuracy was poor.²²⁵ This was as much a technical deficiency as it was one of skill. The problem was never satisfactorily resolved because rifle grenades were inherently inaccurate. For this reason, rifle grenades tended to be fired in barrages to ensure that enough of them landed close enough to the target for the desired effect to be achieved, whether it be to force the enemy into the open where they could be dealt with rifle fire and Lewis guns, or to prevent the enemy from returning fire. There tended to be fewer rifle grenades taken on an operation than hand grenades because of their weight so their effect was limited in comparison with the Lewis gun which was used in a tactically similar way but much more flexibly because of the comparative ease of providing Lewis guns with plenty of ammunition.

Grenade fighting went through three phases, although the distinction between them was blurred. Change occurred dynamically rather than as a series of step changes. Initially, grenade fighting was an ad hoc affair, the object of which was merely to out-bomb the enemy bombers. Here, the problems were those of supplying enough grenades and reliability which limited any sense of tactical thinking about their use. As they became more plentiful and more reliable, a systemised method of fighting was developed for specialists known as bombers who formed a separate part of a platoon. Although bombers were expected to maintain their musketry skills, the level of technical expertise and tactical skill with grenades required of them meant that they were formed into separate sections which only engaged in bombing. Finally, bombing was absorbed into standard infantry tactics, thereby doing away with bombing as a specialism. Now, bombing was an adjunct to the traditional skills of the infantryman which transformed him into a technician proficient in a variety of weapons, including the hand grenade, the rifle grenade, the rifle, the bayonet and the Lewis gun. He resorted to the grenade only when necessary.

Thus, the First World War may be distinguished from the Russo-Japanese War. In Manchuria, grenade fighting was no more than a revival of old siege-fighting techniques and, as such, may best be equated with phase one. Subsequent phases did not develop. Although GHQ and, indeed, the Ministry of Munitions, viewed grenade fighting on the Western Front as no more than an extension of what had occurred in Manchuria, clearly a quite different process occurred. Moreover, far from supplanting the rifle and bayonet, grenades emphasised the value of the infantryman's traditional weapons and skills and the importance of flexible firepower to enable the infantry to fight more effectively when faced by machine-guns, pillboxes and stongpoints.

Notes

- ¹ J E Edmonds, *History of the Great War, Military Operations, France and Belgium, 1914*, (London, 1925), vol. 1, p. 399.
- ² Aggression and its effect on the activity on any given part of the British-held line was is covered by Tony Ashworth, *Trench Warfare, 1914–1918, The Live and Let Live System*, (London, pbk ed., 2000).
- ³ MUN4/2604 Letter from QMG General Maxwell to War Office dated 27 August 1915 gave the following ‘estimated’ daily expenditure per division as follows:
- 4,500 rifle grenades
 - 7,000 percussion-fuzed grenades
 - 7,000 time-fuzed grenades
 - 160 grenades for West Spring Guns
 - 160 grenades for Leach catapults
- ⁴ See SS135 Instructions for the Training of Divisions for Offensive Action, December 1916, p. 52.
- ⁵ It is unclear when this phrase first appeared but it was probably sometime in 1915.
- ⁶ See, for example, Bill Rawling, *Surviving Trench Warfare, Technology and the Canadian Corps, 1914–1918*, (London, 1992), pp. 43, 48, 49, 86, 118, 217. Rawling is generally imprecise and inaccurate in his discussion of grenades and the tactics of grenade warfare. See also John Lee ‘Some Lessons of the Somme: the British Infantry in 1917’ in Brian Bond (ed.), *Look to your Front*, (Staplehurst, 1999), pp. 80–2, 83; Mark Connelly, *Steady the Buffs, A Regiment, a Region, & the Great War*, (Oxford, 2006) pp. 71, 101, 119, 123, 131, 135, 148; and Chris McCarthy’s ‘Queen of the Battlefield’ in Sheffield & Todman (eds), *Command and Control on the Western Front, The British Army’s Experience 1914–18*, (Staplehurst, 2004), pp. 176–7, 181–2, 188–9, 191.
- ⁷ MUN 4/2604 letter dated 25 June 1915.
- ⁸ CDS74 The Training and Employment of Grenadiers, October 1915, p. 1.
- ⁹ Captain A O Pollard, *Fire-Eater, The Memoirs of a VC*, (London, 1932), p. 93.
- ¹⁰ See, for example, comments about bombers in Paddy Griffith, *Battle Tactics of the Western Front, The British Army’s Art of Attack 1916–18*, (New Haven, 1996), p. 113.
- ¹¹ SS398 The Training and Employment of Bombers, March 1916, p. 7.
- ¹² *Op cit.* p. 1.
- ¹³ MUN 5/383/1600/14 Lt-Col O F Brothers, The Development of Weapons Used in Trench Warfare, p. 40.
- ¹⁴ *Ibid.*
- ¹⁵ *Ibid.*
- ¹⁶ SS182 Instructions on Bombing, Part I, British and German Bombs, December 1917, pp. 22–39.
- ¹⁷ Instructions on Bombing, Part I, *op cit.* p. 4.
- ¹⁸ *Ibid.*
- ¹⁹ Training and Employment of Grenadiers, *op cit.* p. 24.
- ²⁰ The terms used here are those used at the time. It is unfortunate that some were applied to more than one component because of the different meanings of the word. Cap is one such term. Thus, it meant a closure or lid and a percussion cap.
- ²¹ Training and Employment of Grenadiers, *op cit.* p. 24.
- ²² *Op cit.* p. 33.
- ²³ *Ibid.*
- ²⁴ Training and Employment of Grenadiers, *op cit.* p. 34. See Chapter 5.
- ²⁵ Training and Employment of Grenadiers, *op cit.* p. 31.
- ²⁶ *Op cit.* p. 30.
- ²⁷ *Op cit.* p. 29.
- ²⁸ There were at least two types of tool. One was an angled sheet of steel with engaged in slots in the raised rim of the plug, while another, simpler, tool was a length of heavy-gauge wire with the ends bent over to engage apertures in the plug.
- ²⁹ See Chapter 5.
- ³⁰ T 173/802 Minutes of Proceedings before the Royal Commission on Awards to Inventors, claim of Mr Vickery (Mills Grenades) Evidence of Major C E W Beddoes, Thursday, 27th January 1921, pp. 3–4.
- ³¹ Training and Employment of Bombers, March 1916, *op cit.* p. 38; and Instructions on Bombing, Part II, November 1917, p. 50.
- ³² Training and Employment of Grenadiers, *op cit.* p. 29.
- ³³ T 173/802, *op cit.* p. 4.
- ³⁴ Training and Employment of Bombers, September 1916, p. 59.
- ³⁵ *Op cit.* p. 7. Teaching by numbers was specifically recommended for handling grenades.
- ³⁶ Training and Employment of Bombers, September 1916, *op cit.* p. 58.
- ³⁷ Instructions on Bombing, Part I, *op cit.* p. 6.
- ³⁸ Discussed in Chapter 5.
- ³⁹ It first appeared in Training and Employment of Bombers, March 1916, *op cit.* p. 45.

- ⁴⁰ Training and Employment of Bombers, September 1916, *op cit.* p. 59.
- ⁴¹ Rick Landers, *'Grenade' British and Commonwealth Hand and Rifle Grenades*, (Dural, 2001), p. 45.
- ⁴² Instructions on Bombing, Part I, *op cit.* p. 6
- ⁴³ Articles Manufactured by RE Workshops, p. 2 and Plate 12.
- ⁴⁴ *Op cit.* p. 27 and Plate 233.
- ⁴⁵ Training and Employment of Bombers, September 1916, *op cit.* p. 59.
- ⁴⁶ *Op cit.* p. 56.
- ⁴⁷ *Op cit.* p. 57.
- ⁴⁸ Instructions on Bombing, Part I, *op cit.* pp. 7, 12.
- ⁴⁹ Training and Employment of Grenadiers, *op cit.* p. 28.
- ⁵⁰ Training and Employment of Bombers, March 1916, *op cit.* p. 44.
- ⁵¹ *Op cit.* p. 43.
- ⁵² See Chapter 5.
- ⁵³ Training and Employment of Bombers, September 1916, *op cit.* pp. 61–2, 66.
- ⁵⁴ Instructions on Bombing, Part I, *op cit.* p. 13.
- ⁵⁵ *Op cit.* p. 15.
- ⁵⁶ *Op cit.* p. 7.
- ⁵⁷ Training and Employment of Bombers, March 1916, *op cit.* p. 56.
- ⁵⁸ Instructions on Bombing, Part I, *op cit.* p. 7.
- ⁵⁹ Army Council Instruction No. 330, 28 March 1918, pp. 1–2.
- ⁶⁰ SS190 Rifle Grenade Discharger, No. 1, Mark I, Description and Instructions for Use, October 1917; Instructions on Bombing, Part I, *op cit.* p. 10.
- ⁶¹ The nose cap of the SMLE enclosed the end of the muzzle and included a sight protector and a bayonet boss. The boss served a double purpose. It allowed a bayonet to be fixed and prevented damage to the end of barrel. Forcing off the nose cap would, therefore, damage the barrel and the sights. See Musketry Regulations, Part I, 1909, p. 4 and Plates II and III. See also *Textbook of Small Arms*, (London, 1929), p. 48, fig. 11 and plate XI.
- ⁶² Army Council Instruction No. 330, *op cit.* p. 1.
- ⁶³ Instructions on Bombing, Part I, *op cit.* p. 10.
- ⁶⁴ Training and Employment of Bombers, March 1916, *op cit.* p. 43.
- ⁶⁵ Training and Employment of Bombers, September 1916, *op cit.* Plates 7 and 8.
- ⁶⁶ Amendment to SS182, *op cit.* pp. 6 and 8, Plates VII and X.
- ⁶⁷ Training and Employment of Bombers, March 1916, p. 56. See also Instructions on Bombing, Part II, *op cit.* pp. 67–9.
- ⁶⁸ Frederick Marten Hale, *Great War "Souvenir" 1914–1918*, photographs on pp. 6, 15 in T 173/252.
- ⁶⁹ Instructions on Bombing, Part I, *op cit.* p. 9.
- ⁷⁰ *Ibid.*
- ⁷¹ Amendment to SS182, "Instructions on Bombing" Part II, November 1918, p. 9.
- ⁷² Instructions on Bombing, Part II, p. 19.
- ⁷³ Training and Employment of Grenadiers, *op cit.* p. 2.
- ⁷⁴ *Op cit.* p. 2; Training and Employment of Bombers, March 1916, *op cit.* p. 6.
- ⁷⁵ Training and Employment of Grenadiers, *op cit.* p. 2.
- ⁷⁶ Training and Employment of Bombers, March 1916, *op cit.* p. 6.
- ⁷⁷ Training and Employment of Grenadiers, *op cit.* p. 2.
- ⁷⁸ *Ibid.*
- ⁷⁹ Instructions on Bombing, Part I, *op cit.* p. 11.
- ⁸⁰ Training and Employment of Bombers, September 1916, *op cit.* p. 6.
- ⁸¹ Training and Employment of Grenadiers, *op cit.*, p. 17. Training and Employment of Bombers, September 1916, *op cit.* p. 7. Instructions on Bombing, Part II, *op cit.* p. 8.
- ⁸² Instructions on Bombing, Part I, *op cit.* p. 11.
- ⁸³ Training and Employment of Bombers, March 1916, *op cit.* pp. 6–7.
- ⁸⁴ Notes on Field Defences, 1914, p. 14.
- ⁸⁵ *Ibid.*
- ⁸⁶ *Op cit.* p. 31.
- ⁸⁷ *Ibid.*
- ⁸⁸ Notes from the Front, Part II, *op cit.* pp. 60–1.
- ⁸⁹ Musketry Regulations, *op cit.* p. 287. Field Service Regulations, Part I, Operations, 1909, pp. 174 and 181.
- ⁹⁰ Notes from the Front, Part II and Further Notes on Field Defences, February 1915, Preface.
- ⁹¹ See, for example, the booklets Notes from the Front, Part I and Part II, published by HMSO in 1914. The exact date of publication of these booklets is uncertain but at least late September 1914.
- ⁹² Training and Employment of Bombers, September 1916, *op cit.* p. 15.
- ⁹³ Training and Employment of Bombers, March 1916, *op cit.* p. 13.

- ⁹⁴ Training and Employment of Bombers, September 1916, *op cit.* p. 15.
- ⁹⁵ *Op cit.* pp. 15–16.
- ⁹⁶ *Op cit.* pp. 13–14.
- ⁹⁷ *Op cit.* p. 14.
- ⁹⁸ Training and Employment of Grenadiers, *op cit.* pp. 16–17.
- ⁹⁹ Memorandum on the Training and Employment of Grenadiers in Notes from the Front, Part IV, May 1915, pp. 19–25.
- ¹⁰⁰ Training and Employment of Grenadiers, *op cit.* p. 1.
- ¹⁰¹ CDS66 Notes British, French and German Grenades, September 1915.
- ¹⁰² Training and Employment of Grenadiers, *op cit.*
- ¹⁰³ See, for example, Training and Employment of Bombers, March 1916, *op cit.* pp. 3–7.
- ¹⁰⁴ Instructions on Bombing, Part II, *op cit.* p. 6.
- ¹⁰⁵ Training and Employment of Bombers, March 1916, *op cit.*
- ¹⁰⁶ WO 32/4905 Titles and Designations of Units, General (Code 15(A)): Bombers. Term to be applied to grenade throwers instead of ‘Grenadiers’, which is reserved for Grenadier Guards.
- ¹⁰⁷ MUN 5/321A *History of the Ministry of Munitions*, vol. XI, *The Supply of Munitions*, Part 1 *Trench Warfare Supplies*, p. 79. See also Anthony Saunders, *Weapons of the Trench War, 1914–1918*, (Stroud, 1999), p. 15.
- ¹⁰⁸ Training and Employment of Bombers, March 1916, *op cit.* p. 5.
- ¹⁰⁹ Training and Employment of Bombers, March 1916, *op cit.* p. 4.
- ¹¹⁰ *Op cit.* pp. 4–5.
- ¹¹¹ *Op cit.* p. 5.
- ¹¹² Training and Employment of Bombers, March 1916, *op cit.* p. 10.
- ¹¹³ See, for example, Captain J C Dunn, *The War the Infantry Knew, 1914–1919, A Chronicle of Service in France and Belgium*, (London, 1987), p. 128.
- ¹¹⁴ Training and Employment of Bombers, September, 1916, *op cit.* p. 3.
- ¹¹⁵ See, for example, Robert David Williams BA (Hons), ‘A Social and Military History of the 1/8th Battalion, The Royal Warwickshire Regiment, in the Great War’, unpublished MPhil thesis, Birmingham University, 1999, p. 98.
- ¹¹⁶ Instructions on Bombing, November 1917, *op cit.* p. 5.
- ¹¹⁷ See Chapter 3.
- ¹¹⁸ Training and Employment of Bombers, March 1916, *op cit.* pp. 57–8. The German document was dated 12 December 1915.
- ¹¹⁹ Training and Employment of Bombers, September, 1916, *op cit.* pp. 87–99.
- ¹²⁰ Instructions on Bombing, Part I, British and German Bombs, December 1917.
- ¹²¹ The earliest manual, that of September 1915, included information on German grenades, an intelligence practice that was continued throughout the war.
- ¹²² Instructions on Bombing, Part II, Training and Employment of Bombers, November 1917.
- ¹²³ *Op cit.* pp. 7–32.
- ¹²⁴ Training and Employment of Grenadiers, *op cit.* pp. 2–5, 16–18; Training and Employment of Bombers, March 1916, *op cit.* pp. 5–15; Training and Employment of Bombers, September 1916, *op cit.* pp. 6–18.
- ¹²⁵ Training and Employment of Bombers, March 1916, *op cit.* p. 36.
- ¹²⁶ *Op cit.* pp. 36–7.
- ¹²⁷ Instructions on Bombing, Part II, *op cit.* pp. 30–1.
- ¹²⁸ Training and Employment of Bombers, March 1916, *op cit.* p. 36.
- ¹²⁹ *Ibid.*
- ¹³⁰ Instructions on Bombing, Part II, *op cit.* p. 30.
- ¹³¹ *Op cit.* p. 32.
- ¹³² *Trench Warfare Supplies*, *op cit.* p. 72.
- ¹³³ T 173/802, *op cit.* pp. 2, 8. *Trench Warfare Supplies*, *op cit.* p. 72–3. See also Brothers, *op cit.* pp. 41–2.
- ¹³⁴ *Op cit.* p. 2.
- ¹³⁵ SS152 Instructions for the Training of the British Armies in France, revised edition, January 1918, pp. 6, 8.
- ¹³⁶ Instructions on Bombing, Part II, *op cit.* p. 6 cites Section 5 Paragraph 9 but this refers to signallers, not bombers. There is a curious anomaly in that Part II was apparently issued before the revised edition of SS152 which it cites.
- ¹³⁷ SS152 Instructions for the Training of the British Armies, *op cit.* p. 6
- ¹³⁸ T 173/802, *op cit.* p. 2.
- ¹³⁹ Instructions for the Training of the British Armies, *op cit.* pp. 8–9.
- ¹⁴⁰ *Op cit.* p. 12.
- ¹⁴¹ *Op cit.* pp. 25, 29.
- ¹⁴² *Op cit.* pp. 48–9.
- ¹⁴³ *Op cit.* p. 52.
- ¹⁴⁴ *Op cit.* p. 53.

- ¹⁴⁴ *Op cit.* pp. 54–5.
- ¹⁴⁵ *Op cit.* p. 93.
- ¹⁴⁶ Brothers, *op cit.* p. 43.
- ¹⁴⁷ See, for example, Training and Employment of Grenadiers, *op cit.* pp. 6–15.
- ¹⁴⁸ *Op cit.* p. 6.
- ¹⁴⁹ *Op cit.* pp. 6–7.
- ¹⁵⁰ For detailed instructions regarding bomb stores see Instructions on Bombing, Part II, *op cit.* pp. 44–7.
- ¹⁵¹ Training and Employment of Bombers, March 1916, *op cit.* p. 31.
- ¹⁵² *Op cit.* p. 14.
- ¹⁵³ *Op cit.* pp. 14–15. See also Training and Employment of Bombers, March 1916, *op cit.* pp. 29–31.
- ¹⁵⁴ Notes on Field Defences, 1914, *op cit.* p. 31.
- ¹⁵⁵ Training and Employment of Grenadiers, *op cit.* p. 10; Instructions on Bombing, Part II, *op cit.* pp. 20–1.
- ¹⁵⁶ Training and Employment of Bombers, March 1916, *op cit.* p. 30.
- ¹⁵⁷ *Op cit.* p. 30 and Training and Employment of Bombers, September 1916, *op cit.* p. 37.
- ¹⁵⁸ Instructions on Bombing, Part II, *op cit.* p. 43.
- ¹⁵⁹ Training and Employment of Bombers, March 1916, *op cit.* pp. 4, 8–9.
- ¹⁶⁰ Instructions on Bombing, Part II, *op cit.* p. 6.
- ¹⁶¹ SS143 Instructions for the Training of Platoons for Offensive Action, February 1917, *op cit.* p. 66. Curiously, this makes reference to Instructions on Bombing, Part II which did not appear until November 1917. This suggests that the date of one of them is incorrectly printed in the document concerned.
- ¹⁶² Training and Employment of Bombers, September 1916, *op cit.* p. 3. Instructions on Bombing, Part II, *op cit.* p. 5.
- ¹⁶³ Training and Employment of Grenadiers, *op cit.* p. 7.
- ¹⁶⁴ CDS383 Extract from ‘Notes on Minor Tactics of Trench Warfare’ by ‘A Casualty’, June 1915, reprinted December 1915, p. 3.
- ¹⁶⁵ See, for example, Kathryn Louise Snowden, ‘British 21st Infantry Division on the Western Front 1914–1918, A Case Study in Tactical Evolution’, unpublished MPhil thesis, Birmingham University, p. 56. The movement outwards by bombers is mentioned here but the significance of the direction of movement is not discussed.
- ¹⁶⁶ Notes on Minor Tactics, *op cit.* pp. 9–10.
- ¹⁶⁷ *Op cit.* pp. 12–13 and Plate 9.
- ¹⁶⁸ Snap shooting is firing aimed shots at momentary targets.
- ¹⁶⁹ Training and Employment of Bombers, September 1916, *op cit.* p. 12.
- ¹⁷⁰ Training and Employment of Bombers, March 1916, *op cit.* pp. 8–9.
- ¹⁷¹ Training and Employment of Bombers, September 1916, *op cit.* p. 11.
- ¹⁷² *Op cit.* pp. 11–13 and Fig. 1.
- ¹⁷³ These were typically No. 27 grenades containing white phosphorus which had an incendiary effect as well as producing smoke. See Landers, *op cit.* pp. 88–90. See also The Training and Employment of Bombers, September 1916, *op cit.* p. 20.
- ¹⁷⁴ Training and Employment of Bombers, September, 1916, *op cit.* p. 23.
- ¹⁷⁵ *Op cit.* p. 19.
- ¹⁷⁶ *Op cit.* p. 14. See also Notes on Minor Enterprises, *op cit.* p. 6.
- ¹⁷⁷ These mortars fired only smoke or chemical rounds.
- ¹⁷⁸ *Op cit.* p. 14.
- ¹⁷⁹ Sir John Macdonald advocated that anyone involved in trench fighting be armed with a knife. See *The Times* correspondence 29 November 1915, 2 February 1916, 29 June 1916. Macdonald was a retired brigadier-general and a former governor of Edinburgh Castle.
- ¹⁸⁰ Notes on Minor Enterprises, *op cit.* p. 6. The Training and Employment of Bombers, September, 1916, *op cit.* p. 26.
- ¹⁸¹ Training and Employment of Bombers, September 1916, *op cit.* p. 28.
- ¹⁸² The small box respirator, worn on the chest, did not see widespread use until 1917. The improved versions used a rubber face mask with a nose clip, while the active part contained carbon filters and anti-gas chemicals. See SS143 Instructions for the Training of Platoons for Offensive Action, 1917, June printing, p. 12. See also Instructions on Bombing, Part II, *op cit.* pp. 61, 62, 64, 66, 67, 68, 69, 70, 71, 72 which show photographs of bombers wearing the box respirator.
- ¹⁸³ Training and Employment of Bombers, September 1916, *op cit.* p. 28.
- ¹⁸⁴ SS197 Notes on Minor Enterprises, March 1916, p. 5.
- ¹⁸⁵ *Op cit.* p. 6.
- ¹⁸⁶ SS119 Preliminary Notes on the Tactical Lessons of the Recent Operations, July 1916, p. 2.
- ¹⁸⁷ Training and Employment of Bombers, September, 1916, *op cit.* pp. 22–3.
- ¹⁸⁸ *Ibid.*
- ¹⁸⁹ *Op cit.* pp. 24–5.
- ¹⁹⁰ Preliminary Notes, *op cit.* p. 2.

- ¹⁹⁰ *Ibid.*
- ¹⁹¹ Training and Employment of Bombers, September, 1916, *op cit.* p. 24.
- ¹⁹² See Frank Richards, *Old Soldiers Never Die*, (London, 1933), p. 247 and Rawling, *op cit.* p. 162.
- ¹⁹³ Instructions on Bombing, Part II, *op cit.* pp. 33, 39–40.
- ¹⁹⁴ *Op cit.* pp. 34–5. See also SS155 Notes on Dealing with Hostile Machine Guns in an Advance, April 1917.
- ¹⁹⁵ Instructions on Bombing, Part II, *op cit.* pp. 36, 38–41. CDS50 Tactical Notes, July 1915, p. 2. ‘Notes on Minor Tactics of Trench Warfare’, *op cit.* p. 3.
- ¹⁹⁶ Instructions on Bombing, Part II, *op cit.* pp. 37–8.
- ¹⁹⁷ *Op cit.* p. 41.
- ¹⁹⁸ Connelly, *op cit.* p. 131.
- ¹⁹⁸ Instructions on Bombing, Part II, *op cit.* pp. 39–40.
- ¹⁹⁹ *Op cit.* p. 40.
- ²⁰⁰ *Op cit.* pp. 40–1.
- ²⁰¹ Instructions for the Training of Platoons, June printing, *op cit.* p. 8.
- ²⁰² Instructions on Bombing, Part II, *op cit.* p. 15.
- ²⁰³ *Op cit.* pp. 16–19.
- ²⁰⁴ See *The Times* correspondence 29 November 1915, 2 February 1916 and 29 June 1916.
- ²⁰⁵ Instructions on Bombing, Part II, *op cit.* p. 19.
- ²⁰⁶ Instructions for the Training of Platoons, June printing, *op cit.* pp. 11–14.
- ²⁰⁷ Amendments to SS143, November 1917.
- ²⁰⁸ *Ibid.*
- ²⁰⁹ SS143 The Training and Employment of Platoons, February 1918, pp. 6, 7.
- ²¹⁰ *Op cit.* p. 8.
- ²¹¹ *Op cit.* p. 21.
- ²¹² Instructions for Training of Platoons, June printing, *op cit.* p. 6.
- ²¹³ *Op cit.* pp. 21–2.
- ²¹⁴ Instructions for Training of Platoons, June printing, *op cit.* p. 7.
- ²¹⁵ *Op cit.* pp. 22–3, 24. The rifle grenade was also described as such in June 1917. See Instructions for Training Platoons, June 1917 printing, *op cit.* p. 7.
- ²¹⁶ *Op cit.* p. 26.
- ²¹⁷ *Op cit.* p. 28.
- ²¹⁸ Instructions for the Training of Divisions, *op cit.* p. 52.
- ²¹⁹ See, for example, Griffith, *op cit.* pp. 68–9.
- ²²⁰ This was probably the Battle of Festubert, 9–26 May 1915.
- ²²¹ MUN 4/2604, letter dated 25 June 1915.
- ²²² Griffith, *op cit.* p. 68.
- ²²³ Discussed in Chapter 4.
- ²²⁴ Instructions for the Training of Divisions, *op cit.* p. 52.
- ²²⁵ *Op cit.* p. 53.

8 The Tactical Employment of Mortars

Mortars were not viewed as expedients in quite the same way as were grenades, although, had there not been a shortage of howitzers, it is possible that the mortar would have remained an anachronism. That medium and heavy mortars were manned by gunners was hardly surprising given that the mortar was a form of artillery. The light mortar, however, was worked exclusively by the infantry,¹ while the 4-inch Stokes mortar and the Livens projector were operated solely by the Special Brigade.² Thus, responsibility for mortars was not vested entirely in the artillery but was spread across different branches of the army, part of a pragmatic and flexible approach to novel munitions adopted by GHQ. It was an accident of circumstance that the light mortar was manned by the infantry, whereas the mortars operated by the Special Brigade were only ever used for chemical warfare. The manning of light mortars by infantrymen was a novel approach to operating artillery. While the MGO was not entirely happy about it, he had to be pragmatic because there were not enough trained gunners to man light mortars as well as the medium and heavy mortars in addition to conventional artillery.³ Not surprisingly, perhaps, the tactical use of light mortars developed along quite different lines from that of medium and heavy mortars. Here were the seeds of a profound change that was to occur in the tactics of the BEF when the mobility of the light mortar began to play a significant role in the evolution of deep battle.

This chapter examines the evolution of the tactical use of mortars, focusing principally on the 2-inch Woolwich medium mortar, the 9.45-inch heavy mortar and, especially, the 3-inch Stokes light mortar. The chapter discusses the significance of tactical developments in respect of the wider context of large-scale offensive operations as well as in relation to smaller scale operations and the tactics of defence. The early improvised mortars that preceded these weapons were too unreliable and had too short a range, while their ammunition was too scarce for their use to have any real tactical meaning.⁴ They tended to be used piecemeal until about mid-1915 when production of mortars and ammunition increased.⁵ Autumn 1914 to autumn 1915 was a period of intensive learning for BEF in all aspects of warfare on the Western Front. Certainly, no one had much idea of what might be achievable with mortars. This was new ground. However, the development of tactics for mortars should not be seen as having been inevitable, since the mortars with which the BEF had to work until mid-1915 were more of a nuisance than a help to all concerned, interfering with day-to-day life in the trenches because they provoked retaliation from the Germans.

As part of the discussion, this chapter looks at drills. The tactical use of mortars was related in their loading and firing drills which, in turn, were directly related to their engineering design. This is not to imply that medium and heavy mortars could have been employed in a similar way to how the Stokes was used had they been differently engineered. On the contrary: the weight of the mediums and heavies and their ammunition precluded mobility.

Rather, it is to suggest that light mortars would have been employed similarly to medium and heavy mortars had the loading and firing drills been similar, which was a possibility when the Stokes was first used, despite its novel means of operation. Hence, it is appropriate to discuss the various drills associated with the mortars under discussion here. Previous writers who have touched upon the tactical employment of trench mortars on the Western Front have not examined drills.⁶ Moreover, previous discussions of tactics have tended to be non-specific so that the differences between light, medium and heavy mortars have tended to be blurred. There has been no in-depth discussion of tactics in which the evolution of mortar tactics is considered in light of the development of deep battle.

Unlike grenades, trench mortars did not figure in any of the trench warfare booklets produced by GHQ in 1914, whereas machine-guns, conventional artillery and cooperation between the artillery and the infantry were always important features.⁷ Indeed, mortars did not figure in any of the booklets produced in the first half of 1915.⁸ This is indicative of the insignificance of their role in the BEF. This changed during the second half of 1915 but the first manual devoted to the employment of trench mortars did not appear until March 1916,⁹ while a one-page leaflet had been issued in October 1915 in respect of the 4-inch Stokes mortar which was first used operationally at Loos, to fire smoke bombs.¹⁰ The first drill manual did not appear until April 1916; this combined a technical handbook with drill instructions for the 3-inch Stokes mortar.¹¹ A drill manual for the 2-inch medium mortar did not appear until May 1916 despite the fact that this mortar had been in service for more than a year.¹²

Finally, this chapter considers whether the tactics developed by mid-1918 for the employment of the Stokes mortar had a significant effect on infantry tactics and, hence, on three-dimensional warfare.

Organisation and Drill

It is significant that the handling of a trench mortar was described as a drill, whereas the handling procedure for a grenade was never termed as such. There was, of course, another reason for this differentiation, namely, the greater complexity of handling a mortar and its ammunition compared to the process of arming and throwing or discharging a grenade. Drills inevitably had their origin in the engineering design of the munition concerned and nowhere was this more apparent than with the Stokes mortar.

Drill is a sequence of actions taken by the members of a mortar detachment to carry out a specific task such as setting up the mortar or loading and firing it. The number of actions in a drill was determined by the technical characteristics of the mortar and its ammunition. There were several drills for each mortar, including preparing to advance to a new location, setting up the mortar at that location, laying the mortar on a target, loading and firing, and handling misfires. The number of men in the detachment, also termed a sub-section, depended on the technical characteristics of the mortar. The 2-inch medium was served by a detachment of five.¹³ The 3-inch Stokes mortar was served by five infantrymen,¹⁴ while the 9.45-inch heavy mortar and the 6-inch Newton medium mortar were both served by seven gunners.¹⁵ This compares with a detachment of ten for a 18-pounder field gun.¹⁶

Mortars were organised into batteries of four. By 1917, Stokes batteries had been expanded to include eight mortars, divided into two half-batteries of four, each half-battery comprising two sections each divided into two sub-sections of one mortar each.¹⁷ This remained the standard organisation for the rest of the war.¹⁸ The sub-section of one mortar and its crew was always the basic unit of all mortar batteries. The leader of the sub-section was usually a senior NCO and was designated No. 1. Each member of the detachment had a specific task. In 1916, the No. 1 of a 2-inch mortar detachment relayed orders from the battery commander, laid the mortar for range and deflection, loaded the propellant charges and rammed them home, examined the fuzes, removed the safety pins or prepared the percussion fuzes as required, removed and replaced the clinometer and periscope before and after firing, inserted an ignition cartridge in the firing mechanism and fired the mortar. After firing the mortar, he sponged out the barrel and ejected the spent cartridge. The No. 2 planted the aiming posts,¹⁹ assisted the No. 1 in his tasks, cleaned the stem of the bomb and the muzzle, loaded the bomb and spun it to the right to ensure that it was fully home. The No. 3 set the fuzes and handed the ammunition to the No. 2, repeating aloud all orders concerning the fuze and the charge. Nos 4 and 5 prepared the ammunition for loading.²⁰ It is significant that the barrel had to be sponged between each shot, in the manner of a Napoleonic cannon. This was to remove any fouling and ensure that the barrel did not overheat. The sequence for laying, loading and firing the 2-inch mortar comprised at least twenty actions, followed by another two before the sequence was repeated.²¹ The 2-inch mortar had to be re-laid after each round.

The drill for loading and firing the 6-inch Newton, with its detachment of seven, was rather different from the sequence of its predecessor because its bombs had no stem and the mortar was fired on the Stokes principle.²² Again, the No. 1 was in command. He laid the mortar, examined the charges fitted to the bomb by the No. 4 and examined the fuze fitted by the No. 7 who also fitted the exploder.²³ After each round, the No. 2 cleaned the bore with a gas ejector, a form of rammer which was pushed down the barrel, and helped the No. 1 lay the mortar. The No. 3 was the loader and, hence, the firer. He removed the safety pins and the fuze cap prior to loading. Nos 5 and 6 helped to get the ammunition ready. The No. 7 was in charge of the ammunition. Unlike the 2-inch mortar, the Newton's ammunition was prepared prior to a shoot by inserting the propellant cartridge and fixing the incremental charges to the tail. The sequence for laying, loading and firing the Newton comprised eleven actions, followed by two more after the round had been fired.²⁴ There was no need to relay the mortar after each round nor to remove and replace the sighting gear each time a round was fired. Clearly, the Newton was more efficient and faster to operate than the 2-inch mortar it replaced.

This drill was similar to that used to lay, load and fire the 9.45-inch mortar, although the distribution of responsibilities was different. Thus, the No. 2 laid the mortar for line, while Nos 3 and 4 adjusted the elevation gear and traversed the mortar. That the gunner responsible for laying the mortar did not also make the physical adjustments to the gear was due to the design and size of the mortar which precluded one man doing all three tasks.

The No. 5 handed the charge to the No. 1 who fitted it to a special tool before ramming it home. The tool was necessary because of the separate combustion chamber in the 9.45-inch mortar. No. 5 also sponged the barrel after each round. The No. 6 fitted exploders and fixed and set the fuzes. No. 1 was in command, laid the mortar for elevation and fired it.²⁵ In addition, Nos 3, 4 6 and 7 loaded the bombs with the loading tray which required a man at each corner. The 9.45-inch mortar required a sequence of thirty-one actions followed by another eight actions before the mortar was ready for reloading.²⁶ The sequence could be modified when the mortar crew was reduced by two men but this only redistributed some of the actions without reducing their number.²⁷ The mortar had to be re-laid each time because the barrel had to be depressed to 20° in order to load a round from the loading tray which had to be fitted to the muzzle. Moreover, the elevating gear had to be clamped then released each time although the later use of the Heap self-locking gear simplified matters somewhat.²⁸ This mortar was the most complex of all of those in service with the BEF.

The Stokes was the simplest mortar to lay, load and fire. In 1916, the No. 1 laid the mortar for line and range, using the clinometer to set the range and elevated or depressed the mortar using the bevel gear. The No. 3 withdrew the safety pins and handed the bombs to the No. 2 who passed them to the No. 1 who then dropped them down the barrel. Meanwhile Nos 4, 5 and 6 prepared more bombs.²⁹ Although the commander was supposed to check the elevation between each round, by mid-1917, the commander was only expected to do this as often as was practical, although every four or five rounds was considered advisable.³⁰ The sequence included no more than seven actions.³¹ Because the rate of fire of a Stokes mortar was so much higher than any other in the BEF, the orders issued by the battery commander not only included range and the method of fire but also the time interval between each round, given in seconds.³²

In order to facilitate rapid fire, it was essential that each member of the detachment took up the correct position in relation to each other and the mortar. This was, of course true of all mortars but, whereas the detachments of medium and heavy mortars took cover when each round was fired, in case of a premature or a misfire, this was not practical with the Stokes.³³ Thus, the detachment remained with the mortar while it was in action. The No. 1 stood on the right of the mortar with the No. 2 standing behind him and the No. 3 a few paces further back.³⁴ A year later, this had been completely changed. Now, the No. 1 stood on the left, facing the muzzle with the No. 2 on the right, also facing the muzzle. The No. 3 was positioned on the left of the No. 2 in line with, and facing, the base plate. The No. 5 was positioned by the ammunition and the No. 4 was positioned between him and the No. 3.³⁵ With bomb orientated so that the lever on the pistol head³⁶ faced downwards, the No. 4 removed the lower safety pin and passed the bomb to the No. 3 who then removed the other safety pin and passed the bomb to the No. 2 who took the pistol head in his right hand, his palm facing up, and placed his left hand, palm down, on the body of the bomb. He placed the base inside the muzzle until given the command to fire when he dropped the bomb down the barrel, quickly taking away his hand. This sequence was repeated until cease fire was ordered.³⁷ By mid-1918, this was amended to allow for the No. 146 all-ways fuze that

was fitted to some rounds.³⁸ The No. 2 had to check that the tape had not been disturbed by the removal of the safety pin, by sight in daylight but by feeling with the right forefinger at night.³⁹ The firing drill could be performed by only four men if necessary.

Misfire drill was essential for all mortar detachments because misfires were unavoidable although their incidence could be reduced by good maintenance.⁴⁰ In the early years of the war, there was an almost cavalier approach to dealing with misfires, as typified by the 2-inch mortar misfire drill. The detachment waited 1 minute, after which, a second ignition cartridge was inserted in the rifle mechanism and fired.⁴¹ By 1917, this blasé approach had been abandoned for a more measured and careful one in which a second cartridge was only used if the original one had not fired, which meant that it had to be examined.⁴² If the cartridge had fired, the detachment had to wait a further 2 minutes before unloading, preferably behind cover. The risk of firing a second cartridge without checking the state of the first one was, at best, a short round, but, at worst an explosion of the propellant, a premature and a burst barrel.⁴³

There were at least eight possible causes of a misfire in the Stokes mortar, including a bent striker, a bent cartridge holder and fouling in the bore.⁴⁴ Fouling, condensation in the bore, and poorly rammed home charges could cause misfires in the medium and heavy mortars. Sponging out the bore helped eliminate fouling, while well-practised loading and firing drills helped prevent misfires due to inefficiency. When the 9.45-inch mortar misfired, the detachment had to take cover for the mandatory minute before the No. 1 approached the mortar to examine the cartridge. If the cartridge had been fired, everyone had to stand clear for another 5 minutes. If nothing happened after 5 minutes, the mortar could be unloaded and a new charge rammed home. Unloading the 9.45-inch mortar was something of a rigmarole. The fuze had to be set to 'safety' before it and the exploder could be removed from the bomb while it was still inside the mortar. A tool called a bomb extractor was screwed into the bomb, in place of the fuze, and the bomb was then pulled out of the barrel. Finally, the charge was extracted with another special tool.⁴⁵

A misfire in a 6-inch mortar was no simpler to handle than one in the 2-inch mortar despite the fact that the Newton incorporated a misfire plug. The detachment still had to wait 1 minute, followed by 2 minutes if a second attempt at firing the propellant with the Bickford fuze inserted through the plug vent was unsuccessful.⁴⁶ Then, the mortar had to be unloaded. The Newton had to be dismantled so that the bomb could be slid out of the barrel. The No. 2 supported the middle of the barrel while the No. 3 tipped up the breech under the direction of the No. 1 who waited at the muzzle to catch the bomb before it fell on the ground. Having caught it, the No. 1 removed the fuze while the bomb was still in the muzzle and finally took out the bomb.⁴⁷ The mortar then had to be remounted and re-laid.

Misfires in a Stokes were slightly easier to deal with if only because the mortar was lighter and easier to manhandle. In 1916, when the pistol head fuze was the sole fuze in service with Stokes bombs, the procedure required the No. 2 to lift the breech out of the base plate and raise it so that bomb slid down the barrel. Once the bomb had started to move, the No. 1 placed his hand over the muzzle to stop the bomb from falling out. He checked that the striker was still engaged and that the lever had not been released. He then



Fig. 66 *An Australian Stokes mortar detachment demonstrating misfire drill* (Australian War Memorial)

extracted the bomb, taking care not to let the lever fly off, and re-inserted the safety pin.⁴⁸ By late 1917, the misfire procedure had been changed. Now, the No. 3 raised the breech and the No. 2 had the responsibility for catching the bomb.⁴⁹ The barrel was raised still further after the bomb had been removed to dislodge any fouling. When the No. 146 all-ways fuze was fitted, the misfire procedure was slightly different. Now, the No. 2 pushed the safety bar back into the fuze before removing the bomb, then unscrewed the fuze and reset it so that it could be screwed back into the bomb.⁵⁰

Misfire drills needed to be safe and effective. Moreover, they had to be well-rehearsed and conducted calmly. Clearly, the engineering of the mortars and the design of fuzes dictated the nature of procedures. In essence, the simpler and lighter the mortar, the simpler and quicker the procedure. The sooner the misfire was dealt with, the sooner the mortar would be back in action. Unfortunately, misfires could result in detonation of the propellant before the mortar could be unloaded, thereby rendering the mortar unserviceable and presenting a real danger to the detachment. It is noteworthy that some 2-inch mortar detachments wore body armour although it is not known whether this was officially provided or purchased privately.⁵¹

Battery positions and emplacements

It was not unusual for a battery to fire on a specified target, then relocate to another position because the act of firing gave away its position which led to retaliation by enemy artillery, mortars or rifle grenades. This was especially true when a mortar had fired a lot of rounds.⁵² Thus, two important drills for all mortar detachments were mounting and dismounting their mortar.⁵³ When bringing the mortar into action in a new location, everything had to be put together from the component parts. The emplacement and the mortar bed had to be constructed according to specific instructions. This was less a drill, perhaps, than it was a chore but it had to be done correctly in order to protect the mortar and the crew as well as allow the mortar to shoot on the targets it was there to engage. Mortars were also sited in permanent emplacements. Whole sections of training manuals were devoted to the appropriate positioning of a battery and the correct construction of the emplacements.⁵⁴

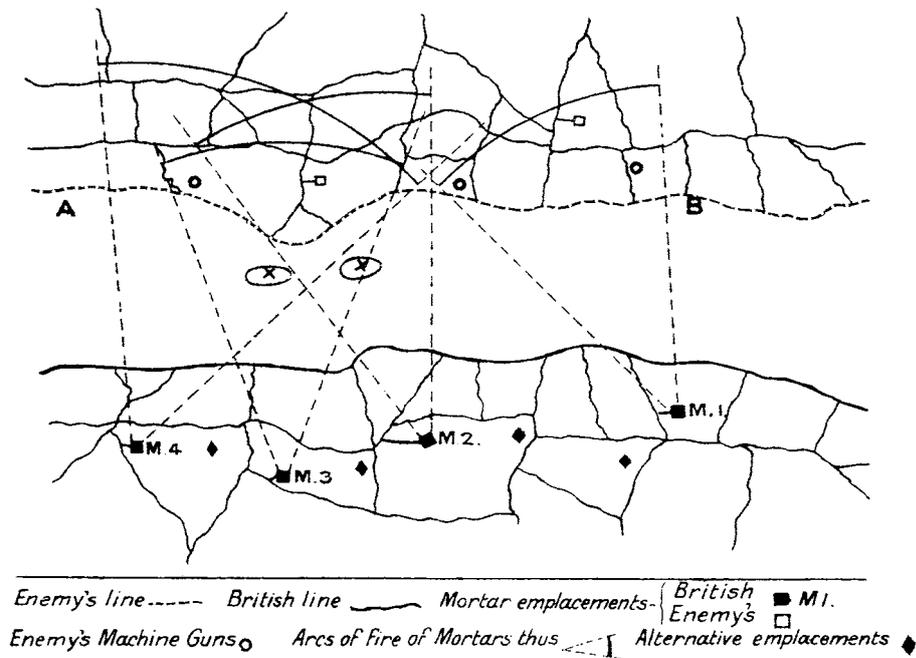


Fig. 67 Trench mortar battery positions in relation to the front line and enemy mortars machine guns. Arcs of fire are concentrated in the craters X. Three mortars are focused on the salient while all four enfilade the enemy front line and communication trenches. A—B is the extent covered by the battery (Artillery Notes No. 6 – Trench Mortars, March 1916)

The position of the battery was largely determined by the range of its mortars but it was also dependent upon the known disposition of enemy mortars and machine guns that could engage the battery.⁵⁵ Hence, the emplacements were dispersed behind the front-line trenches over a distance of some few hundred yards. They had to be located sufficiently distant from each other to ensure that the battery did not present a single target.⁵⁶ If the battery was intended to protect the British line, the location of the emplacements was chosen to cover vulnerable points in the British trench network and, wherever possible, to provide enfilade fire and crossfire in the event of an enemy break-in.⁵⁷ Irrespective of whether the battery was intended for attack or defence, the important aspect of any emplacement was the arc of fire. A wide arc enabled the mortar to engage different targets without changing position.⁵⁸ Other considerations included the suitability of the site for observing the fall of shot, yet the location had to be out of direct sight of the enemy. When the battery was to support an offensive operation, it had to be placed far enough forward to enable the mortars to engage targets at the back of the enemy's first line.⁵⁹ Emplacements had to be positioned so that the activities of the mortar did not hinder the infantry going about their routines or specified tasks. This meant that emplacements had to be dug from a communication trench, rather than from a fire trench or a support trench.⁶⁰

It was essential that the emplacements were concealed from the air⁶¹ and that the shelter for the crew was bomb-proof.⁶² Ideally, the roof of a permanent emplacement was made from reinforced concrete. The ammunition store had to be positioned at least one traverse away from the mortar and provided with protection against enemy fire. In the case of heavy mortars, the magazine needed to have at least 15 feet of earth over it. By 1917, medium and heavy mortars were often provided with emplacements that were below ground with only an opening to shoot through.⁶³ This had to be made so that the mortar could fire over the parapet when it was depressed to its lowest firing angle, that is, 45°, with a traverse of 90°.⁶⁴ A depth

of 6 feet was recommended for emplacements but these had to be revetted and provided with cross-shoring to prevent collapse. All emplacements had to be drained. The layout of the emplacement varied according to the type of mortar although they were always made as small as possible.⁶⁵ In 1916, a permanent emplacement for a 2-inch mortar was typically rectangular, with two parallel trenches connecting the mortar pit to the ammunition store that was set some distance to its left. The trenches effectively formed an island which divided the mortar pit from the magazine. The mortar was fired by the No. 1 by means of a lanyard attached to the trigger of the firing mechanism, after having first retreated behind the island so that he was protected in the event of a premature. Only the mortar pit was open.⁶⁶



Fig. 68 (left) A 2-inch mortar emplacement in the Middle East. See Fig. 69. Note the shape and the sandbags. The No. 1 is about to pull a lanyard to fire the mortar. He is wearing body armour (IWM)

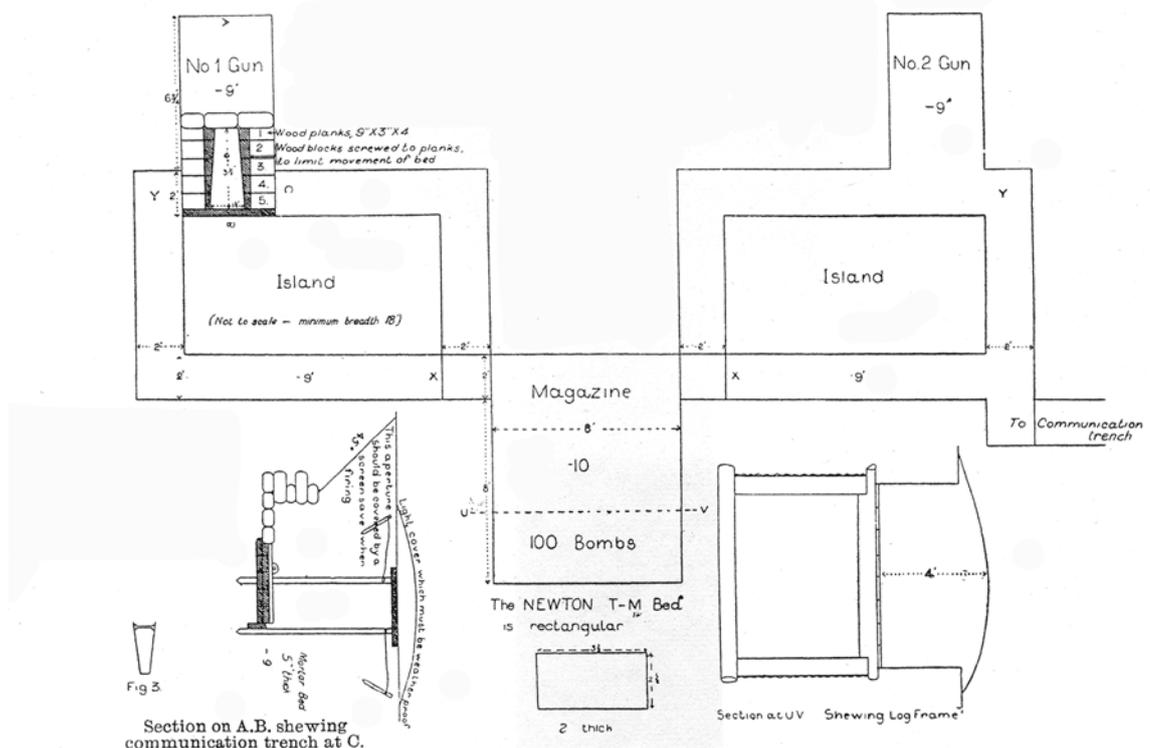


Fig. 69 Double emplacement for medium mortars. Fig. 68 illustrates an emplacement of this type (Artillery Notes No. 6 – Trench Mortars, March 1917)

By mid-1917, a more sophisticated arrangement was also in use; in effect, two emplacements with a common magazine, with very narrow security trenches round the rectangular islands in each emplacement, connected via one of the trenches at the entrance to the magazine.⁶⁷ Ideally, such a double emplacement was not set out in a neat geometrical pattern but had the pits and magazine misaligned to make it more difficult to spot from the air, to which end, the emplacement was also camouflaged. This arrangement was also suitable for the 6-inch Newton. The 9.45-inch mortar had an L-shaped emplacement, the mortar pit, known as the gun chamber, being located at the junction of the upright and horizontal components of the L.⁶⁸ The L was 30 feet by 24 feet, while the chamber was 8 feet square inside. The crew dugout, at the end of the upright of the L, was 10 feet by 6 feet inside, and the magazine, at the end of the horizontal, was 12 feet by 6 feet inside, all at a depth of 6 feet, reinforced with timber pitprops and beams, and corrugated iron sheeting.⁶⁹ This represented a major work. Because the mortar's mounting could be rotated on a traversing ring in the base plate, this allowed the mortar to be rotated so that the barrel pointed towards the magazine for loading.⁷⁰ It was this facility which determined the shape of the emplacement. The 2-inch mortar and the 6-inch Newton both needed to be loaded from the front which meant that space had to be provided and this dictated the shape of the pit.

In every instance, a temporary emplacement was also constructed in another location as soon as the mortar had been mounted at the first location. Although the alternative emplacements were simpler in design and construction than those at the first location, they had to be provided with suitable beds for the mortars so that, in the event of having to move the battery to the new location, the mortars could be mounted and brought into action as quickly as possible.⁷¹ In all emplacements, the mortar bed had to be provided with a sufficiently strong foundation to prevent the mortar moving when fired. Although this was a bigger problem for heavy mortars than for light mortars, it is true to say that, without a firm bed, a mortar of any size and calibre was largely ineffective. The construction of the foundation varied according the materials available in the locality as well as the nature of the ground. A foundation for a 2-inch mortar on marshy ground was typically made up of several layers comprising a 4-inch base layer of straw on which was placed two hurdles of brushwood, followed by a layer of filled sandbags that had to be rammed down. This was topped by 1.5-inch planking on which was another layer of rammed-down sandbags around several wooden beams 4 feet by 4 inches by 2.5 inches. The mortar's wooden bed was set on top of this, all of which was contained in a hole about 2 feet deep. The edges of the bed were supposed to be flush with the ground so that the bed could be sandbagged for added security.⁷² Alternatively, 5-inch diameter wooden piles could be driven to a depth of up to 4 feet, depending on the ground conditions and a wooden platform constructed from 4-foot deals⁷³ 9 inches deep by 3 inches wide. The mortar bed sat on top.⁷⁴ In the case of the 9.45-inch mortar, the bed had a foundation of steel-reinforced concrete.

The Stokes mortars were emplaced quite differently from the mediums and heavies. In 1916, Stokes mortars could be sited in a fire trench although it was not unusual for an emplacement to be dug behind the parados.⁷⁵ Later, a small recess was cut in the back of the trench for the mortar.⁷⁶ These were no more than temporary positions, however, as there were obvious

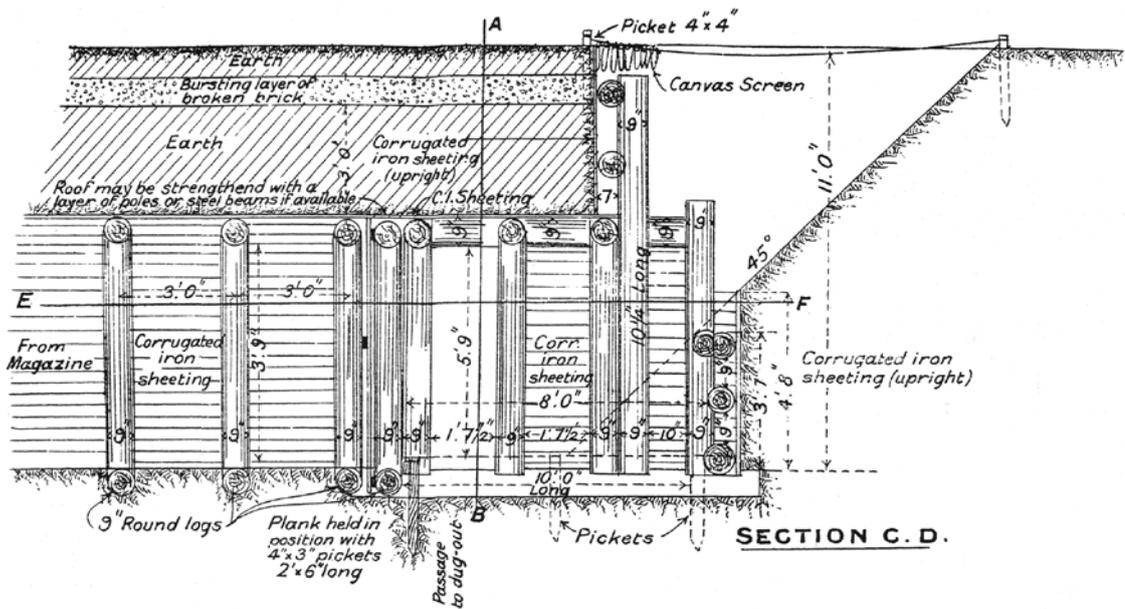
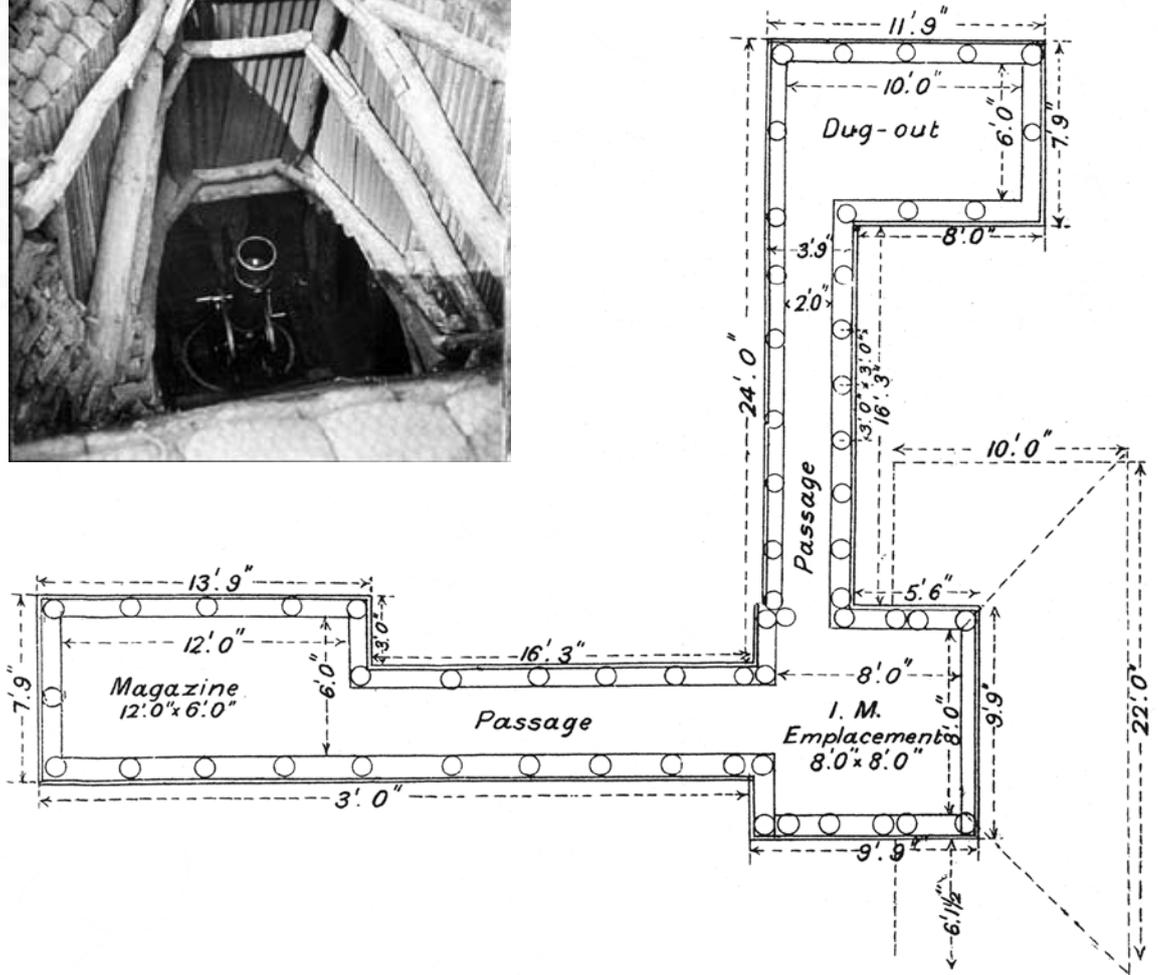


Fig. 70 Compare the photograph of a 9.45-inch mortar emplacement with the plan and side elevation of the recommended design. Note the depth of cover above the mortar pit in the photograph compared with the cover in the side elevation. In the plan, the horizontal dimension of 3 feet is an error for 30 feet (drawings from Artillery Notes No. 6 – Trench Mortars, March 1917)

drawbacks to putting the mortar among the front-line infantry, not least being the obstacle the detachment presented to the normal passage of personnel along a trench. The Stokes could be set up in a suitable location in no-man's-land, such as a large crater, especially if this was in preparation for an attack, a trench being dug out to the crater.⁷⁷ A position in no-man's-land had the advantage of extending the target area of the mortar further into the enemy's position.⁷⁸

The Stokes mortar was unique in that it could be set up almost anywhere. However, it suffered from the same problem that beset all mortars when kept in one location for any length of time, namely, a propensity to sink into the ground after prolonged firing. Under such circumstances, the Stokes needed a wooden bed to provide it with a firm base. It was not unknown for beds of the heavier mortars to sink into soft ground so that larger sub-beds had to be provided by the Royal Engineer Workshops. By 1918, permanent emplacements for pairs of mortars, corresponding to the section of a battery, had been devised for the Stokes.⁷⁹ This was dug in a disused trench, preferably at night, then camouflaged. Each mortar pit was 6 feet by 6 feet, one each side of an island at the back of which was the ammunition recess, which was 10 feet deep, 10 feet long and 6 feet wide. Such emplacements were spaced 20 yards apart.⁸⁰ On at least one occasion, an emplacement for two mortars was built in the cellar of a damaged house.⁸¹ The ammunition store in a permanent emplacement was intended to hold 200 rounds for each Stokes mortar.⁸²

Whenever the Stokes was set up, at least two V-shaped holes were dug to take the base plate so that it could be kept at right-angles to the bore and repositioned according to the target. Alternatively, a semi-circular trough was dug, around which the base plate could be moved according to the direction of the target.⁸³ The base plate had to be aligned with the target. The feet of the bipod had to be trodden down and sandbagged to ensure that the mortar did not move unduly as each round was fired.⁸⁴ The bipod legs had to be at right-angles to the barrel and parallel with the base plate. The end cap of the breech, which engaged one of three recesses in the base plate, was sandbagged to prevent movement.⁸⁵ This arrangement remained the standard practice throughout the war, although it is possible that the holes and the sandbags were dispensed with once semi-open and open warfare developed.⁸⁶



Fig. 71 Stokes mortar emplacement, June 1918. There are three men in the picture, two with the mortar. Note the sandbags and corrugated iron and the wet conditions (Australian War Memorial)

Gunnery

Various methods of fire were possible with all mortars: battery fire, section fire and so-called gun fire. Battery fire required all the mortars to fire, right to left in sequence with a specified time interval between each shot, typically 10 seconds. Section fire required only those mortars in specified sections to open fire, again firing at specified intervals. Gun fire allowed each mortar to fire independently, in which case, each round could be fired at a specified interval or as rapidly as possible.⁸⁷ Rapid fire was one of the features which distinguished the Stokes mortar from all other mortars.⁸⁸ The number of rounds to be fired could be specified or the mortars might fire until ordered to cease fire. In a Stokes detachment, the No. 2 sponged out the barrel after firing had ceased and replaced the muzzle cap, while unused ammunition was returned to the ammunition recess in the emplacement.⁸⁹ Sponging out was an essential act with all mortars to reduce barrel temperature and to remove any fouling. Indeed, in the case of the 9.45-inch mortar, it was essential after each round.

Another option was salvo fire in which all the mortars in the battery, or specified sections, fired simultaneously. Salvo fire was recommended as early as spring 1916. It had the advantage of putting several bombs into the air at the same time which meant that the enemy was less able to dodge them.⁹⁰ Time intervals were often given for all methods of fire but when an interval was not given, the mortars had to be fired as quickly as possible.⁹¹ Usually, the number of rounds to be fired was specified. Unlike artillery shells, mortar bombs were slow enough to be seen in flight and, singly, could be dodged. Salvos made it harder for the enemy to pinpoint the location of the battery. However, so long as ammunition was scarce, mortars were only supposed to fire enough rounds to achieve the object of the shoot. While only one salvo might be fired when ammunition was in short supply, when ammunition became more plentiful, such restrictions were applied less rigidly. More rounds were expended per mortar on targets in 1917 than had been the case in 1915 or 1916.⁹²

Targets of opportunity were not usually considered to be feasible for heavy and medium mortars. From a technical perspective, they were not suitable for quick re-laying on to different targets. Direct line of sight with the aid of a periscope was common practice, which relied on good optics and a well-made graticule.⁹³ Other methods adapted from the artillery were also used. The angle to the target from an aiming point could be measured and the dial sight set accordingly on the aiming point.⁹⁴ Such targeting techniques, of course, relied on good measurements and an accurately calibrated dial sight. But it was undermined by the fact that the dial site had to be set on the target after each round had been fired. Alternatively, a compass bearing could be measured on the map and the mortar bed then set squarely on this line but this relied on the availability of accurate maps of which there was still a shortage in 1916. These methods were used to determine the line of fire and, once found, the aiming posts were set along the axis of the mortar and used to lay the mortar on the target with the periscope or the dial sight. This process did not lend itself to the engagement of targets of opportunity.

The situation was exacerbated by the necessity of having to fire ranging shots for elevation, line and correct fuze length.⁹⁵ The latter was necessary because of the use of time fuzes.⁹⁶ The inaccuracy of mortars meant that a target had to be bracketed, although this

was also common with the artillery. Ideally, a short bracket of 10 yards had to be established and verified before the mortar could fire for effect. Between three and five rounds had to be fired to achieve a short bracket at between 250 yards and 260 yards range.⁹⁷ A 10-yard bracket could be, at worst, up to 100 square yards if the line was not corrected before bracketing, as this would spread the shots left and right as well as long and short of the target. To hit a relatively small target, such as a machine-gun position, under such conditions would require the expenditure of a large number of rounds to ensure that it was neutralised. The whole matter was made more complicated by the need to ensure that the mortar did not move as each round was fired.⁹⁸

In 1916, mortars had to engage in registration in the same way in which artillery registered shots but the mortars had to do it during an artillery shoot on nearby targets or under cover of a shrapnel barrage which kept the enemy below ground.⁹⁹ No more than three mortars were supposed to register on the same target at the same time and their fire had to be spasmodic rather than regular in order to disguise their presence and their intent. The reason for the precautions was the relative ease with which it was possible to identify the location of a mortar from its muzzle flash and report as well from the trajectory of its bomb. Registration was only valid for the day on which it was conducted because of the effect of prevailing weather conditions on trajectories. On the day on which the mortars were to fire for effect, a few rounds had to be shot on a datum point, which had already been carefully registered, to determine the appropriate correction, known as the 'error of the day'.¹⁰⁰ This technique was refined as the war progressed and, by 1918, it was realised that the error of the day might, indeed, need to be changed several times on the day in question because of changing weather conditions.¹⁰¹

Inaccurate shooting was a constant problem with mortars, although less so with the Stokes than with mediums and heavies. Many of the causes of inaccurate fire were technical in nature rather than inefficiency on the part of the men serving the mortar but some were largely outside their control. Apart from the difficulties associated with hard ground and those associated with soft ground, which caused the mortar to skid in the first instance and sink in the second, the ground might not be level so that the bomb's trajectory deviated from the target line. Wind speed and direction affected the bomb, while temperature affected the power of the propellant charge; the higher the temperature, the more powerful the charge. In all mortars except the Stokes and the Newton, each bomb might be rammed home to a different extent so that the size of the combustion chamber varied. Bombs varied in weight which also affected trajectory. Weight variations could be overcome by tying weights to the tail and grouping bombs of the same or similar weight.¹⁰² The bombs were then fired by group. By 1917, bombs for the 2-inch mortar were marked 'HV' if they weighed more than the specified weight range, while those below this range were marked 'L'. Bombs for the 9.45-inch mortar were marked 'heavy', 'medium' or 'light' according to their weight.¹⁰³ Damp charges could also cause inaccurate shooting as could fouled bores and worn barrels.¹⁰⁴ Bent or distorted fins on bombs could cause short rounds. With the Stokes, some causes of inaccurate shooting were a direct result of design features, such as the breech cap, a

component separate from the barrel, which might not be properly screwed in place thereby allowing gas to escape. The design of the bomb also caused inaccuracies because it tended to tumble in flight. When ring charges were introduced, they had to be placed directly over the apertures in the cartridge holder, otherwise the flash from the cartridge did not properly ignite the rings which caused short rounds.¹⁰⁵

Communication between the mortars and the battery commander was crucial to the effectiveness of a battery. Effective gunnery depended on communication between the battery and the forward observer. Forward observers for the mortars were usually the artillery's forward observers. These men used magnifying periscopes of far better optical quality than any periscope provided to the infantry.¹⁰⁶ Telephone cables were frequently cut by enemy artillery fire, so alternative arrangements were needed and these usually took the form of runners.¹⁰⁷ Visual signals were also used but in smoke or at night they were of little value. Communication between the mortars, the battery commander, the brigade commander and the advancing infantry were likely to be fragmentary. Thus, it was essential that the mortars and the infantry had pre-arranged SOS signals to call for assistance and that everyone knew the objective and the line of advance.¹⁰⁸

Tactical roles of mortars

Light mortar batteries were an integral part of an infantry brigade, whereas medium and heavy mortars were part of the divisional artillery. However, the mediums and heavies were sometimes attached to infantry brigades, in which case, command passed temporarily to the infantry brigadiers concerned.¹⁰⁹ Mediums, heavies and light mortars were used for different purposes. Heavy mortars were preferably sited near roads or railways to obviate the necessity of constructing a special road to reach the emplacements.¹¹⁰ Neither the mortar nor its ammunition was transportable by manpower alone. The main purpose of heavy mortars was to destroy enemy dugouts, trenches and strongpoints in the enemy's first line, thereby freeing the artillery's howitzers to hit targets out of the range of the mortars.¹¹¹ Mediums were sometimes employed for the same task but they were also used to destroy barbed-wire entanglements from about the end of 1915.¹¹² Light mortars were principally anti-personnel weapons, lacking the power to penetrate dugouts.¹¹³ They were far easier to move than heavy and medium mortars and this influenced their tactical employment. Neither 9.45-inch nor 3-inch bombs were fitted with fuzes that would enable them to destroy barbed wire without cratering the ground in the process. Similarly, the 3-inch bomb was insufficiently powerful to destroy dugouts, while the 9.45-inch bomb was unsuited to anti-personnel work in support of an attack because the magnitude of the explosion made it dangerous to friendly troops.¹¹⁴ Heavies and mediums supplemented an artillery bombardment that preceded an operation, targeting strongpoints in particular. When a bombardment extended over several days, the mediums and heavies did not open fire until the last day for fear of being discovered and hit by a counter-bombardment.¹¹⁵

In the spring of 1916, there was still much to be learned about such tactical uses of mortars.¹¹⁶ The light mortars in service with the BEF at that time included the highly unreliable 3.7-inch and 4-inch patterns. In theory, these could be moved forward in an

attack to support the infantry but it was not until the widespread use of the Stokes mortar that this sort of infantry support became a realistic proposition.¹¹⁷ The rapid fire of a Stokes mortar had a significant effect on enemy troop concentrations prior to a counter-attack, especially when such concentrations were in the open.¹¹⁸ That the earlier light mortars were intended to provide the same support was more a hope than a reality since they lacked the reliability and rapidity of fire of the Stokes. Mediums could be used to provide support provided their emplacements had been dug close enough to the front line prior to the attack.

By the beginning of 1917, emphasis was placed on all mortars being part of the overall artillery plan with clear zones and specific tasks being allocated to the batteries.¹¹⁹ The rapid fire of the Stokes mortar was now used to harass the enemy during the final stages of a preliminary bombardment, supplementing shrapnel fired by 18-pounders.¹²⁰ Stokes batteries, located in the fire trenches or in no-man's-land, fired a barrage beyond the objective of the infantry assault to prevent the enemy from bringing up reinforcements or organising a counter-attack.¹²¹ This would not have been feasible with the 3.7-inch and 4-inch mortars. The role of the Stokes as an infantry support weapon was also developed as the advantages of using it in conjunction with Lewis guns and bombing teams became apparent.¹²² Barrages in support of the infantry and in support of bombing parties proved to be very effective.¹²³ Thus, during 1917, at the level of sections, platoons and companies, the Stokes mortar became integrated into an all-weapons infantry group.

Stokes mortars performed a similar interdiction role in support of a raid. Almost as soon as raiding became a feature of British operations on the Western Front, the value of mortar support became apparent.¹²⁴ In early 1916, this necessitated registration prior to the operation without revealing that the target was about to be raided.¹²⁵ By 1917, the Stokes was commonly used to support raids, typically to put down a barrage in front of bombers.¹²⁶ Providing tactical support to bombers by firing over their heads and suppressing fire on the flanks during an attack along a trench was standard practice in 1918.¹²⁷ The mortars also covered the withdrawal of the raiding party.

Although medium mortars were less mobile than the Stokes, two mediums were sometimes organised into an ad hoc section which moved forwards to support the infantry but it needed a GS wagon or a couple of pack animals.¹²⁸ This dated back to about the end of 1916 when 2-inch mortars were still in service.¹²⁹ The idea was that mediums could deal with concrete pillboxes and wire obstacles should they be encountered by the advancing infantry. However, unlike Stokes detachments who could count on carrying parties to transport their ammunition, medium mortar detachments could only rely on themselves.¹³⁰ For the most part, once the infantry assault was in progress, the mediums and heavies played no further part in an operation.

Tactical employment of the Stokes mortar

If there had been any doubts about the tactical value of the Stokes mortar, they were dispelled during the opening battles on the Somme in July 1916. Several novel tactical approaches to using the Stokes were tried, none of which was feasible with mediums, heavies or, significantly,

any other light mortar in British service. These were the result of pragmatism based on experience and knowledge of the capabilities of the mortar. The high rate of fire of the Stokes, the speed with which it could be brought to bear on new targets and its portability all encouraged battery detachments to devise new ways of applying these advantages to shoots. So successful were some of these novel tactical approaches that GHQ disseminated details of them throughout the BEF within a few weeks of their introduction.¹³¹

Stokes mortars were set up at the head of Russian saps which, prior to 1 July, had been dug from the trenches held by the Manchesters. These mortars put down a barrage on the German trenches a few minutes before the infantry climbed out of their trenches to cross no-man's-land.¹³² The Manchesters suffered few casualties as a consequence. The lesson was absorbed into the evolving tactical use of light mortars. That is not to suggest that tactical barrages of this sort were widely practised, however. In June 1917, following the fighting at Arras and Messines, GHQ found it necessary to emphasise again this tactical lesson by disseminating it to company commanders, squadron leaders and commanders of light mortar batteries.¹³³ This was an indication of the increasing autonomy of the commanders of Stokes batteries. They were clearly expected to use their initiative when targets presented themselves, rather than seek permission from higher authority before engaging them. This allowed the batteries to take advantage of the speed with which a Stokes mortar could be laid on to targets and its high rate of fire which had a decided effect. However, by 1918, independent action by a Stokes battery without regard to friendly troops in the area was discouraged as this could cause more trouble to them than to the enemy.¹³⁴ Thus, the battery commander needed definite orders from the brigade or battalion to which the mortars were attached to ensure that the mortars were used in the most efficient way. Indeed, each division drew up a list of suitable targets for harassing fire.¹³⁵ This was an indication of the level of cooperation that had developed between the various elements involved in an operation.

Cooperation between riflemen, Lewis gunners and bombers, especially rifle grenadiers reached its apotheosis in 1918. A Stokes barrage allowed rifle grenadiers to get close enough to engage the target, at which point, the mortars ceased firing.¹³⁶ The work of a Stokes battery did not end with the capture of the objective. The mortars now put down a barrage on likely approach routes by which the enemy might launch a counter-attack. However, because of the limitations on ammunition during an advance, resources had to be husbanded. The value of the Stokes in deciding the outcome of a battle was considerable so that sometimes only a few rounds were needed to force the enemy to surrender.¹³⁷ This required good communications to be maintained between batteries, infantry commanders and brigade. It was a long way from the vagaries of 1915 and the uncertainties of 1916.

The nature of the targets and how they were engaged demonstrates the evolution of how the tactical use of the Stokes mortar began to exceed what had been thought possible at the beginning of 1916. Prior to a brigade assault in spring 1917, a 4-minute barrage from a Stokes battery neutralised five enemy machine-guns at a range of 550 yards, achieved with the green cartridge and two incremental rings.¹³⁸ The details of the specific charge used was

significant. The barrage was in accordance with the methods that had been developed over the previous year for dealing with enemy machine-guns which had not been neutralised by the preliminary artillery bombardment. Such methods included cooperation of infantry, rifle grenadiers and Stokes mortars with Vickers machine-guns and Lewis guns.¹³⁹ This coincided with recent changes to the organisation of the infantry platoon.¹⁴⁰

By 1918, Stokes batteries were divided into two groups: those which would go forward with the advancing infantry; and the reserve, which remained in the British line. The latter typically engaged machine-gun positions, trench junctions, shell craters in front of the German trenches and similar choke points during the final stages of the preliminary artillery bombardment.¹⁴¹ The Stokes detachments which were tasked with going forward did not participate in this part of the operation. These, in addition to engaging similar targets that had not been neutralised in the bombardment as they were encountered by the advancing infantry, could be used to engage snipers and local pockets of resistance. Such was the flexibility of the Stokes batteries that a section could be attached to each of the assaulting battalions, the section placing itself in a central position with respect to the battalion's frontage.¹⁴² These sections crossed no-man's-land with the second wave of infantry, preferably before the Germans could fire a counter-bombardment. The alternative was to cross during the counter-bombardment after its weak spots had been determined. Spotting the deficiencies of the German barrage was a technique that was learned during 1917. By identifying them, it was possible to minimise casualties among the second and third waves. By mid-1917, of course, the notion of linear waves of attacking infantry was giving way to a more flexible concept of infiltration by infantry assault groups; the Stokes sections detailed to advance with the infantry was incorporated within this developing system. The point here is that the Stokes mortars advanced after the main assault but not so far behind it that the mortars could not provide support.

A single Stokes mortar could have an enormous effect on the enemy. At Arras, a single mortar fired twenty rounds on a group of Germans who had become isolated in a trench.¹⁴³ This forced them to retreat but they were contained by several more rounds from the same mortar whose detachment lengthened its range to fire over their heads. Some seventy-two of the enemy, including two officers were taken prisoner.¹⁴⁴ The significance here is that the detachment were able quickly to increase the range of the mortar to deal with the developing situation, something which would have been impractical, if not impossible, with the Stokes's predecessors and, indeed, with medium and heavy mortars. A similar event occurred when a mortar fired over the heads of a German working party in no-man's-land. In this instance, the commander used the Stokes in an ingenious way. Gradually, he decreased the range so that the Germans were forced towards the British front trench with the result that they were taken prisoner.¹⁴⁵ This showed the precision with which the Stokes could be used. Again, this would have been impossible to achieve with any other mortar used by the BEF. This sort of action by the mortar detachment required that they were intimately familiar with the effect of elevation on range for a given cartridge and number of ring charges. The skill which such knowledge imbued allowed a detachment to use the accuracy of the Stokes to full advantage.

The accuracy of the Stokes was superior to that of other mortars in British service. A fine example of accurate shooting was demonstrated when a mortar crew targeted their German counterparts who were trying to set up a light mortar of their own. The second round from the Stokes made the Germans scatter, leaving their mortar exposed. A barrage then scored three direct hits on the enemy mortar. It is unclear, however, just how many rounds had to be fired in order to achieve this but it was in excess of ten and may have been as many as thirty.¹⁴⁶ The ease with which the mortar could be adjusted for elevation, its accuracy and its high rate of fire meant that it could be used to search dead ground, including mine craters, sunken roads and even sap heads, a practice that was impossible with other mortars.¹⁴⁷

The high rate of fire that was possible with the Stokes was a mixed blessing, however. For it to be sustained, a large stock of ammunition was needed which, if the mortar was taken forward to support the infantry in an advance, might not be available. Moreover, firing off thirty or forty rounds a minute could only be sustained for two or three minutes because the barrel became too hot.¹⁴⁸ Nevertheless, one mortar firing thirty rounds a minute for three minutes expended ninety bombs which, if the mortar was responding to an SOS, was highly effective. SOS ammunition had to be kept fuzed and ready for immediate use but it could not be kept stored in this state for very long because it would deteriorate so it had to be fired off regularly and replenished. The usual rate of fire of six rounds a minute could be sustained for long periods, however, provided the ammunition was available. During the fighting for High Wood on the Somme in July 1916, the Stokes mortars of the 140th Trench Mortar Battery fired 750 bombs in 15 minutes, successfully breaking German resistance in the area.¹⁴⁹ Assuming that it was a full battery of eight mortars, this was six rounds a minute per mortar. Thus, the usefulness of the mortar when it was taken forward was entirely dependent upon ammunition being brought forward at the same time.¹⁵⁰

The provision of sufficient stocks of ammunition was a problem that became apparent during the Somme battles of July 1916. A number of solutions to the conundrum of providing adequate supplies of ammunition for Stokes mortars being taken forward in an advance were tried, including having infantrymen carry a Stokes bomb in addition to their normal fighting kit.¹⁵¹ Supplying forward mortars with adequate quantities of ammunition came down to good planning and organisation.¹⁵² In 1917, and 1918, carriers were detailed to bring ammunition up to the site of the Stokes battery prior to an advance. This became the forward dump. From there, ammunition was carried forward to an agreed rendezvous point in the captured territory and this became the No. 1 dump.¹⁵³ The battery mortars met at this location which was supposed to be located at least 300 yards from the objective.¹⁵⁴ The scheme was to maintain a continuous supply of ammunition from the brigade store behind the British lines to the forward dump in the old front line and, thence, to the No. 1 dump in the captured position in order that the Stokes battery could maintain fire at the rate demanded by circumstances. To this end, carrying parties of ten or more infantrymen were told off for each mortar section accompanying an assaulting battalion.¹⁵⁵ Clearly, this required good planning, with due consideration being given to the cover from hostile fire on the routes along which carriers were to work.¹⁵⁶ In July



Fig. 72 *Stokes mortar ammunition carriers sitting on a light railway truck, Ypres salient, August 1917. Each man carries three rounds, two in a backpack with one on top. The two men on the right have placed their third rounds beside them. Although these men carry 4-inch rounds, this photograph shows the difficulties of carrying ammunition. They sit on a light railway truck. (IWM)*

1916, four members of a Stokes detachment were expected to carry ammunition during an advance. These men wore special vests which accommodated four rounds. This load amounted to some 44 lb. In addition, they were supposed to carry a box of three rounds in each hand, a further 66 lb, making 110 lb in all.¹⁵⁷ In 1917, a rifleman was expected to carry four rounds, although if he left his rifle behind, he was expected to carry six or even eight rounds.¹⁵⁸ In 1918, the load for carriers was somewhat more realistic. One man might carry four rounds in a sandbag, six rounds in a Yukon pack, or six rounds with tump lines.¹⁵⁹ Thus, a party of ten could carry between forty and sixty rounds. As many as forty carriers might be involved in supplying a forward battery.¹⁶⁰

By mid-1918, the tactical use of the light mortar had been adapted for semi-open and open warfare which had developed over the previous year. The mobility of the Stokes allowed batteries to move to any part of the battlefield where the infantry required fire support.¹⁶¹ Up-to-date range tables for determining the appropriate cartridge, the number of ring charges needed and the correct elevation in order to shoot to a precise range, and improvements in gunnery, were at the heart of all tactical changes.¹⁶² Mortar detachments had to be able to engage targets accurately and quickly, irrespective of the style of warfare. Significantly, it was now appreciated that, for a given charge and a given elevation, each round fired would travel a different distance because of small variations in bomb weight, propellant



Fig. 73 *Part of a Stokes mortar detachment prepare ammunition for a shoot (Australian War Memorial)*

charge and wind conditions, for example.¹⁶³ Engaging a target had become a mathematical calculation. Contrary to the fears of the MGO in 1915, infantrymen proved just as capable in this respect as gunners.

Statistical analysis of experimental data determined the distribution of shots from a Stokes mortar for specific elevations and propellant charges. Thus, for a range of 650 yards, the bombs landed within a zone of 590–710 yards, that is ± 60 yards of the target, a spread of 120 yards.¹⁶⁴ The majority of shots landed closer to 650 yards than to 590 yards or 710 yards, with 50 per cent landing in a zone of 635–665 yards, known as the 50 per cent length zone. The 590–710 yards zone was known as the 100 per cent length zone.¹⁶⁵ For any given mortar, the 100 per cent length zone was always approximately four times larger than the 50 per cent length zone. The size of the latter was taken as a measure of accuracy. The distribution of shot was also dependent upon the weather conditions. Length zone accuracy was a technique borrowed from the artillery.¹⁶⁶ It is unclear when it was adopted by light mortars but there appears to be no mention of it in manuals before June 1918. What this statistical analysis also demonstrated was the probability of neutralising or destroying a target with a given number of rounds. It was noted that, for a given number of rounds, two Stokes mortars were as good as four.¹⁶⁷ This was presumably why Stokes batteries were split into two-mortar sections; it maximised the destructive effect of the battery.

The problem for mortar detachments was that it was often impossible for an observer to determine precisely whether a bomb was short or long. This was why the bracket system was used. By 1918, it was more sophisticated than it was a year earlier.¹⁶⁸ The bracketing system overcame and, indeed, took advantage of the distribution curve of the fall of shot and reduced the number of rounds that needed to be fired on a target to neutralise or destroy it. The system worked by finding two elevations which would bracket the target, one firing a bomb short, the other firing it long. This was called the long bracket (LB). The LB was then reduced to a short bracket (SB) which was a multiple of the LB. In other words, the SB was a half, a third or a quarter of the LB. The SB was twice the size of the 50 per cent length zone. From this, it was possible, using range tables, to determine the elevations for a given cartridge and number of ring charges. Once the SB had been determined, its limits were verified by firing at each end of the bracket, then repeating this to confirm the verification, termed VSB. Four rounds were fired at the mean range (MR). If two rounds were over the MR and two were under, the MR was the mean impact point (MIP) and very close to the target. The bracket system entailed firing between seven and ten rounds, depending on the ease of confirming the SB.¹⁶⁹ Once the SB and MR had been established, the mortar fired for effect. In a battery or section, one mortar might be used for ranging but the whole battery might be engaged.

There were two other methods of ranging available to Stokes batteries in 1918. Rapid ranging used two elevations but with a 10-second interval between them.¹⁷⁰ Immediately a bracket was obtained, four rounds were fired at the mean elevation. If necessary, further corrections were made until two rounds went over and two went under the target range. When a Stokes mortar had to engage a target that was close to British troops, a different method of ranging was used, known as creeping.¹⁷¹ In order to determine whether it was too

dangerous to fire on a target that was close to friendly troops, a simple calculation had to be made. If the range was deemed to be dangerous, between 60 yards and 100 yards was added to the distance so that the first round was certain to go over. The range was then reduced by 10 or 20 yards with each successive round until the target was hit or bracketed. Again, this could take up to nine rounds to achieve.¹⁷²

By 1918, the principals of ranging, on which effective shooting depended, were well understood. Deviations from the line of fire had to be corrected before making changes to the elevation for range. Whichever method of ranging was adopted for a given set of circumstances, the first elevation had to be accurately calculated, otherwise the task became much more difficult.¹⁷³ Subsequent changes to the elevation were in whole degrees although the Stokes could be adjusted by half-degrees. When bracketing, the No. 1 had to decide on the change of elevation for the next shot before the first one landed.

In addition to such targets as machine-gun positions, pillboxes, trench junctions, troop concentrations and enemy mortars, the Stokes could also be used to engage tanks. Indeed, such was the importance of this role that, in 1918, experiments were conducted with different types of mounting to allow the mortar to be fired on a flatter trajectory, although this presented a problem with loading the bomb since it would not slide down the barrel if it was at angle of 25° or less.¹⁷⁴ None of these mountings was adopted but an alternative mounting was introduced that would enable the mortar to engage tanks using the rapid ranging technique.¹⁷⁵ The new mounting comprised a sling attached to a collar, fitted with two spade-grips, the collar encircling the barrel about a quarter the distance from the muzzle.¹⁷⁶ The operator held the mortar by the grips, with the sling round his neck, the barrel being held so that the sling was taught. He made adjustments based on an assumed tank speed of 5 mph and the time taken for the round to travel a given distance. The fact that this system was included in the June 1918 manual implies that enemy tanks had been successfully engaged in this way.

The tactical employment of the Stokes mortar had become a science in which a target could be fired on with a high degree of accuracy, provided the detachment was fully trained, especially in ranging techniques. Bombing was an art but mortaring was a science. This was a specialism which required a greater technical expertise than even that required of bombers. While mortar detachments were still infantrymen who were required to maintain their musketry skills, this specialisation, unlike bombing, was not absorbed into the general training of infantrymen. Nevertheless, mortar detachments could still be forced to rely on their rifles if they expended all their ammunition as, indeed, happened to one detachment during the fighting at Arras after they had fired 200 rounds on two German counter-attacks.¹⁷⁷ That the detachment were able to use their rifles illustrates just how close light mortars were to the fighting. The significance here is not so much that they had to fall back on their musketry skills but that they fired so many rounds, although the timescale is not recorded. Nevertheless, such an expenditure of bombs was not feasible with any other mortar in British service. Indeed, it is probable that no mortar in any army at that time could have replicated this feat.

Although by 1918, registration was still taught to mortar detachments, the use of reliable maps, prepared by the surveying section of the Royal Engineers,¹⁷⁸ enabled the Stokes to engage in predicted fire using the same techniques as the artillery.¹⁷⁹ This presented a problem peculiar to mortar batteries in emplacements reinforced with corrugated iron because the metal could disturb the compass needle and adversely affect bearings.¹⁸⁰ As with conventional artillery, barrel wear was now taken into account as were weather conditions and the weight of the bombs. Indeed, the same techniques that had been developed by artillery were adapted for use with the Stokes mortar. Thus, each mortar was calibrated in much the same way in which a howitzer or field gun was calibrated. This entailed measuring the muzzle velocity of each mortar in the battery so that their accuracy could be compared with each other and the map. A correction table was then drawn up for each mortar so that they could all be adjusted to shoot to the same range. Unfortunately, this process was less reliable with mortars than it was with rifled artillery because mortars are low-pressure systems so it was less successful than with conventional rifled artillery. Correction work was done out of the line with dummy rounds.¹⁸¹

Another tactical role of the Stokes mortar was retaliatory fire for which it was admirably suited because of the weight of fire which could put on to a target in short space of time.¹⁸² Here, the intention was not neutralisation but destruction of the source of hostile fire. Although Stokes mortars were the principal weapons, retaliation was sometimes carried out with the assistance of mediums. Again, planning was the key to success, rather than blind shooting in the hope of achieving something. Thus, retaliatory shoots were similar to shooting on SOS lines in that registration and the error of the day were important factors. Surprise was a key element in these shoots and, with this in mind, night shooting on known targets was highly effective.¹⁸³

Training

It is clear that Stokes mortar crews needed to be well trained if they were to operate efficiently and effectively when called upon to support the infantry, whether in defence, in assault, or for a raid. By 1918, the Corps Bombing and Light Trench Mortar Schools ran fourteen-day courses for instructors and reinforcements, and as refreshers for batteries that were resting out of the line. The syllabus covered fifteen topics, from the technical characteristics of the mortar and its ammunition, to ranging, tactics and use of the Stokes in the anti-aircraft role. Specialisation in several of the more important topics followed basic training.¹⁸⁴ Not only dummy rounds but live rounds were fired, amounting to fifty for an officer, twenty-five for an NCO and fifteen for a private, split roughly 1.5 : 1 in favour of dummies.¹⁸⁵ Battery training included tactical exercises but also, significantly, musketry, bayonet fighting and bombing.

Training for heavy and medium mortars was conducted by a Trench Mortar (Heavy and Medium) School which was part of an Army Artillery School.¹⁸⁶ As with similar establishments in France, the primary function was to train instructors and provide refresher courses for mortar detachments who were out of the line. The courses could accommodate eight officers and 100 other ranks (OR). The school establishment included three officers, one warrant officer, two sergeants and twenty-nine OR, including a medical officer and an RAMC orderly.¹⁸⁷

Divisions and brigades ran classes under the supervision of the instructors trained in the Corps and Army schools.¹⁸⁸ It is clear that during the last eighteen months of the war, highly efficient training schemes were a fundamental aspect of the BEF. Mortar schools and classes should be seen in this context. Thus, as with bombing, mortaring eventually become a standard element in the fighting techniques of the BEF, although, unlike bombing, mortaring remained a specialism which only some infantrymen learned. The level of importance of a speciality in the conduct of operations may be gauged by the training programmes that were run for that speciality. It is clear that mortaring had been transformed from an almost amateur pastime with which to annoy the enemy in 1914 into a decisive instrument capable of inflicting considerable damage on him, thereby reducing his ability to fight.

Tactical maturity and the light mortar

There is no question that the trench mortar, in all its forms, was a child of trench warfare. It is not surprising, then, that trench mortars were tied, tactically, to trench warfare. Not only was the trench mortar unrelated to the siege mortar but it gave rise to an entirely novel concept: the infantry mortar. Tactically, this had a profound effect on infantry warfare on the Western Front. Whereas the mediums and heavies became redundant once open warfare reasserted itself during 1918, the light mortar, in the form of the infantry mortar, emerged as a novel and decisive tactical tool.¹⁸⁹

The roles played by mortars were determined by their engineering design, the weight of their bombs and the types of fuzes fitted to them, rather than according to the expectations of GHQ. This was understood at the time.¹⁹⁰ Indeed, GHQ had little expectation of mortars when they first appeared in 1914. Even in 1915, their tactical value seemed limited. However, as the mortars became technically more sophisticated, becoming more reliable in the process, and more was understood about mortars, their tactical roles developed beyond mere retaliation. Indeed, the heavies and, to a lesser extent, the mediums allowed conventional artillery to play a role in deep battle which may not have occurred had there been no heavy and medium mortars. By the end of 1916, light, medium and heavy mortars had distinct tactical roles which played to their strengths. This was a process of fluid change, rather than a series of step changes, driven by practical experience rather than theory. Nevertheless, there remained an ambivalence among the infantry who had to tolerate the retaliation that mortar shoots exacted.¹⁹¹ However, the same applied to rifle grenades which were also thought to provoke retaliation. This, then, was more a reflection of the infantryman's attitude to things that were outside his control than an institutional dislike of novel weapons.

Wilfrid Stokes had always intended that his mortar should be man-portable which was achievable because of its modular construction. The Stokes mortar of 1918 had an overall weight of 113lb: the base plate weighed 29lb, the barrel weighed 49lb and the mounting weighed 35lb.¹⁹² This compares with a barrel of 44lb, a base plate and sight of 37lb and a mounting of 44.5lb, making an overall weight of 125.5lb for the 3-inch mortar with which the British went to war in 1939.¹⁹³ Allowing for the weight of the sight, which was not part of the 1918 Stokes, the weights are much the same for the two mortars. Thus, the



Fig. 74 Part of a Stokes mortar detachment demonstrate the relative ease with which the three elements of the mortar could be carried. The first man carries the barrel, the second the base plate by means of a rope handle, while the third carries the mounting. It is apparent that the men are not over-burdened. This photograph was taken c. 1917



Fig. 75 A Stokes mortar detachment ready to advance. This five-man detachment includes ammunition carriers. The mortar is provided with wooden handles and has no bipod mounting. Note that, with the exception of the man carrying the barrel, they all carry rifles (Light Mortar Training, June 1918)

ease or difficulty with which the British infantry mortars of the First and Second World Wars could be carried was much the same. However, it is likely that the harness used to carry the mortar's components in 1939 made the task easier than in 1918.¹⁹⁴ Moreover, in 1939, the mortar detachment had a vehicle at their disposal for transporting the mortar, its equipment and ammunition but this would have been of limited use in many situations and terrains so that portage would have been unavoidable.¹⁹⁵ However, had the weight of the 3-inch Stokes of 1916–18 presented a major obstacle to its being carried, the 3-inch mortar of 1936 would have addressed this issue. Clearly, this did not happen. Indeed, even the 81 mm infantry mortar currently in service with the British army is only slightly lighter than the 3-inch Stokes of 1918.¹⁹⁶ Objections to carrying the mortar no doubt arose because the Stokes was a novel munition and the idea of carrying such a device in an advance was also novel. There is always resistance to new ideas, especially when it involves soldiers who have to carry things. Thus, a true picture of the difficulty of carrying the Stokes mortar is unlikely to be found in contemporary accounts. Such objections have given rise to the idea that it was a problem when, although it can never have been easy work, especially in the mud, it was not so difficult that the training manuals disclosed steps to ease the burden.¹⁹⁷

Eventually, three tactical roles evolved for the Stokes mortar.¹⁹⁸ Although these were described in relation to an assault, they were more widely applicable and may be regarded as the essence of tactical warfare with the infantry mortar. Thus, the Stokes was used for fire suppression during the assault phase, targeting machine-gun positions and strongpoints, after the main artillery barrage had lifted.¹⁹⁹ The mortars supplemented shrapnel fired by 18-pounders and remained in the British line. In this respect, they were a part of the artillery programme and did not act independently. The Stokes was also employed in a mobile role, moving forward with the infantry, thereby providing the infantry with the means to deal with whatever obstacles they met during their advance, although the problem of carrying forward sufficient ammunition always had to be borne in mind.²⁰⁰ Moreover, close cooperation between the infantry and the detachment was essential. Here, practice was the key. Finally, the Stokes was used for interdiction to help prevent counter-attacks.²⁰¹ In any situation where a Stokes battery moved forward from a static emplacement, the supply of ammunition was fundamental to success and this was a matter of planning and organisation. Thus, the Stokes mortar became an integral part of an infantry brigade and played a significant role in deep battle.

One of the curiosities of the evolution of the tactical employment of the Stokes mortar was the development of techniques for firing it at angles lower than was customary for a mortar.²⁰² That such techniques were used on the battlefield cannot be doubted but their value is less certain. The intention was to enable the Stokes mortar to engage tanks. For all the insight that was gained into the tactical use of the Stokes, the notion of low-angle fire implies that none of it had made a lasting impression, since a mortar was, by definition, a high-trajectory weapon. Yet, it was perhaps the very utility of the Stokes that suggested alternative uses. It was even adapted for anti-aircraft fire, for which purpose a special mirror sight was developed.²⁰³

In 1918, there was a need for a suitable anti-tank weapon and for an anti-aircraft weapon for the infantry, although the pintle-mounted Lewis gun was quite successful in the anti-aircraft role and anti-aircraft artillery had been in service since 1914. Interest in such devices for the infantry was short-lived, however, because the war ended before realistic solutions could be found. In other words, the impetus to invent had gone. Such digressions highlight an aspect of the process of invention, namely, the adaptation of existing technology to devise a new one in the belief that because that a technology works well in one environment it will work well in another quite different one. It was not until the Second World War that suitable anti-tank and anti-aircraft weapons for the infantry were invented.²⁰⁴

Notes

- ¹ SS98/6 Artillery Notes No. 6 – Trench Mortars, March 1916, p. 3.
- ² Maj-Gen C H Foulkes, “Gas!” *The Story of the Special Brigade*, (Edinburgh & London, 1934), pp. 51–2, 99, 109, 166.
- ³ Curiously, only the Stokes mortar manuals make a point of describing the composition of a battery, while the composition of medium and heavy batteries is described in Artillery Notes No. 6 – Trench Mortars. This may reflect the artillerymen’s suspicion that infantrymen needed more guidance than gunners when it came to the organisation of batteries.
- ⁴ MUN 5/321A *History of the Ministry of Munitions*, vol. XI *The Supply of Munitions*, Part I *Trench Warfare Supplies*, pp. 35–9.
- ⁵ *Op cit.* pp. 36–9.
- ⁶ See, for example, Bill Rawling, *Surviving Trench Warfare, Technology and the Canadian Corps, 1914–1918*, (Toronto, 1992), pp. 51, 179; Paddy Griffith, *Battle Tactics of the Western Front, The British Army’s Art of Attack 1916–18*, (New Haven, 1996), pp. 115–16; Andy Simpson, *Directing Operations, British Corps Command on the Western Front 1914–18*, (Staplehurst, 2006), pp. 29, 65; Richard Bryson, ‘The Once and Future Army’ in Brian Bond (ed.), *Look to Your Front*, (Staplehurst, 1999), pp. 33, 49; John Lee ‘Some Lessons of the Somme: the British Infantry in 1917’ in Bond, *op cit.* pp. 79–80.
- ⁷ See, for example, Notes from the Front, Parts I and II, issued by GHQ in 1914, and Parts III and IV, issued February 1915 and May 1915, respectively.
- ⁸ Such booklets continued to be issued by GHQ in 1916.
- ⁹ Artillery Notes, March 1916, *op cit.* There is no indication that this manual superseded an earlier one.
- ¹⁰ CDS78 Precautions to be taken when firing smoke shell from the Stokes mortar, October 1915.
- ¹¹ Handbook for the Stokes Trench Mortar, 3”, Mark I, April 1916.
- ¹² SS110 Medium Trench Mortar Gun Drill, 2” Trench Mortars, May 1916.
- ¹³ *Op cit.* p. 3. See also revised March 1917 printing, p. 3.
- ¹⁴ Handbook for the Stokes Trench Mortar, *op cit.* p. 3.
- ¹⁵ SS147 9.45in Trench Mortar Drill, March 1917, p. 1; SS181 (revised edition) Trench Mortar Drill 6-in (Newton) Trench Mortar, March 1918, p. 1.
- ¹⁶ I V Hogg & L F Thurston, *British Artillery Weapons and Ammunition 1914–1918*, (London, 1972), pp. 81, 83.
- ¹⁷ SS183 Light (Stokes) Mortar Drill, September 1917, p. 1.
- ¹⁸ SS189 Light Mortar Training, June 1918, p. 10.
- ¹⁹ These were posts used to assist in laying the mortar.
- ²⁰ Medium Trench Mortar Drill, May 1916, *op cit.* p. 5.
- ²¹ Medium Trench Mortar Drill, March 1917, p. 5.
- ²² Trench Mortar Drill, Newton Mortar, *op cit.* p. 1.
- ²³ An exploder was similar to the detonator in a grenade.
- ²⁴ *Op cit.* pp. 2–3.
- ²⁵ 9.45in Trench Mortar Drill, *op cit.* p. 1.
- ²⁶ *Op cit.* pp. 2–3.
- ²⁷ *Op cit.* p. 3.
- ²⁸ GB126324, filed 12 December 1916. Brothers, *op cit.* p. 21.
- ²⁹ Handbook for the Stokes Trench Mortar, *op cit.* p. 4.
- ³⁰ Light (Stokes) Mortar Drill, *op cit.* p. 5.
- ³¹ Handbook for the Stokes Trench Mortar, *op cit.* p. 4.
- ³² *Ibid.*
- ³³ For 6-inch mortar detachment positions see Trench Mortar Drill, Newton Mortar, *op cit.* pp. 2–3. For 9.45-inch mortar detachment positions see 9.45in Trench Mortar Drill, *op cit.* p. 1.
- ³⁴ *Ibid.*
- ³⁵ Light (Stokes) Mortar Drill, *op cit.* p. 4.
- ³⁶ See Chapter 6 for a discussion of the pistol head.
- ³⁷ Light (Stokes) Mortar Drill, *op cit.* p. 5.
- ³⁸ Light Mortar Training, *op cit.* p. 13.
- ³⁹ *Ibid.*
- ⁴⁰ Medium Trench Mortar Drill, May 1916, *op cit.* p. 7. Handbook of the ML 2-inch Trench Mortar, Mark I, 1917, pp. 7, 8. Handbook of Stokes Trench Mortar, *op cit.* p. 7. Light Mortar Training, *op cit.* pp. 7–8, 9. Handbook of the ML 9.45-inch Trench Mortars, Marks I, II and III, pp. 29–30.
- ⁴¹ Medium Trench Mortar Drill, May 1916, *op cit.* p. 5.
- ⁴² Medium Trench Mortar Drill, March 1917, *op cit.* p. 5.
- ⁴³ *Ibid.*
- ⁴⁴ Light Mortar Training, *op cit.* p. 9.
- ⁴⁵ 9.45in Trench Mortar Drill, *op cit.* p. 3.

- ⁴⁶ Trench Mortar Drill, Newton Mortar, *op cit.* p. 3.
- ⁴⁷ *Op cit.* pp. 3–4.
- ⁴⁸ Handbook for the Stokes Trench Mortar, *op cit.* p. 4.
- ⁴⁹ Light (Stokes) Mortar Drill, *op cit.* p. 5.
- ⁵⁰ *Op cit.* pp. 4–5. See also Light Mortar Training, *op cit.* p.14. See Chapter 6 for a discussion of the No. 146 fuze.
- ⁵¹ See, for example, photograph in Anthony Saunders, *Weapons of the Trench War 1914–1918*, (Stroud, 1999), p. 39.
- ⁵² Artillery Notes, March 1916, *op cit.* p. 11.
- ⁵³ See, for example, Medium Trench Mortar Drill, May 1916, *op cit.* p. 4; Medium Trench Mortar Drill, March 1917, *op cit.* pp. 3–4; 9.45in Trench Mortar Drill, *op cit.* pp. 3–4; Trench Mortar Drill, Newton Mortar, *op cit.* pp. 1–2.
- ⁵⁴ See, for example, Artillery Notes, March 1916, *op cit.* pp. 6–8 and the seven diagrams in Appendices A–C.
- ⁵⁵ Artillery Notes, March 1917, *op cit.* pp. 7–8.
- ⁵⁶ Artillery Notes, March 1916, *op cit.* diagram in Appendix A.
- ⁵⁷ Artillery Notes, March 1917, *op cit.* p. 8.
- ⁵⁸ *Ibid.*
- ⁵⁹ *Ibid.*
- ⁶⁰ *Op cit.* p. 7.
- ⁶¹ Aerial reconnaissance by scout planes was a feature of operations on the Western Front from the outset. The need of troops to be mindful of enemy aircraft was a feature of the first issue of Notes from the Front issued in 1914.
- ⁶² Artillery Notes, March 1916, *op cit.* p. 6.
- ⁶³ Artillery Notes, March 1917, *op cit.* p. 9.
- ⁶⁴ Artillery Notes, March 1916, *op cit.* p. 13. See also Artillery Notes, March 1917, *op cit.* Appendix B, No. 3 which shows detailed diagrams of the construction of such an emplacement for a 9.45-inch mortar.
- ⁶⁵ Artillery Notes, March 1916, *op cit.* pp. 7, 13.
- ⁶⁶ *Op cit.* p. 13.
- ⁶⁷ Artillery Notes, March 1917, *op cit.* diagram No. 2 in Appendix B, p. 22.
- ⁶⁸ *Op cit.* Appendix B, No. 3.
- ⁶⁹ *Ibid.*
- ⁷⁰ 9.45in Trench Mortar Drill, *op cit.* p. 2. Handbook of the ML 9.45-inch Trench Mortars, Marks I, II and III, 1918, pp. 5–6.
- ⁷¹ Artillery Notes, March 1916, *op cit.* p. 7; Artillery Notes, March 1917, *op cit.* p. 9.
- ⁷² Artillery Notes, March 1916, *op cit.* diagram p. 15; Artillery Notes, March 1917, *op cit.* p. 25.
- ⁷³ A deal is a length of pine timber.
- ⁷⁴ Artillery Notes, March 1916, *op cit.* diagrams pp. 18, 19; Artillery Notes, March 1917, *op cit.* p. 25.
- ⁷⁵ Artillery Notes, March 1916, *op cit.* p. 3. Artillery Notes, March 1917, *op cit.* pp. 4–7.
- ⁷⁶ Light Mortar Training, *op cit.* p. 17.
- ⁷⁷ *Ibid.*
- ⁷⁸ Artillery Notes, March 1917, *op cit.* p. 4.
- ⁷⁹ Light Mortar Training, *op cit.* p. 14.
- ⁸⁰ *Op cit.* 40.
- ⁸¹ *Op cit.* p. 16. Although it is evident that the drawing and description relate to a specific example, rather than merely to a suggestion, no information is given about where or when this emplacement was constructed.
- ⁸² Light Mortar Training, *op cit.* p. 40.
- ⁸³ *Op cit.* p. 8.
- ⁸⁴ Handbook for the Stokes Trench Mortar, *op cit.* p. 6.
- ⁸⁵ See Light Mortar Training, *op cit.* pp. 18–19 for various diagrams relating to sandbagging the base plate.
- ⁸⁶ *Op cit.* p. 8.
- ⁸⁷ *Op cit.* p. 14.
- ⁸⁸ Handbook for the Stokes Trench Mortar, *op cit.* p. 4.
- ⁸⁹ Light Mortar Training, *op cit.* pp. 13–14.
- ⁹⁰ Artillery Notes, March 1916, *op cit.* p. 11.
- ⁹¹ Medium Trench Mortar Drill, March 1917, *op cit.* p. 6. See also Trench Mortar Drill, Newton Mortar, *op cit.* p. 4.
- ⁹² See Output section in Chapter 4 for a discussion of output or mortars and ammunition.
- ⁹³ In an optical system, a graticule is a cell which carries cross-hairs. In the case of artillery periscopes, the cross-hairs could be marked for range.
- ⁹⁴ Artillery Notes, March 1916, *op cit.* p. 9.
- ⁹⁵ *Ibid.*
- ⁹⁶ Discussed in Chapter 6.
- ⁹⁷ Artillery Notes, March 1916, *op cit.* p. 9.
- ⁹⁸ *Op cit.* p. 10.
- ⁹⁹ *Op cit.* p. 11.
- ¹⁰⁰ Artillery Notes, March 1917, *op cit.* p. 18.

- ¹⁰¹ Light Mortar Training, *op cit.* p. 31.
- ¹⁰² Artillery Notes, March 1916, *op cit.* p. 10.
- ¹⁰³ Artillery Notes, March 1917, *op cit.* p. 17.
- ¹⁰⁴ Light Mortar Training, *op cit.* p. 10.
- ¹⁰⁵ *Ibid.*
- ¹⁰⁶ For a discussion of periscopes and the difficulties of making optically good instruments see Saunders, *Dominating the Enemy, War in the Trenches 1914–1918*, (Stroud, 2000), pp. 73–99.
- ¹⁰⁷ Artillery Notes, March 1917, *op cit.* p. 8.
- ¹⁰⁸ Light Mortar Training, *op cit.* p. 41.
- ¹⁰⁹ Artillery Notes, March 1917, *op cit.* p. 3. See also Simpson, *op cit.* p. 29. Heavies also came under Corps control.
- ¹¹⁰ Artillery Notes, March 1916, *op cit.* p. 3.
- ¹¹¹ *Op cit.* p. 5. Artillery Notes, March 1917, *op cit.* p. 4.
- ¹¹² SS98/5 Artillery Notes No. 5 – Wire Cutting by Artillery, p. 1.
- ¹¹³ See Chapter 6. Rawling is mistaken when he states that Stokes mortar bombs were ‘useful for destroying deep dugouts’ and that they were used to destroy dugouts at Vimy. Indeed, Rawling’s assessment of the usefulness of mortars is unhelpful as he fails to draw a proper distinction between the three categories. See Rawling, *op cit.* pp. 83, 106.
- ¹¹⁴ See Chapter 6.
- ¹¹⁵ Artillery Notes, March 1917, *op cit.* p. 5.
- ¹¹⁶ Wire Cutting by Artillery, *op cit.* pp. 1–2.
- ¹¹⁷ Artillery Notes, March 1916, *op cit.* p. 3.
- ¹¹⁸ Artillery Notes, March 1917, *op cit.* pp. 3, 5.
- ¹¹⁹ *Op cit.* p. 4.
- ¹²⁰ SS135 Instructions for the Training of Divisions for Offensive Action, December 1916, p. 50.
- ¹²¹ Artillery Notes, March 1917, *op cit.* p. 4.
- ¹²² *Op cit.* p. 5.
- ¹²³ Preliminary Notes on Tactical Lessons, *op cit.* p. 7.
- ¹²⁴ SS107 Notes on Minor Enterprises, March 1916, p. 3.
- ¹²⁵ *Op cit.* p. 4.
- ¹²⁶ Artillery Notes, March 1917, *op cit.* p. 5.
- ¹²⁷ Light Mortar Training, *op cit.* pp. 38, 39, 42.
- ¹²⁸ Training and Employment of Divisions, *op cit.* p. 65.
- ¹²⁹ Instructions for Training of Divisions for Offensive Action, *op cit.* p. 51.
- ¹³⁰ Training and Employment of Divisions, *op cit.* p. 65.
- ¹³¹ SS119 Preliminary Notes on the Tactical Lessons of the Recent Operations, July 1916.
- ¹³² Peter Hart, *The Somme*, (London, 2005), p. 191.
- ¹³³ SS169 Employment of 3-in Stokes Mortars in Recent Fighting, June 1917.
- ¹³⁴ Light Mortar Training, *op cit.* p. 42.
- ¹³⁵ *Ibid.*
- ¹³⁶ *Op cit.* p. 38.
- ¹³⁷ *Op cit.* pp. 38–9.
- ¹³⁸ Employment of 3-in Stokes Mortars in Recent Fighting, *op cit.*
- ¹³⁹ SS155 Notes on Dealing with Hostile Machine Guns in an Advance, April 1917.
- ¹⁴⁰ See Chapter 7 with regard to the reorganisation of bombers within the platoon in 1917.
- ¹⁴¹ Light Mortar Training, *op cit.* p. 37.
- ¹⁴² *Op cit.* pp. 37–8.
- ¹⁴² Employment of 3-in Stokes Mortars in Recent Fighting, *op cit.* A similar process is mentioned in Simpson, *op cit.* p. 106, termed a draw-net barrage, suggesting that the lessons described in this leaflet had been absorbed into the tactical system within a few months of its issue.
- ¹⁴⁴ *Ibid.*
- ¹⁴⁵ *Ibid.*
- ¹⁴⁶ *Ibid.*
- ¹⁴⁷ Light Mortar Training, *op cit.* pp. 36–7.
- ¹⁴⁸ *Op cit.* p. 36.
- ¹⁴⁹ Hart, *op cit.* p. 389.
- ¹⁵⁰ Light Mortar Training, *op cit.* p. 37.
- ¹⁵¹ Rawling, *op cit.* p. 83. The author has found no corroborative reference in British sources. Rawling cites Canadian sources.
- ¹⁵² Artillery Notes, March 1916, *op cit.* p. 8.
- ¹⁵³ *Op cit.* pp. 44–5.
- ¹⁵⁴ *Op cit.* p. 38.

- ¹⁵⁵ SS135 The Training and Employment of Divisions, January 1918, p. 63. This uses the phrase ‘mortar detachment’ but it is unclear whether the term was being used in the same way as the mortar and artillery manuals so that detachment can be taken to mean each mortar or whether it was used more loosely to mean battery or section. The latter is possible since sections were attached to battalions in an attack.
- ¹⁵⁶ Light Mortar Training, *op cit.* p. 45.
- ¹⁵⁷ Handbook for the Stokes Trench Mortar, *op cit.* p. 8.
- ¹⁵⁸ Artillery Notes, March 1917, *op cit.* p. 6.
- ¹⁵⁹ Training and Employment of Divisions, *op cit.* p. 69. A Yukon pack was worn on the back. It was used for carrying forward all kinds of equipment and stores following an advance.
- ¹⁶⁰ Artillery Notes, March 1917, *op cit.* p. 6.
- ¹⁶¹ Light Mortar Training, *op cit.* p. 39. Training and Employment of Divisions, *op cit.* p. 63.
- ¹⁶² Light Mortar Training, *op cit.* p. 20–2.
- ¹⁶³ *Op cit.* p. 21.
- ¹⁶⁴ Light Mortar Training, *op cit.* pp. 21–2.
- ¹⁶⁵ *Ibid.*
- ¹⁶⁶ *Op cit.* p. 22.
- ¹⁶⁷ *Op cit.* p. 38.
- ¹⁶⁸ *Op cit.* p. 22–3.
- ¹⁶⁹ *Ibid.*
- ¹⁷⁰ *Op cit.* p. 23.
- ¹⁷¹ *Ibid.*
- ¹⁷² *Op cit.* p. 24.
- ¹⁷³ *Ibid.*
- ¹⁷⁴ ‘The Work of the Royal Engineers in the European War’, *The Royal Engineers Journal*, vol. XXXIX, no. 1, March 1925, pp. 77–8, Plate XVI and Photos I, II and III.
- ¹⁷⁵ Light Mortar Training, *op cit.* p. 28.
- ¹⁷⁶ *Op cit.* pp. 61, 63, 66. ‘The Work of the Royal Engineers’, *op cit.* p. 78.
- ¹⁷⁷ Employment of 3-in Stokes Mortars in Recent Fighting, *op cit.*
- ¹⁷⁸ Griffith, *op cit.* pp. 154–5.
- ¹⁷⁹ Light Mortar Training, *op cit.* pp. 29–31.
- ¹⁸⁰ *Op cit.* pp. 30–1.
- ¹⁸¹ *Ibid.*
- ¹⁸² Light Mortar Training, *op cit.* p. 41.
- ¹⁸³ *Ibid.*
- ¹⁸⁴ Light Mortar Training, *op cit.* pp. 50–1.
- ¹⁸⁵ *Op cit.* p. 51.
- ¹⁸⁶ SS152 Instructions for the Training of the British Armies in France, January 1918, p. 7.
- ¹⁸⁷ *Op cit.* pp. 40–1.
- ¹⁸⁸ Instructions for the Training of British Armies, *op cit.* pp. 6, 12, 15.
- ¹⁸⁹ Griffith makes the point that medium mortars were provided with special carriages to take them forward during the 100 days in 1918, whereas the heavies played no part. See Griffith, *op cit.* p. 116.
- ¹⁹⁰ Artillery Notes, March 1916, *op cit.* p. 3.
- ¹⁹¹ Griffith, *op cit.* p. 115. Tony Ashworth, *Trench Warfare, 1914–1918, The Live and Let Live System*, (London, 2000), p. 70.
- ¹⁹² Light Mortar Training, *op cit.* p. 3.
- ¹⁹³ Small Arms Training, Volume 1 Pamphlet No. 9, Mortar (3-inch), 1939, reprinted March 1940, Ottawa, p. 2. This 3-inch mortar was introduced in 1936.
- ¹⁹⁴ *Op cit.* p. 38.
- ¹⁹⁵ *Op cit.* p. 3.
- ¹⁹⁶ See www.army.mod.uk/equipment/pw/pw_81m.htm and www.armedforces.co.uk/army/listings/10098.html for weights (accessed July 2007).
- ¹⁹⁷ For objections regarding weight see, for example, Rawling, *op cit.* pp. 154, 179 and Griffith, *op cit.* p. 116.
- ¹⁹⁸ Training and Employment of Divisions, *op cit.* p. 63.
- ¹⁹⁹ *Op cit.* pp. 63–4.
- ²⁰⁰ *Op cit.* p. 64.
- ²⁰¹ *Op cit.* p. 65.
- ²⁰² Light Mortar Training, *op cit.* pp. 33–4.
- ²⁰³ *Op cit.* pp. 46–49.
- ²⁰⁴ An anti-tank rifle grenade was invented in 1918, the No. 44, and issued to the BEF in small numbers (see Rick Landers, ‘Grenade’ *British and Commonwealth Hand and Rifle Grenades*, (Dural, 2001), pp. 130–1.

9 Conclusions

Asking the right question

Paradoxically, the factors which worked to create stalemate on the Western Front in 1914 also determined its subsequent resolution in 1918. Understanding the relationship between mobility and firepower was fundamental to overcoming the mutual siege which dominated the Western Front. The emergence of new tactical approaches to breaking the deadlock during 1916 and 1917 and the invention of novel munitions during 1915 and 1916 for the kind of warfare the deadlock encouraged were driven by the same impetus, namely, a need to overcome the immobility. Firepower, rather than being a substitute for mobility, which had tended to be the polarised view before the war,¹ became its partner in three-dimensional warfare, a fundamentally different approach to warfare from earlier doctrines, made possible by a greater understanding of the strengths and weaknesses of the technology of modern weapon systems, especially artillery. These new techniques evolved during 1917 and became decisive for the BEF in the battles of 1918. Now, airpower, artillery and mobile forces were used cooperatively to disrupt the enemy's ability to fight, targetting front-line and second-line positions, his batteries, communications centres, and headquarters, while interdicting areas in which reinforcements might form up for counter-attacks.² The question of whether the novel munitions of trench warfare contributed to the development of new tactics on the Western Front has not been satisfactorily addressed hitherto. This thesis aims to provide a definitive answer.

The question is not as simple as it first appears. The means by which these munitions were provided to the BEF was very far from straightforward since, in 1914, no infrastructure nor organisational framework existed to address the provision of such munitions. This is not to imply incompetence or inefficiency on the part of anyone or any agency involved in this undertaking. On the contrary, the achievement of providing the BEF with appropriate munitions for trench warfare, and in the quantities needed, is one of the unsung triumphs of British ingenuity and engineering during the First World War, as well as a huge achievement of organisation and management. Ironically, so great was the British achievement that there is a tendency to take for granted the existence of these munitions, quite overlooking the fact that, for all practical purposes, none existed in 1914.³ Such munitions had to be invented before they could be manufactured, let alone mass-produced by firms which had no prior knowledge of munitions work. That all this became a reality was an achievement that far exceeded contemporary expectation.⁴ The question which arises from this, then, is: how was this feat of ingenuity and engineering accomplished?

Part of the responsibility for the underplaying of this achievement lay with the Ministry of Munitions and with Lloyd George, the first Minister of Munitions. Both omitted to give due credit to anyone outside the Ministry and both failed to acknowledge fully the British

engineer as a resourceful inventor. In mitigation, there was at that time a general belief that German engineering was superior, that German organisation was a model of efficiency to which everyone else could only aspire, a belief that ignored the fact that many of the great engineers of the nineteenth century were British and the fact that the Germans were somewhat less than efficient in their use of new technology in the First World War. Indeed, this belief has proved very resistant to the facts.⁵

Lloyd George and the Ministry lauded grand inventions such as the tank because it was politically useful to do so while they were somewhat condescending to inventions which were not perceived as war-winners, especially when their origins lay outside the Ministry of Munitions. The Mills grenade and the Stokes mortar were both invented before the creation of the Ministry. It is noteworthy that the Stokes was adopted because of political intervention by Lloyd George, not because he recognised it as militarily significant; he could score political points by doing so. It was a way of highlighting his dynamism against the short-sighted obstructionism of the War Office.⁶ The reality is that in mid-1915 the Stokes showed little to distinguish it from any other mortar then in service with the BEF so that there was no reason why the War Office should adopt it.⁷ Lloyd George was not prescient, merely shrewd in backing the Stokes mortar; if it failed to perform well, his reputation would be unaffected but ordering its supply when others had turned it down could only enhance his reputation as it would show his willingness to do whatever was necessary to help the army while others did little or nothing. This was a deliberate obfuscation of the truth. It is significant that the first Stokes mortars would have been sent to the Dardanelles, not the Western Front, where mortars were in even shorter supply; hence, opinion was likely to have been much kinder in the Dardanelles had the adoption of the Stokes proved to have been a mistake.⁸ Although it has been portrayed as good judgement by Lloyd George, this is a generous interpretation of a canny political act.⁹

Neither mortars nor grenades were ever seen in the same light as the tank. Yet, mortars and grenades had a greater impact on warfare during 1914–18 than the tank accomplished. These munitions were regarded as mere expedients which would become redundant as soon as open warfare reasserted itself on the Western Front, a notion that was reinforced by the belief among the British that the hand grenades and mortars of 1914–18 were merely British versions of the devices ‘re-introduced’ during the Russo-Japanese War. This belief was still held in 1919 despite persuasive contrary evidence and it has remained largely unchallenged ever since.¹⁰ So, the question arises whether the grenades and mortars used by the BEF on the Western Front were, indeed, derived from those of the Russo-Japanese War or were, in fact, novel. This leads to another question, namely, whether novelty, if they were, indeed, novel, made a difference to their impact on the Western Front.

The problem here is one of understanding the relationship between invention, both as a process and as a product of that process, and manufacture. It goes to the fundamental issues of utility, functionality and reliability of a device; in other words, does it work, does it work efficiently, does it always work? In this respect, the performance of the prototype is irrelevant; it is the performance of the manufactured device which matters. The engineering process by which an invention is turned from a prototype into a mass-producible device is

crucial to the utility, functionality and reliability of every one of the mass-produced devices since each one has to be identical within specified limits or tolerances. In this way, uniformity is possible. Uniformity allows the development of standardised handling procedures, drills and tactics because each device can be relied upon to perform in the same way. This is not an intrinsic quality of a prototype, however, and usually has to be engineered into the device. Functionality as predicted by the inventor and a capability of being mass produced are quite different characteristics.

A feedback loop connects invention with development and manufacture so that the process of invention may continue into production and beyond, thereby ensuring that functionality, utility and reliability are maintained at a high level or are improved. Normally, the developmental stages are sequential and, altogether, might take many years to complete. For this reason, in 1914, the MGO did not believe that novel munitions could be devised, manufactured and supplied to the army before a war ended.¹¹ In the case of the novel munitions of trench warfare, the process was radically altered because of a drastically reduced timescale in which to devise, manufacture and supply them. What took years in peacetime had to be achieved in months. Thus, these stages had to be conducted concurrently, rather than sequentially, a difficult situation made worse by the fact that there was no body of knowledge to which to refer for guidance. As a consequence, there was a lack of coordination between inventors, the War Office and GHQ. Contrary to what the Ministry of Munitions wanted posterity to believe, the Ministry was little better in this regard than the War Office had been.

This was an unprecedented situation which required unorthodox methods. Not only did it have a profound effect on which novel munitions were provided to the BEF but the manner in which it was handled demonstrated a remarkable adaptability by all those concerned. Some writers have condemned the apparent disorganisation of the approach to resolving the many problems associated with this situation as *laissez faire* and *ad hoc* but such descriptions betray a lack of understanding of the processes involved under peacetime conditions as well as a misunderstanding of the unusual circumstances under which these munitions were provided to the BEF during the First World War.¹² It is misleading to describe the process of invention, manufacture and supply as a linear process, even in peacetime.¹³ It is far more disordered, partly because of the inevitable dead-ends and failures, some of which feed back into the system and cause the process to change direction.

Thus, in order to address the question about the effect on warfare of the novel munitions under discussion here, it is first necessary to put them into historical context, particularly from a technological perspective, and thereby ascertain just how novel these munitions were at the time of the First World War. This immediately raises two further questions, namely, what is meant by novel and what is meant by invention. The provisions of any Patents Act are framed so that, together, they define the conditions a new device must satisfy in order to be considered patentable. This thesis has used a definition of invention based on what constitutes a patentable invention according to the 1977 Act. This is a verifiable test which can be applied universally irrespective of the field of invention. Thus, an invention has to be new, capable of industrial application and involve an inventive step, that is, lack obviousness.

Although the question of obviousness did not apply to the 1907 Act, the Act in force at the time of the First World War, nevertheless, it helps to distinguish what was inventive at that time. Obviousness is a matter of informed opinion rather than of fact, but it is a useful tool with regard to inventiveness. If an invention was not obvious to a person skilled in the art at the time the invention was created, it was, indeed, an invention. This can be used to test whether the improvisations of the Russo-Japanese War, for example, did, indeed, anticipate the devices of the Western Front.

In order to address the issue of novel munitions and their effect on warfare, then, it is necessary to break down the question into the many problems which had to be addressed at the time, and, thereby, examine all the elements that went into the provision of these munitions, starting with the matter of novelty.

Prior to this thesis, it was generally assumed that the munitions under discussion here were either versions of traditional siege warfare devices or were derivatives of the improvised munitions of the Russo-Japanese War.¹⁴ Hitherto, questions concerning the novelty of the devices supplied to the BEF for trench warfare have not been asked. This raises the issue of what drives an engineer to invent; what is the impetus? After all, inventors do not invent in the abstract but do so in order to find a practical solution to a particular problem. This, then, raises the question of whether improvisation differs from invention. For something to be novel, it has to be new. In other words, it has to be of a previously unknown configuration. Improvisation implies that the configuration is known and, therefore, not new. Thus, in general, improvisation is distinct from invention as it can be argued that, by definition, improvisation can only be applied to something of a known configuration. It follows, then, that any device of the First World War which satisfies this criteria cannot have been novel in the sense in which the term is being applied here.

If these munitions were, indeed, novel, the BEF clearly had no experience of them. This raises questions concerning the attitude of GHQ to new weapons in general and to the novel weapons of trench warfare in particular. There is also the matter of how the BEF coped with devices of which it had no knowledge. Then there is the question of how the numbers and types of new weapons effected their operational use and, hence, tactics. The issue of usefulness is also raised in this context: how useful to operations on the Western Front were any of these devices? Which brings us back to the issue of technology and whether the technical design of a munition affected its operational use. This, of course, is related to functionality.

Thus, the question of whether the novel munitions of trench warfare contributed to the development of new tactics on the Western Front is not quite as simple as it appears. It conceals a wide range of hitherto unasked questions relating to the invention, manufacture, supply and operational use of munitions which were not part of the British army's equipment in 1914 but which had become standard issue by 1918. The question then becomes: why were these munitions adopted as standard equipment when they had been introduced as mere stopgaps and expedients? How had this come about and what was different about these munitions in 1918 compared to their predecessors in 1914 and 1915?

The question of novelty

The trench fighting that arose in wars before the First World War provided little impetus to invent specialised munitions for such fighting. Between 1855 and 1914, there were many inventions in the fields of small arms, artillery and their ammunition, especially fuzes, as well as in explosives and propellants, but there were hardly any that related to grenades.¹⁵ None related to trench mortars until 1908, the same year in which the rifle grenade was patented by Marten Hale who had not been inspired by any war to create such a device.¹⁶ Although a number of British inventors invented percussion-fuzed hand grenades during the nineteenth century, the War Office was not interested in the concept. The American Civil War inspired a few American inventors to devise hand grenades, both percussion-fuzed and time-fuzed. These new types of hand grenade were unreliable and their utility was low. The British took no notice of them and the Americans lost interest.¹⁷ Only the French were sufficiently interested in one design to import it. This was the Adams which became the French M1870 bracelet grenade which was still in service in 1915.¹⁸ No hand grenade was invented in response to the Crimean War, the Russo-Turkish War or the Boer War. The best that can be said is that these new designs received a luke-warm reception.

Conversely, hand grenades were improvised by British soldiers in the Crimea and in South Africa.¹⁹ In the American Civil War, wooden mortars were improvised by the Union forces besieging Vicksburg.²⁰ Grenades were improvised by both sides during the Russo-Japanese War, while the Japanese improvised a wooden mortar. On the Western Front in 1914 and 1915, grenades and mortars were improvised by British, French, Belgian and German troops. The Royal Engineers made almost everything from cooking stoves to body armour.²¹ While improvisation tended to be the art of the enthusiastic amateur, the Royal Engineers took it to a new level by using workshop facilities so that their improvisations took on the appearance of factory-made items. The Newton 3.7-inch mortar was a prime example. Nevertheless, improvisation was not usually a serious attempt to satisfy any more than a local need. Even in the Russo-Japanese War, improvisation was the resort of desperation of local garrisons rather than an attempt to address an absence of a much-needed munition for the entire army.²² The improvisations of the Russo-Japanese War were transformed into devices of greater significance than they merited by the military observers, who reported on everything they saw but without proper analysis.

In only two instances did improvisation lead to invention prior to the First World War and both occurred during the Russo-Japanese War: the percussion-fuzed hand grenade and the light mortar.²³ It is noteworthy that neither saw action and both were only indirectly related to the improvisations that preceded them. Both were reported to the War Office which led to the British attempting to devise a percussion-fuzed hand grenade of their own on the basis that it might prove useful.²⁴ The difference between the British No. 1 hand grenade, the Japanese percussion-fuzed grenade of the Russo-Japanese War, and the American Ketchum grenade of 1861 is slight and they were similar to the grenade devised by William Parlour in 1834. This demonstrates that inventors tend to re-invent the obvious when they are unaware of any prior art. Over a period of eighty years, the concept of a percussion-fuzed grenade

remained essentially unchanged, yet no one had succeeded in devising one that worked efficiently and reliably. It also shows that the War Office failed properly to consider just what it was asking the Royal Laboratory to design in the early 1900s or even what it proposed to do with the grenades once it had them.

When the British set about developing a percussion-fuzed grenade during the First World War, a quite different conceptual approach from these earlier grenades was necessary because the No. 1 proved to be too simplistic. This highlights a fundamental aspect of invention, both as a process and as a product of that process, and which is especially pertinent to mechanical devices: novelty lies in novel approaches to functionality, rather than in alternative designs of the same thing. If a device embodies a mechanism of a hitherto unknown configuration, then, it is probably inventive, although that is no guarantee that it will work. The problem is in determining whether a new device satisfies this criterion.

The question of whether the grenades or mortars used by the BEF were novel cannot, of course, be reduced to generalisations. The question can only be addressed by examining the mechanism of each device since novelty is specific to a given device rather than general to all. Nor can the question be answered merely by picking out what was new since almost every grenade and certainly every mortar was new at the time of the First World War. These devices can be divided into three categories: improvised; new but not novel; and novel. Much of the inspiration for the improvised grenades can be traced to the designs of Major R L McClintock, RE, which dated from 1913.²⁵ Although the origins of his designs are unclear, they were almost certainly derived from his experience in handling explosives, rather than from the devices of the Russo-Japanese War. Thus, all those hand grenades that were re-engineered from the improvisations of 1914 and 1915, such as the Nos 6, 7, 8 and 9 hand grenades, can be traced back to McClintock. Although they were all new, none were novel. They were all stopgaps and had been abandoned by the end of 1915.

That the impetus to invent trench warfare munitions had not arisen before the First World War is not to imply that any of the devices invented between 1914 and 1918 could not have been invented at any time during the previous hundred years, although the absence of high explosives until the 1880s would have been a considerable obstacle to success. Nevertheless, the engineering was quite within the capabilities of Victorian engineers. The key issue is that, prior to the First World War, engineers lacked the impetus to invent novel munitions of this sort. During the second half of the nineteenth century, commercial interest became the greatest impetus to invent. The increasing ease with which engineers could protect their inventions by patenting, made possible by improved patent legislation, with the consequent rise of intellectual property as a commercial asset, changed engineers and engineering. There was a massive increase in the number of patents in all fields of endeavour during this time, not just in military engineering. It is significant that a number of companies came into existence for the duration of the First World War for the sole purpose of making money from patented inventions.²⁶ The increase in the number of munitions inventions between 1852 and 1914, and during the First World War, should be seen in this light. Moreover, engineers felt that they could find solutions to almost any

problem. It was in this milieu that Frederick Marten Hale, William Mills, Henry Newton, Wilfrid Stokes and men like them worked and invented. Of all these men, Marten Hale was the most commercially aggressive. He held the most patents and, more importantly, he pursued in the courts anyone who infringed them.²⁷

The problem with novelty at the time of the First World War is its uncertainty. Whereas some inventions are clearly novel, the novelty of others is less easy to establish. The fact that a patent was granted for an invention did not mean that the device was even new, let alone novel, merely that it satisfied certain criteria which related to newness.²⁸ The Burn discharger, for example, patented in 1917, was not new since devices of this type are known from the sixteenth century but some features of the Burn device were novel.²⁹ The Stokes mortar was undoubtedly novel as nothing like it had ever existed prior to its creation. Indeed, it embodied an entirely new concept in munitions for this was the first true light infantry mortar. The hand grenade invented by William Mills was not, strictly speaking, new because it was based on the earlier Roland grenade. It was, however, novel because it incorporated features which allowed the device to function as intended. From a functional perspective, the Roland and the Mills are differentiated by a simple truth: the Mills device worked whereas the Roland did not. This, of course, raises the issue of whether a device is inventive if it does not work. This is a complex matter as it relates to the role of failure in the process of invention. It could be argued that Roland's British patent was invalid because the grenade did not work, although Mills never challenged it on this ground. Nevertheless, for a patent to be valid, the invention has to be workable, although this does not have to be proved during prosecution of the application. It only becomes an issue if the validity of the patent is challenged in court.³⁰ If proved invalid, the patent is revoked. In this respect, Mills was far more generous of spirit and, indeed, money than Marten Hale who would have probably challenged the Roland patent had he been in Mills's shoes.

Not only was the first Mills grenade, the No. 5, novel but it introduced a new concept: the automatically lit time-fuzed hand grenade. It could be argued that the Roland introduced this concept but, as already stated, the Roland did not work. The No. 23 Mk III, developed from the No. 5, was also novel. It included features not seen in any previous hand grenade and solved defects in the No. 5. The No. 23 Mk III was a second-generation device and was even further removed from the No. 5 than the No. 5 was from the Roland. This illustrates the effect of the feedback loop on the development of the Mills type of hand grenade and shows that invention was a continuing process rather than one which ended when a device went into production. Although this was of particular relevance to British First World War hand grenades, it also applies to most other devices invented and developed in peacetime, from vacuum cleaners to battleships. Indeed, this may be discerned in the engineering of the nineteenth century as well as in the twentieth and illustrates that a sequential or linear model of development as proposed by Trebilcock is too simplistic.³¹

The munitions devised by Henry Newton were novel and had no basis in any prior device. Their simplicity, like the mortar invented by Wilfrid Stokes, was the antithesis of much pre-war engineering by the armaments firms, such as Vickers, which tended

towards complexity, as typified by their complicated wartime designs of trench mortars. The inventions of Newton and Stokes arose from a different philosophical approach to engineering from that followed by the armaments industry. Newton and Stokes wanted to find the most straightforward solution to a problem, irrespective of what custom dictated, whereas the armaments firms were, in many ways, tied to preconceived ideas of what form the solutions ought to take. This is almost certainly why the inventions of Newton and Stokes were unconventional both in form and functionality. It is probably no coincidence that the munitions invented by Marten Hale, who was associated with armaments through his work with explosives, were much more complex than those of Newton or Stokes. There is also the inference that, in the years before the war, the War Office was unlikely to take seriously any device which was too simple because simplicity implied amateurishness and inefficiency.

It is significant that the major inventions in the field of trench warfare munitions were made by civilian engineers who had no prior connection with the armaments business, rather than by anyone in the established armaments firms. This was not merely because the armaments firms were too busy with conventional munitions to spare time for grenades and mortars but was due to the institutionalisation of ideas over the previous fifty years about what form weapons ought to take. This allowed very little room for radically different ideas. The Royal Laboratory, for example, had a very poor record of invention and development when it came to grenades and mortars. It is interesting to speculate on what might have been the consequence had these firms been given the task of inventing and manufacturing such munitions. There would have been no Mills grenade and no Stokes mortar. The Mills grenade came about because William Mills met Albert Dewandre who was seeking commercial production of the Roland grenade in January 1915.³² Dewandre had no thought of contacting a firm such as Vickers.³³ Had he done so, it is unlikely that the result would have been the Vickers equivalent of the Mills grenade. Indeed, it is likely that the MGO's fears would have been realised and no grenade would have been ready until at least mid-1916. When Vickers was asked by the War Office to devise a mortar, it based its design on an unexceptional pre-war Krupp device. The mortar served its purpose but it was a stopgap measure. Conversely, the Newton 6-inch mortar which replaced it was superior in every respect, although it, too, proved to be transitory and became redundant when open warfare resumed in 1918.

Thus, it is clear that the novel munitions of trench warfare used by the BEF were, indeed, novel and had no basis in earlier devices from the Russo-Japanese War. The idea that grenades were reintroduced in the Russo-Japanese War is mistaken since, in fact, they had never gone away.³⁴ They had been in sporadic use since they went out of favour in the mid-eighteenth century but they had never been entirely abandoned. The use of grenades in the Russo-Japanese War was in this tradition. The motivation to improvise them was little different from that which had encouraged British troops to improvise grenades in the Crimea and in South Africa. As for the invention of percussion-fuzed grenades, these were all re-inventions of a flawed concept. The case of the rifle grenade was very different, however. It did not exist until 1908 and, consequently, had no connection with the Russo-Japanese War.

As far as mortars are concerned, the devices improvised and invented by the British during the First World War had no connection with the mortars improvised by the Japanese in Manchuria, nor with the Nakamura mortar. Although the Germans devised trench mortars in the light of their observations in Manchuria, their mortars bore no resemblance to the Japanese devices and were effectively scaled-down howitzers.³⁵ The British use of mortars on the Western Front was in direct response to the German mortars. In this respect, the First World War mortar may be said to be derived from those of the Russo-Japanese War but from an inventive and functional perspective there was no connection at all.

It is clear that the First World War, and the Western Front in particular, inspired civilian inventors in a way that no previous war had done. Not only did they invent grenades and mortars but many other devices for trench warfare including body armour and periscopes.³⁶ The most likely reason for this burst of creativity is that, unlike small arms and artillery, the munitions of trench warfare required neither specialist equipment nor an understanding of conventional arms in order to contrive new devices, although their manufacture required a level of expertise comparable with that used to make conventional munitions. It is significant that many of the early devices, patented in Britain, were impractical and unworkable.³⁷ Awareness of the need for trench warfare munitions cannot have been the sole impetus to invent. The rise of engineering as a solution to problem-solving in Britain during the nineteenth century was also a significant factor, aided by commercial interests in intellectual property brought about by the improvements in patent legislation since 1852. There was a strong commercial incentive to invent.

The role of manufacture

The development of manufacturing techniques was as important to the provision of these munitions as the development of effective devices. Without mass production, there would have been too few grenades and too little mortar ammunition to have allowed grenades and mortars to play significant roles in trench warfare. That these munitions had an impact on warfare was in no small way due to the numbers that became available from about mid-1915 onwards. The tens of millions of grenades and mortar bombs used by the BEF during the First World War was unprecedented. In the Russo-Japanese War, the numbers of grenades used in action was irrelevant to the conduct and outcome of battles and the numbers pale into insignificance when compared to the quantity used by the BEF in one month, let alone nearly four years of trench warfare.³⁸

It is easy to take the achievement of mass production as an inevitable consequence of turning the country's engineering firms over to munitions work. However, this was no simple task since munitions production was not the same as other forms of manufacturing; and it had not been done before. Without the development of new techniques and new ways of approaching quality assurance, the number of grenades and the quantity of mortar ammunition would have remained small. It was, at first, a painfully slow and sometimes chaotic process in which everyone concerned had to learn as they went. That the learning process accelerated and that the level of expertise rose at an ever-increasing rate says much

about the quality of British engineering in the many small firms which became engaged in this work. This was perhaps one of the great strengths of British engineering firms; their adaptability and their capability to absorb new skills, quickly and efficiently.

However, mass-production of trench warfare munitions by commercial engineering firms did not come about because of far-sightedness by anyone in the War Office or, indeed, the Ministry of Munitions. On the contrary, it was introduced because the established armaments firms were unable to take on the manufacture of novel munitions due to their capacity being fully occupied with manufacturing conventional munitions. Thus, there was no option but to engage commercial firms. This was not merely a question of persuading such firms to become arms manufacturers; it entailed approaching the manufacture of munitions from a quite different perspective. Commercial firms were in no position to acquire the machinery or the skills associated with decades of experience in munitions manufacture. It had to make munitions to the required standard by another route.

This gave rise to the Outside Engineers Branch (OEB) which controlled the production of novel munitions by the contracted firms. At the same time, new processes were devised, including group manufacture, which increased output and eased quality control. The greatest improvement came in standardisation of working practices within these firms. Group manufacture was so successful that it was subsequently applied to the manufacture of conventional munitions by commercial contractors.³⁹ Thus, innovation lay not only in the engineering of the munitions but also in the means by which they were mass produced. Without these new methods of production, the BEF would have received very few of the novel munitions it needed for trench warfare. From late 1915, production in Britain was increasing rapidly as the contractors reached the point where they could mass produce with a low rejection percentage. In the meantime, the BEF had found an alternative source of trench warfare munitions: the Royal Engineers in France.

Had it not been for the Royal Engineers Workshops attached to the First and Second Armies and other Royal Engineers facilities, the BEF would have been forced to rely on locally made improvisations throughout 1915. It might have been possible for the BEF to have purchased some additional grenades, mortars and ammunition from the French but this assumes that the French had some to spare which was unlikely as they were in much the same situation as the British.⁴⁰ Without the Royal Engineer Workshops, the most likely scenario is that GHQ would have had no alternative but to abandon grenades and mortars as viable munitions. The dismal stopgaps sent out from Britain and the unpredictable improvisations made by local workshops would have been inadequate in both quality and in quantity for them to have been taken seriously by GHQ. A year's delay in the mass production of reliable and effective trench warfare munitions would have led to the BEF having to find a quite different solution to the problem of German grenades and mortars.

There is the question of how much British and French use of these munitions persuaded the Germans to escalate their use of them. The British, French and Germans all developed new weapons to counter technological advances by the enemy so it is not unlikely that an arms race of sorts developed during 1915, fuelled by a need to retaliate in kind. This is how

gas warfare developed.⁴¹ It is supported by the fact that, for the first year of the war, these munitions were not critical to the conduct of British operations. They were not significant to operations until they were mass produced. Had they not been mass produced, they would have probably remained peripheral to operations until mobile warfare returned when they would have been abandoned so that they would have been no more than a footnote in the history of warfare. It could be argued that mass production had a greater effect on new forms of fighting than the new munitions with which they were conducted. Inevitably, the greater the availability of a munition, the more it is used.

The circumstances under which the manufacture of trench warfare munitions occurred, as opposed to the manufacture of all types of munitions, set the production of trench warfare munitions apart from any other manufacturing activity during the First World War. That invention, modification and evaluation all occurred concurrently with the development of manufacturing techniques, and the fact that output was effected by demand from GHQ throughout these processes, demonstrate that this was, indeed, a unique circumstance, particular to trench warfare munitions and particular to the First World War. Their production did not resemble the four-phase process outlined by Robinson nor, indeed, presage it.

While the large-scale production of munitions, such as SAA, had occurred before the outbreak of the First World War, it is moot point whether this constituted mass production; it is outside the scope of this thesis to discuss the broader picture of the manufacture of munitions. However, prior to 1914, no munition was produced on the scale of production that occurred during the First World War. The achievement of producing novel munitions on a huge scale in so short a timescale was unprecedented.

Organisation and management

None of this would have been possible without a bureaucratic system of organisation and management. The complexity of the process of providing these munitions was compounded by the initial lack of a system. The organisational achievement of the War Office has been overshadowed by the political squabbling that followed the shell crisis of 1915 and the creation of the Ministry of Munitions. Whatever the shortcomings of the War Office in its provision of conventional munitions to the BEF, this only indirectly effected its efforts to provide trench warfare munitions. An infrastructure had to be started from scratch but it was independent of the customary procurement procedures and was aided by the fact that these munitions were not regarded as important as shells and guns. That they were seen as temporary expedients which would enable the BEF to deal with the temporary problem of static warfare meant that they were regarded as a side issue until about mid-1915. Thus, there was no need to deal with them in the same way as shells and guns. The grenade and the mortar only became important after nearly a year of war.

The change of attitude coincided with the creation of the Ministry of Munitions in June 1915. The obvious conclusion is that it was effected by the new Ministry but this would be to subscribe to the history of trench warfare munitions according to the *History of the Ministry of Munitions*. This was written, before the war ended, with the intention not merely of

describing the role played by the Ministry for the benefit of posterity but also to aggrandise it to the detriment of the War Office. The *History* was as much a political document as it is an historical one. The idea that nothing of consequence occurred before the creation of the Ministry of Munitions can be traced to this document. What is hidden within the *History* is the fact that those people in the War Office who had made considerable progress in organising the provision of novel munitions to the BEF were absorbed en masse in the new Ministry. Their files went with them and were rejacketed as Ministry of Munitions files so that their War Office origins quietly disappeared.

The achievements of the new Ministry in providing trench warfare munitions were built on a foundation established by the War Office. In particular, the sub-section in the Directorate of Fortification and Works, run by Colonel Louis Jackson, was fundamental to what was later achieved because this was the origin of the OEB. The main criticism that has been levelled at the War Office in its handling of novel munitions is that it was disorganised because of its ad hoc approach, whereas the Ministry of Munitions had a hierarchical structure in which no aspect of the provision of novel munitions was left to chance.⁴² While there is some truth in this assessment, the conclusion that the Ministry was, therefore, superior to the War Office is mistaken. Indeed, such a conclusion is not supported by the evidence, the *History of the Ministry of Munitions* notwithstanding. Such a conclusion is based on the assumption that ad hoc equates with disorganised and is, itself, premised on the notion that an organisational framework for the provision of grenades and mortars existed at the outbreak of war when, in fact, not only did none exist but no requirement for one existed.

Extemporisation and the creation of ad hoc organisations to deal with unusual situations is a very British approach to problem-solving but, in relation to the First World War, it has tended to be derided for being ineffectual.⁴³ Often, the supposed German model of efficiency is used as a yardstick. However, this is to confuse bureaucracy with competence. It is notable that the Ministry of Munitions was far more bureaucratic in dealing with inventions and trench warfare munitions than the War Office had been. A bureaucracy offers less freedom than an ad hoc approach because of their differing philosophical bases. Whereas a bureaucratic system may be highly desirable in an environment in which working practices have evolved over a long period of time, it is less helpful in a situation where nothing is certain and change is commonplace. The complexity of the provision of these munitions meant that stability was hard to achieve and, hence, the flexibility to adapt was a considerable advantage. Had a bureaucratic system for dealing with these munitions existed in 1914 and 1915, it is likely that it would have failed just as the system for supplying shells failed. This is not to suggest the War Office was not bureaucratic or hierarchical but it had the advantage of experience, whereas the Ministry of Munitions had all the disadvantages of being new. Ironically, it was itself ad hoc and short-term, which cannot have escaped those who wrote the *History of the Ministry of Munitions*.

The Ministry had the advantage of more staff and a larger budget to deal with trench warfare munitions than the War Office before it. It also benefited from the experience of the War Office

staff transferred to the Ministry on its creation. Nevertheless, the provision of trench warfare munitions in the new Ministry was often no better organised than it had been in the War Office. For all its posturing, the Ministry was rife with territorialism, backbiting and interdepartmental rivalry. All this was made worse, rather than being mitigated, by the cosmopolitan mix of its staff who came from the War Office, the services, industry and other civil service departments unconnected with the military.⁴⁴ Whereas in the War Office, everyone was aware of working practices, this was not the case with the new Ministry. Moreover, Lloyd George had persuaded industrialists to work in the new Ministry in order to bring commercial business practices to the provision of all munitions, which did not accord with Civil Service practices. There was inevitably a clash. The Ministry of Munitions was not the model of efficiency and cooperation which the *History* and Lloyd George presented to Parliament and the public.

And yet, the achievements of the Ministry in the provision of trench warfare munitions were remarkable. There is no doubt that, had the Ministry of Munitions not existed, the War Office would probably not have achieved a similar feat of organisation and management simply because it lacked the manpower and the resources for the task, although it would have fared better than the débâcle with the provision of shells implies. The provision of trench warfare munitions during the First World War effectively necessitated setting up an enormous manufacturing business almost overnight to produce munitions which had yet to be invented, using an unskilled and inexperienced labour force to both make and inspect the munitions. Although not all the credit should be given to the Ministry of Munitions, nevertheless, it not only oversaw the mass production of these munitions by commercial contractors, but it also instigated evaluation and development programmes which led to the successful resolution of many engineering and production problems with the first-generation devices.

However, this achievement came about somewhat in spite of the organisational structure of departments and sections within the Ministry, rather than because of good management practices. The mere fact that the organisational framework within the Ministry changed several times shows that the ideal arrangement was never achieved, although such changes also reflected changing circumstances. The conflict of bureaucratic procedure with changing demands from GHQ, and with changing munitions as they became technically more advanced, could not be resolved by imposing a regime which looked effective on paper but which worked less well in practice. This not only stifled innovation, it also caused confusion over areas of responsibility. Because of the unique situation of having to supply munitions that had yet to be invented, it had proved effective in 1915 for research and supply to operate together from the same department as it allowed direct feedback from the Front to effect changes in munitions that were imperfect, thereby speeding up the whole process. The conflict between research and supply was considerable in the new Ministry because it was not customary to handle them in this way. It is hardly surprising that attempts were made to separate them.⁴⁵ In an ideal world, they would have been independent but there was no time for the sequential process this required. In one sense, those involved with developing and supplying these munitions fell into two categories: those who saw the necessity of keeping them together; and those who failed to understand why keeping them together

was beneficial and wanted to separate them. It is perhaps significant that Louis Jackson, a Royal Engineer, epitomised the former, while his deputy in the Trench Warfare Department, Alexander Roger, an accountant, epitomised the latter. After a short time, Roger got his way which may be seen as the rise of bureaucracy at the expense of efficiency. Here was an instance where experience of military matters and of innovation came into direct conflict with commercial experience, illustrating that military demands cannot be served by purely commercial practices.

Having to provide new munitions under such circumstances was, and remains, a unique event. Inventing new munitions to deal with unexpected situations has an ancient history, of course, and can be traced back to at least Archimedes at Syracuse in 212 BC. What makes the First World War different from all other wars where new devices have been created to meet a new demand is the scale of the undertaking. For example, more than 75,000,000 Mills grenades of all patterns were manufactured in about three and a half years, itself an achievement, but even more remarkable considering that the Mills grenade was invented in January 1915 and mass production was under way by the following October. Neither before nor since the First World War has a vast infrastructure been created to deal with the manufacture, evaluation, inspection and supply of munitions which had not existed hitherto.

In France, the Royal Engineers and Royal Engineer establishments played a greater role in providing the BEF with trench warfare munitions than the *History of the Ministry of Munitions* conceded. It is unclear whether the authors of the *History* were aware of what the Royal Engineers had accomplished or whether they chose to overlook it because it had nothing to do with the Ministry of Munitions. However, the lack of acknowledgement of the Royal Engineers' contribution epitomised the attitude of the Ministry of Munitions to all other departments and agencies concerned with novel munitions. In this respect, it was supercilious, arrogant, uncooperative and politically biased. The role of the Royal Engineers in providing trench warfare munitions was far more significant than the *History* suggests.⁴⁶ Unfortunately for the Royal Engineers, there was no comparable document to proclaim its achievements. The *History* was not merely a record of the short-lived Ministry of Munitions but it was also, intentionally, a politicised document which presented a biased account of what had occurred during the war in order to praise the Ministry. The War Office did nothing to provide a different view by writing a history of its own wartime endeavours.

The evolution of the department which dealt with inventions and trench warfare munitions reflected the complex relationship between invention, development, manufacture, military requirement, operational experience and the evolution of tactical systems for the employment of these munitions. An ideal arrangement was never achieved. The departments were of their time, expedient and transient and, as such, did not resemble the permanent research establishments. The trench warfare departments, for all practical purposes, ceased to exist by the autumn of 1918 because they were no longer needed and their personnel returned whence they came. Hence, they played no part in the research community which emerged from the war and contributed nothing directly to the research corps described by Edgerton.

While, in some ways, the relationship between these departments, the army and the commercial contractors engaged to manufacture trench warfare munitions, resembles a proto-form of the relationship between the state, industry, the military and technology described by Edgerton, the resemblance is only skin deep. Functionally, the relationship was quite different, a marriage of convenience rather than an arranged one.

Inventors and inventions

At the end of the war, the American government awarded Henry Newton \$100,000 for this contribution as an inventor to the prosecution of the war and put him at the top of a list of British inventors.⁴⁷ Although this reflected which British inventors most affected America's war, rather than the war fought by the BEF, nevertheless, this illustrated the importance of inventors to the prosecution of war on the Western Front as well as the significance of the contribution made by Newton. All lists are, of course, biased and, as such, need to be treated with the same scepticism as statistics since the relative importance of one inventor with regard to another depends on the criteria being applied.

As far as the munitions of trench warfare are concerned, it is complicated by the fact that in many instances other inventors improved the original inventions, as in the case of the Mills grenades. The No. 5 Mills was derived from the Roland, while the No. 23 Mk III was derived from the No. 5 by way of inventions made by, among others, Vickery and Gibbons. Other inventors contributed to the manufacture of the centrepiece, its fabrication having an affect on the speed of manufacture of the grenade.⁴⁸ Many contributed to the grenade known as the Mills. It is, perhaps, a little perverse that the name was kept, since the No. 23 Mk III only resembled the No. 5. Indeed, the No. 23 Mk III could have been legitimately called the Vickery or the Mills-Vickery. When the Stokes mortar was married with the Brandt ammunition in the 1920s, the mortar was known as the Stokes-Brandt. Whereas the Stokes mortar was a product of Stokes's imagination and owed nothing to any previous device, had the mortar not existed, Newton would not have invented the incremental ring charge, let alone the 6-inch medium mortar. This illustrates the difficulties in picking out which inventions are the most significant, as most depend upon the existence of earlier inventions or were the product of more than one inventor.

The attempt to devise an effective and safe percussion-fuzed hand grenade demonstrates the complex relationship between perceived need, practicalities and failure. The differences between different versions of the same device were sometimes small but on such differences could rest the successful operation of the device or yet another failure. And always, engineers were spurred on by the belief that such a device was wanted by the BEF. The biggest obstacle to success was probably inconsistency. Whereas a trial might show that a particular configuration worked, another trial at another time and place with the same configuration could produce quite different results.⁴⁹ Failure was probably the greatest impetus to invent during 1917 and 1918. Under these circumstances, each succeeding version of a device depended for its existence upon the failure of the preceding version. The line of development from the earliest version to the latest could be complex so that the latter bore little resemblance to

the first version. This can be seen in the development of the Humphries percussion-fuzed grenade, the origin of which was the No. 15 Ball grenade.

While Henry Newton may have been one of the most prolific of the wartime inventors and William Mills may be the most famous, their contributions should not be seen in isolation but as parts of a large and complex whole. It is not meaningful to discuss inventors as though they can be listed in a league table of importance. All inventors worked towards a common goal, although some, like Marten Hale, were more commercially minded about it than others. The number of successful patent applications during the war is indicative of the role of commerce in these endeavours.⁵⁰ After about the end of 1915, there was gradual change in focus, reflecting the change in importance of particular problems as greater experience with the munitions was gained at the Front. Thus, in early 1915, the emphasis was on entirely new devices of novel configurations, whereas, in late 1917, the emphasis was on improving the functionality or the means of fabrication of existing devices.

Throughout the war, some names kept appearing as patentees but there were many new inventors, so that the number of inventors concerning themselves with trench warfare munitions increased. This indicates the growing awareness among engineers of the relevance of these munitions to trench warfare, emphasised by the increasing number of small engineering firms involved in their production. It also shows an increasing sophistication in the technology of these munitions. While in mid-1918, Wilfrid Stokes bemoaned the fact that the Ministry of Munitions tended to complicate the engineering when they should have been working towards simplifying it, the patents granted at this time show that simplicity did not necessarily improve the functionality and reliability of a device.⁵¹ Indeed, the improvements made to the Stokes mortar and its ammunition tended towards greater complexity.

Increasing the complexity of a device did not necessarily mean that it became more difficult to make or use. In general, there are two sorts of complexity when it comes to mechanical devices: that which is due to a lack of understanding of the principals on which a device operates; and that which arises from improving specific elements within a mechanism in order to increase its efficiency. In the latter case, increasing complexity tends towards increasing functionality, although there is an optimum point at which reliability begins to decrease. Thus, there is a trade-off between functionality and reliability. This process can be seen in the evolution of the percussion-fuzed hand grenade, although it is a moot point whether the optimum point was ever reached since the reliability of all percussion-fuzed grenades was always too low to make them viable service munitions. As for the Mills grenade, it could be argued that the optimum point was reached in 1917 since little further change was made to the device over the next fifty-five years. With increasing complexity, reliability becomes the dominant factor although greater experience with a given technology tends to increase utility and reliability despite an increase in complexity.

British engineers played a crucial role in the provision of trench warfare munitions. Their inventions were fundamental to the BEF's ability to conduct trench warfare operations. The ability of engineers to solve problems of functionality, especially when these were connected to production difficulties, was as important as the original inventions because this allowed

the rapid development of second-generation devices. There is no question that, without inventors of the calibre of Mills, Newton and Stokes, for example, the BEF would have been in dire straits. Most of the significant trench warfare inventions were the creations of engineers such as these who had no previous experience of munitions. That the BEF had the trench warfare munitions it needed is not attributable to the work of a few inventors but should be seen as the result of the work of many engineers throughout the war. Their inventions spanned a wide range of engineering, from vented cap holders in time-fuzed hand grenades to mountings for mortars, from ring charges to fuzes for mortar bombs, from fins to casings, from fabrication techniques to materials technology. The number of inventions relating to trench warfare munitions that were patented between October 1914 and October 1918 ran into many hundreds.⁵²

Tactics and technology

The relationship between tactics and technology is not a simple one, and what applies to one technology may not apply to another. Moreover, there is a delay between the introduction of a technology and any change in tactics that this might engender. It follows that any modification to that technology also has a lead time in respect of any consequential tactical change. Advances in technology do not necessarily lead to modifications of tactics, however, as the former may simply facilitate a more effective application of existing tactics. In addition, tactical developments may have an effect on subsequent technological advances by means of a feedback loop. Hence, this is a dynamic relationship rather than one that is fixed.

The relationship of the technologies of the munitions of trench warfare and tactical developments relating to their operational use during the First World War was complicated by the fact that all the processes involved in providing these munitions occurred concurrently. The development of a tactical system was initially discouraged by the lack of standardisation and the uncertain reliability of the munitions concerned, reducing their operational use to inspired guesswork. Up to about early 1916, few soldiers had direct contact with grenades or mortars, although they would have heard plenty of rumours about their hazards.⁵³ By the beginning of 1917, this had completely changed so that few soldiers from any branch of the BEF would not have had direct contact with hand grenades or experienced British trench mortars in action. In the last year of the war, the grenade ceased to be a weapon of the specialist and became a weapon used by every infantryman, while the light mortar became the infantry's mobile artillery. While hindsight may turn this into an inevitable progression, this perception is very far from the reality of the developing tactical use of grenades and mortars.

For a tactical system to be developed for a given munition, that munition must be available in large enough numbers to allow a significant number of troops to be trained in its use. Moreover, the munition has to be perceived as conferring an advantage on its users and has to be reliable. So long as grenades were regarded as a side-show, no tactical system was likely to be devised for their use. The tactics of hand grenade warfare were distilled from practical experience, rather than being developed from theory, so that their evolution depended upon

the availability of reliable hand grenades in large numbers. So long as the BEF was equipped with a diversity of stopgap grenades, tactics remained at their most basic because the grenades were unreliable, the number of types too great, and their availability too uncertain from one week to the next. Thus, the use of hand grenades was the province of specialists and, so long as grenades remained specialist weapons, their use was limited and tactics did not evolve. For grenade tactics to develop, a reliable mass-produced hand grenade was required.

Grenade tactics moved beyond merely out-bombing enemy bombers and tit-for-tat raids as soon as the Mills grenade replaced the stopgap devices. As more Mills grenades became available, the number of accidents with the Mills began to increase. This led to changes in handling procedures which consolidated grenade tactics because the No. 5 became safer to use. This, then, led to an increase in tactical sophistication, aided by the increased availability of rifle grenades and the integration of bombing squads with Lewis gunners. The introduction of a systemised approach to training bombers in mid-1915 led to a more rigorous approach to grenade warfare. By 1916, grenade tactics were developing beyond the enthusiastic amateurism of the first year of trench warfare.⁵⁴

In the case of trench mortars, the limiting factors all related to their functionality. They were slow and inaccurate, and ammunition was scarce until mid-1915. As these issues were addressed from a technological standpoint, so the problems were diminished and distinctive roles for heavy, medium and light mortars began to emerge in 1916. Nevertheless, the tactical use of heavy and medium mortars, both operated by gunners under the control of the divisional artillery, remained essentially artillery support in that these mortars allowed the howitzers to engage more distant targets. In this respect, the heavies and mediums assisted indirectly in the development of deep battle. These mortars were a product of trench warfare and once open warfare returned they became redundant mainly because they were too difficult to move. Moreover, they became unnecessary as their main function had been to drop large amounts of high explosive on underground positions, in the case of heavy mortars, and to destroy barbed wire, in the case of the mediums. In neither case were they able to provide direct infantry support which became an increasingly important role for light mortars during 1918.

At the start of the First World War, the BEF had no infantry-support weapons other than a few Vickers and Maxim machine-guns. It was due to the inadequate numbers of these weapons that the Lewis gun was introduced.⁵⁵ By 1918, the infantry could call on a range of support weapons without recourse to the artillery. Principal among these were the Lewis gun, the rifle grenade and the Stokes mortar, as well as the hand grenade. While the Stokes mortar did not exist before 1915, both the Lewis gun and the rifle grenade had been invented and tested some years before the outbreak of war but neither had been adopted by the army as they had been thought to be unnecessary to the normal conduct of operations.⁵⁶ By 1917, the Stokes mortar, the Mills grenade, the rifle grenade and the Lewis gun had already begun to alter the nature of infantry warfare. It is not the purpose of this thesis to measure the effect of one weapon against the others to determine which of them brought about the greatest change since it was not the effect of one weapon on its own but rather the effect of their use in combination which brought about change. While the infantry platoon of 1914 was

trained in musketry and bayonet work and could expect some support from the artillery, the infantry platoon of 1918 was an all-weapons unit in which everyone was trained in musketry, bayonet fighting and bombing, with use of the Lewis gun a skill that was widespread if not universal.⁵⁷ Operating the Stokes mortar was a specialism but its crew were still trained in the use of rifle, bayonet and bomb. Tactically, the infantry platoon of 1918 was much more flexible than the infantry platoon of 1914.

The tactics of the light mortar were the tactics of the Stokes mortar. The technical characteristics of the Stokes meant that it was portable, quick to set up and accurate, with a very high rate of fire. Such was the sophistication of light mortar tactics in 1918, that the same principles that were applied to the artillery for predicted fire were applied to the Stokes mortar. Had the BEF been equipped with a light mortar which lacked the capabilities of the Stokes, the light infantry mortar would not have emerged as a potent weapon. Fundamental to the development of light mortar tactics was the incremental ring charge, invented by Newton, which allowed targets in depth to be engaged as well as laterally, giving the Stokes a larger area of fire than was possible with any other mortar. The speed with which new targets could be engaged by the Stokes meant that targets of opportunity could be fired on, while the relative ease with which the mortar could be carried forward and set up in a new location meant that the limiting factor was supply of ammunition rather than technical capability. The Stokes had a versatility that all other mortars lacked and provided the infantry with the means to engage the sort of targets which at the beginning of the war could only be engaged by artillery. Its capabilities allowed the development of an entirely novel form of infantry warfare.

The technologies of trench warfare munitions and the development of tactics for their use were directly linked by feedback in both directions. Thus, tactical changes encouraged technical developments, while technical capabilities allowed usage beyond what had been considered obvious. Indeed, the evolution of tactics may be seen as a transition from the obvious to the novel. Thus, in 1918, the tactics of grenade warfare and those of light mortar operations exceeded the sum of expectations of such munitions in 1915. It was obvious to throw grenades in a tit-for-tat fashion but it was novel to attack an enemy trench with bombers and rifle grenadiers above ground while bayonet men advanced along the trench while Lewis gunners provided supporting fire. Similarly, it was obvious to fire mortars at enemy machine-guns and mortars in a tit-for-tat fashion but it was novel to combine rifle grenadiers with light mortar fire to support an infantry assault on a strongpoint, or to use the rapid fire of the Stokes for interdiction.

A new model of infantry warfare

By mid-1918, the British infantryman had become a technician, trained to use the hand grenade and the rifle grenade as well as the rifle and bayonet. He was likely to have fired a Lewis gun, even if he was not employed as a Lewis gunner. He understood the different roles of grenades, light mortars and light machine-guns. More importantly, he was trained to be part of an all-weapons team who could engage a wide variety of targets without necessarily

calling for artillery support. He was expected to combine firepower with mobility and to be flexible in attack and defence, making full use of all the platoon's weapons.

The Mills grenade was a major factor in this transformation. The bomber had been transformed from an enthusiastic amateur into a proficient infantryman via a specialist bomber. By 1918, all infantrymen were bombers. For all the fears of GHQ that hand grenades would have a detrimental effect on how the infantryman used his traditional weapons of rifle and bayonet, the cult of the bomb was a myth. The infantryman remained as skilled with a rifle and a bayonet as he had ever been, although the twenty aimed shots a minute of the pre-war regulars was gone for ever. Far from adversely affecting the use of rifle and bayonet, the Mills grenade had the opposite effect. Shooting skills and bayonet skills were crucial to all bombing tactics which were dependent upon the reliability of the grenades. Throwing grenades was never advocated nor taught as an alternative to shooting and bayoneting.⁵⁸ There was, however, a change in emphasis in the use of the rifle fire, which was encouraged by the rise of the grenade. This concerned weight of fire into a given area.⁵⁹ The grenade assumed an importance in 1915 which it had hitherto lacked and this was seen both at the time and subsequently as a threat to the role of musketry.⁶⁰ However, it is clear from the manuals which dealt with the training and employment of bombers that musketry skills were as important as ever.

Despite resistance by the advocates of old-fashioned musketry to the notion that the infantry should be armed with weapons that emphasised firepower rather than skill,⁶¹ the fighting on the Western Front demonstrated beyond doubt that weight of fire was a factor that had to be considered both technologically and tactically if mobility was to be maintained on the battlefield.⁶² This idea emerged from a realisation that the infantry needed more than one type of weapon with which to engage the different sorts of target that it encountered. This was a significant change of emphasis from the principles of fire and manoeuvre practised by the pre-war British infantry. Whereas in 1914, infantrymen tended to engage other infantrymen, in 1918, they might have to engage fortified positions, trench mortars, bombers, machine-guns, communications centres and headquarters, reserve positions, assembly areas, or tanks, undertake immediate counter-attacks, and coordinate an advance over ground and along trenches in order to defeat an enemy, irrespective of whether he was in a fortified position or in the open. This was not a case of applying an indirect approach, as later advocated by Liddell Hart, but a matter of flexible mobility which, ironically, a diversity of firepower gave to the infantry.⁶³

The fighting on the Western Front proved beyond doubt that it was not feasible to engage such targets with rifle fire alone even when backed up with the point of a bayonet, not least because of the effect of artillery. Moreover, it was not always feasible to wait for artillery support. However, neither was it feasible simply to exchange the rifle and bayonet for another weapon and expect the outcome to be different. The key lay in a coordinated operation. This, of course, required an appreciation of the advantages and disadvantages of the range of weapons with which the infantry were now armed. The great fear had been that, in the upheaval, the rifle and bayonet would be abandoned in favour of new weapons, such

as the grenade, which were perceived as requiring less skill to use than the rifle and bayonet. Yet, at the same time, it was realised that these new weapons needed specialised training. This apparent contradiction was an expression of the reluctance to embrace fully the notion that warfare was being changed by the weight of fire that could be brought to bear by artillery and infantry, even in 1914. This conflict of ideas was due to the arguments about firepower versus mobility that had remained unresolved before the First World War, although military opinion favoured the apparently obvious superiority of mobility over firepower.⁶⁴

The practicalities of war on the Western Front allowed no room for a debate over the superiority of the rifle and bayonet over the bomb; there was no question that the bomb was a necessary evil. What no one anticipated, however, was that the bomb, in the shape of the Mills grenade, would go a long way to giving back the infantry its mobility. Although bombing as practised in 1916 tended to bring an advance to a halt because the bombing squads moved along the trenches which were at right-angles to the line of advance, by 1918, placing the bombers outside the trenches, instead of in them, meant that momentum was more likely to be maintained. Moreover, bombing parties were supported by Lewis guns and Stokes mortars which increased the weight of fire that could be brought down on the enemy, especially when they were forced into the open by the bombers.

The balance between firepower and mobility is, of course, perceived differently according to the point of view of the observer. Thus, what overwhelms an opponent, allows the attacker to regain his mobility precisely because of the immobility that has been forced on his enemy by overwhelming firepower. The dominance of artillery in a war in which nearly 60 per cent of British casualties were caused by high explosive shells has tended to obscure the fact that this applied to infantry firepower as well as to the artillery.⁶⁵

By the end of 1915, there was little doubt that new skills and new tactics were necessary if the deadlock which firepower had forced on the Western Front was to be broken. The new infantry weapons which deadlock engendered had become standardised and their use systemised by the end of the war. Thereafter, the infantry platoon has continued to be armed with light mortars, light machine-guns and grenades, in addition to the rifle and bayonet, although the form of these weapons has changed and their tactical use has continued to develop. By the end of the war, firepower in infantry fighting was acknowledged as important to the conduct and outcome of operations, even in open warfare. The irony is that, whereas the British army standardised grenades and light mortars, it resisted putting automatic weapons into the hands of every infantryman until the 1950s,⁶⁶ while the US and Soviet armies adopted self-loading or fully automatic rifles during the 1930s largely as a result of the experience of the Western Front.⁶⁷ The Western Front demonstrated the necessity of providing the infantry with sufficient firepower to allow it to remain mobile in the face of heavy opposition. This was only possible because of the invention of the Mills grenade and the Stokes mortar, along with all the many other related inventions which improved the functionality, utility and reliability of these and other novel munitions. By 1918, they were no longer novel but had become conventional and warfare had been changed by them.

Notes

¹ Tim Travers, *The Killing Ground, The British Army, The Western Front and the Emergence of Modern Warfare, 1900–1918*, (London, pbk ed, 1990), p. 67.

² See Jonathan Bailey, ‘The First World War and the Birth of Modern Warfare’ in MacGregor Knox and Williamson Murray (eds), *The dynamics of military revolution, 1300–2050*, (Cambridge, 2001), pp. 132–153; and Bailey, *Field Artillery and Firepower*, (Annapolis, 2004), pp. 240–71. See also Paddy Griffith, *Battle Tactics of the Western Front, The British Army’s Art of Attack 1916–18*, (New Haven, 1996), pp. 153–8.

³ Although Bill Rawling, *Surviving Trench Warfare, Technology and the Canadian Corps, 1914–1918*, (Toronto, 1992), discusses the introduction of the new munitions, the process of invention, its significance to the provision of trench warfare munitions is not explored. Similarly, Griffith, *op cit.* does not address the matter of invention.

⁴ MUN 5/321A *History of the Ministry of Munitions*, vol. IX, *Review of Munitions Supply*, Part II *Design and Inspection*, p. 45. MUN 5/120/810/6 Notes on Design.

⁵ Unfortunately, this is outside the scope of this thesis but it is worth mentioning that the British developed more effective gas warfare technologies and techniques than the Germans despite the fact the latter were the first to use poison gas. The German tank devised in response to the British and French devices was so ponderous that the Germans preferred to use captured British tanks. For the view that the Germans were superior technologically to the British, see Hillary Rose and Stephen Rose, *Science and Society*, (London, pbk ed., 1977), pp. 29, 35–6. See also David Lloyd George, *War Memoirs*, 6 vols, (London, 1933), pp. 615–16.

⁶ Lloyd George, *op cit.* pp. 268–9, 619–20.

⁷ *Annual Report of the President, Ordnance Board for the year 1915*, (London, 1917), p. 312 in MUN 5/120/810/6.

⁸ For wanting to send the Stokes mortar to the Dardanelles, see Guy Hartcup, *The War of Invention, Scientific Developments, 1914–18*, (London, 1988), p. 66.

⁹ Hartcup, *op cit.* p. 66.

¹⁰ MUN 5/383/1600/14 Lt-Col O F Brothers, The Development of Weapons Used in Trench Warfare, p. 39.

¹¹ *Design and Inspection, op cit.* p. 45.

¹² See, for example, Michael Pattison, ‘Scientists, Inventors and the Military in Britain 1915–19: The Munitions Inventions Department’, *Social Studies of Science*, vol. 13, no. 4, 1983, pp. 521–68, especially pp. 559–60, and ‘The Munitions Inventions Department, A Case Study in the State Management of Military Science, 1915–1919’, unpublished PhD thesis, especially pp. 217–18, 219, 221.

¹³ Clive Trebilcock, “Spin-Off” in British Economic History: Armaments and Industry, 1760–1914’, *The Economic History Review*, New Series, vol. 22, no. 3 (December 1969), pp. 474–90; ‘Legends of the British Armaments Industry’, *Journal of Contemporary History*, vol. 5, no. 4 (1970), pp. 3–19; ‘British Armaments and European Industrialization, 1890–1914’, *Economic History Review*, New Series, vol. 26, no. 2, 1973, pp. 254–72.

¹⁴ Although this assumption is not necessarily expressed explicitly, it is often implied.

¹⁵ *Abridgements of Specifications*, 1855–1914, Classes 9 (i) ammunition and ammunition receptacles; 9 (ii) torpedoes, explosives and pyrotechnics; 92 (i) ordnance and machine-gun carriages and mountings; 92 (ii) ordnance and machine-guns; and 119 small arms.

¹⁶ T 173/252 *The Great War “Souvenir” 1914–1918*, p. 11.

¹⁷ Jay Luvaas, *The Military Legacy of the Civil War*, (Lawrence, 1988), p. 40.

¹⁸ CDS74 The Training and Employment of Grenadiers, October 1915, p. 44.

¹⁹ See, for example, DHB/55 in the Cheshire and Chester Archives. This contains the papers of Colonel Hugh Robert Hibbert (1828–95) and mainly relate to his service in the Crimean War. In a letter dated 21 April 1855, Hibbert states ‘We have a new invention to annoy our friends [the Russians at Sebastopol] in their pits. It consists in filling empty soda water bottles full of powder, old twisted nails and any other sharp or cutting thing we can find at the time, sticking a bit of tow in for a fuse then lighting it and throwing it quickly into our neighbours [sic] pit where it bursts’.

²⁰ F Stansbury Haydon, ‘Grant’s Wooden Mortars and some Incidents of the Siege of Vicksburg’, *The Journal of the American Military Institute*, vol 4, no. 1, p. 33–8.

²¹ Colonel G H Addison (ed.), *The Work of the Royal Engineers in the Late European War, 1914–19, Miscellaneous*, (Chatham, 1927), pp. 257, 259, 260, 266–70.

²² WO 33/1520 *The Russo-Japanese War, Selection of Reports from Officers attached to the Japanese Forces*, vol. 2, ‘Russian and Japanese Hand Grenades’, Report by Captain Sir A Bannerman, Bart., Royal Engineers, Port Arthur, 28 December 1904, (London, 1906), pp. 508–9 and plate 37.

²³ The Japanese wooden mortar does not qualify as a light mortar, whereas the untried metal Nakamura mortar was designed to be a man-portable weapon. See WO 33/1524, *The Russo-Japanese War, Selection of Reports from Officers attached to the Japanese Forces*, ‘Japanese Bomb Mortars’, Report by Lieut-Colonel A L Haldane, DSO, General Staff, Head-Quarters, Second Army, 17 August 1905, pp 362–4.

- ²⁴ WO 33/1524, *The Russo-Japanese War, Selection of Reports from Officers attached to the Japanese Forces*, 'Russian Hand Grenades' description by Lt-Col Haldane, p. 360; 'Japanese Hand Grenades', Three Reports by Lieut-Colonel A L Haldane, DSO, General Staff, Manchuria 13 June, 15 July, 3 August 1905, p. 355; 'Japanese Bomb Mortars', p. 363. Major Joseph E Kuhn, *Reports of Military Observers attached to the Armies in Manchuria during the Russo-Japanese War*, Part III, (Washington, 1906), p. 193.
- ²⁵ Major R L McClintock, 'An Extemporised Hand Grenade', *The Royal Engineers Journal*, April 1913, pp. 193–200 and 'An Extemporised Rifle Grenade, The Bangalore "Universal" Grenade', *The Royal Engineers Journal*, November 1914, pp. 281–294.
- ²⁶ For example, Pall Mall Grenades Limited, set up in 1915. See BT 31/22958/141366.
- ²⁷ T 173/252, *op cit.* T173/110 Beaton Messrs G & Sons Ltd, No. 39 Rifle Grenade (Steuart Pattern). Claim before the Royal Commission on Awards to Inventors. Report by the Chairman dated June 1925.
- ²⁸ Stephen van Dulken, *British Patents of Invention, 1617–1977, A Guide for Researchers*, (London, 1999), pp. 27–9.
- ²⁹ *Textbook of Small Arms*, (London, 1929), p. 124. GB126692.
- ³⁰ Van Dulken, *op cit.* p. 35.
- ³¹ See, for example, Trebilcock, "'Spin-Off" in British Economic History', *op cit.* pp. 474–90; 'Legends of the British Armaments Industry', *Journal of Contemporary History*, vol. 5, no. 4 (1970), pp. 3–19; 'British Armaments and European Industrialization, 1890–1914', *Economic History Review*, New Series, vol. 26, no. 2, 1973, pp. 254–72.
- ³² King's Bench Division, 1917 R No. 45, Roland & Others *v.* Mills & Another. Proof of Evidence of Mr William Mills, p. 7.
- ³³ It is interesting to speculate whether Dewandre knew that the Roland did not work and sought non-armaments firms to manufacture it because they would not realise that it did not work.
- ³⁴ *Textbook of Small Arms*, *op cit.* p. 105.
- ³⁵ Major James E Hicks, *Notes on German Ordnance 1841–1918*, (New York, 1937), pp. 54–76.
- ³⁶ Anthony Saunders, *Dominating the Enemy* (Stroud, 2000).
- ³⁷ It is not always apparent to those unaccustomed to examining patent specifications that the device described in a specification is unworkable and such a determination requires some knowledge of devices which are known to work. See also *Annual Report*, *op cit.* pp. 307–37, 377, 384, 385.
- ³⁸ July–December 1904, The Japanese used 44,000 grenades. WO 33/1526, *The Russo-Japanese War, Reports from Officers Attached to the Japanese Forces in the Field*, vol. 5 (London, 1906), Table V Special Supplementary Stores, p. 330. For one month in mid-1915, one division was expected to need in excess of 210,000 time-fuzed grenades; see MUN4/2604 Letter from QMG General Maxwell to War Office dated 27 August 1915.
- ³⁹ *History of the Ministry of Munitions*, vol. XI, *The Supply of Munitions*, Part 1 *Trench Warfare Supplies*, p. 19. MUN 5/382/1600/10, *op cit.* p. 22.
- ⁴⁰ Hartcup, *op cit.* p. 55.
- ⁴¹ Maj-Gen C H Foulkes, "Gas!" *The Story of the Special Brigade*, (London, 1934), p. 17.
- ⁴² See, for example, Pattison, 'Scientists, Inventors and the Military in Britain 1915–19', *op cit.* and 'The Munitions Inventions Department', *op cit.* Pattison has been quoted by later writers in respect of the War Office versus the Ministry of Munitions.
- ⁴³ See, for example, Pattison, 'Scientists, Inventors and the Military in Britain 1915–19', *op cit.*; Griffith, *op cit.* pp. 104–5; Hartcup, *op cit.* pp. 23–7.
- ⁴⁴ Lloyd George, *op cit.* pp. 243, 245.
- ⁴⁵ Lloyd George claimed that he was in favour of manufacture and design being kept together. Lloyd George, *op cit.* p. 618.
- ⁴⁶ Griffith makes a similar point. See Griffith, *op cit.* p. 103.
- ⁴⁷ Saunders, *Weapons of the Trench War 1914–1918*, (Stroud, 1999), p. 158. Newton papers.
- ⁴⁸ *Abridgements of Specifications*, Class 9 (i), 1915–18, *op cit.*
- ⁴⁹ This was epitomised by the conflicting views about the DG grenade, discussed in Chapter 4.
- ⁵⁰ Some patents were not granted until several years after the war, for example, Newton's patents were not granted until the 1920s. It is unclear why this should have been the case.
- ⁵¹ *Patent Abridgements*, Classes 9 (i), 9 (ii), 92 (i), 92 (ii), 119, *op cit.*
- ⁵² *Ibid.*
- ⁵³ See, for example, Captain J C Dunn, *The War the Infantry Knew, 1914–1919*, (London, 1987), p. 148.
- ⁵⁴ SS398 The Training and Employment of Bombers, March 1916.
- ⁵⁵ Griffith, *op cit.* p. 121. John Terraine, *White Heat, The New Warfare 1914–18*, (London, 1982), p. 79. Travers, *op cit.* pp. 65–6. Regarding the Lewis gun see *Textbook of Small Arms*, *op cit.* p. 154.
- ⁵⁶ Regarding the Lewis gun, see Travers, *op cit.* p. 65. Regarding the rifle grenade, see WO 32/18989, Hales Rifle Grenade.
- ⁵⁷ SS143 The Training and Employment of Platoons, February 1918, pp. 6, 7.
- ⁵⁸ See any of the bombing instructions, such as, for example, Memorandum on the Training and Employment of Grenadiers in Notes from the Front, Part IV, May 1915; Training and Employment of Bombers, September 1916; and Instructions on Bombing, Part II, November 1917.

⁵⁹ See, for example, *Instructions on Bombing*, *op cit.*

⁶⁰ Mark Connelly, *Steady the Buffs! A Regiment, a Region, & the Great War*, (Oxford, 2006), p. 140.

⁶¹ Captain Todhunter, the Experimental Officer at the School of Musketry, Hythe, was one just man. See Saunders, *Dominating the Enemy*, *op cit.* p. 160. For Todhunter's reports on trials see WO 140/13, WO 140/14, and WO 140/15.

⁶² Similar points are made by Travers and Griffith, for example.

⁶³ Basil Liddell Hart, *The Strategy of the Indirect Approach*, (London, 1941).

⁶⁴ Travers, *op cit.* p. 67.

⁶⁵ Maj-Gen J B A Bailey, *Field Artillery and Firepower*, (Annapolis, 2004), p. 240, fn. 2.

⁶⁶ Based on the Belgian FN automatic rifle, the British L1A1 self-loading rifle was produced by Royal Small Arms Factory at Enfield and BSA in Birmingham c.1958–82. See John Walter, *Modern Military Rifles*, (London, 2001), p. 40.

⁶⁷ Walter, *op cit.* pp. 8–11.

Glossary & Abbreviations

3-inch Stokes	light mortar used exclusively by the infantry to fire high-explosive bombs
4-inch Stokes	Stokes mortar used exclusively by the Special Brigade to fire smoke and gas bombs
50 per cent length zone	area in which 50 per cent of mortar bombs land
AEF	American Expeditionary Force
all-ways fuze	fuze which functions irrespective of the angle of impact
amatol	high explosive; 50 : 50 mixture of ammonium nitrate and TNT
ammonal	high explosive; mixture of powdered aluminium and ammonium nitrate
angular error	horizontal deviation from line of fire, measured in degrees
anticipate	to predate a device which is believed to be inventive
ANZAC	Australian and New Zealand Army Corps
ballistics	study of the behaviour of projectiles; internal ballistics concerns what happens to the projectile inside a barrel; external ballistics concerns the projectile in flight; terminal ballistics concerns what happens when the projectile hits a target
base-plug	closure piece which screws into the aperture of a grenade through which centrepiece has been inserted
battery fire	all the mortars fire in sequence, right to left, with a specified time interval between each shot, typically 10 seconds
bed	substantial structure on which a mortar is mounted to provide stability
BEF	British Expeditionary Force
Bickford safety fuze	type of fuze material which burns at a consistent rate, invented by William Bickford in 1831
BIR	Board of Invention and Research
BL	breech-loading
black powder	gunpowder
blank	cartridge of propellant which is enclosed by a wad rather than a bullet
blast pattern	distribution of fragments caused by an explosion
blind	fuze mechanism that fails to function when activated
bomb	alternative term for a hand grenade; also the term applied to the projectiles fired by a mortar

bomber	infantryman trained to throw hand grenades
bracketing	gunnery term; process of finding the range of a target by firing rounds long and short of the target
breech	enclosed end of a barrel in which the propellant is burned
cap	percussion cap or primer cap used for ignition of fuze or propellant
centrefire	type of cartridge in which the primer cap is at the centre of the base
centrepiece	enclosure in a hand grenade, comprising two or more chambers, to contain the cap, detonator and fuze assembly
chemical grenade	grenade containing composition other than high explosive, eg incendiary, smoke or lachrymatory
CIGS	Chief of the Imperial General Staff
C-in-C	Commander-in-Chief
CIW	Chief Inspector Woolwich
clinometer	device fitted to mortar to measure the elevation of the barrel
Coehorn	type of mortar, named after its seventeenth-century Dutch inventor, Menno van Coehorn
coil spring	spring in the form of a helix
cotter pin	split pin
CRE	Commander Royal Engineers
creep spring	another term for a coil spring
CSOF	Chief Superintendent Ordnance Factories
cup attachment	device for preventing a Mills lever from moving after the pin has been removed, thereby allowing a rodged Mills grenade to be fired as a rifle grenade
cup discharger	device fitted to a rifle muzzle for discharging grenades without the need for rods
DDA	Deputy Director of Artillery
deflection	gunnery term pertaining to angle of traverse
detonation wave	high-pressure pulse at the expansion front of an explosion
detonator	a device containing a sensitive explosive that is capable of igniting a high explosive
DG grenade	percussion-fuzed grenade invented by Leslie Daniels and Charles Gardiner
DGMD	Director-General Munitions Design Department
dial sight	sight on which range can be set by means of a dial; fitted to some mortars
direct-action fuze	instantaneous mechanism; works by impact with a surface

DoA	Directorate of Artillery
DoFW	Directorate of Fortification and Works
DoPB	Department of Printed Books, Imperial War Museum, London
egg grenade	small ovoid hand grenade
elevation	vertical angle of a barrel
error of the day	corrections to mortar fire according to weather conditions
expansion chamber	chamber at the breech which allows the propellant gases to reach a predetermined pressure before acting on the projectile
Experimental Officer	officer in charge of the Experimental Section at GHQ; officer in charge of evaluations at the School of Musketry, Hythe
Experimental Section	section attached to GHQ for experimental and evaluation work on novel munitions; also an evaluation section at Hythe
Experiments Committee	formed from GHQ staff in mid-1915 to advise the Ministry of Munitions of work conducted by Experimental Section
fire for effect	destroy or neutralize a target
first principles	the fundamental laws of physics or engineering
fragmentation	distribution and size of fragments from a grenade or mortar bomb detonation
friction lighter	ignition device which uses friction of a sensitive composition against a rough surface to produce a flame
ft sec⁻¹	feet per second (unit of velocity)
fulcrum	point about which a lever rotates
functionality	how the form and mechanical arrangement of a device relate to its operation
fuze	device for igniting explosive
FW3a	Engineer Munitions Branch
gas-check disc	obturator fitted to the base plug of a No. 36 grenade to enable it to be fired from a cup discharger
GHQ	General Headquarters
GOC	General Officer Commanding
graticule	cell in an optical system which carries cross-hairs, sometimes marked for range
graze fuze	very sensitive fuze, operated by inertia
GS	general service
gun fire	independent fire by each mortar in a section or battery
gunnery	science of shooting artillery and mortars with accuracy and precision

hand grenade	grenade designed to be thrown by hand
Heath Robinson	William Heath Robinson (1872–1944), British illustrator renowned for the eccentric inventions which he drew, especially at the time of the First World War
HV	marking applied to 2-inch mortar bombs heavier than a specific weight
high explosive	stable explosive which releases a great deal of energy on detonation
impact mechanism	percussion-fuze activated by impact with a surface, eg direct-action fuze or graze fuze
incremental ring charge	rings of propellant added to the tail of a mortar bomb to increase range by a known distance for a given elevation
infantry mortar	light mortar operated exclusively by the infantry
inspection	process of quality assurance to ensure that components are within tolerance
invention	device or process which is not part of the state of the art
KR	King's Regulations
L	marking applied to 2-inch mortar bombs lighter than a specified weight
lachrymatory compound	tear gas
LB	long bracket; two elevations of fire, one long and one short of the target; first bracket when determining range of a target
lethality	measure of efficiency of a grenade or mortar bomb to cause incapacitating injuries
Livens projector	one-shot mortar for firing gas bombs known as drums; invented by Captain Livens, RE
LoC	List of Changes in War Matériel and of Patterns of Military Stores; issued each month from 1860 by War Department and its successors
lyddite	high explosive, compressed picric acid, named after Lydd, Kent
MDD	Munitions Design Department
MGO	Master General of Ordnance
MID	Munitions Inventions Department
MIP	mean impact point
misfire	failure of propellant to ignite properly
ML	muzzle-loading
mousetrap mechanism	striker mechanism with a rotary action
MR	mean range
NA	National Archives, Kew

NCO	non-commissioned officer
needle pellet	striker in a percussion-fuzed grenade, operated by inertia under the action of a creep spring
NPL	National Physical Laboratory, a government research facility set up in 1900 to bring together science and industry
OB	Ordnance Board
obturation	process of sealing propellant gases in a breech or barrel as a projectile travels up the bore
obturator	device for sealing propellant gases in a breech or barrel
obviousness	absence of an inventive step in the creation of a new device or process (as defined by the 1977 Patents Act)
OEB	Outside Engineers Branch
OR	other ranks
patent	legal monopoly granted to an inventor, or his assignee, for a limited period in exchange for full disclosure of the invention; a form of intellectual property
patent specification	legal document which describes an invention in accordance with patent legislation
pdr	pounder; pertains to the weight of a shell fired from a gun and, hence, defines the size of the gun
percussion fuze	fuze which operates by impact with a surface
percussion cap	small metal container of sensitive explosive compound detonated by impact
pistol head	fuze based on the mechanism of a Mills grenade, used on bombs for 3-inch Stokes mortar; operates similarly to a gun mechanism
plastics	a synthetic polymeric material; the 's' differentiates the term from 'plastic' which is a type of behaviour exhibited by metals under certain conditions as defined by Hooke's Law
pneumatic mortar	one fired by the action of a compressed gas, such as air
precision engineering	skilled machining operations of complex shapes
premature	detonation of rifle grenade or mortar bomb on being launched, typically in the barrel; also applies to hand grenade which detonates too soon
prior art	term borrowed from the patents profession; all devices and knowledge pertaining to them in a given field before the invention of a novel device in that field; also referred to as the state of the art
priority date	date of a first patent application
pyrophoric	the ability to spontaneously ignite in moist air

QF	quick-firing; relates to artillery, specifically to a type of breech mechanism
RAF	Royal Air Force, formed by the amalgamation of the RFC and the RNAS in 1918
RAMC	Royal Army Medical Corps
rapid ranging	two elevations with a 10-second interval between them
rarefaction wave	tensile relief wave which travels in the opposite direction to the shock wave through the body of a grenade or mortar bomb, for example, and determines fragmentation
RE	Royal Engineers
registration	determining range of target by firing on it and making corrections until a short bracket is obtained
reliability	state of readiness of a device to operate as intended and the probability of successful operation when used in an operational environment
RFC	Royal Flying Corps
rifle grenade	grenade discharged from a rifle, by means of an attached rod, which fits inside a rifle barrel, or from a cup discharger
rifle grenadier	infantryman trained to fire rifle grenades
rimfire	cartridge in which the primer is in protruding rim of its base
RNAS	Royal Naval Air Service
Roburite	proprietary name of a high explosive; mixture of ammonium nitrate and dinitrochlorobenzene or dinitrobenzene
Russian sap	sap with head cover
SAA	small arms ammunition
safety device	means by which a fuze is prevented from operating
salvo fire	simultaneous fire by all mortars in a battery or by specified sections
SB	short bracket; two elevations of fire, one long and one short of the target, twice the size of the 50 per cent length zone
section fire	specified sections of a battery shoot, each mortar firing at a specified interval
siege mortar	high-trajectory, thick-walled, high-pressure gun on a mounting that is massive enough to absorb the recoil
segmentation	use of grooves in the body of a grenade to form raised segments in the belief that this determines fragmentation
SMLE	short, magazine, Lee-Enfield; British service rifle
SOS fire	artillery or mortar bombardment on a predetermined area on a prearranged signal

Special Brigade	branch of the Royal Engineers which conducted gas warfare
super calibre	ammunition which has a larger diameter than the bore of the barrel from which it is fired
T and P fuze	time and percussion fuze used in artillery shells; can be set to fire according to time or impact
time fuze	fuze which burns for a predetermined length of time
TNT	high explosives; 2,4,6-trinitrotoluene
tolerance	permissible variation in a dimension, usually measured in thousandths of an inch (thou)
ton in⁻²	tons per square inch (unit of pressure)
trajectory	flight path of a projectile
traverse	to adjust the line of fire horizontally
trade (the)	small and medium-sized engineering firms engaged in the manufacture of commercial products
trench mortar	thin-walled, low-pressure weapon, firing sub-sonic ammunition at an angle of about 40°–80°
tumble	to deviate from a stable flight path so that the projectile falls end over end along its trajectory
TWC	Trench Warfare Committee
TW(D)D	Trench Warfare (Design) Department
TWD	Trench Warfare Department
TWRD	Trench Warfare Research Department
TWSD	Trench Warfare Supply Department
utility	fitness for purpose of a device
VSB	verification of short bracket
white phosphorus	pyrophoric form of phosphorus used to generate smoke
windage	gap between the projectile and the barrel along which it travels; ie the difference in size between the bore and the diameter of the projectile at its widest point
Yukon pack	a type of backpack for carrying heavy loads

Sources and Bibliography

PRIMARY SOURCES

Archival sources

Cheshire and Chester Archives

DHB/55 The papers of Colonel Hugh Robert Hibbert (1828–95)

Department of Special Collections and Western Manuscripts, Bodleian Library, Oxford

Addison papers D2/5 Department of Trench Warfare, and gas warfare, 1915–17, (fols 251–348) MS Addison dep. c. 74

Liddell Hart Centre, Imperial College London

Robertson: 8/5/80, 30 November 1916

Robertson: 8/5/81, 1 December 1916

National Archives, Kew

Board of Trade

BT 31/22958/141366 Pall Mall Grenades

BT 31/32204/139711 Newton Brothers Ltd

BT 209/482 Patents & Designs Act 1907

Cabinet Office

CAB 1/16/23 responsibilities of DGMD

CAB 1/16/27 trench mortars

CAB 17/120 coordination of inventions committees

Home Office

HO 213/618 Claim in Respect of Stokes Mortar and Shell

Ministry of Munitions

MUN 4/426 Inventions and Suggestions: Reports by the Munitions Invention Department

MUN 4/766 Publication of Patents

MUN 4/2557 grenades

MUN 4/2604 grenades

MUN 4/2615 Trench Mortar & Ammunition Requirements

MUN 4/2638 6" Newton Trench Mortar

MUN 4/3047 Inventions and Suggestions: procedure for submission by officers at the Front

MUN 4/3076 Reports of Munitions Inventions Department

MUN 4/3589 Intelligence Service reports, 16 June – 21 November 1917

MUN 4/3590 Intelligence Service reports, 20 December 1917 – 30 May 1918

MUN 4/4520 Co-ordination of Invention, Research and Design, 14 September 1918

MUN 4/6870 History of the Trench Warfare Supply Department, provisional notes by Sir Alexander Roger

MUN 4/6878 Trench Warfare Committee papers

MUN 5/41/263.6/15 Transfer of Jackson from the War Office to the Ministry of Munitions

MUN 5/41/263.6/20 regarding lack of cooperation between the Trench Warfare Supply Department and Trench Warfare Research Department in 1917

MUN 5/43/263.8/3 Memoranda etc concerning the transfer of responsibility from the War Office to the Ministry of Munitions Nov 1915 – Jan 1916

MUN 5/43/263.8/13 Correspondence 18 November to 4 December 1915 on coordination between Munitions Inventions Department and Trench Warfare Department

MUN 5/43/263.8/19 Memorandum on the Function and Organisation of the Munitions Inventions Department

MUN 5/117/700/4 Munitions Inventions Department, Report of the Departmental Committee on Reconstruction, July 1917

MUN 5/118/700/27 Collection of Papers re Inventions, 1915–1916

MUN 5/120/810/6 *Annual Report of the President, Ordnance Board for the year 1915*, (London, 1917)

MUN 5/120/810/6 Notes on Design, Prepared in Historical Records Branch, 18 January 1919

MUN 5/196/1610/1 Nomenclature

MUN 5/196/1610/3 List of Changes in War Matériel and of Patterns of Military Stores relating to trench mortars and ammunition, covering approximately January 1915 to November 1916

MUN 5/196/1611/4 Minutes on defects in Stokes time fuze for 3” HE shell

MUN 5/196/1610/12, Extracts from Lieut F A Sutton’s Diary Relating to the Early History of the Stokes Gun, 12 June 1915 – 31 October 1915

MUN 5/196/1610/17 Instruction to pay royalties to Société de Construction de Batignolles in respect of 9.45-inch mortar

MUN 5/196/1610/18 Memorandum on diversity of types of trench howitzers

MUN 5/196/1610/21 Memorandum on French Trench Howitzers

MUN 5/197/1640/5 Production of grenades

MUN 5/197/1640/7 Newton Pippin rifle grenade

MUN 5/197/1640/9 Ordnance Board Minute on use of grenades

MUN 5/199/1660/17 Memorandum on Hill ‘vacuum’ gun

MUN 5/321A *History of the Ministry of Munitions*, 12 volumes, 1918–22

MUN 5/357/700/1 Formation and Organisation of the Munitions Inventions Department

MUN 5/357/700/1/B History of the Formation and Organisation of the Munitions Inventions Department, June 1915 – October 1916 (contained in MUN 5/357/700/1)

MUN 5/357/700/2/10 Regulations as to taking out Patents for Inventions as laid down in Appendix XVIII of the King’s Regulations (contained in MUN 5/357/700/2 Work of Munitions Invention Department from 1915 to 1919)

MUN 5/357/700/2/11 Regulations as to taking out Patents for Inventions as laid down for Civil Officers and Employees of the Ministry of Munitions (contained in MUN 5/357/700/2)

MUN 5/357/700/2 List of Approved Inventions Submitted to MID (contained in MUN 5/357/700/2/13)

MUN 5/357/700/2 Functions of a Ministry of Inventions and Research (contained in MUN 5/357/700/2/17)

MUN 5/382/1600/6 History of Trench Warfare Supply, Part I, Departmental Organisation for the Production of Trench Warfare Stores, first draft

MUN 5/382/1600/7 Trench Warfare Supply Department, June 1915 – September 1917

MUN 5/382/1600/8 Notes on the History of Trench Warfare Research, Aug 1914 – May 1915

MUN 5/382/1600/10 History of the Production of Trench Warfare Stores by the Trade, July 1915 – December 1917

MUN 5/382/1600/11 Record of History and Work, Ministry of Munitions, Trench Warfare Supply Department, OEB

MUN 5/383/1600/14 The Development of Weapons Used in Trench Warfare

MUN 5/384/1610/2 Trench Warfare Supply History, TW3(B), Medium Trench Mortars and their Ammunition

MUN 5/384/1610/4 Notes on the early history of the Stokes gun 8 January 1915 – 30 October 1915

MUN 5/384/1610/9, Personal Notes on the Work and History of TW3 by A P Stockings

MUN 5/384/1610/16 Record of History and Work Ministry of Munitions Trench Warfare Supply Department TW3(D) Trench Howitzers and Ammunition by Mr W A Tanner

MUN 5/384/1630/2 Record of History and Work, Ministry of Munitions, Trench Warfare Supply Department, TW3(F)
MUN 5/385/1640/1 History of the Grenade Section, Trench Warfare Supply Department
MUN 5/385/1650/1 Work of Trench Warfare Section 5 on flame projectors, sprayers, etc. from June 1915 to March 1916
MUN 5/385/1650/6 History of the Supply of Flame Projectors, June 1915 – March 1918
MUN 7/273 mortar invented by Captain Stokes, RE
MUN 7/305 Invention of, or suggestions for Heat Ray, by E. Russell-Clarke
MUN 7/310 Censorship and exports of technical publications
MUN 9/21 coordination of Ministry of Munitions and War Office activities

Public Record Office

PRO 30/57/49 Western Front 1914: correspondence. Field Marshal Sir John French and others, and Lord Kitchener

Supply

SUPP 5/935 No. 1 Mk 2 rifle grenade launcher
SUPP 6/184 Ordnance Board proceedings
SUPP 6/185 Ordnance Board proceedings
SUPP 6/186 Ordnance Board proceedings
SUPP 6/187 Ordnance Board proceedings
SUPP 6/509 Report of Proceedings of Ordnance Committee, Trench Warfare Section, 11 December 1915 to 23 April 1917
SUPP 28/40 grenades

Treasury

T 173/1 Procedures of the Royal Commission on Awards to Inventors
T 173/26 Procedures in cases where patent infringement and validity not seriously disputed
T 173/110 claim by Beaton and Sons; Royal Commission on Awards to Inventors
T 173/146 claim by Burn; Royal Commission on Awards to Inventors
T 173/230 claim by Gibbons; Royal Commission on Awards to Inventors
T 173/252 claim by Hale; Royal Commission on Awards to Inventors
T 173/253 claim by Hale; Royal Commission on Awards to Inventors
T 173/350 claim by Mills; Royal Commission on Awards to Inventors
T 173/453 claim by Stokes; Royal Commission on Awards to Inventors
T 173/477 claim by Tunbridge (Mills); Royal Commission on Awards to Inventors
T 173/502 claim by Vickery; Royal Commission on Awards to Inventors
T 173/556 claim by Beaton; Royal Commission on Awards to Inventors
T 173/578 claim by Burn; Royal Commission on Awards to Inventors
T 173/697 claim by Ley (Mills); Royal Commission on Awards to Inventors
T 173/728 claim by Newton; Royal Commission on Awards to Inventors
T 173/791 claim by Tunbridge (Vickery/Gibbons); Royal Commission on Awards to Inventors
T 173/802 claim by Vickery; Royal Commission on Awards to Inventors

War Office

WO 32/4905 Titles and Designations of Units
WO 32/5152, Shortage of artillery ammunition in the field 1914–1915
WO 32/9281 Interdepartmental conference on co-ordination of inventions committees. Formation of Munitions Inventions Department
WO 32/9285, Patents, Rewards and Royalties, Transfer of Responsibility to Ministry of Munitions
WO 32/18989, Hale Rifle Grenade

WO 33/14 Lieutenant-Colonel T L Gallwey and Captain H J Anderson, 'Report upon the Military Affairs of the United States of America', 1864

WO 33/337 A Report by Major J M Home, 2nd PWO Gurkhas lately attached to the Russian Army in Manchuria, 1905

WO 33/934 Handbook on Bombs and Grenades

WO 33/1520 *The Russo-Japanese War, Selection of Reports from Officers attached to the Japanese Forces*, vol. 2, (London, War Office, 1906)

WO 33/1524 *The Russo-Japanese War, Selection of Reports from Officers attached to the Japanese Forces*, vol. 4, (London, War Office, 1906)

WO 33/1526, *The Russo-Japanese War, Reports from Officers Attached to the Japanese Forces in the Field*, vol. 5 (London, War Office, 1906)

WO 44/631 Ordnance Board papers

WO 44/634 Ordnance Board papers

WO 55/3044 The use of patents by the War Office, 1898–1904

WO 106/432 mortars

WO 108/5551 Journal of the Principal Events connected with the Russo-Japanese War, February 1905

WO 140/13 Reports on trials, School of Musketry

WO 140/14 Reports on trials, School of Musketry

WO 140/15 Reports on trials, School of Musketry

WO 142/206 Proceedings of the Trench Warfare Department

WO 142/207 Proceedings of the Trench Warfare Department

WO 142/208 Proceedings of the Trench Warfare Department

WO 142/221 A collection of drawings of shells, bombs, etc, and useful information pertaining to design – compiled by Major Lister)

WO 142/337 Report on the Activity of the Special Brigade during the War

Official publications

Abridgements of Specifications, various volumes covering 1855–1930 in Classes:

- 9 (i) ammunition and ammunition receptacles (author's collection)
- 9 (ii) torpedoes, explosives and pyrotechnics (author's collection)
- 92 (i) ordnance and machine-gun carriages and mountings (author's collection)
- 92 (ii) ordnance and machine-guns (author's collection)
- 119 small arms (author's collection)

CDS50 Tactical Notes, July 1915 (DoPB)

CDS66 Notes British, French and German Grenades, September 1915 (DoPB)

CDS74 The Training and Employment of Grenadiers, October 1915 (author's collection)

CDS78 Precautions to be taken when firing smoke shell from the Stokes mortar, October 1915 (DoPB)

CDS383 Extract from 'Notes on Minor Tactics of Trench Warfare' by 'A Casualty', June 1915 and reprinted December 1915 (DoPB)

Copyright, Designs and Patents Act 1988 (Patent Office)

Description and Use of Ring Charges in 3-inch Stokes Trench Howitzers, issued by the Ministry of Munitions, nd (author's collection)

Field Service Regulations, Part I, Operations, 1909 (author's collection)

Grenade Training Manual, US War Department, January 1918 (author's collection)

Handbook for the Stokes Trench Mortar, 3", Mark I, April 1916 (Norman Bonney)

Handbook of the ML 2-inch Trench Mortar, Mark I, Land Service, 1917 (Norman Bonney)

Handbook of the ML 9.45-inch Trench Mortars, Marks I, II and III, 1918 (DoPB)

Handbook of the ML Stokes 3-inch Trench Mortar Equipments, Land Service 1919, 1920 (DoPB)

'History of Patents and the Patent Office', undated (Patent Office)

List of Changes in War Matériel and of Patterns of Military Stores (NA; DoPB)

Manual for Hand Bombers and Rifle Grenadiers, GHQ AEF, February 1918 (author's collection)

Manual for Trench Artillery, United States Army, Part III The Newton 6-inch Trench Mortar, July 1918 (author's collection)

Manual of Patent Practice, fifth edition, 31 May 2004 (Patent Office)

Manual of Patent Practice, June 2006 (Patent Office)

Memorandum on the Training and Employment of Grenadiers in Notes from the Front, Part IV, May 1915 (DoPB)

Musketry Regulations, Part I, 1909 (author's collection)

Notes from the Front, Part I, 1914 (author's collection)

Notes from the Front, Part II, 1914 (author's collection)

Notes from the Front, Part II and Further Notes on Field Defences, February 1915 (author's collection)

Notes from the Front, Part III and Further Notes on Field Defences, February 1915 (author's collection)

Notes from the Front, Part IV and Further Notes on Field Defences, May 1915 (author's collection)

Notes on Field Defences, 1914 (author's collection)

Patents Act 1977 (Patent Office)

Patents and Designs Act 1907 (NA)

Patents and Designs Act 1908 (NA)

Range Table of 3-inch Stokes' Mortar, July 1917 (author's collection)

Range Table for 3-inch Stokes Mortar (Provisional), September 1917 (author's collection)

Small Arms Training, Volume 1 Pamphlet No. 9, Mortar (3-inch), 1939, reprinted March 1940 (author's collection)

SS98/5 Artillery Notes No. 5 – Wire Cutting by Artillery (DoPB)

SS98/6 Artillery Notes No. 6 – Trench Mortars, March 1916 (DoPB)

SS107 Notes on Minor Enterprises, March 1916 (DoPB)

SS110 Medium Trench Mortar Gun Drill, 2" Trench Mortars, May 1916 (DoPB)

SS110 Medium Trench Mortar Gun Drill, 2" Trench Mortars, May 1916, revised March 1917

SS119 Preliminary Notes on the Tactical Lessons of the Recent Operations, July 1916 (DoPB)

SS126 The Training and Employment of Bombers, September 1916 (DoPB)

SS135 Instructions for the Training of Divisions for Offensive Action, December 1916 (DoPB)

SS135 Instructions for the Training of Divisions for Offensive Action, December 1916, amendments August 1917 (DoPB)

SS135 The Training and Employment of Divisions, January 1918 (DoPB)

SS139/6 Artillery Notes No. 6 – Trench Mortars, March 1917 (DoPB)

SS143 Instructions for the Training of Platoons for Offensive Action, February 1917 (DoPB)

SS143 Instructions for the Training of Platoons for Offensive Action, 1917, June printing (DoPB)

SS143 Amendments, November 1917 (DoPB)

SS147 9.45in Trench Mortar Drill, March 1917 (DoPB)

SS152 Instructions for the Training of the British Armies in France, January 1918 (DoPB)

SS155 Notes on Dealing with Hostile Machine Guns in an Advance, April 1917 (DoPB)

SS169 Employment of 3-in Stokes Mortars in Recent Fighting, June 1917 (DoPB)

SS171 Notes on Inventions and New Stores No. 1 (NA)
 SS171/2 Notes on Inventions and New Stores No. 2 (NA)
 SS171/3 Notes on Inventions and New Stores No. 3 (NA)
 SS171/4 Notes on Inventions and New Stores No. 4 (NA)
 SS181 (revised edition) Trench Mortar Drill 6-in (Newton) Trench Mortar, March 1918 (DoPB)
 SS182 Instructions on Bombing, Part I, British and German Bombs, December 1917 (DoPB)
 SS182 Instructions on Bombing, Part II, Training and Employment of Bombers, November 1917 (author's collection)
 SS182 "Instructions on Bombing." Part I, Amendment, March 1918 (DoPB)
 SS182 "Instructions on Bombing." Part II, Amendment, November 1918 (DoPB)
 SS183 Light (Stokes) Mortar Drill, September 1917 (DoPB)
 SS189 Light Mortar Training, June 1918 (DoPB)
 SS190 Rifle Grenade Discharger, No. 1, Mark I, Description and Instructions for Use, October 1917 (DoPB)
 SS197 Notes on Minor Enterprises, March 1916 (DoPB)
 SS398 The Training and Employment of Bombers, March 1916 (author's collection)
 Trench Warfare, Articles Manufactured by RE Workshops in France, E-in-C, GHQ, undated (Norman Bonney)

Patents

Belgian

BE249834 Roland (grenade)

British

GB303 [1692] Dallowe (grenade)
 GB6159 [1831] Bickford (fuze)
 GB1798 [1862] Johnson (shell)
 GB19365 [1895] Hathaway (grenade)
 GB15273/00 Youlton (hyperscope)
 GB24814/01 Youlton (hyperscope)
 GB5791/03 Youlton (hyperscope)
 GB20238/05 Pedersen (grenade)
 GB14605/06 Hale (grenade)
 GB15045/08 Hale (grenade)
 GB19345/08 Krupp (ammunition)
 GB11561/09 Hale (obturator)
 GB29292/09 Hale (cartridge)
 GB19397/10 Krupp (ammunition)
 GB4925/11 Hale (grenade)
 GB21792/11 Hale (grenade)
 GB26764/11 Hale (grenade)
 GB10219/13 Hale (grenade)
 GB18766/13 Roland (grenade)
 GB7935/14 Hale (grenade)
 GB2468/15 Mills (grenade)
 GB4392/15 Roodhouse (grenade)
 GB5900/15 Sangster (grenade)
 GB5901/15 Sangster (grenade)
 GB7636/15 Mills (grenade)
 GB7710/15 Leach (catapult)

GB8755/15 Hale (grenade)
GB10515/15 Mills (centrepiece)
GB10882/15 Stokes (mortar)
GB10883/15 Stokes (mortar bomb)
GB11223/15 Mills (striker)
GB11803/15 Brodie (shrapnel helmet)
GB13095/15 Sutton (fuze)
GB13445/15 Armstrong Whitworth, Wale & Murray (mortar bomb)
GB16083/15 Parkes (centrepiece)
GB16327/15 Adshead (centrepiece)
GB16869/15 Société de Construction des Batignolles (mortar/bomb)
GB17397/15 Findlay (centrepiece)
GB17898/15 Parkes (centrepiece)
GB100700 Viven & Bessiere (cup discharger)
GB100891 Pratt (helmet gun)
GB102173 Walker (centrepiece)
GB102364 Salisbury (centrepiece)
GB104836 Viven & Bessiere (cup discharger)
GB106461 Pratt (helmet gun)
GB106555 Oritor & Starkey (centrepiece)
GB108741 Joubert (folding hilt)
GB110068 Gibbons (lever)
GB112633 Midgley & Vandervell (fuze)
GB114122 Gibbons (centrepiece)
GB119329 Midgley & Vandervell (fuze)
GB119761 Midgley & Vandervell (fuze)
GB120606 Brodie (shrapnel helmet)
GB122509 Stokes (incremental ring charge)
GB124469 Thring (grenade gun)
GB124478 Thring (grenade gun)
GB124809 Stokes (fuze)
GB124837 Daniels & Gardiner (grenade)
GB125100 Chamier (grenade)
GB125399 Midgley & Vandervell (fuze)
GB125436 Chamier (grenade)
GB125447 Lane (mortar bomb)
GB125649 Midgley & Vandervell (fuze)
GB126324 Heap (elevating gear)
GB126335 Midgley & Vandervell (fuze)
GB126692 Burn (cup discharger)
GB127279 Billant (grenade)
GB127626 Wilson (fuze)
GB129004 Humphris (grenade)
GB129005 Humphris (grenade)
GB129042 Daniels & Gardiner (grenade)
GB129299 Constantinesco (mortar)
GB129362 Constantinesco (mortar)
GB130017 Cole (fuze)
GB130091 Vickery (fuze)

GB130389 Vickery (fuze)
GB130629 Kennedy (fuze)
GB131025 Kennedy (fuze)
GB131288 Brandt (mortar bomb)
GB131374 Vickery (fuze)
GB160881 Ley (grenade)
GB166149 Newton (mortar/ammunition)
GB166162 Newton (mortar)
GB166563 Newton (grenade)

American

US33089 Ketchum (grenade)
US41615 Ganster & Schuyler (fuze)
US42082 Ganster & Schuyler (fuze)
US42262 Ganster (grenade)
US45806 Adams (grenade)
US932214 Krupp (ammunition)
US1003079 Krupp (ammunition)
US1035486 Sokolowski (grenade)
US1041894 Sokolowski (grenade)
US1126871 Roland (grenade)
US1303163 Charmier [sic] & Curtis (grenade)

Private papers

Henry Newton dissertation (in the possession of the Newton family)
William Mills, papers concerning Roland & Others *v.* Mills & Another, King's Bench Division,
1917 R No. 45 (copy in the possession of Norman Bonney)
Letter written by Ralph Goodwin, June 1976 (Mrs Jan Baggaley)
emails to the author from Norman Bonney, 2003–08

SECONDARY SOURCES

Published books

Addison, Colonel G H, (ed.), *The Work of the Royal Engineers in the Late European War, 1914–19, Miscellaneous*, (Chatham, 1927)
Anon, *Abridgements of the Patent Specifications Relating to Firearms & Other Weapons, Ammunition & Accoutrements from 1588–1858*, (London, 1960)
Anon, *Battles and Leaders of the Civil War*, (Edison, nd)
Anon, *Handbook of Artillery*, (Washington, 1925)
Anon, *Textbook of Small Arms*, (London, 1929)
Archer, Denis H R (ed.), *Jane's Infantry Weapons*, 4th ed., (London, 1978)
Ashworth, Tony *Trench Warfare, 1914–1918, The Live and Let Live System*, (London, pbk ed., 2000)
Bailey, Maj-Gen J B A, *Field Artillery and Firepower*, 2nd ed., (Annapolis, 2004)
Becket, Ian F W, *The First World War, The Essential Guide to Sources in the UK National Archives*, (London, 2002)
Bidwell, Shelford and Dominick Graham, *Fire-Power, British Army Weapons and Theories of War, 1904–45*, (London, 1982)
Bond, Brian (ed.), *Look to Your Front*, (Staplehurst, 1999)

- Brose, Eric Dorn, *The Kaiser's Army, The Politics of Technology in Germany during the Machine Age, 1870–1918*, (New York, 2001)
- Chester, D N, (ed.), *Lessons of the British War Economy*, (Cambridge, 1951)
- Carver, Field Marshall Lord, *British Army in the 20th Century*, (London, 1998)
- Coates jr, Colonel James Boyd (ed.), *Wound Ballistics*, Medical Department United States Army in World War II, 1962, 2nd ed
- Coggins, Jack, *Arms and Equipment of the Civil War*, (Mineola, 2004)
- Connelly, Mark, *Steady the Buffs, A Regiment, a Region, & the Great War*, (Oxford, 2006)
- Cooper, Paul W, *Explosives Engineering*, (London, 1996)
- Crowell, Benedict, *America's Munitions, 1917–1918*, (Washington, 1919)
- Dean, Bashford, *Helmets and Body Armor in Modern Warfare*, (New Haven, 1920)
- Dennis, Peter & Jeffrey Grey (eds), *1918, Defining Victory*, (Canberra, 1999)
- Dewar, George, *The Great Munitions Feat, 1914–1918* (London, 1921)
- Dulken, Stephen van, *British Patents of Invention, 1617–1977, A Guide for Researchers*, (London, 1999)
- Dunn, Captain J C, *The War the Infantry Knew, 1914–1919, A Chronicle of Service in France and Belgium*, (London, 1987)
- Edgerton, David, *Warfare State, Britain, 1920–1970*, (Cambridge, 2006)
- Edmonds, J E, *History of the Great War, Military Operations, France and Belgium, 1914*, 2 vols, (London, 1925)
- Edmonds, J E, *History of the Great War, Military Operations, France and Belgium, 1915*, 2 vols, (London, 1927)
- Edmonds, J E, *Military Operations France and Belgium, 1916*, 2 vols, (London, 1932)
- Ellis, John, *Eye-Deep in Hell, The Western Front 1914–18*, (London, 2002)
- Featherstone, Donald, *Weapons and Equipment of the Victorian Soldier*, (Poole, 1978)
- Fleischer, Wolfgang, *German Trench Mortars and Infantry Mortars, 1914–1945*, (Atglen, 1996)
- Foulkes, Maj-Gen C H, “Gas!” *The Story of the Special Brigade*, (Edinburgh & London, 1934)
- Fuller, J F C, *Tanks in the Great War 1914–1918*, (London, 1920)
- George, David Lloyd, *War Memoirs*, 6 vols, (London, 1933)
- Grave, L W de, *The War History of the Fifth Battalion The Sherwood Foresters, Notts and Derby Regiment, 1914–1918*, (London, 1930)
- Griffith, Paddy, *Rally Once Again*, (Marlborough, 1987)
- Griffith, Paddy, *Battle Tactics of the Western Front, The British Army's Art of Attack 1916–18*, (New Haven, 1994)
- Haber, L F, *Poisonous Cloud, Chemical Warfare in the First World War*, (Oxford, 1986)
- Hardy, Robert, *Longbow, A Social and Military History*, (Cambridge, 1976)
- Hart, Basil Liddell, *The Strategy of the Indirect Approach*, (London, 1941)
- Hart, Peter, *The Somme*, (London, 2005)
- Hartcup, Guy, *The War of Invention, Scientific Developments, 1914–18*, (London, 1988)
- Hicks, Major James E, *Notes on German Ordnance 1841–1918*, (New York, 1937)
- Hogg, I V and L F Thurston, *British Artillery Weapons and Ammunition 1914–1918*, (London, 1972)
- Holmes, Richard, *Firing Line*, (London, 1985)
- Holmes, Richard, *Tommy, The British Soldier on the Western Front 1914–1918*, (London, 2004)
- Hughes, Maj-Gen B P, *Firepower: Weapons Effectiveness on the Battlefield, 1630–1850*, (London, 1974)
- Kemp, Anthony, *Weapons and Equipment of the Marlborough Wars*, (Poole, 1980)
- Knightley, Philip, *The First Casualty*, (London, 1987)
- Knox, MacGregor & Williamson Murray (eds), *The dynamics of military revolution, 1300–2050*, (Cambridge, 2001)
- Kuhn, Major Joseph E, *Reports of Military Observers attached to the Armies in Manchuria during the Russo-Japanese War*, Part III, (Washington, 1906)
- Landers, Rick, ‘Grenade’ *British and Commonwealth Hand and Rifle Grenades*, (Dural, 2001)
- Liddle, Peter H (ed.), *Homes Fires and Foreign Fields, British Social and Military Experience in the First World War*, (London, 1985)

- Luvaas, Jay, *The Military Legacy of the Civil War*, (Lawrence, 1988)
- McNeill, William H, *The Pursuit of Power*, (Chicago, 1984)
- Moore, William, *Gas Attack: Chemical Warfare 1915 to the Present Day*, (London, 1987)
- Newton, James D, *Uncommon Friends*, (New York, 1987)
- Penhallow, Dunlap Pearce, *Military Surgery*, (London, 1916)
- Pollard, Captain A O, *Fire-Eater, The Memoirs of a VC*, (London, 1932)
- Rawling, Bill, *Surviving Trench Warfare, Technology and the Canadian Corps, 1914–1918*, (Toronto, 1992)
- Reid, William, *The Lore of Arms*, (Abingdon, 1976)
- Richards, Frank, *Old Soldiers Never Die*, (London, 1933)
- Richter, Donald, *Chemical Soldiers, British Gas Warfare in World War One*, (London, 1994)
- Rose, Hillary and Stephen Rose, *Science and Society*, (London, 1977)
- Ross, Steven T, *From Flintlock to Rifle*, (London, 1996)
- Saunders, Anthony, *Weapons of the Trench War, 1914–1918*, (Stroud, 1999)
- Saunders, Anthony, *Dominating the Enemy*, (Stroud, 2000)
- Scott, J D, *Vickers, A History*, (London, 1963)
- Sheffield, Gary, *Forgotten Victory, The First World War: Myths and Realities*, (London, 2001)
- Sheffield, Gary & Dan Todman (eds), *Command and Control on the Western Front, The British Army's Experience 1914–18*, (Staplehurst, 2004)
- Simpson, Andy, *Directing Operations, British Corps Command on the Western Front 1914–18*, (Staplehurst, 2006)
- Stern, Sir Albert, *Tanks 1914–1918, The Log-Book of a Pioneer*, (London, 1919)
- Tarassuk, Leonid and Claude Blair (eds), *The Complete Encyclopaedia of Arms & Weapons*, (London, 1982)
- Terraine, John, *The Smoke and the Fire*, (London, 1980)
- Terraine, John, *White Heat, the New Warfare 1914–18*, (London, 1982)
- Travers, Tim, *The Killing Ground, The British Army, The Western Front and the Emergence of Modern Warfare, 1900–1918*, (London, 1990)
- Travers, Tim, *How the War was Won*, (London, 1992)
- Walter, John, *Modern Military Rifles*, (London, 2001)

Papers and unpublished PhD & MPhil theses

- Gusewelle, J K, 'The Board of Invention and Research. A Case Study in the Relations between Academic Science and the Royal Navy in the First World War', unpublished PhD thesis University of California, 1971
- Pattison, Michael, 'The Munitions Inventions Department, A Case Study in the State Management of Military Science, 1915–1919', unpublished PhD thesis, Teesside Polytechnic, 1981
- Reid MBE, Major (Retired) R J, 'The Development of Artillery Ammunition' paper presented at the Winter Meeting of the Royal Artillery Historical Society, 19 January 2005, at Larkhill
- Snowden, Kathryn, 'British 21st Infantry Division on the Western Front, 1914–1918, A Case Study in Tactical Evolution', MPhil thesis, Birmingham, 2001
- Wilkes, J, 'Fragmentation Data for Eight Grenades', RARDE report TR1/12/72, October 1972
- Williams, Robert, 'A Social and Military History of the 1/8th Battalion, The Royal Warwickshire Regiment, in the Great War', MPhil thesis, Birmingham, 1999

Magazine & journal articles

- Anon, 'The Work of the Royal Engineers in the European War, 1914–19', *The Royal Engineers Journal*, September 1924
- Anon, 'The Work of the Royal Engineers in the European War', *The Royal Engineers Journal*, vol. XXXIX, no. 1, March 1925

- Haydon, F Stansbury, 'Grant's Wooden Mortars and some Incidents of the Siege of Vicksburg', *The Journal of the American Military Institute*, vol 4, no. 1, (spring 1940), pp. 30–8
- Martel, Captain, 'The Use of Inventions in War', *The Royal Engineers Journal*, December 1924
- McClintock, Major R L, 'An Extemporised Hand Grenade', *The Royal Engineers Journal*, April 1913, pp. 193–200
- McClintock, Major R L, 'An Extemporised Rifle Grenade, The Bangalore "Universal" Grenade', *The Royal Engineers Journal*, November 1914, pp. 281–294
- Pattison, Michael, 'Scientists, Inventors and the Military in Britain 1915–19: The Munitions Inventions Department', *Social Studies of Science*, vol. 13, no. 4, 1983
- Pegler, Martin, 'Mr Mills' grenade', *Arms & Armour*, vol. 1, no. 1, 2004
- Scott, Peter T, 'Mr Stokes and his Educated Drainpipe', *The Great War*, vol. 2, No. 3, May 1990
- Trebilcock, Clive, "'Spin-Off" in British Economic History: Armaments and Industry, 1760–1914', *The Economic History Review*, New Series, vol. 22, no. 3 (December 1969)
- Trebilcock, Clive, 'Legends of the British Armaments Industry', *Journal of Contemporary History*, vol. 5, no. 4 (1970)
- Trebilcock, Clive, 'British Armaments and European Industrialization, 1890–1914', *Economic History Review*, New Series, vol. 26, no. 2, 1973
- Whitmarsh, Andrew, 'The Development of Infantry Tactics in the British 12th (Eastern) Division, 1915–1918', *Stand To!*, January 1997, no. 48

Newspapers and journals

The Derbyshire Advertiser

The Illustrated War News

The Sphere

The Times

Websites

- www.bl.uk/collections/patents (British Library, patent libraries), accessed June 2008
- www-cgsc.army.mil/carl/resources/csi/gabel5/gabel5.asp (Report of Captain Andrew Hickenlooper, Chief Engineer Seventeenth Army Corp, and the Reports of Colonel O. P. Lyles, Twenty-third Arkansas Infantry at Fort Hudson), accessed June 2008
- http://ehistory.osu.edu/uscw/features/Articles_New/display.cfm?NationId=62 (Civil War Newsletter issue of 19 June 2002), accessed June 2008
- http://inventors.about.com/cs/astartinventions/a/HollandThompson_4.htm (Ketchum), accessed June 2008
- www.civilwar.si.edu/weapons_grenades.html (Smithsonian Institution, Ketchum grenades), accessed June 2008
- www.army.mod.uk/equipment/pw/pw_81m.htm, accessed July 2007
- www.remuseum.org.uk/corpshistory/rem_corps_part14.htm (Royal Engineers) accessed July 2008
- www.armedforces.co.uk/army/listings/10098.html (British Army mortar), accessed July 2007
- www.infernal-machines.com/_sgg/m1m4_1.htm (grenades), accessed May 2008
- www.ipo.gov.uk/p-law-manual-practice-patent1977.htm (patentability), accessed June 2008
- www.sdchamber.co.uk (History of the Derby and Derbyshire Chamber of Commerce and Industry 1864–1995), accessed May 2005
- www.pals.org.uk/lais_e.htm (Otto Lais, *Experiences of Baden Soldiers at the Front, vol. 1, Machine-guns in the Iron Regiment (8th Baden Infantry Regiment No.169)*, (Karlsruhe, 1935)), accessed June 2008
- www.millsgrenades.co.uk (grenades), accessed June 2008
- <http://members.shaw.ca/dwlynn/tgrm.htm> (grenades), accessed June 2008
- www.inert-ord.net/brit (grenades), accessed June 2008
- www.uspto.gov/patft/index.html (United States Patent and Trademark Office, patents), accessed June 2008