

# Circumventing the law that humans cannot see in the dark: an assessment of the development of target marking techniques to the prosecution of the bombing offensive during the Second World War

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## ABSTRACT

Royal Air Force Bomber Command entered the Second World War committed to a strategy of precision bombing in daylight. The theory that bomber formations would survive contact with the enemy was soon dispelled and it was obvious that Bomber Command would have to switch to bombing at night.

The difficulties of locating a target at night soon became apparent. In August 1941, only one in three of those crews claiming to have bombed a target had in fact had been within five miles of it. And yet, less than four years later, it would be a very different story. By early 1945, 95% of aircraft despatched bombed within 3 miles of the Aiming Point and the average bombing error was 600 yards. How, then, in the space of four years did Bomber Command evolve from an ineffective force failing even to locate a target to the formidable force of early 1945?

In part, the answer lies in the advent of electronic navigation aids that, in 1941, were simply not available. By 1945, electronic aids such as GEE, *Oboe* and *H2S* were widely in use. Secondary literature on the bombing offensive tends to attribute the improvement in bombing performance to the introduction of these aids.

However, the introduction of these aids was only part of the story. These aids could not, in themselves, circumvent the law that human beings cannot see in

the dark. Having reached the target area with the benefit of navigation aids, some form of identifying the Aiming Point was necessary if the target was to be accurately bombed. Part of the reason for the effectiveness of Bomber Command by early 1945 therefore lies in the development of techniques for the identification and marking of targets.

Although the development of navigation aids is well documented, the development of techniques for target marking has received much less attention. The aim of this thesis is to examine this largely neglected aspect of the bombing offensive. The key question asked is: what difference did the introduction of target marking techniques make to the performance and efficacy of Bomber Command?

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## DEFINITIONS AND ABBREVIATIONS

### Definitions

Aiming Point	The point on the ground that is the briefed target for the raid.
Blind Bombing	Release of bombs without visually identifying the target, using navigation aids to determine position.
Estimated Weight of Attack	The minimum weight of attack necessary to destroy the social and industrial structure within selected areas (towns), measured in tons of bombs per square mile or tons of bombs per population number.
Mean Point of Impact	The mathematical centre of the bomb distribution.
Point of Aim	A point on the ground, marker or pattern of markers on which the Main Force were briefed to aim.
Probable Radial Error	Radius of a circle about the Aiming Point or the Mean Point of Impact within which 50% of the plotted bomb distribution are located.
Random Error	The measure of bomb scatter about the Mean Point of Impact
Systematic Error	The distance of the Mean Point of Impact from the Aiming Point, measured as a direct line.

### Abbreviations

A&AEE	Aircraft and Armament Experimental Establishment
A/C	Aircraft
ACAS	Assistant Chief of Air Staff
ACAS (Ops)	Assistant Chief of Air Staff (Operations)
ACAS (P)	Assistant Chief of Air Staff (Policy)



A/Cdre	Air Commodore
ACM	Air Chief Marshal
AGL	Above Ground Level
AI	Airborne Interception
AM	Air Marshal
AOC	Air Officer Commanding
AOC-in-C	Air Officer Commanding-in-Chief
A/P	Aiming Point
API	Air Position Indicator
ASI	Air Speed Indicator
ASL	Above Sea Level
ASV	Air to Surface Vessel
AVM	Air Vice-Marshal
BC	Bomber Command
BBSU	British Bombing Survey Unit
BDU	Bomber Development Unit
CAS	Chief of Air Staff
C-in-C	Commander-in-Chief
CoG	Centre of Gravity
CoP	Centre of Pressure
c.p.d.	Constant Path Difference
COS	Chiefs of Staff
CRT	Cathode Ray Tube
CSBS	Course Setting Bomb Sight
D Arm R	Director of Armament (Research)

DBO	Directorate of Bomber Operations
D B Ops	Director of Bomber Operations
D C-in-C	Deputy Commander-in-Chief
DD B Ops	Deputy Directorate of Bomber Operations
D O I(O)	Director of Intelligence (Operations)
D/R	Dead Reckoning
DRC	Distant Reading Compass
ETA	Estimated Time of Arrival
Flg Off	Flying Officer
Flt Lt	Flight Lieutenant
Flt Sgt	Flight Sergeant
Gp Capt	Group Captain
GPI	Ground Position Indicator
HC	High Capacity
HF	High Frequency
HQ	Headquarters
HQBC	Headquarters Bomber Command
I.G.	Inspector General
IAS	Indicated Air Speed
I. E.	Initial Equipment
JIC	Joint Intelligence Committee
JPS	Joint Planning Staff
LNSF	Light Night Striking Force
MAP	Ministry of Aircraft Production
MC	Medium Capacity

MEW	Ministry of Economic Welfare
MPI	Mean Point of Impact
MTB	Main Time Base
ORS	Operational Research Section
ORSBC	Operational Research Section Bomber Command
OTU	Operational Training Unit
PFF	Pathfinder Force
P/O	Pilot Officer
PPI	Plan Position Indicator
PRF	Pulse Recurrence Frequency
RE8	Ministry of Home Security Research and Experiments Department 8
SABS	Stabilised Automatic Bomb Sight
SASO	Senior Air Staff Officer
SBA	Standard Blind (later Beam) Approach
SBC	Small Bomb Container
SDF	Special Duties Flight
Sgt	Sergeant
SHAEF	Supreme Headquarters British Expeditionary Force
Sqn Ldr	Squadron Leader
S.S.	'Skywave' Signals
TAS	True Air Speed
TBF	Time of bomb fall
TFF	Target Finding Force
T.I.	Target Indicator

TNA	The National Archives, Kew
ToT	Time on Target
TRE	Telecommunications Research Establishment
TV	Terminal Velocity
U/S	Unserviceable
VCAS	Vice-Chief of Air Staff
VHF	Very High Frequency
Wg Cdr	Wing Commander
W/T	Wireless Telegraphy

“The constant struggle at night is to get light onto the target. I foresee a never ending struggle to circumvent the law that we cannot see in the dark”

Air Commodore Coningham, 9<sup>th</sup> December 1939<sup>1</sup>

## INTRODUCTION

On the night of the 1/2 September 1942, 231 aircraft of Royal Air Force Bomber Command set out to bomb the town of Saarbrücken in south-west Germany. In clear weather, and with the Main Force led in to a target illuminated and marked by the Pathfinders, bombing was both accurate and disciplined, with a total of 205 aircraft reporting good bombing results<sup>2</sup>.

Piloting one of the Main Force aircraft that night was Wing Commander Guy Gibson, later to become famous as leader of the Dams Raid, then commanding a Lancaster squadron in No. 5 Group, Bomber Command. Since this was the first occasion on which Gibson had operated behind the Pathfinders, he arrived in the target area a little early to observe their technique. “Sure enough”, Gibson recalled in his book *Enemy Coast Ahead*<sup>3</sup>, “the Finders laid their long string of flares, the Illuminators hovered around and then dumped bunch after bunch of flares right over the town; the bombs, incendiaries at first, began to fall thick and fast, about a thousand tons of them. Soon the whole area was one mass of flames.”

The post-raid analysis confirmed Gibson’s impression of the raid, and the concentrated attack caused heavy damage<sup>4</sup>.

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<sup>1</sup> Charles Webster and Noble Frankland *The Strategic Air Offensive against Germany 1939-1945, Vol I* (Uckfield: The Naval and Military Press Ltd, 2006) [first published, London, HMSO 1961], p 202.

<sup>2</sup> The National Archives, Kew (TNA) AIR14/3408 Bomber Command Report on night operations, 1/2<sup>nd</sup> September 1942, 9 September 1942.

<sup>3</sup> Guy Gibson, *Enemy Coast Ahead* (London, Bridge Books, 1995), p159.

<sup>4</sup> TNA AIR14/3408 Bomber Command Report on night operations, 1/2<sup>nd</sup> September 1942, 9 September 1942.

There was just one problem - the town bombed was not Saarbrücken. The Pathfinders had in fact illuminated and marked the small town of Saarlouis, some 13 miles to the north-west of Saarbrücken and located in a similar bend in the River Saar<sup>5</sup>. The accuracy of the Main Force attack meant that not a single bomb fell on Saarbrücken<sup>6</sup>.

The unintentional bombing of Saarlouis is an extreme example of one of the main issues confronting Bomber Command in the prosecution of the bombing offensive during the Second World War: the ability of bomber crews to identify targets at night. Indeed, as so succinctly encapsulated by Basil Dickins, navigating to the target area was only the first part the story: the second, more difficult part, was identifying the target itself once in the target area<sup>7</sup>. The significance of this problem is not easily overstated - all the effort and risk involved in mounting a raid comes to nothing if the target cannot be identified and then hit.

The scale of the problem confronting Bomber Command had been brought sharply into focus a year before the attack on Saarlouis in a disturbing report published in August 1941. The Butt Report revealed that of those crews claiming to have bombed a target, in fact only one in three had been within five miles of it. For targets in Germany, that proportion fell to one in four and for targets in the Ruhr, which was frequently affected by industrial haze, the proportion was one in ten. In non-moon periods, this percentage fell further still. Moreover, these figures only applied to those crews that claimed to have

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<sup>5</sup> Named after Louis XIV of France, between 1936 and 1945 the town of Saarlouis was known in Germany as *Saarlautern* in an attempt to conceal the French origin of the town's name, and in some accounts of the raid is referred to as such.

<sup>6</sup> TNA AIR14/3408 Bomber Command Report on night operations, 1/2<sup>nd</sup> September 1942, 9 September 1942. Of the 71 night photographs that were plotted, 70 were centered over Saarlouis and the remainder was over a village just outside of it.

<sup>7</sup> Ronnie Shephard Military Operational Research Archive, Laurier Centre for Military Strategic and Disarmament Studies, Waterloo, Ontario, Canada (RSMORA) Basil Dickins. 'Operational Research in Bomber Command', manuscript. Basil Dickins was the Head of the Operational research Section at Bomber Command HQ.

attacked the target: a third of all crews dispatched did not even claim to have reached the target<sup>8</sup>.

And yet, less than four years after the Butt Report was published, it would be a very different story. In the early months of 1945, Bomber Command carried out a series of raids on smaller towns in Germany - towns such as Pforzheim, Würzburg, Kleve and Hildesheim - that had not previously been the subject of a major attack<sup>9</sup>. These raids were devastatingly effective.

The attack on Pforzheim was typical of the raids in this series. This raid was carried out on the night of the 23/24 February 1945 by a force of 367 Lancasters<sup>10</sup>. Both the marking and bombing were exceptionally accurate, with a total of 1,825 tons of bombs dropped in a raid that lasted just 22 minutes. Within 10 minutes of the opening of the attack, an area measuring 3km by 1.5 km was completely engulfed by a 'firestorm' which completely destroyed the old city centre. The British Bombing Survey Unit estimated that 83% of the built up area of Pforzheim was destroyed, this probably being the greatest proportion of a town destroyed in a single raid during the war<sup>11</sup>.

How, then, in the space of four years did Bomber Command evolve from an ineffective force failing, in most cases, even to locate a target to the efficient and formidable force of early 1945, capable of destroying a town the equivalent size of Rugby or Shrewsbury in a single night?

In part, the answer to these questions lies in the advent of electronic navigation aids that, in 1941, were simply not available to the crews of

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<sup>8</sup> TNA AIR8/1356 'Report by Mr Butt to Bomber Command on his Examination of Night Photographs', 18 August 1941.

<sup>9</sup> Towns in the United Kingdom with similar population sizes include Bracknell, Hastings, Rugby, Shrewsbury and Worcester. Source: 2011 Census

<sup>10</sup> TNA AIR14/3411 Raid Report No 846: Pforzheim 23/24 February 1945, dated 23 March 1945. For a detailed account of the raid on Pforzheim, see Tony Redding, *Bombing Germany: the final phase. The destruction of Pforzheim and the closing months of Bomber Command's war* (Barnsley: Pen & Sword Aviation, January 2015).

<sup>11</sup> Sebastian Cox. (ed) *The Strategic Air War Against Germany 1939-1945: The official report of the British Bombing Survey Unit* (London: Frank Cass, 1998). See also Martin Middlebrook and Chris Everitt *The Bomber Command War Diaries*, (Harmondsworth: Viking, 1985), p669, which quotes the official report of the British Bombing Survey Unit.

Bomber Command. By 1945, navigation and blind bombing aids such as GEE, *Oboe* and *H2S* were widely available. These aids turned navigation from an art into a science. However, this is not to say that these aids solved the problem of navigation entirely and it would be some time before the whole of the force would be equipped. Moreover, as Basil Dickins observed, the difficulties involved in navigating to the target area were relatively small compared to the difficulty of identifying the target itself. Part of the reason for the effectiveness of Bomber Command by early 1945 therefore lies in the development of technologies and techniques for the identification and marking of targets.

Although the development of navigational aids is well documented in literature about the bombing offensive, the development of technologies and techniques for target marking has received much less attention. The aim of this thesis is, therefore, to examine this largely neglected aspect of the bombing offensive, with a view to understanding and quantifying the contribution that the development of target marking techniques made to the effectiveness of the bombing offensive. It is essentially a technical study of the techniques employed and the results achieved in the context of the night bombing offensive conducted by RAF Bomber Command<sup>12</sup>.

Part of the aim of this thesis is to address some of the questions raised by the development of target marking techniques in the bombing offensive. The key question asked is: what difference did the introduction of target marking techniques make to the performance and efficacy of Bomber Command? It is this question that underpins the whole of the thesis, and much of the following is intended to provide an answer to that question. However, other questions arise along the way including why, given that a pathfinding technique was a regular feature of night raids made by the German Air Force from mid-1940 onwards, such techniques were only introduced by Bomber Command

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<sup>12</sup> It is recognised that specialist target marking techniques were also developed for use in daylight raids towards the end of the Bombing Offensive. However, whilst sharing some similarities with target marking techniques uses at night, those techniques were in other respects significantly different with different characteristics. For that reason, target marking techniques for daylight raids have been omitted from this study.



comparatively late in the offensive? Questions such as these are not addressed in secondary literature on the subject, and seeking to answer those and other questions here contributes to a wider understanding of the bombing offensive. In asking and answering these questions, the thesis will quantify the contribution that the development of target marking techniques made to the improvement in performance achieved by Bomber Command throughout the bombing offensive and will invite us to rethink current explanations in secondary literature about the efficacy of Bomber Command at that time.

A considerable amount has been written about the prosecution and outcomes of the bombing offensive, both in primary and secondary literature. Within this body of literature, the subject of target marking does of course feature extensively, albeit almost exclusively in descriptive rather than analytical terms. It is therefore necessary at the outset to define where this thesis sits in relation to the existing literature on the bombing offensive, and to describe how the approach taken in this thesis differs from that in the existing literature on the subject. In this context, it is logical to begin with the two officially published documents on the bombing offensive: the Air Historical Branch narrative (AHB narrative)<sup>13</sup> and the official history of the bombing offensive, *The Strategic Air Offensive against Germany 1939 -1945*<sup>14</sup>.

The AHB narrative was written in 1950 and is in six volumes covering the genesis and entire duration of the offensive. Although all six volumes discuss the development of target marking techniques, Volume 4, Part II The Experimental Force, is of particular relevance<sup>15</sup>. This covers the introduction of the first electronic navigation and blind bombing aids, as well as the target marking techniques that were associated with the introduction of those devices. It also charts the formation of the Pathfinder Force and the development of the techniques that would become the mainstay of the operational techniques employed by Bomber Command in the later part of the

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<sup>13</sup> TNA AIR41/42 Air Historical Branch narrative: The RAF in the Bombing Offensive against Germany, 6 Volumes.

<sup>14</sup> Webster and Frankland *The Strategic Air Offensive*

<sup>15</sup> TNA AIR41/42 Air Historical Branch narrative: The RAF in the Bombing Offensive against Germany, Volume VI, Part II.

offensive. At one level this volume of the AHB narrative covers some of the ground that this thesis will examine.

The AHB narrative is, as the title implies, primarily a descriptive history of the bombing offensive. There is an element of analytical explanation: Sebastian Cox points in particular to the first volume as combining narrative with analytical insight<sup>16</sup>. However, in relation to target marking, this analytical element does not extend to a detailed assessment of the relationship between the characteristics of the navigation aid employed and the profile of the target marking technique associated with it. For example, the AHB narrative dismisses the initial averaging technique using H2S as being 'for various reasons' not very successful but does not go on to explain what those reasons were<sup>17</sup>. One of those reasons related to the Principle of Cumulative Dispersion which, as explained later in this thesis, is absolutely fundamental in determining the effectiveness of all target marking techniques but to which H2S was particularly prone as a direct consequence of the very principles on which it worked. The AHB narrative does not make that connection. The omission of such important concepts, whilst understandable in the context of a historical narrative, does not explain how target marking worked or, by extension, how it contributed to the prosecution of the bombing offensive.

This is not to in any way diminish the value of the AHB narrative. As Christina Goulter points out, the AHB narratives have provided the foundation for many scholars' work and that, without them, 'our feel for the scope of the RAF's contribution to the Allied war effort would be much more limited'<sup>18</sup>. However, whilst the AHB narrative refers to many of the techniques examined in this thesis, it does not do so in any detail, particularly in respect of the technical aspects of those techniques. Consequently, whilst the AHB narrative provides

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<sup>16</sup> Sebastian Cox 'Setting the Historical Agenda; Webster and Frankland and the Debate over the Strategic Bombing Offensive against Germany, 1939-1945', in Jeffrey Grey (ed) *The Last word? Essays on Official History in the United States and British Commonwealth*, (Westport CT: Praeger, 2003), page 149.

<sup>17</sup> TNA AIR41/42 TNA AIR41/42 Air Historical Branch narrative: The RAF in the Bombing Offensive against Germany, Volume VI, Part II.

<sup>18</sup> Christina J.M. Goulter, *British Official Histories of the Air War*, in Grey (ed) 'The Last word?', p159.

a convenient framework within which to examine the development of target marking techniques, it leaves plenty of scope to examine the technical aspects associated with those techniques and to further our understanding of the role played by target marking in the bombing offensive.

If the AHB narrative may be considered as being primarily a descriptive history of the bombing offensive, the official history produced under the auspices of the Cabinet Office is of a different order. Published as four volumes in 1961 following a lengthy and troubled gestation period, the official history is widely regarded as being the best single analysis of the British strategic bombing offensive. The reason for this, according to Cox, lies in the historical and literary skills of the authors, Sir Charles Webster and Noble Frankland, and the analytical framework established for the book by Frankland in his earlier research in the Air Historical Branch. This leads Cox to suggest that, in terms of depth of research and the rigor of analysis, the official history compares favourably with many of the other British official military histories<sup>19</sup>.

In the conclusion of his essay on the official history, Cox describes that work as being 'unrivalled' as a guide to the development of the operational techniques employed by Bomber Command. This is undoubtedly the case, insofar as no other single publication before or since has described these techniques in a similar level of detail. But "unrivalled" is a comparative term and, as Goulter reminds, official histories do not necessarily represent the definitive word on particular subjects<sup>20</sup>. Thus, the official history is not, and neither was it intended to be, definitive in terms of the operational techniques employed by Bomber Command. The official history does include detailed descriptions of target marking techniques and, in general terms, relates them to the various navigation and blind bombing aids that were available. However, the primary purpose in describing those techniques was to inform

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<sup>19</sup> Sebastian Cox, *Setting the Historical Agenda; Webster and Frankland and the Debate over the Strategic Bombing Offensive against Germany, 1939-1945* in Grey (ed) *The Last word?* page 159.

<sup>20</sup> Christina J.M. Goulter, *British Official Histories of the Air War* in Grey (ed) *The Last word?* page 133.

the progression of the strategic air offensive against Germany as part of narrating and then explaining the history of that offensive. The robust analytical approach taken in writing the official history was therefore primarily directed at the prosecution, purpose and outcomes of the bombing offensive, rather than the techniques that underpinned it.

It follows that the analysis of the operational techniques employed by Bomber Command in the official history was limited to that necessary to inform the main purposes of that document in terms of analysing the progression and outcome of the bombing offensive. To give just one example, the official history describes the *Shaker* target marking technique in the context of the resultant improvements in bombing accuracy but principally as a prelude to explaining that the results did not conform to Air Ministry expectations before the introduction of the GEE navigation aid upon which the *Shaker* technique was predicated<sup>21</sup>. No attempt is made, however, to relate the results achieved using the *Shaker* technique to the technical characteristics of the GEE navigation aid. By not addressing this causal link, the official history does not provide a comprehensive understanding of the contribution made by the *Shaker* target marking technique to the bombing offensive. For similar reasons, the same is also true of the other target marking techniques employed by Bomber Command and the navigation aids with which they are associated.

Consequently, the AHB narrative and the official history only take us so far in our understanding of the role played by target marking techniques in the prosecution of the bombing offensive. There remains levels of detail relating to the development of those techniques that sit below the level of analysis provided by the AHB narrative and the official history. It is within these additional layers of detail that the technical reasons behind the characteristics and limitations of the navigation aids upon which target marking techniques relied are to be found. It is these characteristics and limitations that in turn dictated the profile of the various target marking techniques and, ultimately,

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<sup>21</sup> Webster and Frankland *The Strategic Air Offensive*, pages 387 to 397.

the results that could be achieved using them. In order to fully understand the development of target marking techniques and the contribution they made to the bombing offensive, it is therefore necessary to descend into these layers of detail that sit below the AHB narrative and the official history. The intention of this thesis is to work within these lower layers of detail and build upon the analysis in the AHB narrative and the official history.

The same also applies to secondary sources on the bombing offensive. The history of Bomber Command during the Second World War has been extensively documented in secondary literature. The scope covered by this literature encompasses the whole spectrum of the bombing offensive, ranging from the high-level strategic conduct of the offensive<sup>22</sup> to personal accounts of the aircrew involved on bombing operations<sup>23</sup>. Within this spectrum, there are descriptions of the tactics adopted by Bomber Command, the equipment used and the techniques evolved to make best use of the equipment available. There are also detailed accounts of individual raids<sup>24</sup>, or groups of raids<sup>25</sup>, together with commentaries on the outcome of those raids, and on the success and failures of the bombing offensive as a whole. The literature contains numerous references to the target marking techniques employed by Bomber Command. These references tend to reflect the broad spectrum covered by the available literature, ranging from wider concepts such as the formation of the Pathfinder Force to descriptions of the target marking

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<sup>22</sup> For example, Max Hastings *Bomber Command* (London: Michael Joseph Ltd, 1979); Denis Richards *The Hardest Victory: RAF Bomber Command in the Second World War* (London, 1994), Robin Neillands *The Bomber War: Arthur Harris and Allied Bomber Offensive 1939-1945* (London: John Murray, 2001) and, more recently, Richard Overy *The Bombing War; Europe 1939-1945* (London: Allen Lane, 2013).<sup>22</sup> For example, Leonard Cheshire, *Bomber Pilot* (Hutchinson, London and St Albans 1943), Guy Gibson, *Enemy Coast Ahead* and John Searby *The Everlasting Arms* (London:Kimber, 1988).

<sup>23</sup> For example, Leonard Cheshire, *Bomber Pilot* (Hutchinson, London and St Albans 1943), Guy Gibson, *Enemy Coast Ahead* and John Searby *The Everlasting Arms* (London:Kimber, 1988).

<sup>24</sup> Of particular relevance to target marking, these include Martin Middlebrook. *The Peenemunde Raid 17/18 August 1943* (, London: Penguin Books 1988: first published Allen Lane, London 1982) and a number of works on the Dresden firestorm raid, including David Irving *The Destruction of Dresden* (London: Futura Publications, 1980: first published 1963) and Frederick Taylor *Dresden: Tuesday, 13<sup>th</sup> February 1945* (London, 2004).

<sup>25</sup> These works describe some of the major 'battles' undertaken by Bomber Command, including Alan Cooper *Air Battle for the Ruhr* (Shrewsbury: Airlife Publishing Ltd, 1992), Martin Middlebrook *The Berlin Raids: R.A.F. Bomber Command Winter 1943-44* (London Penguin Books, 1990: first published Viking, 1988) and Kenneth Lowe *Inferno: The fiery destruction of Hamburg 1943* (New York, NY: Scribner, 2007).

techniques adopted for individual raids. Furthermore, some elements of the literature include detailed technical descriptions of the equipment associated with target marking techniques - in particular, the main navigation aids<sup>26</sup> - whereas some elements of the available literature include descriptions of the principal target marking techniques themselves<sup>27</sup>.

Within this extensive body of literature, the development of target marking techniques is a largely neglected subject. In particular, there is a tendency in secondary literature to attribute the improvement in bombing accuracy achieved by Bomber Command in the later years of the offensive to the introduction of navigation aids. For example, in his book *Hardest Victory*, Denis Richards, in referring to the Battle of the Ruhr in 1943, states that "Oboe and H2S had without doubt set new standards of bombing accuracy" but makes no reference to the role played by the target marking techniques in securing that improvement<sup>28</sup>. Norman Longmate, commenting on the improvements in accuracy in the closing months of the war, ascribes this to the increased range of GEE, *Oboe* and G-H as the Allied forces advanced in Europe<sup>29</sup>. In his book, *The Bomber War*, Robin Neillands devotes a chapter to "The scientific air war, 1939-1942", in which the basic characteristics of GEE, *Oboe* and H2S are explained. However, whilst the formation of the Pathfinder Force is covered in a later Chapter, the development of target marking techniques does not come in for the same level of attention<sup>30</sup>. More recently, Richard Overy has observed that the introduction of *Oboe* and H2S contributed to raising the average accuracy of the attacking force and provides relative statistics for attacks using these two devices. However,

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<sup>26</sup> In particular, Michael Cumming *Beam Bombers: The Secret War of No. 109 Squadron* (Stroud, Gloucestershire: Sutton Publishing, 1998), which covers the development of *Oboe* blind bombing device, and Sir Bernard Lovell, *Echoes of War: The Story of H2S Radar* (Bristol: Adam Hilger, 1991).

<sup>27</sup> These include Gordon Musgrove *Pathfinder Force: a History of 8 Group* (London: Macdonald and Jane's Publishers, 1976) and Sean Feast *The Pathfinder Companion: War Diaries and Experiences of the RAF Pathfinder Force: 1942-1945* (London: Grub Street, 2012).

<sup>28</sup> Richards, D. *The Hardest Victory: RAF Bomber Command in the Second World War* (London, 1994), p169.

<sup>29</sup> Longmate, N. *The Bombers: The RAF Offensive against Germany, 1939-1945* (London: Hutchinson, 1983), p330.

<sup>30</sup> Neillands, R. *The Bomber War: Arthur Harris and Allied Bomber Offensive 1939-1945* (London: John Murray, 2001), Chapter 3, p 60 to p78.

despite noting that concentration could be lost if the Pathfinders missed the aiming point, there is no attempt to relate the relative accuracy achieved using Oboe and H2S to the target marking methods employed in association with them<sup>31</sup>.

There is an inherent assumption in these works that navigating to the target was in itself sufficient and little attention is paid to the mechanics of delivering bombs onto the target. Even where reference to target marking is made, there is no attempt to establish a causal link between target marking techniques and the concepts of bombing accuracy and concentration. For example, the conclusion to the official history, whilst acknowledging that Bomber Command had received new equipment in the form of radar aids and had devised more efficient tactical methods through the creation of the Pathfinder Force, does not make the association between the two<sup>32</sup>. This thesis will show that such assumptions have resulted in an incomplete and inaccurate understanding of the capabilities of Bomber Command, and have therefore contributed to a misunderstanding of the strategic and tactical employment of the bomber force during that period.

It is acknowledged that the basic techniques employed by Bomber Command for marking targets sometimes do receive mention - those known by the familiar codenames of *Newhaven*, *Parramatta* and *Wanganui*. Occasionally, reference is even made to specific target marking techniques: for example, in describing the 'firestorm' raid on Dresden in February 1945, several authors describe or even make direct reference to a technique known as the "5 Group fan", a technique fundamental to the generation of the Dresden firestorm that is the focus of their work<sup>33</sup>.

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<sup>31</sup> Overy *The Bombing War; Europe 1939-1945*, page 347.

<sup>32</sup> Webster, C and Frankland, N. *The Strategic Air Offensive*, Vol iii, page 286.

<sup>33</sup> More correctly referred to as Sector Marking, the "5 Group fan" was a technique developed by No. 5 Group Bomber Command in which each individual aircraft bombed the Target Indicators on a different compass heading and using different time delays for bomb release, thus spreading the bomb pattern in a fan shape originating from the A/P. Using a combination of high explosives and incendiaries, this technique was highly effective in creating the widespread fires necessary to generate a 'firestorm'. Both Irving *The Destruction of Dresden* and Taylor *Dresden: Tuesday, 13<sup>th</sup> February 1945* describe this technique in detail in these works.

However, little coverage has been devoted to the development of those techniques, or the extent to which those techniques contributed to the effectiveness of the bombing offensive. Where on occasion reference is made to such techniques - as in relation to the Dresden 'firestorm' raid - reference is typically and understandably made solely in the context of specific raids, with no attempt to place the technique described into context in terms of its evolution and effectiveness. Rarely, if ever, is it explained why a particular target marking technique was chosen and how it worked in practice.

The latter point leads to a wider question about the reaction of policy makers to the experience and improved performance gained from the employment of target marking techniques, and how the evolution of these techniques influenced the choices made by policy makers in the employment of the bomber force. This is an important, but hitherto neglected, element of the debate concerning the use of Bomber Command for area bombing rather than against precision targets such as oil and transportation. This in turn leads to a further question about the relationship between policy-making, operational experience and the introduction of new technologies. Although that relationship is alluded to in secondary literature in terms of the introduction of navigation aids, little attention has been devoted to the development of target marking techniques in that relationship. This thesis will address these questions, and place the development of target marking techniques into context in the relationship between the technological capability of Bomber Command and the options thereby presented to policy-makers for the deployment of the bomber force.

Still less attention has been devoted to the evolution and refinement of target marking techniques in the light of experience, or to the development of those technologies essential for the deployment of those techniques. In particular, no attempt has been made in secondary literature to define the precise relationship between the navigation or blind bombing aid used and evolution of target marking techniques. The inherent characteristics of those aids largely dictated the target marking technique that could be used in conjunction



with them, and this in turn had a significant effect on bombing accuracy and concentration. Although this relationship is sometimes referred to in secondary literature in general terms, this thesis will define that relationship, not only in terms of the technical reasons that underpin it, but also in terms of the tactical implications for the conduct the bombing offensive and the effectiveness of the respective target marking techniques.

Although a number of journal articles have been published covering topics peripheral to the development of target marking techniques, none of these relate directly to target marking techniques. Thus, the journals of the Royal Institute of Navigation, the Institute of Electrical Engineers and the Operational Research Society have all featured articles of broad relevance to the topics covered in this thesis: for example, articles published by the Institute of Electrical Engineers on the GEE and *Oboe* electronic navigation aids have informed the descriptions of those devices in this thesis, and the Royal Institute of Navigation published articles on the navigation technique of dead reckoning that is in part relied on in lieu of a description of that technique in Chapter 1 of this thesis<sup>34</sup>. Similarly, the Royal Air Force Air Power Review, the Royal Air Force Historical Society and the Journal of Strategic Studies have featured numerous articles covering aspects of the bombing offensive, particularly in relation to the leadership and strategic aspects of the bombing offensive<sup>35</sup>, but have published none that directly address the development of target marking techniques.

A number of published and unpublished theses have covered aspects of the development of target marking. Of these, the two most relevant are the Master of Arts and doctoral theses of Rex F.Cording. The former, 'Press on Regardless: A history of the origins and achievements of the R.A.F.'s

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<sup>34</sup> Alec Aylife, 'The development of Airborne Dead Reckoning: Part I – Finding the Wind', *The Journal of Navigation*, 54, (May 2001) p 223-233 and 'The development of Airborne Dead Reckoning: Part II – Staying on Track', *The Journal of Navigation*, 54, (October 2001),p463-476.

<sup>35</sup> Sebastian Cox, 'Sir Arthur Harris and some Myths and Controversies of the Bomber Offensive', *RAF Historical Society Journal*, (2010), 47, p11-12 and Randall T.Wakelam, 'Bomber Harris and Precision Bombing – No oxymoron Here', *Journal of Strategic Studies*, 2012, 14 (1).

Pathfinder Force 1916-1945', is in two parts<sup>36</sup>. The first part deals at length with the deficiencies in the R.A.F. before 1939, and includes sections on bombing photography, training and navigation. The second part deals specifically with the formation of the Pathfinder Force, with sections on the experience of Bomber Command in the early war years and on "1942; The Year of Experimentation". In this latter respect, the structure is similar to that adopted in this thesis.

However, the coverage of the thesis is wide ranging and the style adopted by Cording is largely descriptive. This scatter-gun approach touches upon many aspects of the bombing offensive, including those that have no tangible association with the subject of target marking in the bombing offensive or which are at most incidental to the development of the techniques involved: for example, Cording devotes considerable wordage in speculating as to why Group Captain Cheshire was vetoed by Air Vice Marshal Bennett for a role in the Pathfinder Force, and to the use of the GEE navigation aid in the post-war Canberra aircraft. Indeed, Cording's main focus is the formation of the Pathfinder Force and the personalities involved, such that the technical aspects of target marking do not feature until the end of the thesis and then not prominently.

The same focus is repeated in Cording's doctoral thesis<sup>37</sup>. Titled 'The Other Bomber Battle: An examination of the Problems that arose between the Air Staff and the AOC Bomber Command between 1942 and 1945 and their Effects on the Strategic Bomber Offensive', the main focus of the thesis is the clash of personalities between Air Chief Marshal Sir Arthur Harris, AOC Bomber Command, and Group Captain Sydney Bufton, Deputy Director (later Director) of Bombing Operations at the Air Ministry. The thesis does not deal with the technical aspects of target marking but does examine the debate surrounding the formation of the Pathfinder Force in some detail. However,

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<sup>36</sup> Rex F. Cording, 'Press on Regardless: A history of the origins and achievements of the R.A.F.'s Pathfinder Force 1916-1945' University of Canterbury, MA Thesis 1992.

<sup>37</sup> Rex F. Cording, 'The Other Bomber Battle: An examination of the Problems that arose between the Air Staff and the AOC Bomber Command between 1942 and 1945 and their Effects on the Strategic Bomber Offensive', University of Canterbury, PhD Thesis 2006.

again consistent with the main focus of the work, the analysis concentrates upon the clash of personalities between the individuals involved. In doing so, the thesis fails to set the debate into the proper context, specifically in terms of the ramifications for the continuation of the strategic bombing offensive should results then being achieved not improve. It also fails to place the outcome of the debate, namely the formation of the Pathfinder Force, into the context of the remainder of the offensive, including the subsequent development of target marking techniques by other Groups.

Some aspects of target marking are also covered in the Robert Owen's doctoral thesis, 'Considered Policy or Haphazard Evolution? No 617 Squadron RAF 1943-1945'<sup>38</sup>. That thesis is primarily concerned with the means and motives behind the wartime role of No 617 Squadron, and looks beyond the well-known operations with which the squadron is usually associated<sup>39</sup>. The thesis is arranged chronologically and two chapters cover the period when No 617 Squadron, under the leadership of Group Captain Leonard Cheshire, experimented with low-level target marking<sup>40</sup>. This would later develop into the target marking techniques developed by No. 5 Group Bomber Command and which are considered in detail in Chapter 7 of this thesis.

Consistent with the main focus of Owen's thesis, those chapters are largely devoted to the debate surrounding a role for No 617 Squadron following the costly low-level raids on the Dortmund-Ems Canal and pending the availability of the Tallboy bomb for high-level precision bombing. The reference to the development of target marking techniques by the squadron is made in the context of the decision to employ the experience of the squadron in low-level attack firstly against CROSSBOW sites and then aero-engine factories. This explains that the low-level marking technique was developed in response to the failure of conventional techniques using proximity markers dropped using

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<sup>38</sup> Robert Malcolm Owen, 'Considered Policy or Haphazard Evolution? No 617 Squadron RAF 1943-1945' University of Huddersfield, PhD Thesis 2014.

<sup>39</sup> Principally the Dams Raid of May 1943 and the attacks against the Tirpitz battleship in 1944.

<sup>40</sup> Chapter 2 (September 1943 – January 1944) and Chapter 3 (February 1944– May 1944)

*Oboe*. However, whilst these target marking techniques are described in some detail, the main focus of the work is the search for a suitable role for the squadron rather than the technical aspects of the target marking techniques. Thus, there is no analysis of why the techniques were successful compared with the conventional techniques used initially. Moreover, for understandable reasons given the scope of the thesis, it does not go on to explore the evolution of the low-level target marking technique developed by No 617 into wider application by No 5 Group and ultimately into the highly efficient techniques that fall under the general description of 'offset' marking'.

In summary, two key points arise from this examination of the literature on the bombing offensive. Firstly, nowhere in this extensive body of literature is the technical aspect of target marking covered in detail: for example, considerations that are vital to the effectiveness of target marking, such as the concepts of 'Systematic Error', 'Point of Aim', 'Probable Radial Error' about the 'Mean Point of Impact' and the 'Principle of Cumulative Dispersion', as well as factors affecting the visibility of Target Indicators and relationship between the navigation aid and the profile of target marking techniques, either do not feature in this literature or, if they do, are given only cursory mention. This thesis fully addresses these considerations as a means of determining the effectiveness of target marking. Moreover, nowhere in this body of literature is the contribution of target marking to the outcome of the bombing offensive considered as a separate entity. It follows that this thesis breaks new ground by addressing an element of the bombing offensive that is not covered in existing literature, at least to the level of detail to which this thesis descends in seeking to understand the technical aspects that underpin the techniques of target marking and ultimately the contribution of target marking to the outcomes of bombing offensive.

This thesis will show that the development of target marking techniques was dependent upon the employment of technologies that, at the time, were innovative and at the cutting edge of known science. It will be shown that the development and success of target marking techniques came about by combining the best technologies available at the time - navigation aids, Target

Indicators and flares, as well as the aircraft involved. This examination will be set in the wider context of the increasing use and reliance of technology at that time, not only in terms of military applications, but also in terms of the progression of society at large. In this respect, the thesis will reference and build upon the work of authors such as David Edgerton<sup>41</sup>, Guy Hartcup<sup>42</sup> and Richard Overy<sup>43</sup> on these issues. These authors explain the contribution made by advances in technology to Allied victory in all aspects of the Second World War, including major advances in major technologies such as the jet engine and the atomic bomb. This thesis will cite the development of target marking techniques as a lesser-known but nonetheless important example of the exploitation of technological advance to improve operational performance and efficiency. In doing so, this thesis will also explore the counter-argument that the evolution of existing techniques using known technologies is more important than the introduction of new technologies of unknown effectiveness and as such will complement the existing literature on the evolution of operational research by authors such as Maurice Kirby<sup>44</sup> and Randall Wakelam<sup>45</sup>, and David Edgerton's arguments that the exploitation of existing technologies has been underrated<sup>46</sup>.

Although the advancement in navigation aids and other technologies was crucial to the development of target marking techniques, this thesis will nonetheless recognise that the employment of those techniques on bombing operations necessarily involved the human factor and that this was itself fundamental to the outcome in terms of bombing accuracy and concentration. For example, some of the most widely used target marking techniques required bomb aimers to quickly identify, under the stress of operational conditions, the Mean Point of Impact of a constantly changing group of Target Indicators. The difficulties associated with this requirement, and the

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<sup>41</sup> David Edgerton *Britain's War Machine* (London: Penguin Books Ltd, 2012).

<sup>42</sup> Guy Hartcup *The Effect of Science on the Second World War* (Basingstoke, Hampshire: Palgrave Macmillan, 2003).

<sup>43</sup> Richard Overy *Why the Allies Won*, (2<sup>nd</sup> Edition. London: Pimlico 2006).

<sup>44</sup> Maurice Kirby *Operational Research in War and Peace: The British Experience from the 1930's to 1970* (London: Imperial College Press 2003).

<sup>45</sup> Randall Wakelam *The Science of Bombing* (University of Toronto Press, Toronto 2009).

<sup>46</sup> Edgerton *Britain's War Machine*

associated errors resulting from the 'Principle of Cumulative Dispersion'<sup>47</sup>, had a significant impact on the concentration of bombing, which in turn was a major factor in the outcome of raids. However, whilst the importance of concentration is sometimes referred to secondary literature, this human element in the causal link between concentration and target marking is not made.

The principal sources used in compiling this thesis are contemporary reports and correspondence held in The National Archives. In particular, from 1941 onwards the Operational Research Section at Bomber Command (ORSBC) produced a series of reports and memoranda relating to bombing performance. Included within these are reports specifically relating to the performance of the navigation and blind bombing aids then in use, as well as reports covering the results achieved using the various target marking techniques. The statistical evidence provided by these reports has been relied upon to provide the factual basis to inform the discussion of the main issues. The vast majority of these documents are of a highly technical nature and generally are not referred to in secondary literature on the Bombing Offensive.

Much of the historical context has been provided by the private papers of Air Chief Marshal Sir Charles Portal (Chief of Air Staff 1940 -1945)<sup>48</sup>, Air Chief Marshal Sir Arthur Harris (Air Officer Commanding-in-Chief Bomber Command 1942-1945)<sup>49</sup>, Air Commodore Sidney Bufton (Director/Deputy Director of Bomber Operations, Air Staff 1941-1945)<sup>50</sup>, Lord Cherwell<sup>51</sup> and Sir Henry Tizard<sup>52</sup>. These individuals each played an important role in the conduct of the bombing offensive and each made an important contribution to the development of target marking techniques. Additional information and perspectives have been sourced from published biographies of the above, as well as the autobiographies and biographies of others involved in various

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<sup>47</sup> In relation to target marking, the Principle of Cumulative Dispersion states that, if successive aircraft aimed at the M.P.I. of all the markers visible, the aggregate M.P.I. was itself subject to a cumulative error which rapidly became greater than that of the individual attempts.

<sup>48</sup> Christ Church Library, Oxford (CCL)

<sup>49</sup> Royal Air Force Museum, Hendon, London (RAFM)

<sup>50</sup> Churchill College, Cambridge (CCAC)

<sup>51</sup> Nuffield College, Oxford (NC)

<sup>52</sup> Imperial War Museum, London (IWM)

aspects relating to target marking, including Air Chief Marshal Sir Wilfrid Freeman<sup>53</sup> (Vice Chief of Air Staff 1940-1942), Marshal of the Royal Air Force Sir John Slessor<sup>54</sup> (As Air Marshal John Slessor, Air Officer Commanding No 5 Group Bomber Command); Air Vice Marshal Donald Bennett<sup>55</sup> (Air Officer Commanding No 8 Pathfinder Group Bomber Command) and Air Commodore John Searby<sup>56</sup> (as Wing Commander John Searby, a “Master Bomber” with No 8 Pathfinder Group).

Information about the wider context of the bombing offensive has been taken from a number of published works, notably the four volumes of *The Strategic Air Offensive against Germany 1939-1945* by Charles Webster and Noble Frankland<sup>57</sup>. In addition to the Raid Reports held in The National Archives, material relating to individual raids has been found in *The Bomber Command War Diaries: An operational reference book* by Martin Middlebrook and Chris Everitt<sup>58</sup> and from various books relating to specific operations or series of operations.

Any discussion on target marking techniques requires a firm understanding of the bombing and navigation aids on which they were based. Indeed, as will be shown in this thesis, the overall profile of each target marking technique was derived from the characteristics of the particular bombing or navigation aid employed. It follows that, in order to understand how these techniques were developed, it is first necessary to understand the technology and science behind each bombing or navigation aid. A technical description of these aids to the level of detail necessary to fully understand how they functioned requires a considerable amount of text. Consequently, the approach adopted

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<sup>53</sup> Anthony Furse *Wilfrid Freeman; The Genius behind Allied Air Supremacy 1939-1945* (, Staplehurst, Kent: Spellmount Ltd 1999).

<sup>54</sup> Sir John Slessor *The Central Blue* (London: Cassell, 1956).

<sup>55</sup> Air Vice Marshal D.C.T. Bennett *Pathfinder* (London and St Albans: Goodall Publications, 1988: first published London, 1958). There have also been several biographies of Donald Bennett, including Alan Bramson *Master Airman: A biography of Donald Bennett CB, CBE, DSO* (Shrewsbury: Airlife Publishing Ltd, 1985), A.S. Jackson *Pathfinder Bennett* (Lavenham, Suffolk: Terence Dalton, 1991) and John Maynard *Bennett and the Pathfinders* (London: Arms and Armour Press, 1996).

<sup>56</sup> Searby *The Everlasting Arms*

<sup>57</sup> Webster and Frankland *The Strategic Air Offensive against Germany*.

<sup>58</sup> Middlebrook and Everitt *The Bomber Command War Diaries*

here is to provide a summary of the main characteristics of each bombing or navigation aid in Chapter 2 to assist the reader in understanding the discussion that follows, but to refer the reader to detailed technical description of these devices in other publications for additional information. The principal sources for the technical descriptions in Chapter 2 are documents held in The National Archives, but additional information has been taken from a number of published works, including *Beam Bombers: The Secret War of No.109 Squadron* by Michael Cummings<sup>59</sup> and *Echoes of War: The Story of H2S Radar* by Sir Bernard Lovell<sup>60</sup>, as well as articles published by the Institute of Electrical Engineers.

In order to achieve the aims stated above, this thesis will examine the development of target marking techniques in a number of discrete sections based on key topics. This approach has been adopted in deference to the technical nature of the subject matter, it being considered that the compartmentalisation of the text into discrete topics best facilitates the detailed explanation of and discussion about the technical aspects of the bombing offensive. It is acknowledged that this approach makes it more difficult to place these discrete topics into context with one another and the bombing offensive as a whole, and that a certain amount of repetition between sections becomes necessary. It is also recognised that the alternative approach, that of chronological narrative of the development of target marking techniques, would enable the development of target marking techniques to be charted in relation to the progress of the bombing offensive over time and would provide a wider context in which to place those developments.

The relative advantages and disadvantages of these two approaches were carefully evaluated at the outset. However, the essence of this thesis is an examination of the highly technical techniques involved in target marking, and as such priority must be given to ensuring that these technical issues are

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<sup>59</sup> Cumming. *Beam Bomber:*

<sup>60</sup> Lovell, *Echoes of War*



properly examined and their individual contribution to the bombing offensive fully understood. Consequently, on balance, it is considered that the advantages gained in adopting a thematic compartmentalisation approach outweigh any disadvantages in terms of disruption to the chronological narrative.

The individual sections in this thesis are devoted to those events, individual techniques and technologies identified as being most salient to the development of target marking techniques during the course of the bombing offensive. The following is a short summary of the contents of each individual chapter.

### *Before Target Marking*

This Chapter benchmarks the bombing performance of Bomber Command before the development of target marking techniques. This is based principally on the findings of the Butt Report. Published in August 1941, the Butt Report revealed the scale of the problem confronting Bomber Command at that time in terms of the accuracy of night bombing. The Butt Report is of fundamental significance to the development of target marking techniques in that, some commentators argue, the findings of the Butt Report acted as a catalyst for improvements in navigational techniques and were influential in the formation of the Pathfinder Force. This Chapter examines the findings of the Butt Report in detail, and considers how those findings influenced subsequent events impacting upon the development of target marking techniques.

### *Blind Bombing*

This Chapter examines the bombing performance of the principal blind bombing aids (*GEE, Oboe, H2S, G-H, S.S.LORAN*) used during the bombing offensive. The Chapter includes a brief technical description of these blind bombing aids, with emphasis on the limitations associated with each. The main purpose of this Chapter is to benchmark the performance of the principal blind bombing aids when used in isolation and thereby enable a comparison

to be made when used in conjunction with target marking techniques in later chapters. This Chapter will therefore address one of the key questions asked by this thesis, in terms of the results that Bomber Command might have achieved without the introduction of target marking techniques. A secondary purpose of this Chapter is to introduce the reader to the main blind bombing aids on which the various target marking techniques were based and which are discussed in later chapters. This Chapter will also place the development of the principal blind bombing aids in the context of existing literature on the importance of new technology on the conduct and outcome of the Second World War.

### *Early Target Marking Techniques*

This Chapter briefly describes the first attempts by Bomber Command at target marking during the period 1940 to 1941, before offering a comparison with the techniques employed by the Luftwaffe's specialist target finding unit Kampfgruppe 100. The main part of the Chapter describes in detail the development of the first dedicated target marking technique used by Bomber Command (*Shaker*), with the emphasis on the relationship between that technique and the particular characteristics of the GEE navigation aid on which it relied. The results achieved using the *Shaker* technique are examined in order to provide a benchmark against which the results achieved using later target techniques on the same target set can be compared, and thereby demonstrate the direct relationship between the characteristics of particular navigation aids and the results achieved by target marking techniques that relied upon it.

### *The formation of the Pathfinder Force*

The formation of the Pathfinder Force in August 1942 is one of the most significant events - if not the most significant event - in the development of target marking techniques. Indeed, as No.8 (PFF) Group<sup>61</sup>, the Pathfinder Force is inextricably linked to the development of target marking techniques

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<sup>61</sup> The Pathfinder Force was not given Group status until officially re-designated as No.8 (PFF) Group on the 13<sup>th</sup> January 1943.

throughout the bombing offensive. This Chapter details the debate surrounding the formation of the Pathfinder Force, including the role played by key individuals in that debate. The Chapter includes a review of the debate surrounding the creation of the Pathfinder Force in secondary literature, and discusses the proposition that the concept of a target finding force was under consideration earlier and more widely than generally acknowledged in secondary literature.

### *Pathfinder Force target marking techniques*

This Chapter comprises a technical description and appraisal of the principal target marking techniques developed by the Pathfinder Force (*Newhaven, Parramatta, Wanganui*). Particular emphasis is given to the evolution and refinement of these techniques in the light of operational experience, and to the relationship between the characteristics and accuracy of each technique and the navigation aid used. This Chapter introduces the important concepts of the “Systematic Error” and the ‘Principle of Cumulative Distribution’, and details the attempts made to minimise the errors caused by these factors through the development and evolution of the target marking techniques throughout the remainder of the bombing offensive. The Chapter examines the effect on bombing performance following the introduction and subsequent development of these target marking techniques.

### *No 5 Group Pathfinding Techniques*

As the bombing offensive progressed, No. 5 Group Bomber Command increasingly developed its own target marking techniques, a capability that would eventually culminate in No.5 Group effectively operating as an independent force and which would enhance the tactical freedom of the bomber force. This Chapter describes the development of target marking techniques by No 5 Group (*Visual Groundmarking, Offset, Line, Sector*) and attempts an objective assessment of the relative merits of the techniques adopted by this Group and the Pathfinder Force. With the use of comparative data, this Chapter explores the proposition that the target marking techniques

developed by No. 5 Group were superior in terms of accuracy and effectiveness compared with those used by the Pathfinder Force, notably in relation to precision attacks in the build-up to OPERATION OVERLORD. The relationship between the respective Group Commanders of No 5 Group and the Pathfinders (and their relationship with Harris), one of the most interesting aspects of the bombing offensive, is also discussed.

### *The role of the Master Bomber*

First used for guiding small-scale precision raids from mid-1943, the role of the 'Master Bomber' became increasingly used to guide large-scale attacks by the Main Force as the bombing offensive progressed. Some of these raids - such as the attack on the research establishment at Peenemünde in August 1943 - were significant because of their individual outcome. Others - such as the firestorm raid on Darmsdadt in September 1944 - reflected the ever-increasing capability of Bomber Command to devastate large urban areas. This section traces the evolution of the role of Master Bomber from its inception in 1943 to the conclusion of the bombing offensive, and assesses the contribution made by this tactic to the effectiveness of bomber operations. The role of the Master Bomber was not confined to any one of the target marking techniques described in earlier Chapters, and for that reason is considered separately in this Chapter.

### *Conclusion*

The cumulative findings of these individual topic-based sections provide a comprehensive understanding of the development of target marking techniques during the course of the bombing offensive, which makes it possible for an informed assessment to be made of the contribution that the development of target marking techniques made to the effectiveness of the bombing offensive.

## CHAPTER ONE: BEFORE TARGET MARKING

The purpose of this Chapter is to 'benchmark' bombing accuracy before the advent of any navigation aids or target marking techniques. The performance of Bomber Command using traditional navigation techniques will then be compared with the performance achieved with the benefit of navigation aids and various target marking techniques in later chapters. This chapter will also explain some of the basic principles relating to the navigation of aircraft, and explore the extent to which features on the ground are visible at night.

Bomber Command entered the Second World War committed to a strategy of precision bombing in daylight. Pre-war tactics were based on the assumption that well flown self-defended bomber formations would survive contact with the enemy and enable precision bombing of purely military objectives. Consequently, the vast majority of pre-war training took place in daylight, with the emphasis on formation flying and precision bombing from moderate altitudes and with an average of only 8% of training sorties taking place at night<sup>1</sup>. The theory that self-defended bomber formations would survive contact with the enemy was soon dispelled, as early operations in daylight during the opening months of the war incurred prohibitive losses. It rapidly became apparent that, if Bomber Command was to play any sort of role, it would have to switch to bombing at night.

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<sup>1</sup> TNA AIR14/57 Bomber Command Annual Training Report, 1938.

At first, Bomber Command proceeded on the basis that bombing at night required no change in the overall strategy. Indeed, Air Commodore Coningham, AOC No 4. Group, told Bomber Command in February 1940 that ‘...the accuracy of night bombing will differ little from daylight bombing’<sup>2</sup>. However, there would be an early and growing realisation that Bomber Command lacked the capability to successfully attack precision targets at night and this led some, notably Charles Portal as Commander in Chief of Bomber Command and then as Chief of Air Staff, to advocate that these prime targets should only be attacked on moonlit nights<sup>3</sup>. On other nights, Portal considered, it would be better to attack industrial areas rather than precise objectives and this has led several commentators to identify this as one of the first steps towards ‘area bombing’<sup>4</sup>. Nonetheless, as Portal’s biographer observes, Portal never lost sight of the superiority of precision bombing if that could be achieved and initially there remained a belief that such targets could be successfully attacked if weather conditions were favourable<sup>5</sup>.

Despite the initial optimism expressed in some quarters, including Portal, the reality was starkly different. The first attempt at night bombing - on the Hornum seaplane base on the island of Sylt - had been a complete failure when, notwithstanding reports of accurate bombing by the crews taking part,

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<sup>2</sup> Webster and Frankland *The Strategic Air Offensive, Vol iv* Appendix 6, p212. Letter from Coningham to Groom.

<sup>3</sup> TNA AIR2/4474 Letter C-in-C Bomber Command to Air Ministry dated 16 July 1940. See also Webster and Frankland *The Strategic Air Offensive, Vol i*, p150.

<sup>4</sup> Peter Gray, *The Leadership, Direction and Legitimacy of the RAF Bomber Offensive from Inception to 1945* (London: Continuum International Publishing Group, 2012), p169.

<sup>5</sup> Denis Richards, *Portal of Hungerford* (London, 1977), p307.

no damage was visible following photographic reconnaissance<sup>6</sup>. The warning signs were already there for those who cared to look. The raid had taken place in moonlight against a coastal target, with strict instructions to the Groups to send only the most experienced crews. Nonetheless, nearly 20% of crews taking part failed to locate the target at all, and no visible damage was inflicted on the target itself. The Bomber Command report on the raid reached the inescapable conclusion that: "The operation does not confirm that as a general rule, the average crews of our heavy bombers can identify targets at night, even under the best conditions...."<sup>7</sup>. The report went on to conclude that: "Our general opinion is that under war conditions the average crew of a night bomber could not be relied upon to identify targets at night except under the very best conditions of visibility, even when the target is on the coast or a large river.....if the target has no conspicuous aids to its location, very few inexperienced crews would be likely to find it under any conditions". It was not an auspicious start of the night bombing campaign.

Nor was this the first warning that finding targets at night would be problematic. From the very first night of the war, Whitley bombers of No. 4 Group had been groping their way in the darkness over Germany engaged on leaflet dropping. The Group Commander - the same Air Commodore Coningham who a month earlier had declared that the accuracy of night bombing will differ little from daylight bombing - was already aware of the difficulties that his crews were experiencing and was sufficiently concerned to

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<sup>6</sup> TNA AIR14/2782 Report on air operations against the German Air Station on the night of 19/20<sup>th</sup> March 1940, dated 10 April 1940. A total of 50 aircraft took part in the raid, with 41 crews reporting that they had located the target.

<sup>7</sup> Ibid. Also quoted, in part, in Hastings *Bomber Command*, p82.

report as much to Bomber Command Headquarters<sup>8</sup>. Indeed, the warning signs were present even before the outbreak of war. In the last two years before hostilities, 478 Bomber Command aircraft engaged on night cross-country exercises over England force-landed away from their bases having become lost<sup>9</sup>. If these crews, using 'Bradshaw navigation'<sup>10</sup> and with towns and cities illuminated, became lost with such regularity it should not have been surprising that crews were unable to locate to navigate accurately over blacked-out enemy territory.

The problem of finding a target at night was two-fold. First, the crew had to navigate to the general area of the target using dead-reckoning<sup>11</sup>. The principles of dead-reckoning are set out in the Manual of Air Navigation (AP1234) published in 1938<sup>12</sup>, but essentially requires two vectors, i) the course and airspeed of the aircraft and ii) the direction and speed of the wind. The former gave the theoretical position of the aircraft in conditions of zero wind and is therefore known as the air position vector; the latter being known as the wind vector. These vectors were computed to produce a third vector, this being the track and ground speed of the aircraft. It was this third vector that dictated the progress of the aircraft over the ground<sup>13</sup>.

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<sup>8</sup> Webster and Frankland *The Strategic Air Offensive, Vol i*, p212.

<sup>9</sup> TNA AIR14/57 Bomber Command Annual Training Report, 1938.

<sup>10</sup> 'Bradshaw navigation' was derisory RAF slang for the practice of following railway lines as a means of navigation, named after George Bradshaw, the inventor of the railway timetable.

<sup>11</sup> Usually abbreviated to D/R. Also known as 'Deduced Reckoning'.

<sup>12</sup> TNA AIR20/1905 Manual of Air Navigation (AP 1234), 1938 (Reprint). See also Aylife, *The development of Airborne Dead Reckoning: Part I – Finding the Wind, Part II – Staying on Track*, p463-476.

<sup>13</sup> Eric Cropper. *Back Bearings: a Navigator's Tale 1942 to 1974* (Barnsley: Pen & Sword Aviation, 2010), p19.



The principal difficulty with D/R navigation is the calculation of the wind vector which not only changes over time, but usually differs in both strength and direction at various altitudes. The only practical means of calculating the wind vector is to compare the air position vector with a known ground position. Consequently, D/R navigation can only be continued with any degree of accuracy if the position of the aircraft can be confirmed by 'taking a fix'. Prior to the introduction of electronic and radar navigation aids, the principal methods of taking a fix were by map reading; astro-navigation (using a sextant); and radio-direction finding. However, map reading relies upon a clear sight of the ground, whereas both astro-navigation and radio-direction finding were difficult and lengthy processes, and ultimately unreliable. Moreover, at best, astro-navigation and radio-direction could only get an aircraft to the target area<sup>14</sup>.

Notwithstanding the difficulties involved, calculating the wind vector is essential to D/R navigation because the heading needs to be adjusted to make good the desired track. Moreover, any errors in dead-reckoning due to an inaccurate wind vector are cumulative over distance and it was found that D/R navigation on its own produced errors of 10% of the distance flown, equating to errors of 30-40 miles for most targets in Germany<sup>15</sup>. It follows that the significant errors in navigation during early bombing operations largely resulted from the inaccurate forecast of wind vectors compounded by the

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<sup>14</sup> Webster and Frankland *The Strategic Air Offensive, Vol i*, p210.

<sup>15</sup> TNA AIR14/2693 Operational Research Section Bomber Command (ORSBC) Report No S.252 The effect of the development of navigational and blind bombing techniques of the efficiency of bombing operations during World War II (Aug 1941 – May 1945), dated October 1945.

inability of crews to calculate the true wind vector by checking ground position with a reliable fix.

Having navigated to the general area, the second problem was locating the particular target. As early as May 1939, Sir Edgar Ludlow-Hewitt, at that time Commander in Chief of Bomber Command, observed that it was important to know 'exactly what type of target was worthwhile allotting for attack at night...' although nothing was done to resolve that question before hostilities commenced<sup>16</sup>. Consequently, Bomber Command transitioned to a night force with little or no understanding of the visibility of targets at night.

The task of determining the visibility of targets at night fell to the Whitley crews of the early leaflet raids. The reports of the crews taking part were a portent of the difficulties soon to be faced by Bomber Command. In October 1939, Air Commodore Coningham reported that the ability of crews to see a target depended upon the state of the moon and the weather; whether the target was blacked out or self-illuminating; the height at which the aircraft was flying; and the dazzle from searchlights<sup>17</sup>. In moonlight, it was found that areas of water became self-illuminating by reflection of the moonlight and that large rivers, canals and lakes could be seen from above 12,000ft. Small rivers, on the other hand, were not visible above 8,000ft whereas railway lines were visible at certain angles from a 'surprising height'. Small towns could be

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<sup>16</sup> Webster and Frankland *The Strategic Air Offensive, Vol i* p113.

At that time, Sir Edgar Ludlow-Hewitt was C-in-C Bomber Command.

<sup>17</sup> Webster and Frankland. *The Strategic Air Offensive Vol i*, p206. Report by Air Commodore Coningham to Bomber Command 11<sup>th</sup> October 1939.

seen from heights to 4,000ft to 6,000ft, but separate buildings were not visible from above 3,000ft to 4,000ft.

However, on dark nights with no moon, only crews flying at low level could distinguish land from water, and only self-illuminating objects such as blast furnaces were visible at height. The solution, ventured Air Commodore Coningham, was a timed run to the target from visible features nearby although, when tried in January 1940, bombing runs at 6,000ft from ten, fifteen and twenty miles produced errors of 1,200 yards, 4,480 yards and 5,280 yards respectively<sup>18</sup>. In the light of this report, the later optimism expressed by Air Commodore Coningham about the accuracy of night bombing, referred to above, is difficult to reconcile.

As early as November 1940, Bomber Command was already well aware that only one third of aircraft despatched reached their targets<sup>19</sup>. By early 1941, there was growing realisation within the Air Staff that it was futile to attempt the destruction of precision targets in anything other than moonlit nights. A paper produced in April 1941 by the Deputy Director of Bombing Operations (D.D.B. Ops) accepted that successful attack on specific targets at night can only be undertaken in clear moonlight and, it followed, that for three-quarters of each month it was only possible to obtain satisfactory results by concentrated attacks of working class and industrial areas in selected towns. It was further accepted that it was a matter of the greatest difficulty to find

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<sup>18</sup> Webster and Frankland *The Strategic Air Offensive Vol i. p209* Report on trials on 18<sup>th</sup>, 20<sup>th</sup> and 26<sup>th</sup> January 1940. The technique of offset bombing, or more correctly offset marking, would be used with considerable success by No. 5 Group later in the conflict, as discussed in Chapter Six.

<sup>19</sup> TNA AIR14/64 Minutes of the Group Navigation Officers Conference, 12 November 1940.

these selected towns on moonless nights unless they were located on or near water<sup>20</sup>. This was essentially the same conclusion that Bomber Command had itself reached exactly a year beforehand following the first night bombing attack of the war<sup>21</sup>.

By mid-1941, not only was there a general acceptance within the Air Staff and Bomber Command that the average crew was unable to locate precision targets other than in perfect conditions<sup>22</sup>, there were growing doubts about the accuracy of bombing in other quarters. One of those concerned was Lord Cherwell, the personal scientific advisor to the Prime Minister, who on his own initiative commissioned an independent investigation into the matter. This investigation was carried out by Mr David Bensusan-Butt, an economist in the Statistical Section of the War Cabinet secretariat<sup>23</sup> and his report, known as the Butt Report, was to have far reaching consequences for the outcome of the bombing offensive.

The Butt Report was issued to Bomber Command on 18 August 1941<sup>24</sup>. The report examined “about 650” photographs taken during night bombing

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<sup>20</sup> Webster and Frankland *The Strategic Air Offensive, Vol iv*, p137. Paper on bombing policy by D.D.B. Ops dated 24<sup>th</sup> April 1941, attached with minor revisions as an appendix to the Ministry Directive dated 9<sup>th</sup> July 1941.

<sup>21</sup> See the description above of the attack on the sea-plane base at Hornum on the 19/20 March 1940.

<sup>22</sup> Webster and Frankland *The Strategic Air Offensive, Vol iv*, p137. Paper on bombing policy by D.D.B. Ops dated 24<sup>th</sup> April 1941, attached with minor revisions as an appendix to the Ministry Directive dated 9<sup>th</sup> July 1941

<sup>23</sup> Overy. *The Bombing War; Europe 1939-194*, p267.

<sup>24</sup> TNA AIR8/1356 ‘Report by Mr Butt to Bomber Command on his Examination of Night Photographs’ 18 August 1941.

operations between 2 June and 25 July 1941<sup>25</sup>. The statistical conclusions of the Butt Report, set out in a summary right at the beginning, were as follows:

1. Of those aircraft recorded as attacking their target, only one in three got within five miles.
2. Over the French ports, the proportion was two in three; over Germany as a whole, the proportion was one in four; over the Ruhr, it was only one in ten.
3. In the Full Moon, the proportion was two in five; in the new moon it was only one in fifteen.
4. In the absence of haze, the proportion is over one half, whereas in thick haze it is only one in fifteen.
5. An increase in the intensity of A.A. fire reduces the number of aircraft getting within five miles of their target in the ratio three to two.
6. All these figures relate only to aircraft recorded as *attacking* the target; the proportion of the *total sorties* which reached within five miles is less by one third (original emphasis).

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<sup>25</sup> The figure of “about 650” photographs is derived from the summary of the Report. However, the key findings of the Report are mostly based on a sample of 633 photographs, with a slightly higher total of 649 photographs used solely in the analysis of the ‘Effects of Haze’ – the additional six photographs reckoned in this part of the Report relate to alternative targets.

Thus, of the total sorties dispatched only one in five got within five miles of the target, i.e with[in] the 75 square miles surrounding the target<sup>26</sup>. The magnitude of this error is neatly encapsulated by Norman Longmate who, making a comparison with London, observed that a bomb aimed at the Houses of Parliament would have been counted as being on target if it had landed on Streatham Common, Hammersmith Broadway or the East India Dock Road<sup>27</sup>. The findings of the Butt Report are therefore a grim indictment of the capability of Bomber Command at that time.

In most accounts of the bombing offensive, reference to the Butt Report is confined to this headline result and to the debate that followed<sup>28</sup>. However, for the purposes of benchmarking the effect of target marking, the detailed findings of the Report are of particular importance and it is therefore necessary to conduct a forensic examination of them.

The main text of the Butt Report sets out the basis for the statistical analysis, beginning with a brief description of the methodology. In this context, it is explained that the 650 photographs relate to 28 targets, 48 nights and 100 separate raids<sup>29</sup>. The Butt Report then reviews of the success of attacks over the period as a whole, confirming that the total number of photographs

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<sup>26</sup> Although the figure 75 square miles' is used in the Report, the actual area of a target area having a radius of 5 miles is 78.55 square miles.

<sup>27</sup> Longmate. *The Bombers*, p121.

<sup>28</sup> Hastings. *Bomber Command*, p.p 108-109; Longmate. *The Bombers*) p.p. 120-122; Neillands. *The Bomber War: Overy. The Bombing War; Europe 1939-1945* (Allen Lane, London 2013), p.p. 267-268; Richards. *The Hardest Victor.,* p.p. 96-97; Anthony Verrier *The Bomber Offensive* (Pan Books, 1974), p.p. 133-135.

<sup>29</sup> The 28 targets attacked are not specified in the Report, although some indication of these targets is given later in the Report where the targets are divided into target groups.

purporting to represent the target, target area or believed target area was 633. Of this total, 326 (51%) were not plotted; 113 (18%) were plotted outside the target area and 194 (31%) were plotted inside the target area (see Fig 1/).

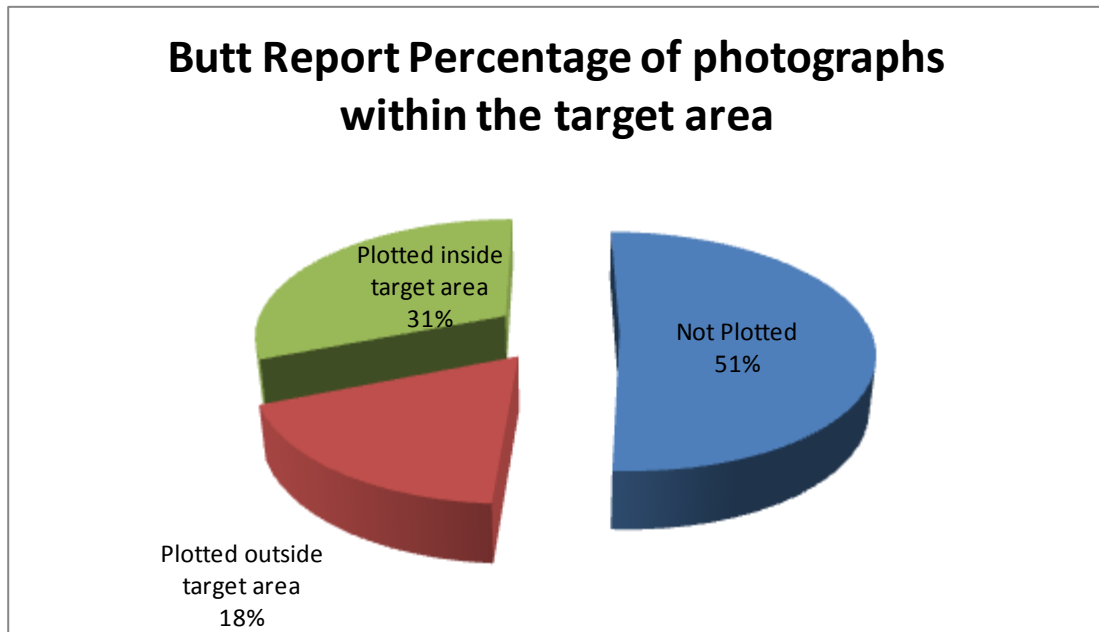


Fig 1/ Butt Report: Percentage of photographs within the target area

The conclusion reached in this part of the Butt Report is that only about one third of aircraft claiming to reach the target actually reach it<sup>30</sup>. No doubt realising the significance of this conclusion, the Butt Report then makes two very important qualifications to this figure:

- a) that the figure of one third (and all other percentages in the Butt Report) relates to aircraft recorded as having attacked the primary target, not to the total aircraft dispatched. During the period covered by the Butt Report, a total of 6,103 aircraft were dispatched but only 4,065 claimed to have attacked the primary target: – 66% of those

<sup>30</sup> The figure of 'about one third' is the 31% of photographs plotted within the target area.

dispatched. Thus, the Butt Report concluded, of the total number of aircraft dispatched only one fifth actually reached the target.

- b) That by defining the target area as having a radius of five miles, an area of over 75 square miles is taken<sup>31</sup>. This must mean, the Butt Report observes, that for any town other than Berlin the vast majority of the target area consists of open country. It therefore follows that the proportion of aircraft actually dropping their bombs on built up areas must be very much less than the roughly one third of aircraft reaching the target area.

The majority of the Butt Report is devoted to the analysis of those factors affecting the success of attack, namely ground features, moonlight, haze, cloud, and Anti-Aircraft fire. In terms of the subsequent development of target marking techniques, the first four factors are of particular relevance and it is therefore helpful to consider the findings of the Report in relation to these factors in more detail.

In relation to ground features, the sample was too small to allow analysis of how easily individual targets could be found and therefore the Butt Report divided the targets into five groups: French ports<sup>32</sup>; German ports<sup>33</sup>; the

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<sup>31</sup> As indicated above, although the phrase 'over 75 square miles' is used in the Report and is retained here, the actual area of a target area having a radius of 5 miles is 78.55 square miles. The origin of the choice of five miles as the target area is not clear. A later report by the Operational Research Section of Bomber Command implies that the choice of five miles in the Butt Report was an arbitrary one.

<sup>32</sup> Brest, Lorient and La Pallice



Ruhr<sup>34</sup>; All Germany<sup>35</sup>; and All targets. The effect of ground features on the ease with which these target groups could be found is then presented in the following table and shown here in Fig 2/ below<sup>36</sup>:

		Photographs		
Target Groups	No. of Raids	Total	In Target	% In Target
French ports	9	94	60	64
German Ports	21	91	16	18
Ruhr	38	225	21	9
All Germany	91	539	134	25
All targets	100	633	194	31

Table 1/ Butt Report: target groups

<sup>33</sup> Bremen, Emden, Hamburg and Kiel

<sup>34</sup> Cologne, Dortmund, Duisburg, Dusseldorf, Essen, Hamm, Schwerte

<sup>35</sup> Unlike the other groups, the individual targets in this group are not specified in the Report. However, targets in Germany other the ports and the Ruhr attacked during this period included Berlin, Frankfurt and Hannover. Source: The Bomber Command War Diaries

<sup>36</sup> The presentation of this table is slightly modified here to facilitate representation in diagrammatic form, although the statistical contents remain unaltered.

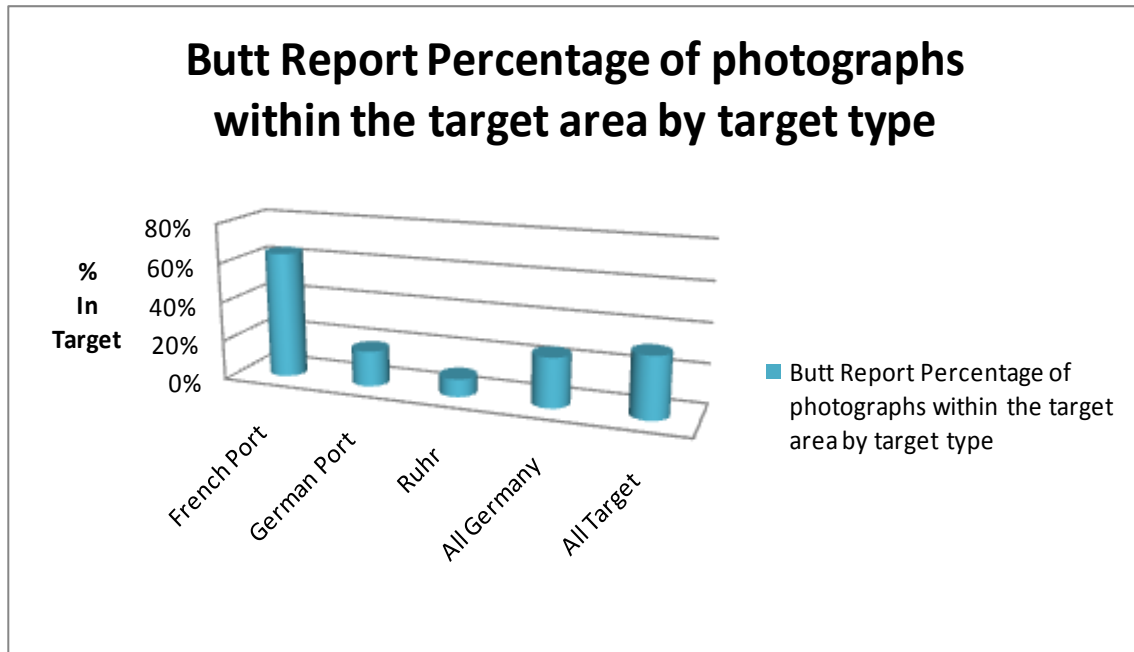


Fig 2/ Butt Report: Percentage of photographs within the target area by target type

The Butt Report then analysed the relative success with which targets were reached in three phases of the moon cycle: full moon, half moon and new moon<sup>37</sup>. To this was added the effect of haze, for which purposes all references to haze were classified into 3 categories based upon the classification in crew reports:

- (1) 'Nil' or 'slight' or 'clear', etc = Nil
- (2) 'Some haze', 'hazy', etc = Medium
- (3) 'Thick haze', 'very hazy', etc = Thick

By combining the phase of the moon with the amount of haze, the report arrives at what are termed as the 'nine states of visibility'. Taking the degree

<sup>37</sup> In each case, the moon period was defined as the night of that phase (full, half and new) and three nights before and after.

of success (say 60-70%) attained in Full Moon conditions with Nil haze as a value of 100, the Report summarises the results for the 'nine states of visibility' as follows and shown here in Fig 3/ below<sup>38</sup>:

Moon	Haze		
	Nil	Medium	Thick
Full	100	40	23
Half	100	32	7
New	40	(4)	(3)

Table 2/ Butt Report: the 9 states of visibility

<sup>38</sup> For reasons that are not explained, this table in the Butt Report reverts to the description of haze found in the pilots reports rather than the descriptions of 'Nil', 'Medium' and 'Thick' provided by the Meteorological Branch, and as used in the preceding table. For consistency, the latter have been retained here. The figures in brackets are based on too small a sample to be significant.

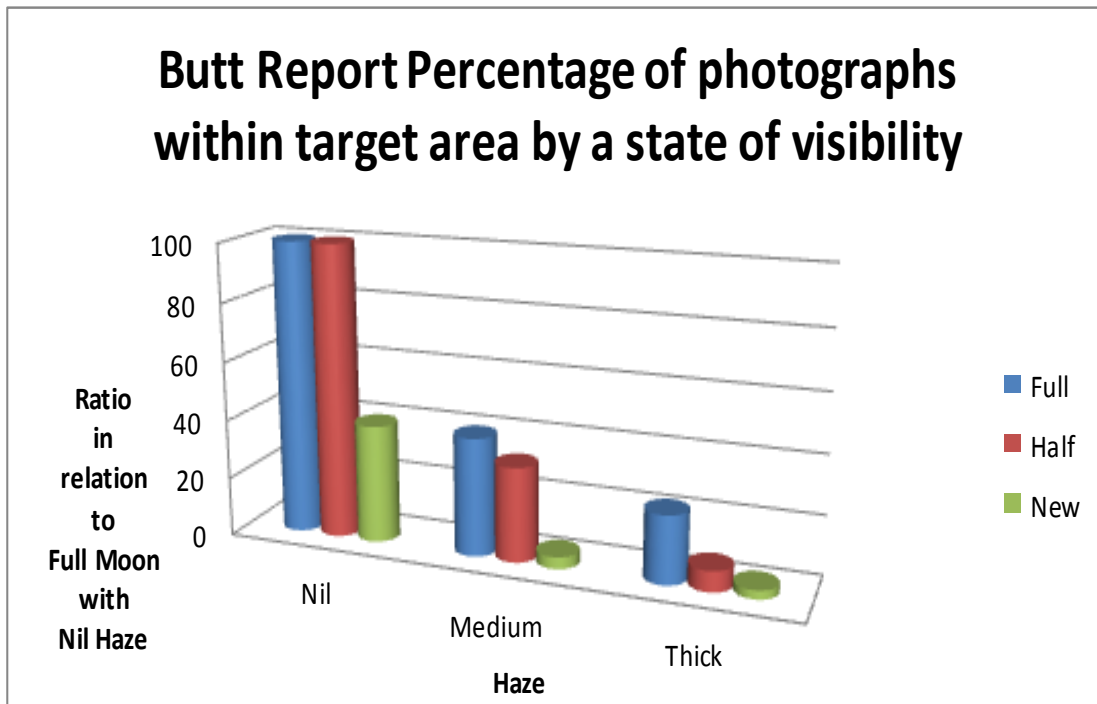


Fig 3/ Butt Report: Percentage of photographs within target area by state of visibility

Next, the Butt Report conducts a similar exercise in relation to the effect of cloud cover. As with the effect of moonlight and haze, the level of cloud cover is divided into categories according to the forms rendered with the photographs. The three categories are:

- (1) Little = nil, clear, slight, one tenth to three tenths cloud cover<sup>39</sup>
- (2) Medium = medium, cloudy, four tenths to six tenths cloud cover
- (3) Heavy = dense, heavy, seven tenths to ten tenths cloud cover

<sup>39</sup> This is another example in the Report where the categories set out in the table differ from those set out in main text. For the sake of clarity, the categories used in the table here have been matched with their respective description in the main text. The Report follows the then practice of measuring cloud cover in 'tenths', since replaced by the 'Okta' (eighths) as the standard measure of cloud cover.

Using these categories, the following results were obtained and shown here as Fig 4/ below.

Moon	Cloud Amount	Successful Photographs Taken <sup>40</sup>		
		In Target Area	Total	No. In Target Area as Percentage of Total
Full	Heavy	1	19	(5)
	Medium	7	15	(46)
	Little	64	116	55
Half	Heavy	2	16	(12)
	Medium	3	13	(23)
	Little	43	91	47
New	Heavy	-	17	(0)
	Medium	1	19	(5)
	Little	4	47	8

<sup>40</sup> This table was based upon a smaller sample of reports (353 photographs, compared to 633 in most cases, or 649 in one case) and the Butt Report acknowledges is therefore less reliable. The numbers in brackets are based on a sample too small to be significant.

All Phases	Heavy	3	52	6
	Medium	11	47	23
	Little	111	254	44
Total		125	353	35

Table 3/ Butt Report: effect of cloud cover

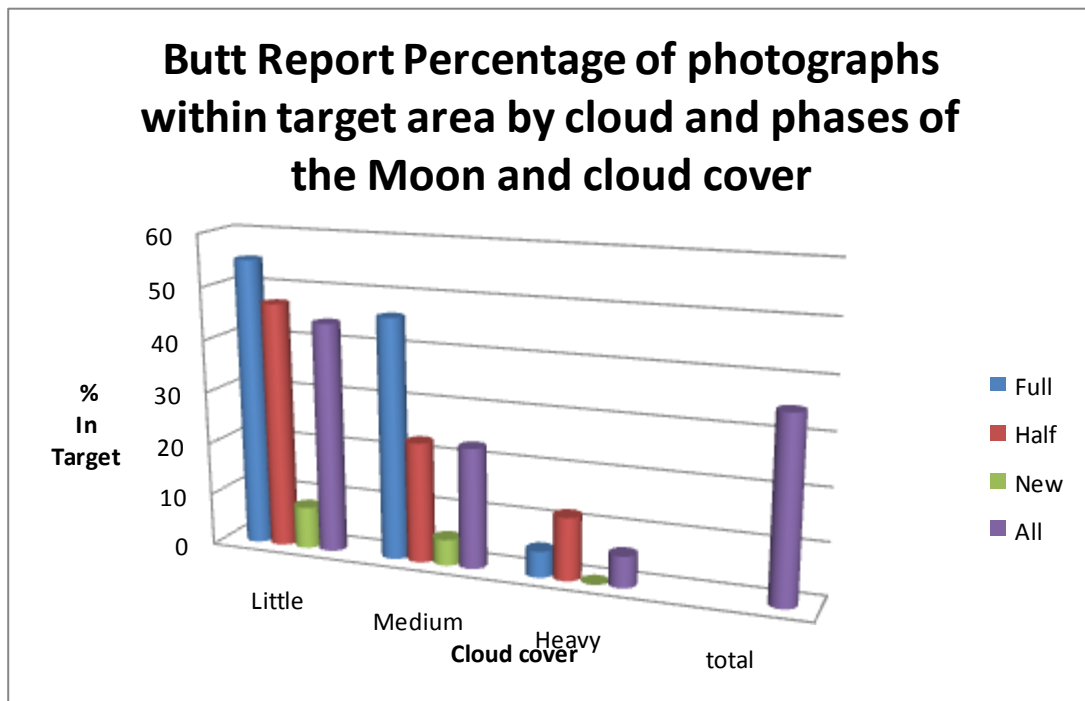


Fig 4/ Butt Report: Percentage of photographs within target area by cloud and phases of the moon

The Butt Report was concerned with locating a target area of some 75 square miles whereas target marking techniques would relate to the identification of a specific Aiming Point (A/P). Nonetheless, the same basic principles relating to the visibility of the ground at night apply equally to both. Consequently, in

relation to target marking, perhaps the key finding in the Butt Report is the importance of ground features on the percentage of aircraft reaching the target area, particularly the presence of distinctive water features such as docks. Also significant is the effect of the haze, given that industrial haze was an ever-present feature over many German cities. During the full or half moon periods, the analysis of the 'nine states of visibility' showed that even the presence of medium haze significantly reduced the number of aircraft reaching the target area. In conditions of a new moon and thick haze, even assuming no cloud cover, very few aircraft got within five miles of the target. In the context of the improving German defences at this time, which would shortly force Bomber Command to abandon large scale operations during the full moon period, the performance of Bomber Command during the 'nine states of visibility' demonstrates the scale of the task facing those charged with finding a target at night and therefore the value of target marking techniques.

Based on the findings summarised above, the Butt Report made a number of recommendations for further study. These can be distilled down into two key recommendations:

1/ That, whilst the figures in the report should not be rejected 'without enquiry', it was very desirable that they should be checked in every possible way and that such an enquiry should be carried out, and

2/ That a statistical branch should be formed under a fully trained statistician to assess night photographs and provided with sufficient clerical staff to maintain records and carry out the computations involved.

The Butt Report was the first to statistically analyse the performance of Bomber Command in relation to the various factors that affected visibility of the ground at night. In this respect, it is difficult to underestimate the importance of the Butt Report. This is not to say that the Butt Report should be taken as in any way definitive - indeed, the Butt Report did not itself claim to be infallible - but wherever there is possibility of error in the results, the Butt Report is quick to explain why the results are considered to be a good indication of the true outcomes.

Even with this caveat in mind, the results in the Butt Report are nothing short of startling, and none more so than the overall finding that only one in five of the total sorties dispatched got within five miles of a target measured as over 75 square miles. The importance of the Butt Report has been questioned by Richard Overy, who contends that its significance can easily be exaggerated<sup>41</sup>. However, it is beyond the remit of this thesis to enter that debate. The purpose of referring to the Butt Report in detail here is that it represents the first scientific attempt to quantify the performance of Bomber Command. Moreover, although some at Bomber Command sought to challenge the findings of the Report - the Official History records that the Commander in Chief Bomber Command, at that time Sir Richard Pierse,

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<sup>41</sup> Overy. *The Bombing War; Europe 1939-1945*, p268.



opined that “ I don’t think at this rate we could have hoped to produce the damage which is known to have been achieved” – the accuracy of the statistical findings have not been seriously challenged. These findings therefore provide a reliable statistical benchmark for the performance of bomber command without electronic navigation aids and before the introduction of organised target marking.

It is a truism that the first stage to solving any problem is to acknowledge that the problem exists. The Butt Report had achieved this first stage - albeit begrudgingly within Bomber Command itself - but it was next necessary to solve the problem now acknowledged to exist. As described above, one of the recommendations of the Butt Report was that a statistical branch should be formed under a fully trained statistician to assess night photographs and this ultimately led to the formation of the Operational Research Section in Bomber Command (ORSBC). Throughout the remainder of the bombing offensive, ORSBC would undertake extensive research into the accuracy and effectiveness of bombing and target marking techniques, the findings of which are extensively relied upon in this thesis<sup>42</sup>.

Between November 1941 and April 1942, ORSBC published a series of reports on the performance of Bomber Command in terms of target identification. The purpose of the analysis was to identify those features most commonly relied upon by crews to identify a target and, therefore, to better understand the errors crews were making in target identification. Although

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<sup>42</sup> For a detailed description of the formation and history of the Operational Research Section at HQ Bomber Command, see Dickins. ‘Operational Research in Bomber Command’ and Wakelam, *The Science of Bombing*.

ORSBC produced reports on the accuracy of bombing at regular periods until the end of the war, the three reports detailed here were the only reports produced by ORSBC that adopted the same five mile target area used in the Butt Report. Furthermore, each of these reports considered the difficulties of target identification in conjunction with bombing accuracy, presented the data in essentially the same format and related to periods when no navigation aids were available. All subsequent ORSBC reports on overall bombing accuracy used a three mile target area as the basis for analysis and, for the most part, presented the data in a different format to that used in these reports. All subsequent ORSBC reports also covered periods during which at least one navigation aid was in operational use. It is therefore convenient to consider these three reports as a series for the sake of comparison with the findings in the Butt Report.

The first, albeit preliminary, analysis conducted by ORSBC considered operations carried out in October 1941<sup>43</sup>. This analysis showed that 12% of aircraft plotted were within 5 miles of the target and a further 8.5% within 6 to 10 miles. Of those crews claiming to have identified the target, photographs showed that 26% were within 5 miles of it, with a further 17% crews within 6 to 10 miles. Those crews unable to identify the target (48%) cited poor visibility due to haze and cloud cover as the main reasons.

The features given by the crews as the means of target identification were variously given as follows:

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<sup>43</sup> TNA AIR14/1758 ORSBC Memorandum No.19 "Preliminary Note on Questionnaire relating to Target Identification", 19 November 1941,. The 'Questionnaire' was the insertion of three questions relating to target identification on the pilots post raid forms.

Feature	No. of times given
Rivers	27
Docks	18
Coastline	11
Railways	2
Lakes	2
Promontory	1
Autobahn	1

Table 3/ ORSBC Report: features given by crews as means of target identification Source: TNA AIR14/1758. ORSBC Memorandum No.19 'Preliminary Note on Questionnaire relating to Target Identification', 19 November 1941.

Commenting on these findings, the ORSBC report made three observations: i) that rivers made particularly unreliable landmarks; ii) that coastlines were a more reliable guide but could be deceptive, and iii) that views of docks were not decisive. The general conclusion drawn was that reliance should not be placed on one feature alone, but should be based on a number of features in conjunction.

The second analysis on target identification conducted by the ORSBC was a more comprehensive undertaking<sup>44</sup>, the stated purpose of which was to identify which ground features provided the greatest help in identifying targets. The report found that two factors affected the degree of success achieved in identifying targets: i) the weather conditions, and ii) the height at which the aircraft flew. In relation to the former, it was noted that only on three occasions where there was thick haze or cloud did the crews claim to have identified the target – and on none of these were the crew proved correct by the photograph. Similarly, of those crews claiming to have identified the target in conditions of moderate cloud or haze, the photographs showed only 16% to have been within 5 miles.

In the remaining instances where crews claimed to have identified the target, visibility was described as good (84%). Nonetheless, only 55% of these crews were correct in their claim. Moreover, on one of the nights within the period covered<sup>45</sup>, visibility was exceptionally good. On this night, of those crews claiming to have identified the target, 91% were proved to be correct. If this raid is discounted from the figures, the percentage of crews claiming to have reached the target which actually did so falls from 48% to 35% - a figure consistent with that reached in the Butt Report.

In relation to the height at which aircraft flew, the investigation showed that there was little difference in the ability of crews to identify targets at altitudes above 13,000ft. However, below that height, smaller ground features such as

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<sup>44</sup> TNA AIR14/1758 ORSBC Report 31 'The Visual Recognition of Ground Features as an Aid to Target Identification at Night', 14<sup>th</sup> February 1942.

<sup>45</sup> The night of 28<sup>th</sup>/29<sup>th</sup> December 1941

bridges and breakwaters became discernable, and this provided valuable evidence of position.

The main body of the report was devoted to the reliability of various ground features in identifying targets, beginning with an overall appreciation of the benefit of relying on more than one feature for this purpose. The results were set out in the following table.

No. of ground features identified	Total No. of aircraft returning photos	No. of photos showing target area	% of aircraft returning photos within target area
1	86	28	38
2	53	25	47
2+	28	23	82

Table 4/ ORSBC Report: 'Percentage of aircraft within target area by number of features identified'. Source: TNA AIR14/1758 ORSBC Report 31 'The Visual Recognition of Ground Features as an Aid to Target Identification at Night', 14 February 1942.

It may be seen from the above results that the percentage of aircraft within the target area increases with the number of ground features identified, with a significant increase when two or more ground features are identified. This reflects the importance of regular position fixes, cross referenced with two or more ground features, to accurate D/R navigation. However, it may also be noted that the proportion of crews that identified more than one ground

feature is almost the inverse of the percentage within the target area. Although not identified directly in the report, this relationship is likely to have been the basis for the recommendations that followed.

The implications of these findings were crucial to the eventual introduction of target marking. In order to positively identify a target by means of two or more ground features, crews would need to spend a significant amount of time in the target area searching for those features. However, as these results showed, relatively few crews were in fact identifying more than two ground features and therefore achieving the commensurate accuracy in target identification.

The report then examined the effectiveness of specific ground features in identifying targets<sup>46</sup>. The results were again expressed in a table, reproduced here as Table 5/, and shown diagrammatically as Fig 5/ below:

Feature		Total Photos	Photos in target area	%
A	Docks	61	32	52
B	Rivers	47	8	17
C	Coast <sup>47</sup>	39	20	51

<sup>46</sup> The report does this both in the main body of the report and in an Appendix, which gives specific examples where each ground feature was relied upon by crew. For convenience, these considerations are amalgamated here, and the format in which the information presented altered.

D	Town	11	6	55
E	Breakwaters	9	6	67
F	Lakes	9	2	22
G	Bridges	6	3	50
H	Railways	4	1	25
I	Canal	3	3	100

Table 5/ ORSBC Report: 'Effectiveness of specific ground features in identifying targets'. Source: TNA AIR14/1758 ORSBC Report 31 'The Visual Recognition of Ground Features as an Aid to Target Identification at Night', 14 February 1942.

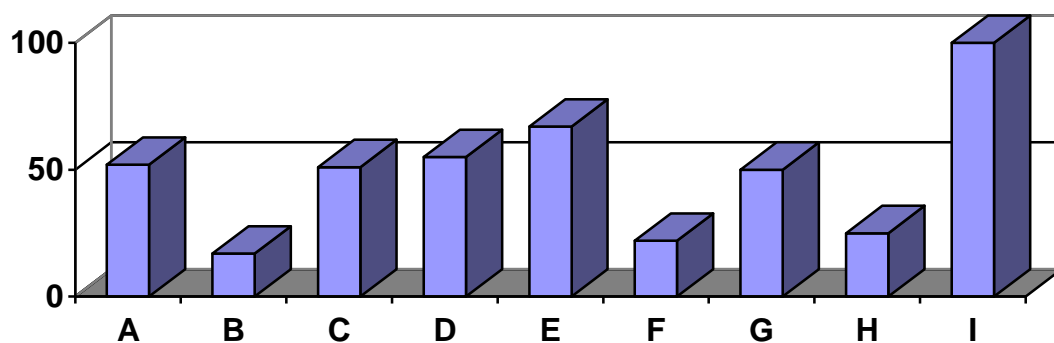


Fig 5/ ORSBC Report: 'Effectiveness of specific ground features in identifying targets'. Source: TNA AIR14/1758 ORSBC Report 31 'The Visual Recognition of Ground Features as an Aid to Target Identification at Night', 14 February 1942.

The report noted that, despite the popularity with crews for pinpointing position, only 17% of pinpoints based solely on rivers were correct. As with the previous report, coastal features and docks appeared to be a fairly reliable

<sup>47</sup> This category included bays, estuaries and promontories, but not breakwaters.

means of target identification but the report considered that lakes did not make particularly good landmarks. The report does not consider other features in any detail but offers the general observation that railways were only correctly identified in conjunction with another feature and that, of the six instances where towns were correctly identified, only on two occasions were the towns identified in isolation and without corroboration by another landmark feature - on both occasions, this was in good visibility.

On the basis of this analysis, the report offered five conclusions:

- i) In order to identify a position, at least two and preferably more ground features should be recognised and their relative position checked.
- ii) Rivers are a very unreliable landmark, but bridges may sometimes make them less so.
- iii) Coastal targets are the most easily recognised, docks being the most frequently mentioned and most reliable feature.
- iv) The size of ground features such as rivers, lakes and coastal features are frequently misjudged from height, and
- v) Small rivers, lakes and canals are so numerous in Germany and so easily confused that little reliance can be placed upon them.



In closing, the authors considered that the report served to emphasise the “immense difficulties” which confronted crews in the task of recognising their targets at night. The report goes to express the view that little success could be expected unless the weather is reasonably good, but that in favourable conditions it ought to be possible for a larger proportion of aircraft to reach their targets than were doing so.

The final report in this series covered the period between December 1941 and February 1942<sup>48</sup>. This report differed from the preceding reports in that for the first time an attempt was made to assess the number of aircraft which, having reached the five mile target area, then went on to reach the target itself. During this period, 60% of crews claimed to have reached the target. However, only 45% of the photographs showing ground detail were plotted within the five mile target area, such that only 27% of the total sorties dispatched actually reached within 5 miles of the target. The report then categorised this overall result in relation to levels of illumination and cloud cover, with the findings as follows and shown here as Fig 6/ below:

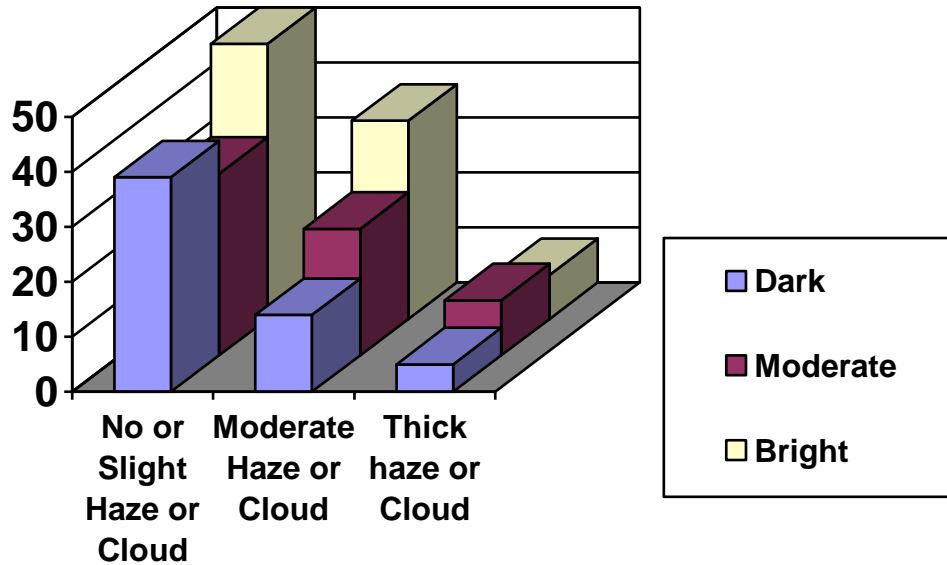
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<sup>48</sup> TNA AIR14/2692 ORBCS Report S.45 ‘Success of bombing operations as shown by night photographs Dec.41 – Feb 42’, 22 April 1942.

Weather Conditions	Illumination	Total Sorties Despatched	No. Claiming Attack	No. of photos showing ground detail	No. of photos showing target area	%	% June – Nov 1941
No or Slight Haze or Cloud	Bright	484	347	154	105	68	50
	Moderate	49	37	25	14	56	33
	Dark	163	120	90	46	51	39
Moderate Haze or Cloud	Bright	442	321	22	8	36	36
	Moderate	205	152	17	2	12	23
	Dark	761	500	45	9	20	14
Thick Haze or Cloud	Bright	1252	672	30	5	17	8
	Moderate	172	73	11	3	27	10
	Dark	533	222	37	2	5	5

Table 6/ ORSBC Report; percentage within target area. Source: TNA AIR14/2692 ORBCS Report S.45 "Success of bombing operations as shown by night photographs Dec.41 – Feb 42", 22<sup>nd</sup> April 1942.

### % of photos within target area June - Nov 1941



### % of photos within target area Dec 1941 - Feb 1942

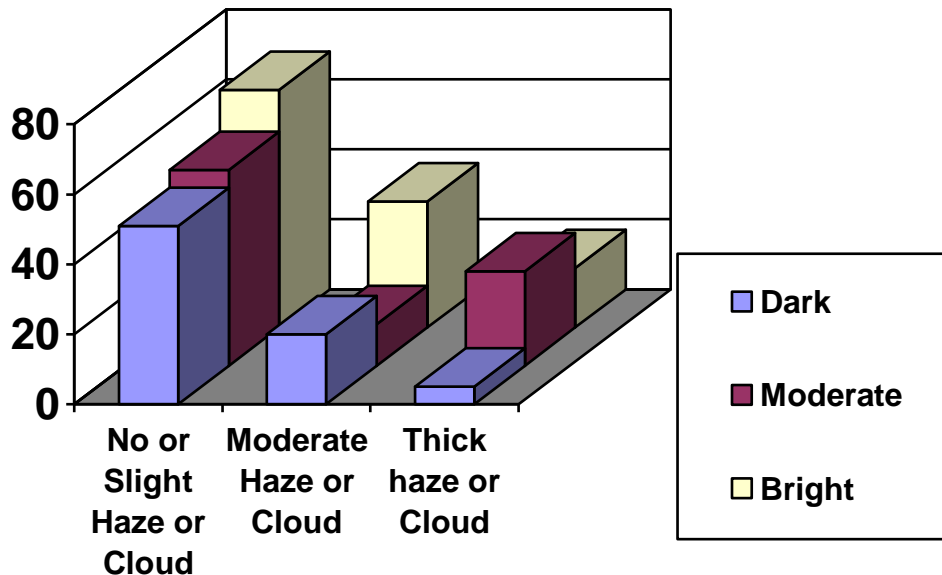


Fig 6/ ORSBC Report: 'Comparative charts for June - Nov 1941 and Dec 1941 - Feb 1942'. Source: TNA AIR14/2692 ORBCS Report S.45 'Success of bombing operations as shown by night photographs Dec.41 – Feb 42', 22 April 1942

Comparison of these results with the two previous ORSBC reports indicates that, in overall terms, there was a modest improvement in bombing performance during this period. It may be noted that in conditions of no or slight haze or cloud the percentage of aircraft claiming to have attacked that in fact reached the target area had risen to 50% irrespective of the moon period. However, in conditions of moderate or thick cloud cover, especially on dark nights, the percentage of crews claiming to have attacked reaching the target area was consistently low. Moreover, these figures relate only to those aircraft claiming to have attacked. Measured against the total number of aircraft dispatched, the performance was even lower.

The report then goes on to estimate the degree of concentration in space on the target itself by determining the distance of the plotted photographs from the A/P<sup>49</sup>. This was achieved by plotting the percentages of the total photographs within a given circle around the target against the area in square miles around the A/P. The results were plotted on a graph as curves, repeated for different weather conditions, the shape of which close to the origin showed the concentration in space around the A/P. This graph is reproduced below as Fig 7/, in which the 'x' axis is the area in square miles around the aiming point and the 'y' axis is the percentage of photographs within a given circle around the target<sup>50</sup>.

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<sup>49</sup> In the context of bombing performance, the term 'concentration' is usually used to describe the number of aircraft bombing within a given time period. However, in this report, 'concentration' is used in relation to the distances of plotted night photographs from the Aiming Point.

<sup>50</sup> For purposes of comparison with the Butt Report, an area of 75 miles around the aiming point corresponds to a distance of five miles from the target. A distance from the target of one

### Distribution of plotted photographs around the target

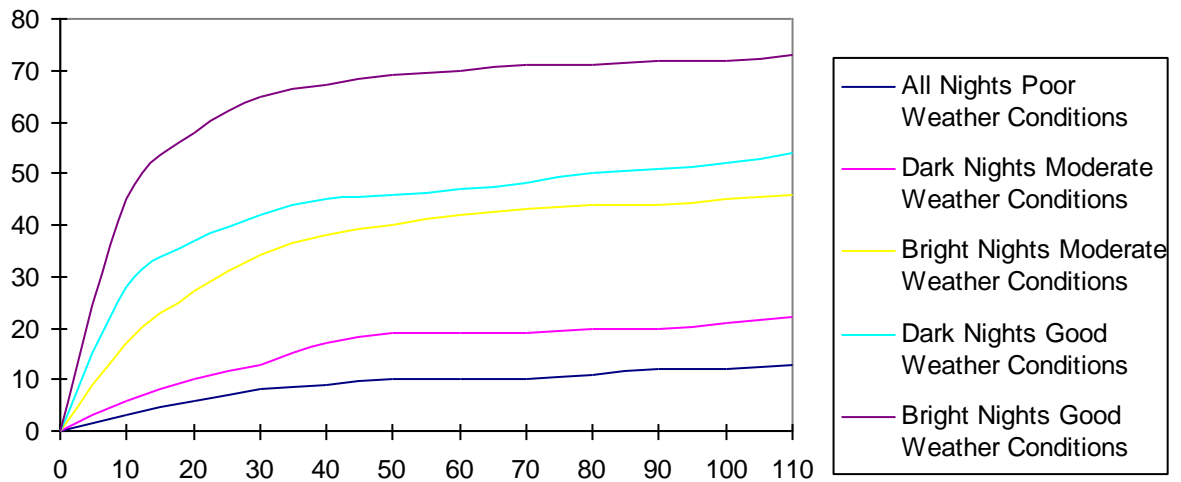


Fig 7/ ORSBC Report: Distribution of plotted photographs around the target. Source: TNA AIR14/2692 ORBCS Report S.45 'Success of bombing operations as shown by night photographs Dec.41 – Feb 42', 22 April 1942.

In good weather conditions (i.e no or slight haze or cloud) and irrespective of moon period, the shape of the curve was consistently steep close to the origin, indicating good concentration around the A/P. In conditions of moderate cloud cover with bright moonlight, this shape was still evident but less pronounced. On dark nights with moderate cloud cover and on all nights with heavy cloud cover, the shape of the curves was shallow throughout. It may also be seen that, of those aircraft that reached within 5 miles of the target, 75% actually got within 2.5 miles. In good conditions, about 25% of aircraft that reached the target actually got within 1 mile of the A/P but that when there was cloud cover this figure fell below 10%.

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mile equates to an area of 3.142 square miles and a distance of 3 miles to an area of 28.3 square miles.

To put these figures into perspective, it should be remembered that these percentages relate only to those aircraft known to have reached the target area. In conditions of thick haze or cloud cover, it was still the case that only 5% of aircraft dispatched reached the target area. Moreover, these figures related only to the five mile target area, a notional area equivalent to 78 square miles.

The ORSBC report next looked at the percentage of aircraft that attacked 'useful' areas whether within the designated target area or not. For this purpose, the report categorised the type of country revealed in night photographs into three categories; i) useful targets, these being built up areas, docks and marshalling yards; ii) outskirts and villages, and iii) open country, this being classed as 'wasted effort'. The results are set out in the following Table 7/ below<sup>51</sup>.

Weather Conditions	Illumination <sup>52</sup>	Percentage of photos taken with bombing showing		
		Useful Targets	Villages & outskirts	Open Country
	Bright	49	12	39
	Moderate	37	10	53

<sup>51</sup> The figures in brackets indicated where ORS deemed the sample too small to be significant.

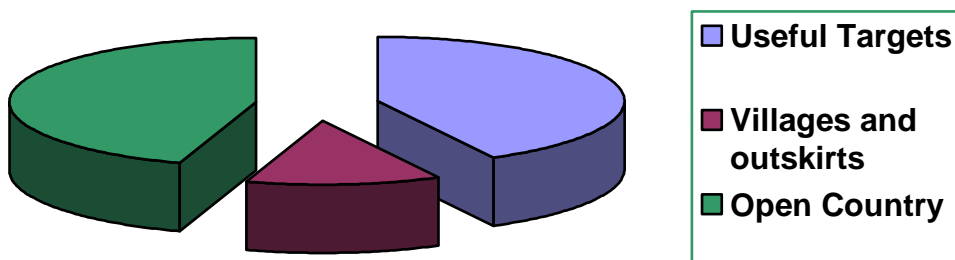
<sup>52</sup> The original version of this table in the ORS report did not contain an average of results in all conditions of illumination. This has been added to facilitate the visual presentation of the data.

No or slight haze or cloud				
	Dark	41	16	43
	Average	42.33	12.66	45.00
Moderate haze or cloud	Bright	19	0	81
	Moderate	8	38	54
	Dark	7	17	76
	Average	11.33	18.33	70.33
Thick haze or cloud	Bright	7	4	89
	Moderate	(40)	(0)	(60)
	Dark	9	18	73
	Average	18.66	7.33	74.00

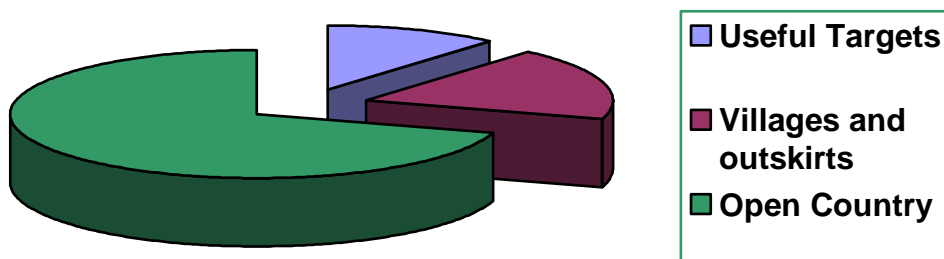
Table 7/ ORSBC Report: percentage of aircraft that attacked 'useful' areas. Source: TNA AIR14/2692 ORBCS Report S.45 'Success of bombing operations as shown by night photographs Dec.41 – Feb 42', 22 April 1942.

The results obtained by averaging the percentage of photos for the average of each category in all weather conditions can be presented visually, in Fig 8/ below;

### No or slight haze or cloud



### Moderate haze or cloud





## Thick haze or cloud

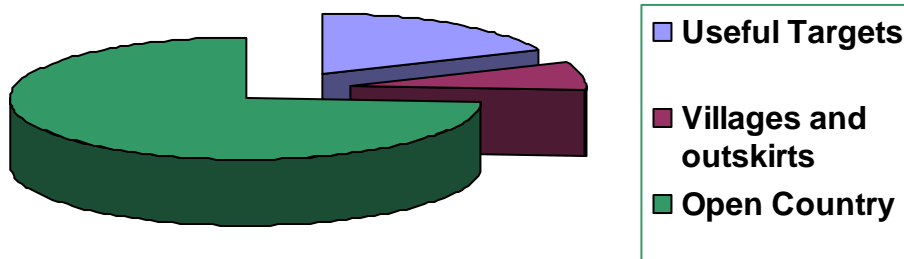


Fig 8/ Percentage of photos taken with bombing showing useful targets in relation to villages & outskirts and open country. Source: TNA AIR14/2692 ORBCS Report S.45 'Success of bombing operations as shown by night photographs Dec.41 – Feb 42', 22 April 1942.

The results presented in this table are interesting because they represent the first attempt to quantify the acknowledgement made in the Butt Report that not all of the five mile target area used as the measurement of bombing performance comprised worthwhile targets. The results suggest that even in clear conditions, somewhat less than half of the bombs dropped during this period by aircraft claiming to have attacked fell on useful targets and approaching half the bombs fell in open countryside. In anything other than clear conditions, somewhere approaching three quarters of all bombs dropped by aircraft claiming to have attacked fell in open countryside and only 19% fell on useful targets. Again, it should be remembered that these figures only include aircraft claiming to have attacked, representing approximately two thirds the total number of aircraft dispatched. Although the results shown above must necessarily be treated with some caution, the overall trend tends

to support the pattern emerging in other ORSBC reports that bombing performance at this time deteriorated markedly in anything other than clear conditions.

The series of reports produced by ORSBC in relation to target identification are significant because they represent the first scientific attempts to understand the reasons underlying the findings of the Butt Report. It is also significant that the findings of these reports, in terms of the percentage of crews that actually reached the target area, are generally consistent with the findings of the Butt Report. The three reports produced by ORSBC therefore not only confirmed the findings of the Butt Report, they defined the nature of the problem faced.

In essence, the Butt Report and the ORSBC reports confirmed that the average crew was unable to locate a target other than in good visibility, either because ground features could not be seen due to cloud or haze or because the altitude at which the sortie was flown precluded recognition of the smaller ground features necessary to provide cross checks of position. This was compounded by the fact that the small rivers, lakes and canals are so numerous in Germany and so easily confused that little reliance could be placed upon them. The difficulty faced by bomber crews was that the basic tenet of navigation, that of Dead Reckoning, was dependent upon the identification of successive landmarks, without which cumulative errors equating to 10% of the distance flown errors resulted in less than 10% of aircraft getting within five miles of a target of 75 square miles. The result was

that even under optimum conditions, less than 50% of bombs dropped were falling on useful targets and that in conditions of thick haze or cloud three quarters of bombs dropped were falling on open country. If the bombing offensive was to be taken to Germany with any prospect of success, some means of assisting average crews to reach the target was needed. Electronic navigation aids such as GEE and H2S would ultimately provide the answer. However, having reached the target area, crews would be faced with similar problems in locating the actual A/P. The following chapter will examine the extent to which electronic navigation and blind bombing aids were able to provide the answer to that particular problem.

## CHAPTER TWO: BLIND BOMBING

The previous chapter demonstrated that, in the absence of any form of navigation aid, only two thirds of the aircraft dispatched by Bomber Command claimed to have attacked a target having an area of 75 square miles and that even in the best weather conditions only one half of all crews claiming to have attacked the target actually got within five miles of it. That level of bombing performance was clearly inadequate, either in terms of being able to accurately hit precision target sets such as oil and communication, or to achieve the concentration in time and space necessary to make what would later become known as 'area attacks' effective. The basic reasons for the cumulative failures to reach the target area were due to weather conditions and the human factor - as Air Commodore Coningham had put it, the inability to circumvent the law that humans cannot see in the dark<sup>1</sup>. One potential means by which bombing performance might have been improved was therefore to remove the human factor - to bomb 'blind' using bombing aids that functioned irrespective of the nine states of visibility. This chapter will assess the bombing performance of Bomber Command in terms of accuracy and concentration achieved using the main blind bombing devices in isolation. These devices are, in order of introduction into operational use: GEE, *Oboe*, H2S, G-H and S.S LORAN. For the purpose of this exercise, 'blind bombing' is defined as bombs dropped purely on the basis of information provided by the device being used, with no visual sighting of the target at any stage.

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<sup>1</sup> Webster and Frankland *The Strategic Air Offensive, Vol I*, p202.

The concept of an accurate blind bombing device is the 'holy grail' of the bomber commander, in that at one stroke it largely removes the two greatest causes of bombing error from the equation: the vagaries of the weather and human error. The latter includes factors already discussed, including the limitations of the human eye when it came to visually identifying targets at night, and factors to be discussed later, such as the requirement for a bomb aimer to assess quickly the Mean Point of Impact (M.P.I.) of a mass of target markers. Furthermore, a bomber force in which each aircraft is equipped with its own blind bombing device greatly simplifies the planning of bombing operations and, by removing the need for some aircraft to carry target markers rather than bombs, increases the bomb lift capacity of the bomber force. These, then, are the reasons why Bomber Command would have preferred to rely upon blind bombing as the method of choice were that possible.

The primary purpose of this chapter is to quantify the effectiveness of blind bombing as a benchmark against which bombing performance with target marking techniques can later be compared. The quantification of the results achieved with blind bombing will be undertaken in relation to each blind bombing device in turn, using a combination of contemporary assessments of bombing accuracy (where available) and discussion on the practical limitations arising from the characteristics of each device. This in turn will enable an estimate to be made as to whether the employment of blind bombing techniques alone could have achieved the same outcomes as were

achieved using target marking techniques. It is acknowledged at the outset that this can only be an estimate because, for reasons that will become apparent, blind bombing on a large scale never became part of the bombing offensive. Such an assessment is, however, necessary in order to understand why in practice blind bombing turned out not to be the panacea for the bomber commanders and why it became necessary for Bomber Command to adopt target marking as standard in bombing operations, and in doing so to accept the limitations and disadvantages associated with target marking techniques.

A secondary purpose of this Chapter is to place the development of technologies associated with target marking techniques in the context of the importance of and reliance upon technology during the Second World War. This Chapter will therefore refer to work by authors such as David Edgerton, Guy Hartcup and Richard Overy on this subject and, citing the example of the cavity magnetron, will place the technologies used in target marking techniques into the context of the contribution made by other, better known technological development during this period.

With these objectives in mind, it is possible to now turn to the assessment of the main blind bombing devices in terms of accuracy and concentration achieved.

## GEE

The first of these navigation aids was GEE. The GEE system was sometimes referred to in contemporary documents as “TR1335” or “Gee”, with the use of the term GEE only coming into more widespread use in mid-1942.<sup>2</sup> For consistency, the term “GEE” is used here throughout.

The GEE system employed the principles of hyperbolic navigation, in which the difference in timing between the reception of two signals are used to calculate the distance from ground stations and from these produce a series of lines of constant path difference (c.p.d.) between the two ground stations<sup>3</sup>. In the GEE system, these c.p.d. lines were referred to as ‘position lines’. The GEE system typically employed three ground stations, one ‘Master’ and two ‘Slave’ stations, each of which transmitted pulsed radio signals: the Master station transmitted the ‘A’ pulse, the Slave stations the ‘B’ and ‘C’ Pulses respectively. These pulsed transmissions produced a series of position lines, these being known as the A-B and A-C position lines. The series of position lines thus produced, known as a Grid<sup>4</sup>, were marked on ‘lattice charts’. Measuring the time difference between the Master and Slave stations for both the A-B pulse and the A-C pulse gave the respective position lines and, by plotting the intersection of the two position lines on the lattice chart (see Fig 10/ below), a location was revealed that could be one of only two possible

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<sup>2</sup> The circumstances behind the false designation of TR1335 are described in R.V. Jones *Most Secret War*, (Ware, Hertfordshire: Wordsworth Editions Limited, 1998), p.p.215 to 222 and in Alfred Price *Instruments of Darkness*, (London: Macdonald and Jane’s, 1977), p.p. 98 to 104.

<sup>3</sup> TNA, AIR10/3910 The “GEE” System Manual. Unless otherwise stated, the description of the GEE system here is derived from that document.

<sup>4</sup> The term “GEE” was derived from the use of these grids.

positions. Any form of additional navigation could then be used to eliminate one of those positions and therefore determine the correct position of the aircraft at the time that the fix was taken.

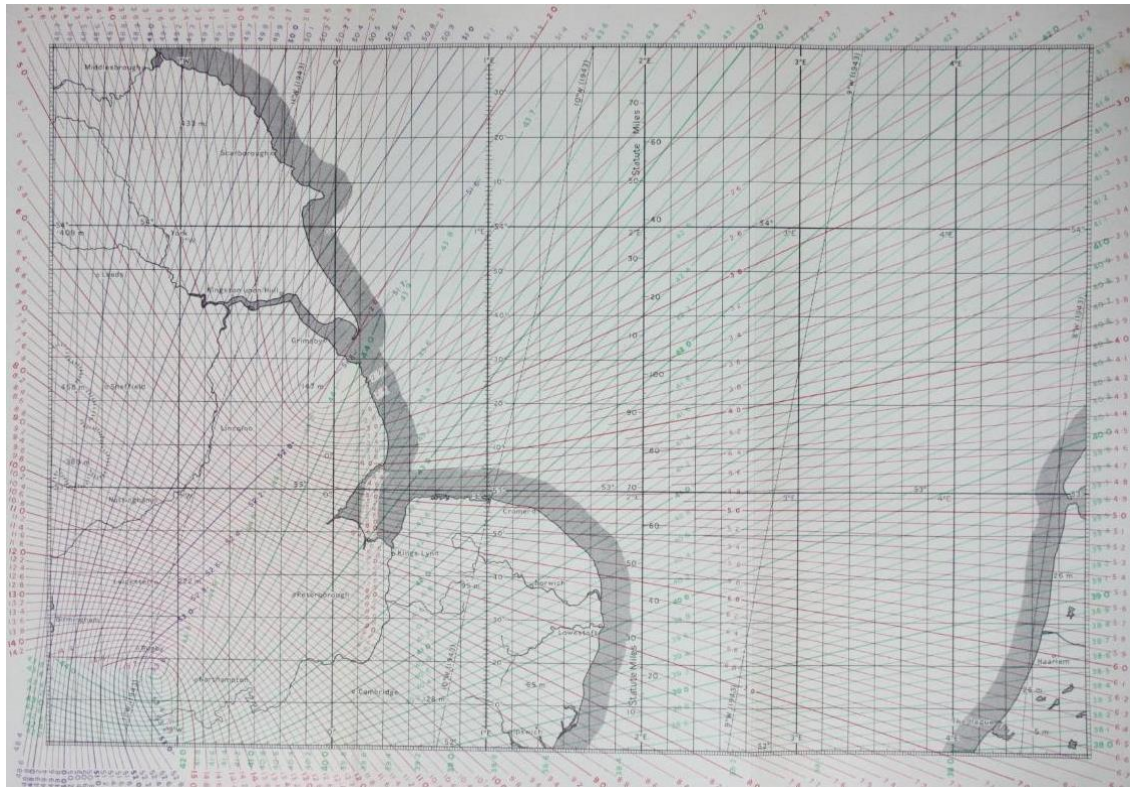


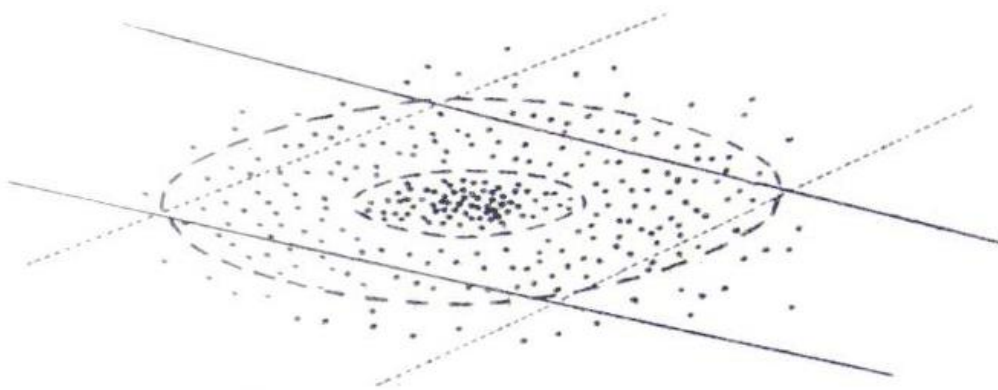
Fig 9/ GEE Lattice chart. Note that the angle of cut between the A – B position lines (red) and the A – C position lines (green) decreases with range, with the results that the area of the diamond lattices shapes increase in area with range (the significance of which is explained below). Source: TNA, AIR10/3910, The “GEE” System Manual.

The GEE system suffered from the two systematic disadvantages, the first being limited range. The precise coverage achieved by GEE varied according to atmospheric conditions but, due to the refraction of radio signals in the earth’s atmosphere, was a little in excess of optical. GEE coverage was normally calculated on the basis of ‘safe’ cover, this being the coverage that may be expected other than in abnormal conditions i.e on 90% of occasions.



In conditions of safe cover, the maximum range of GEE was circa 350 to 400 miles.

The second systematic disadvantage associated with GEE is that accuracy declined with the 'angle of cut'<sup>5</sup> and therefore with range. Trials to assess the accuracy of GEE showed a strong correlation with the law of probability<sup>6</sup>, and it was therefore usual to express the accuracy of GEE in terms of an ellipse within which 50% of the plots fell – the '50% ellipse'<sup>7</sup>. It should be noted, however, that the 50% ellipse related to GEE fixes plotted and not to the position of bombs dropped using the device. The latter were subject to other influences acting upon the fall of the bombs, such as ballistics, trajectory and cross trail<sup>8</sup>, and consequently did not necessarily conform to an elliptical pattern. A hypothetical 50% ellipse is shown in Fig 12/ below.



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<sup>5</sup> In relation to GEE, the 'angle of cut' is the angle at which the two position lines subtend at any given point.

<sup>6</sup> TNA AIR14/1313 Memorandum from Headquarters Bomber Command to Headquarters No. 3 Group, 5 January 1942. These trials were carried out by the specially formed No.1418 Flight in 1942, using the Mull of Galloway as an approximation of the range and angle of cut that would be experienced over the Ruhr.

<sup>7</sup> An ellipse is defined as a regular oval shape resulting when a cone is cut by an oblique plane that does not intersect the base. In the measurement of bombing accuracy, the error ellipse is an oval shape within which any given percentage of the bombs fall.

<sup>8</sup> 'Cross Trail' was the path taken by a bomb or marker through the air after release in relation to the direction in which the aircraft was travelling at the moment of release, and taking into account the effect of wind on the bomb or marker as it fell.

The ratio of the major and minor axis of the ellipse, and the direction in which the axis lie, could be calculated for any given point in a GEE system and therefore some measure of the accuracy of the system at that point found. The geometrical accuracy<sup>9</sup> of the GEE chain at any point may be described by constructing on a lattice chart the smallest ellipse that passed through the four corners of the diamond formed by two pairs of intersecting position lines, and then plotting the fixes within that ellipse. The position lines on a lattice chart were spaced 0.1 GEE units apart, such that the area of the ellipse thus created varied according to the spatial separation of the position lines at that particular point.

Lower angles of cut resulted in longer lattice diamonds and, since the length of the axes of the ellipse was derived from the four corners of the lattice diamond, the area of the ellipse increased at low angles of cut. It therefore followed that the accuracy of GEE declined as the angle of cut reduced. Given that the angle of cut decreased with range from the ground stations, it further followed that the length of the axes increased with range from ground stations and therefore that accuracy decreased with range from the ground stations. In general terms, the minor axis of the ellipse increased in proportion to the range and the major axis approximately in proportion to the square of the range. In addition, the inclination of the major axis to the line adjoining the point to the Master decreased inversely with range.

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<sup>9</sup> Geometrical accuracy is that due to the station and aircraft positions, and does not allow for any decrease in signal strength.

Although designed as a navigation aid, it was also possible to use GEE to home onto to a specific position, and therefore as blind bombing device. Trials to establish the accuracy of GEE as a blind bombing device, using the Mull of Galloway as an approximation of the range and angle of cut that would be experienced with targets in the Ruhr<sup>10</sup>, were carried out by a specially formed unit, No.1418 Flight<sup>11</sup>, in accordance with recommendations made by ORSBC<sup>12</sup>. The results indicated that, if applied to Essen as a target, blind bombing by GEE using a constant line of approach would result in 90% of bombs falling within an ellipse measuring sixteen miles long by two and a half miles at its widest. In the event, this was to prove optimistic.

The first operational use of GEE purely as a blind bombing device took place on the night of 22/23 April 1942<sup>13</sup>. The results from this raid, together with the results from other raids where individual aircraft were known to have released their bombs purely on the basis of GEE co-ordinates, were assessed by ORSBC in a report dated 18 May 1942<sup>14</sup>. The report measured the standard deviation of the position shown by aerial photographs of where the bombs dropped from the position indicated by GEE co-ordinates. This technique enabled the results of several raids to be directly compared, and shown visually using the GEE lattice for Essen as zero and plotting the standard

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<sup>10</sup> TNA AIR14/1313, Letter from the Under Secretary of State to Air Officer Commanding-in-Chief Bomber Command, 31 December 1941.

<sup>11</sup> TNA AIR14/1313, Memorandum from Headquarters Bomber Command to Headquarters No. 3 Group, 5 January 1942.

<sup>12</sup> TNA AIR14/1769, Operational Research Section Report S.26 "Operational use of GEE II – Proposed Experiments for GEE Development Flight", 7 January 1942.

<sup>13</sup> Middlebrook and Everitt *The Bomber Command War Diaries*, p259. This raid, on Cologne, was carried out by 69 GEE-equipped aircraft.

<sup>14</sup> TNA AIR14/1769, Operational Research Section Report S.47, "Operational accuracy of blind bombing with T.R.1335, March and April, 1942", 18 May 1942.

deviation of each bomb plot in relation to zero. The resulting diagram is shown as Fig 11/ below.

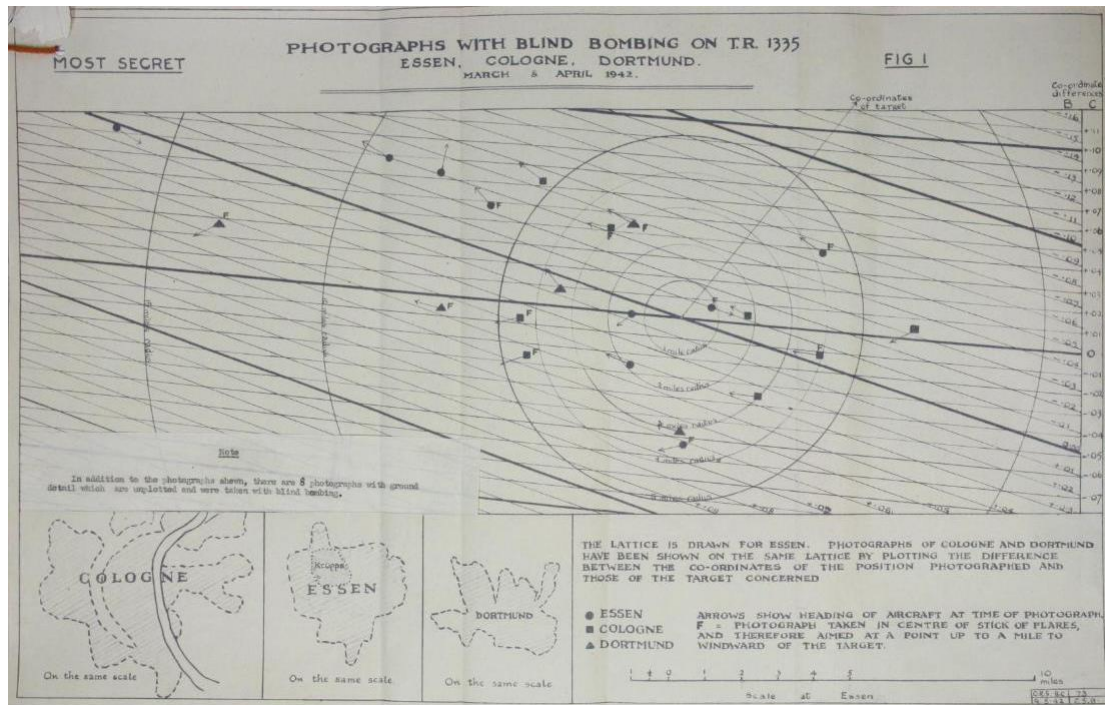


Fig 11/ Map showing standard deviation from the GEE co-ordinates of bombs dropped using GEE as a blind bombing device. The position of the bombs dropped, expressed as a standard deviation from the GEE co-ordinates of the target, are shows symbols (circle for Essen; square for Cologne; triangle for Dortmund). The arrows attached to the symbol show the heading of the aircraft at the time of bomb release. Source: TNA, AIR14/1769, Operational Research Section Report S.47, "Operational accuracy of blind bombing with T.R.1335, March and April, 1942", 18 May 1942.

These results showed that the accuracy achieved by blind bombing with GEE on operations was three times worse than that achieved in operational trials carried by No.1418 Flight, and that the bomb density to be expected by blind bombing was therefore about 10% of that estimated from the results obtained in the trials. On the basis of the results obtained on operations, ORSBC

estimated that for targets in the Ruhr and for Cologne about 50% of the bombs dropped would be within 5 miles of the target<sup>15</sup> and about 10% within 2 miles.

Although this represented a significant improvement over the results presented in the Butt Report, this represents the maximum achievable using GEE as a blind bombing device. It is clear from the evidence in this report that, when used solely as a blind bombing device, GEE was incapable of consistently hitting a target area of 3 x ½ miles upon which the Air Staff had based the concept of Estimated Weight of Attack.

## OBOE

“*Oboe*” was a generic name for a series of radar blind bombing aids based upon the measurement of distance by ground stations<sup>16</sup>. The following relates only to those versions of *Oboe* based upon the principle of the “Circle of Constant Path Range”<sup>17</sup>.

*Oboe* was based on the fact that a radar pulse travels in a straight line and at

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<sup>15</sup> The reference to an area of 5 miles is unexplained and somewhat curious, given that ORSBC were instrumental in switching to the 3 mile zone and used that standard in other reports during this period.

<sup>16</sup> Cumming. *Beam Bombers: The Secret War of No. 109 Squadron*. The name “*Oboe*” originated with the Telecommunications Research Establishment, where scientists involved in the development of the early versions of the equipment described the note produced by the system as similar that produced by the musical instrument. The system had previously been referred to as “*Howler Chaser*”, but this term was dropped in favour of the term “*Oboe*”.

<sup>17</sup> *Ibid*. These versions were *Oboe* Mk I, II and III. Earlier versions of *Oboe*, known as “*Blind Bombing Cherbourg*” and “*Trinity*” respectively, were essentially experimental versions that employed a different technique for tracking the path of the aircraft and which saw only limited operational use.

a constant speed<sup>18</sup>. It was therefore possible for a radiolocation station on the ground to constantly measure the distance between that ground station and an identified aircraft with an extremely high degree of accuracy. Thus, an aircraft could be made to fly along an arc at a constant distance from a ground station, this arc being the circumference of a circle the radius of which would be the distance between the ground station and the target. This circle was known as the Circle of Constant Path Range. The radius of the circle flown by the aircraft could then be adjusted to the exact distance from the ground station to the target, known as the “Geographical Range”, and the aircraft controlled to be accurately tracked over the target. This first ground station was known as the tracking station, or more usually as the “Cat” station.

A second ground station, located at least one hundred miles away from the first and in such a manner that the base line was formed between the two, measured the range of the aircraft and the ground speed component along the line from the ground station to the target, and from this information monitored the progress of the aircraft along the Circle of Constant Path Range until the aircraft reached the point at which the bombs should be released in order to hit the target. The exact release point would first have to be calculated in relation to the aircraft’s height, ground speed and the trajectory of the bomb after release according to the type of bomb load carried. When this exact position was reached, the second ground station signaled the navigator in the aircraft to release the bombs. This second ground station was

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<sup>18</sup> TNA AIR20/1471 ‘Oboe – how it works’, a Telecommunications Research Establishment paper dated 2<sup>nd</sup> July 1943’, and TNA AVIA7/917 HQ No. 60 Group ‘The History of Oboe, 1940 to 1945’. See also F.E.Jones, ‘Oboe – A Precision Ground-Controlled Bombing System’, *Journal of the Institute of Electrical Engineers*, vol 93, part IIIA, no 2, 1946 and A.H. Reeves, ‘Oboe: history and development’, *Journal of the Institute of Electrical Engineers*, special issue on historical radar, October 1985. Unless otherwise stated, the description of the OBOE system here is based upon these documents.

known as the release station, or more usually as the “Mouse” station<sup>19</sup>.

The operational technique for using *Oboe* was as follows<sup>20</sup>. The Circle of Constant Path Range along which the aircraft was to be controlled to the target was an arc A -T, where A is the starting point and T is the target. Position A was typically about 10 minutes flying time from T. Each aircraft would navigate individually to a pre-determined position just short of position A, known as the Waiting Point, and when instructed to so would approach position A from a direction perpendicular to it. A series of morse signals would then indicate when the aircraft should turn onto the arc A-T.

Once broadly established on the arc A - T, the control of the aircraft was achieved by wireless transmissions. When the aircraft was exactly on track, the pilot received a steady continuous tone his headphones (the “equisignal”). Deviation from track was defined by a series of dots and dashes superimposed on the steady tone - dashes if the aircraft was closer to the ground station than the correct track; dots if the aircraft was further away from the ground station than the correct track. The limit of this fine control represented a deviation of 175 yards on either side of the track: when this limit was reached, the equisignal disappeared completely, and only clear dots and dashes were heard.

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<sup>19</sup> TNA AVIA7/917 HQ No. 60 Group “The History of Oboe, 1940 to 1945”. The term “Mouse” derived from an earlier version of Oboe that was based largely on the German “X-Gerät” equipment for the “X-Verfahren” blind bombing system. This early version of Oboe used the reversible clock principle, that was itself based on the mechanical clock used in the X-Gerät system. The ticking of the mechanical clock in the latter had reminded the salvage party recovering the X-Gerät system from a crashed bomber as a “Mickey Mouse” clock and the term Mickey Mouse was subsequently adopted for the electrical clock that formed part of the early version Oboe. Abbreviated to “Mouse”, the term came to be used for the release station in Oboe as well as for similar devices in other systems (such as G-H). By the simple expedient of association of ideas, the tracking station then became known as “Cat”.

<sup>20</sup> This description of the operational technique for using Oboe is a summary of the key elements.

Instructions from the "Mouse" station were transmitted to the aircraft by means of a steady tone keyed at intervals by the letters A,B,C and D. These signals warned the navigator of time to target, with A =10 minutes; B = 8 minutes; C = six minutes; and D = three minutes, this last signal also being the warning that the timing for the bomb release was about to begin. At the exact moment the release point was reached, the "Mouse" station issued the release signal, which consisted of a further warning of five "dots" followed by a "dash" (the Morse letters '5T'). Upon receipt of this signal, the navigator pressed the bomb release. The principle of the *Oboe* system is shown diagrammatically in Fig 12/ below.

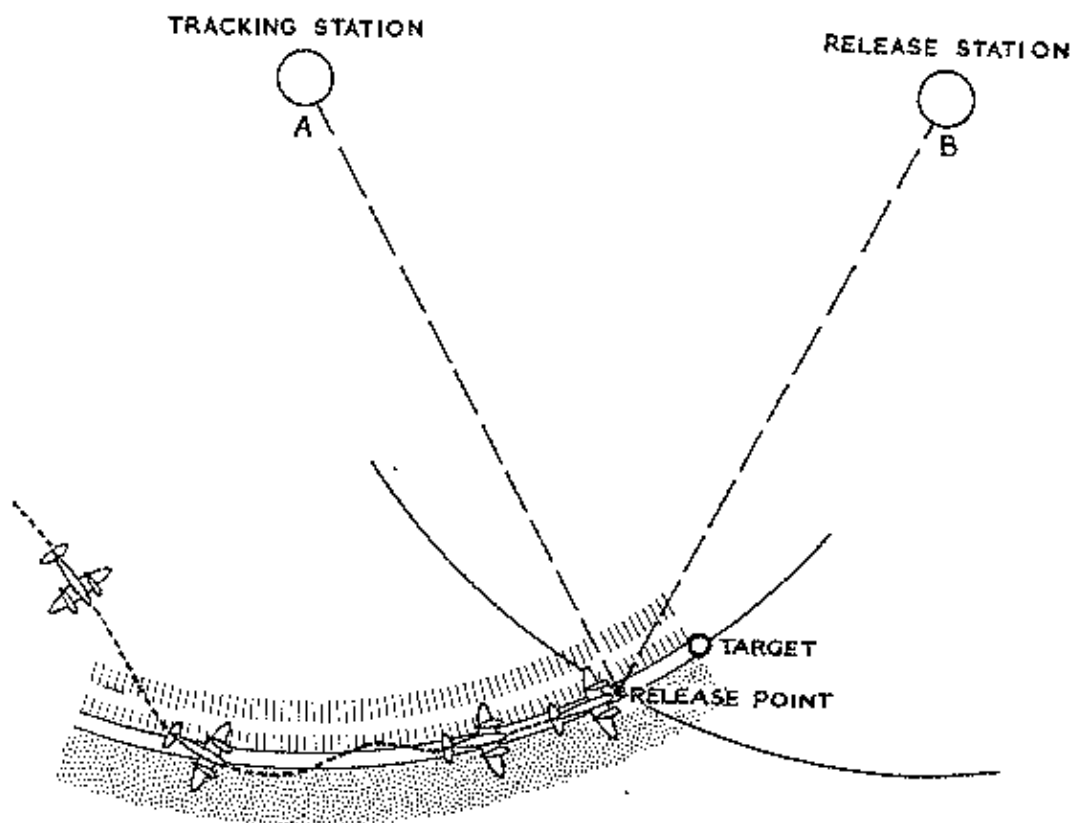


Fig 12/ The Oboe principle. Source: TNA AVIA7/917, "The History of Oboe, 1940 to 1945"



The practical application of these principles did, however, present a number of technical issues. These may be summarized as relating to; i) range; ii) number of aircraft that could be controlled by the ground stations; iii) angle of cut; iv) frequency modulation; vi) the measurement of ground speed; and vii) calculation of the trajectory of the bomb after release. The most significant issues were those relating to range and the number of aircraft that could be controlled by the ground stations. These two issues are discussed in more detail below. It should however be noted that, in addition to these technical issues, the successful operation of *Oboe* required very accurate flying, not only in terms of keeping the aircraft precisely on track, but also because the calculations required in terms of the bomb release relied upon achieving a precise groundspeed, altitude and heading at the point of release. Any significant deviation from the specified values for any of these variables would introduce a random error above the systematic limits of accuracy of the system.

The range of *Oboe* was limited by the fact that radar pulses travel in straight lines and therefore tangential to the surface of the earth. Consequently, the range at which *Oboe* remained effective was limited to a little over optical and depended upon the altitude at which the aircraft was flying<sup>21</sup>. Range increased with altitude such that, at an altitude of 28,000 ft, the maximum range at which

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<sup>21</sup> Theoretically, because radar pulses travel in straight lines, the range of *Oboe* was purely that possible by line of sight. However, in practice and as with the GEE radio pulses, a limited amount of refraction of the radar pulses occurred and accordingly the range of *Oboe* slightly exceeded that possible purely by line of sight.

*Oboe* signals could be received was in the region of 270 miles<sup>22</sup>, just sufficient to cover the Ruhr and Cologne but not key targets in northern and southern Germany. Moreover, although in pure radar terms the accuracy of *Oboe* was not affected by range, one effect of increasing range was to reduce the 'angle of cut'. In relation to *Oboe*, the angle of cut was the angle at which the pulse recurrence frequencies were received by the aircraft in relation to the respective ground stations. The accuracy of *Oboe* was broadly inverse to the angle of cut, being particularly pronounced in relation to range errors at low angles of cut.

It should also be noted that the maximum range of *Oboe* could only be achieved by flying at high altitude, typically at 28,000ft or above. None of the heavy or medium bombers used by Bomber Command could reach that altitude<sup>23</sup>. Furthermore, as an aircraft approaches its maximum (or absolute) ceiling, there is a tendency for it to become longitudinally and laterally less stable, such that the maximum altitude at which an aircraft remains fully controllable is somewhat lower<sup>24</sup> than its stated absolute ceiling<sup>24</sup>. Since the

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<sup>22</sup> In an attempt to overcome this range limitation, a 'repeater' system was developed whereby the pulse signals were relayed to the bombing aircraft by another flying along the line between each ground station and the target. The 'repeater' system did not see widespread operational use'

<sup>23</sup> Richards *The Hardest Victory*, Appendix III, p356. The best service ceiling of any of the heavy bombers was that of the Avro Lancaster which could reach 22,500ft. The service ceiling of the Handley Page Halifax was 18,200ft (later versions 20,000ft), with that of the Short Stirling being circa 16,500ft. The service ceiling of the Vickers Wellington was 19,600ft. The service ceiling of the de Havilland Mosquito Mk IV, this being the version in service when *Oboe* was introduced, was 33,000ft. Later versions of the Mosquito could reach 39,000ft. Performance figures for the service ceiling of bomber aircraft of the period vary between available sources, but those quoted above are consistent with the range of figures quoted in other sources and consequently are considered reliable.

<sup>24</sup> In this context, 'fully controllable' means the ability of the aircraft to accept the minor control inputs from the pilot necessary to achieve the precise values of groundspeed, height and heading required by *Oboe*.

accuracy of *Oboe* depended largely on accurate flying, the effective operating altitude of the heavy and medium bombers was significantly below that required to use *Oboe* as a blind bombing device over Germany.

The only aircraft in Bomber Command service capable of reaching the required altitude at the time *Oboe* was introduced was the de Havilland Mosquito which, with a service ceiling considerably in excess of 28,000ft, was not approaching its maximum ceiling at the altitudes normally required for *Oboe* operations and therefore remained fully controllable about all axis at that altitude. However, the Mosquito could only accommodate a bomb load of 4,000lb, approximately one third of the bomb load typically carried by the heavy bombers on raids to the Ruhr<sup>25</sup>.

One of the major limitations with the early versions of *Oboe* was that one ground station was only able to control aircraft at a rate of approximately one every ten minutes. Controlling more than one aircraft simultaneously could therefore only be achieved with additional ground stations, with each pair working on a different frequency. A system was later developed using different pairs of frequencies, each pair of frequencies being known as a "Channel". In this system, known as 'K *Oboe*'<sup>26</sup>, three channels were allocated to *Oboe* and therefore at best *Oboe* operations were limited to just three stations being used at any one time. Consequently, even with 'K' *Oboe*, the maximum number of aircraft that could be controlled was approximately one

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<sup>25</sup> Richards *The Hardest Victory*, Appendix III, p356.

<sup>26</sup> 'K' for coincidence, so-called because a coincidence valve was the key feature of the anti-jamming circuitry in this version of *Oboe*.

every three to four minutes<sup>27</sup>.

As a blind bombing system, *Oboe* was largely devoid of systematic errors. The most likely source of error with the *Oboe* system was therefore flying error, in terms of maintaining the correct tracking, groundspeed and altitude. A report by ORSBC issued in January 1945 calculated that the average tracking error was 35 yards<sup>28</sup>; the average groundspeed error at the operational height of 28,000 feet was 4.0 mph; and that the average height variation was 202 feet. The report concluded that these errors were insignificant<sup>29</sup>.

In the absence of systematic error and with only minor random errors, *Oboe* was an extremely accurate blind bombing device. Evidence regarding the operational accuracy of *Oboe* as a blind bombing device only became available from December 1943<sup>30</sup>, following large scale use of the device for precision attacks against CROSSBOW targets in northern France<sup>31</sup>. At a conference in April 1944, ORSBC reported that, over Northern France, *Oboe* as a blind bombing device had a Probable Radial Error of 150 yards from an altitude of 12,000ft and 300 yards at an altitude of 25,000ft. In this context, the shorter range enabled *Oboe* to be used at a lower altitude than was possible over Germany although any commensurate benefit in accuracy was to some

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<sup>27</sup> A later version of *Oboe*, '*Delta Oboe*', was under development which would have enabled any number of aircraft to be controlled at any one time, but this did not become operational until after the Second World War.

<sup>28</sup> The tracking error was the lateral distance from the exact Circle of Constant Path Range. Note this related to tracking and not the heading of the aircraft.

<sup>29</sup> TNA AIR14/4602, Operational Research Section Report S.202 '*Oboe Flying Errors and Bombing Accuracy*', January 1945.

<sup>30</sup> As opposed to evidence in relation to the accuracy of *Oboe* for target marking for which, prior to that date, *Oboe* had principally been used.

<sup>31</sup> CROSSBOW targets were the launching sites for the V1 flying bomb.

extent offset by the high angle of cut over Northern France. It was also reported that, over the Ruhr, the Probable Radial Error was 400 yards at an altitude of 28,000ft<sup>32</sup>.

However, notwithstanding the accuracy of bombing with *Oboe*, the significant operational limitation imposed by the ability of the system to control aircraft at a rate of (at best) approximately one every three to four minutes severely limited the value of *Oboe* as a blind bombing device. There was clearly a role for *Oboe* to play in terms of small scale precision attacks, and in this role *Oboe* made an important contribution to countering the threat of the V1 weapon and in the preparations for OPERATION OVERLORD<sup>33</sup>. However, the limitation imposed by the relatively modest bombload carried by the de Havilland Mosquito, together with the limit on the number of aircraft that the system could handle at any one time, ensured that the use of *Oboe* as a blind bombing device was incapable of delivering the weight and concentration of bombs required to achieve the Estimated Weight of Attack considered by the Air Staff as being necessary to destroy the social and industrial structure within selected areas.

H2S

H2S was a centimetric navigation and blind bombing radar system carried

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<sup>32</sup> TNA AIR14/2687 Operational Report Section Report B108, 'Minutes of meeting to discuss OBOE PERFORMANCE held at A.W.A.S. on 5.4.44 at 14:30 hours', 10 April 1944.

<sup>33</sup> OPERATION OVERLORD was the invasion of France in June 1944.

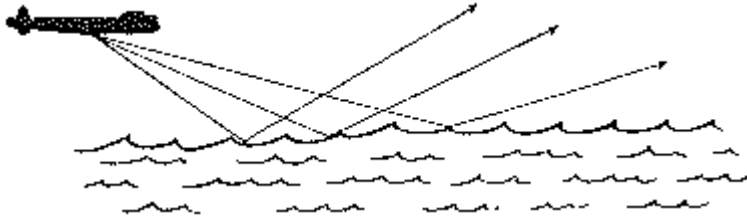
within the aircraft<sup>34</sup>.

The H2S system exploited the fact that radiated microwave signals travel in straight lines at a constant speed and are reflected back (known as echoes or returns) from suitable surfaces as 'diffuse reflection' or 'scatter' i.e. in many different directions. The pattern of diffuse reflection varies according to the characteristics of the surface with which the incident signal (i.e. that transmitted by the radar device) comes into contact. The strongest returns are generated when three reflecting surfaces are located at right angles to one another, which causes the incident signal to return along its own path (known as 'backscatter'). This juxtaposition of right angles is known as a 'corner reflector', and occurs in varying degrees according to the characteristics, or 'reflective qualities', of the surface.

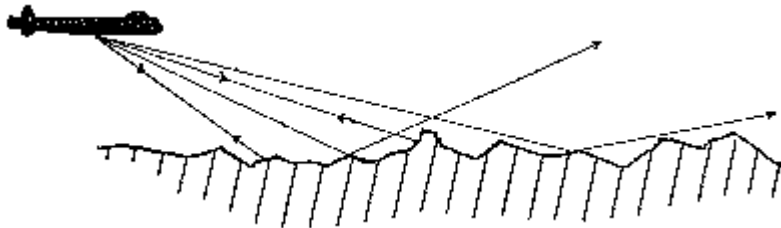
Built up areas contain a large number of corner reflectors and therefore have good reflective qualities. Open countryside tends to have fewer corner reflectors and produces less 'backscatter', such that the reflective qualities are not as good as built up areas. As a surface, water acts as a mirror and produces no 'corner reflectors', such that the incident signal is reflected away at an angle of 90 degrees and produces no backscatter. Water is therefore a poor reflector of microwave signals. The reflective qualities of the various surfaces are illustrated in the Fig 13/ below.

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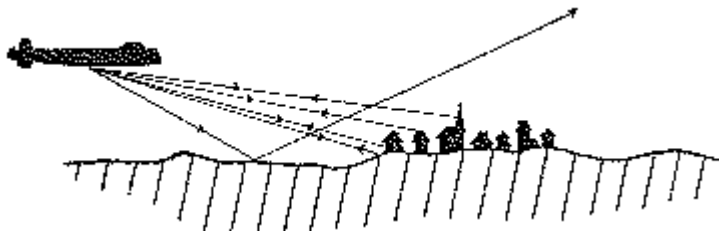
<sup>34</sup> See Lovell, *Echoes of War* for a detailed account of the history and development of H2S.



Water. No corner reflectors, resulting in no backscatter.



Open countryside. Few corner reflectors, resulting in moderate backscatter.



Built-up areas. Numerous corner reflectors, resulting in strong backscatter.

Fig 13/ H2S: The reflective qualities of different surfaces. Source: The Lovell Papers, Imperial War Museum.

The varying strength of radar responses could be translated into varying degrees of brightness when displayed on a cathode ray tube (C.R.T.) which,

in the H2S system, was presented as a radial time base referred to as the Plan Position Indicator (P.P.I.). H2S exploited the difference in the relative strength of radar responses between built up areas, open countryside and water to 'map' the terrain below the aircraft on the PPI (see Fig 14/ below). However, because H2S relied on diffuse reflections, not all of the objects on the surface produced a return, such that the response shown on the PPI was only an approximation of the shape of the object.

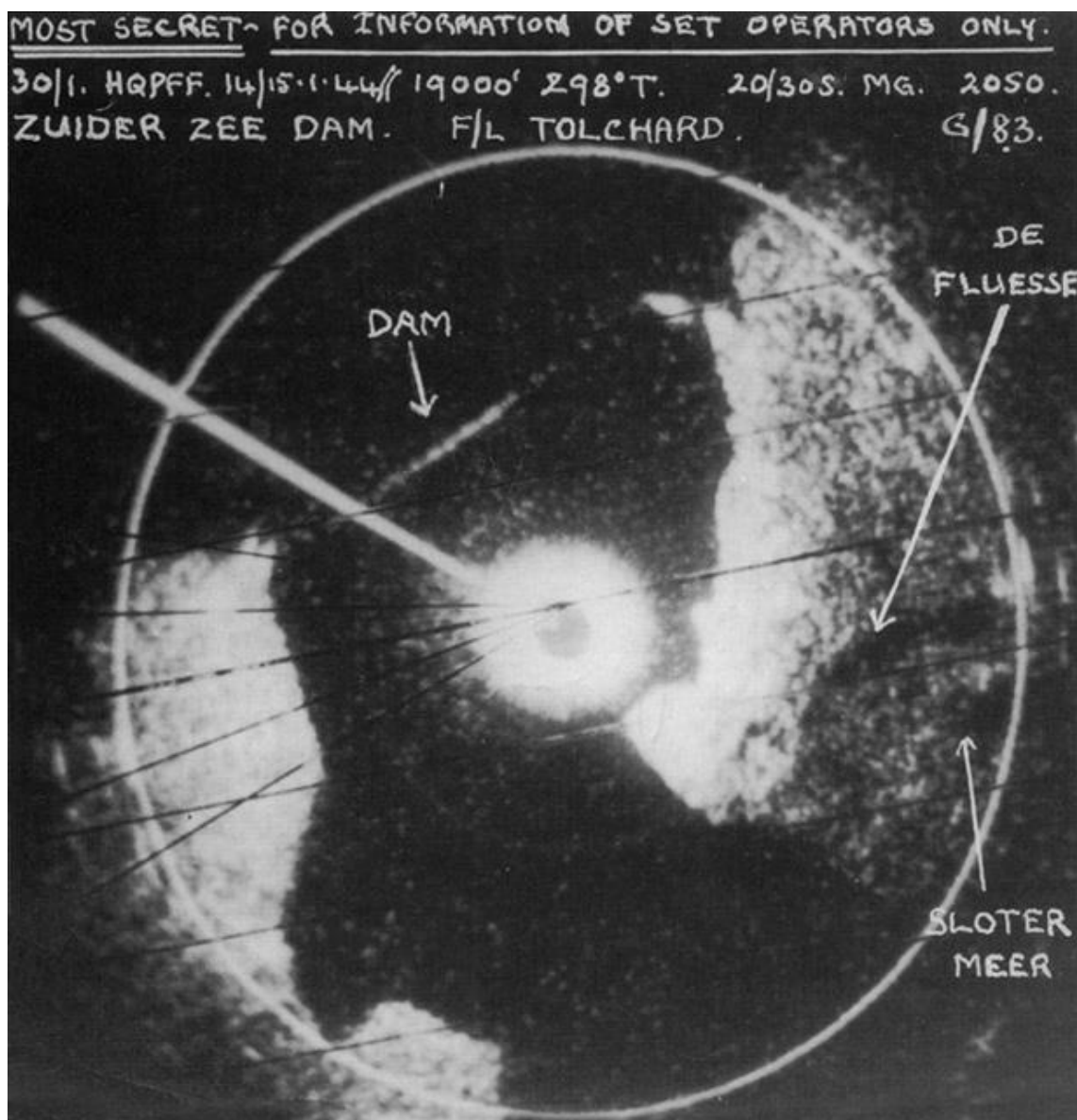


Fig 14/. H2S: Plan Position Indicator. This image of the Zuider Zee (now the IJsselmeer) demonstrates the relative strength of radar responses between open countryside and water.



The Zuider Zee and adjoining lakes (De Fleussen and the Slotter Meer) show as dark areas, whereas the surrounding countryside and the Zuider Zee Dam are brighter. This image was taken in 1944 using a Mk III H2S, in which the resolution was considerably sharper than in earlier versions, although even so the ground returns in the centre of the P.P.I. obscure a large area of the picture. Source: The Lovell Papers, Imperial War Museum.

Moreover, because microwaves travel in straight lines, they are prevented from reaching (and therefore being reflected by) the area behind the first reflecting object encountered. This area is then said to be 'in shadow'. This has two implications. Firstly, where the response comprises a series of objects (such as the response from a town), the response will not include returns from all of the objects within it, such that the shape of the response as a whole (i.e the town as a whole) will be distorted. It follows that the shape of a town as shown on the P.P.I. would not correspond with the shape of the town as shown on a map. This distortion was more pronounced at shallow angles of look (i.e the angle between the aircraft and the object on the ground) and therefore more pronounced at greater range from the object. Secondly, where the object is shielded by high terrain (such as a town in a valley), part of or even the whole of that town may be in shadow at shallow angles of look. These were both systematic disadvantages of H2S as a blind bombing device.

The problems encountered at shallow angles of look were, however, less significant than those encountered at steep angles of look. In order to provide all-round coverage, it was necessary for the H2S scanner to rotate through 360 degrees and that the transmission/reception of the microwave signals was not interrupted by the structure of the aircraft. In the heavy bombers with

which Bomber Command was equipped<sup>35</sup>, the only suitable location was immediately aft the bomb bay. The ideal shape for the scanner was a full paraboloid, but the limited ground clearance aft the bomb bay precluded the installation a full paraboloid and therefore the scanner in the early versions of H2S was a truncated or 'sliced' paraboloid. The main deficiency with the truncated paraboloid scanner was the difficulty in maintaining a satisfactory image on the P.P.I. as the angle of look increased which, at close range, was a mixture of gaps, fades and heavy ground returns. The problem was particularly acute within the crucial 10 mile range or "bombing scale" where the target could be completely obscured by heavy ground returns in the form of a "ground return ring" emanating from the centre of the P.P.I.

Another disadvantage with H2S as a blind bombing device was the problem of 'slant range'. In early versions of H2S, the radial distance from the centre of the P.P.I. was linearly related to the range of the target from which the radar response was received. Compared with a normal map, the P.P.I. picture would therefore be distorted since the 'slant range' is only equal to the actual range ('ground range') at zero altitude. The difference between slant range and ground range decreases with distance from the object but increases with altitude. Since the typical height of bombing operations was between 15,000ft and 20,000ft the discrepancy between slant range and ground range was significant. In later versions of H2S, the discrepancy between ground range and slant range was to some extent overcome by a 'scan corrected display' which automatically corrected the picture on the P.P.I. to take account of slant

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<sup>35</sup> At that time, these were the Short Stirling, Handley Page Halifax and the Avro Lancaster.

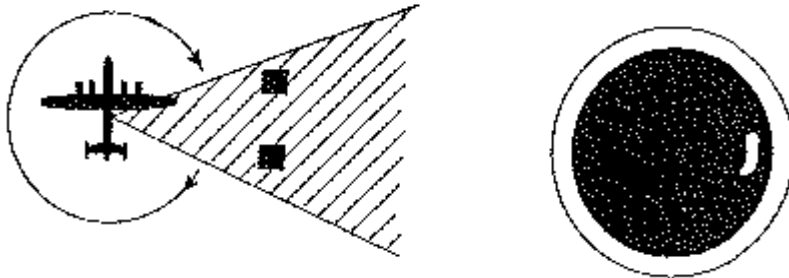
range.

In addition to these disadvantages, the early versions suffered from the disadvantages of sharing in the pitch and roll of the aircraft due to the rigid mounting of the scanner. Consequently, at steeper angles of bank and pitch, the scanner would alternately receive no returns and then be swamped by ground returns as the position of scanner changed relative to the ground. Later versions of H2S were gyroscopically 'roll stabilised' to mitigate this effect up to angles of bank of 30°.

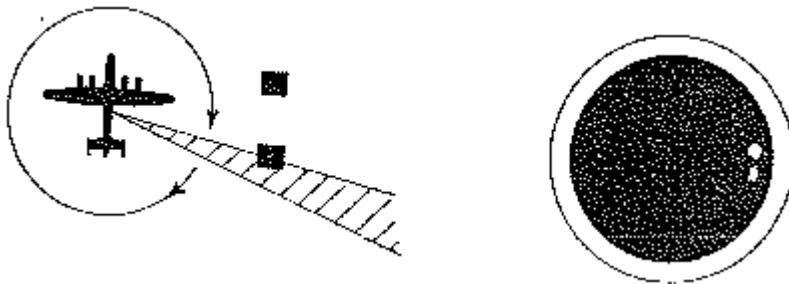
As a general principle, the resolution achieved on any radar device improves as the width of the microwave wavelength decreases. This principle is shown illustratively in Figure 15/ below. Microwave wavelengths are categorized into 'bands' - all the bands used by H2S were 'centimetric' wavelength bands. During the Second World War, versions of H2S were produced in the 10 centimetre<sup>36</sup> wavelength band (within the 'S-band' of 7.5cm to 15cm wavelengths): the 3 centimetre wavelength band (within the 'X-band' of 2.5 to 3.8 com wavelengths) and the 1.25 centimetre wavelength (within the 'K-band' of 1.1cm to 1.7 cm wavelengths).

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<sup>36</sup> Although usually referred to as 10 Centimetre in relation to H2S, the 'S' band version of H2S actually operated on a wavelength of 9.1 centimetres.



Wider wavelengths showing two towns as a single return.



Narrow wavelength showing two towns as two separate returns.

Fig 15/ The effect of reduced wavelength on image resolution. Source: The Lovell Papers, Imperial War Museum

The early versions of H2S (MkI and MkII) produced a beam width of 6 degrees. The reduction in the microwave wavelength required an increased power output from the cavity magnetron, this only being achieved in later versions of H2S such as the MkIII, (which produced a beam width of 3 degrees) and the Mk VI (which produced a beam width of 5/8 degrees). It follows that the earlier versions of H2S, particularly the Mk 1 and Mk II that operated on S-band wavelengths, provided comparatively poor resolution which made the identification of ground returns more difficult.

The issues outlined above, although significant, do not cover all of the disadvantages of H2S as a blind bombing device but provide some indication of the difficulties faced in seeking to use H2S in that role. Initial assessments of the accuracy of bombing using H2S indicated that, due to the limitations inherent within the H2S system, the Probable Radial Error of bombs dropped roughly equated to the mean radius of the target; that is to say that, on average, 50% of bombs dropped would fall within the built up area of the target, irrespective of the actual size of the target area<sup>37</sup>. There was, consequently, a definite correlation between the area of the target and the concentration of bombing achieved when using H2S. However, these assessments were based upon information obtained from raids in which Mk II H2S was used both for blind bombing and groundmarking. A more reliable

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<sup>37</sup> TNA AIR14/2686 Operational Research Section Report S111 'Accuracy of H2S as a blind bombing device', 16 December 1943 and TNA AIR14/2687 Operational Research Section Report S189 'H2S Blind Bombing Accuracy – 1<sup>st</sup> October 1943 to April 30<sup>th</sup> 1944', 13 August 1944

indication of the value of H2S purely as a blind bombing device is therefore provided by two trial raids conducted specifically to establish the accuracy of H2S in that role: the first against Ludwigshafen, and the second against Brunswick.

The raid against Ludwigshafen, on the night of 17/18 November 1943, was carried out by a force of 85 aircraft from No.8 Pathfinder Group<sup>38</sup>. Of those bombs dropped blindly using H2S alone, 60% were within the built up area of Mannheim-Ludwigshaven and 50% were within 1.5 miles of the A/P<sup>39</sup>. The range error was calculated to be three times that of the line error, an indication of the problem of allowing for 'slant range'. In general, the results achieved were consistent with those previously obtained suggesting that, notwithstanding that the Ludwigshaven raid was carried out by the experienced H2S operators of the Pathfinder Force, an average of 50% of bombs within the built up area of the target was approaching the maximum that could be achieved using the MkII version of H2S purely as a blind bombing device.

The raid on Brunswick was out carried on the night of 12/13 August 1944 by 324 aircraft purely using Mk II H2S and with bombsights rendered

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<sup>38</sup> The formation of No. 8 Pathfinder Group is discussed in more detail in Chapter 4.

<sup>39</sup> TNA AIR14/2686 Operational Research Section Report S112 'The H2S Blind Bombing Attack on Ludwigshaven, 17/18 November 1944', 18 December 1943.

inoperative<sup>40</sup>. The raid was conducted solely by Main Force squadrons with no Pathfinders taking part and without the dropping of any marker flares. The ORSBC Report on this raid estimated that 2.5% of those aircraft that attacked were within 1 mile of the A/P; 10% within 2 miles; and 14% within 3 miles<sup>41</sup>. The remaining 73.5% were beyond three miles from the A/P but, due to the lack of photographic cover, could not be precisely plotted. Photographic cover did however reveal that at least 50 aircraft aimed their bombs at a factory some 10 miles south-west of Brunswick which, it was suggested, gave similar returns on H2S to Brunswick itself<sup>42</sup>.

The TRE continued to improve the resolution achieved with H2S with the Mk III, which operated on the X-Band wavelength and entered operational use in November 1943<sup>43</sup>. The Mk III also featured improvements such as a scan corrected display and roll stabilisation. However, as will be shown later in this thesis, the introduction of Mk III H2S did not alter the fundamental relationship between Probable Radial Error and the mean radius of the target achieved using Mk II H2S. The K-band H2S MkIV did provide sufficient resolution to be viable as a blind bombing device but did not enter operational use with Bomber Command during the Second World War<sup>44</sup>. Consequently, throughout the entire Bomber Offensive, H2S was never capable of achieving the

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<sup>40</sup> TNA AIR14/848 Operational Research Section Report (unnumbered) 'Night raid on Brunswick – 12<sup>th</sup>/13<sup>th</sup> August 1944', 14 September 1944. This report confirms that 379 aircraft were dispatched on the raid, with 324 claiming to have attacked.

<sup>41</sup> Ibid.

<sup>42</sup> Ibid

<sup>43</sup> Lovell, *Echoes of War: The Story of H2S Radar*, Chronology of Radar Developments, page xix.

<sup>44</sup> Ibid, page 256.

accuracy and concentration necessary to achieve the Estimated Weight of Attack.

## G-H

G-H was a radio blind bombing aid based upon the "H principle" or "twin-range principle" of location determination<sup>45</sup>.

The "H principle" involved two ground stations, each consisting of a transmitter and receiver (the "transceiver"), with a second transceiver in the aircraft. In order to establish its position, the aircraft would transmit a pulse ('transmission pulse') to the two ground stations. At the moment of reception, the transceiver at each ground station would be triggered into sending back a pulse ('echo pulse') on a different frequency from the transmission pulse, from which the position of the aircraft could be calculated by measuring the range to each ground station<sup>46</sup>. The "H principle" or "twin-range principle" of location determination is shown diagrammatically in Fig 16/ below.

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<sup>45</sup> TNA AIR10/3359 Gee-H Navigator's Manual. Unless otherwise stated, the description of the G-H system here is derived from that document.

<sup>46</sup> This was the opposite of the *Oboe* navigation system, in which transmissions from two ground stations triggered pulses in the aircraft under control. For this reason, G-H is sometimes described as "*Oboe* in reverse".



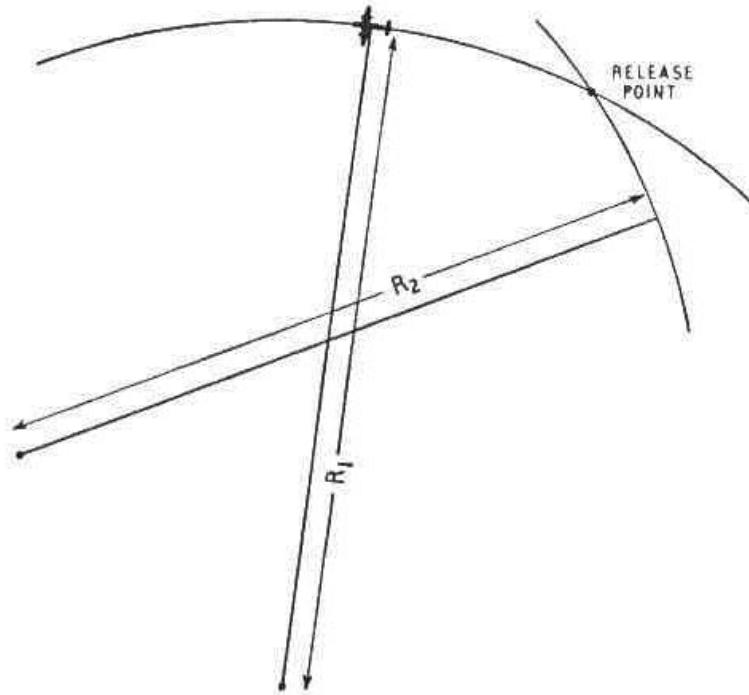


Fig 16/ The "H principle" or "twin-range principle" of location determination. Source: TNA AIR10/3359 Gee-H Navigator's Manual.

The G-H navigation aid utilised much of the oscilloscope display and the receiver unit in the existing GEE navigation aid and was designed to operate on the same frequencies as the GEE navigation aid (between 20 and 85 MHz), so that the existing receiver and display equipment in the GEE system could be used without modification<sup>47</sup>. The time taken between the sending of the transmission pulse and the receipt of the echo pulse, representing *twice* the distance between the aircraft and the ground station, could then be measured.

The systematic errors associated with G-H were confined to a limited number of variable factors, including: inputting the correct Wind Velocity; accurate achievement of the True Height and correct groundspeed; and the aircraft

<sup>47</sup> For this reason, G-H is sometimes referred to as Gee-H or GEE-H, although the hyperbolic GEE navigation system itself played no part in the operation of G-H.

being both on the correct track and the correct heading at the point of release, with errors in heading being more significant than errors in track. In practice, the main faults with G-H were largely side-effects of re-using the existing GEE equipment, not least in the limitation imposed by using the relatively low frequency at which GEE operated.

The G-H system was first used operationally on the night of 3/4 November 1943, when 36 aircraft attacked the Mannesmannrohrenwerke in Düsseldorf<sup>48</sup>. The accuracy possible with G-H was immediately apparent, with a Probable Radial Error of only 750 yards and with no significant systematic errors<sup>49</sup>. However, this raid was by way of an operational trial and it was not until mid-1944 that G-H came into full operational use with No.3 Group of Bomber Command<sup>50</sup>. Thereafter the accuracy of G-H remained consistently high throughout its operational use, with an average Probable Radial Error of 450 yards and an average distance of the M.P.I. from the A/P of 150 yards in the period October-December 1944<sup>51</sup>.

However, despite these advantages, G-H played only a relatively minor role in the bombing offensive and equipped (at most) one-third of the aircraft in one

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<sup>48</sup> TNA AIR14/1446 Operational Research Report S120 'G-H Attack on Düsseldorf 3<sup>rd</sup> November 1943', 7 November 1943.

<sup>49</sup> Ibid.

<sup>50</sup> TNA AIR2/5462 Operational Research Section Report S211 'An analysis of G-H raids (October-December 1944)', 1 March 1945. The first large-scale attack mounted by No.3 Group using the G-H 'formation leader' technique was mounted on the 18<sup>th</sup> October 1944, with the town on Bonn the target'

<sup>51</sup> Ibid. The period October-December 1944 is the last in which comprehensive information is available, subsequent reports on G-H performance by the Operational Research Section concentrating on those raids where specific systematic or random errors resulted in poorer than average accuracy.

Bomber Command Group<sup>52</sup>. Moreover, G-H could only be used by a maximum of 80 aircraft at any one time and therefore its value as a blind bombing device by individual aircraft, either by day or at night, was limited. This meant that the role of G-H as a blind bombing device was confined to daylight formation attacks. This in turn imposed a number of operational constraints including, crucially, that the weather was clear at the bombing height in order to facilitate formation keeping, which dictated that G-H attacks could only be mounted when the cloud tops did not exceed 17,000ft (this being the maximum operational height at which the G-H signals could be received over the target areas)<sup>53</sup>. Consequently, G-H formation attacks could only take place within a narrow weather 'window' which, given the weather in Northern Europe, significantly reduced the value of G-H as a blind bombing device.

## LORAN

LORAN<sup>54</sup>, an abbreviation for Long Range Navigation, is a family of radio navigation systems that employ the principles of hyperbolic navigation, and therefore operate on the same principle as GEE<sup>55</sup>. Two versions of LORAN were evaluated by Bomber Command during the Second World War: the 'Homing Chain' and the 'Skywave Synchronization Chain', the latter more usually referred to as "S.S. LORAN". The former was found not to offer any advantages over GEE and consequently was little used, although S.S.

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<sup>52</sup> Ibid

<sup>53</sup> Ibid

<sup>54</sup> Although now largely superseded by GPS navigation systems, LORAN remains in limited use worldwide as a back-up to those systems, particularly for sea-borne traffic

<sup>55</sup> The principles of hyperbolic navigation are described in Appendix 2 in relation to GEE, and are therefore not repeated here.

LORAN was used operationally for navigation and as a blind bombing device.<sup>56</sup>

S.S. LORAN differed from GEE principally in that it employed a lower frequency which, because lower frequency signals are refracted more easily in the earth's atmosphere, could be received considerably in excess of optical and therefore at a much greater range than was possible with GEE. The lower frequencies used also enabled a greater 'baseline' between ground stations, resulting in position lines that were nearly parallel and thereby increasing the angle of cut at longer ranges. In consequence, with S.S.LORAN the angle of cut was greater than 70° over all of the coverage and the maximum accuracy was over Germany and the occupied countries<sup>57</sup>.

S.S. LORAN made use of radio signals (known as "skywave signals") reflected from the lowest of a number of ionized layers in the Earth's upper atmosphere (see Fig 17/ below). This layer, known as the "Abnormal E" or "1<sup>st</sup> E" layer, only occurs during the hours of darkness and consequently S.S. LORAN did not function outside these hours.

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<sup>56</sup> TNA, AIR10/4170 LORAN Airborne Equipment (AN/APN4): Operator's Manual of Instruction, May 1944 and TNA. AIR14/1650, Manual for Operation of Airborne LORAN", September 1943. This description of S.S.LORAN is derived from these two documents.

<sup>57</sup> In contrast, with GEE the angle of cut decreased with range and GEE was most accurate at short ranges, including over Britain.

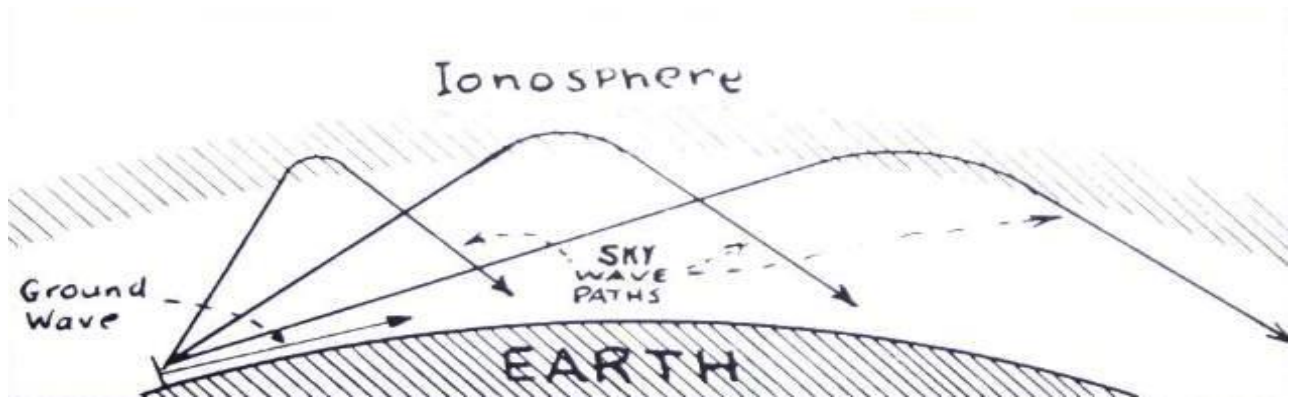


Fig 17/ Principle of Skywave Synchronization Chain. Source: TNA, AIR10/4170 "LORAN Airborne Equipment (AN/APN4): Operator's Manual of Instruction", May 1944

S.S.LORAN comprised two pairs of ground stations, each comprising one Master and one Slave ground stations, spaced over 1,000 miles apart<sup>58</sup>. The frequencies operated by the ground stations were locked in pairs with the position lines for each pair of ground stations shown on lattice charts similar to those used with the GEE. Each pair of frequencies was referenced by a single integer number known as a 'RATE', of which there were seven RATES within in the LORAN system as a whole; S.S. LORAN operated on RATES 4 and 5 only. The locking of frequencies in pairs meant that, unlike with the GEE system, with S.S.LORAN it was not possible to take readings on two position lines simultaneously, such that each fix obtained was a "running fix" in relation to one position line. It was therefore necessary for the operator to switch to the other RATE position line to obtain a second running fix and to take into account the time delay between the two running fixes in order to determine the position of the aircraft at the time the second fix was taken. The attendant

<sup>58</sup> The RATE 4 stations were located at Port Erroll, Scotland (Master) and Bizerta, Tunisia (Slave), and the RATE 5 stations were located at Oran, Algeria (Master) and Appolonia, Libya (Slave).

time delay was an important consideration in terms of the use of S.S. LORAN as a blind bombing device<sup>59</sup>.

S.S LORAN had an effective range in the region of 1,400 miles, and therefore included all of Germany and the majority of mainland Europe (although coverage did not extend to the North Sea or English Channel). In trials<sup>60</sup>, S.S. LORAN was found to have a probable 50% radial error of 2.1 miles averaged over the whole coverage, consistent with the fact that the position lines in S.S. LORAN were nearly parallel. The trials also indicated that there was no significant systematic error within S.S. LORAN and that the probable 50% radial error of 2.1 miles was due to random errors comprised of the variations with skywave signals and manipulation errors<sup>61</sup>.

The value of S.S. LORAN as a blind bombing device was limited by the relatively poor accuracy over the entire coverage and by the complications in bombing technique arising from the necessity to take a 'running fix'. However, from August 1944, S.S. LORAN was used operationally by the Light Night Striking Force (LNSF – part of No.8 Group Bomber Command<sup>62</sup>) for 'nuisance

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<sup>59</sup> An experienced S.S.LORAN operator could reduce the time delay between two running fixes to 30 seconds, although an aircraft travelling at 200 miles per hour would travel over 1½ miles in that time.

<sup>60</sup> TNA AIR14/1869 Operational Research Section Report S.195 'S.S. LORAN Trials', 13 December 1944. The trials were carried out by the Bombing Development Unit.

<sup>61</sup> The manipulation errors, i.e those caused by the operator, were calculated in the ORSBC report to account for 1.8 of the 2.1 total probable 50% radial error. Since the manipulation errors were constant over area, the standard deviation was deemed to arise from variations in the skywave signals.

<sup>62</sup> For more information on the Light Night Striking Force, see Feast *The Pathfinder Companion* and Musgrove *Pathfinder Force*.

raids' on major German towns, notably Berlin<sup>63</sup>. The purpose of these raids, undertaken by small numbers of Mosquito aircraft, dictated that accuracy was not the priority and accordingly no attempt was made to analysis of the accuracy achieved by S.S. LORAN as a blind bombing device. To the extent that S.S. LORAN effectively guaranteed that the small number of bombs that could be carried by the Mosquitoes would fall within a large built-up area in any weather conditions, the device made a useful contribution to the bombing offensive. However, even to a lesser extent than GEE, S.S. LORAN was incapable of providing Bomber Command with a blind bombing device of sufficient accuracy to obviate the need for target marking.

The above appraisal of the blind bombing devices available to Bomber Command during the Second World War demonstrates that they varied considerably in their application and effectiveness. The two devices based on the principles of hyperbolic navigation, GEE and S.S.LORAN, were not sufficiently accurate and GEE was also compromised by its comparatively short range. The airborne radar device, H2S, was not limited by range but similarly was not sufficiently accurate. On the other hand, the two radar devices based upon the measurement of distance using ground stations, Oboe and G-H, were extremely accurate but only a limited number of aircraft could use them at any one time and for most of the bombing offensive were limited by the short range at which they could operate. These characteristics and shortcomings ensured that these blind bombing devices, even had they

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<sup>63</sup> TNA AIR25/2044 No.571 Squadron Operational Record Book. The use of S.S. LORAN as a blind bombing device is also referred to in Musgrove. *Pathfinder Force*: p207 and in Appendix VII.

been available in sufficient quantity to equip the entire bomber force, would not have been able individually or cumulatively to deliver the Estimated Weight of Attack considered necessary to destroy the social and industrial structure within selected areas.

In practice, at no stage during the bombing offensive were any of these blind bombing devices available in sufficient quantity to equip the entire bomber force. This in part was due to the timing in which these various devices were introduced into service and their effective lifespan once in service. The first blind bombing device to be used operationally, GEE, did not enter service until early March 1942 and enjoyed an effective operational life of less than six months, by which time enemy jamming had rendered GEE ineffective over Germany and any potential for blind bombing had been denied<sup>64</sup>. No blind bombing devices were available to Bomber Command between the jamming of GEE in early August 1942 and the introduction of *Oboe* and H2S in January 1943, and large-scale blind bombing attacks using G-H did not commence until October 1944. Consequently, for over half the bombing offensive<sup>65</sup>, Bomber Command had no blind bombing devices available and for much of the remainder there were periods where one or more of the blind bombing

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<sup>64</sup> TNA, AIR20/8593, R. Cockburn, *The History of TRE* and Alfred Price, *Instruments of Darkness; the History of Electronic Warfare* (London: William Kimber & Co. Limited, 1977). The jamming of GEE had commenced on the 4<sup>th</sup> August 1942 using temporary makeshift transmitters although, because of their low power, these were only fully effective beyond the GEE horizon. With the introduction of purpose designed jamming equipment towards the end of 1942, the jamming of GEE became completely effective over the whole of occupied Europe until the introduction of GEE MkII which, with the ability to select and change frequencies when airborne, enabled the worst of the jamming to be avoided.

<sup>65</sup> Excluding operational trials and the limited use of the early versions of *Oboe*, the blind bombing devices described in this Chapter were available over a period of 34 months out of a bombing offensive lasting 69 months.



devices had either not yet entered operational use or their effective lifespan had already elapsed.

Moreover, the common denominator between all of the blind bombing devices available to Bomber Command was that, at least when first used operationally, they were only available in sufficient quantity to equip a small proportion of the force<sup>66</sup>. In the case of GEE, only one third of the bomber force was equipped with the device when it was introduced into service and at no point during the five months when GEE remained effective over Germany was more than 80% the bomber force was equipped with it<sup>67</sup>. Similarly, when H2S was introduced into service in early 1943, only 12 sets of the equipment were available and by July 1944 still only 40% of sorties were carried out by aircraft equipped with H2S<sup>68</sup>. The point is academic in the case of *Oboe* and to some extent G-H, neither of which could be operated by more than a few aircraft at any one time in any event, although the introduction of G-H was postponed until such time as sufficient sets were available to equip enough G-H leaders to guide large formations. It follows that even if these devices had proven to be sufficiently accurate as blind bombing devices, for much of the bombing offensive the proportion of the bomber force equipped with them would not have been able to deliver the Estimated Weight of Attack considered necessary to destroy the social and industrial structure within

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<sup>66</sup> S.S.LORAN was known not to be sufficiently accurate before being introduced into operational use and for that reason was only ever contemplated for a limited role with the LNSF.

<sup>67</sup> TNA AIR14//2693 Operational Research Section Report S252 "The effect of the development of navigational and blind bombing techniques on the efficiency of bombing operations during World War II", October 1945.

<sup>68</sup> Sir Arthur Harris *Despatch on War Operations 23<sup>rd</sup> February 1942 to 8<sup>th</sup> May 1945* (London: Frank Cass, 1945), Appendix A, paragraph 84, page 72.

selected areas using only aircraft so equipped. Furthermore, the corollary resulting from the piecemeal introduction of these various blind bombing devices was to create an imbalance in capability within the bomber force, in which a minority enjoyed the benefit of blind bombing devices that was denied to the majority.

It is therefore apparent that at no point in the bombing offensive was the stage reached where Bomber Command was equipped with a blind bombing device that would enable each individual aircraft, or even a sizeable proportion of the force, to independently bomb targets with sufficient accuracy to provide the required degree of concentration in both time and space. The inevitable conclusion is that until and unless all aircraft could have been equipped with an accurate blind bombing device, some form of target marking technique was essential to guide the aircraft not so equipped, and which comprised the majority of the bombing force, to the target. The logical solution was to take advantage of the various electronic and radar devices available that, whilst not adequate for blind bombing, nonetheless possessed characteristics that could be utilised to guide aircraft not so equipped to the target. Indeed, the Official History suggests that some form of target-finding force "...had become inevitable from the moment that GEE was introduced"<sup>69</sup>. The following Chapters will explore how Bomber Command evolved target-marking techniques based upon the electronic and radar aids described above, and the effect that the introduction of those techniques had on the performance of Bomber Command.

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<sup>69</sup> Webster and Frankland *The Strategic Air Offensive* Volume 1, p418.

However, before turning to the development of those target marking techniques, the opportunity is taken here to consider the contribution made by technology in the development of those techniques and, by extension, the contribution made by technology to the bombing offensive. The importance of technology in warfare has been the subject of much secondary literature, particularly in terms of the significant advancements made in technology during the Second World War. In his book *Britain's War Machine*, David Edgerton describes the Second World War as “an experts’ war”, not just between experts on opposing sides but, referring to the political aspects of scientific research and debate, also between experts on the same side<sup>70</sup>. The importance of technology is also one of the key themes explored by Guy Hartcup in his book *The Effect of Science on the Second World War*<sup>71</sup>. The approach taken by Hartcup is to analyse the contribution made by some of the more significant technologies developed during the Second World War, albeit the overall conclusion reached is at best a tentative one. A more convincing analysis of the importance of technology in the Second World War is provided by Richard Overy in his book *Why the Allies Won*<sup>72</sup>, and reaches the clear conclusion that the development and use of technologies formed one of reasons why the Allies won the Second World War. More recently, in his book *How the War was Won: Air-Sea Power and Allied Victory in World War II*,<sup>73</sup> Phillips O'Brien concluded that the outcome of the conflict was not determined

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<sup>70</sup> Edgerton *Britain's War Machine*, p123.

<sup>71</sup> Hartcup *The Effect of Science on the Second World War*

<sup>72</sup> Overy *Why the Allies Won*

<sup>73</sup> Phillips O'Brien, P.P. *How the War was Won: Air-Sea Power and Allied Victory in World War II*, (Cambridge: Cambridge University Press, 2015)

by the major land battles but through predominance in air and sea power, in which the science lead held by the Allies was a crucial factor.

The development of technologies in association with target marking techniques in many ways embodies the issues discussed in the above mentioned works. Nowhere is this better illustrated than in the development of the cavity magnetron. The cavity magnetron was a device capable of producing a microwave signal of sufficient power to generate a radar response. The H2S system utilised the cavity magnetron to generate microwaves in the centrimetric wavelength band of sufficient power to provide the range and image resolution necessary for the system to be of use as a navigation and bombing aid.

The development of the cavity magnetron is a microcosm of the development of technology in the Second World War as described in literature on this subject, in terms of the importance of the technology - Hartcup concludes that the cavity magnetron was an invention probably even more important than the atomic bomb<sup>74</sup>; its derivation from civilian organisations – an example of, as Edgerton terms it, a modern weapon that was the product of the civil imagination, in that the cavity magnetron was developed largely by teams at Birmingham University and the Cavendish Laboratory at Cambridge<sup>75</sup>; and as an example of what Edgerton refers to as “an experts’ war” in which experts outside of government clashed with those within it and experts battled

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<sup>74</sup> Hartcup *The Effect of Science on the Second World War*, p185.

<sup>75</sup> Edgerton *Britain’s War Machine*, p123.

politicians within the politically charged debates<sup>76</sup>. In relation to H2S, the debate centred on the risk that the use of H2S in bomber aircraft would inevitably result in an example of the cavity magnetron falling into enemy hands<sup>77</sup>.

Similar assessments may also be made in relation other technologies upon which target marking techniques relied, notably those based upon hyperbolic navigation (GEE) and the principle of the “Circle of Constant Path Range” (*Oboe*). In this sense, the development of technology associated with target marking techniques is representative of that of many technologies used in the Second World War. For that reason, the causal relationship between the characteristics of the navigation/bombing aids employed and the target marking techniques used in association with them, which the following Chapters will demonstrate, is itself a reflection of the importance of technology in the Second World War. It is the employment of the first of these technologies in association with target marking, GEE, that attention is now turned.

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<sup>76</sup> *Ibid.*

<sup>77</sup> For details of this debate, see Lovell, *Echoes of War* and *Price Instruments of Darkness*

### CHAPTER 3: EARLY TARGET MARKING TECHNIQUES

The previous chapter concluded with the proposition that the piecemeal introduction of various blind bombing devices throughout the course of the bombing offensive created an imbalance in the ability of parts of the bomber force to locate targets, the corollary being that the adoption of some form of target marking technique was both essential and inevitable. In this context, the Official History observes that the introduction of GEE had automatically led to the position whereby the part of the force equipped with it would always be better equipped for target finding than the remainder<sup>1</sup>. This Chapter will describe how Bomber Command evolved the first target-marking technique, known as *Shaker*, based upon the electronic aid GEE. The development of the *Shaker* technique represented uncharted territory for Bomber Command, and the principles on which this technique was based formed an intrinsic part of some of the more advanced techniques developed as the bombing offensive progressed. Consequently, the evolution and performance of the *Shaker* technique is considered in some detail in this Chapter in order that the lessons learned in the development of that technique and the improvements subsequently secured with later target marking techniques may be properly appreciated. However, it is first necessary to put this advance into context by reference to the ad hoc and improvised attempts at target marking that had taken place up until that point.

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<sup>1</sup> Webster and Frankland *The Strategic Air Offensive, Vol I*, p418.

By the outbreak of the Second World War, the use of flares to illuminate a target was already an established part of the tactics for night bombing. The Royal Air Force Manual of Air Tactics (Manual) of November 1937<sup>2</sup> contained a section devoted to night bombing which acknowledged the difficulty of identifying an objective “not contrasted with its surroundings” and the good definition of conspicuous objects on the ground from the air in undiffused moonlight. The Manual also noted that a characteristic of night bombing is that, although a target is often visible from overhead, it cannot be seen during the run-up to it and that, when using flares, from directly above ground detail could be obscured by the prominence of the flare in the foreground. The sequence of attack advocated by the Manual was therefore to locate the target by means of parachute flares and then, once the objective was identified, to turn and drop a marker bomb. The aircraft was then to make a second turn and release the bombs with the aid of the marker bomb. This tactic, it should be remembered, relates to attacks made by individual aircraft that had navigated to the target area without any outside assistance. However, the Manual did include a tantalising reference to the use of fast independent aircraft flying ahead of the main bomber force for the purpose of dropping parachute flares over the target to lead bombers to their objective, and so relieve them of the necessity of dropping their own flares.

If the above sounds like a system for target marking, the reality was something different. At that time, Bomber Command possessed two types of parachute flare, the 4.5” and the 5.5” flares, usually referred to as

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<sup>2</sup> TNA AIR10/1430 Royal Air Force Manual of Air Tactics AP1234, November 1937. The section on night bombing is within Chapter V.

'reconnaissance' flares. Both types could illuminate the ground for a distance of 1,000 yards from their optimum operating height of 1,500 to 2,000 feet above ground level. However, whilst the optimum illumination in terms of both coverage and detail visible was readily achieved at the altitudes flown in peacetime, at the altitudes required in wartime conditions the delay set on the time fuze caused the flare to ignite significantly above the optimum height. The illumination provided by these parachute flares was therefore much reduced and, because these flares were not 'hooded', from above the glare from the flare in the foreground tended to obscure the ground detail.

The other drawback was the so-called 'marker bomb' which, at that time, was the standard 4lb incendiary bomb<sup>3</sup>. Tests conducted at the Aeroplane and Armament Experimental Establishment (A&AEE) at Martlesham Heath had established that batches of 15 such incendiary bombs would be visible from a distance of 8 to 10 miles, and remained visible for 15 minutes<sup>4</sup>. Consequently, although it was noted that at distance ground features could not be discerned by the illumination created, the incendiary bomb would provide a good point of aim. The obvious implication of these findings - that one batch of such incendiaries could not distinguished from a similar batch of incendiaries placed elsewhere by another aircraft, and which would be an equally good point of aim for following aircraft - was not addressed by the A&AEE.

Indeed, there is no record of any such experiments being undertaken to verify whether the attack sequence for night bombing set out in the Manual actually

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<sup>3</sup> The saga of the development of a true 'marker bomb' is detailed in Chapter Five.

<sup>4</sup> TNA AVIA18/501 Report by the Aeroplane and Armament Experimental Establishment 'Incendiary bombs – Investigation of value as Mark Bombs in Night Bombing', 15 June 1937.



worked under operational conditions. This may be explained by the fact that, at the outbreak of hostilities, the bomber force was considered by the Royal Air Force to be 'daytime' force, with the bomber reliant upon the mutual protection afforded by good formation keeping to defend itself. When the fallacy of this tactic was rapidly exposed in early operations, and Bomber Command turned to the cover of darkness for protection, the lack of experimentation in night bombing tactics meant that it was woefully unprepared for a night offensive. It therefore initially fell to individual squadrons and, indeed, individual crews to experiment with their own tactics for illuminating targets.

At the forefront of these experiments were the squadrons in No.4 Group which, equipped with the Armstrong Whitworth Whitley aircraft, specialised in night bombing. At this early stage, experiments centred on the use of the 4.5" reconnaissance flare by individual aircraft to illuminate the target for their own benefit, in which flares were dropped in the vicinity of the target on the first run and the bombs dropped in the light provided by those flares on a second run<sup>5</sup>. The technique was rarely successful, partly because the flare did not burn long enough and had usually bunt out before the aircraft could return to complete the bombing run, exacerbated by the fact that the bomb sight then in use – the Course Setting Bomb Sight (CSBS) - required a lengthy straight and level approach at a pre-determined altitude and airspeed<sup>6</sup>. Mostly, however, the technique failed because, as discussed previously, the standard of

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<sup>5</sup> Hugh Melinsky *Forming the Pathfinders: the career of Air-Vice Marshal Sydney Bufton* (Stroud, Gloucestershire: The History Press, 2010), Chapter 4, p26.

<sup>6</sup> TNA AIR14/941 Instruction Notes on the Course Setting Bomb Sight Mark VIIIA. This version of the CSBS was functionally identical to the Mark IX.

navigation was such that the aircraft were generally not in the vicinity of the actual target and as such the ability or otherwise of a flare to adequately illuminate the target area was entirely academic. In his book *Bomber Pilot*, Group Captain Leonard Cheshire describes a typical raid during this period in which, having reached the Estimated Time of Arrival (ETA) for the target area, a flare was dropped which only showed “.....trees, woods, fields vaguely and, I thought, hills, but nothing else: nothing to show whereabouts we were”. After dropping a succession of flares over a period of nearly two hours, Cheshire was still unable to positively identify the target<sup>7</sup>.

It was also a Whitley squadron of No. 4 Group, No.10 Squadron based at Dishforth, that on the night of 17/18 May 1940 organised possibly the first attempt to mark a target for other crews using flares<sup>8</sup>. The squadron was commanded at that time by the one of the RAF's best-known characters, Group Captain W.E. Staton, who detailed his best crews to drop flares and fire Verey lights<sup>9</sup> over the target (an oil refinery at Bremen) to guide other aircraft of the two Dishforth-based squadrons. The success of this experiment is difficult to assess. The Squadron ORB confirms that oil refineries at Bremen were attacked on this night but provides no further details, although Middlebrook and Everitt state that some fires were started<sup>10</sup>. Shortly after this raid took place, Staton was succeeded as commanding officer of No.10

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<sup>7</sup> Cheshire, *Bomber Pilot* p.p.48 to 54. Cheshire was a Pilot Officer with No.102 Squadron at the time of the raid described in *Bomber Pilot*.

<sup>8</sup> TNA AIR27/141 No.10 Squadron Operations Record Book. This first attempt at target marking is described in Hastings *Bomber Command*, p85.

<sup>9</sup> Verey lights were a distress flare, named after the inventor Edward Wilson Verey (1847–1910), an American naval officer who developed a single-shot breech-loading snub-nosed pistol to fire the flare. Also known Very flares, Verey lights (note correct spelling is 'Verey', rather 'Very') were fitted as standard in RAF aircraft for use as both distress flares and the signal 'colours of the day' when challenged.

<sup>10</sup> Middlebrook and Everitt *The Bomber Command War Diaries*, p44.

squadron by (then) Wing Commander S.O.Buften, who instigated the practice of picking the best crews in the squadron to lead each attack<sup>11</sup> and who would later play a key role in the formation of the Pathfinder Force.

Independently of the attempts made by the Dishforth-based squadrons, the two Whitley squadrons based at neighbouring Drifffield conducted their own experiments in target marking. In June 1940, the two squadrons were briefed to attack a troop concentration about 35 miles inland from Rotterdam<sup>12</sup>. After the briefing, it was suggested by F/O 'Jimmy' Marks<sup>13</sup> that every crew made a time and distance run from the centre of Rotterdam, easily identified by the fires still burning from the bombing of the port by the Luftwaffe on the 14 May, and that at the ETA over the target each aircraft dropped a flare and fired a Verey light. Despite ideal weather conditions and assurances from all the aircrew that took part that a careful time and distance run was made<sup>14</sup>, the first attempt failed and not one of the aircraft taking part saw the flares or Verey lights from the other aircraft. On a second attempt, only the four best crews were to drop flares at the end of the time and distance run. On this occasion, four flares and four Verey lights were visible within three to five seconds following the end of the time and distance run, one of which was

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<sup>11</sup> Melinsky *Forming the Pathfinders*, p58.

<sup>12</sup> TNA AIR27/655 No 77 Squadron Operations Record Book.

<sup>13</sup> Later, as a Wing Commander and C/O of No. 35 Squadron, 'Jimmy' Marks would play a pivotal role in the early operations of the Pathfinder Force. For more information on the career of 'Jimmy' Marks, see William Anderson, *Pathfinders* (Jarrolds, 1946) and Feast *The Pathfinder Companion*.

<sup>14</sup> Amongst the aircrew taking part on this raid was the (then) Pilot Officer Leonard Cheshire (although no mention is made of these attacks in his biography *Bomber Pilot*.) and (then) Pilot Officer 'Hamish' Mahaddie. As a Group Captain, 'Hamish' Mahaddie would later play a significant role in the Pathfinder Force and would later record his experiences in a book: Mahaddie, H. *Hamish: the story of a Pathfinder* (Shepperton: Ian Allen, 1989).

reported to have pinpointed the target. This flare was then reinforced by other crews and an accurate attack was claimed<sup>15</sup>.

It is symptomatic of these early attempts at target marking that they were carried out at unit level, sometimes at the instigation of relatively junior officers. Moreover, there is no evidence to suggest that the squadrons at Driffield were aware of the similar experiments carried out by the squadrons based at neighbouring Dishforth, notwithstanding that both bases were within No. 4 Group.

Just prior to these *ad hoc* experiments taking place, a conference had been held at Bomber Command Headquarters to discuss tactical questions<sup>16</sup>. At the suggestion of the Commander-in-Chief, then AM Charles Portal, No.4 Group was requested to experiment with the use of specially picked crews to drop flares to guide following aircraft. On the 3rd June 1940, during a raid on the Homberg oil refinery near Duisburg, two flare carrying aircraft were timed to arrive over the target 30 minutes before the remainder of the force. Each of these aircraft carried 30 flares, compared with the normal compliment for a Whitley of six, and remained in the target area continuously dropping flares. Due to the limitation of the flares then in use, the flare dropping aircraft were restricted to a maximum height of 6,000ft, the resulting increased risk faced

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<sup>15</sup> TNA AIR27/655 No 77 Squadron Operations Record Book. This experiment is also described in at least three secondary sources: Chris Blanchett *From Hull, Hell and Halifax: an illustrated history of No.4 Group, 1937-1948* (Hersham, Surrey Midland Publishing, 2nd Edition, 2006); Michael Bowyer *Pathfinders at War* (Shepperton: Ian Allen Limited, 1977); and Mahaddie *Hamish: the story of a Pathfinder*. The account in each is essentially the same although, because it is based upon the experience of Group Captain Mahaddie, who as a Pilot Officer with No. 77 Squadron took part both of these raids, credence can be attached to this account.

<sup>16</sup> TNA AIR14/787 Notes of a conference at Headquarters Bomber Command on Monday 6 May 1940 to discuss certain tactical and other questions.

being acknowledged as a necessity with this technique. The experiment was repeated on the following night.

The experiment was not a success<sup>17</sup>. The crews of the main bombing force complained that the number and distribution of flares was confusing and made it difficult to identify the target. The consensus of opinion amongst these crews was that they preferred to use their own flares to enable them to locate the target. A further objection was that the flare carrying aircraft were required to drop a number of flares in order to locate the target themselves before dropping a concentration of flares to guide following aircraft. If the initial flare dropping aircraft were unable to locate the target before the arrival of the following aircraft, the flares dropped to locate the target were liable to confuse the crews of those aircraft. Conversely, if the flare dropping aircraft located the target quickly, either the flares would burn out before the following aircraft arrived or they would be obliged to remain in the target area for a lengthy period. At a time when there no navigation aids to assist crews in precise time keeping, this was a significant issue.

The experiment also raised issues that would surface again later in relation to target marking techniques. The view expressed by Air Commodore Coningham was that the technique “...savourers of putting too many eggs in one basket...”on the basis that, if the flare carrying aircraft failed to arrive, the whole of the attack may be delayed or disorganised. It was also explicitly recognised that success depended upon the initial flare dropping aircraft

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<sup>17</sup> TNA AIR14/106 Memorandum Air Commodore Coningham. AOC No. 4 Group, to AM Portal, C-in-C Bomber Command, 7 June 1940.

being able to identify the target correctly and that, if the 'first shot' was not on the correct target, the following aircraft would be misled. In this respect, Air Commodore Coningham observed that even if the main body of attackers sighted flares ahead that did not mean that the flare carrying aircraft had correctly identified the target. Coningham also commented that previous attempts to indicate the target using selected crews to drop incendiary bombs suffered from the same problem. His recommendation to Portal was to advise against further experiments at that time and that individual aircraft should continue to locate targets for themselves, believing that a concentration of individually navigated aircraft arriving over the target in a short space of time would result in an unmistakable beacon of flares and/or a conflagration<sup>18</sup>.

This was an interesting experiment, and one which even at this early stage identified the main issues that would later become associated with target marking, namely: the importance of the relative timing of the marking and main force elements; the need for a distinctive marker for the A/P; and the risk that an error in marking the target could lead the entire attack astray. There are two other significant aspects of this experiment. The first of these is the date of June 1940. As discussed below, the evolution of target marking techniques by Bomber Command is widely considered to be in response to the employment of a specialist target finding unit by the Luftwaffe<sup>19</sup>. However, the unit concerned - Kampfgruppe 100 - did not operate in the target finding

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<sup>18</sup> Ibid

<sup>19</sup> For example, M.Chorlton *The RAF Pathfinders: Bomber Command's Elite Squadrons* (Newbury, Berkshire: Countryside Books, 2012), page 13; Hastings *Bomber Command*, p190; Melinsky *Forming the Pathfinders*, p67; Overy *The Bombing War; Europe 1939-1945*, p290; J. Stubbington, *Kept in the Dark: The denial to Bomber Command of vital Ultra and other intelligence information during World War II* (Barnsley: Pen & Sword Aviation, 2010), p118.

role until September 1940, some three months after the experiments by No 4 Group<sup>20</sup>. The second significant aspect is that the experiment was suggested by AM Portal. Whilst there is no record of Portal's response to the results of this experiment, he would later as Chief of Air Staff play a crucial role in the formation of the Pathfinder Force (although how pro-active a role will be discussed later). The instigation of this experiment is therefore an early indication that Portal may have harboured doubts about a tactic whereby each aircraft individually located the target was capable of delivering the results required. Indeed, at the same conference at which he instructed No.4 Group to undertake experiments using specially selected crews to lead attacks, Portal had also stated that some form of marker bomb was essential to obtain accuracy and asked that No.3 Group experiment with the use of marker bombs<sup>21</sup>. This is further evidence that Portal was early to recognise the need for some form of target marking and explain why he ultimately supported the formation of the Pathfinder Force.

The first coordinated attempt to mark a target took place on the night of 16/17 December 1940, when 134 aircraft attacked Mannheim<sup>22</sup>. This raid, prepared under the code-name OPERATION ABIGAIL RACHEL, was important in the wider context of the bombing offensive, in that it was the first occasion on

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<sup>20</sup> Kenneth Wakefield, *The first Pathfinders; the Operational History of Kampfgruppe 100, 1939-1941* (Crécy Books Ltd, 1992), p102. Wakefield explains that a target finding role had long been envisioned for Kampfgruppe 100 but that it was not until September 1940 that the technique was actually employed.

<sup>21</sup> TNA AIR14/787 Notes of a conference at Headquarters Bomber Command on Monday 6<sup>th</sup> May 1940 to discuss certain tactical and other questions. At that time, the term 'marker bomb' still meant the 4lb incendiary bomb. No. 3 Group was chosen because the Wellington aircraft with which the Group was equipped was the most suited to accommodate a mixed load of incendiary and H.E. bombs.

<sup>22</sup> TNA AIR14/2670 Night Bomb Raid Sheets Vol VII, December 1940; AIR24/200 Bomber Command Operations Record Book; Middlebrook and Everitt, *The Bomber Command War Diaries*, p111.

which a city centre itself was the A/P and therefore the first so-called 'area raid'<sup>23</sup>. The plan to concentrate the largest possible number of aircraft on a single target, OPERATION ABIGAIL, had been specifically sanctioned by the War Cabinet on the 12 December 1940 as 'an experiment'<sup>24</sup>, with Mannheim (codenamed '*Rachel*') selected from the list of three cities authorized for attack<sup>25</sup>. The ABIGAIL plan called for the attack to be opened by a force of Wellingtons from No.3 Group flown by the 'most experienced crews available' and armed only with incendiaries, with the following crews instructed to take as their A/P the fires raised by this initial force<sup>26</sup>. This raid is therefore a significant milestone in the development of target marking techniques as being the first occasion whereby crews of the Main Force were relieved of the responsibility of locating the A/P.

The raid took place in clear conditions during the full-moon period, and 75% of the aircraft dispatched claimed to have reached the target<sup>27</sup>. Initial reports suggested that the majority of bombs had fallen in the target area with the town centre said to have been "left in flames"<sup>28</sup>, although subsequent reconnaissance photographs indicated a wide dispersal. This was confirmed

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<sup>23</sup> For the background to this raid, which was effectively a reprisal for the Luftwaffe raids on Coventry and Southampton, see Webster and Frankland *The Strategic Air Offensive*, Vol I, p.p.225 to 227.

<sup>24</sup> TNA CAB65/16/12. The three targets authorized for attack were Bremen (codenamed "Jezebel"); Düsseldorf (codenamed "Delilah"); and Mannheim (codenamed "Rachel").

<sup>25</sup> TNA AIR20/5195 Bomber Command Operations Order No.127, 13 December 1940.

<sup>26</sup> TNA AIR20/5195 Bomber Command Operations Order No.126, 4 December 1940.

<sup>27</sup> TNA AIR14/2670 Night Bomb Raid Sheets Vol VII, December 1940; AIR24/200 Bomber Command Operations Record Book; Middlebrook and Everitt *The Bomber Command War Diaries*, p111. The Night Bomb Raid Sheet and the Bomber Command Operations Record Book do not agree on the number of aircraft taking part in this raid and the figure quoted here represents the higher of the two. If the lower figure is used, 62% of aircraft dispatched claimed to have reached the target.

<sup>28</sup> TNA AIR24/200 Bomber Command Operations Record Book, 16/17 December 1940.



by reports from Mannheim, which indicated that the largest fires were not in the city centre but in the residential suburbs<sup>29</sup>.

The inevitable conclusion was that the initial wave of fire-raisers had not been accurate, and this led to the first wider debate about the value of target marking. Pierse suggested that the fires started outside the target area had “led the following crews astray”, and that the operation orders had been too rigid in requiring crews to aim at the fires started by the initial wave. Air Vice-Marshall Bottomley, who had recently assumed command of No.5 Group, agreed and considered that the initial fire-raising attack constituted ‘an added risk of failure’ because the fires might be in the wrong place or they might be decoys started by the Germans<sup>30</sup>. Air Vice-Marshall Coningham<sup>31</sup> took a different view, believing that the principle of an initial fire-raising force was sound and that the Germans, who employed a specialist fire-raising force, “had the right method”<sup>32</sup>. Indeed, he went further, claiming that “Bomber Command could do equally well, and better, if we pick our best units and specialise on similar lines”<sup>33</sup>. In view of Coningham’s comments following his own Group’s experiment with target marking, where he had recommended that such techniques not be pursued, his apparent volte-face only six months later may initially appear surprising and even disingenuous. However, the more generous explanation might be that Coningham had come to believe

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<sup>29</sup> TNA AIR41/40 Air Historical Branch Narrative: The RAF Bomber Offensive against Germany; Vol II Restricted Bombing Sept 1939- May 1941. This document contains a translation of the contemporary report produced by the city of Mannheim.

<sup>30</sup> TNA CAB65/16/12 Memo Bottomley to Bomber Command HQ, 26 December 1940.

<sup>31</sup> Air of Authority - A History of RAF Organisation. Arthur Coningham was promoted from Air Commodore to (Acting) Air Vice-Marshall on 12 September 1940 and confirmed as Air Vice-Marshall on 14 April 1942.

<sup>32</sup> TNA CAB65/16/12 Memo Bottomley to Bomber Command HQ, 26 December 1940.

<sup>33</sup> Ibid

that, in order to obtain similar results to those achieved by the Luftwaffe, it was not sufficient to simply select the best crews and that it was necessary employ a specialist unit to carry-out the initial fire-raising role.

The 'right method' to which Coningham referred was the use by the Luftwaffe of Kampfgruppe 100 in the role of an "Anzünder-gruppe" or "Beleuchter-gruppe" - a fire-raising group, tasked with starting fires to guide other aircraft to the target area<sup>34</sup>. The Luftwaffe had been quick to appreciate the difficulties in locating a target on moonless nights or in conditions of heavy cloud cover, even if that target was at relatively short range and as large and distinctive as London. To overcome these difficulties, from September 1940<sup>35</sup> the inclusion of Kampfgruppe 100 as an Anzünder-gruppe was a regular (but not ever-present) feature of Luftwaffe night raids, relying on incendiary bombs to illuminate the target area by means of fires - a technique known as "Azünderleistung", literally 'Fire Control Method'. There were, however, significant differences between the Fire Control Method employed by Kampfgruppe 100 and the experiment conducted by Bomber Command in OPERATION ABIGAIL RACHEL.

The first key difference was that the fires started by Kampfgruppe 100 were intended to illuminate the target area and were not intended to act as points of aim for the following crews. Indeed, for the first few months of Beleuchter-gruppe operations, Kampfgruppe 100 aimed at specific targets and carried a mixed load of incendiary and high explosive bombs. It was not until December

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<sup>34</sup> Until that time, Kampfgruppe 100 had been employed on precision attacks (mostly on aircraft factories) using the X-verfahren blind bombing device, with mixed results.

<sup>35</sup> Wakefield *The first Pathfinders*,p102

1940 - ironically about the time that OPERATION ABIGAIL RACHEL took place - that Kampfgruppe 100 routinely carried all-incendiary loads<sup>36</sup>. This is perhaps best illustrated in relation to the attack on Coventry on the night of 14/15 November 1940, for which Kampfgruppe 100 was allocated aiming points on the east side of the city whereas other Luftwaffe units were allocated specific factories as targets<sup>37</sup>. The spatial separation of these specific targets clearly indicates that the role of Kampfgruppe 100 was confined to guiding other aircraft to the general target area, on arrival at which crews identified their own specific A/P.

The second key difference is that rather than concentrating these fire-raising aircraft in time at the start of the raid<sup>38</sup>, the technique employed was to space the aircraft of Kampfgruppe 100 at intervals of between two and five minutes throughout the raid, in between which the aircraft of other units would make their attacks. Moreover, whereas the ABIGAIL plan called for the attack to be opened by the fire-raising force, Kampfgruppe 100 not always timed to be the first over the target.

The final, and perhaps most significant difference, is that Kampfgruppe 100 was guided to the target area by a blind-bombing device. Kampfgruppe 100

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<sup>36</sup> Ibid, p129. The first attack on which Kampfgruppe 100 carried an all-incendiary load was that on Sheffield on 15/16 December 1940, that being the night before OPERATION ABIGAIL RACHEL.

<sup>37</sup> Norman Longmate *Air Raid: the bombing of Coventry, November 1940*, (London:Hutchinson, 1976), Chapter 3 and Winston G. Ramsay (ed), *The Blitz: Then & Now, Vol II*, Battle of Britain Prints International Limited, 1988. For example, Kampfgeschwader 27 were allocated the Alvis aero-engine works and Kampfgeschwader 55 the Daimler Works.

<sup>38</sup> Although it usual for aircraft of Kampfgruppe 100 to begin arriving close to the start of the raid, it was not always the case that these were first aircraft timed to arrive over the target.

was the only unit equipped with X-verfahren<sup>39</sup>, a blind bombing device that employed a series of intersecting radio beams to release the bombs automatically, giving a theoretical accuracy of 300 yards at a range of 180 miles<sup>40</sup>. The use of X-verfahren effectively ensured that the incendiaries dropped by Kampfgruppe 100 would fall in the general target area and avoid the dispersion of attack that undermined OPERATION ABIGAIL RACHEL.

Although the 'fire-raising' technique developed by Kampfgruppe 100 had a significant influence on the fire-raising technique adopted in OPERATION ABIGAIL RACHEL and, indeed, the formulation of British bombing policy in 1941/1942, the success achieved by Kampfgruppe 100 in the fire-raising role was overestimated at the time. On no occasion is this better illustrated than in the infamous attack on Coventry on the night of 14/15 November 1940, which was one of the most concentrated raids undertaken by the Luftwaffe during this period and caused damage significantly in excess of anything achieved by Bomber Command at that time. This raid, carried out under the codename of *Mondscheinsonate* (Moonlight Sonata)<sup>41</sup>, was deliberately mounted during a period of ideal weather conditions with good visibility and bright moonlight. In the event, notwithstanding that the *Beleuchter* aircraft of Kampfgruppe 100 were all timed to arrive over the target in the first hour of the raid, 103 of the total of 552 aircraft dispatched failed to reach the target<sup>42</sup>. In another raid that

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<sup>39</sup> This device is sometimes erroneously referred to in secondary literature as X-Gerät, this being the term for the equipment carried in the aircraft. The correct term for the system as a whole, including the ground transmitting stations, is X-verfahren.

<sup>40</sup> The X-verfahren system was influential in the development of the early *Oboe* systems 'Blind Bombing Cherbourg' and 'Broody Hen'.

<sup>41</sup> This operation is usually referred to in British sources as *Mondscheinsonate* (Moonlight Sonata) but also appears as "*Mondscheinserenade*" (Moonlight Serenade) in some documents.

<sup>42</sup> Ramsay (ed), *The Blitz: Then & Now, Vol II*.

took place a few nights later in similarly good conditions, against Birmingham on the 19/20 November 1940, a total of 83 aircraft out of 439 dispatched failed to reach the target<sup>43</sup>. Consequently, notwithstanding the employment of a specialist target finding force on these two raids, 19% of those aircraft dispatched failed to reach the target, a figure not significantly different from that achieved by Bomber Command in OPERATION ABIGAIL RACHEL under similarly favourable weather conditions.

Therefore, despite possessing an accurate blind bombing system employed by a specialist target finding force, 'fire-raising' on the scale provided by Kampfgruppe 100 was not in itself sufficient to provide an unmistakable beacon to guide the main force to a target. On those occasions where the 'Fire Control Method' employed by Kampfgruppe 100 did prove successful, the target was nearly always located close to a prominent water feature, such as the distinctive bends of the River Thames through London or the docks of Bristol, Southampton and Liverpool. Against inland targets such as Coventry and Birmingham that lacked distinctive landmarks, the Luftwaffe was equally as reliant upon good weather conditions as Bomber Command, notwithstanding the 'pathfinders' of KG100 had the benefit of the X-verfahren system. Moreover, the overall accuracy, or rather the inaccuracy, of German raids was known to the British at this time. In his comments on the Butt Report., Portal had remarked that that 24% of aircraft had reached their targets<sup>44</sup>. Therefore, Kampfgruppe 100 was a dubious role model on which

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<sup>43</sup> Ibid.

<sup>44</sup> TNA AIR/1356 Minute CAS to Prime Minister, 11 September 1941.

to base Bomber Command's own fire raising techniques and, later, on which to base arguments for the creation of the Pathfinder Force.

In the event, Bomber Command would have to wait another year before it possessed a blind-bombing device of its own and could seek to emulate what some believed to be the 'the right method' employed by Kampfgruppe 100<sup>45</sup>. In the interim, Groups and squadrons continued with the use of flares by individual aircraft or, at most, by individual squadrons, and it was not until a year after Portal had initiated the first experiment in the use of specially picked crews to drop flares to guide following aircraft that the idea was raised again. On this occasion, the messenger was the Inspector General (I.G.) of the Royal Air Force, at that time none other than the former Commander-in-Chief of Bomber Command, Air Chief Marshal Sir Edgar Ludlow-Hewitt. In a letter dated 15 May 1941 to the then current incumbent of the post of C-in-C Bomber Command, Air Marshal Sir Richard Pierse, the I.G. described conversations that he had had with aircrew on the subject of flare dropping<sup>46</sup>. The I.G. explained that 'they all agreed that the flares were extremely good' and that 'a flare dropped by another aircraft anywhere ahead of them was of far greater value to themselves than a flare dropped by their own aircraft'. The I.G. also noted that *one unit* (emphasis added) recognised the value of dropping flares for one another and exploited that advantage by arranging that each aircraft would in any event drop all of its flares whether it wanted them

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<sup>45</sup> This was the GEE navigation aid – see Chapter 2.

<sup>46</sup> TNA AIR14/106 Letter dated 15 May 1941 from Air Chief Marshal Sir Edgar Ludlow-Hewitt to Air Marshal Sir Richard Pierse, C-in-C Bomber Command.

for itself or not, so as to assist following aircraft<sup>47</sup>. The I.G. gathered that this unit routed its aircraft closely, so as to get the maximum benefit from the flares. Other squadrons, it was noted, despite recognising the value of flares, had not made any special arrangements to take advantage of it. It is instructive to note that idea of a more co-ordinated approach to the dropping of flares had arisen as a result of discussion with operational aircrew and that, although all crews recognised the value of flares, only one unit had made any attempt co-ordinate their use.

The I.G. had concluded his letter by suggesting that the C-in-C may consider the use of flares to guide following aircraft a point worth pursuing, to which Pierse's response was to request each Group to summarize its use of flares<sup>48</sup>. Although it transpired that all Groups used flares, the technique varied considerably. In No.1 Group, one squadron had experimented with the tactical use of flares as suggested by the I.G. with good results, although generally it was considered that flares should be used by individual aircraft to assist in pin-pointing the location of the target. This Group also indicated that due to minimum operational height of 16,000 ft now employed it had modified the standard 4.5" flare so as to give it a longer delay so as to burn at 3-4,000 ft over the target<sup>49</sup>. No. 3 Group found that flares were more beneficial to following aircraft than the aircraft that dropped the flare but, in 'GOODWOOD'

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<sup>47</sup> Although not specifically identified by the I.G., this is likely to have been No.10 Squadron, who as described above was at the time commanded by (then) Wing Commander S.O.Bufton and which is known to have used this tactic.

<sup>48</sup> TNA AIR14/106 Letter dated 19 May 1941 from Air Marshal Sir Richard Pierse, C-in-C to Nos. 1, 2, 3, 4 and 5 Groups, Bomber Command. No. 2 Group, which at that time was primarily involved in daylight attacks on tactical targets, did not respond.

<sup>49</sup> This was still a compromise, given that the optimum height for these flares was 1,500ft to 2,000ft

type operations where numerous aircraft were involved, crews did not like using flares when uncertain of their position because of the risk of misleading other aircraft<sup>50</sup>. The specialist night-bombing No.4 Group confirmed that it was experimenting with the tactical use of flares as suggested by the I.G, commenting that success depended upon a concentration of flares, and was modifying the bomb cells in the wing of its Whitley aircraft to accommodate flares as a more efficient means of dropping them than the vertical stowage in the fuselage. The response from No.5 Group was more circumspect, given that the Group had relatively little experience in their use<sup>51</sup>. However, in principle, the Group agreed in principle with the method proposed by the I.G.

It is evident from these responses that by mid-1941 there was already a considerable body of experience and opinion within Bomber Command regarding the use of flares for target finding, and that tactics were being modified in response to changing operational requirements. However, these experiments were still taking place at unit level and there was no attempt to co-ordinate findings or develop tactics for target marking. Moreover, it was apparent that improved defences were by this time forcing aircraft to operate at higher altitudes, at which not only were the then standard flares ineffective in illuminating ground detail in the target area, but from which ground features *en route* were not discernible and navigation to the target more difficult. As the Butt Report was soon to show, Bomber Command was therefore still in the

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<sup>50</sup> At this time, the strength of the bomber force employed on any particular raid was denoted by a code name, these having the name of a racecourse. 'Goodwood' meant a large scale raid.

<sup>51</sup> The Handley Page Hampden aircraft with which the Group was equipped at that time was only capable of carrying two flares, whereas the Vickers Wellington which equipped Nos. 1 and 3 Groups could carry three flares and the Armstrong Whitworth Whitley used by No.4 Group normally carried six flares.



position whereby the standard of navigation was such that the aircraft were generally not in the vicinity of the actual target, in which case the value of tactics along the lines of those mentioned by the I.G. was entirely academic.

Moreover, the difficulty of locating the target was just one of several problems facing Bomber Command at this time. The extent and scope of these problems is succinctly captured in a paper titled 'Facing Facts' produced in December 1941 by Air Vice-Marshal Baldwin, AOC No 3 Group<sup>52</sup>. The paper began with the observation that the considerable improvement in results following the increase in strength of Bomber Command had failed to materialise. Baldwin advanced two main reasons for this failure: the scattered nature of the attacks, and the lack of concentration of such damage as was effected. The causes that led to that "somewhat haphazard method of attack" were said by Baldwin to have been an inability to navigate to the selected objective, a failure to locate the objective even when the navigation proved accurate to within a few miles of the A/P and a failure to hit the A/P assuming that it could be identified. According to Baldwin, in the order of priority in which he considered they were influencing the effectiveness of attacks, these failures could be attributed to a lack of training, inaccurate weather forecasts, the effectiveness of enemy defence measures and a lack of adequate technical aids. The paper produced by Baldwin is therefore a convenient vehicle through which to briefly explore the problems facing Bomber Command at the end of 1941 and thereby provide the context in which target marking techniques would be developed.

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<sup>52</sup> TNA AIR14/1939 Letter Air Vice-Marshal Baldwin to Air Marshal Sir Richard Pierse, 7 December 1941.

In his paper, Baldwin's concerns in relation to lack of training were focused on the poor supervision of inexperienced pilots once they reached operational squadrons<sup>53</sup>. However, there were also wider concerns within Bomber Command in relation to the quality of navigation training. By late 1941, navigation training was about to undergo somewhat of a transformation. In February 1939, in response to a suggestion from the Air Ministry that Observers should be responsible for navigation, the C-in-C of Bomber Command had declared that "navigation is not difficult" and that there was "no earthly reason why Captains should not be masters of this simple subject"<sup>54</sup>. As a result, early Bomber Command operations had been mostly conducted with the pilot(s) having responsibility for navigation. Subsequently, as described by Jerrod<sup>55</sup>, there was an increasing realisation that navigating an aircraft at night required a specialist. Consequently, from 1942 onwards, navigation was generally undertaken by specialist navigators within crews composed increasingly of role specialists.

Nevertheless, at the end of 1941, navigation remained a problem. In a letter to the Air Ministry dated 17 April 1942, Harris complained that he was "not at all happy" about the standard of navigation in Bomber Command and pressed for

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<sup>53</sup> Ibid

<sup>54</sup> TNA AIR/69 Letter from Air Chief Marshal E.R. Ludlow-Hewitt, C-in-C Bomber Command, to Air Vice-Marshal Sholto Douglas, Assistant Chief of the Air Staff, 27 February 1939.

<sup>55</sup> Jefford, C.G. *Observers and Navigators: and other non-pilot aircrew in the RFC, RNAS and RAF* (Shrewsbury: Airlife Publishing Ltd, 2001)

the appointment of Station Navigation Officers at every base and the formation of a Directorate of Navigation within the Air Ministry<sup>56</sup>.

Harris' letter of the 17 April 1942 was in fact a follow up of a wider-ranging letter on the subject of navigation sent to the Air Ministry a month before.<sup>57</sup>

The Air Ministry response, interestingly penned by Freeman rather than Portal himself, is unlikely to have been to Harris' liking<sup>58</sup>. The Air Ministry claimed to have always recognised the importance of air navigation but rejected the idea of a Directorate of Navigation, suggesting that it was neither necessary nor justified. Instead, some re-organisation within the Air Ministry was proposed to enhance the profile of navigation, together with the re-establishment of a Bomber Development Unit to focus on the study of navigation problems. The Air Ministry also proposed the establishment of squadron navigation officers, suggesting that they should be observers or navigators, and confirmed that a higher standard of navigation training was being given at Operational Training Units. However, as a parting shot, Freeman opined that the failure to find targets had been largely due to weakness in tactical study and tactical planning, and that the "righting of that failure rest primarily in your hands". This led Freeman to conclude his response by indicating that the most pressing need was for an effective means of initial identification and marking of the target, and that a properly constituted and well-trained target finding force was the primary requirement.

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<sup>56</sup> TNA AIR14/69 Letter AOC Bomber to Command to Air Chief Marshal Sir Charles Portal, Air Ministry, 17 April 1942.

<sup>57</sup> TNA AIR14/69 Letter AOC Bomber to Command to Air Chief Marshal Sir Charles Portal, Air Ministry, 24 March 1942.

<sup>58</sup> TNA AIR14/69 Letter Air Chief Marshal Sir Charles Portal, Air Ministry to AOC Bomber to Command to, 23 May 1942.

Harris did not let that response lie unanswered, and immediately questioned Freemans opening comment that the Air Ministry had always recognised the importance of Air Navigation as being unsupported by factual evidence<sup>59</sup>. Harris then countered Freeman's criticism of the lack of tactical study and planning, pointing to the establishment of the Operational Research Section within Bomber Command and the increased use of night photographs. Indeed, Harris went further, suggesting that the failures in tactical study and planning were due to the failure of the Air Ministry to allocate appropriate personnel to the task. However, Harris saved his most acerbic comment to the suggestion that the failure to navigate to the target was primarily due to errors in tactics, commenting that that statement alone shows an "apparent inability to appreciate the first importance of air navigation".

This exchange of correspondence is interesting, occurring as it did at a time when the formation of a target finding force was the subject of much debate (see Chapter 4). It demonstrates a general acceptance that the quality of training was in need of improvement, just as Baldwin had indicated in his paper, but that this was just one part of a wider problem. Another part of that problem, also identified by Baldwin, was that of weather forecasting.

The difficulty in terms of weather forecasting for Bomber Command operations was that the weather systems generally travelled from west to east. Thus, weather forecasters were able to predict with some accuracy

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<sup>59</sup> TNA AIR14/69 Letter AOC Bomber to Command to Air Chief Marshal Sir Charles Portal, Air Ministry, 3 June 1942

conditions over Bomber Command's bases by studying approaching weather conditions to the west and over the Atlantic but, as Baldwin observed, did not have the necessary information to predict conditions over the Continent<sup>60</sup>. As a result, inaccurate forecasts over the planned route and target area failed to predict cloud cover, wind strength and wind direction. These were factors essential to accurate D/R as well as pinpointing the target. Baldwin's recommendation was the creation of long-distance Weather Reporting Flights and these would later materialise as the highly successful "Pampa Flights" carried out by the specially formed 1409 (Met) Flight<sup>61</sup>. However, in late 1941, inaccurate weather forecasting remained a significant problem facing Bomber Command.

In relation to the increased effectiveness of the enemy defences, Baldwin's point was the simple and obvious one: they had forced the bomber aircraft to fly at heights from which it was not possible to identify ground features at night, even in conditions of good visibility<sup>62</sup>. Baldwin's concern in this respect appears to have been directed at bombing accuracy but, for the reasons set out earlier, the difficulty caused by not being able to recognise ground features also holds true for navigation.

The final factor identified in Baldwin's paper was the lack of adequate technical aids<sup>63</sup>. The first deficiency identified was the absence of an efficient

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<sup>60</sup> TNA AIR14/1939 Letter Air Vice-Marshal Baldwin to Air Marshal Sir Richard Pierse, 7 December 1941

<sup>61</sup> TNA AIR29/867 1409 Meteorology Flight, later 1409 Long Range Meteorological Flight.

<sup>62</sup> TNA AIR14/1939 Letter Air Vice-Marshal Baldwin to Air Marshal Sir Richard Pierse, 7 December 1941

<sup>63</sup> Ibid

flare. At that time, Bomber Command was using the 4.5" reconnaissance flare<sup>64</sup>. This was a cordite bomb which ignited when drawn from a canister by a parachute<sup>65</sup>, the deployment of which was controlled by a time fuze activated instantaneously at the point of release. The ignited flare fell at a rate of 500ft/min below the parachute, and could illuminate the ground in a white light for a distance of 1,000 yards from its optimum operating height of 1,500 to 2,000 feet above ground level<sup>66</sup>. The time activation period of the time fuze remained constant, such that the altitude at which the flare ignited was directly related to the altitude of the aircraft at the point of release: the higher the initial release, the greater the altitude at which the flare ignited. Consequently, as the operational altitudes increased in response to improving German defences, the delay set on the time fuze caused the flare to ignite significantly above the optimum altitude, with the result that the illumination provided by these parachute flares was much reduced. The need identified by Baldwin was therefore for a flare that opened at a height above ground which optimized the illumination provided.

The 4.5" reconnaissance flare was not 'hooded', such that the upward glare would dazzle the bomb aimer and prevent ground detail from being seen. Moreover, the presence of ground haze would diffuse the light produced by the flare and exacerbate the upward glare. This was entirely counter-productive to the purpose of dropping the flares in the first instance.

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<sup>64</sup> TNA AIR10/2393 Air Publication 1661H, Vol 1 'PFF Special Marker Equipment', October 1944. The correct technical nomenclature of this projectile was 'Flare, a/c, Reconnaissance 4.5"', although the abbreviated term 4.5" reconnaissance flare is used throughout this thesis.

<sup>65</sup> TNA AIR20/4813 Air Ministry, Directorate of Armament Requirement note 'Summary of P.F.F. Special Weapons for target marking and illuminating', 1 February 1945.

<sup>66</sup> TNA AIR10/2393 Air Publication 1661H, Vol 1 'PFF Special Marker Equipment', October 1944.

The principal requirement that Baldwin identified was therefore for a 'hooded' flare<sup>67</sup>. Even though a hooded flare was operational in America in 1941, the development of a hooded flare for Bomber Command did not begin until early 1943 and a hooded flare was not introduced into operational use until January 1944. The delay was caused by experimentation in establishing the shape and form of the parachute, which also served as the 'hood'. The main issue was finding a material of sufficient opacity to reduce the upward glare but which, in the quantity adequate to provide a parachute of a surface area capable of supporting the flare at the required rate of descent and shielding the upward glare, was sufficiently thin to be accommodated within the casing and yet strong enough not to tear on release. The production version that emerged was a 7" reconnaissance flare suspended on a parachute having an area of 18 square feet<sup>68</sup>. Once introduced into operational use the hooded flare represented a significant improvement on the ordinary 4.5" reconnaissance flare. The reduced glare resulting from the use of the hooded flare was a significant factor in the success of the *Newhaven* technique in the last year of the bombing offensive (see Chapter Five) and in particular the low-level target marking techniques developed by No 5 Group, a key component of which was the illumination of the target area by flares dropped 'blind' from a high level by aircraft equipped with H2S (see Chapter Six).

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<sup>67</sup> TNA AIR14/1939 Letter Air Vice-Marshal Baldwin to Air Marshal Sir Richard Pierse, 7 December 1941

<sup>68</sup> TNA AIR10/2393 Air Publication 1661H, Vol 1 'PFF Special Marker Equipment', October 1944. The correct technical nomenclature of this projectile was 'Flare, a/c, Reconnaissance 4.5", Hooded, No 2, Yellow/Air', although the abbreviated term 'hooded flare' is used throughout this thesis.

In almost a side-note, Baldwin also expressed the hope that improved wireless aids would very shortly be forthcoming and enable “more accurate tracks to be flown”<sup>69</sup>. Baldwin did not go into further detail, but a letter from Bomber Command in March 1942 referred to the “science” of navigation as having progressed far beyond the “railway line stage” (‘Bradshaw’ navigation) and that the failure of crews to reach and locate targets was due to a lack of suitable navigation equipment<sup>70</sup>. The paper went on to suggest that the Air Position Indicator (A.P.I) should be given the highest priority as a necessary adjunct to GEE in order to solve the “other half” of the D/R navigation problem (i.e. beyond the range of GEE).

Although not by any means comprehensive, ‘Facing Facts’ encapsulates the main problems facing Bomber Command at the end of 1941. A number of the recommendations made by Baldwin would materialise later in the bombing offensive, notably the ‘Pampa Flights’, the hooded flare and the A.P.I., and these would go some way to solving the problems identified in this paper. However, whilst the anticipated improvement in results had failed to materialise in 1941 using existing methods, the reasons for that failure remained. It was the very problems identified in ‘Facing Facts’ that Bomber Command sought to address by the introduction of target marking and, by the start of 1942, Bomber Command was about to employ the first of the recognised target marking techniques: that known as ‘*Shaker*’.

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<sup>69</sup> TNA AIR14/1939 Letter Air Vice-Marshal Baldwin to Air Marshal Sir Richard Pierse, 7 December 1941

<sup>70</sup> TNA AIR14/69 Letter AOC Bomber to Command to Air Chief Marshal Sir Charles Portal, Air Ministry, 24 March 1942.



The first step towards the 'right method' had been taken when the first operational trial of Bomber Command's first navigation aid - GEE - took place on the night of the 11/12 August 1941. However, on the following night, a GEE-equipped aircraft was lost on operations and fearing that the device may be compromised even before being introduced into widespread service, operational trials were hastily curtailed<sup>71</sup>. Nonetheless, GEE appeared to offer much promise and Bomber Command began preparing for its entry into operational service. The clear expectation was that GEE would have a limited operational life before being subject to countermeasures, with the most sanguine estimates being in the region of three to six months. Accordingly, in December 1941 ORSBC produced a report that considered the operational use of GEE<sup>72</sup>, noting in introduction that "its value will be great" and that it was "especially important that it should be used at the outset to the maximum advantage". The report recognised that new tactical possibilities would arise from the introduction of the instrument, and that it was "clearly desirable that careful consideration should be given to the planning of the operations".

The report was quick to point out that GEE enabled the exact time and direction of attack to be laid down within narrow limits and that operations could be planned so that within a few minutes a very large weight of bombs could be dropped. The resultant concentration was recognised as increasing the damage caused to industrial areas through overwhelming civil defence

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<sup>71</sup> For interesting accounts of the attempts made to prevent the existence of GEE becoming known to the Germans following the loss of this aircraft, see R.V. Jones *Most Secret War: British Scientific Intelligence 1939-1945* (London: Wordsworth Editions Limited, 1998), Chapter 25, and *Price Instruments of Darkness* p.p. 98 to 101.

<sup>72</sup> TNA AIR14/695 Operational Research Section Report S23 'Operational use of GEE', Operational Research Section Bomber Command', 1 December 1941.

services but was also fundamental to the possibilities that followed, none of which would have been possible without the accurate timing offered by GEE navigation.

The first of these possibilities was concentrated flare dropping. It was suggested in the report that on nights with good visibility it would be possible to attack small targets which had been identified by concentrated flare dropping by a small number of GEE equipped aircraft carrying a large number of flares, timed to arrive over the target before the main attack in order to illuminate the target area<sup>73</sup>. It was acknowledged that the timing and general planning of such operations would need to be carefully worked out, which would subsequently prove to be more involved than was perhaps envisaged at the time. However, the technique of concentrated flare dropping described was, in effect, the rudiments of target marking techniques that later became standard<sup>74</sup>.

A second possibility was blind bombing. With the accuracy of GEE expected at that time<sup>75</sup>, the ORSBC report suggested that GEE should prove effective on raids on targets covering about one square mile<sup>76</sup>, even in conditions of dense cloud. Moreover, it was suggested that in conditions of haze but no cloud, the fires started by GEE equipped aircraft would be visible as a guide

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<sup>73</sup> Ibid

<sup>74</sup> For example, the '*Newhaven*' technique later used extensively by the Pathfinder Force was essentially based upon the visual identification of the target on the ground with the benefit illumination from flares.

<sup>75</sup> TNA AIR14/1313 Memorandum from Headquarters Bomber Command to Headquarters No 3 Group, 5 January 1942. The memorandum assumed between half a mile and three miles over the Ruhr.

<sup>76</sup> Ibid. As pointed out in the memorandum, this would include the Krupps Works in Essen, a key target at this time.

to non-GEE equipped aircraft following. Here, then, was a principle that in a modified form would also form the basis of target marking techniques that later became standard<sup>77</sup>.

A third possibility was 'attack by fire'. Acknowledging from the outset that concentration would be even more important if an attack by fire was to overcome the civil defence services, ORSBC nonetheless considered that it would be possible to plan an attack such that a large number of GEE equipped aircraft could drop their incendiaries within a few minutes of each other, thereby starting a conflagration that following non-GEE equipped aircraft could aim at<sup>78</sup>. This concept would later form the basis of the *Shaker* target marking technique (see below).

This report from ORSBC<sup>79</sup> is significant because, some three months before the first large scale use in operations, the tactical possibilities offered by GEE were recognised as extending beyond purely an aid to navigation. The report also clearly appreciated that the main advantage offered by GEE was the concentration of attacks in time and space, and that it was this, more than any other factor, that opened up the tactical possibilities of opening attacks with concentrated flare dropping or attack by fire. In so doing, this report foreshadowed the development of target marking techniques that would later underpin the remainder of the bombing offensive. Moreover, whilst it was

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<sup>77</sup> The '*Parramatta*' technique of ground marking later used extensively by the Pathfinder Force adopted the same principle of dropping markers blind for following aircraft to aim at, albeit using Target Indicators to mark the target rather than fires.

<sup>78</sup> TNA AIR14/695 Operational Research Section Report S23 'Operational use of GEE', Operational Research Section Bomber Command, 1 December 1941

<sup>79</sup> *Ibid*

believed at the time that GEE would be sufficiently accurate for blind bombing, the emphasis was on techniques that would enable GEE equipped aircraft to assist other aircraft not so equipped to locate the target. It therefore follows that even before GEE was used operationally, there was a recognition that, at least until such time as the entire force was equipped with device, the true value of GEE beyond a navigation aid was not as blind bombing instrument, but rather as an aid to target marking.

This report had been prepared entirely on the initiative of ORSBC, and had been sent to Air Vice-Marshal Robert Saundby, SASO at Bomber Command on the 2 December 1941 under cover of a minute from B.G.Dickins, Head of ORSBC commenting that 'I do not know to what extent the special operational use to which GEE might be put has been considered, but it has occurred to us that a Memorandum on the subject might be useful'<sup>80</sup>. The reply, from Air Commodore Williams, Deputy SASO, indicated that "This is the first time that I have seen a detailed paper on the possible operational employment of "Gee". It is very useful and I am sure will form the basis for drawing up a detailed programme of experiments"<sup>81</sup>.

It is not clear whether the ORSBC Reports had been given wider circulation outside Bomber Command, but in January 1942 the Air Staff produced a detailed note on the employment of GEE that came to broadly similar

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<sup>80</sup> TNA AIR14/695 Loose Minute, Dickins, OIC ORSBC to SASO Bomber Command, 2 December 1942.

<sup>81</sup> TNA AIR14/695 Loose Minute, Dickins, D/SASO Bomber Command to OIC ORSBC, 2 December 1942.

conclusions<sup>82</sup>. The Air Staff considered that, on the estimates of the accuracy then expected from the device, GEE would be most effectively used in carrying out 'heavy, concentrated and continuous bombing of a few selected area targets in Western Germany'. The plan outlined in the note was, in summary, the destruction of the homes, factories, commercial premises and warehouses of the key workers and employees living in the selected areas; the key workers and employees themselves; and the general morale of the people living and working in the selected areas and adjoining towns. This plan was called UNISON.

The UNISON plan was not itself new, and had been outlined in general terms by the Air Ministry in a letter dated 25 October 1941<sup>83</sup> with the detailed plan issued a month later<sup>84</sup>. The plan proposed incendiary bombing attacks against individual towns in Germany, to be repeated until the 'Effective Weight of Attack' had been reached<sup>85</sup>. Each attack would be opened by a fire raising echelon in order to saturate the defences and start a conflagration that would act as a beacon 'so distinctive as to be impossible for the enemy to simulate by decoys' to guide the 'main force' following<sup>86</sup>. It was recognised that the success of the plan depended upon on the weight of incendiaries dropped by the fire raising echelon. For that reason, the UNISON plan required that the

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<sup>82</sup> TNA AIR14/695 Area Attack Employing 'GEE', dated 16 January 1942. This note was tabled by D/B. Ops at a meeting on the 17 January 1942 to discuss the operational employment of GEE.

<sup>83</sup> TNA AIR14/696 Letter D.C.A.S. to C-in-C Bomber Command 25 October 1941, with outline plan attached.

<sup>84</sup> TNA AIR14/696 Bomber Command Instruction No.58, 10 November 1941.

<sup>85</sup> The 'Effective Weight of Attack' was the effort estimated to be required for the destruction of each of the town selected for attack. The Effective Weight of Attack for four key towns - Essen, Cologne, Duisberg and Dusseldorf - was set out in an Appendix to the note.

<sup>86</sup> The concept behind UNISON was also not new, and had been tried a year previously as part of ABIGAIL RACHEL.

initial fire raising force was comprised of 'heavy' bombers in order to maximise the number of incendiaries carried, for which 60,000 was stipulated to be dropped over a 20 minute period. Moreover, it was recognised that success also depended upon the 'skill and determination' of the initial fire raising echelon in finding the target.

The Air Staff note of the 16 January 1942 did, however, propose a slight variation to the original UNISON plan in that the initial fire raising echelon was also to include a small number of GEE equipped aircraft carrying a 100% load of flares. It was also proposed that the Main Force, timed to arrive 45 minutes after the initial fire raising echelon, would be preceded by a similar number of GEE equipped flare carrying aircraft, or that GEE equipped aircraft should drop flares at fixed times throughout the main force attack. The expectation was that, by using this technique, the GEE equipped aircraft would be able to bomb (in clear or cloudy conditions) an area measuring 3 x one half miles, and that the Main Force would be able to drop their bombs within the confines of a built up area covering 20 square miles. The Air Staff note believed that by using GEE it would be possible to operate effectively on an average of 20 nights per month<sup>87</sup> and that, assuming a bombing efficiency of 50%, it was suggested that operations against the four selected towns could be completed in one to two months.

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<sup>87</sup> As previously described, accurate bombing required clear conditions and moonlight which, on average, meant that effective attacks were possible on 3 nights per month.

The operational use of GEE was the subject of a conference held at Bomber Command Headquarters on the 17 January 1942<sup>88</sup>. The conference first considered how best to employ GEE in various weather conditions, both in terms of leading non-equipped aircraft and for blind bombing. The conclusion reached was that blind bombing using GEE should only occur in conditions whereby non-equipped aircraft would be unable to locate the target even with the assistance of GEE-equipped aircraft. In all other conditions, i.e. where the ground would be visible from operational altitudes, GEE should be used to lead non-equipped aircraft to the target.

The conference next considered how best GEE could be used to lead the bombing force to the target, with consideration given to fire raising and the dropping of flares. In relation to the latter, the conference acknowledged that there was considerable uncertainty about the best technique for the use of flares to guide 'follower' aircraft. Accordingly, the conference agreed that trials should be undertaken as soon as the accuracy of GEE had been established<sup>89</sup>.

The task of drawing up detailed plans for these trials fell to ORSBC, which on the 24 January 1942 issued a report setting out proposals for a trial based largely upon the dropping of single 4.5" flares by a number of aircraft

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<sup>88</sup> TNA AIR14/1769. Notes of a discussion on the Operational Use of TR1335 held at Headquarters Bomber Command on 17 January 1942. Attendees at this conference included Air Marshal Baldwin, (Acting) C-in-C Bomber Command; Air Vice-Marshal Saundby, S.A.S.O. Bomber Command; Air Commodore Baker, D.B.Ops, Air Ministry; and B.G.Dickins, Head of Operational Research Section, Bomber Command.

<sup>89</sup> The recently formed No.1418 Flight was still in the process of undertaking the experiments advocated by the Operational Research Section to establish the accuracy of GEE.

equipped with GEE<sup>90</sup>. Taking up this recommendation, Bomber Command confirmed in a letter to No.3 Group dated 30 January 1942<sup>91</sup> the desirability of determining the best method of employing GEE fitted aircraft to assist the main striking force<sup>92</sup> and that it was particularly important to evolve sound tactical principles for the employment of this “new and revolutionary” device in order that the maximum use may be made of it before effective countermeasures were developed. The letter went on to confirm that of the techniques outlined by ORSBC, i.e. fire-raising and concentrated flare dropping, it was the technique for the latter which required investigation in terms of the relative advantages of using individual flares; groups of flares, both in sticks and bundles; the optimum number of flares to have burning over a target at any one time; and the operational value of searcher flares<sup>93</sup> and coloured flares.

Instructions for the trial were issued on the 4 February 1942, although the trial itself did not take place until 13 February.<sup>94</sup> The trial, known as “CRACKERS”, used Sulby station on the Isle of Man as the ‘target’<sup>95</sup> and took place in ideal conditions. The trial was divided into four phases involving GEE equipped Wellington aircraft dropping individual flares or sticks of six bundles

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<sup>90</sup>TNA AIR14/3293 Operational Research Section Report S30 ‘The operational use of Gee III: The use of flares in conjunction with GEE’, 24 January 1942.

<sup>91</sup> TNA AIR14/695 Letter Bomber Command Headquarters to AOC No. 3 Group, 30 January 1942. In this letter, GEE was referred to throughout as T.R. 1335.

<sup>92</sup> The terminology used in this letter is interesting, in that this is clearly based upon an underlying concept of dividing the bomber force into a ‘main force’ and, whilst not expressly termed but by implication, a differently equipped ‘target finding force’.

<sup>93</sup> Searcher flares were a more powerful version of the standard reconnaissance flare.

<sup>94</sup> TNA AIR14/695 No. 3 Group Exercise Instruction No.1, 4 February 1942.

<sup>95</sup> Sulby station was selected because the range and ‘angle of cut’ in relation to the ground stations was broadly similar to that for targets in the Ruhr, and consequently was expected to provide a realistic simulation of the strength and accuracy of the GEE signals received.



of flares at one minute intervals, onto which non GEE equipped aircraft were to attempt to home.

The results from "CRACKERS" were discussed at a conference at No. 3 Group Headquarters on the 15 February 1942, and reported to Bomber Command Headquarters in a memorandum that same day<sup>96</sup>. It was generally agreed that the individual flares were not sufficiently bright to illuminate the target, but that bundles of flares spaced approximately one mile apart gave excellent results, enabling crews to pick out a sizeable target from 12-15,000 ft.. The overall conclusion of the conference was that the best technique for the use of GEE would be to illuminate the target with sticks of flares from zero hour to z+10, with further GEE equipped aircraft dropping full incendiary loads at z+5. It was recommended that any aircraft in these echelons that positively identified the target should drop coloured flares. It was further recommended that the main striking force of non-GEE equipped aircraft began arriving at zero hour in order to take advantage of the flares being dropped and to assist in spreading of the conflagration caused by the GEE equipped incendiary aircraft.

In view of a systematic error with the GEE pulse in the first trial, Air Marshal Baldwin<sup>97</sup> decided that a further trial was required. This second trial,

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<sup>96</sup> TNA AIR14/695 Memorandum from Group Captain J.A. Gray, No 3 Group Headquarters to Headquarters Bomber Command, 15 February 1942.

<sup>97</sup> Air of Authority - A History of RAF Organisation. Previously an Air Vice-Marshal when commanding No 3 Group, Baldwin was promoted to Air Marshal when he took up the appointment as the (Acting) Commander-in-Chief Bomber Command, following the dismissal of the previous Commander-in-Chief Air Marshal Sir Richard Pierse in January 1942 and pending Air Marshal Arthur Harris taking up his appointment Commander-in-Chief on the 22 February 1942..

“CRACKERS II”, took place on the 19 February 1942 with the railway station at Brynkir in North Wales as the target<sup>98</sup>. Phase One of the trial was to be a scaled-down repeat of CRACKERS. Phase Two was the bulk-dropping of flares by a Stirling aircraft.

The weather for the CRACKERS II exercise was clear, but with ground haze, with the moon in the first quarter<sup>99</sup>. The dropping of flares in Phase One was again considered helpful in enabling the following aircraft to home onto the target from 20 to 30 miles away, but the best results were obtained by the sticks of 11 bundles of 4 flares at 5 second intervals dropped by the Stirling aircraft. It was agreed that the latter illuminated the ground ‘really well, if anything, could have been dropped with greater spacing without reducing the illumination of the ground’<sup>100</sup>. The recommendation was that attacks led by GEE equipped aircraft should open with an echelon of 8 flare carrying aircraft, each dropping 12 bundles of 3 flares at 10 second intervals, thereby giving a line of illumination of six miles<sup>101</sup>. Further echelons of three GEE equipped aircraft would then follow at 3 minute intervals until z+20.

The outcome of the CRACKERS trials and the recommendations in terms of the operational techniques for the employment of GEE were forwarded to the

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<sup>98</sup> TNA AIR14/695 No. 3 Group Exercise Instruction No.2, 19 February 1942. The actual exercise took place that same night.

<sup>99</sup> Although crews reported ground haze in the target area, the density of the ground haze was significantly less than that typically encountered over the Ruhr. Although not realised at the time, this would have significant implications for the effectiveness of flares in the manner proposed in the CRACKERS exercises when used in actual operations against targets in the Ruhr.

<sup>100</sup> TNS AIR14/695 Memorandum from No.3 Group Headquarters to Headquarters Bomber Command ‘Report and recommendations on Exercise CRACKERS II’, 20 February 1942.

<sup>101</sup> This recommendation assumed that the flare carrying aircraft would be Wellingtons, and that the airspeed at the time of the drop would be 180 mph.

Air Ministry on the 23 February 1942<sup>102</sup>. The Air Ministry considered that the method of illumination proposed may prove insufficient in operational conditions and that greater intensity of illumination may be achieved if the first aircraft to see the target dropped coloured flares, and then following aircraft confined their flares to the immediate vicinity of the target<sup>103</sup>. However, commenting post-war on Harris' *Despatch on War Operations*, Group Captain Bufton implies that the Air Staff had more fundamental concerns about the value of the "CRACKERS" trials<sup>104</sup>. In his comments, Group Captain Bufton suggests that the Air Staff were of the view that experiments to investigate the possibilities of flare concentration were not sufficiently exhaustive and that better potentialities of the scheme might have been obtained if more experiments had been carried out with concentrations of flares rather than sticks of flares. The opinion of the Air Staff was that some of the difficulties subsequently experienced when GEE became operational could have been overcome if the optimum employment of flares had been determined by more extensive trials and if a target finding force had been formed to drop flares on the basis of a carefully devised and developed technique relying on flares dropped by GEE to locate the area, visually dropped flare concentrations to illuminate the target and the laying of an initial and substantial concentration of incendiaries. The letter dated 26 February 1942 is, however, the only formal response found from the Air Staff in relation to the CRACKERS exercises and it would appear that Group Captain Bufton's comments were made with the benefit of hindsight and without foundation.

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<sup>102</sup> TNA AIR14/695 Letter C-in-C Bomber Command to D/CAS, 23 February 1942.

<sup>103</sup> TNA AIR14/695 Letter D/CAS to C-in-C Bomber Command, 26 February 1942.

<sup>104</sup> TNA AIR2/9726 Comments of Group Captain Bufton on Harris' *Despatch on War Operations*.

Based upon the outcome of the CRACKERS exercises, on 21 February 1942 Bomber Command HQ issued a memorandum to the Groups formalising the procedure for operations using GEE<sup>105</sup>. The attacking force was to be divided into three sections. Section 1, to be known as ‘the illuminators’, comprised 20 GEE equipped Wellingtons from No.3 Group carrying flares only, the sole purpose of which was to illuminate ground detail sufficient for the next section to identify the A/P<sup>106</sup>. This first section would later become known as the ‘3 Group Flare Force’. The second section, to be known as ‘the target markers’, comprised GEE equipped aircraft from Nos. 3, 4 and 5 Groups carrying maximum possible number of incendiaries, to be dropped as closely as possible on the A/P as illuminated by the first section. The third section, to be known as ‘the followers’, was to comprise non-GEE equipped aircraft from all Groups<sup>107</sup>. This technique was codenamed ‘*Shaker*’ and was the first true target marking technique. The basic *Shaker* technique, ‘illuminators’ preceding ‘target markers’ to be followed by the ‘main force’, would remain as the foundation of many target marking techniques throughout the bombing offensive.

In the interim, without even waiting for the outcome of the “CRACKERS” trials or, indeed, conducting ‘sufficiently exhaustive’ trials of their own, the Air Staff

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<sup>105</sup>TNA AIR14/695 Memorandum from Headquarters Bomber Command to Nos. 1,3, 4 and 5 Groups, 21 February 1942.

<sup>106</sup> The memorandum stipulated that 8 aircraft should drop flares at zero hour, the remainder at 3 minute intervals until z+12. This was essentially the same procedure for opening the attack as recommended following the CRACKERS exercises, the only difference being that the duration of the illumination period was reduced from z+20 to z+12.

<sup>107</sup> This last section was the equivalent of the ‘main force’ referred to the Air Staff note dated 16<sup>th</sup> January 1942.

had on the 14 February 1942 issued a new directive to Bomber Command predicated on the introduction of GEE<sup>108</sup>. The new directive confirmed that, in the opinion of the Air Staff, the introduction of GEE would confer upon Bomber Command the ability to concentrate its effort to an extent not previously possible. The introduction of GEE should, the directive continued, be regarded as a revolutionary advance in bombing technique, so that during the period of its effective life as a *target marking device* it would enable much more effective results to be achieved (emphasis added). The directive accepted that it was unlikely, even under the best possible conditions, that the period during which GEE remained effective would exceed six months. The directive therefore considered it a matter of 'first importance' that the advantages conferred by GEE were exploited to the full in the limited period available before counter-measures could be developed and accordingly authorised the maximum effort possible. The directive included a list of selected area targets within the range of GEE<sup>109</sup> and indicated that the 'cardinal principle' which should govern the use of GEE from the outset should be the concentration upon one target until the effort estimated to be required for its destruction had been achieved<sup>110</sup>. The directive confirmed that, of these

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<sup>108</sup> Webster and Frankland *The Strategic Air Offensive, Vol iv*, Appendix 8, p418. Directive Air Vice-Marshal N.H.Bottomley (Deputy Chief of Air Staff) to Air Marshal J.E.A. Baldwin (Acting) Air Officer Commander-in-Chief, Bomber Command, 14 February 1942 In the wider context of the bombing offensive, it was this Directive that formally initiated the policy of 'area bombing' and for that reason is sometimes known as the 'area bombing directive'.

<sup>109</sup> For this purpose, the directive assumed that GEE had a range of 350 miles from Mildenhall in Suffolk, one of the main No 3 Group bases at that time, although why this location was chosen is not explained given that the range of GEE was measured from the ground stations.

<sup>110</sup> This was the UNISON plan. The four selected towns listed as primary industrial areas, all within the Ruhr, were Essen, Duisberg, Dusseldorf and Cologne. These were same four towns listed in the Air Staff note of the 16 January 1942. The effort estimated to be required for the destruction of each of these towns was set out on Annexe C of the directive. In relation to Essen, covering an area of 70 square miles and with a population of 650,000 people, this was given as 1,000 tons of bombs on the basis of 7 tons per square mile or 1,600 tons per 800 of the population, in both cases assuming 50% efficiency.

targets, Essen was the most important and therefore suggested that Essen should be attacked first in order that maximum benefit could be derived from the element of surprise.

The Directive also recognised that only a small proportion of the force would be equipped with GEE during its effective life, and that it was therefore also a matter of 'first importance' that tactical methods for the employment of GEE for target marking were developed and applied to the maximum effect possible. In that context, the Directive referred to the Air Ministry letter dated 25 October 1941 in which the principles and scale of attack using incendiary weapons was set out<sup>111</sup>.

Authority to commence operations using GEE from the 15 February 1942 had already been given in a letter from the Air Ministry dated 4 February 1942<sup>112</sup>. However, before GEE and the *Shaker* technique was to be tried on the difficult target of Essen, it was decided to conduct an experiment with the use of flares against a lightly defended target<sup>113</sup>. The target chosen was the Renault factory at Boulogne-Billancourt, just to the west of Paris, which was attacked on the night of 3/4 March 1942. The plan of attack called for the massed use of flares, although GEE was not yet operational and therefore this was not to be the full *Shaker* technique<sup>114</sup>. The attack, carried out at very

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<sup>111</sup> The principles and scale of attack using incendiary weapons set in the letter dated 25<sup>th</sup> October 1941 would become formalised as the UNISON plan – see above.

<sup>112</sup> TNA AIR14/695. Letter from Air Commodore Baker, D.B.Ops, to Air Officer Commanding-in-Chief Bomber Command, 4 February 1942.

<sup>113</sup> TNA AIR14/695 Memorandum Headquarters Bomber Command to Headquarters Nos 1, 3, 4 and 5 Groups, 21 February 1942.

<sup>114</sup> TNA AIR14/695 Letter D.B.Ops, Air Ministry to Air Officer Commanding-in-Chief Bomber Command, 26 February 1942

low level, was successful with over 90% of photographs showing ground detail within one mile of the target. Post raid reconnaissance confirmed that significant damage had been caused to the factory<sup>115</sup>. Bomber Command fully recognised that the challenges presented by attacks on Essen and elsewhere would be significantly greater than those faced at Billancourt. However, the purpose of the raid was to test the flare technique and in that respect the experiment had been a resounding success. This would later result in the Billancourt raid being prayed in aid of the formation of a Target Finding Force.

The first operational use of the full *Shaker* technique took place on the night of 8/9 March 1942 when 211 aircraft attacked Essen<sup>116</sup>. This raid was the first in a series of 12 major attacks on Essen over the following three months led by GEE equipped aircraft using variations of the *Shaker* technique<sup>117</sup>. Further to the trials carried out by No.1418 Flight, the approach to the target would be along the 'B' lattice lines and the error ellipse would cover the major part of the built-up area<sup>118</sup>. This in theory would ensure that all aircraft would pass within one mile of the target.

In accordance with the Bomber Command HQ Memorandum dated 21 February 1942, the attacking force comprised three sections: 'illuminators',

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<sup>115</sup> TNA AIR14/3408 Bomber Command Report on Operations, night 3<sup>rd</sup>/4<sup>th</sup> March 1942.

<sup>116</sup> TNA AIR14/3408 Bomber Command Report on Operations, night 8<sup>th</sup>-9<sup>th</sup> March 1942. Although modest in scale in comparison with operations later in the bomber offensive, in accordance with the 14 February Directive this was a maximum effort raid at the time.

<sup>117</sup> TNA AIR14/1769 ORSBC, Note on attacks on Essen March 8/9<sup>th</sup> – June 8<sup>th</sup>/9<sup>th</sup>, 24 July 1942, and Middlebrook and Everitt *The Bomber Command War Diaries*, p254. The single exception was on the night of 6<sup>th</sup>/7<sup>th</sup> April 1942 when the attack was carried out using the *Samson* technique of blind-bombing using GEE.

<sup>118</sup> TNA AIR14/695 Loose Minute, Wing Commander Saye to S.A.S.O. Bomber Command, 28 February 1942. Wing Commander Saye proposed that, because of the complexities involved, the planning of all GEE operations should be carried out at Bomber Command Headquarters.

'target markers' and 'followers'<sup>119</sup>. The illuminators each dropped a stick of flares six miles in length, with the centre of the stick aimed at the target. In order to avoid being distracted by decoys, these flares were to be dropped 'blind' using GEE and therefore only the most experienced GEE operators were assigned the role of illuminator<sup>120</sup>. The sticks of flares were intended to illuminate an area six miles in length by one mile wide, parallel to the main axis of the GEE 'error ellipse'. Sufficient aircraft were allocated to this role to maintain illumination throughout the initial phase of the attack, this being known as the 'flare period'. The 'target markers', again all GEE-equipped and carrying all-incendiary loads, were timed to arrive during the 'flare period' using the same 'B' lattice line as the illuminators. However, the 'target markers' were to aim visually using in the light of the flares dropped by the illuminators, with the intention of starting an unmistakable conflagration to identify the target for the non-GEE equipped 'followers'.

The *Shaker* technique employed in the raids against Essen remained essentially unchanged throughout the series. The main focus for experimentation was the duration of 'flare period', which varied between 15 and 45 minutes without, it would appear, making much difference to the outcome. On the fourth raid in the series, on the night of 25/26 March 1942, a few specially selected crews were equipped with red flares which were to be dropped only if the target was positively identified. However, despite conditions offering good visibility, this innovation did not prevent a significant proportion of the bombs dropped from being aimed at a decoy site at

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<sup>119</sup> TNA AIR14/695 Memorandum from Headquarters Bomber Command to Nos. 1,3, 4 and 5 Groups, 21 February 1942. See above.

<sup>120</sup> TNA AIR14/3408 Bomber Command Report on Operations, night 8<sup>th</sup>/9<sup>th</sup> March 1942.



Rheinberg, 18 miles outside Essen. Although not successful on this occasion, this refinement of the *Shaker* technique foreshadowed principles that would later form the foundation of standard pathfinding techniques in which 'visual markers' dropped specially coloured flares (and, later, Target Indicators) on an A/P illuminated by white flares<sup>121</sup>.

The results achieved using the *Shaker* technique in this series of raids on Essen were disappointing and were set out in a detailed note produced by ORSBC dated 24 July 1942<sup>122</sup>. In the first eight raids in the series, 90% of bombs fell at distances of between 5 and 100 miles from the target and, in three of those raids, no bombs fell within five miles of the A/P<sup>123</sup>. Only three of the raids resulted in any damage in Essen itself, and on no occasion was significant damage caused to the Krupp works. Although bombs did result in significant damage to other towns in the Ruhr, it was not the result envisaged or hoped for following the introduction of GEE. The main issue was one of timing. The common denominator linking the three most successful raids was that the flares were more concentrated than in the other raids. The best concentration of flares was achieved in the raid on the 1/2 June and considerable damage was caused, if not to Essen, but to other towns in the Ruhr (including considerable damage to the Thyssen Steel Works in Hamborn)<sup>124</sup>. The lesson drawn by ORSBC from this series of raids was that

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<sup>121</sup> This sequence would later form the basis of the 'Newhaven' technique employed by the Pathfinders.

<sup>122</sup> TNA AIR14/1769 ORSBC Note on attacks on Essen March 8/9<sup>th</sup> – June 8<sup>th</sup>/9<sup>th</sup>, 24 July 1942

<sup>123</sup> TNA AIR8/688 Summary of Bomber Command Reports on Germany since 1 March 1942, undated.

<sup>124</sup> This raid was the second of the 'Thousand Bomber' raids.

concentration of flares in both time and space was essential for a successful attack<sup>125</sup>.

One of the other main concerns related to the bomb aiming carried out by the 'target markers'. At this stage in the bombing offensive, few crews included a specialist bomb aimer and in most crews bomb aiming was carried out either by the second pilot or the navigator. Moreover, the bomb sight in use at this time was still the CSBS, which required a long setting up procedure and bombing run. Consequently, in the GEE-equipped 'target markers', this necessitated the navigator to leave the GEE indicator at the crucial time in order to operate the bomb sight, such that it was not possible for the navigator to confirm the aircraft's position using GEE close to the target itself. The immediate consequence of this was to deny one of the main advantages of GEE in terms avoiding decoys or misplaced fires from preceding aircraft.

The ORSBC note went on to make a number of recommendations for future operations. The first suggestion, in view of the issue with navigators leaving the GEE indicator to take up bomb aiming duties, was that specialist bomb aimers should be part of every crew and that protocols for crew cooperation be devised, particularly between pilot, navigator and bomb aimer. A further suggestion, in response to comments from aircrews that the industrial haze throughout the Ruhr caused flares to create glare that obscured ground detail, was that the illuminators should drop flares not on Essen itself, but on a prominent landmark nearby. The 'target markers' could then drop their

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<sup>125</sup> TNA AIR14/1769 ORSBC, Note on attacks on Essen March 8/9<sup>th</sup> – June 8<sup>th</sup>/9<sup>th</sup>, 24 July 1942.

incendiaries on the basis of a 'time and distance' run from the landmark thus illuminated.

However, the most far-reaching recommendation was the need for a marker bomb. The suggestion put forward by the ORSBC was that marker bombs should be dropped by crews that included experienced GEE operators and bomb aimers, and that were fully trained and well practised in crew cooperation. It was recommended that the aircraft should be equipped with every available aid to accuracy, including *Oboe*, which at that time was still in development. ORSBC went so far as to suggest a plan of attack for the use of marker bombs in which, following the initial dropping of flares by the 'illuminators' using GEE, visually aimed marker bombs would be dropped by specialist crews at intervals throughout the attack sufficient to ensure that at least one marker bomb was visible at all times. Other aircraft would drop incendiaries by aiming at the marker bombs.

In suggesting this plan, ORSBC had identified the importance of a distinctive marker to guide 'the followers' to the *A/P*. The *Shaker* technique had only been successful to any degree in attacks on Essen where the initial flares had been well concentrated and therefore provided a distinctive point of aim for the 'followers'. The major drawback with the idea put forward by ORSBC was the lack of an effective marker bomb. Such devices were in development but not in operational use at that time. In the event, GEE became subject to enemy jamming before the plan of attack outlined by ORSBC could be tried although the basic structure - the visual aiming of a distinctive marker using

illumination provided by the 'blind' dropping of flares – would later become a standard technique where weather conditions permitted sight of the ground (when it would be generally known as 'visual groundmarking').

Although the *Shaker* technique had not proved successful in attacks on the Ruhr, it was used with some success elsewhere. In the most effective attack in which the *Shaker* technique was used, against Cologne on the night of 13/14 March 1942, some 58% of bombs fell within 3 miles of the A/P. On this occasion, the *Shaker* plan worked reasonably well with 17 of the 20 illuminators dropping flares blindly using GEE. The first flares went down within 30 seconds of the specified time and with only one short break illumination was continuous for the first 30 minutes of the raid. It is significant that this was a dark night with no moon and drifting medium cloud, and that this was one of the earliest attacks using GEE. This level of performance had only been achieved once before against this target, in perfect weather conditions and with a full moon, in July 1941, when 60% of the bombs were within the target area. It is a measure of the success achieved using the *Shaker* technique on this occasion that the average bombing performance on dark nights against this target was closer to 10% within the target area<sup>126</sup>.

The other significant consideration was that the *Shaker* technique was restricted to targets within GEE coverage. Outside of that coverage, whilst the core principles of the *Shaker* technique could still be applied - 'illuminators', 'target markers' and 'followers' - the initial flare dropping element would need

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<sup>126</sup> TNA AIR14/695 Operational Research Section Report S.54 'Review of Operational Use of T.R. 1335 March-May 1942', 5 July 1942.

to be conducted visually with the inherent risk of bomb aimers being unable to identify the A/P or being misled by decoys. This problem was not of such consequence where the target was easily identifiable due to conspicuous ground features, such as Lübeck and Rostock, both of which were coastal ports and which experienced the two most successful attacks during this period<sup>127</sup>. However, the location of the target, and moreover the visual identification of the A/P, remained problematic where the target lacked prominent ground features: for example, a short series of raids in May 1942 against Stuttgart, a particularly difficult target to locate due to its position within a series of deep valleys, was a complete failure due to the presence of ground haze and an effective decoy site<sup>128</sup>.

Despite these shortcomings, the *Shaker* technique was a significant step forward and resulted in a tangible improvement in the overall efficiency of Bomber Command. In the six months prior to the introduction of GEE, the average efficiency of Bomber Command, defined as the percentage of aircraft despatched which bombed within three miles of the A/P, was static at 23%<sup>129</sup>. In the six months following the introduction of GEE, which therefore included the entire period during which the *Shaker* technique was employed, the average efficiency rose to 30%, reaching a peak of 33% in June 1942 before

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<sup>127</sup> For a full description of the raids on Lübeck and Rostock, see Webster and Frankland *The Strategic Air Offensive*, Volume 1, p.p. 391-395, and Middlebrook and Everitt *The Bomber Command War Diaries*; p.p. 251, 259-260.

<sup>128</sup> Middlebrook and Everitt *The Bomber Command War Diaries*, p.p.264-265.

<sup>129</sup> TNA AIR14/2693 Operational Research Section Report S.252 'The Effect of the development of navigational and blind bombing techniques on the efficiency of bombing operations during World War II (Aug 1941-May 1945)', October 1945.

falling back towards the end of the period (largely due to GEE being jammed at the beginning of August 1942)<sup>130</sup>.

To what extent was this improvement in efficiency the result of the *Shaker* technique? There can be no doubt that a significant part of this increased efficiency was due the improvement in navigation resulting from GEE, which resulted in a greater proportion of the force navigating to within a few miles of the target. However, at no point in this period was more than 80% of the bomber force equipped with GEE and in the early part of the period the proportion of the force so equipped was considerably below that level<sup>131</sup>. It must therefore be assumed that the *Shaker* technique assisted those crews not equipped with GEE in locating the target area, and in that sense contributed to the overall improvement in efficiency. Moreover, in view of the fact that this period covered the largely unsuccessful series of raids on Essen, and noting also that efficiency fell back again when GEE became unavailable over Germany, the improvement in overall efficiency during this period can in substantial part be attributed to the *Shaker* target marking technique.

The period covered by this Chapter includes the first, tentative attempts at target marking at unit level to the introduction of *Shaker*, the first dedicated target marking technique. The early experiments with the dropping of flares by individual aircraft or at unit level had proved totally inadequate. The fire-raising technique, so avidly seized upon by Bomber Command in the mistaken belief that it was 'the right method' when employed by the Luftwaffe,

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<sup>130</sup> Ibid.

<sup>131</sup> Ibid.

also proved disappointing. The *Shaker* technique, although a significant advance on earlier attempts at target marking and reasonably successful against 'easy' targets, did not prove adequate when used against heavily defended targets. This was particularly true in the Ruhr where the combination of industrial haze and the absence of ground features defeated the use of flares unless an exceptional concentration was achieved. The other difficulty faced by bomber Command was that the Ruhr, whilst on the optimum 'line of shoot', was at the extreme range of GEE coverage with correspondingly high angles of cut, such that GEE was not sufficiently accurate to routinely achieve the required concentration of flares. Consequently, on the majority of occasions illumination of the target area was neither adequate nor continuous, such that the 'target marker' crews, who were required to aim visually in the light of the flares, were rarely able to discern the A/P.

The significance of the *Shaker* technique in terms of the development of target marking techniques lies in the lessons learned from its failures rather than the success that it achieved. The main lesson learned was the importance of establishing a distinctive marking of the A/P. On those occasions where the *Shaker* technique was successful, the illuminators had achieved a significant concentration of flares. ORSBC had identified the importance of providing a distinctive marker for the A/P and this had led to the recommendation to develop a marker bomb. In the form of the Target Indicator in particular, marker bombs of various descriptions would later become an essential component of target marking techniques.

However, a distinctive marker bomb was of no value, and indeed could be entirely misleading, if not placed in the correct position. This was also recognised and led to the suggestion that the vital task of dropping the marker bomb was undertaken not only by specialist crews, but by a specialist role within those crews. As target marking techniques became ever more complicated as the bombing offensive progressed, role specialisation became essential with perhaps the most specialist, and difficult, task being that being the dropping of the 'marker bomb' on the A/P (a role that would later become known as the 'primary visual marker'). The *Shaker* technique provided an early indication of the importance of role specialisation in bomber crews and the lesson learned would, through the establishment of bomb aimers as standard within heavy bomber crews, also contribute to an overall improvement in the efficiency of Bomber Command.

The lessons learned from the *Shaker* technique laid the foundations for the development of more advanced target marking techniques. These new techniques would not themselves rely on GEE for the initial target location; as expected, the operational life of GEE over Germany barely lasted six months and, with that, the *Shaker* technique fell by the wayside. The new target marking techniques would rely on a new generation of navigation aids - principally *Oboe* and H2S - and would benefit from vastly improved pyrotechnics. These new techniques would also need to solve two problems that the *Shaker* technique did not address: target marking beyond the optical range of ground stations and techniques for conditions in which ground detail



was not visible. However, before detailing the development and performance of those techniques, it is necessary to consider the debate surrounding the formation of the specialist target marking force that would eventually employ them – the Pathfinder Force.

## CHAPTER FOUR: FORMATION OF THE PATHFINDER FORCE

Although the formation of the Pathfinder Force (PFF) is identified in many accounts of the bombing offensive as being one of the factors leading to a significant improvement in bombing performance from 1943 onwards, in most cases such reference is made *en passant* with only the briefest description of the events that led to the formation of that force. Where reference is made to the formation of the PFF, it is usually in the context of the relationship between Harris as C-in-C of Bomber Command and the Air Staff in general, and one individual in particular:- Group Captain Sydney Bufton who, as Deputy Director of Bombing Operations (D.D.B.Ops), is usually held as being the prime advocate of what he termed a 'Target Finding Force'<sup>1</sup>. The latter was also the focus of the chapter devoted to the formation of the Pathfinder Force in the doctoral thesis by Rex F. Cording<sup>2</sup>. However, these accounts ignore the wider context underlying the debate surrounding the formation of the PFF and fail to acknowledge the important, and in some cases crucial, role played by a number of other individuals within the Air Staff, Bomber Command and elsewhere. This Chapter analyses the events leading to the formation of the PFF, identifying the contributions made by various individuals in that debate or, in places, where key individuals failed to intervene at critical points. This Chapter will show that far from being the 'one man crusade'

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<sup>1</sup> For example: Hastings *Bomber Command*, p.p.190 to 191; Richards *The Hardest Victor*, p.p. 145 to 146; and Anthony Verrier *The Bomber Offensive* (London: Batsford,1968), p148.

<sup>2</sup> Rex F. Cording, *The Other Bomber Battle: An Examination of the Problems that arose between the Air Staff and the AOC Bomber Command between 1942 and 1945 and their effects on the Strategic Bomber Offensive*, PhD Thesis, University of Canterbury, New Zealand, 2006.

sometimes portrayed, the need for a specialist target finding force was a widely held view both within the Air Staff and Bomber Command, and had been so for a considerable period of time before the PFF was born. The Chapter will explore the reasons why the gestation period of the PFF was so lengthy and the birth so painful. The approach taken in this Chapter is to firstly identify the contributions made to the debate by various individuals in a broadly chronological order, and then to identify the key issues and themes that arise. This examination will set into context the debate surrounding the formation of the PFF, in particular the belief held by the Air Staff that a target finding force was one of several measures necessary to improve the performance of Bomber Command and therefore preserve the concept of a strategic bombing offensive as an integral part of the overall Allied strategy. The Chapter will conclude with a review of the references to the formation of the PFF in secondary literature, through which it will be shown that this important topic has either been largely overlooked or misrepresented by authors and commentators.

The concept of a specialist target finding force was not itself new. Neither was the concept uniquely a British one, with a target finding force having been a feature of German night raids on Britain since September 1940. The Luftwaffe unit engaged in that task, Kampfgruppe 100, did not mark the target using flares but used the 'Fire Control Method' to illuminate the target area by means of fires<sup>3</sup>. Consequently, although the concept of a specialist target finding force was not new, the concept of a specialist force to provide a

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<sup>3</sup> Wakefield *The first Pathfinder*, p102.

specific point of aim for following aircraft was innovative. In some respects, the formation of a specialist target finding force arose *de facto* with the introduction of GEE, given the disparity in the ability to locate targets between the minority of aircraft equipped with the device and the majority not so equipped. Indeed, the Official History suggests that some form of target-finding force "...had become inevitable from the moment that GEE was introduced"<sup>4</sup>.

However, the concept of a target finding force was under consideration long before navigation aids such as GEE were introduced. The earliest reference to a target finding force appears to date from August 1940 when Portal, then C-in-C Bomber Command, proposed using aircraft flown by specially picked crews who would locate the target with parachute flares and drop the marker bomb as close as possible to it<sup>5</sup>. Shortly afterwards, in late 1940, the idea of a target finding force arose out of the debate following the failure of OPERATION ABIGAIL RACHEL (see previous chapter). Although some, including Air Vice-Marshal Bottomley, had considered that the initial fire-raising attack constituted 'an added risk of failure' through fires starting in the wrong place, Air Vice-Marshal Coningham had taken a different view, believing that the principle of an initial fire-raising force was sound and that Bomber Command would improve if "we pick our best units and specialise on similar lines [to the Luftwaffe]"<sup>6</sup>. The significance of this comment is the reference to both 'best' and 'specialise', two concepts that were to central to

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<sup>4</sup> Webster and Frankland *The Strategic Air Offensive, Vol 1*,p418.

<sup>5</sup> TNA AIR14/106 Letter from Headquarters Bomber Command to the Under Secretary of State, Air Ministry, 20 August 1940.

<sup>6</sup> TNA CAB65/16/12 Memo Bottomley to Bomber Command HQ, 26<sup>t</sup> December 1940

the debate surrounding the formation of the Pathfinder Force that was to follow and which, it would appear, had led him to change his views about the efficacy of target marking.

There is further anecdotal evidence that the creation of a target finding force was under consideration at the Air Ministry at this time. In his autobiography *Pathfinder*<sup>7</sup>, (then) Air Vice-Marshal Donald Bennett, who would lead the Pathfinder Force throughout the bombing offensive but who at that time was engaged in the Atlantic Ferry<sup>8</sup>, refers to an occasion when he was invited to meet with the Director of Bombing Operations (D.B. Ops), Air Commodore John Baker, and his Deputy, at that time Air Commodore Aubrey Ellwood. In his autobiography, Bennett claims to have pointed out that if a force of experienced navigators were to be given better equipment than available in ordinary bomber aircraft, and if they were given “fireworks of some description with which to attract the main force to the target, it should be possible for them to act as leaders and get the whole of the bomber effort on at least some of the target”. Bennett goes on to claim, somewhat immodestly, that this was “the first seed which I sowed on the subject of the Path Finder Force which subsequently was to turn Bomber Command from failure to success”. Setting aside Bennett’s overstated claim, and notwithstanding that no record of this meeting has been found, the personnel involved were all in post at that time

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<sup>7</sup> Bennett. *Pathfinder*, p.p 91 to 93. This meeting is also referred to in Bramson, *Master Airman*, p.p.51 and 52 and, although no official sources are quoted, the author based much of his work on interviews with Donald Bennett.

<sup>8</sup> The Atlantic Ferry Organisation was responsible for ferrying American-built aircraft to Britain as part of then Lend-Lease arrangements. Bennett was with the Atlantic Ferry Organisation from July 1940 until August 1941. In addition to being an experienced pilot, Bennett was seventh holder in the world of the civil First Class Navigator’s Licence. For further details of Bennett’s career before leading the Pathfinder Force, see Bramson *Master Airman*.

and there is no reason to suggest that the meeting did not take place<sup>9</sup>. This supports the contention that the concept of a target finding force was under discussion in late 1940/early 1941.

At the same time, it also appears that the concept of a target finding force was gaining ground at grass roots level. In January 1941, D.A.C.Dewdney, the advisor to Bomber Command on the oil offensive, embarked on a tour of operational units to discuss with aircrew first hand the apparent inability to hit oil installations. Dewdney reported a widespread belief amongst aircrew that it was necessary for the target to be marked by specially picked crews to start fires to guide following aircraft. The overall impression reached by Dewdney was that there was a need for more effective means of identifying targets<sup>10</sup>.

The creation of a specialist target finding force had been one of the suggestions made by Lord Cherwell in response to the Butt Report<sup>11</sup>. In September 1941, Cherwell had written to Churchill advising that Bomber Command should "...re-examine most carefully making specially expert navigators, or bombers equipped with special navigation aids, fly ahead of the main body to light fires in the right region for the rest to home on", adding "as the Germans do". A copy of Cherwell's paper had been passed to Portal, who declared himself entirely in agreement with Cherwell as to the 'supreme importance' of improving navigational methods. The training of expert fire-

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<sup>9</sup> Circumstantial evidence, largely from Bennett's own autobiography, would suggest that this meeting took place in either December 1940 or January 1941. It was Cleland, at that time a Wing Commander seconded to the Air Ministry, had invited Bennett to the meeting.

<sup>10</sup> Webster and Frankland *The Strategic Air Offensive, Vol I*, p229. Letter Dewdney to Pierse, 1 February 1941.

<sup>11</sup> CCAC Bufton Papers, File 5/1 Minute Cherwell to Churchill, 2 September 1941.

raising crews along the lines of KG100 and the development of marker bombs were among the actions that Portal proposed in his response to Churchill's request for action following the publication of the Butt Report, although Portal did point out that the C-in-C of Bomber Command considered that it would be 'tactically unwise' to rely upon special fire raising crews until more accurate navigation aids were available<sup>12</sup>. Portal was also keen to stress that, as he put it, "it is not generally realised that the German technique was only really successful either under good weather conditions when navigation to the target area would have been a relatively simple matter for any reasonably trained crew – e.g. Coventry – or against short range or fringe targets where good geographical features enabled following crews to obtain fixes which guide them to the target, apart altogether from the fires raised e.g London, Southampton, Plymouth, Bristol, Swansea, Liverpool". It would therefore appear that Portal was acutely aware of the limitations of the fire-raising technique and that, whilst anxious to provide a positive response to address Churchill's concerns, was also anxious to manage expectations. As discussed below, Lord Cherwell would later return to the subject of a target marking force.

Portal was himself already on record as supporting the concept of a target finding force. As early as August 1941, Portal had written to Sir Henry Tizard, then working at the Ministry of Aircraft Production, concerning the future use of GEE<sup>13</sup>. Portal was mindful that GEE would initially only be available in limited numbers, and suggested to Tizard that the best option may be to use

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<sup>12</sup> CCL Portal Papers, File 2 Memorandum Portal to Churchill 11 September 1941.

<sup>13</sup> IWM Tizard Papers, Letter Portal to Tizard, 17 August 1941

GEE to emulate the method employed by Kampfgruppe 100. His proposal was therefore that the limited number of GEE sets should be used by specially selected and trained crews who would create fires in the target area to guide the remainder of the bomber force. It is interesting to note that Portal's letter pre-dated receipt of the Butt Report and was therefore the result of pro-active tactical foresight rather than any reaction to criticism of existing methods.

Neither was Portal alone at the Air Ministry in holding these views; Squadron Leader Morley at Bomber Operations 1 was of a similar mind. In the same month that Portal had written to Tizard, Morley produced a lengthy assessment of the night bombing policy being pursued by Bomber Command in which he noted, *inter alia*, that the German fire-raising crews were both specially equipped and specially trained for the task<sup>14</sup>. In Morley's view, the fires started by these specialist crews acted as a ".....first class marker beacon to the main force...." and he strongly urged that Bomber Command should adopt similar tactics. Although OPERATION ABIGAIL RACHEL subsequently showed that fire-raising was not in itself a reliable method of target marking, this does not detract from the essential point that Morley was making, namely that the crews undertaking that task should be specially trained and equipped.

Nor was the concept of forming a specialist target finding force confined to the Air Ministry: by late 1941, the possibility of forming a specialist target finding

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<sup>14</sup> CCAC Bufton Papers, File 3/10 'Night Bombing Policy', 25 August 1941.



force was also under consideration within Bomber Command. On the 1<sup>st</sup> November 1941, the Navigation Section produced a paper entitled 'The Problem of Navigating to, Locating and Bombing of a Target by Night'<sup>15</sup>. Having identified the potential errors arising from D/R navigation, map reading at night and astro navigation, the paper proposed a solution in the formation of 'Squadrons specially trained and equipped for the task of target location'. The paper stressed the importance of crew selection and recommended that the hand-picked crews be equipped with the latest navigational aids and radio equipment as a matter of priority. This paper was circulated to the AOC's of Nos. 1, 3, 4 and 5 Groups. The responses received are interesting in the context of the debate that was to follow later.

Air Vice-Marshal Oxland, AOC of No. 1 Group, agreed that there was ".....a strong case for the formation of a target marking force. The possibility that the target locators will make a mistake and lead the 'followers' astray is admitted but it is considered that occasional, perhaps frequent, successes might counter balance the failures'<sup>16</sup>. Air Vice-Marshal Carr, who had taken over from Air Vice-Marshal Coningham as AOC No.4 Group in July 1941, agreed that previous attempts using selected squadrons acting as fire-raisers had not always been successful, noting that some crews were of average efficiency. He concluded that '.....target finding Squadrons composed of selected and specially trained pilots, assisted by all the aids to navigation presently

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<sup>15</sup> TNA AIR14/516 Navigation Section, Bomber Command HQ 'The Problem of Navigating to, Locating and Bombing of a Target by Night', 1 November 1941.

<sup>16</sup> Ibid Oxland to Pierse, 10 November 1941

available, seems to be the best solution, and to offer the most favourable prospect of successful target location'<sup>17</sup>.

The AOC's of Nos. 3 and 5 Groups took a different view. Air Vice-Marshal Baldwin, AOC of No. 3 Group, admitted the need for selected crews to lead bombing raids but opposed the formation of target locating squadrons, citing the loss of experienced crews from front-line squadrons and a lowering of *esprit-de-corps*. In his view, crews selected to lead raids should be drawn from normal front-line squadrons<sup>18</sup>. Air Vice-Marshal Slessor, AOC No. 5 Group, strongly opposed the formation of specialist target finding squadrons, perceiving problems with training and questioning why crews could not be trained to find their own targets<sup>19</sup>. His preferred solution, which was already standard procedure within No. 5 Group, was that the best individual crews were selected as raid leaders.

The paper produced by the Navigation Section at Bomber Command is significant, not least in terms of its timing. The debate surrounding the creation of a Target Finding Force is usually painted in secondary literature as being between the Air Staff and Bomber Command, sometimes being personalised as being a battle of minds between Bufton and Harris. By way of example, Hastings describes the debate surrounding the creation of a Target Finding Force as "...one of the most bad tempered debates of the war between the Air Ministry and Harris", adding that "Harris reserved his most

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<sup>17</sup> Ibid Carr to Pierse, 14 November 1941.

<sup>18</sup> Ibid Baldwin to Pierse, 10 November 1941. Baldwin would later put this precept into practice with the formation of the '3 Group Flare Force' to lead attacks using the *Shaker* technique.

<sup>19</sup> Ibid Slessor to Pierse, 6 November 1941.

virulent disdain for the Air Ministry's Directorate of Bomber Operations" (i.e. Bufton)<sup>20</sup>. Neillands simply refers to the debate as being between Harris and Bufton<sup>21</sup>. Similarly, Richards focuses almost exclusively on the roles played by Bufton and Harris but makes brief reference to Portal's involvement<sup>22</sup>. Overy takes a broader view and brings Freeman into the picture, but the focus is again on the battle of words between Harris and Bufton<sup>23</sup>. The common denominator, however, is that none of these authors make reference to the views held by others within Bomber Command that were contrary to that expressed by Harris in the debate surrounding the creation of a Target Finding Force. The paper produced by the Navigation Section confirms that support for the formation of a specialist target marking squadrons was held within some elements of Bomber Command even before the debate was fully engaged. This dispels any credence to the suggestion that the idea of a Target Finding Force was the sole preserve of the Air Staff and places a very different emphasis on the debate that was to follow. This paper not only moves the debate about the formation of a target finding force forward by nearly six months but, more significantly, pre-dates the involvement of those who would later be central to the debate when it was fully engaged in the Spring of 1942.

One of those to receive a copy of the Bomber Command paper was (then) Group Captain Bufton, who co-incidentally had taken over from Air Commodore Ellwood as D.D.B.Ops on the very day on which the Bomber

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<sup>20</sup> Hastings, *Bomber Command*, p190.

<sup>21</sup> Neillands, *The Bomber War: Arthur Harris*, p.p.124-125.

<sup>22</sup> Richards, *The Hardest Victory*, p.p. 145-146.

<sup>23</sup> Overy *The Bombing War*; p.p.291-292.

Command paper was issued and who would later emerge as the true advocate of the formation of a Target Finding Force. An experienced bomber pilot, Sydney Osborne Bufton had commanded No. 10 Squadron, where he had been a keen advocate of the flare-dropping technique pioneered by the Whitley squadrons in No.4 Group (see Chapter 3)<sup>24</sup>. Bufton welcomed the Bomber Command paper, commenting that even if targets were not located on every occasion, Bomber Command would be no worse off than by using the then current methods<sup>25</sup>. Bufton was, however, confident that if conditions made it possible for targets to be identified and marked, then there was every possibility that the bomber force would become an effective force. He urged that the scheme be given a trial which, in his view, would achieve such results as to bring about a change of mind among the Group Commanders that did not support the ideas set out in the Bomber Command paper. Bufton then took the opportunity to expound his own ideas relating to a Target Finding Force, including the concepts of locating crews close together to facilitate discussion and the organic development of tactics, and the desirability that the Target Finding Force should be equipped with the same aircraft type in order to simplify raid planning. These ideas would later become familiar and well-rehearsed in the debate surrounding the formation of a Target Finding Force.

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<sup>24</sup> The career of Sydney Bufton is set out in detail in Melinsky, *Forming the Pathfinders*, Chapter 4. In summary, after commanding No.10 Squadron, Bufton was posted in April 1941 to form No.76 Squadron, one of the first units to be equipped with the four-engined Handley Page Halifax bomber. A month later, Bufton was promoted to the rank of Group Captain and posted as Station Commander of RAF Pocklington, one of the newly constructed No. 4 Group bases. Bufton then took up position as Deputy Director of Bombing Operations (D.D.D.B. Ops) in November 1941.

<sup>25</sup> CCAC Bufton Papers, File 3/6, Bufton to Baker, 4 December 1941.

The formation of special squadrons to 'initiate raids and start fires' was also proposed by ORSBC in a memorandum dated 22<sup>nd</sup> December 1941<sup>26</sup>. ORSBC pointed out that the misidentification of the target was a serious matter which had '...been responsible for much misdirected effort'. It was the opinion of the ORSBC that such mistakes were less frequently made by the more experienced crews, and on that basis strongly encouraged that the best use was made of the knowledge and experience of these crews. It was therefore suggested that the best crews should be formed into special "crack" squadrons specifically to undertake the task of identifying and using incendiaries to provide a beacon for following crews. Interestingly in the context of the debate to follow, ORSBC suggested that, if possible, there should be one such squadron in each Group but that one alternative could be to designate the two best crews in each squadron for fire raising duties.

The foregoing demonstrates that by the end of 1941 the concept of a specialist Target Finding Force had been under consideration in many quarters over a considerable period of time, but without ever progressing beyond the idea stage. The Official History suggests that this may in part have been due to the lack of a suitable navigation aid and partly because the Royal Air Force distrusted the idea of elite squadrons<sup>27</sup>. However, the concept of a specialist Target Finding Force was already well known at the time when the operational introduction of GEE was being discussed in late 1941. If the availability of a navigational aid was considered a prerequisite to the formation of a specialist Target Finding Force, the opportunity to form such a force was

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<sup>26</sup> TNA AIR14/3062 Operational Research Section Memorandum M88 'The success of night bombing attacks: an appreciation', 22 December 1941.

<sup>27</sup> Webster and Frankland *The Strategic Air Offensive, Vol I*, p419.

open to Bomber Command at that time but was not taken. Moreover, by the time that the Pathfinder Force was eventually formed in August 1942, GEE had ceased to be effective over Germany and the opportunity to initiate a new era of target marking to optimise the impact of GEE, on which so much hope had been placed, was lost.

Bufton lost no time in setting out his views on the need for a Target Finding Force and on the 5 November 1941, even before formally taking up his position at the Air Ministry, he drafted a memorandum entitled 'Suggestion for increasing efficiency of night attack' in which he compared the approach of two different squadrons to the task of target finding<sup>28</sup>. Both of the squadrons were well known to Bufton. The first, No.405 Squadron, was newly established with little operational experience. The other squadron was No. 10 Squadron, which Bufton had previously commanded and was one of the pioneers of the flare dropping technique developed by the Whitley squadrons of No. 4 Group. Bufton became aware that the inexperienced crews of No.405 Squadron were sent out individually and were relying on unconfirmed sightings of bodies of water such as coastal inlets, canals and bends in rivers to locate targets. These were the very features that ORSBC had found to be unreliable navigational landmarks. The result was that few crews were accurately locating the target. By contrast, the experienced No.10 Squadron had developed the technique whereby crews arrived in the target area at approximately the same time and proceeded to drop flares, with a Verey light being fired when the target was positively identified (see Chapter 3). By using

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<sup>28</sup> TNA AIR20/4782 Memorandum by D.D.B.Ops, 'Suggestion for increasing efficiency of night attack', 5 November 1941.

this technique, the least experienced crews were guided to the target area by the more experienced crews.

Buften considered the difference in technique between these squadrons to be analogous to the difference in the target finding ability between experienced and inexperienced crews throughout Bomber Command as a whole. He recognised that the results produced by the flare dropping tactics employed by a few individual squadrons would be too small to improve the overall efficiency of the bomber force. His idea was therefore to apply the flare dropping technique used by No. 10 Squadron on a larger scale to serve the whole of Bomber Command by employing a dedicated Target Finding Force composed of the best crews, and which would specialise in locating and marking the target. Buften considered that the employment of a Target Finding Force would obviate the necessity for an initial fire raising attack, but that the most effective results would be achieved by using extensive flare dropping to provide a focus for the incendiary attack and to ensure that no aircraft were diverted by decoy fires.

This first memorandum was followed by a Minute dated 20th November 1941 in which Buften expanded upon his ideas for a specialist target finding force<sup>29</sup>. This Minute addressed the issue of creating a specialist unit within a Command comprised of individual squadrons, each operating as an entity in its own right and each believing, rightly or wrongly, that it was as good as if not better than other squadrons. Buften was quick to acknowledge that these

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<sup>29</sup> Ibid Minute D.D.B.Ops to D.B.Ops, 'Tactical Developments – Bomber Command', dated 20 November 1941.

squadrons may be disinclined to rely on other squadrons to find the target, and that Groups may be reluctant to have its squadrons led to a target by aircraft of another Group. In response to these concerns, Bufton drew an analogy with other military operations. "No Military Commander....", Bufton pointed out, "...if he intended to capture a town, would hand a rifle to each of his thousand men and tell them to get on with it in their own way". And yet this, in Bufton's view, was exactly what Bomber Command was doing by sending out individual squadrons, and even individual crews within those squadrons, to attack targets with no co-ordination of effort. "He would organise his forces... ", Bufton continued, "...giving each unit a special job with special equipment so that the co-ordinated effort of them all produces a maximum effort". Bufton's idea was to apply the concept of a specialist role with specialist equipment to the bombing offensive. In that context, he believed it inevitable that some crews performed above the average and that some fell below the average. Bufton believed that, if a target was to be found at all, those crews of above average ability would be most likely to find it. He therefore suggested that the top 10% of crews should be given any new navigational aids that might become available and formed into a specialist target finding force to locate targets for the average and below average crews. Bufton conceded that some may argue that such a scheme would have a depressing effect on the remaining 90% of crews, but he himself believed that the reverse would be the case. He believed that these crews would aspire to be selected for the Target Finding Force and, in raising their own performance in order to be selected, the efficiency of the whole would be improved.



Bufton submitted his ideas to the Director of Bombing Operations (D.B. Ops), Air Commodore John Baker, on the 20 November 1941<sup>30</sup>. Baker considered that Bufton's ideas were worth pursuing, and suggested that his Minute of the 5 November and the Memorandum of 20 November be welded into a single paper in a form that could be sent demi-officially to S.A.S.O. Bomber Command<sup>31</sup>. The resulting paper, dated 29 November 1941, was Bufton's outline for a Target Finding Force<sup>32</sup>. The paper began with a historical review, in which it was pointed out that the standard of target finding by crews had declined as a result of experienced crews trained pre-war being replaced by crews having undertaken shorter training periods. This drop in crew standards has been exacerbated by the creation of a searchlight belt which had forced aircraft to fly at a height which made the recognition of ground features more difficult, and at which the standard flare then in use was ineffective. This historical review was followed by a review of tactics in which Bufton noted that the application of tactics tended towards individual attack, and that the few attempts to lead attacks by a fire-raising force had not been well organised and had consequently been ineffective. The remainder of the paper was devoted to tackling what Bufton believed to be the great difficulties of the 'last 20 miles' to the target, in which Bufton expounded his ideas on the creation of a Target Finding Force of flare dropping aircraft comprised of above average crews. It is clear that Bufton was developing his ideas because, for the first time, the paper contained details about the composition of such a force, which it was suggested should comprise four or five squadrons. The paper also

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<sup>30</sup> Ibid Minute D.D.B.Ops to D.B.Ops, 'Tactical Developments – Bomber Command', dated 20 November 1941.

<sup>31</sup> Ibid Minute D.B.Ops to D.D.B.Ops dated 22nd November 1941.

<sup>32</sup> Ibid Paper dated 29<sup>th</sup> November 1941, 'Increase in striking power by application of tactics'.

stressed the importance of co-ordinating the flare dropping force, indicating that it was essential that the crews were briefed together to ensure that timings were calculated on the same basis.

This important paper was the first to set out Bufton's ideas for the creation of a Target Finding Force for wider circulation. Although the ideas and concepts set out in this paper would continue to be refined, the basic elements of the proposed Target Finding Force are included and would remain effectively unchanged in the debate to follow. It may be noted that the ideas set out in this paper share some similarities with that produced by the Navigation Section at Bomber Command on the 1<sup>st</sup> November 1941, particularly in relation to the need for specially picked crews equipped with the latest navigation aids. Consequently, at this point in November 1941, there was considerable consensus between the Air Staff and Bomber Command in terms of the need for a Target Finding Force. However, although Bufton sent a copy of his paper to Bomber Command<sup>33</sup>, there is no record of a reply being received and there the matter rested for some months.

In order to understand the reasons why the proposal to create a Target Finding Force was being pursued at this stage, and also to place the debate to come into context, it is necessary to briefly review the position of the bombing offensive at this time<sup>34</sup>. The winter of 1941/42 has been described as

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<sup>33</sup> TNA AIR14/516 Letter with enclosure Bufton to Air Commodore T.M.Williams, Deputy Senior Air Staff Officer, Headquarters Bomber Command, 30 November 1941.

<sup>34</sup> For more detail on the difficulties facing Bomber Command at this time, see TNA AIR41/42 Air Historical Branch Narrative: The RAF Bomber Offensive against Germany: Vol III 'Area Bombing and Makeshift Force June 1941 – Feb 1942' and Vol IV 'A period of Expansion and Experiment March 1942 to January 1943'. See also Webster and Frankland *The Strategic Air*

the nadir of the bombing offensive. Losses were on the increase, and by November were close to the magical figure of 5%, beyond which the continuation of the offensive became unsustainable. Pierse had been sacked as C-in-C Bomber Command when his misreading of the weather forecast for the night of the 7/8 November 1941 led to the loss of 37 aircraft, 12% of the force sent and more than double the previous highest for a single night's operation<sup>35</sup>. The 'conservation Directive' had been issued on the 13 November 1941 and operations were drastically curtailed<sup>36</sup>. For much of this period, Portal was in Washington for the first Anglo-American conference and, pending a permanent replacement for Pierse, Air Marshal Baldwin was Acting C-in-C Bomber Command. At the same time, questions about the value of the bombing offensive were being raised in Parliament, not least because of the significant proportion of industrial resources allocated to it in relation to the results achieved, as revealed by the Butt Report. The claims from the Royal Navy for additional allocation of aircraft for the Battle of the Atlantic were ever present, in addition to which events in North Africa and the Far East placed further demands on the aircraft that were available. The bombing offensive was therefore under close scrutiny at this time and, unless results improved, a serious question mark hung over the continuation of the offensive.

However, there was light at the end of the tunnel. Portal had been busy in Washington, and had recruited Air Marshal Harris, then heading the British

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*Offensive Vol I*, Chapter VI 'The Mounting Offensive: The crisis of Strategic Bombing. November 1941-December 1942'.

<sup>35</sup> Middlebrook and Everitt *The Bomber Command War Diaries*, p218.

<sup>36</sup> Webster and Frankland *The Strategic Air Offensive, Vol IV*, Section III, Appendix 8 (xx) Directive dated 13 November 1941. Air Vice-Marshal N.H. Bottomley (Deputy Chief of Air Staff) to Air Marshal Sir Richard Pierse.

Delegation there, as the new C-in-C Bomber Command. Harris took up his new position on the 22 February 1942, by which time the 'conservation Directive' has been lifted and a new Directive authorising the employment of the bomber force without restriction was in place<sup>37</sup>. The bomber force that Harris inherited now possessed a new navigation aid - GEE - and comprised a greater proportion of the new heavy bombers. Moreover, there was now the prospect that Bomber Command would be joined in its efforts by the United States Army Air Force, which would provide added impetus to the bombing offensive. Consequently, whilst fully aware of the seriousness of the political situation facing them, it seemed to the Air Staff that if the current storm of criticism could be weathered, then the potential of the bomber could still be realised. The creation of a Target Finding Force was perceived by the Air Staff as being one means by which to unlock that potential.

In the interim, the formation of a Target Finding Force had been raised again in January 1942, this time not in its own right but as an adjunct to another proposal being advanced by the Air Staff: - the formation of a Bomber Development Unit (BDU). In a minute to Air Vice-Marshal Norman Bottomley, Deputy Chief of Air Staff, dated the 28 January<sup>38</sup>, Baker suggested that the nucleus of a Target Finding Force should be established simultaneously with a BDU. Baker's idea was for a force of some six squadrons, each equipped with "every possible navigational aid", including some not necessarily

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<sup>37</sup> Ibid. Section III, Appendix 8 (xxii) Directive dated 14 February 1942. Air Vice-Marshal N.H.Bottomley (Deputy Chief of Air Staff) to Air Marshal J.E.A Baldwin (Acting Air Officer Commanding-in-Chief, Bomber Command)

<sup>38</sup> TNA AIR20/4809 Minute Baker to Bottomley, 28 January 1942.

available to the whole Command<sup>39</sup>. This would, Baker considered, rapidly bring about a marked increase in the efficiency of the selected squadrons, which in turn would inevitably result in a raising of the standard throughout the Command. Baker noted that there was potentially already a BDU and a Target Finding Force available in the GEE development flight and the GEE equipped squadrons of No. 3 Group<sup>40</sup>. Baker suggested that the scheme should be discussed with A.C.A.S (T) and Tizard before introducing it to Bomber Command.

The Air Staff were understandably keen to ensure that the seriousness of the situation was not lost on the new C-in-C of Bomber Command. On the 27 February 1942, Baker wrote to Bottomley expressing concern that Harris might not be aware of the political and strategical issues facing Bomber Command and suggesting that a brief discussion with Portal would immediately make the position clear<sup>41</sup>. Baker then offered an intriguing insight into the Air Staff view of Bomber Command, which he considered was not a well-knit team presumably, in his view, due to the lack of imaginative, coordinated and positive direction and control. With an eye to the main chance of getting the Target Finding Force idea in front of Harris at the earliest opportunity, Baker attached a copy of a paper produced by Bufton that referred to the political situation and explained why tactics that may have proved successful in the early days of the bombing offensive were now ineffective against improved German defences. Bufton urged “most strongly

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<sup>39</sup> In addition to GEE, at that time not yet in service, Baker referred to *Oboe*, H2S and the Air Position Indicator, equipment that would not reach operational status for at least another year but which, when they did become available, did so initially in only limited numbers.

<sup>40</sup> The latter sometimes known as the ‘3 Group Flare Force’ – see Chapter 3.

<sup>41</sup> TNA AIR20/788 Minute from D.B.Ops to D.C.A.S, 27 February 1942.

and with the utmost conviction” that a Target Finding Force should be formed immediately and that the “dead wood throughout Bomber Command” should be cut away, and “so tighten the sinews of control that the bomber force may be wielded and directed as a dynamic, flexible and hard hitting instrument”. Perhaps sensing that some of the wording in Bufton’s paper was not exactly diplomatic, Baker left it to Bottomley’s discretion whether Portal should see it, but added that in his own view ‘something along these lines’ should be put in front of the C-in-C if Bomber Command was to achieve the high aims of the Air Staff plans.

There is no record to indicate whether Bufton’s paper was shown to Harris, but it is known that the issue of a Target Finding Force did come to the C-in-C’s attention at this time from another source. The criticism in the House of Commons and the House of Lords of Bomber Command’s achievements had also prompted Lord Cherwell to return to the subject of a Target Finding Force. In a letter to Portal dated 27 February 1942<sup>42</sup>, Cherwell lamented the lack of experimentation to determine how more bombs could find their targets. His principal argument was, nonetheless, that Bomber Command should be able to rely upon ten to twenty bombers to get to what he termed “the right place”. His proposed solution was that one of the bomber groups should be tasked with finding the target and that “with an active minded man of the Slessor type in charge, with a fairly free hand to try out all sorts of flares, etc as well as varying forms of tactics, it seems to me that a great deal might be achieved”. His nomination of Air Vice-Marshal Slessor for the leadership of

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<sup>42</sup> CCL Portal Papers, 1942. File 9, 3A Letter Cherwell to Portal, 27 February 1942.

such a force is interesting in the light of the latter's subsequent admission that he did not favour the creation of a Target Finding Force. In his reply, Portal indicated to Cherwell that he personally supported the idea and that he was referring it to Harris who, he considered, 'had a very active mind on this kind of subject'<sup>43</sup>.

Portal forwarded Cherwell's letter to Harris on the 1 March 1942<sup>44</sup> but, whatever his expectations of Harris' 'active mind' may have been, the opening lines of his response could not have been encouraging. "I seldom find myself in disagreement with you over such matters", Harris began<sup>45</sup>, "but this time I am. Long ago, in 5 Group, I adopted the practice of sending picked crews first, in order to illuminate the targets for the rabbits". On taking over at Bomber Command, Harris found that all Groups now adopted that tactic. Harris then explained that he could see no way of filling one particular group entirely with superior crews, not least because to transfer such crews from the other groups would have the most "appalling effects" on the morale of the remainder. It seems likely that Harris' response took in earlier correspondence relating to the formation of a Target Finding Force, because reference is made to issues (such as transferring crews from other Groups) that were not part of Cherwell's proposals. Nonetheless, the battle lines for the debate to follow were now set.

It is again not clear how widely Harris' views were devolved through the Air Staff but, in early March 1942, concerned at the lack of progress, Baker asked

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<sup>43</sup> Ibid. File 9, 3C Letter Portal to Cherwell, 28 February 1942.

<sup>44</sup> RAFM Harris Papers, Folder H81. Letter Portal to Harris, 1 March 1942.

<sup>45</sup> Ibid Letter Harris to Portal, 2 March 1942.

Buften to summarise the arguments in support of the creation of a Target Finding Force. On the 11<sup>th</sup> March 1942, Buften provided a detailed response which built upon the ideas outlined in previous papers and also took the opportunity to comment upon recent bombing operations<sup>46</sup>. Buften stressed that it would be impossible to achieve the required degree of concentration unless the flare force and the incendiary force had a common working basis and understanding. The only solution, in his view, was to have a Target Finding Force that was well drilled, of high morale and of the highest quality. Buften was now proposing a Target Finding Force comprised of six squadrons from No. 3 Group<sup>47</sup> and suggested that these squadrons, which were located close together on airfields around the Cambridgeshire/Suffolk/Norfolk border, should maintain the closest liaison and operate as one force, and that if necessary their geographical disposition could be made closer. Buften advised that the commanders of these squadrons should be selected for their initiative, imagination and enthusiasm, and that the selected squadrons should be reinforced with one or two first class crews from each squadron in Bomber Command. Buften suggested that the force should be under the control of a specially selected officer with operational experience and the rank of Group Captain, a comment that makes it difficult to avoid the conclusion that Buften was lining himself up for that role. Buften also pointed to the increase in the morale of crews following the Billancourt raid<sup>48</sup>, and opined

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<sup>46</sup> TNA AIR20/4782 Memorandum Buften to Baker, 11 March 1942.

<sup>47</sup> Although not expressly stated in Buften's paper, these squadrons were part of the '3 Group Flare Force' and were largely equipped with the GEE navigation aid.

<sup>48</sup> As detailed in Chapter 3, the Billancourt raid served as an operational trial of the large scale of use of flares in advance of their use as part of the *Shaker* technique. The trial was a success and, partly because it followed a long period of poor results for Bomber Command and partly due to the minimal loss of aircraft, it resulted in a significant uplift on the morale of the crews.



that the success resulting from the increased efficiency following the creation of a Target Finding Force would produce a similar uplift in morale. Bufton concluded by expressing the opinion that, even with the use of GEE, the present offensive will 'fall down' unless there was a change in methods and that it was essential that the target finding force should be formed at once.

Although there is no evidence to demonstrate that this paper was sent to Bomber Command, it is reasonable to assume that it was because Baker and Bufton attended a conference of the Group Commanders at High Wycombe on 13 March 1942 at which the proposal to create a Target Finding Force was discussed<sup>49</sup>. The events surrounding this conference are the subject of much reporting in secondary literature on the subject of the formation of the Pathfinders although much of this, including the oft-mentioned confrontation between Bufton and Harris at a meeting in the latter's office before the conference opened, is unsubstantiated. This reported confrontation arose when Harris commented that crews taken from front-line squadrons to form a *corps' d'elite* would lose their chance of promotion, in reaction to which Bufton is said to have thumped the table and exclaimed: "Sir, you will never win a war like that: these people don't know if they will be alive tomorrow and couldn't care less about promotion". At that, Harris is said to have looked at his watch, declared that it was time for lunch and walked off. It is then said that Harris, in opening the conference, remarked that he had called the conference to discuss the very emotive subject of a Target Finding Force and that "I was almost assaulted in my office over this matter this morning". Harris

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<sup>49</sup> TNA AIR14/695 Minutes of Conference on TR1335 Technique and Tactics held at HQ.B.C on 13 March 1942.

is then reported to have gone on to say “I need hardly tell you that I am totally opposed to the idea, but I wouldn’t mind hearing your views”. According to these accounts, the conference voted unanimously against the idea of creating a Target Finding Force, and Baker and Bufton returned to the Air Ministry ‘with their tails between their legs’<sup>50</sup>.

The Minutes of the conference held on 13 March 1942 tell a less dramatic story, and cast some doubt over the veracity of the version of events as recalled by Bufton and subsequently relied upon in some secondary literature on the subject. The first observation to make is that the conference was not called specifically to discuss the creation of a Target Finding Force. Indeed, the subject of the Target Finding Force came towards the end of the agenda<sup>51</sup>. There is nothing in the Minutes to suggest that Harris confined himself to stating his own views in introducing the subject. In fact, the Minutes show a much more balanced approach, in which Harris outlined both the reasons for and against the formation of a Target Finding Force. The Minutes do however record that the Group Commanders present, which included the AOC’s of Nos. 1, 3, 4 and 5 Groups, each stated that if the best crews were ‘creamed-off’ from their squadrons little would remain except very inexperienced crews, although the Minutes do not record what effect the Group Commanders believed this would have on bombing performance. The Minutes do not record what conclusion, if any, was reached on the issue.

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<sup>50</sup> Proceedings of the Royal Air Force Historical Society, Issue No 6 – September 1989. Account given by Air Vice-Marshal Bufton of the meeting with Harris. This account is recounted by Melinsky, *Forming the Pathfinders*, p68.

<sup>51</sup> TNA AIR14/695 Minutes of Conference on TR1335 Technique and Tactics held at HQ.B.C on 13 March 1942.

One the most interesting aspects of this conference are the views of the Group Commanders. As set out above, Oxland (AOC No. 1 Group) and Carr (AOC No.4 Group) had previously supported the idea of a Target Finding Force when proposed by the Navigation Section of Bomber Command the previous November. Air Vice-Marshal Baldwin, AOC of No. 3 Group, had opposed the formation of target locating squadrons but had also admitted the need for selected crews to lead bombing raids. Only Slessor, AOC of No. 5 Group, remained consistent in opposing the formation of a Target Finding Force. It is noteworthy that the topics under discussion at this conference included the results of the Billancourt raid, in which an early form of target marking proposed by Bufton himself was employed with considerable success. The conference was therefore held at a time when the currency of target marking was high, and before the limitations of the *Shaker* technique had been revealed in operations. Consequently, there is nothing to explain the apparent *volte face* of Oxland and Carr on the subject other than, perhaps uncharitably, a lack of integrity and professionalism in the face of Harris' strength of personality as C-in-C.

One generally accepted sequence of events now has a chance encounter between Bufton and Harris on the steps of the Air Ministry in the days following the conference at Bomber Command HQ<sup>52</sup>. As Bufton arrived at the Air Ministry on the 16 March 1942, Harris' Bentley drew up and, as Bufton

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<sup>52</sup> Bufton himself gave a detailed account of that encounter to the Proceedings of the Royal Air Force Historical Society, Issue No 6 – September 1989 but versions of it have appeared in secondary literature before and since. To give just three examples, both Melinsky, *Forming the Pathfinders*, p68, and Henry Probert *Bomber Harris; His Life and Times*, (London: Greenhill Books, 2001) p226 recite this version of events in some detail. A truncated version appears in Hastings *Bomber Command*, p191. However, the AHB Narrative makes no mention of this encounter.

stepped aside and saluted, Harris is reputed to have said; “Good morning, Bufton, what are you going to do to me today?”. Bufton’s reply of “Well. I didn’t plan to do anything. Sir” was followed by an invitation from Harris “Well, if you’ve got any ideas, please write to me”. Having been supported by all his Group Commanders in his opposition to a Target Finding Force at the conference only a couple of days previously, it may be speculated that Harris’ invitation was hardly intended to re-open the debate. However, Bufton wasted no time in taking up the invitation and the following day sent a detailed, three-page letter setting out his ideas about a Target Finding Force. It is sometimes claimed in secondary literature that the letter of 17 March 1942 was the opening salvo in the Target Finding Force debate but, as detailed above, that is evidently not the case<sup>53</sup>. Nonetheless, that letter was the first in a series of correspondence between Bufton and Harris on this matter and, for that reason, deserves detailed analysis here.

Perhaps being mindful of Harris’ distrust of the Air Ministry, Bufton makes it clear in the introduction to his letter that the idea of a Target Marking Force had been maturing for a considerable time, and that the ideas had been developed as a result of experience in operational units as well as in the Air Ministry<sup>54</sup>. Bufton then confirmed that the question of target location had been given a great deal of thought as a result of the poor results indicated by night photographs, and that the immediate solution appeared to be the placing of a

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<sup>53</sup> For example, Anthony Furse, John Maynard and Charles Messenger all mention Bufton’s letter of the 17 March as being the first in which he (Bufton) sets out his ideas on the Target Marking Force. This inaccurate recording of events is discussed in more detail, with references, later in this Chapter.

<sup>54</sup> TNA AIR14/3527. Letter Bufton to Harris, 17 March 1942. The copy in TNA is signed, in type, by ‘H.Bufton’, with a handwritten correction from Sydney Bufton pointing out that ‘H Bufton’ is his brother.

large concentration of flares over the target by selected crews. At the same time, Bufton noted, the Air Ministry had advocated the fire raising technique which, if it was to be successful, relied upon the initial fire raising party placing a sufficient concentration of incendiaries in the correct place to provide an unmistakable conflagration. The formation of a Target Finding Force, using flares to locate the target for the initial fire raising party and so assist them in providing an unmistakable conflagration, was a natural progression of the fire raising technique.

Bufton next made his key point. Citing his own operational experience, Bufton expressed the view that individual squadrons and Groups were parochial in their outlook, such that ideas on tactics were not widely discussed and that, so long as these squadrons were widely dispersed, no discussions on tactics would take place and no headway made in devising the best techniques. Bufton's strongly held view was that tactics could only be worked out by the units themselves but, by locating a number of squadrons close together and giving them sole responsibility for target marking, these squadrons would devise their own methods in a very short space of time. It was also Bufton's view that, once the initial methods had been devised, concentrating the target marking squadrons together would facilitate the rapid development of those techniques, taking full advantage of new navigation aids such as *Oboe* and *H2S* long before these became widely available throughout Bomber Command. This would, Bufton argued, enable attacks to be made not only against the primary targets in the Ruhr but also against specific targets such as oil refineries and the ball-bearing plants at Schweinfurt. Associated with

this idea of locating target marking squadrons close together was the creation of a 'Bomber Development Unit' to evaluate the various techniques devised at squadron level.

By the time this letter was written, Bufton was aware of the arguments against the creation of a Target Finding Force and he now sought to address those arguments. Acknowledging that the creation of a Target Finding Force would result in the dilution of the remaining squadrons, Bufton countered this by suggesting that the urgency of obtaining immediate results, both for strategical and political reasons, was such that there was a need to reinforce the target finding squadrons with good crews from other squadrons. However, Bufton calculated that this would amount to no more than one crew per front line squadron and that further replacements could be recruited direct from OTU's, and therefore would not be recurring. Similarly, Bufton did not consider the effect on promotion prospects to be a significant issue, and considered that this was outweighed by the inability to effect decisive concentration, particularly in the "critical period" at that time and the "...urgent necessity of providing conclusive evidence of the value of our strategic bomber force to counteract political and other forces which are aiming at its disruption".

In conclusion, Bufton commented that Bomber Command's tactics had come full circle since the initial reliance upon individual operational skill to a complete reliance upon the GEE navigation aid. In addition to maximising the potential of that device whilst in operational service, Bufton was acutely aware

that the use of GEE could be denied to Bomber Command within a few weeks, leading to a reversion to former ineffective tactics. His suggestion was therefore that a Target Finding Force be formed to maximise the value of GEE, and to remain as a spearhead once the use of GEE had been denied to Bomber Command.

This letter is notable as much for its emphasis on the political and strategic importance of improving the performance of Bomber Command as for the advocacy of the tactic of target marking. In that respect, it follows the Minute dated 27 February 1942 from Baker to Bottomley, stressing the importance of making Harris aware of the political and strategic issues facing the bombing offensive. The clear inference is that, from the Air Ministry perspective, there was more at stake than just improving the performance of Bomber Command. The use of phrases such as the “critical period” and the reference to other forces aiming at the disruption of the strategic bomber force is a clear indication that the Air Ministry viewed the creation of a Target Finding Force as essential to preserving the role of Bomber Command in the wider strategy of the war, and to prevent it from being relegated to a supporting role in support of the Army or subordinated to the Navy in the Battle of the Atlantic. The political and strategic issues underlying the formation of a Target Finding Force add yet another dimension to the debate, and one that has not been fully explored in secondary literature.

In April 1942, further criticism of the bombing policy was received in a note from the Joint Intelligence Committee (J.I.C.). In a response to the Air Staff

jointly prepared with the Director of Intelligence, Operations (D. of. I.(O))<sup>55</sup>, Bufton affirmed that the bombing policy had recently been subject to criticism and that, unless results rapidly improved, would again be subject to close scrutiny. The paper indicated that study of the results achieved by the German 'blitz' in the winter of 1940/41 had revealed the importance of concentration of bombing if good results were to be achieved and noted that, where the Luftwaffe had persisted in attacks when weather conditions were unfavourable, concentration of bombing had not been achieved. The paper commented that much of Bomber Command's effort had been wasted in conditions which did not allow concentration to be achieved and that, even in good weather conditions and with the use of the GEE navigation aid, the necessary concentration still had not been achieved. The paper suggested that even with the benefit of navigation aids only a small proportion of crews possessed the necessary combination of ability and determination to locate and mark a precise point, and that it was essential that these crews were coordinated into one unit in order to ensure that the target was unmistakably marked for the remainder. The paper concluded with a stark warning; if results fell below expectations, there was a "...very grave risk of our striking force being subjected to a constitutional change which disregards the accepted principles of the role of a bomber force. This might prove calamitous in spite of an apparent justification for the disintegration of Bomber Command. There are powerful agents at work to bring this about."

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<sup>55</sup> TNA AIR20/2795 D.D.B. (Ops)/Dof.I (Ops) Paper 'Bombing Policy', 6 April 1942.



This paper was sent to Air Vice-Marshal Norman Bottomley, Deputy Chief of Air Staff, who in turn forwarded it to the Vice-Chief of Air Staff (V.C.A.S.), Sir Wilfrid Freeman. In the accompanying Minute<sup>56</sup>, Bottomley indicated that he was strongly in favour of the proposal to create a Target Finding Force but that Harris had not reacted favourably when the proposal had been put to him. Harris was, as Bottomley quoted, still going through the “whole gamut of experimentation of bomber tactics” with the new GEE navigation aid before he would make any decision. Bottomley suggested that, with the life of GEE expected to be relatively short, a decision must very soon be made on “whether or not a specially trained and constituted Target Finding Force is necessary to achieve the concentration which is essential to the success of our operations”.

At about the same time, Freeman received a response from Baker to the comments made by the J.I.C.<sup>57</sup>. Having responded to the detailed points raised by the J.I.C., Baker returned to the underlying issue of the increasing criticism of the strategic bombing offensive being voiced not only in the other services and departmental circles, but also by the public. These could not, he opined, be countered with promises of future results or by the meagre results achieved in the past. The difficulty, Baker believed, was the failure of Bomber Command to appreciate the need for closer tactical direction and control of the bomber force in face of the increasing strength of enemy defences. To be successful, he went on, attacks would require co-ordinated tactical direction as well as determination and technical skill, and this could only be achieved if

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<sup>56</sup> Ibid Minute Bottomley to Freeman, 8 April 1942.

<sup>57</sup> TNA AIR20/4809 Memorandum Baker to Freeman, 9 April 1942.

each operation was controlled at Command level in conjunction with a Target Marking Force. Baker considered that the strategical situation was a critical and urgent one and that, although Harris was not convinced that a drastic change in methods was necessary, Bomber Command could not afford to experiment with minor variations on the old individual tactics. Harris' concerns in relation to the creation of a *corps d'elite* were noted, but Baker considered that in the situation then prevailing this and other parochial matters did not apply, and that in any event the successful operation of a Target Finding Force would have an immediate effect on the morale of the whole Command. Baker concluded with the assertion that the problem of tactical control and co-ordination of the bomber force was the most imperative if future bombing policy was to be effective.

In the meantime, Bufton's letter of 17 March had not elicited a response from Harris, and so in early April the Directorate of Bombing Operations tried another approach and sought to exploit contacts still held with those having recent operational experience to gain support for the creation of a Target Finding Force<sup>58</sup>. A paper was produced, essentially repeating the arguments set out in Bufton's letter of 17 March, setting out the advantages of a Target Finding Force together with the objections that had been made against it, and asking two questions: did the recipient agree with the proposal to form a Target Finding Force on the basis outlined, or were the objections sound enough to abandon the scheme? The paper was endorsed with a note from

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<sup>58</sup> CCAC Bufton Papers 3/17

Portal<sup>59</sup>, stating that: “The *corps d’elite* principle is only bad when all units have the same job. The T.F.F. has a different job and would therefore be regarded as a specialist force and not a *corps d’elite*.” A total of sixteen responses were received<sup>60</sup>, all strongly supporting the creation of a Target Finding Force.

Notwithstanding that the request for views on this matter was accompanied by a promise of confidentiality, Bufton sent copies of these replies to Harris under cover of a letter dated 11 April 1942<sup>61</sup>. Commenting upon the unanimity of thought in these letters and that the views expressed confirmed the Air Staff view so completely, Bufton opined that the replies represented the truest commentary that could be obtained on the proposition of a Target Finding Force. Although it was perhaps disingenuous on Bufton’s part to renege upon the promise of confidentiality in sending these replies to Harris, the latter’s subsequent criticism that Bufton had broken Service conventions by contacting officers without going through the Air Officer Commanding is unfounded: Portal was himself aware of the approach and indeed had contributed to it. In relating these events in his book *Bomber Harris: His life and Times*, Probert refers to comments made in Harris’ *Despatch on War Operations* as indication of the resentment Harris felt following Bufton’s actions and considers Harris’ subsequent response to Bufton (the letter dated

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<sup>59</sup> CCAC Bufton Papers 3/18, Portal to Bufton, undated

<sup>60</sup> CCAC Bufton Papers 3/17. The replies received included letters from experienced pilots such as Donald Bennett, who would go on to lead the Pathfinder Force; J.B. ‘Willie’ Tait, who would later lead No.617 Squadron; and J.H. ‘Groucho’ Marks, one of the early pioneers of Pathfinding techniques when commanding No.35 Squadron.

<sup>61</sup> CCAC Bufton Papers 3/12, Bufton to Harris, 11 April 1942. Copy also in TNA AIR14/3523.

17<sup>th</sup> April 1942 – see below) to be “remarkably restrained” in the circumstances<sup>62</sup>.

This time, Harris did respond but not before again seeking the views of his Group Commanders during a conference held on the 16 April 1942. Harris began his response, dated 17 April 1942<sup>63</sup>, by stating that he had a “fairly open mind” on the subject of a Target Finding Force but that he was not yet convinced by the arguments put forward. Harris went on to say that, whilst he appreciated and paid attention to the “lads that really do the work” (surely a carefully worded dig towards the Air Staff), that his Group Commanders were unanimously against the idea, as were the majority of station commanders. The counter-suggestion then put forward was that using the evidence of night photographs, the squadrons in each Group producing the best results would be designated as the Target Finding Force for the following month. This would have the benefit of engendering competition between squadrons to displace the squadrons holding the title of Raid Leaders during the preceding month. Harris continued by expressing the view that, generally speaking, when the target can be seen at all it is being correctly found and that the progressive development of GEE technique had led to the majority of bombs landing in built up areas of the Ruhr usefully close to the intended target. In those circumstances, Harris concluded, he was not prepared to accept all the very serious disadvantages of a *corps d’elite* in order to secure possibly some improvement on methods which are already proving reasonably satisfactory.

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<sup>62</sup> Probert *Bomber Harris: His life and Times*, p.p.226- 227.

<sup>63</sup> TNA AIR14/3523 Letter Harris to Bufton, 17 April 1942.

This last point underlines the essential difference between Bufton and Harris in terms of their respective views on the relative value of precision bombing and area bombing. The Official History makes this point very clearly, commenting that a key difference pervading the whole debate about the creation of a Target Finding Force was that Bufton envisaged that Bomber Command should be attacking precision targets but recognised that the area bombing was a preparatory phase through which Bomber Command would inevitably have to pass before it could perfect the technique of precise attack. Harris, on the other hand, regarded area bombing as an end in itself and, if pursued vigorously enough, as a means of winning the war. The Official History contends that the whole future tactical development of Bomber Command hung between these two extremes of opinion and that it was the ultimate aim of the bombing offensive which conditioned the processes of design, scientific investigation and production of equipment for, and the training of, operational aircrews<sup>64</sup>. However, the Official History fails to point out that a Target Finding Force (and target marking techniques) could serve two masters. Consequently, the formation of a Target Finding Force was not in itself a necessary precursor to precision bombing: as shown in Chapter Six, it was the application of those target marking techniques using the technology available at the time which ultimately dictated operational tactics and, therefore, potentially the overall strategy.

Bufton was not about to let the matter drop there and, taking Harris on his word that he had an 'open mind' on the subject, in a letter dated 8 May 1942

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<sup>64</sup> Webster and Frankland *The Strategic Air Offensive, Vol I*, p422.

challenged the notion that existing methods were “proving reasonably satisfactory”<sup>65</sup>. Bufton had a point. It is difficult to reconcile Harris’ view that existing methods which are already proving reasonably satisfactory with a letter sent to Oxland, AOC of No. 1 Group, in which Harris describes the bombing of Rostock on the night of 23/24 April 1942 as “Hopeless”<sup>66</sup>. In support of his argument, Bufton referred to recent attacks on three targets: Essen, a heavily defended German target within GEE range; Rostock, a lightly defended German target outside GEE range; and Gennevilliers, a lightly defended and easily located short range target. In relation to Essen, 90% of all photographs plotted showed bombs dropped between five and one hundred miles from the target. In relation to Rostock, 78% of photographs plotted were further than five miles from the target. The night photographs for the raid on Gennevilliers showed that only 12% of aircraft claiming to have reached the target had in fact done so. Bufton suggested that these results, all achieved under better weather conditions than could normally be expected, proved that it was not possible to provide an unmistakable conflagration when ‘second class’ crews were mixed in with the ‘first class’ crews in the initial attack. These results proved, he argued, that the first class crews must be coordinated in one body not as a *corps d’elite*, but as specialist experts essential to the success of large scale operations.

Bufton then took the opportunity to respond to Harris’ objections to the creation of a Target Finding Force, and to comment on Harris’ suggestion of a Raid Leader scheme. This, considered Bufton, was flawed in that the efforts

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<sup>65</sup> TNA AIR14/3523 Letter Bufton to Harris, 8 May 1942.

<sup>66</sup> TNA AIR8/688 Letter Harris to Oxland, dated 22 May 1942.

of the good crews in the designated squadron would be vitiated by the less efficient crews marking places other than the target, thereby leading to a dispersion of effort. The other fundamental flaw, according to Bufton, was that inferior squadrons would be led to the target by the designated squadron, with the result that the inferior squadron would become the designated squadron the following month. The scheme also suffered from defects that the number of first class crews in the leading squadron would be insufficient to start an unmistakable conflagration, and that the geographical separation of the squadrons would prevent the organic growth of tactical methods and techniques. Bufton concluded his letter with two suggestions that were hardly likely to endear him to Harris. Firstly, he questioned, in terms, whether the matter of the Target Finding Force had been put to the Station Commanders impartially and with a full appreciation of the critical situation facing the bombing offensive. Not content with that, Bufton then asserted that the objection to the Target Finding Force was a manifestation of a wider issue, this being a conflict of ideas between older officers with wider experience and a growing number of younger officers with recent operational experience. It may be imagined that that Bufton's closing remark, in which he hoped Harris would not "take objection to the frankness of these views, which are born only of a very great concern for the success of the Bomber Force", was more likely to have had the opposite effect.

Harris did not reply to this letter. However, the Senior Air Staff Officer at Bomber Command, Robert Saundby, requested that the figures quoted by Bufton were checked. The officer given that unenviable task, Wing

Commander Ops 1.b N W Marwood-Elton, reported on the 11 May 1942 that Bufton's figures were essentially correct<sup>67</sup>. Although Marwood-Elton was able to claim that the ever-present haze over Essen was a contributing factor to the poor results there, he was forced to concede that the failure of the Rostock and Gennevilliers raids were harder to explain and "constitute a good argument for a target locating force". Expressing his own views on the creation of a Target Finding Force, and no doubt aware of Harris' views on the subject, Marwood-Elton attempted a delicate balancing act. Acknowledging that the crews which found the target strengthened the morale of a squadron, he considered that if these crews were placed in a Target Finding Force the number of ordinary crews finding the target despite faulty navigation, bad weather and decoys would increase. On the other hand, he concluded, somewhat implausibly and without any explanation, the number of crews not finding the target due to enemy defences would also increase. On that basis, Marwood-Elton reached the somewhat incongruous conclusion that, on balance, Bomber Command would not be much better off. However, incongruous or not, this conclusion clearly met with Harris' approval and the paper was annotated with "No further action".

On 20 May 1942, the report by Mr Justice Singleton for the Defence Committee on the Bombing of Germany was published (the 'Singleton Report')<sup>68</sup>. The terms of reference of the Singleton Report were:

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<sup>67</sup> TNA AIR14/3523 Loose Minute, Marwood-Elton to Saundy, dated 11 May 1942.

<sup>68</sup> TNA AIR8/1015 Report by Mr Justice Singleton for the Defence Committee on the Bombing of Germany, 20 May 1942. The copy in TNA is marked 'C.A.S. Personal Copy'.



In the light of our experience of the German bombing of this country, and of such information as is available of the results of our bombing of Germany, what results are we likely to achieve from continuing our air attacks on Germany at the greatest possible strength during the next six, twelve and eighteen months respectively.

Lurking beneath these stated terms of reference was the unasked question, and one which the urgency and importance attached by the Air Staff to the formation of a Target Finding Force was already playing no small part: was a better use of the resources employed in the bombing offensive possible?

Singleton began his report by exploring results using T.R.1335<sup>69</sup>, noting some of the difficulties that had arisen in target locating notwithstanding the use of that navigation aid. As part of his investigations, Singleton interviewed two officers from Bomber Command of “great experience” and found that they were “completely satisfied with the accuracy of T.R.1335 *provided that it is used by a specially trained crew*” (emphasis added). The officers had qualified this by indicating that it was only in the last few miles that difficulties were encountered and that these could only be overcome by “determination and will power”. Singleton then made the observation that not all crews were of the same calibre, and that the officers he interviewed were “firmly convinced of the desirability of a specially trained Target Finding Force” which, they believed, would “lead to greatly increased efficiency in bombing”. Singleton declined to offer his own opinion on the matter but instead offered an overall

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<sup>69</sup> T.R.1335 was the technical reference for the GEE navigation aid, and has been retained in the context of this report.

conclusion that results “ought to have been much better than they appeared to have been” and that there was a feeling “in some quarters” that it had “not yet been shown how effective an instrument a bomber force can be, and that great improvement in results ought to be sought”.

What led Singleton to raise the matter of the formation of a Target Finding Force in his report? One clue may be found in the conclusion to the report, where Singleton indicates that Air Commodore Baker had arranged for Singleton to see various people who could help the inquiry. Singleton also makes reference to various documents being made available to him and it is reasonable to assume that these were provided by Baker. As detailed above, as Director of Bombing Operations at the Air Staff, Baker was a strong proponent of the formation of a Target Finding Force and it is likely that the people Baker arranged for Singleton to see were known by Baker to be of a similar mind. Given the language used by Singleton, in particular in relation to the difficulties caused by aircraft not equipped with T.R.1335, which was one of the main reasons advanced in support of a Target Finding Force, it is also a reasonable assumption that Singleton had seen the papers produced by the Air Staff on that matter. If that was indeed the case, that Singleton did not lend his own support to the formation of a Target Finding Force must have come as a disappointment to the Air Staff.

The day after the Singleton Report was published, the Air Staff issued a paper that openly criticised the tactical direction of the bombing offensive<sup>70</sup>. The formation of a Target Finding Force was not in itself central to the criticisms of Bomber Command raised in this paper, which centred on staffing issues and the lack of central control of the bomber Groups. However, the paper also complained that suggestions made by the Air Staff on tactical issues were ignored and, in that context and without directly referring to a Target Finding Force, repeated the need for a;

‘special force composed of the most able and determined crews. This force, with every new navigational and scientific aid at its disposal, would develop its own specialised technique for fulfilling its role of finding, illuminating and marking the target for the less skilful crews which constitute the large majority of the bomber force.’

Although these were not new ideas, they heralded the first contribution to the debate by a further and influential senior official at the Air Staff: the Vice-Chief of the Air Staff, Sir Wilfrid Freeman. Although the paper was largely prepared by the Directorate of Bombing Operations, Freeman had recommended a number of changes to the draft. These changes did not specifically relate to the creation of a ‘special force’ but were made in order to strengthen the wording of the paper, commensurate with Freeman’s view that “I think your only way with Bert is to treat him rough”<sup>71</sup>. This would not be the last time that

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<sup>70</sup> CCAC Bufton Papers, 3/14 Air Staff paper, ‘The Tactical Direction of the Bomber Force’, 21 May 1942.

<sup>71</sup> CCAC Bufton Papers, 3/14. Freeman to Baker, 19 May 1942.

Freeman's more direct approach would feature in the debate surrounding the creation of a Target Finding Force.

A few days after this paper was issued, the Air Staff returned to the theme of a Target Finding Force. In a paper dated 25 May 1942 entitled *The Target Finding Force*<sup>72</sup>, the main arguments in support of a Target Finding Force were again rehearsed. This paper was in effect a re-working of Bufton's letter of the 17 March 1942, with little in the way of additional detail but with the inclusion of two new points. The first of these new points, taking up a theme central to the Air Staff paper issued a few days previously, was that a Target Finding Force would necessitate the detailed planning and control of each operation at Command level, and therefore address one of the main failings in the direction of the bombing offensive to date (as perceived by the Air Staff). The second new point was a refutation of the 'raid leader' scheme initiated by Harris. Whilst conceding that a small number of the best crews in the lead squadron may successfully mark the target, it was suggested by the Air Staff that the majority of crews were of lesser ability and that their failure to accurately locate the target would only position potential decoys. The paper concluded with a repeat of the familiar concern in relation to the continuation of the bombing offensive:

"We must face the fact that our bombing has achieved only a small proportion of the results of which it is capable", the paper concluded, "and that up to the present it has not exerted a decisive influence on the outcome of the war. If

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<sup>72</sup> TNA AIR14/785 Air Staff paper, 'The Target Finding Force', 25 May 1942.

we continue with our present methods we shall fail in our purpose; it will become increasingly difficult to oppose, truthfully and logically, the strong pressure to divert the bomber force to other strategical employment; and the doctrine of strategic bombing will remain unsubstantiated. The only possibility of success is considered to lie in the formation of a target finding force, and as time is the vital factor it is recommended that this be done without delay."

Although this conclusion set out the Air Staff concerns in the starkest terms to that date, the real significance of this paper lies not in its content. Nearly all of the points made in this paper had been rehearsed in Buffon's earlier letters, including the threat to the very continuation of the bombing offensive if no action was taken. However, these letters did not carry the weight afforded to official documents. The significance of this paper lies in the fact that it was filed as an Air Staff paper and therefore had the implicit backing of the Portal as Chief of Air Staff. In theory at least, this should have been sufficient to elevate the formation of a Target Finding Force to a level where Bomber Command could not fail to act.

The views expressed in this paper were echoed by (then) Air Commodore Aubrey Ellwood, at that time Assistant Commandant at the Royal Air Force College. Ellwood, who had been Buffon's immediate predecessor as Deputy Director of Bombing Operations, had attended a lecture at the College given by Bottomley and had been concerned to discover that the reluctance to accept suggestions on tactics made by the Air Staff, evident to him in late 1941, was still prevalent. He had also been concerned by the reasons given

by Saundby for not forming a Target Finding Force. In June 1942, Ellwood delivered a paper to the Royal Air Force College setting out the arguments in support of the creation of a Target Marking Force<sup>73</sup>, in which he repeated a point also made in the Air Staff paper of 21 May that Bomber Command had already conceded the need for a specialisation in target marking by initiating the raid leader scheme. Ellwood concluded that it would be “manifestly absurd” for Bomber Command not to take the final step and form the Target Finding Force.

Further support for the creation of a Target Finding Force also arrived from an unexpected quarter. Tizard had been sent a copy of the Air Staff paper *The Target Finding Force*, and in a letter dated 6 June 1942 had endorsed the conclusions therein. “I think”, Tizard confided to Bottomley, “that if you are to get worthwhile results in the bomber offensive you will have to develop a highly trained and efficient target finding force”<sup>74</sup>.

At this point, early June 1942, Harris had still not responded to Bufton’s letter dated 8 May or the Air Staff paper of 25 May. Concerned at the lack of progress, Bottomley minuted Freeman with the suggestion that a further paper be prepared advocating the formation of a Target Finding Force<sup>75</sup>. However, Freeman was of the view that there was little to be gained from a long drawn out correspondence with Bomber Command. Freeman instead suggested to Portal that a conference should be held to discuss the subject,

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<sup>73</sup> TNA AIR20/3078 Paper presented to the Royal Air Force College by Air Commodore A.B.Ellwood ‘The Tactical Handling of the Bomber Force’, June 1942.

<sup>74</sup> IWM Tizard Papers, File 355, Tizard to Bottomley, 6 June 1942.

<sup>75</sup> TNA AIR20/3802 Minute Bottomley to Freeman, 2 June 1942.

to be attended by officers from Bomber Command and representatives from the Assistant Chief of Air Staff' (Operations) Department <sup>76</sup>. Portal concurred and the conference was provisionally scheduled for the 11 June 1942 but was destined never to take place. The conference was at first postponed for reasons unrelated to the target finding force debate and then subsequent events rendered the need for the conference redundant before it could take place.

Harris was clearly not about to have a Target Finding Force imposed upon him without a struggle and arranged for a conference with his own staff in order to prepare for the (anticipated) forthcoming conference with the Air Staff <sup>77</sup>. In opening his conference, Harris stated that he would like to get the views of the Groups on the formation of a Target Finding Force before discussing the subject with the Chief of Air Staff. Harris pointed out that bombing accuracy had improved since the introduction of GEE, but that it was important that no possible means of improving bombing accuracy was ignored and that many of the troubles might be cured if it was possible to form a Target Finding Force of sufficient size composed entirely of experts. Having thus given the impression that he was not averse to the formation of a Target Finding Force in principle, Harris then reeled off several reasons why a force of sufficient size could not be raised within the Command. To these, Harris added his standing objection in relation to the loss of promotion prospects for these crews selected for the force.

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<sup>76</sup> Ibid. Minute Freeman to Portal, 3 June 1942.

<sup>77</sup> TNA AIR14/2058 Minutes of Conference held at HQBC, 10 June 1942.

The Minutes of the meeting record that the A.O.C. of 3 Group, notwithstanding that his own '3 Group Flare Force' was at that time engaged in illuminating the target area as part of the *Shaker* technique then being employed, agreed the C-in-C's remarks. Carr, the AOC of No 4 Group, previously on record as saying that target finding squadrons offered the 'most favourable prospect' of successful target location, did a complete *volte-face* and now agreed with the AOC of 3 Group. The majority of the Station and Squadron Commanders present, the latter including Freeman of No.3 Group and 'Groucho' Marks of No.4 Group, both of whom had indicated their support for a Target Finding Force in response to Buffon's questionnaire of April 1942, now declared themselves against the formation of a Target Finding Force due to the "bankruptcy in crews and aircraft". Dickins, Head of ORSBC, who had himself previously proposed the formation of special squadrons to 'initiate raids and start fires' in a memorandum produced in December 1941, remained silent on the matter. Dickins' stance on this occasion later led to criticism by Blackett, Zuckerman and Freeman Dyson, the latter a junior member of ORSBC, who subsequently opined that Dickins was "a career Civil Servant" whose guiding principle was "to tell the commander in chief things that the commander in chief liked to hear", such that the ORSBC was too timid to challenge any essential element of policy<sup>78</sup>, and to the comment by Hartcup that Dickins was "a highly competent civil service scientist, but did not have the stature or independence of mind of Blackett and Williams"<sup>79</sup>. The position adopted by those who had previously supported the formation of a

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<sup>78</sup> Wakelam. *The Science of Bombing*, p38.

<sup>79</sup> Hartcup. *The Effect of Science on the Second World War*, p110. The 'Williams' referred to by Hartcup in this context was E.J.Williams, who succeeded Blackett as head of the Operational Research Section at Coastal Command.



Target Finding Force, and who now agreed with Harris that it was impracticable, is perhaps best described as disingenuous but is nonetheless a testament to the Harris's forceful personality.

Following this meeting, Harris wrote to Portal to confirm that he still opposed the creation of a Target Finding Force<sup>80</sup>. Harris began by stating that each Group Commander had brought with him his best Target Finding Squadron Commander and that all were "utterly opposed" to the formation of a Target Finding Force *along the lines which hold favour in the Air Ministry*" (emphasis added here and below). *Their* arguments, Harris continued, were that Bomber Command already had a Target Finding Force by electing the best squadrons and the best crews to lead attacks, and *all* were insistent that there was nothing in particular to be gained by these crews belonging to one Unit. Harris added that *he* had persuaded *them* to hold inter-Group Raid Leaders Conferences once or twice a month, at which the best crews leading attacks would suggest means of improving upon past performances. Harris also indicated that there was a universal desire that the best crews should be entitled to wear a special badge, a proposal with which Harris found himself in "full agreement". Following the introduction of GEE, the main difficulty, Harris continued, was not finding the target but seeing the target, and considered that a target finding expert would have no better ability to see a target under conditions of haze and searchlight glare than anybody else (original emphasis). Harris also pointed to restrictions on foreign and colonial personnel, technical issues and obsolescent aircraft restricting the pool from

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<sup>80</sup> TNA AIR8/688 Letter Harris to Portal, 12 June 1942.

which crews for the Target Finding Force could be drawn, and expressed the opinion that crews drawn from the few remaining squadrons would therefore be below the standard of those in his Raid Leader scheme. Harris concluded by stating that his existing Raid Leader scheme “provides all the requirements of the Target Finding Force fanatic, bar living together in special Units”, and that all his AOC’s and their best squadron commanders were decisively and adamantly opposed to the ‘getting together requirement’.

This is a remarkable letter. In effect, Harris had conceded the need for a Target Finding Force in principle; had accepted the need for the Target Finding Force to share information in order to improve technique, and had initiated a means of doing so; and had proposed that members of the Target Finding Force should be afforded special status. These were all features of the Target Finding Force proposed by the Air Staff. The only difference between Harris’ new position and the Air Staff proposal was the requirement that the Target Finding Force should be located close together. As the Official History points out, the debate had moved from one of principle to one of method<sup>81</sup>.

Although the letter to Portal of the 12 June 1942 is sometimes referred to in secondary literature as being Harris’ definitive response on the subject of the Target Finding Force, Harris did in fact write a second letter the following day<sup>82</sup>. That letter, to which no reference is made in secondary literature, is a detailed response to the Air Staff letter dated 25 May 1942, in which Harris

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<sup>81</sup> Webster and Frankland *The Strategic Air Offensive, Vol I*, p430.

<sup>82</sup> TNA AIR14/785 Letter Harris to Portal, 13 June 1942.

attempts to explain the failures at Gennevilliers, Rostock and Essen. The former failed, claimed Harris, because Gennevilliers was a small target that was difficult to find, and because the bombsight with which Bomber Command was equipped was unsuitable<sup>83</sup>. Harris blamed the failure of the first Rostock on the “wild behaviour of the Polish crews, but claimed that subsequent raids were successful, whereas the failure of the raids on Essen was attributed to the difficulty in seeing the target due to the industrial haze. “No target finding force”, Harris suggested, “ would overcome this obstacle”.

Harris went on to say that “some success” had been obtained by using the best crews from all Groups to lead the attack and that the more unreliable crews ,who were “likely to drop incendiaries in the wrong place”, had been eliminated from the early stages of the attacks. Harris then points to a whole series of technical reasons why some of the aircraft types with which Bomber Command was equipped were unsuitable for use by a Target Finding Force<sup>84</sup>, with the result that a Target Finding Force would be largely drawn from a small number of squadrons equipped with the Stirling and the Wellington III. From this, Harris concluded that Bomber Command was not of sufficient size to form a Target Finding Force or, if a smaller force was formed, it would not be viable. Harris’ final point was refute the suggestion that his force was now

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<sup>83</sup> At this time, this was still the MkIX Course Setting Bombsight, a pre-set vector bombsight which required the bomber to maintain straight and level flight, and which could not be adjusted in flight to take account of changing wind conditions.

<sup>84</sup> For example, the Handley Page Hampden and Avro Manchester squadrons were due to convert to other types; the Avro Lancaster squadrons were training for specialist roles; the Handley Page Halifax could not carry a large quantity of incendiaries due the configuration of the bomb bay; the Vickers Wellington IC squadrons were not equipped with GEE, and the range of the Vickers Wellington IV was not sufficient for some targets in Germany. In addition, Harris considered that crews from Commonwealth squadrons were not suitable.

completely reliant upon the GEE navigation aid, claiming that some of the most successful attacks had been outside GEE range<sup>85</sup>.

Again, some of the arguments advanced by Harris in this letter opposing the creation of a Target Finding Force could equally be advanced in support of the case for creating such a force. In particular, Harris' admission to using the best crews from all Groups to lead the attack and eliminating the more unreliable crews from the early stages of the attacks is tantamount to the creation of a Target Finding Force in anything but name.

It was at this juncture that Portal at last entered the fray and on 14 June replied in detail to Harris' letter<sup>86</sup>. Portal opened with a telling observation;

“As I read your letter, both you and those of your Command with whom you have discussed the scheme, agree on the urgent need for finding some method of using the best of your crews to identify and mark the target so as to enable the remainder to concentrate their attack on it and thus avoid the present waste of effort which results from the majority of your attacks being dissipated over a wide area. I take it that you also agree that something must be done to prevent less expert crews from lighting fires in the wrong place during the first stage of an attack”.

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<sup>85</sup> Although not specifically identified in the letter, two of the most successful raids in this period, those against Rostock and, in particular, Lubeck, were well beyond GEE range, albeit that these raids were carried out against coastal targets in perfect weather conditions.

<sup>86</sup> TNA AIR2/7649 Letter Portal to Harris, 14 June 1942. Copies also in the Portal Papers, File 9, 31a and in the Harris papers. It may be noted that Portal refers only to Harris' letter of the 12 June, making no reference to that of the following day.

Portal then made the observation that, whilst Harris opposed the formation of a Target Finding Force along the lines suggested by the Air Staff, the suggestions that followed in Harris' letter all implied the admission that such a force was necessary without presenting a reasonable argument against the Air Staff proposal. Portal noted that the proposals included the singling out of the crews with a distinctive badge, a proposal to which he (Harris) had so strongly opposed on the grounds that it would create a *corps d'elite*. On this point, Portal accepted that "to pack one unit with experts at the expense of other units which have to do the same job is most unsound and bad for morale" (original emphasis). Portal then made it clear that this was "emphatically not what we are proposing" and that, because the Target Finding Force would have an entirely different and far more difficult task than the ordinary "follow up" squadrons, there was a "need and a justification for having a formation containing none but expert crews".

Portal's next observation was an equally telling one. "Over a period of three months", noted Portal, "your attitude seems to have progressed from the complete rejection of the Target Finding Force proposal, through a Target Finding Squadron phase to this present raid leader suggestion. I cannot feel that it is logical that you should now reject the final and essential step of welding the selected crews into one closely knit organisation which, as I see it, is the only way to make their leadership and direction effective".

The remainder of Portal's letter was largely devoted to rejecting the technical arguments advanced by Harris against the formation of a Target Finding

Force, whilst also taking the opportunity to remind Harris that the use of GEE, on which is raid leader scheme depended, was likely to be denied to Bomber Command within a few months. When that occurred, Portal considered, Harris' raid leader scheme could not ensure the leadership which the average crews required to overcome their great and increasing difficulties. Portal did, however, seize upon Harris' point about the difficulty of seeing the target at night which, he felt, was a convincing indication that the methods employed to date were "not equal to the occasion". "What we need to aim at", Portal continued, "is an effective degree of illumination and incendiarism in the right place and only in the right place. It is our opinion that this admittedly difficult task can only be done by a force which concentrates upon it as a specialised role, and which excludes those less experts crews whose less discriminating use of flares or incendiaries in the vicinity of the target have recently led so many of our attacks astray" (original emphasis). In the opinion of the Air Staff, said Portal, such a force would be analogous to that of the Reconnaissance Battalion of an Army Division and would "immediately open up a new field of improvement, raising the standard and thus the morale which could not fail to be reflected throughout the whole force". Referring back to the Singleton Report, Portal concluded his letter with the familiar refrain that any failure to effect a radical improvement may well endanger the whole of the bomber policy.

Interestingly, there are two versions of Portal's letter in existence. The copies held in The National Archives<sup>87</sup> and in the Harris Papers at the Royal Air

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<sup>87</sup> TNA AIR2/7649 and AIR8/688, Letter Portal to Harris, 14 June 1942.

Force Museum<sup>88</sup> both include a paragraph in which Portal appears to prevaricate when it comes to ordering Harris to form a Target Finding Force. This paragraph, which is not included in the copy of this letter held in the Portal Papers at Christchurch College, Oxford,<sup>89</sup> gives a valuable insight into Portal's character as a commander and to his relationship with Harris, and therefore warrants quoting at length<sup>90</sup>.

"....I fully recognise the practical difficulties", the paragraph begins, "and, although I do not consider that the proposals which you have made go nearly far enough, I am reluctant to impose the Air Staff proposal upon you while you object so strongly to it. I would therefore like to discuss the subject with you tomorrow as a preliminary to holding the conference arranged for next Thursday, and I hope we shall be able to formulate an agreed scheme".

Here is a situation in which Portal, himself already on paper as an advocate of a Target Finding Force, fails to exert his authority in order to secure a proposal which originated from his own staff and which was widely, although as shown below not universally, supported in the Air Staff. The more generous interpretation of Portal's actions is to suggest that his approach reflected what would now be termed a "collaborative" management style, in which the opinion of those concerned with technical matters was welcomed and evaluated as part of the decision making process. A less generous interpretation would suggest that this was an early indication of Portal's

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<sup>88</sup> RAFM Harris Papers, H69 Letter Portal to Harris, 14 June 1942.

<sup>89</sup> CCL Portal Papers, File 9, 31a, Letter Portal to Harris, 14 June 1942.

<sup>90</sup> Paragraph 10 of the letter in the copies held in The National Archives and the Royal Air Force Museum.

naivety and weakness as a military commander, especially when faced with a strong personality such as Harris', a trait that some commentators claim would later resurface with the debate surrounding precision oil targets in 1944. The debate between Portal and Harris about oil targets is covered in the Official History<sup>91</sup> but is also covered in some detail by, amongst others, Gray, Hastings, Richards and Verrier. In his book, Hastings concludes that in this episode "...Portal finally showed himself unable to exercise authority over Sir Arthur Harris"<sup>92</sup>, whereas Verrier describes Portal as being "impotent when dealing with his subordinate"<sup>93</sup> and Gray suggests that Portal was "...either naïve, suffering from wishful thinking or merely being placatory..."<sup>94</sup>. Richards takes a different view, being generally supportive of Portal's actions<sup>95</sup>. The debate is also covered extensively in the doctoral thesis by Rex F. Cording, with Cording reaching the conclusion that Portal allowed a subordinate to flagrantly and repeatedly ignore Air Staff requirements and, by so doing, allowed questions to be raised about his leadership qualities and weakened his position as a leader<sup>96</sup>.

Buften, fearful that Portal had provided Harris with an escape route, immediately advised Freeman that he "...wished to disassociate himself from the possibility of a compromise"<sup>97</sup>. Buften's reaction is itself a clear indication that Portal's letter went out with this paragraph included, which therefore

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<sup>91</sup> Webster and Frankland *The Strategic Air Offensive*, Vol III, p.p. 77 to 94.

<sup>92</sup> Hastings *Bomber Command*, p.427.

<sup>93</sup> Verrier *The Bomber Offensive*, p.p. 283 and 284.

<sup>94</sup> Gray *The Leadership, Direction and Legitimacy of the RAF Bomber Offensive*, p.p. 268 to 274

<sup>95</sup> Richards *The Hardest Victory*, p.p. 263 to 267

<sup>96</sup> Cording, *The Other Bomber Battle*, Chapter Seven.

<sup>97</sup> TNA AIR20/3078 Note Buften to Freeman, 15 June 1942.



raises the question about the status of the version held in the Portal Papers (and, indeed, to their wider validity). There are a number of possible explanations for this, but two in particular would appear to present themselves. The first is that Portal had already decided that a Target Finding Force would be formed and omitted this paragraph from the final draft of the letter in order to appease Bufton following his (Bufton's) note to Freeman disassociating himself from any possibility of a compromise. One version of subsequent events would lend support for this possibility for, according to Bufton, on the same day that he wrote to Harris, Portal called to confirm that, following discussion with Freeman, the Target Finding Force would be formed and that he (Portal) would be meeting with Harris the next day to discuss the matter<sup>98</sup>. However, the fact that the letter went out with the additional paragraph included would militate against that possibility.

A second, and more likely, possibility is that the original letter was drafted by Freeman in Portal's absence, and that the paragraph was later added by Portal. There is some merit in this version of events, because Portal is known to have been on leave on the date that the letter was issued, not returning to duty until the 15 June. In his biography of Freeman, Anthony Furse relates how Freeman was deputising for Portal when he had occasion to call on Bufton and the matter of the Target Finding Force was raised. Freeman is said to have taken the file and, after perusing the correspondence, indicated that he would take the matter up with Portal on his return. Freeman had previously advised Bufton that the only way with Harris was "to treat him

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<sup>98</sup> CCAC Bufton Papers, 5/13, Bufton to Martin Middlebrook, 7 April 1983.

rough” and the copy held in the Portal Papers is consistent with that approach. Portal’s letter is dated the day before he returned to duty, thereby raising the possibility that Freeman, with his more robust approach to dealing with Harris, had drafted the letter for Portal’s signature on his return, and that Portal had added the paragraph later. This scenario is favoured by Furse, noting that it was entirely in character that Portal should have added the paragraph on the copies held in The National Archives and the Royal Air Force Museum. Furse then goes on to suggest, somewhat improbably given that the copy in the Harris Papers includes the additional paragraph, that the fact that Harris then agreed so promptly to form a Target Finding Force implies that he received the version drafted by Freeman without that extra paragraph. Portal’s biographer, Denis Richards, is silent on this point, despite citing references to this letter in his book<sup>99</sup>.

The other factor that points strongly to the fact that Harris received the copy with the additional paragraph is that the meeting referred to by Portal in the letter did indeed take place on the 15 June. There is no record of the discussion that took place, or of who attended the meeting, although it is likely that Freeman was also present<sup>100</sup>. The outcome, however, was that Harris was ordered to form a Target Finding Force, renamed at Harris’ insistence as the ‘Pathfinder Force’<sup>101</sup>, thus bringing to a conclusion a debate that lasted over six months.

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<sup>99</sup> Denis Richards *Portal of Hungerford* (London: Heinemann, 1977), p306.

<sup>100</sup> Furse *Wilfrid Freeman*, p207. Furse records that Harris is said to have started the meeting by stating that a “Target Finding Force would only be established over my dead body”, but there is no documentary evidence to support that contention.

<sup>101</sup> RAFM Harris Papers, H49. Letter Harris to 1,3,4,5,91 and 92 Groups, 20 June 1942.

The foregoing description of the events demonstrates that a number of individuals and organisations made significant, and at times crucial, contributions to the formation of the Pathfinder Force. It is entirely fair to say that Bufton was the main advocate of the 'Target Finding Force', and made most of the technical arguments in favour of a specialist unit. Accordingly, the lion's share of the credit for the formation of the Pathfinder Force must go to him. However, as the Official History points out, it was not possible for the Deputy Director of Bomber Operations, as Bufton then was, to dictate to the Commander-in-Chief that a Target Finding Force be formed. Bufton must therefore have had support at all levels across the Air Staff, and it is therefore necessary to consider the role that others within the Air Staff played in the formation of the Pathfinder Force.

Firstly, the contribution made by Baker, as Director of Bombing Operations, should not be underestimated. Baker appears to have been involved in the initial discussions about a Target Finding Force before Bufton joined the Directorate of Bombing Operations, including the meeting with Bennett in late 1940/early 1941. It was Baker who considered that Bufton's initial ideas for the creation of Target Finding Force were worth pursuing and who, by suggesting that his ideas should be sent demi-officially to Bomber Command, brought the debate to the table. The resulting paper, dated 29 November 1941, was Bufton's outline for a Target Finding Force and this would not have been produced or issued without Baker's encouragement. It was Baker who subsequently wrote to Bottomley expressing concern that Harris might not be aware of the political and strategical issues faced by Air Staff, and who

instructed Bufton to prepare a paper that again stressed the importance of forming a Target Finding Force. In early March 1942, concerned at the lack of progress, it was Baker who asked Bufton to summarise the arguments in support of the creation of a Target Finding Force, and later it was Baker who advised Freeman that solving the problem of tactical control and co-ordination of the bomber force, which included the formation of a Target Finding Force, was most imperative if future bombing policy was to be effective. It is also likely that Baker provided much of the information, including meetings with personnel known to favour a Target Finding Force, to Justice Singleton and which may have contributed to Singleton's inclination towards the creation of a Target Finding Force. Finally, it was Baker who responded to the paper by the J.I.C. by indicating that a successful bombing offensive could only be achieved if each operation was controlled at Command level in conjunction with a target marking force. The contribution made by Baker in terms of supporting and directing the efforts of Bufton, whilst not widely acknowledged, was nonetheless significant if not instrumental.

The role played by Freeman as Vice-Chief of the Air Staff is a particularly interesting one. Apart from recommending a number of changes to a paper produced by the Air Staff following the publication of the Singleton report, Freeman remained silent during the early stages of the debate. Freeman's first important contribution came towards the end of the debate, when in June he persuaded Portal that there was little to be gained from a long drawn out correspondence with Bomber Command and that a conference should be held to discuss the subject. Although that conference never took place, this

intervention led to the sequence of events culminating in Portal's letter of 14 June and the subsequent meeting at which Harris was instructed to form a Target Finding Force. Freeman's role in the letter of 14 June is also potentially pivotal, in that the evidence supports the contention that it was Freeman who drafted that letter. It is also likely that Freeman attended the meeting with Harris on the 15 June. It is this late intervention in the Target Finding Force debate which has led some commentators, notably Anthony Furse, Max Hastings and Richard Overy, to suggest that Freeman's role was a decisive one. Furse suggests that "The deadlock between Bomber Command was only broken by Freeman's decisive intervention in June"<sup>102</sup> and Hastings suggests that "Harris began to lose the battle when the file passed to Freeman, the Vice-Chief of Air Staff"<sup>103</sup>. Overy suggests that "The crisis point came in June when Wilfred (*Sic*) Freeman, acting on Portal's behalf as Vice-Chief of Air Staff, finally seized the initiative after weeks of fruitless arguments with Harris over tactical merits. He told Harris that he would have to accept the logic of a specialist force"<sup>104</sup>.

The interesting background to this is that Freeman himself did not support the concept of a Target Finding Force. "Personally," he wrote in a minute to Portal on the 3 June, "I have never liked the idea of a Target Finding Force along the lines recommend (in Bufton's letter dated 25 May), but nevertheless I believe we are now being forced to adopt it. In any event I can see little harm in giving it a trial"<sup>105</sup>. The irony, therefore, is that it was Freeman who played a decisive

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<sup>102</sup> Furse *Wilfrid Freeman*, p202.

<sup>103</sup> Hastings *Bomber Command*, p190.

<sup>104</sup> Overy *The Bombing War*, p292.

<sup>105</sup> TNA AIR20/3802 Minute Freeman to Portal, 3 June 1942

role in persuading Harris to form a Target Finding Force, of which neither man was in favour.

In contrast, the contribution made by Portal is less than impressive. Portal is on record as one of the earliest advocates of a Target Finding Force, having proposed the formation of a specialist target finding unit long before Bufton presented his own ideas. As early as April 1942, Portal had endorsed Bufton's approach to operational pilots on the subject of the Target Finding Force and therefore must have been aware of the resistance that Bufton had been experiencing to his proposals. In view of his known support for the concept, it may have been expected that Portal could have used his position to progress the formation of a Target Finding Force, particular in view of the wider context in which the debate was taking place and the consequences should the results achieved by Bomber Command not improve. That he did not, and that it was left to Freeman to take up the mantle, reflects poorly on Portal and tends to suggest a weakness in management style. It also undermines the suggestion made by Portal's biographer, Dennis Richards, that the "establishment of the Pathfinder Force was not the least of Portal's services to the bombing offensive"<sup>106</sup>.

The role played by Harris is, perhaps, the most interesting. Harris is usually portrayed in literature as being wholly opposed to the concept of a *corps d'elite* within Bomber Command and as being generally obstructive to all attempts to have the creation of a Target Finding Force imposed upon him. In

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<sup>106</sup> Richards *Portal of Hungerford*, p306.

particular, much is made of Harris' dislike of the Directorate of Bombing Operations and of the ideas of a relatively junior officer (Bufton) being forced upon him. As Hastings observes, "Harris reserved his most virulent disdain for the Air Ministry's Directorate of Bomber Operations, whose staff acted as the Chief of Air Staff's personal advisors and agents in all matters relating to bombing policy"<sup>107</sup>. However, this does Harris an injustice. Much of Harris' objection to the creation of a Target Finding Force was based on his own preference for having target marking squadrons in each Group, which he believed would "lead to a good deal of healthy competition and new ideas could be more easily tried out in this way"<sup>108</sup>. As the bombing offensive progressed, and Bomber Command expanded, Harris took the opportunity to implement his idea of having target marking squadrons in individual groups. Initially, this involved the creation of specialist target squadrons in No. 5 Group but later both No. 1 Group and No.3 Group also established their own target marking capability. As will be shown in Chapter Six, the formation of the specialist target marking squadrons in No.5 Group did indeed result in competition with the Pathfinder Force and ultimately led to the development of more effective target marking techniques than those adopted by the Pathfinder Force<sup>109</sup>. It is arguable whether these improved techniques would have evolved had separate target finding squadrons not been formed within No. 5 Group and, albeit with the benefit of hindsight, this provides a vindication of Harris' ideas.

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<sup>107</sup> Hastings *Bomber Command*, p190.

<sup>108</sup> Sir Arthur Harris, *Bomber Offensive*, p128.

<sup>109</sup> These techniques included 'Offset Marking' and the '5 Group Fan' which, as discussed in Chapter Seven, represented the ultimate development of target marking techniques during the bombing offensive.

It must however be recognised that, when the debate on the creation of a Target Finding Force was taking place in early 1942, Bomber Command was not of sufficient size to operate effectively at individual group strength and it was only the subsequent expansion of Bomber Command that made the formation of specialist target marking squadrons within individual groups a viable proposition. It should also be recognised that the techniques introduced by No. 5 Group were evolutions of techniques initially developed by the Pathfinder Force, and that neither No. 4 Group nor No. 6 Group established their own target marking squadrons, relying on the Pathfinder Force to mark targets throughout the bombing offensive. The weakness of Harris' position was therefore his failure to appreciate that in 1942 Bomber Command was simply not in a position to implement his own ideas about forming target marking squadrons in each Group and that the creation of a Target Finding Force, whilst necessary in order to improve operational efficiency in its own right, was also a necessary step towards the position envisaged by Harris whereby each Group would have its own specialist target finding squadrons. It is was a measure of Harris' personality that, having adopted his position, he was not about to accept the proposals being put forward by the Directorate of Bombing Operations, and failed to accept the logic and merits of the proposals being put to him. This has led to Harris being unfairly depicted as a dogmatic, obstructive individual wholly at odds with the Air Staff, which obscures the fact this his own ideas had much merit and that it was only his timing that was misplaced.



Two key themes arise in coverage of the debate surrounding the creation of a Target Finding Force in secondary literature. Firstly, it is often claimed in secondary literature that Bufton's letter of the 17 March 1942 was the opening salvo in the Target Finding Force debate: for example, Anthony Furse<sup>110</sup>, John Maynard<sup>111</sup> and Charles Messenger<sup>112</sup> all mention Bufton's letter of the 17 March as being the first in which he (Bufton) sets out his ideas on the Target Finding Force. As detailed above, that is evidently not the case. As a consequence, few accounts of the creation of Pathfinder Force refer to the gradual evolution of the idea from earlier beginnings. Moreover, although most accounts acknowledge the leading role played by Bufton, few accounts refer to the inputs of other individuals or organisations.

This last point leads to the second key theme arising from the coverage in secondary literature: a tendency for authors to claim sole or principal credit for creation of the Pathfinder Force for one individual. Thus, as described above, Denis Richards ascribes the creation of the Pathfinder Force to Portal whereas, with more justification, Anthony Furse claims that the 'deadlock' between Harris and Bufton was only broken by Freeman's intervention<sup>113</sup>. Others, such as Melinsky, attribute the credit for forming the Pathfinder Force almost exclusively to Bufton<sup>114</sup> whereas Bennett claims that he himself sowed the seeds of the force that he would later lead. In the manuscript for *Operational Research in Bomber Command* ("the OR manuscript"), Dickins

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<sup>110</sup> Furse *Wilfrid Freeman*, page 201.

<sup>111</sup> Maynard *Bennett and the Pathfinders*, p54.

<sup>112</sup> Charles Messenger, *'Bomber' Harris and the Strategic Bombing Offensive, 1939 -1945*, (London: Arms and Armour Press, 1984), p84.

<sup>113</sup> Furse *Wilfrid Freeman*, p202.

<sup>114</sup> Melinsky, *Forming the Pathfinders*, p66 to 77.

claims that the ORSBC memorandum of the 22 December 1941 “appears to be the first reference to the possibility of a special Pathfinder Force”<sup>115</sup>. This quote is reproduced in full by Wakelam in his book *The Science of Bombing*, in a section of the book covering the early contributions made by ORSBC to the bombing offensive<sup>116</sup>. However, although made in good faith, the statement in the OR manuscript is patently inaccurate but is neither corrected nor put into context by Wakelam in his book, which is therefore misleading in describing the role played by ORSBC in the formation of the Pathfinder Force.

From the other perspective, amongst those who support Harris, notably Saward<sup>117</sup> and Messenger<sup>118</sup>, there is a tendency to focus on the exchange between Harris and Portal in June 1942 and to make little, if any, reference to the debate that preceded that exchange. Saward even goes so far as to suggest that the pathfinding principle promoted by Bufton was developed by Harris when he commanded a squadron in Iraq during the early 1920’s. This leads Saward to claim that the arrival of Harris at Bomber Command immediately led to a greater application of target-finding and target-marking principles. As demonstrated here, this of course was not the case but Sawards’ claims nonetheless serve as an example of how the perspective of

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<sup>115</sup> RSMORA. *Operational Research in Bomber Command*, p52.

<sup>116</sup> Wakelam *The Science of Bombing*, p57. This is a quote from *Operational Research in Bomber Command*.

<sup>117</sup> Dudley Saward, *‘Bomber’ Harris*. Although Chapter 15 of Saward’s book is entitled ‘Preparations for Pathfinder’, the debate surrounding the creation of the Pathfinder Force occupies only a small part of that chapter and then is largely confined to Portal’s letter of 14 June 1942.

<sup>118</sup> Messenger *‘Bomber’ Harris and the Strategic Bombing Offensive, 1939 -1945*. Messengers’ book also contains a chapter ostensibly devoted to the creation of the Pathfinder Force (Chapter Four, entitled ‘The Coming of the Pathfinders’) although much of this is devoted to technical descriptions of navigational aids, with little coverage of the debate itself.

individual authors can influence accounts of the debate surrounding the creation of the Pathfinder Force.

The conclusion must be reached, therefore, that to date none of the accounts in secondary literature of the debate surrounding the creation of the Pathfinder Force have presented a comprehensive and objective analysis of that debate. This has inevitably led to misconceptions about the nature of the debate and the roles that various individuals played within it. It is also reasonable to conclude that none of the accounts place the debate into proper context, namely the serious question mark that hung over the continuation of the offensive at that time. In the absence of a proper analysis, and by considering the debate in a vacuum, the importance of the debate that took place and the eventual outcome has not to date been fully explored.

The formation of the Pathfinder Force, and the basic techniques upon which all subsequent target marking would be based, are discussed in the next Chapter.

## CHAPTER FIVE: PATHFINDER FORCE TARGET MARKING TECHNIQUES

The previous chapter examined the events leading to the formation of the Pathfinder Force. This Chapter covers the development of target marking techniques in the period during which target marking was the sole provenance of the Pathfinder Force, and therefore covers the period from the commencement of operations by the Pathfinder Force in August 1942 until April 1944<sup>1</sup>. This period encompasses the three 'Bomber Battles' of 1943/1944<sup>2</sup>, and covers a period in which the striking power of the bomber force increased significantly. Target marking techniques involving the use of a Master Bomber are considered in Chapter Seven and are therefore not covered in this Chapter, even if chronologically they occurred during the period under consideration here<sup>3</sup>. This Chapter examines the development and evolution of the various target marking techniques used by the Pathfinder Force, and will quantify the effect on bombing performance arising from the employment of those techniques. It will show that to a large extent the characteristics and limitations of the navigation/bombing aid employed dictated the target marking techniques that could be used in conjunction with it. The Chapter will also show that there was direct correlation between the target marking technique employed and the bombing performance achieved. The Chapter will identify the two phenomena that arose directly from the introduction of target marking techniques, known as the 'Systematic Error' and

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<sup>1</sup> After that date, No 5 Group (and to a lesser extent Nos. 1 and 3 Groups) began to develop their own target marking techniques. These are examined in Chapter Six.

<sup>2</sup> These were: the Battle of the Ruhr (5/6 March to 30/31 July); Battle of Hamburg (24/25 July to 2/3 August); and the Battle of Berlin (18/19 November 1943 to 30/31 March 1944).

<sup>3</sup> The Peenemunde raid of 17/18 August 1943 is one such example. Although this raid did introduce a significant development in target marking technique, that technique in part involved the use of a Master Bomber and is therefore considered in Chapter Seven.

the 'Principle of Cumulative Distribution', and will examine how the elimination or reduction of bombing errors resulting from these phenomena was fundamental to securing improvements in bombing accuracy.

The Pathfinder Force (PFF) was formed on the 15 August 1942, under the command of (then) Group Captain Donald Bennett<sup>4</sup>. At the time of its formation, the PFF was composed of five squadrons, comprising of four 'standard' squadrons, one drawn from each of the existing night Bomber Groups<sup>5</sup>, and a 'special' squadron then involved in the development of the *Oboe* bombing aid<sup>6</sup>. The four squadrons drawn from the Bomber Groups each flew a different aircraft type of aircraft, the performance of which varied significantly in terms of operational ceiling and cruising speed. This presented an immediate problem for the PFF in terms of co-ordinating the timing of the various elements of the target marking techniques, not least because of these aircraft types only the Avro Lancaster was capable of accepting subtle adjustments to speed in level flight<sup>7</sup>. It followed that of the four types only the Avro Lancaster possessed the flexibility of airspeed to enable it to make up time lost to inaccurate wind forecast or navigational error, and therefore carry out the marking role at the appointed time. There was also a significant

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<sup>4</sup> Maynard. *Bennett and the Pathfinders*, p.p.79 to 93. This work contains detailed account of the formation of the PFF.

<sup>5</sup> These squadrons were: 7 Squadron from No 3 Group (Short Stirling); 35 Squadron from No 4 Group (Handley Page Halifax); 83 Squadron from No 5 Group (Avro Lancaster); and No 156 Squadron from No 1 Group (Vickers Wellington III).

<sup>6</sup> This was No 109 Squadron, equipped with the De Havilland Mosquito IV.

<sup>7</sup> The Short Stirling, the Mk1 version of which was equipped with 'Exactor' throttle controls, was particularly poor in this respect. Not only did the Stirling have a lower cruising speed than the other types, the Exactor throttle was initially designed for use in flying boats such as the Short Sunderland, in which rapid throttle response was not a requirement. The Exactor throttle was hydraulically operated and could not translate commands for more power as quickly as conventional 'rod and chain' throttle designs used in the other main bomber types. Once established at cruising speed, the Stirling was therefore relatively inflexible in terms of rapid and accurate adjustment of airspeed.

disparity in the serviceability rate of the four aircraft types. Consequently, in order to ensure that all elements of a technique were completed, it was necessary to employ only the most reliable type (the Avro Lancaster) on specialist roles involving only a few aircraft. The capability and flexibility of the early PFF techniques was therefore limited from the outset by these constraints.

In the initial raids, the PFF employed a technique based upon the use of the flares which, in some respects, was similar to the *Shaker* technique<sup>8</sup>. The initial PFF element, known as 'Finders', were timed to arrive in the target area at zero hour minus one minute or zero hour minus two minutes. These aircraft dropped bundles of white reconnaissance flares at intervals of between eight to twelve seconds to form either three or five parallel lines, each some two miles apart. If the A/P was positively identified, a distinctively coloured marker flare was dropped to indicate the location of the A/P. The next phase, the 'Illuminators', dropped bundles of white reconnaissance flares at intervals of between two and five seconds over the A/P. There were two variations on this technique, dependant upon the strength of the wind at 2,000 ft (this being the height at which the flares would be burning at their strongest). In conditions of nil or little wind, the flares were placed in an arc on the far side of the A/P relative to the direction of approach. In conditions of strong winds, the flares were dropped in two parallel lines, one on each side of the A/P and each starting at about ½ mile short of the A/P. The direction of these lines was into-wind, thus ensuring that the movement of the flares was along the lines and

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<sup>8</sup> AIR14/2058 Bomber Command note, 'The Path Finder Force, Organisation and Work of the Path Finder Force', 22 December 1942. This note was produced to advise Main Force crews of the role of the PFF and the techniques used by the PFF.

that the flares drifted past the A/P. It also ensured that the A/P was not obscured by smoke from the flares. In both variations, the Main Force aimed visually at the A/P as illuminated by the flares. This technique was not allocated a specific code-name, but was usually referred to in contemporary documents as the 'Finder' technique. It may be noted that in these initial raids there was no attempt to mark the A/P on the ground, and the role of the PFF was therefore to find and illuminate the target rather than to mark it.

The first development of this technique came on the night of the 28/29 August 1942 during a raid on Nuremburg in which, for the first time, the PFF marked the target with a marker bomb<sup>9</sup>. This raid is therefore an important milestone in the evolution of target marking techniques. The marker bomb used on that occasion was a 'Red Blob Fire'. This was a crude adaptation of the casing of a 250lb incendiary bomb filled with a mixture of benzol, rubber and phosphorous, and was designed to ignite on impact with the ground. However, the Red Blob Fire was soon supplanted as a marker bomb with the introduction of the 'Pink Pansy', first used in the raid on Düsseldorf on the night of the 10/11 September 1942<sup>10</sup>. This was a converted 4,000 lb High Capacity bomb casing, also filled with a mixture of benzol, rubber and phosphorous. The mixture in the Pink Pansy was treated with a dye such that it ignited with a distinctive brilliant pink flash, from which its name derived.

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<sup>9</sup> TNA AIR14/3408 Final Raid Report No 140: Nuremburg, 28/29 August 1942, 1 October 1942. See also Middlebrook and Everitt. *The Bomber Command War Diaries*, p304; Feast. *The Pathfinder Companion*, p19 and Musgrove *Pathfinder Force*, p16.

<sup>10</sup> TNA AIR14/3408 Final Raid Report No 150: Dusseldorf, 10/11 September 1942 dated 1 November 1942. See also Martin Middlebrook, Chris Everitt. *The Bomber Command War Diaries: An operational reference book* (Viking, 1985),page 308

The drawback of both the Red Blob Fire and the Pink Pansy as marker bombs was that, following the initial brilliant flash upon ignition, the glow produced quickly faded. Consequently, some method had to be found of prolonging the period of time in which the A/P was marked for the Main Force. The answer was for other PFF aircraft to drop incendiaries aimed at the initial glow of the marker bomb, thereby establishing a long-lasting point of aim for the Main Force. These PFF aircraft were known as 'Backers-up' and were spread at regular intervals throughout the Main Force. However, as shown by the earlier *Shaker* technique, the drawback of this technique was that fires did not provide a distinctive point of aim and were prone to decoy. The use of incendiaries was therefore only a temporary expedient pending the availability of a more distinctive marker bomb.

The introduction of the marker bomb heralded a change in the technique employed by the PFF, first introduced during the raid on Bremen on the night of the 4/5 September 1942<sup>11</sup>. The PFF element was now split into three forces: 'Illuminators'; 'Visual Markers' and 'Backers-up'. It was now the Illuminators who used bundles of white flares to illuminate the target area and, as the name suggests, it was the role of the Visual Markers to identify the A/P visually using the light from the white flares, and then to mark the A/P with the marker bomb. A further variation introduced at this time was for the Illuminators to drop coloured flares to mark the extremities of the target area, red flares to mark the west of the target area and green flares to mark the

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<sup>11</sup> TNA AIR14/3408 Final Raid Report No 145 :Bremen, 4/5 September 1942, 14 October 1942. See also Middlebrook and Everitt. *The Bomber Command War Diaries*, p306.



east<sup>12</sup>. At that time, the role of Backers-up was to drop all-incendiary loads on the marker bombs, with the Main Force instructed to aim for the marker bomb if visible or, if not, the conflagration produced by the incendiaries dropped by the Backers-up. This sequence of illumination, marking and backing-up would form the basis of most ground-marking techniques used by the PFF henceforth.

In November 1942, Bennett held a conference at Pathfinder Force HQ to discuss the performance of the PFF during these initial raids<sup>13</sup>. Those attending were generally appreciative of the assistance given by PFF in locating the target but offered a number of criticisms of the methods employed. The main area of dispute concerned the use of flares. Nos. 1 & 3 Groups indicated that the flares were too concentrated and that, particularly in conditions of ground haze, the glare from these flares made identifying the A/P difficult. These Groups considered that ground markers were preferable in such conditions, and also favoured the marking of a landmark near the target area from which a timed run could be made to the A/P. However, No. 5 Group took a different view and was opposed to ground marking. This Group considered that illumination of the A/P by flares was always preferred and instructed its crews to bomb at lower altitudes in order to ensure that the A/P was positively identified. No. 4 Group, represented on this occasion by (then) Wing Commander Cheshire, who would later play a leading role in the development of target marking techniques, took a different view again, stating that a marker without any illumination was the optimum solution. The

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<sup>12</sup> Musgrove; *Pathfinder Force*; p16.

<sup>13</sup> TNA AIR14/3062 Minutes of Conference of Group Officers and BQD Commanders held at Wyton on the 28<sup>th</sup> November 1942 at 11:00 hours.

suggestion was also put forward by No 5 Group that one or two aircraft should be detailed to control the PFF and re-direct its effort if conditions required. This is the first official record found of reference to what would later become known as the Master Bomber technique<sup>14</sup>. The meeting does not appear to have reached a definite conclusion on any these points, although the ideas expressed would subsequently feature in the experiments made by PFF in refining their techniques. However, the differences in the preferred approach expressed at this conference would surface again once No 5 Group developed its own target marking techniques.

The effectiveness of the initial raids led by the PFF was also the subject of a report produced by ORSBC<sup>15</sup>. The approach taken in this report was to compare the results achieved in the PFF led raids against results achieved on the same target prior to the formation of the PFF. The main findings were that six of the raids yielded better results and four yielded similar results. In five out of the six raids in which results were better than previously achieved, the results were 50% above expectation and in the sixth raid were 100% above expectation. Three of the raids were less successful than previous experience suggested, and in two of those raids the attack was completely 'diverted'<sup>16</sup> by the misidentification of the intended target by the PFF<sup>17</sup>. In good weather

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<sup>14</sup> The role of the Master Bombing is considered further in Chapter 8.

<sup>15</sup> AIR14/1804 ORSBC report 'An Assessment of the success of operations led by the P.F.F.', 22 September 1942.

<sup>16</sup> In this context, 'diverted' refers to the fact that another target was bombed, but is in effect a euphemism to cover the fact that the intended target was missed altogether.

<sup>17</sup> TNA AIR14/3408 Final Raid Report No 142: Saarbrucken 1/2 September 1942, 9 September 1942. One of these three was the raid on Saarbrucken on the 1/2 September 1942 referred to in the introduction to this thesis, in which the intended target was misidentified by the PFF and the nearby town of Saarlautern (now Saarlouis) was marked instead, resulting in significant damage in that town and no bombs falling on the intended target of Saarbrucken.

conditions, the PFF had been successful in increasing the effectiveness of every raid which they led but in moderate weather conditions their involvement had not on any single occasion resulted in an improvement. Within GEE coverage, the operations led by the PFF had been more successful than previously but outside GEE coverage there was no improvement. The report noted that PFF was not at that time composed of experts, and concluded that the improvement achieved was therefore due to the employment of the target markers which, by preventing the scattering of bombing, had resulted in a greater concentration. A second report covering a total of 21 raids in the period from the first PFF led operations to late November 1942 generally reinforced these findings, and in particular noted that the PFF had never failed to improve upon expectations in good weather conditions but had never exceeded expectations in bad weather conditions<sup>18</sup>.

This initial period of PFF operations, from inception until December 1942, is referred to in ORSBC reports as Phase 1 and covers the period when only limited navigation aids and primitive marker bombs were available<sup>19</sup>. Nonetheless, a number of key characteristics emerge. The first is that without the benefit of a navigation aid (at that time GEE), the target was still generally not positively identified. It follows that the employment of target marking techniques could have had no bearing on the outcome in terms of the percentage of bombs within 3 miles of the A/P where the target itself has not been located with the use of a navigation aid. This was an early indication that

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<sup>18</sup> AIR14/1804 ORSBC Report 'Notes on the effectiveness of P.F.F. operations to 21/22 November', undated

<sup>19</sup> TNA AIR14/1804 ORSBC Memorandum B.199 'Effectiveness of P.F.F. Phase II – January to March 1943', 21 April 1943.

the success of any target marking technique was itself dependant upon the accuracy and coverage of the navigation aid employed. The fact that results then exceeded expectations within GEE coverage indicates that the employment of target marking techniques resulted in greater concentration in bombing from the Main Force than was previously achieved, the clear implication being that when the target was positively identified with the aid of a navigation aid, target marking was very effective in enabling the crews of aircraft not so equipped to bomb the target accurately. The GEE navigation aid was of course an integral component of the earlier *Shaker* target marking technique, and the conclusion to be drawn must be that the improvement in results achieved by the PFF compared to those achieved previously was due to the relative distinctiveness of the marker bombs used by the PFF compared to the incendiaries used in the *Shaker* technique.

However, the most significant characteristic identified by ORSBC was that the misidentification of the target by the PFF resulted in the entire attack being diverted away from the intended objective. This was an extreme example of the 'Systematic Error'<sup>20</sup>. The Systematic Error was an entirely new phenomenon that arose directly from the employment of target marking techniques, and is of such significance to the development of those techniques that a detailed explanation of it is necessary here.

Prior to the introduction of target marking techniques, each individual bomber crew would aim for the designated A/P of the raid. Irrespective of accuracy in

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<sup>20</sup> The term Systematic Error in this context is not to be confused with the more general terms of 'systematic errors', the latter being errors inherent within any instrument, such as navigational or blind bombing aids.

relation that point, the bomb distribution around the A/P conformed to the principles of 'Gaussian distribution' or 'normal distribution'. Gaussian distribution is a measure of probability of a single event occurring applicable where there are a large number of events. The Gaussian Distribution Function provides that 68% of all events will be within one standard deviation of the mean of all events. The Gaussian Distribution Function is shown graphically as a bell-shaped curve, in which the steepness of the curve reflects the number of events occurring close to the mean: - a large number of events occurring close to the mean results in a steep curve, a small number of events results in a shallow curve (see Diagram 18/ below). Prior to the employment of target marking techniques, the mean of the bomb distribution for the purposes of the Gaussian Distribution Function curve always corresponded to the M.P.I. of all the bombs dropped. Because bomb distribution prior to the introduction of target marking was usually widely dispersed around the A/P, the resultant Gaussian Distribution Function curve was typically shallow but nonetheless the mean always corresponded with the A/P<sup>21</sup>.

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<sup>21</sup> For example, a Gaussian Distribution Function curve based on the figure quoted in the Butt Report that only one in five of the total sorties got within five miles of the target would be very shallow, almost flat, bell-shaped curve.

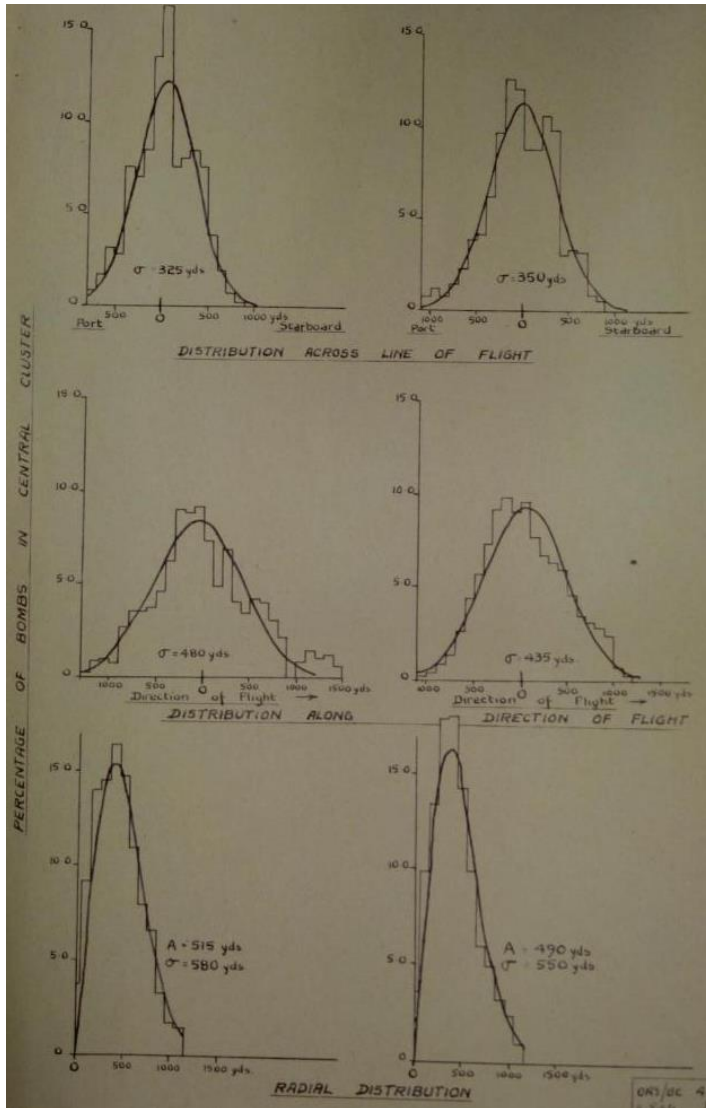


Fig 18/ Gaussian Distribution Function curves for bomb distribution. These curves relate to the attack on the marshalling yard at Aulnoye on the 25/26 March 1944, in which there were two separate A/P's and therefore two curves were shown. Note that in both cases the range error (the distribution along the direction of flight) is greater than then line error (distribution across the line of flight). Note the steepness of the curve for Radial Distribution, indicating that this raid was well concentrated. Source: TNA AIR14/2692 ORSBC S.167 'The Distribution of Bombs Achieved in Oboe Groundmarking attacks on Marshalling Yards by Bomber Command between 6<sup>th</sup> March and 11<sup>th</sup> April 1944', 16 May 1944.

The employment of target marking techniques had two consequences for bomb distribution. Firstly, because crews aimed at the target markers rather than the A/P, the mean of the Gaussian Distribution Function curve no longer corresponded to the designated A/P but corresponded to the M.P.I. of bombs

around the target makers. Thus, if the target markers were displaced in relation to the A/P, the mean of the Gaussian Distribution Function curve would no longer corresponded to the designated A/P for the raid. The linear distance from the A/P to the M.P.I. of the bomb distribution around the target makers defined the extent of the Systematic Error. The second consequence was that bombing concentration improved with the introduction of target marking techniques. Consequently, the shape of the Gaussian Distribution Function curve changed, becoming steeper and with a narrower base.

The combination of these two consequences was that, if the target markers were displaced in relation to the A/P, only a proportion of the bombs dropped on or close to the M.P.I. of the bomb distribution would fall on or close to the A/P. The proportion of bombs falling on or close to the A/P was a function of the extent of the Systematic Error and the degree of concentration achieved. The optimum result was a highly concentrated raid in which the M.P.I. of the target markers coincided with the A/P. In practice, the M.P.I. of the target markers rarely coincided exactly with the A/P but was often sufficiently close to it that the base of the Gaussian Distribution Function curve (i.e the bomb distribution) overlapped the A/P to a greater or lesser extent. In extreme cases, where the M.P.I. of the target markers was considerably displaced in relation to the A/P and the attack was well concentrated, no part of the base of the Gaussian Distribution Function curve overlapped the A/P and the target was missed altogether. The raid on Saarlouis described in the Introduction to this thesis is an example where the displacement from the A/P and the

concentration of the bomb distribution was such that no bombs fell on the intended target.

Increasing the number of aircraft that located the target and achieving a greater concentration of bombing had been two objectives long held by the Air Ministry and were two of the main motivations behind the creation of the PFF. It is therefore somewhat ironic that, whilst a greater concentration of bombing was achieved, because of the Systematic Error the introduction of the PFF initially resulted in an overall reduction bombing accuracy, which fell from a percentage of 35% of bombs within 3 miles of the A/P in August- September to 25% in October - November<sup>22</sup>. Consequently, from the very moment that target marking was introduced as a regular component of bombing raids at night, the challenge facing Bomber Command was to get the M.P.I. of the target markers to coincide with the A/P for the raid, and thereby reduce or eliminate the Systematic Error.

The tools required to address the issue of the Systematic Error began to arrive at the end of 1942 with the introduction of the *Oboe* blind bombing aid<sup>23</sup> into operational use on the night of 20/21 December 1942<sup>24</sup>. This was the first in a series of experimental raids in which the operational technique for use of *Oboe* was trialled including, at the beginning of January 1943, trials in which

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<sup>22</sup> Harris, *Despatch on War Operations*, Part 5, Page 55, Table 10.

<sup>23</sup> The principles of the *Oboe* blind bombing device are set out in Chapter 2, with a detailed technical description set out in Appendix 3.

<sup>24</sup> TNA AIR14/3408 Final Raid Report No 226: Lutterade, 20/21 December 1942, 9 February 1943. See also Middlebrook and Everitt. *The Bomber Command War Diaries*, p338. The first *Oboe*-aimed bombs were dropped by Squadron Leader H.E.Bufton and his navigator Flight Lieutenant E.L.Ifould of No 109 Squadron. 'Hal' Bufton was the brother of Sydney Bufton, who had championed the formation of a Target Finding Force. For more information on this series of trial *Oboe* raids, see Cumming, *Beam Bombers*, p.p. 87 to 95.



PFF Mosquitoes using *Oboe* provided ground-marking or sky-marking for small formations of heavy bombers. These raids proved that *Oboe* was highly accurate but also showed that *Oboe* was prone to technical failure. The *Oboe* system could in any event only control one aircraft every 10 minutes on each Channel and, with two Channels covering the Ruhr and one Channel covering the French ports, any failures of the equipment could result in a significant gap in the marking.

The marking technique devised to overcome this issue was first suggested by ORSBC, which suggested that *Oboe* aircraft drop coloured markers at Zero hour and then subsequently at ten minute intervals<sup>25</sup>. This would, ORSBC advised, provide an “unmistakable mark over the target for a period of about five minutes” and, it was suggested, it would be an advantage if *Oboe* could drop markers at intervals of every five minutes. This report concluded with the recommendation that the use of *Oboe* as aid to the location of targets in the Ruhr should be put forward as an extremely urgent operational requirement.

The original concept proposed by ORSBC was forwarded to the Air Ministry, which proposed several improvements to the proposal made by ORSBC including, most importantly, use of the Mosquito aircraft and the alterations to the marker bomb in order that it could be accommodated within the bomb-bay of that aircraft<sup>26</sup>. It was also the Air Ministry that actioned the duplication of the

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<sup>25</sup> TNA AIR14/900 ORSBC Report S53 ‘The Operational Use of *Oboe* Mark 1 for Target Location’, 18 June 1942. It should be noted that the coloured markers referred to by ORSBC in this report were the Target Indicators in conjunction with which *Oboe* would eventually be used but which at the time were still under development.

<sup>26</sup> TNA AIR14/900. Letter from Air Vice Marshal Bottomley, Assistant Chief of the Air Staff, to Air Marshal Harris, Officer Commanding-in-Chief Bomber Command, 25 June 1942.

ground stations in order that *Oboe* aircraft could mark the target once every five minutes, as recommended by the ORSBC<sup>27</sup>. The technique ultimately employed differed from that originally suggested by ORSBC insofar as Backers-up would drop secondary markers of a contrasting colour to replenish the primary markers between *Oboe* sorties, thereby ensuring the continuity of marking throughout the raid. The Main Force was instructed to aim for the primary markers if visible, or the M.P.I. of the secondary markers if not. Using this technique, the first major raid in which *Oboe* provided ground-marking for the Main Force took place on the night of 27/28 January 1943, when 157 aircraft made a concentrated raid on Düsseldorf<sup>28</sup>.

A few days prior to the *Oboe* ground-marking raid, on the night of 16/17 January 1943, Target Indicators (T.I.)<sup>29</sup> had been used operationally for the first time during a raid on Berlin. The T.I. solved the seemingly unsolvable conundrum of combining good ballistic qualities and a high terminal velocity without penetrating into the ground by packing pyrotechnic candles into a bomb casing but then, by using a barometric fuze, ejecting the pyrotechnic candles at a pre-determined height above ground level. The pyrotechnic candles burned from the point of ejection from the parent projectile and would continue to burn on the ground, where they would form a distinctive pattern.

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<sup>27</sup> Ibid. Letter from Air Vice Marshal Bottomley, Assistant Chief of the Air Staff, to Air Marshal Harris, Officer Commanding-in-Chief Bomber Command, 19 July 1942

<sup>28</sup> TNA AIR14/1804 ORSBC Memorandum B.199, 'Effectiveness of P.F.F. Phase II – January to March 1943', 21 April 1943. This raid is also described as being successful in Middlebrook and Everitt, *The Bomber Command War Diaries*, p348.

<sup>29</sup> TNA AIR10/2393 PFF Special Marker Equipment, Air Publication 1661H, Vol 1, October 1944. The correct technical nomenclature is 'Bomb, A/C, Target Identification, 250lb, No 1 (followed by colour as appropriate)'

The pyrotechnic candles were usually coloured red, green or yellow<sup>30</sup>. The T.I. was constantly developed and, by February 1945, there were some 36 different versions (referred to by 'Serial Numbers')<sup>31</sup>

One of the main advantages of the T.I. was that its ballistic characteristics were identical to those of a H.E. bomb for most of the trail<sup>32</sup> and could therefore be aimed with a degree of accuracy nearly equivalent to a H.E. bomb (or, when used in conjunction with *Oboe*, the trail angle could be accurately calculated and input into the calculations). The limitation was that the trail angle changed abruptly at the point at which the pyrotechnic candles were ejected from the casing, going from a terminal velocity of 1,000 feet per second for the parent projectile to a terminal velocity of only 100/200 feet per second for the individual pyrotechnic candles. The latter would therefore cascade to the ground vertically rather than following the trail angle of the parent projectile such that, in still air, the pyrotechnic candles would land short of a bomb following a ballistic trail angle to ground level. Moreover, as a result of this low terminal velocity, the pyrotechnic candles were prone to drift and this resulted in T.I.'s being less accurate than an H.E. bomb of equivalent weight, particularly in strong winds.

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<sup>30</sup> The convention was to refer to Target Indicators as 'T.I.' followed by the colour in brackets: i.e. T.I. (Red), T.I. (Green) and T.I. (Yellow). This convention is followed in this thesis

<sup>31</sup> TNA AIR20/4813 Air Ministry, Directorate of Armament Requirement note 'Summary of P.F.F. Special Weapons for target marking and illuminating', 1 February 1945.

<sup>32</sup> The trail, or trail angle, was the path taken by a bomb or marker through the air after release. Due to the forward speed of the aircraft at the point of release, the trail angle initially included an element of forward motion which rapidly reduced and, subject to the height at which the bomb was released, eventually assumed a nearly vertical path.

Although the use of the T.I. introduced a number of new operational issues, this was the first time in the bombing offensive that Bomber Command had possessed a marker bomb capable of providing a distinctive point of aim. The introduction of the T.I. simultaneous with the introduction of *Oboe* and H2S completed the tools necessary for Bomber Command to become an effective force, and the importance of this as an intrinsic component of effective target marking techniques cannot be overstated.

The second blind bombing/navigation aid, H2S, made its operational debut on the night of 30/31 January 1943 during a raid on Hamburg<sup>33</sup>. However, whereas the use of *Oboe* could be relied upon to place the T.I.s close to the A/P, it was recognised from the outset that H2S would not be sufficiently accurate to replicate that degree of accuracy and that it was therefore necessary to devise a different marking technique for use in conjunction with H2S. The method initially adopted was an averaging technique whereby 'primary markers' were dropped blind using H2S, thereby avoiding errors due to the misidentification of the target by visual means<sup>34</sup>. Backers-up were then instructed to drop secondary markers of a contrasting colour aimed visually at the M.P.I. of the primary markers. By these means, any errors in the placement of the primary markers would be averaged out, such that the M.P.I. of the secondary markers would coincide with the A/P. The Main Force was then instructed to aim at the M.P.I. of the secondary markers.

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<sup>33</sup> TNA AIR14/1804 ORSBC Memorandum B.199 'Effectiveness of P.F.F. Phase II – January to March 1943', 21 April 1943. This raid is also described by Middlebrook and Everitt *The Bomber Command War Diaries*, p350. The docks and the River Elbe presented a clear image on the H2S sets and the PFF were able to identify Hamburg from an average range of 23 miles. However, the raid was not a success and bombing was scattered over a wide area.

<sup>34</sup> This technique would later become known as *Blind Parramatta*.

One of the features of the averaging technique and subsequently of most of the target marking techniques used with both *Oboe* and H2S was that, if no primary markers were visible, PFF Backers-up and the Main Force were instructed to aim for the M.P.I. of all the secondary markers visible, an exercise known as 'visual centring'. Up until this point of the bombing offensive, bomb aimers were instructed to aim for a single fixed point on the ground (i.e. the designated A/P, or individual marker bombs). However, visual centring required a different technique the difficulty of which was, until the Main Force became largely equipped with the Mk XIV bombsight in late 1943, exacerbated further by the limitations of Mk IX Course Setting Bombsight insofar as any small movements in the air resulted in large bombing errors<sup>35</sup>.

The importance of visual centring was that, if successive aircraft aimed at the M.P.I. of the markers visible, the aggregate M.P.I. was itself subject to a cumulative error which rapidly became greater than that of the individual attempts. This was known as the Principle of Cumulative Dispersion<sup>36</sup> and was a significant factor in determining bombing accuracy. Once the importance of visual centring became fully appreciated, considerable efforts were made to understand the psychological and physiological factors that contributed to the assessment of a complicated pattern of ground markers under operational conditions. In order to understand the contribution made by

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<sup>35</sup> TNA AIR14/941 Instruction Notes on the Course Setting Bomb Sight Mark VIIIA. This version of the CSBS was functionally identical to the Mark IX.

<sup>36</sup> TNA AIR14/2715 A.W.A. Paper 'Notes on the Practical use of Marker Bombs', undated. In explaining the principle of cumulative dispersion, the A.W.A. paper drew an analogy with pellets from a shotgun, in which the mean radius of the pellet pattern from a single shot is less than the average error in aim.

target marking techniques to the bombing offensive, it is essential to understand the reasons behind the difficulty in estimating the M.P.I. of a number of secondary markers over a relatively wide area and the implications of that difficulty to bombing accuracy.

Starting in January 1944, the problem of visual centring became the subject of a series of detailed studies. A preliminary report by ORSBC concentrated upon the characteristics of T.I.'s and conditions within the target area in terms of fire, smoke, dust and haze<sup>37</sup>. The primary conclusion was that the colour of the T.I. was the most notable recognition feature. The other key finding was that bomb aimers generally had difficulty explaining how they selected the T.I. estimated to be the M.P.I. of the marker pattern. The disturbing implication was that Main Force bomb aimers did not understand how the target marking techniques employed by the Pathfinder Force actually worked, and this prompted the publication by ORSBC of a simplified guide to the main techniques used by the Pathfinder Force for circulation to Main Force crews<sup>38</sup>.

This guide, entitled 'Bombing of Target Marking: Notes for the guidance of operational crews', essentially set out the rationale for target marking. The guide stressed that the success or failure of any raid depended not only on the skill of the PFF to locate and mark the target but, to "an equal degree", on the intelligent co-operation of every pilot, navigator and bomb aimer in the Main Force. It was emphasised that the responsibility of the bomb aimer was "doubly great" in this respect and, when faced by a multitude of T.I.'s on

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<sup>37</sup> TNA AIR 14/1884 ORSBC Report 'The visibility of Target Indicators with Special Reference to the Colour Vision Problem', 9 January 1944.

<sup>38</sup> RSMORA Dickins, *Operational Research in Bomber Command*, p.p. 62-63.

reaching the target area, posed the question to bomb-aimers 'At which should I aim?' In answer to that question, the remainder of the note explained the characteristics of T.I.'s and stressed the importance of visual centring based upon all the T.I.'s visible rather than relying upon a single set of markers<sup>39</sup>. In many respects, this was a remarkable document, not only because it sought to address one of the most important operational issues confronting Bomber Command through the equivalent of 'distance learning' but also because of a perceived need to address the concern that some crews were not relying upon target markers at all.

Given the difficulties experienced by bomb aimers in assessing the M.P.I. of a pattern of ground markers, ORSBC considered it vital that further research was conducted into the psychological and physiological performance of bomb aimers in distinguishing target markers from the overall picture of the target area, and in assessing the centroid of a pattern of markers taking into account the inequalities in the prominence of the individual markers forming that pattern. Work on this latter aspect was to be carried out at Cambridge University<sup>40</sup>.

In the interim, in May 1944 ORSBC conducted a detailed study of the characteristics and visibility of target indicators<sup>41</sup>. This study found that the visibility of Target Indicators depended on three broad factors: movement, colour and form on the ground. The movement was the result of the cascade

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<sup>39</sup> TNA AIR14/2058 ORS 1(c) Note 'Bombing of Target Marking: Notes for the guidance of operational crews', 31 January 1944.

<sup>40</sup> TNA AIR 14/1884 Minute 15, ORS 1 (c) to ORS 1, March 1944.

<sup>41</sup> TNA AIR14/4140 ORSBC Report No 99 'The Visibility and Recognition of Target Indicators', 6 May 1944.

of the individual candles to the ground, although this was for a limited period of time only. Once on the ground, the pattern of Target Indicators was usually obscured by buildings and ORSBC considered that recognition was usually made by colour rather than pattern in such circumstances.

With these basic principles in mind, the ORSBC report considered the recognition of Target Indicators in terms of the characteristics of the Target Indicator itself; the position of the Target Indicator on the ground; and the assessment by the bomb aimer. From an aircraft at the normal operational altitude of circa 20,000 feet, the typical sighting angle of Target Indicators on the ground was approximately 45°. It was found that, at this angle, 9 out of 10 Target Indicators that fell within a built up area would be obscured by buildings, such that only 10% of the Target Indicators dropped would be visible to a bomb aimer. It was also noted that accurately placed Target Indicators tended to 'flicker' because, it was assumed, they were partly obscured by trees or by the internal structure of a damaged building. By contrast, Target Indicators that fell on open ground were clearly visible and formed a distinctive ground pattern. In terms of the area bombing of towns, this created the paradox that inaccurately placed markers were more prominent than those that were accurately placed in the built-up area. Because bomb aimers were usually instructed to aim at the M.P.I. of all the visible Target Indicators, and given that only 10% of Target Indicators falling in built-up areas would be visible, there was a tendency for bomb aimers to assess the M.P.I. based largely upon the un-obscured and therefore more prominent Target Indicators that fell in open country. The corollary was that



the pattern of Target Indicators, and therefore the M.P.I. of those markers, would be distorted towards the more prominent markers in open country.

ORSBC concluded that this was one of the causes of the phenomenon known as 'creepback', in which the bomb distribution moved progressively away from the A/P in the direction of approach of the bombers as a raid developed. In some cases, creepback could be extensive: in the raid on Berlin on the night of the 31 August/1 September 1943, the creepback extended some 30 miles from the A/P. Although Bomber Command often planned the raids so that the line of approach to the A/P overflowed the built up area of a city, such that the creepback inflicted some damage there, creepback inevitably reduced the concentration of the bomb distribution at the A/P and therefore detracted from the efficiency of the attack<sup>42</sup>.

The ORSBC report identified two main causes of error in the recognition of Target Indicators related to psychological or physiological factors. The first of these was the colour vision of bomb aimers, the minimum standard for which was 'Defective-safe'. ORSBC concluded that bomb aimers with this lower standard of colour vision would be less capable of recognising Target Indicators, particularly where they were partially obscured by smoke. ORSBC accepted that requiring all bomb aimers to have normal colour vision would not be practical for other reasons but recommended that bomb aimers with a specialist role in target marking should only be accepted if they had normal colour vision.

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<sup>42</sup> The Hamburg raids in July 1943 (OPERATION GOMMORAH) described below were a good example of this.

The main psychological factor was the concept 'visual centring' itself. The ORSBC report concluded that there were many reasons why bomb aimers incorrectly assessed the M.P.I. of the Target Indicators, the principal one being that the average bomb aimer was only able to pick out a proportion of the total number of markers that were visible at any one time. In this context, it should be noted that the pattern of Target Indicators was constantly changing as some markers burnt out and new markers were dropped. A further reason was the aforementioned obscuration of Target Indicators at the relatively shallow angle of view by smoke and buildings and, by comparison, the relative prominence of Target Indicators that fell on open ground. It was recognised that any decision by a bomb aimer to discard the former in preference for the latter would fundamentally alter the assessment of the M.P.I. of the distribution of Target Indicators.

The ORSBC report recognised that visual centring was a difficult task for the average bomb aimer. One of the recommendations made was that, in the training of bomb aimers, less time should be spent on the identification of targets and more time devoted to visual centring. However, the research carried out by Cambridge University revealed a more fundamental psychological issue with visual centring<sup>43</sup>. This research concluded that there was a "capricious disregard" of certain markers and that there was no correlation between those markers that were ignored. These results were consistent with the earlier ORSBC finding that bomb aimers had difficulty

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<sup>43</sup> TNA AIR14/1884 Minute 48, OIC ORSBC to T1, 7 July 1944.

explaining how they selected the T.I. estimated to be the M.P.I. of the marker pattern, and therefore validated the existing concerns in this respect.

The researchers at Cambridge University offered a simplified but readily implemented solution whereby bomb aimers were instructed to aim for a point '.....such that there were as many markers beyond it, as in front of it, and as many to the left as to the right of it'. A more comprehensive solution was the publication by the Air Ministry Psychology Unit at Cambridge University of a training package<sup>44</sup> and, later, the introduction of a synthetic trainer for instructing bomb aimers of the Pathfinder Force in the visual centring of Target Indicators, although this was not extended to Main Force bomb aimers<sup>45</sup>. These measures were a tacit acknowledgement that target marking techniques had fundamentally changed the nature of the bombing offensive. Nonetheless, notwithstanding the recognition that reliance on a ground pattern of Target Indicators to guide the Main Force was not without its own difficulties, these measures were not in place until almost the end of the bombing offensive. It follows that Bomber Command operated for a significant proportion of the bombing offensive with the majority of crews receiving no training in this important skill, the acquirement of which was an important component of overall bombing accuracy.

In early 1943, and now equipped with *Oboe* and H2S, and with the benefit of proper Target Indicators, the PFF led a series of attacks against French,

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<sup>44</sup> Ibid. Minute 51, ORS 4(d) to OIC ORSBC, 19 January 1945, covering the undated note 'Commentary for Use with Transparencies for the Air Ministry Bombing Teacher'.

<sup>45</sup> TNA AIR20/7738 Flying Personnel Research Committee paper 'The Sythentic Training of Pathfinder and Bombers in the Visual Centring of Target Indicators', July 1945.

Italian and German targets. ORSBC referred to this series of raids as Phase II of the PFF operations although, in practice, much of this period was one of experimentation with target marking techniques. The techniques trialled during this period, both with *Oboe* and H2S, were based on the two basic forms of ground-marking and sky-marking. In both cases, experimentation was based largely upon variations in timing and spacing of the various elements of each technique, particularly the Backers-up, in order to ensure continuity of marking throughout the raid. The general approach taken was for the first raid to be on a small scale using only PFF aircraft, with subsequent raids involving progressively larger Main Force components. For example, the first use of *Oboe* for sky-marking took place against Düsseldorf on the night of 31 December 1942/1 January 1943 and involved only two *Oboe* Mosquitoes and 8 Lancasters, all from PFF, whereas the last in the series involved 3 *Oboe* Mosquitoes and 80 Lancasters from Nos. 1 and 5 Groups<sup>46</sup>. The former raid was a further milestone in the bombing offensive, in that it was the first occasion on which an aircraft aimed at a marker in the air as opposed to a point on the ground.

One of the early innovations, first used on the night of 30/31 January 1943, was the preparation of dual marking plans for both ground-marking and sky-marking on the same raid. This later became a standard feature of raid planning but at this time was part of the gamut of experiments on target marking techniques, which also included ground-marking by both *Oboe* and

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<sup>46</sup> TNA AIR14/3410 Final Raid Report No 223: Dusseldorf, 31 December 1942/1 January 1943, 24 February 1943. See also Middlebrook and Everitt *The Bomber Command War Diaries*, p.p. 340, 341 and 348 and Musgrove *Pathfinder Force*, p25..

H2S<sup>47</sup> and sky-marking solely by H2S<sup>48</sup>. The interesting characteristic of these experiments is that they were essentially a case of trial and error and, other than the standard night raid reports produced by ORSBC, there is no evidence to suggest that these experiments were based upon scientific advice or anything other than the lessons learned by the operational units and PFF headquarters. In view of the importance previously attached by the Air Ministry to the creation of a 'Target Finding Force' and the parallel establishment of a Bomber Development Unit, it is surprising that there was not a more formal framework in place for the evaluation of target marking techniques.

In the event, some indication of the effectiveness of PFF led operations to that date was obtained at a further conference held at PFF Headquarters in February 1943<sup>49</sup>. The two main issues raised by the Groups were the difficulty experienced by crews in estimating the M.P.I. of ground-markers and the timing of the marking components. In relation to the former, part of the issue was that the crews were not certain which markers should be taken into account and, because crews were unable to estimate the hypothetical centre of concentration, tended to focus on the most obvious marker. One of the reasons for this, it was suggested, was that crews did not have sufficient confidence in the *Parramatta* technique. In that context, the Groups

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<sup>47</sup> TNA AIR14/3410 Final Raid Report No 256: Cologne 2/3 February 1943m 29 March 1943. See also Middlebrook and Everitt *The Bomber Command War Diaries*, p350. This raid was not a success to the cloud cover over the target.

<sup>48</sup> Ibid. Final Raid Report No 264: Wilhelmshaven 11/12 February 1943, 21 April 1943. See Middlebrook and Everitt *The Bomber Command War Diaries*, p353. On this raid, the skymarking was very accurate and a successful raid followed, aided in part by bombs falling on a naval ammunition store in which the subsequent explosion devastated an area of some 120 acres of the naval dockyard and the town.

<sup>49</sup> TNA AIR14/3062 Minutes of Conference held at Headquarters Pathfinder Force on 27 February 1943.

complained that crews had received no training in estimating the M.P.I. of a group of markers and were not familiar with the PFF techniques. The representative from No. 5 Group even went so far as to say that his Group still preferred the illumination of the target area to ground-marking. The greatest concerns were, however, in relation to the timing of the marking components. The Groups complained that the marking was frequently late, such that the Main Force arrived before marking commenced or there was insufficient interval between the first markers and the arrival of the Main Force. It was explained that this was to some extent due to the reliance on the Stirling aircraft for the initial marking (this because a significant proportion of the few H2S sets available were fitted in Stirlings<sup>50</sup>) which, because of the slow speed of the aircraft and its poor turn of speed, was unable to make up lost time. This was a familiar concern, and one that Bennett had expressed upon the formation of the PFF, but which would not be fully resolved until the heavy bomber element of the PFF was wholly equipped with the Lancaster. As before, aside from a general consensus that these matters would be addressed, there is no record of any actions taken following this conference although the timing of the marking component would be subject to continued experimentation and refinement as the offensive progressed.

The effectiveness of the PFF during Phase II was comprehensively assessed by ORSBC in April 1943<sup>51</sup>. The report adopted the same approach used in assessing the effectiveness of the PFF in Phase I and compared the results

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<sup>50</sup> H2S was first fitted into the Handley Page Halifax and the Short Stirlings in PFF because Roy Chadwick, the Chief Designer at Avro, had initially resisted the fitting of H2S in the Lancaster.

<sup>51</sup> TNA AIR14/1804 ORSBC Memorandum B.199 'Effectiveness of P.F.F. Phase II – January to March 1943', 21 April 1943

achieved in the PFF led raids against results achieved on the same target prior to the formation of the PFF in similar weather<sup>52</sup>. ORSBC found that in the 13 ground-marking raids during this period, the PFF located the target on 12 occasions (92%) but that the A/P was only unambiguously marked on the two raids in which *Oboe* was employed exclusively. In these raids, the use of *Oboe* on its own resulted in a significant improvement in accuracy of the Main Force, with an average of 35% of bombs within 3 miles of the A/P compared with an average of 15% for the same target in raids pre-PFF<sup>53</sup>. In the 11 raids where H2S was used during Phase II, only on the 7 occasions (63%) where it was used in conjunction with *Oboe* was the A/P unambiguously marked. On the remaining 5 ground-marking raids, in all of which H2S had been used exclusively, the markers were all in the wrong place. Overall, where H2S was used on its own, accuracy of the Main Force declined in relation to pre-PFF operations on the same target, with just 9% of bombs being within 3 miles of the A/P compared with an average of 15% for the same target in raids pre-PFF. ORSBC also found that in the 18 sky-marking raids during this period, the PFF had located the target on each of the 4 occasions for which data was available<sup>54</sup>. On each of those 4 occasions, the sky-markers had been dropped using *Oboe* only and the A/P was unambiguously marked, giving results for

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<sup>52</sup> Ibid. The figures used by ORSBC in this memorandum did not include performance on Italian or French targets, or those achieved in raids on Berlin. These were considered to be not representative of the conditions encountered over Germany, with which the bomber offensive was largely concerned at that time.

<sup>53</sup> Ibid. The figures used by ORSBC for raids pre-PFF relate to specific targets under similar weather conditions and therefore are not necessarily representative of bombing performance pre-PFF across all targets under all weather conditions.

<sup>54</sup> Ibid. There was insufficient data on the remaining 14 skymarking raids to assess accuracy of the marking.

the Main Force some 300% better than would have been expected against those targets in similar conditions<sup>55</sup>.

The ORSBC memorandum is further evidence of the intrinsic relationship between the accuracy of target marking and the blind bombing/navigation aid employed for the purpose of locating the target. On no occasion during this period was the A/P not unambiguously marked when *Oboe* was used for ground-marking or sky-marking. This was due to the combination of the technical characteristics of *Oboe* and the distinctiveness of the T.I. *Oboe* was a very accurate blind bombing device that had no significant systematic errors and only minor random errors. The use of *Oboe* ensured that the primary markers were dropped close to the A/P, with relatively little scatter of T.I.s away from the A/P. The resultant concentration of T.I.s around the A/P simplified the task of the Backers-up in terms of estimating the M.P.I. of the primary markers which in turn resulted in a good concentration of secondary markers around the A/P. The result was distinctive grouping of markers around the A/P that was easily visible to the Main Force crews.

As expected, H2S had not achieved the same accuracy in the placement of the primary markers as *Oboe*. In fact, the results achieved had been consistent with the findings of the Bomber Development Unit (BDU) in training flights that the bombing errors using H2S tended to increase with the size of

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<sup>55</sup> Ibid. On one of those raids, against the difficult target of Essen on the night of 9<sup>th</sup>/10<sup>th</sup> January 1943, 53% of markers were plotted within 3 miles of the A/P, compared with an expectation of 20% against this target in similar weather conditions.



the target attacked<sup>56</sup>. ORSBC established that the average probable error<sup>57</sup> of 1.5 miles of target markers dropped blind using H2S during Phase II corresponded almost exactly to the average size of all towns attacked (excluding Berlin) during this period. When Berlin was included, with its larger area, the average probable error increased to 2.0 miles. ORSBC found that there was no systematic error in relation to either range or track, such that the bomb distribution was essentially circular. The average probable error therefore resulted in markers being dropped not only close to the A/P but also at the edge of the target area and outside of it. The averaging technique initially employed had not been successful in providing an unambiguous marking of the A/P and, with relatively few primary markers scattered across the target area, some markers were more prominent than others. This lack of compactness in the pattern of markers not only made visual centring more difficult for the Backers-up, but also produced a tendency for any single T.I. to attract attention irrespective of its accuracy. As a result, H2S was more prone to the Principle of Cumulative Dispersion than was *Oboe*, and the disparity in terms of accuracy was exacerbated.

The performance of H2S during this Phase II must be considered in the light of the fact that this equipment had only recently been introduced and that the number of Y-aircraft<sup>58</sup> available for marking during this period was relatively low, averaging 13 per raid but never exceeding 16 and on occasions as low

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<sup>56</sup> TNA AIR14/4597 ORSBC Report S.99 'The Operational Use of H2S, January to May 1943', 25 August 1943.

<sup>57</sup> The Average Probable Error was the average radial distance of all variates, therefore including gross errors, measured either in relation to the Aiming Point or the Mean Point of Impact.

<sup>58</sup> A 'Y-aircraft' was any aircraft fitted with H2S.

as 6<sup>59</sup>. The version of H2S in use throughout Phase II, the Mk1, operated on the S-band wavelength with a beam width in azimuth of 6 degrees, this being the widest of any version of H2S used operationally. The Mk I represented the most basic version of H2S to be used operationally and suffered from the disadvantages of sharing in the pitch and roll of the aircraft (due to the rigid mounting of the scanner), the discrepancy between the actual range and the slant range of the target (due to the absence of scan correction), and the proliferation of ground returns, gaps and fades at steep angles of look (due to the properties of the truncated paraboloid scanner). Because of these shortcomings, in addition to the inherent drawbacks of distortion due to partial ground return from objects on the ground and 'shadow' associated with the H2S system, the Mk1 version required considerable skill on the part of the operator to interpret the vague images presented on the Plan Position Indicator<sup>60</sup>. The Mk1 H2S was also unreliable and during the Phase II period only 55% of H2S sets were serviceable on arrival in the target area<sup>61</sup>, thereby further reducing the already limited number of Y-aircraft available for marking the target to an average of 7 per raid. This shortage of Y-aircraft was exacerbated by the fact that the two squadrons partially equipped with H2S operated the Handley Page Halifax and the Short Stirling aircraft respectively, with which it was not possible to achieve a high degree of accuracy in timing

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<sup>59</sup> TNA AIR14/4597 ORSBC Report S.99 'The Operational use of H2S. January to May1943', 25 August 1943.

<sup>60</sup> See Chapter 2 for a detailed technical description of the problems of roll stabilisation, slant range and distortion due to partial ground returns and shadow.

<sup>61</sup> TNA AIR14/4597 ORSBC Report S.99 'The Operational use of H2S. January to May1943', 25 August 1943.

due to their inflexibility of airspeed at operational altitudes<sup>62</sup>.

The conclusion reached by ORSBC was that H2S in its then current form (the Mk1) was not sufficiently accurate to permit the Backers-up and the Main Force from being instructed to aim at primary markers dropped by individual Y-aircraft<sup>63</sup>. It was therefore apparent that if H2S was to have a role in target marking a different role had to be found for it and this led ORSBC to make a number of recommendations on the use of H2S. The most significant recommendation arose from the observation that ground-marking had been more successful when the A/P was identified visually with the aid of flares dropped by Y-aircraft. Towards the end of Phase II, experiments had been made with the use of flares in the initial stage of the attack<sup>64</sup>. Instead of dropping primary markers blind using H2S, Y-aircraft had dropped flares over the target area and specially selected PFF crews (known as Visual Markers) had marked the A/P visually with T.I.s. The use of flares to illuminate the target area resulted in a significant increase in the percentage of bombs within 3 miles of the A/P, with an average of 44% over the six raids where flares were used compared with an average of just 11% with the averaging technique. ORSBC therefore recommended that whenever weather conditions permitted the A/P to be identified visually, H2S should be used to illuminate the target area with flares. This became known as the *Newhaven* technique,

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<sup>62</sup> Ibid. These squadrons were No 7 Squadron, equipped with the Short Stirling Mk I, and No 35 Squadron, equipped with the Handley Page Halifax Mk II. The Stirling Mk I was equipped with 'Exactor' throttle controls which was particularly poor in this respect

<sup>63</sup> TNA AIR14/3025 ORSBC Report B.151 'Review of H2S Groundmarking raids on Germany: February – April 1943', 1 July 1943.

<sup>64</sup> Ibid.

and would remain a standard technique used by the PFF throughout the bombing offensive.

The use of flares as part of the *Newhaven* technique was of course dependent upon the ground detail being visible which, in northern Europe, is a comparative rarity. In order that targets beyond *Oboe* range could continue to be attacked with a reasonable degree of accuracy, it was necessary to develop ways in which H2S could be used effectively in conditions of poor visibility. ORSBC therefore also made a series of recommendations relating to the use of H2S when ground detail was not visible<sup>65</sup>. The first of these was in response to an analysis of PFF crew reports, which revealed that on average only 27% of primary markers had been released 'blind' using H2S and that the remaining 63% had been aimed visually or by H2S with a visual check. ORSBC concluded that this had compromised the averaging technique, and emphasised that Y-aircraft should only drop primary markers blind using H2S. ORSBC had discovered a tendency for Backers-up to place their markers on the first primary markers encountered, with the result that marking was usually short of the A/P. To counter this, ORSBC recommended that an A/P was chosen at the far side of the target in relation to the direction of attack, and that Backers-up overshoot the M.P.I. of the primary/secondary markers in order to counter any backward drift of the bombing and to avoid the Main Force being distracted by the first T.I. encountered.

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<sup>65</sup> Ibid

Notwithstanding the difficulties with H2S and the five occasions where the Systematic Error resulted in the entire raid being 'diverted', the average percentage of bombs within 3 miles of the A/P increased to 36% during this Phase II period<sup>66</sup>. However, this improvement in efficiency only restored the efficiency of the Main Force to the level achieved immediately prior to the introduction of the PFF. The challenge facing Bomber Command was therefore to improve the target marking techniques based on *Oboe* and, in particular H2S, with a view to maximising the potential of those devices and overcoming the defects with those devices. The end of Phase II was followed by the first of the 'bomber battles' of 1943, the 'Battle of the Ruhr'. As Bomber Command embarked upon the Battle of Ruhr, the PFF had standardised on three basic target marking techniques, known as '*Newhaven*', '*Parramatta*' and '*Wanganui*'<sup>67</sup>. Although there were numerous variations and subtleties, all PFF target marking techniques fell into one of these basic categories<sup>68</sup>. All of these codenames were prefixed by the term 'Musical' when *Oboe* was used for the initial marking and, later, by the term 'Controlled' when a Master Bomber was employed<sup>69</sup>.

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<sup>66</sup> Harris, *Despatch on War Operations*, Part 5, Page 55, Table 10

<sup>67</sup> Bennett *Pathfinder*, p.p. 153 and 154. The code names of *Newhaven*, *Parramatta* and *Wanganui* were chosen by Donald Bennett himself. *Newhaven* was the home town of Corporal Ralph, a W.A.A.F. clerk serving at Pathfinder Force HQ and *Wanganui*, in New Zealand, was the home town of (then) Squadron Leader Ashworth, a staff officer at Pathfinder Force HQ. *Parramatta* is a town near Sydney in western Australia and was chosen by Bennett in order to "keep the balance" but is not, as sometimes stated, his home town (Bennett came from Toowoomba, near Brisbane).

<sup>68</sup> TNA AIR14/2058 'The Path Finder Force – Its Duty and Aims', undated. This document is an Instruction Manual for Pathfinders crews which details all aspects of PFF operations, including target marking techniques; specialist Pathfinder roles; the role in individual crew members; and aircraft performance and operation. The descriptions of the target marking techniques given here are taken from this document.

<sup>69</sup> Thus, for example, a '*Controlled Musical Parramatta*' attack would be a blind groundmarking raid in which *Oboe* was used to place the initial Target Indicators, with subsequent 'backing-up' and Main Force bombing being corrected by a Master Bomber.

*Newhaven* was visual groundmarking. By definition, *Newhaven* was only employed when ground details was visible from the operational height. In a standard *Newhaven* attack, 'Blind Illuminators' first illuminated the target area with flares dropped 'blind' with the aid of H2S (on some occasions, Blind Markers would also drop T.I.s to indicate the target area, in which case they were known as 'Blind Marker-Illuminators') In a *Visual Newhaven* attack, 'Illuminators' dropped flares visually with the aid of flares dropped in parallel lines over the target area, the latter being dropped 'blind' either by 'Finders' using H2S or by 'Finders (D.R.)' on E.T.A. over the target area as calculated using 'dead reckoning' navigation. In *Musical Newhaven*, there was no illumination of the target by flares and instead 'Blind Markers' dropped red T.I.'s in the target area 'blind' using *Oboe*. With the target area thus illuminated or marked, the A/P was then marked visually by Visual Markers (sometimes referred to as Primary Markers and, later, as Primary Visual Markers) with 'primary markers'. Tests and operational experience showed that red was the most distinctive colour from operational heights, and therefore the primary markers were usually 'TI Red'. The best contrast colour was found to green and therefore the secondary markers were usually 'TI Green'. In most raids of this period, the raid instructions to Backers-up and the Main Force was to aim for the red TIs if visible or the M.P.I. of the Green TIs if not<sup>70</sup>.

Visual Markers were the most experienced and able Pathfinder crews, and usually included a highly specialist bomb aimer. The Visual Markers were

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<sup>70</sup> TNA AIR14/4140 ORSBC Report No 99 'The Visibility and Recognition of Target Indicators', 6 May 1944.

followed by Backers-up, spaced at regular intervals throughout the raid, which dropped 'secondary markers' (aimed visually) of a contrasting colour over the primary markers if visible or, if not, the M.P.I. of secondary markers dropped by other Backers-up . In all cases, the Main Force was instructed to bomb the primary markers if visible or the M.P.I. of the secondary markers if not.

*Parramatta* was blind groundmarking<sup>71</sup>. *Parramatta* was used when the ground was visible but ground detail was obscured by thin cloud or haze in the target area. In a *Parramatta* attack, there was no illumination of the target area and 'Blind Markers' opened the attack by dropping primary markers using *Oboe* or H2S. Backers-up, again spaced at regular intervals of about 2 minutes throughout the raid, dropped secondary markers (aimed visually) of a contrasting colour over the primary markers if visible or, if not, the M.P.I. of other secondary markers dropped by other Backers-up. The Main Force was instructed to bomb the primary markers if visible or the M.P.I. of the secondary markers if not.

*Wanganui* was sky-marking, and was employed when the ground was completely obscured by cloud. In a *Wanganui* attack, 'Blind Markers' dropped flares (known as Sky-markers or Point Release Flares) using *Oboe* or H2S, and were spaced throughout the duration of the attack to ensure that a continuous presence of Point Release Flares was maintained. The Main Force was instructed to aim at the Point Release Flares on a designated

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<sup>71</sup> In some sources, *Parramatta* is erroneously spelt as "Paramatta", but it is the same technique.

heading and at a designated speed and altitude, with wind speed set to zero on the bombsight.

The Battle of the Ruhr covered the period between the 5/6 March 1943 to the 30/31 July 1943, during which 43 major raids were mounted<sup>72</sup>. Two thirds of these raids were against towns in the Ruhr with, for tactical reasons, the remainder widely spread against targets in Germany and Italy. Middlebrook and Everitt suggest that Harris embarked upon the Battle of the Ruhr partly because any target in that area could be reached in the relatively short summer nights but also because the Ruhr was within the range of *Oboe*<sup>73</sup>. The majority of raids against the Ruhr towns would be carried out using *Musical Parramatta* and/or *Musical Wanganui*. The latter resulted in an average of 26% of bombs falling within 3 miles of the A/P with, on one occasion, 44% of bombs falling within 3 miles of the A/P<sup>74</sup>. ORSBC calculated that the use of the *Musical Wanganui* technique had achieved results with 10/10ths cloud cover equivalent to those achieved previously under favourable conditions. Part of the reasons for this, it was concluded,

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<sup>72</sup> Middlebrook and Everitt *The Bomber Command War Diaries*, p363. However, there is some dispute about the end date of the Battle of the Ruhr.. The AHB Narrative takes the raid on Remscheid on the night of 30<sup>th</sup>/31<sup>st</sup> July 1943 as being the end of the Battle of the Ruhr, not least because this was the last major attack on the Ruhr and also includes a heavy *Oboe* groundmarking raid on Essen a few nights previously. This is the same date adopted by Middlebrook and Everitt. Other commentators, including Alan Cooper, also take this raid as marking the end of Battle of the Ruhr. However, Webster and Frankland consider that the raid on Aachen on the 13/14<sup>th</sup> July 1943 marks the end of the Battle of the Ruhr on the basis that, although Aachen itself is not in the Ruhr Valley, this was the last major attack before the series of raids on Hamburg In his *Despatch on War Operations*, Harris includes the Essen and Remscheid raids in his summary of the Battle of the Ruhr.

<sup>73</sup> Ibid

<sup>74</sup> TNA AIR14/1574 ORSBC Report S.102 'The Operational Use of Oboe Mk1A: December 1942 to June 1943', 31 August 1943. The most successful skymarking raid of this period was that against Oberhausen on the night of 14/15 June 1943 which, according the photographic evidence at the time, was assessed as causing 'very severe damage'. The entry on this raid in Middlebrook and Everitt *The Bomber Command War Diaries*, p398 refers to report from Oberhausen, in which it was confirmed that markers were place directly over the centre of the town.



was that the automatic dropping of the point release flares using *Oboe* was initially very accurate and that the system allowed for the drift of the markers to factored into the release co-ordinates, thereby ensuring that the Point Release Flares would be over the A/P at the optimum time. The drawback was that the optimum period of time for an aircraft to 'run-up' on a Point Release Flare was 1½ minutes and that a two-Channel *Oboe* system only allowed the release of one Point Release Flare approximately every five minutes. There was no opportunity for 'backing-up' with sky-marking, and therefore any gap in the *Oboe* sky-marking due to equipment failure would result in the Point Release Flares either burning out or being out of position. Nonetheless, the results obtained with *Musical Wanganui* were a considerable improvement over previous results and, importantly, enabled the offensive to be usefully continued in weather conditions that would previously resulted in no operations being possible or only very limited results being achieved.

However, the major improvement in bombing performance was achieved with *Musical Parramatta* which, against Ruhr targets, resulted in an average of 54% of bombs falling within 3 miles of the A/P<sup>75</sup>. This was a function of the accuracy of the primary markers dropped using *Oboe* and the continuity of the primary marking. ORSBC estimated that the accuracy of the primary markers dropped by *Oboe* during this period ranged from about ¼ of a mile to 1 mile<sup>76</sup>. The highest degree of accuracy achieved during this period was 80% of bombs within 3 miles of the A/P and on no occasion did the percentage of bombs within 3 miles of the A/P fall below 25%, even in moderate weather

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<sup>75</sup>Ibid.

<sup>76</sup> Accuracy in dropping of T.I.s could never match that of bombs due to the fact that TIs burst above ground level and therefore did not follow the ballistic properties of a standard bomb.

conditions. This represented a significant improvement compared with the equivalent figure of 23% for PFF led operations against the same targets prior to the use of *Oboe* particularly since the Ruhr, with a lack of distinctive ground features and an omnipresent industrial haze, has previously proved to be an elusive target. The average figures quoted also concealed the fact that a significant proportion of the bombs falling were concentrated within an area much closer to the A/P than the 3 miles used as the standard measure, and ORSBC estimated that the Probable Radial Error was in the region of ½ mile with a Systematic Error of one mile from the A/P. The resultant concentration of bombing, 90% of which was within 1 mile of the A/P, caused substantial damage to the Ruhr towns: for example, in what Middlebrook and Everitt describe as ‘the outstanding success of the Battle of the Ruhr’, approximately 1,000 acres of Wuppertal, equating to some 80% of the built up area of the town, were destroyed during a raid on the night of 29/30 May 1943<sup>77</sup>. The bomb distribution plot for this raid is shown in Fig 19/ below, and demonstrates the concentration possible with *Musical Parramatta*

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<sup>77</sup> TNA AIR14/3410 ORSBC Final Raid Report No 340: Wuppertal, 29/30 May 1943, 12 August 1943. In addition to the usual difficulties associated with attacks on the Ruhr, the town of Wuppertal was spread along a narrow valley and therefore presented a particularly difficult target.

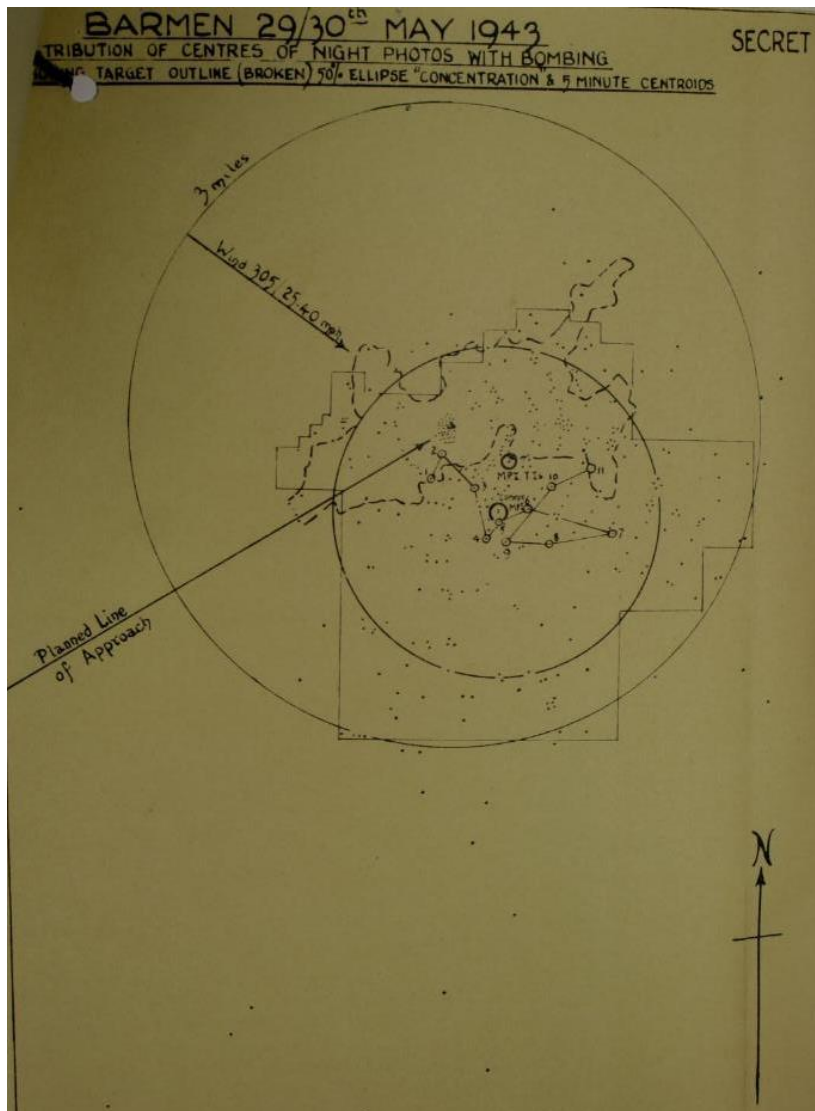


Fig 19/ Bomb distribution plot for the raid on Barmen-Wuppertal, 29/30 May 1943. Source: TNA AIR14/3062 ORSBC Report S.148 'The development in time of 17 raids on German towns in 1943', 23 October 1943.

ORSBC concluded that "the great success achieved by *Oboe* ground-marking raids as compared with other methods is directly attributable to the certainty with which primary T.I. markers can be placed within a fraction of a mile of the A/P, enabling the remaining aircraft to be categorically instructed to aim at a single salvo of T.I.s rather than at the M.P.I. of several"<sup>78</sup>. ORSBC further

<sup>78</sup> TNA AIR14/1574 ORSBC Report S.102 'The Operational Use of *Oboe* Mk1A: December 1942 to June 1943', 31 August 1943.

concluded that the disadvantage of *Musical Parramatta* at that time was that not all of the marking is carried out by *Oboe* aircraft, and that the accuracy with which secondary marking could be laid was considerably less than that achieved with *Oboe* aircraft. It was this lesser accuracy in secondary marking that had resulted in some scatter in the bomb distribution beyond the 3 mile zone. Although not expressed as such by ORSBC, this was a consequence of the Principle of Cumulative Dispersion resulting from human error in the visual aiming of the secondary markers and errors in the estimation by the Main Force of the M.P.I. of the less accurate secondary markers.

In this context, ORSBC observed that accuracy increased steadily throughout the period under review, with the last two raids in the series resulting in 78% and 80% of bombs within 3 miles of the A/P respectively<sup>79</sup>. ORSBC concluded that this was largely due to improvements in the timing of the *Oboe* marking aircraft which, because a continuity of primary markers was maintained throughout the duration of the raid, enabled the Main Force to aim for the fixed position of the primary markers dropped using *Oboe* rather than having to estimate the M.P.I. of the secondary markers. Errors resulting from the Principle of Cumulative Dispersion were therefore avoided, resulting in greater accuracy and concentration close to the A/P. In the earlier raids in the series, the timing of the *Oboe* marking aircraft had been less accurate and there had significant gaps between successive aircraft using the same Channel, such that the Main Force had been obliged to estimate the M.P.I. of the secondary markers dropped by the Backers-up. The resultant bombing was prone to the

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<sup>79</sup> Ibid

Principle of Cumulative Dispersion and consequently less accurate. ORSBC therefore concluded that achieving the optimum bombing accuracy with *Oboe* was dependent upon maintaining a continuity of primary markers and therefore emphasised the importance of increasing the number of Channels available.

By the time that the ORSBC conclusion was published, the point had already been emphatically demonstrated in practice. On the night of the 30/31 July 1943, a total of only 275 aircraft attacked Remscheid, a previously unbombed town on the southern edge of the Ruhr<sup>80</sup>. A third *Oboe* Channel had just been introduced<sup>81</sup> and Remscheid was the first occasion on which continuous primary marking had been maintained throughout the entire raid<sup>82</sup>. The primary marking was exceptionally accurate and, although only 871 tons of bombs were dropped, the British Bombing Survey estimated that 83% of the town was devastated.

The importance of providing a single point of aim was evident and eventually lead to the development of variations of *Musical Parramatta* known as 'Preliminary *Oboe* Marking' and 'Continuous *Oboe* Marking'<sup>83</sup>. In the former, not less than 4 Mosquito aircraft would each drop T.I.s to provide an indication of the A/P, to serve either as the sole target marking or as a basis for full PFF marking. Continuous *Oboe* Marking involved the continuous dropping of T.I.s

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<sup>80</sup> TNA AIR14/3410 ORSBC Final Raid Report No 389: Remscheid, 30/31 July 1943, 26 September 1943 and Middlebrook and Everitt *The Bomber Command War Diaries*, p415.

<sup>81</sup> The first raid on which three *Oboe* Channels were used was that against Essen on the night of 25<sup>th</sup>/26<sup>th</sup> July 1943.

<sup>82</sup> Cumming *Beam Bombers*, p110.

<sup>83</sup> TNA AIR14/1990 Memorandum Bomber Command HQ to Nos. 1, 3, 4, 5, 6, 8 and 100 Groups, 18 June 1944.

over a period of approximately 8 minutes, in which these T.I.s would be the only markers dropped. These two techniques would later form an important component of the target marking repertoire against precision targets post D-Day. It is also significant that *Continuous Oboe Marking* was the only ground-marking technique in the bombing offensive to dispense with secondary marking and therefore in which the placing of the primary markers was fully automated. It was therefore the only ground-marking technique in which the estimation of the M.P.I. of the marking was not required, and which therefore removed the human error factor and avoided the effects of the Principle of Cumulative Dispersion.

Towards the end of the Battle of the Ruhr, Bomber Command launched the first in a series of four major raids against Hamburg<sup>84</sup>. These raids, given the codename 'OPERATION GOMORRAH' at the time, would later become known as the Battle of Hamburg<sup>85</sup>. Hamburg was beyond *Oboe* range and therefore the PFF marking would be based on H2S. The Battle of Hamburg represents a microcosm of the fortunes of target marking techniques based on H2S and for that reasons the first three raids are set out in detail here<sup>86</sup>.

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<sup>84</sup> These raids took place on the 24/25 July; 27/28 July; 29/30 July; and 2/3 August 1943.

<sup>85</sup> OPERATION GOMORRAH was in part designed to take advantage of 'Window', strips of paper backed with metal foil dropped in bundles by the aircraft, which then dispersed in the airflow. Each strip produced an echo on the German radar screens equivalent to a heavy bomber, such that the German radar were swamped with false echoes and the defence system undermined. For a detailed description of the Battle of Hamburg, see Lowe *Inferno: The fiery destruction of Hamburg 1943* or Martin Middlebrook *The Battle of Hamburg: the Firestorm Raid* (London: Penguin Books, 1984: first published, 1980). Re-published by Pen & Sword Aviation in 2012 under the title *Firestorm Hamburg: the facts surrounding the destruction of a German city 1943*.

<sup>86</sup> The fourth raid was planned as a *Wanganui* attack due to the extensive cloud cover predicted, but in the event the bomber force encountered severe thunderstorms and less than half of the bomber force reached Hamburg. The bombing was widely scattered.

The location of Hamburg on the River Elbe, with an extensive area of docks on the south bank, provided a distinctive return on the P.P.I. of the H2S sets. In addition, there was a large lake in the centre of the city - the Alster lake<sup>87</sup> - and, just to the north, a large area of open space known as the Stadtpark. Compared with the surrounding built-up districts, these areas of water and open space contained relatively few 'corner reflectors' and therefore provided distinctive dark patches on the P.P.I. that showed up well against the brighter built-up areas. The raid planners took advantage of this by designating the A/P at the southern end of the Alster lake for the first three raids, and between the northern end of Alster lake and the Stadtpark for the fourth raid.

The weather for the first raid in the sequence was exceptionally clear and the PFF attempted a classic *Newhaven* attack<sup>88</sup>. Backers-up accompanied each wave of the Main Force and for the first time were to act as 'Re-centerers', specifically tasked with re-marking the A/P in an attempt to control 'creepback'. In the event, notwithstanding the clear conditions, the PFF marked five widely spaced areas at distances of between one and three miles from the A/P. A proportion of the Main Force bombed each of these disparate areas, with the majority (some 75%) bombing an area to the north-west of the A/P along the line of approach. However, as shown in Fig 20 below, because of the extent of the creepback (over 6 miles in length), only 45% of bombs fell within 3 miles of the A/P.

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<sup>87</sup> There were in fact two lakes in the centre of Hamburg, both formed by the damming of the River Alster where it is joined with the River Elbe. The smaller of the two lakes – the Binnen Alster – was completely covered by camouflage during the war.

<sup>88</sup> TNA AIR14/3410 ORSBC Final Raid Report No 383: Hamburg, 24/25 July 1943, 6 October 1943.

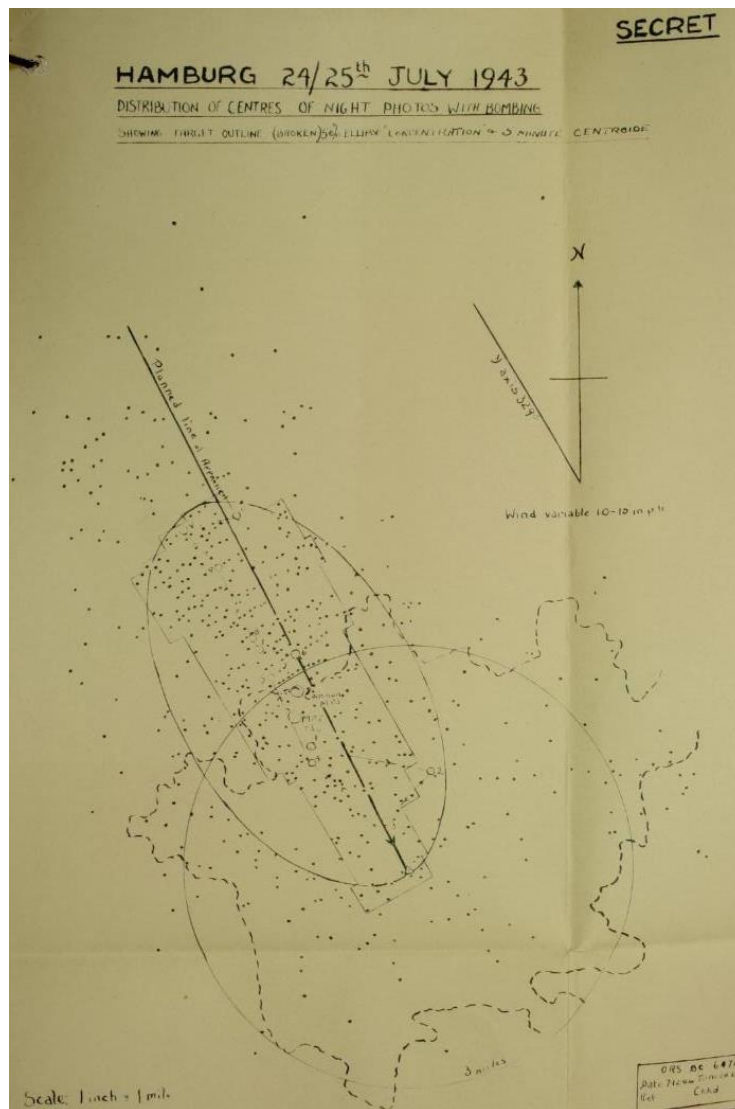


Fig 20/ Bomb distribution plot for the raid on Hamburg, 24/25 July 1943. Note how the 'creepback' extends back in the reciprocal direction to the line of approach and extends well beyond the built up area. The bomb distribution was this Newhaven raid may be compared that for the Musical Parramatta raid on Barmen-Wuppertal shown in Fig 22/. Source: TNA AIR14/3062 ORSBC Report S.148 'The development in time of 17 raids on German towns in 1943', 23 October 1943.

For the second raid in the series, PFF marking was by the *Parramatta* technique<sup>89</sup>. On this occasion, the markers were well concentrated but were short of the A/P by between 1½ and 2½ miles (see Fig 21/ below). Because of the concentration of the initial marking, the Main Force bombing was also

<sup>89</sup> TNA AIR14/3410 ORSBC Final Raid Report No 386: Hamburg, 27/28 July 1943, 11 October 1943.



initially concentrated although the creepback developed later, such that again less than 50% of bombs fell within 3 miles of the A/P. Nonetheless, the initial concentration of bombing was one of the factors that contributed to the firestorm that developed in the eastern suburbs of Hamburg<sup>90</sup>.

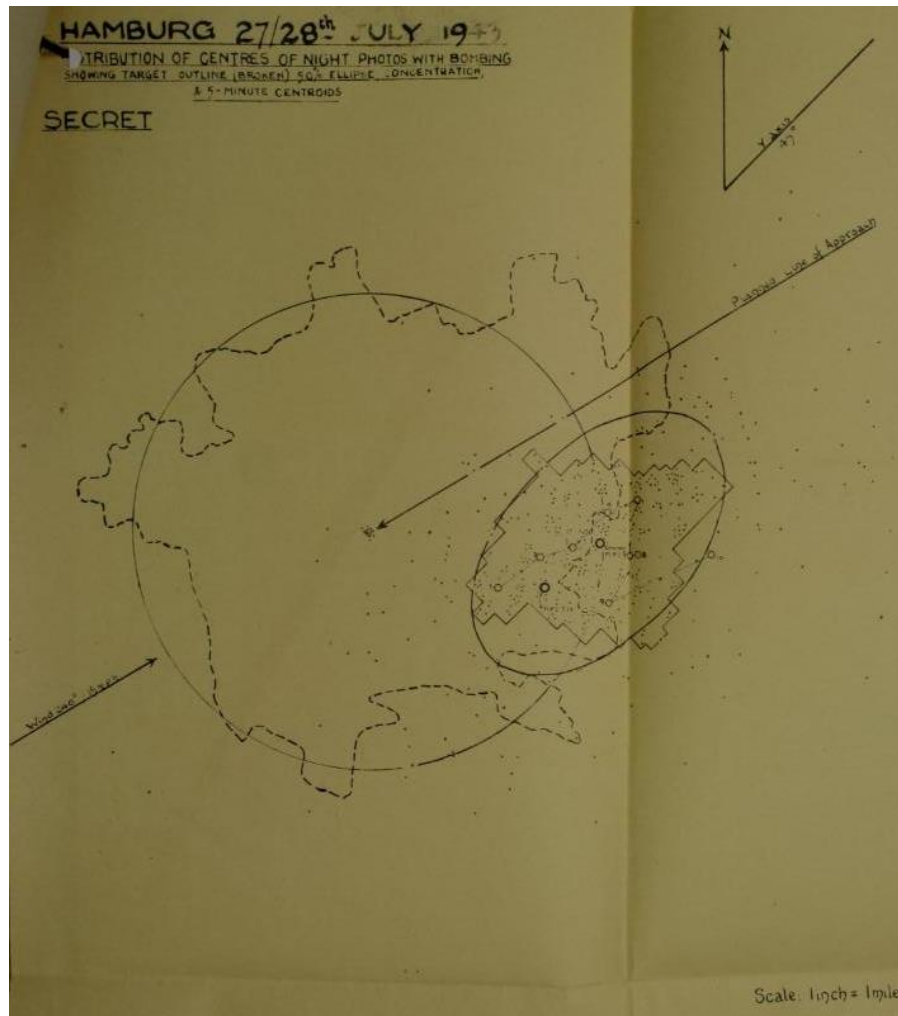


Fig 21/ Bomb distribution plot for the raid on Hamburg, 27/28 July 1943. Note that the bombing is more concentrated than that shown in Fig 23/ but is displaced from the A/P (i.e. there is a systematic error) Note also that 'creepback' has developed parallel with the direction of the line of approach. Source: TNA AIR14/3062 ORSBC Report S.148, The development in time of 17 raids on German towns in 1943, dated 23 October 1943.

<sup>90</sup> Other factors included a higher than usual percentage of incendiaries carried by the Main Force on that night, the warm weather over Germany in the weeks leading up the raid and the densely built up parts of the city on which the main bombing fell.

The third raid in OPERATION GOMORRAH was also a *Parramatta* attack<sup>91</sup>. The first primary markers were accurately placed close to the A/P but, although the range error was minimal, due to a strong crosswind subsequent marking was significantly to the east of the A/P, resulting in a line error of some 3 miles. The Main Force bombing was again well concentrated but short of main primary marking, resulting in a systematic error of over 3 miles to the north-east of the A/P. The majority of bombs nonetheless fell on residential districts of Hamburg, resulting in further substantial damage.

In the first raid in the series, the initial dropping of markers and flares using H2S in the initial phase of the *Newhaven* technique resulted in the primary marking being divided into a number of separate groups. This included some accurate marking and bombing of the A/P in the early stages of the raid. However, post raid analysis showed that three PFF Visual Markers and some aircraft of the early waves of the Main Force returned photographs three miles east of the A/P and other aircraft in the first wave bombed some two-miles north-west of the A/P. The Backers-up were briefly able to re-center the raid due to an exceptionally well-placed group of T.I.s just 300 yards beyond the A/P but, as the raid progressed, secondary marking and bombing tended to drift back along the line of approach. ORSBC traced the resultant lack of concentration on the early scattered marking, which made it difficult for the Backers-up to identify the M.P.I. of the various groups of markers. The tendency was for the Backers-up to aim at the first markers encountered, hence initiating a creepback in the bombing that was accelerated by the Main

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<sup>91</sup> TNA AIR14/3410 ORSBC Final Raid Report No 388: Hamburg, 29/30 July 1943, 12 October 1943.

Force. This was a classic example of the Principle of Cumulative Dispersion in operation with the use of H2S for the initial target marking.

In both *Parramatta* raids the M.P.I. of the marking was significantly displaced from the A/P. On the third raid of the series, this was due largely to the crosswind which resulted in a significant line error. Nonetheless, the fact remains that these errors occurred in relation to a target that, in theory at least, should have provided a number of distinctive features on the P.P.I. and yet this was not sufficient to enable the H2S operators to either accurately identify the A/P or compensate for crosswind. The result was that the Probable Radial Error<sup>92</sup> for these raids was 2.6 miles which corresponded almost exactly with the mean radius of the city (2.5 miles)<sup>93</sup>. Expressed another way, less than half of bombs dropped were within 3 miles of the A/P and it was only the relatively large radius of Hamburg that meant that a large number the of bombs dropped were within the built up area of the city.

OPERATION GOMMORRAH, and particularly the 'firestorm' raid of the 27/28 July, are usually cited as examples of the destructive power of Bomber Command had obtained by 1943 and there is no doubt that the resultant damage to parts of Hamburg was substantial. However, it is instructive to note that this damage was still the result of only half the total bomb tonnage

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<sup>92</sup> The Probable radial Error was the radius of a circle about the Aiming Point or the Mean Point of Impact within which 50% of the plotted bomb distribution are located. This was sometimes referred to as the "50% Zone" or the "50% circle".

<sup>93</sup> TNA AIR14/3025 ORSBC Report S.111 'Accuracy of H2S as a blind-bombing device', 16 December 1943. The title of this report is somewhat of a misnomer because H2S was not used for blind bombing during this period and, as explained in the introduction to the report, the results discussed relate to the bombing performance of the Main Force on raids for which the target marking technique used was based on H2S.

dropped, the remaining half being wasted effort. This point is largely overlooked in secondary literature about the raids on OPERATION GOMMORRAH. This also makes for an interesting comparison with the devastation of 83% of the much smaller town of Remscheid (which occurred between the 3<sup>rd</sup> and 4<sup>th</sup> raids in the series) resulting from the use of *Oboe* to provide the primary marking, which serves to illustrate the extent to which the accuracy of the blind bombing device used to place the primary markers dictated the effectiveness of the raid by reducing the errors resulting from the Principle of Cumulative Dispersion.

Following the Battle of Hamburg, Bomber Command faced a dilemma in terms of its target marking policy. With the longer winter nights approaching, Harris turned his attention to Berlin, which he had always considered to be the ultimate objective. However, Berlin was well beyond *Oboe* range and it was apparent that the version of H2S then in service (the Mk IIA) lacked sufficient definition to enable specific aiming points to be identified, particularly with a large urban area such as Berlin. For this reason, the Official History refers to the area beyond *Oboe* range as a 'zone of relative inefficiency' for Bomber Command<sup>94</sup>.

The future policy to be adopted was discussed at a meeting on Radio and Navigation Policy held at Bomber Command HQ on 3 August 1943<sup>95</sup>. It was generally agreed that whenever weather conditions were good enough to permit ground-marking, the Main Force should use H2S as a navigation aid

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<sup>94</sup> Webster, and Frankland *The Strategic Air Offensive*, Vol II, p161.

<sup>95</sup> TNA AIR14/1321 Minutes of meeting held at Bomber Command HQ on 3 August 1943 to discuss Radio and Navigation Policy.

but, having thereby ensured that they had identified the correct target, should aim at the ground-markers dropped by the PFF. However, when weather conditions did not permit ground-marking, those attending the meeting were generally split into two camps. The first, led by Sir Robert Renwick, Controller of Communication at the Air Ministry<sup>96</sup>, considered that H2S was primarily a blind bombing device and should be used as such by the Main Force. The other camp, led by Bennett, considered that H2S was primarily an aid to navigation and that the Main Force should navigate to the target area using H2S, but should then revert to PFF sky-marking for bombing. Bomber Command favoured urgent improvements to H2S and in particular pressed for the introduction of the 3cm Mk III version<sup>97</sup>, which offered much improved definition. The matter was settled in favour of Bomber Command when ORSBC indicated that, with the current version of H2S, it was unlikely that H2S was sufficiently accurate to distinguish aiming points in towns over 1½ miles radius which, of course, included Berlin. This conclusion illustrates that, at this key stage of the bombing offensive, H2S was not regarded as sufficiently accurate as a blind bombing device to dispense with even the least accurate of the target marking techniques. The target marking policy for the forthcoming Battle of Berlin was dictated by the relationship between the capability of the H2S navigation aid and the ability of the PFF to provide target marking for the Main Force within the limitations of that device.

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<sup>96</sup> Sir Robert Renwick held the joint posts of Controller of Communications at the Air Ministry and Controller of Communications Equipment at the Ministry of Aircraft Production.

<sup>97</sup> The Mk III was the 3 centimetre X-band version of H2S with scan correction and roll stabilisation.

The period between the end the Battle of Hamburg and the beginning of the Battle of Berlin largely comprised raids beyond the range of *Oboe* and therefore within the 'zone of relative inefficiency'. Consequently, H2S (MkIIA) was used for target marking in most of the raids in this period, including raids on seven major German towns. The results achieved in these raids showed a remarkable consistency in the relationship between the Probable Radial Error and the mean radius of the target town; with two exceptions, the Probable Radial Error was practically the same as the mean radius of the target (as shown in Table 8 below).

Target	Probable Radial Error (Miles)	Mean Radius (miles)
Munster	1.2	1.1
Hamburg	2.6	2.5
Mannheim	1.3	2.0
Nurnberg	1.8	1.9
Munich	1.7	2.2
Hannover	2.9	1.5
Berlin	3.9	4.4

Table 8/ Relationship between Probable Radial Error using H2S and mean radius of German towns. Source: TNA AIR14/3025 Operational Research Section Report S.111 'Accuracy of H2S as a blind-bombing device', 16 December 1943.

On the basis of these results, ORSBC concluded that when H2S was used by the PFF for target marking, the results achieved could not be expected to be

better than 50% of the bombs dropped falling within a circle the area of which is equal to the area of the town. This was entirely consistent with the accuracy achieved by the bombing of Hamburg during OPERATION GOMORRAH and would apply equally to Berlin. In relation to the first exceptions to this rule, the Probable Radial Error for Mannheim was significantly less than the mean radius, which ORSBC concluded was due to this town being very compact and thereby resulting in a clear contrast between the built-up area and other ground returns on the P.P.I. In relation to Hannover, the opposite was the case with the Probable Radial Error being significantly greater than the mean radius due, ORSBC concluded, to Hannover being more spread out and consequently providing a weak contrast between the built-up area and other ground returns on the P.P.I. The implication of these findings is that the Mk IIA version of H2S was only capable of achieving good levels of concentration against smaller targets, and certainly during this period H2S led attacks did result in significant damage to some of these smaller towns.

It is instructive that the more successful raids using H2S in this period shared two common denominators: they were all *Newhaven* attacks in which the initial illumination by flares and the primary marking were exceptionally accurate. This enabled the Backers-up to keep the raid well centred and the Main Force to achieve a high degree of concentration. For example, in the Mannheim-Ludwigshafen attack on the 5/6 September 1943 some 74% of aircraft bombed within 3 miles of the A/P; against the usually difficult H2S target of Hannover on the 8/9 October 1943 the figure was 79%; and against

Kassel on the 22/23 October 1943 the figure was 85%<sup>98</sup>. In the latter raid, the concentration achieved resulted in a 'firestorm' developing. However, the bigger point is that *Newhaven* attacks required conditions of good visibility. These conditions rarely occurred, such that the ground detail was rarely sufficiently discernible for the Primary Visual markers to place the primary markers with the accuracy required to replicate the results achieved at Mannheim-Ludwigshafen, Hannover and Kassel. It follows that the majority of raids in the zone of relative inefficiency were conducted with blind ground-marking or sky-marking, and these did not produce sufficient concentration to overcome the Principle of Cumulative Dispersion when H2S was employed in isolation.

The corollary of these findings was that it became imperative that the resolution afforded by H2S was improved if the device was to provide effective target marking in the forthcoming Battle of Berlin. Berlin covered a large area, with a mean radius of 4.4 miles. In previous raids using H2S ground-marking, this had resulted in a Probable Radial Error of some 3.9 miles<sup>99</sup>. This level of accuracy tended to result in a large number of widely scattered fires which could be contained by the civil fire services and which therefore did not combine to form the larger conflagrations necessary to cause the widespread damage achieved during OPERATION GOMORRAH. However, within Berlin were two large areas of open space – the Tiegarten and Templehof aerodrome – which in theory should show up clearly on the

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<sup>98</sup> Webster and Frankland *The Strategic Air Offensive*, Vol II, page 135.

<sup>99</sup> TNA AIR14/3025 ORSBC Report B.151 'Review of H2S Groundmarking raids on Germany: February – April 1943', 1 July 1943.



H2S P.P.I. if resolution could be improved. There were also several large and distinctively shaped bodies of water close to the city – the Muggel See to the east, and the Havel See and Tegeler See to the west – which also should be easily distinguishable on P.P.I. given sufficient resolution.

The introduction of a new version of H2S - the Mk III - was therefore potentially of vital importance to the forthcoming Battle of Berlin. The Mk III was the 3 centimetre X-band version of H2S with a beam width in azimuth of 3 degrees, and therefore offered a significant improvement in resolution compared with the Mk IIA. The Mk III sets were first used operationally on the night of the 18/19 November 1943. However, this 'significant improvement' must be viewed in context because, although resolution was better than with H2S Mk IIA, as shown in Figure 25/ below the image on the P.P.I. still required skillful interpretation by the operator<sup>100</sup>.

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<sup>100</sup> TNA AIR14/3062 ORSBC 'Mk III H2S Intelligence Folder: Berlin', June 1944. Intelligence Folders such as this were prepared for all major city targets and were used to provide navigators with an indication of how the target might appear on the P.P.I. of the H2S system.



Fig 25a Principal landmarks in and around Berlin. Note the distinct line of lakes to the west of Berlin (Tegel See; Havel; Wann-See and Templiner See), and the Gr. Muggel See to the south-east. Note also the large open space of Templehof aerodrome towards the centre of the city.

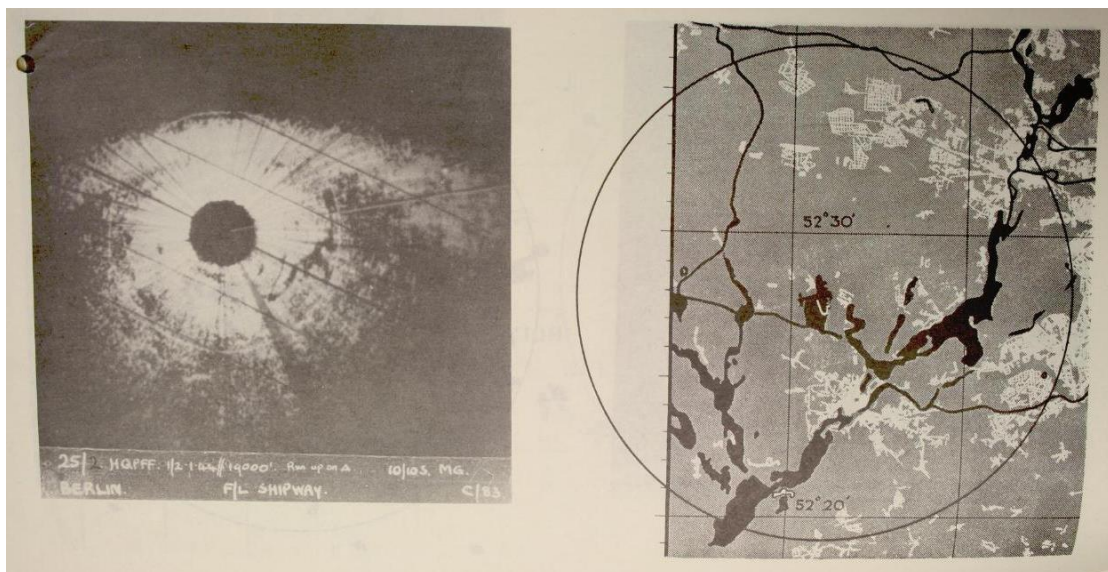


Fig 25b Principal landmarks in and around Berlin. This P.P.I. image was taken on the approach to Berlin from the west (the position of the aircraft is shown at the centre of the circle on the map to the right) and shows the distinct shapes of the Havel and the Wann-See. The Tegel See and the Templiner See are obscured by the ground returns. The image demonstrates the value of H<sub>2</sub>S as a navigation aid.



Fig 25c. Principal landmarks in and around Berlin. This P.P.I image was taken over Berlin itself (the position of the aircraft is again shown at the centre of the circle on the map to the right). Landmarks within the city itself are totally obscured by the ground returns, but the open space of Tempelhof aerodrome is clearly visible to the south-south-east of the aircraft's position and the Tegel See can just be discerned to the north-west. This image highlights the difficulty of using H2S for blind bombing/markings.

Source: TNA AIR14/3062 ORSBC 'Mk III H2S Intelligence Folder: Berlin', June 1944

The other tactical 'innovation' for the Battle of Berlin was a target marking technique known as the 'Berlin Method'. This was not in itself a new technique, having been used on occasions since the introduction of H2S, but became standard during the Battle of Berlin because of the difficulty in accurately forecasting the weather of this more distant target. The Berlin Method was a combination of the established *Newhaven*, *Parramatta* and *Wanganui* techniques in which marking was provided for one of the ground-marking techniques and sky-marking at the same time.

In addition to the dual ground-marking and sky-marking, there were two elements that were a regular feature of the 'Berlin Method' at this time<sup>101</sup>. The first is 'Special Blind Markers', which were those PFF aircraft equipped with H2S Mk III and which dropped TI (Yellow) purely to indicate to the Backers-up that these were likely to be the most accurate of the primary markers. The other element is that blind marking continued throughout the raid, not just at the opening. This again was to reduce the extent of 'creepback' by providing the Backers-up with a constant supply of primary markers dropped blind by H2S, and therefore not influenced by the inevitable scatter of earlier secondary markers. These innovations were introduced in an attempt to overcome the inherent limitations of H2S where the target was a large urban area and to take advantage of the limited numbers of the higher resolution of the Mk III version that were available.

The accuracy of H2S during the Battle of Berlin period was assessed by ORSBC in a report dated 13 August 1944<sup>102</sup>. The overall finding was that the Probable Radial Error for all H2S attacks was 2.0 miles and was therefore unchanged from that period covering OPERATION GOMORRAH and other raids beyond *Oboe* range. The significant difference, however, was that the mean radius of the towns attacked had fallen from 1.9 miles in the previous period to 1.5 miles, such that the percentage of bombs falling within 3 miles of the A/P fell from 50% to 34%. It may be noted that this period includes those *Newhaven* attacks in which the percentage of bombs within 3 miles of the A/P reached as high as 85%, which suggests some of the other raids achieved

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<sup>101</sup> Martin Middlebrook *The Berlin Raids*, p115.

<sup>102</sup> TNA AIR14/3026 ORSBC Report No S189 'H2S Blind Bombing Accuracy – Oct 1<sup>st</sup> 1943 – April 30<sup>th</sup> 1944'.

considerably less than the average of 34%. It may also be noted that there was no difference in performance between the Mk II and MK III versions of H2S in this respect<sup>103</sup>. Although a large number of raids during this period would have been the carried out using the inherently less accurate sky-marking technique, it must also be recognised that these results cover a period in which target marking techniques had been refined to address the limitations of H2S (including the 'Berlin Method'), such that the results achieved were the optimum that could have been obtained with this device. It is therefore apparent that even the most advanced target marking techniques could not overcome the technical limitations of H2S and, notwithstanding the improved resolution offered by the Mk III, H2S was incapable of achieving an effective concentration expect in the most favourable circumstances.

In his book *Echoes of War*, Lovell is quick to lay the blame for the poor performance of MKIII H2S on the PFF<sup>104</sup>. According to Lovell, a visit to the PFF in March 1944 by one of his colleagues revealed that the relatively few MKIII sets then in service were being "scandalously treated in 8 Group" in that, instead of these sets being given preferential treatment with specially trained crews and priority marking as a special force, they were simply being put in as wastage rate aircraft and carried no more weight than ordinary S-band equipment (i.e the MkIIA). However, the designation of those PFF aircraft equipped with H2S Mk III as Special Blind Markers as part of the Berlin Method indicates that Lovell is not correct in his assertion. Moreover, the results reported by ORSBC are separated between those aircraft using

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<sup>103</sup> Ibid. ORSBC could offer no explanation for this, although it was suggested that this may have been the result of rushing the Mk III into service before it was fully tested.

<sup>104</sup> Lovell, *Echoes of War*, p.p. 211 and 212.

the Mk IIA and MkIII equipments, and show that that there was no significant difference between the two. The assertion by Lovell is one example where his work *Echoes of War* is biased towards the achievements of H2S and is therefore not a totally reliable record of the performance actually achieved with H2S<sup>105</sup>.

At the end of the period covered by this Chapter, ORSBC produced a wide-ranging memorandum in which a number of recommendations were made for improving the efficiency of the PFF<sup>106</sup>. The initial observation was that the outstandingly successful attacks made by Bomber Command during this period were, almost without exception, achieved under conditions when visual identification and marking of the target had been possible. On that basis, ORSBC declared that the *Newhaven* technique was satisfactory and required no further modification. It was, however, concluded that the limited success of *Blind Parramatta* and *Wanganui* was directly attributable to the “difficulties inherent in the use of the present H2S apparatus” and that long-term policy should be to press continuously for the development of better equipment. In the interim, ORSBC considered that improvements could be made in the efficiency with which the (then) existing versions of H2S was used, and it was to this that the remainder of the memorandum was devoted. The recommendations made related to such matters as training, crew selection and the number of crews allocated to marking duties. The latter in particular

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<sup>105</sup> Ibid. Lovell's incomplete and inaccurate recording at page 215 of his book of a meeting concerning the future policy for the employment of H2S in April 1944, and his selective reference to the Brunswick and Ludwigshafen raids referred to in Chapter Two, are further examples.

<sup>106</sup> TNA AIR14/3062 ORSBC Memorandum M64 'Recommendations for improving the efficiency of the P.F.F', 25 August 1944.

raised significant questions about the size of the PFF required to mark more than one target per night, which would become an important consideration in the development of target marking techniques as Bomber Command turned to precision targets in the build-up to OPERATION OVERLORD.

In an attempt to overcome the difficulties associated with *Blind Parramatta*, there was also a suggestion that when visibility was not good enough to permit visual identification of the A/P from 12,000 ft or above even heavily defended targets could be marked by low-flying Mosquitoes. This is an interesting suggestion in that, whilst to this point considerable effort had been devoted to exploiting ever-improving technology in order to improve efficiency, this appears to be an admission that under certain weather conditions the results required could not be attained using the latest technology then available. Consequently, pending the receipt of better equipment, the suggestion offered ORSBC attempts to circumvent the limitations of H2S by taking advantage of the human factor involved in visual marking at low levels in fast aircraft at night. Although this suggestion was not taken up by PFF, it would later become integral to the target techniques evolved by No 5 Group (see Chapter Six).

The key finding to emerge from the examination of target marking techniques in this Chapter is the direct relationship between the accuracy and concentration of bombing achieved and the characteristics of the navigation aid used. The comparative results achieved using the navigation aids available during this period, *Oboe* and H2S, has been obliquely referred to in

secondary literature and that sense, the general relationship is already known. However, even where the connection is made, the reasons behind this difference are not expressly stated or quantified. This reason relates to the Principle of Cumulative Dispersion. In this respect, *Oboe* held a distinctive advantage over H2S in relation to target marking in that, in addition to being more accurate, it minimised the potential for human error (and, in the form of *Continuous Oboe Marking*, removed it altogether). By comparison, even with the most advanced target marking techniques, H2S was incapable of routinely achieving the accuracy and concentration of bombing possible with *Oboe* because it relied upon the estimation of the M.P.I., not only in terms of placing the primary and secondary markers, but also by the Main Force. As such, the target marking techniques that relied upon H2S were prone to human error and the inherent loss of accuracy and concentration due to the Principle of Cumulative Dispersion. This important fact is largely overlooked in secondary literature when extolling the improvements in bombing performance resulting from H2S and, whilst this may not have been fundamental to the area bombing campaign, it would assume much more importance once precision targets assumed greater prominence as the bombing offensive progressed.

The other finding is in some respects a surprising one, in that there was no formal framework for developing and refining the target marking techniques. This lack of a formal process for the development of target marking techniques may also to some extent explain why the Pathfinder Force did not initiate any significant advance on or deviation from the basic techniques that had become standard by early 1943. This failure to explore more fundamental



developments of the basic techniques is all the more surprising given that the Bennett was renowned for his technical expertise in all matters relating to aircraft and navigation. The *Newhaven* technique in particular proved to have significant potential for development but, in order to realise this potential, a means of overcoming the inherent obstacle to bombing accuracy and concentration resulting from the Principle of Cumulative Dispersion - that ground detail was rarely visible from standard operational altitudes - was necessary. This in turn required a significant departure from basic technique adopted up to that time and, whilst ORSBC had alluded to it in recommending improvements to the efficiency of the PFF, it is was left to No 5 Group to exploit this potential with their own target marking techniques. It is to the development of the target marking techniques developed by No 5 Group that the next Chapter is concerned.

## **CHAPTER SIX: NO 5 GROUP TARGET MARKING TECHNIQUES**

The previous chapter covered the principal target marking techniques employed by the Pathfinder Force. Between its inception in August 1942 and early 1944, the marking of targets was the sole province of the Pathfinder Force. However, from January 1944, No 5 Group Bomber Command began to experiment with its own target marking techniques. Although elements of the techniques employed by the Pathfinder Force were retained, the target marking techniques developed by No 5 Group involved a radical departure from those established techniques in two key respects - they were all predicated on marking by aircraft flying at low level and were controlled by a 'Master Bomber'. The role of the Master Bomber would come to have wider application in the development of target marking techniques and for that reason is considered in more detail in the following Chapter. This Chapter concentrates upon the development and evolution of the principal target marking techniques employed by No 5 Group in which a point some distance from the A/P was marked rather than the A/P itself and which, for convenience, can be grouped under the generic term of 'indirect marking'. This Chapter will offer a comparison of the results achieved by indirect marking with those achieved by the standard techniques employed by the Pathfinder Force, and will balance these results against the operational implications of indirect marking. It will also assess the contribution of indirect marking to the achievements of Bomber Command in the last year of the Second World War, including the infamous 'firestorm' raid on Dresden in February 1945. The evolution of its own target marking capability was a

source of considerable tension between the AOC of No 5 Group and the AOC of the Pathfinder Force, and the acrimonious exchanges between these two commanders was one of the most interesting aspects of Harris' tenure as C-in-C of Bomber Command. This Chapter will examine those exchanges in the context of Harris' previous position in relation to the formation of the Pathfinder Force.

The main techniques employed by the Pathfinder Force – *Newhaven*, *Parramatta* and *Wanganui* – were all developed in the context of area raids on large towns and cities. Although the A/P was a precise point on the ground, in early 1944 an average of only 50% of bombs were falling within 3 miles of the A/P and, whilst the resultant concentration was sufficient to cause considerable destruction in built-up areas, even with large towns a significant proportion of the bombs dropped uselessly in the countryside beyond the urban area<sup>1</sup>. There were, however, a number of important small-scale targets outside of built-up areas, including a number of aircraft and aero-engine factories, which in accordance with the 'Pointblank' Directive of June 1943 were to be given priority<sup>2</sup>. Not only were these small-scale targets, a number were in Occupied Territories where avoiding casualties in the civilian population was a political imperative. The accuracy possible with the marking techniques employed by the Pathfinder Force was not sufficient to ensure the

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<sup>1</sup> The first two raids of 'OPERATION GOMORRAH', described in Chapter 5, were a good example of this, in which only 45% of bombs dropped fell within the built-up area of Hamburg.

<sup>2</sup> Webster and Frankland *The Strategic Air Offensive, Vol IV, p158*. The Pointblank Directive is reproduced in full in Appendix 23 of this work. This Directive, issued on 10 June 1943, requested Bomber Command to direct attacks to a number of objectives intended to reduce the strength of German day and night fighter forces including, *inter alia*, the "destruction of German air-frame, engine and component factories".

destruction of such targets without excessive civilian casualties, and it was clear that different target marking techniques would be required against these 'precision' targets<sup>3</sup>.

That is not to say that the new techniques were devised by the deliberate application of known principles of target marking to the problem. Rather, the origin of these techniques can be traced to experiments at unit level and, in particular, to one unit within No 5 Group. This unit was No 617 Squadron which, having suffered a series of costly failures following the Dams Raid, had struggled to find a meaningful role as a precision bombing squadron<sup>4</sup>. In late 1943 and early 1944, and by this time led by Group Captain Cheshire, No 617 Squadron had been employed attacking V1 flying bomb sites in the Pas de Calais as part of OPERATION CROSSBOW, in which the targets were marked by *Oboe* mosquitoes of the PFF and bombing was from a high level using the Stabilised Automatic Bombsight (SABS)<sup>5</sup> and single 12,000lb HC

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<sup>3</sup> The term 'precision' is used here to differentiate this target set from the 'area' attacks on towns and cities upon which Bomber Command had largely concentrated until this time. In this context, the term 'precision' is a relative one and should not be equated to the pin-point accuracy achieved with modern day laser-guided weapons shown, for example, in television news reports on the Gulf Wars and the conflicts in Iraq and Afghanistan. As will be shown in this Chapter, 'precision' in the current context was typically measured in hundreds of yards or, at best, tens of yards.

<sup>4</sup> For details of the operations undertaken by No 617 Squadron following the Dams Raid, see W.J Lawrence *No.5 Group RAF* (London: Faber & Faber, 1951) and Alan W. Cooper *Beyond the Dams to the Tirpitz* (London and St Albans: Goodall Publications, 1991: first published London: William Kimber & Co, 1983). The operations undertaken by No 617 Squadron at this time are also covered in detail by Robert Owen, *Considered policy or haphazard evolution? No.617 Squadron RAF 1943-1945*, PhD thesis, University of Huddersfield, 2014.

<sup>5</sup> Jonathan Falconer. *Bomber Command Handbook 1939-1945* (Stroud: Sutton Publishing Limited, 1998), page 114. The Stabilised Automatic Bombsight (SABS) was a gyroscopically controlled tachometric bombsight capable of achieving greater accuracy than the MK XIV bombsight with which most of Bomber Command was equipped at this time. SABS was more complicated to operate and required a long straight and level approach, such that it was not suitable for Main Force operations. SABS was therefore issued to specialist precision bombing units, including No 617 Squadron, which used the Mk IIA, this version being specifically modified for precision bombing.

bombs<sup>6</sup>. As Robert Owen explains, the marking method employed derived from a technique originally devised by No 5 Group in conjunction with Bennett for the specific purpose of attacking the Rothensee Ship Lift on the Mittelleland Canal with the TALLBOY bomb and the attacks on the V1 flying bomb sites were an extended operational trial of this technique pending the availability of TALLBOY<sup>7</sup>. At the angle of cut in the Pas de Calais, the systematic error of TI's dropped by *Oboe* was typically 300 yards but, using SABS, No. 617 Squadron was achieving an average Probable Radial Error of only 94 yards<sup>8</sup>. The Overall Systematic Error resulting from the combination of *Oboe* and SABS therefore resulted in the majority of the bombs completely missing the A/P, as exemplified by the attack on the V1 site at Flixecourt on the night of 16/17 December 1943, where the marking error was 350 yards but none of the 9 bombs dropped by No 617 Squadron were more than 100 yards from the markers, and the target was missed entirely. The combination of *Oboe* and SABS was not sufficiently accurate for consistently hitting those precision targets<sup>9</sup>.

This led to the squadron devising its own marking technique in which *Oboe* was used to provide proximity markers but the A/P was illuminated by flares and then marked with a Red Spot Fire dropped from 8,000ft<sup>10</sup>. The accuracy

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<sup>6</sup> These HC (high capacity) blast bombs are not to be confused with the later TALLBOY deep penetration bomb designed by Barnes Wallace of the same weight with which No 617 Squadron are more usually associated, but which were MC (medium-capacity) bombs used for a different purpose.

<sup>7</sup> Owen, *Considered policy or haphazard evolution?*. The TALLBOY (M = medium) was the 12,000lb version deep penetration bomb designed by Barnes Wallace, whereas the TALLBOY (L-Large) later became known as the GRAND SLAM.

<sup>8</sup> TNA AIR14/3411 ORSBC Final reports on operations, night raids, Nos.416-620 Vol. IV.

<sup>9</sup> Ibid.

<sup>10</sup> A Red Spot Fire was a 250lb bomb casing filled with cotton wool soaked in a solution of metallic perchlorate dissolved in alcohol. This device, officially designated T.I. Mk I Serial No

of that marker was then assessed by Cheshire and any corrections given to the squadron by VHF<sup>11</sup>. This new method was first used against the V1 site at Flixecourt on the night of 21/22 January 1944 with, in contrast with the earlier raid, considerable success<sup>12</sup>. As Robert Owen points out, some of this success must be attributed to the fact that the Red Spot Fire provided a single point of aim, which better suited the graticule of the SABS precision sight than the ground pattern covering some 100 yards produced by TIs<sup>13</sup>. Nonetheless, it is reasonable to assume that the assessment of the primary marker and the use of VHF to broadcast corrections to the 'main force', both of which would become standard features of the techniques employed by No 5 Group, also played a part in demonstrating that target marking could be used against precision targets.

In February 1944, No 617 Squadron was tasked with precision attacks on aircraft and aero-engine factories<sup>14</sup>. These targets had originally been proposed by the Directorate of Bombing Operations prior to OPERATION CROSSBOW as a continuation of the campaign that had begun with the attacks on Montbeliard and Montlucon (see Chapter Seven) but, as Robert Owen explains, the target selection process was complex involving, amongst other things, the need to minimise civilian casualties being paramount<sup>15</sup>. The original marking technique using *Oboe* and SABS had been shown not be

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8 and not to be confused with the earlier Red Blob Fire, produced a single spot on the ground that lasted for between 15 and 20 minutes but without any great intensity.

<sup>11</sup> No 617 Squadron aircraft had been fitted with VHF for the Dams Raid and was the sole unit equipped with VHF in Bomber Command at this time.

<sup>12</sup> TNA AIR14/3411 ORSBC Final reports on operations, night raids, Nos.416-620 Vol. IV

<sup>13</sup> Owen, *Considered policy or haphazard evolution?*

<sup>14</sup> TNA AIR20/8142 Cypher message Air Ministry to Bomber Command HQ 'Industrial targets in occupied territories: selection for moonlight attack', 8 February 1944.

<sup>15</sup> Robert Owen, *Considered policy or haphazard evolution?*

sufficiently accurate but, with the results achieved using the refined marking technique and subject to clear stipulations, No 617 was given permission to attempt specified targets in this set<sup>16</sup>. The first of these attacks was on the Gnome & Rhone aero-engine factory at Limoges and introduced a further refinement to the technique employed by No 617 squadron.

The attack took place on the night of 8/9 February 1944 in clear conditions and bright moonlight<sup>17</sup>. The initial marking, using 30lb incendiary bombs, was now carried out by Cheshire in a Lancaster from an altitude of 100ft. This initial marking was followed by two Red Spot Fires, dropped by the Deputy Leader from an altitude of 7,000ft. These landed in the centre of the group of incendiaries, providing a clear point of aim for the bombing aircraft, which were then instructed to bomb by Cheshire. The first bomb scored a direct hit on the factory building, and in total ten of the eleven bombs dropped scored direct hits<sup>18</sup>. The Final Raid Report confirms that the M.P.I. of the markers was in the middle of the factory and that the average bombing error around that point was 150 yards. The aero-engine factory was so severely damaged that production effectively ceased<sup>19</sup>.

The attack on Limoges was important in terms of the development of tactics for low-level marking, and several lessons were learned from it. The first was that the aircraft used for the initial low-level marking needed to be more

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<sup>16</sup> TNA AIR20/8142 Cypher message Air Ministry to Bomber Command HQ 'Industrial targets in occupied territories: selection for moonlight attack', 8 February 1944

<sup>17</sup> TNA AIR14/3411 ORSBC Final Raid Report No 525: Limoges, 8/9 February 1944, 1 May 1944.

<sup>18</sup> These bombs were 12,000lb high-capacity blast bombs previously used against CROSSBOW targets.

<sup>19</sup> Middlebrook and Everitt *The Bomber Command War Diaries*, p471.

manoeuvrable than the Lancaster in order to reduce the vulnerability of the marking aircraft<sup>20</sup>. The aircraft eventually selected was the de Havilland Mosquito, and No 617 Squadron was loaned two of these aircraft for this purpose<sup>21</sup>. The other key lesson was the importance of good communication between the Leader/Deputy Leader and the bombing force, effected by V.H.F. radio being installed in the squadron's aircraft<sup>22</sup>. The importance of good communication would be reinforced on several occasions in this series of raids, notably in the attack on a factory at Bergerac when a new type of fuze resulted in the Spot Fires bursting in the air rather than on the ground, so that the markers had a different trail angle and consequently fell on the eastern edge of the target. Realising that the error caused could not be rectified by re-marking the target, the Leader instructed the bombing force to approach the target from the east and aim at the misplaced markers with an intentional overshoot. The result was three out of the five 12,000lb HC bombs hit the target<sup>23</sup>. Similarly, in the attack on the aircraft factory Clermont-Ferrand, the Leader accidentally released his incendiaries short of the target<sup>24</sup>. The Deputy Leader placed his Spot Fires accurately and the Leader instructed the

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<sup>20</sup> TNA AIR14/2062 Memo Headquarters No 54 Base to Headquarters No 5 Group 'Development of precision bombing by No 617 Squadron', 16 March 1944.

<sup>21</sup> RAFM, Aircraft Movement Cards. The two aircraft concerned (ML975 and ML976) were Mk BXVI bomber variants on loan from No 109 Squadron, PFF. This variant was equipped with two-stage supercharged Merlin engines and configured for high-altitude work, and not optimised for the low-level marking role.

<sup>22</sup> It would be more accurate to say that this lesson was re-learned, in that the requirement for V.H.F. radio for control of other aircraft had become apparent when the squadron was training for the Dams Raid.

<sup>23</sup> TNA AIR14/3411 ORSBC Final Raid Report No 556: Bergerac, 18/19 March 1944, 15 June 1944

<sup>24</sup> TNA AIR14/3411 ORSBC Final Raid Report No 554: Clermont-Ferrand, 16/17 March 1944, 3 May 1944



bombing force to ignore the incendiaries and to bomb the Red Spot Fires, with all the larger bombs hitting the target<sup>25</sup>.

The importance of controlling the bombing force was exacerbated by the nature of the weapon used, in this case the 12,000lb HC bomb, although the principle applies to any large bomb. The heavy bombers with which Bomber Command was equipped were only capable of carrying one such bomb and the size of the force employed was small, typically no more than 12 aircraft. Given the accuracy of the SABS, and that the bombing force would be unable to see ground detail at their bombing altitude, any misplacement of the markers inevitably resulted in the target being missed entirely. The failure of the raid could only be averted by the employment of a 'Marker Leader' and the ability of that Leader (and/or Deputy) to observe the marking error and issue instructions to the bombing force to compensate for that error. It was this flexibility that was the advantage of the low-level technique employed by No 617 Squadron in relation to precision targets, and which represented a significant advance over previous techniques. The low-level technique was continually refined by No 617 Squadron, and eventually incorporated some elements of established target marking techniques. In particular, the use of flares to illuminate the target area for the Marker Leader and Deputy Leader, similar in principle to the *Newhaven* technique, became a regular feature of these attacks. The 'flare force' for these attacks was provided not by the Pathfinder Force but by No 106 Squadron, one of the squadrons in No 5

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<sup>25</sup> These two raids are described in detail in W.J.Lawrence *No.5 Group RAF*, p.p. 159 to 162, with summaries in Middlebrook and Everitt *The Bomber Command War Diaries*, p481 and p482 respectively.

Group equipped with H2S and the A.P.I.<sup>26</sup>. This presented some difficulties, not least in terms of communication between the marker aircraft equipped with V.H.F. and the flare force. This led to a recommendation that a Master Bomber be employed for the whole force<sup>27</sup>. Notwithstanding these difficulties and refinements, the basic technique remained unaltered and it was the identification and marking of the target at low level, together with the control of the attack by radio telephony, that resulted in the low-level technique evolved by No 617 Squadron being of such importance to the development of target marking techniques.

At the time that the low-level technique was being developed by No 617 Squadron, Bomber Command was turning its attention to targets in support of the forthcoming OPERATION OVERLORD<sup>28</sup>. One of the most significant target sets in the preparation for OPERATION OVERLORD was the so-called 'Transportation Plan', which required the dislocation of the transport system in the Occupied Territories, including the railway system. Analysts had determined that the most vulnerable points of the railway system were the marshalling yards and had calculated that a density of 3 hits per acre was required to put a marshalling yard out action<sup>29</sup>. The logical development was

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<sup>26</sup> Air Position Indicator. The Air Position Indicator was a basic navigational instrument designed to provide greater accuracy in Dead Reckoning navigation by automatically and continuously indicating the position of aircraft in 'still air' conditions irrespective of any manoeuvres undertaken by the aircraft.

<sup>27</sup> AIR14/2062 Record of conclusions reached at a conference held at RAF Station Woodhall Spa on 26<sup>th</sup> March 1944 to consider the recent combined operations of Nos. 617 and 106 Squadrons, 28 March 1944.

<sup>28</sup> OPERATION OVERLORD was the code name given to the invasion of occupied territories in France

<sup>29</sup> TNA AIR14/3012 ORSBC Report B.281 'Estimation of effort required against German marshalling yards', 12 January 1945. This report makes retrospective reference to the estimate of the density of hits required to put a marshalling yard out of action made prior to OPERATION OVERLORD.

to employ the low-level marking technique devised by No 617 Squadron against marshalling yards in occupied territory. These targets required a larger force than a single squadron and this led to No 617 Squadron being used to provide marking for No 5 Group as a whole for attacks against the marshalling yards at Juvisy and La Chapelle, both within the Paris conurbation and surrounded by housing. The aircraft of the Main Force were not fitted with VHF and therefore were not in direct contact with the Master Bomber. Nevertheless, in both cases the bombing was well concentrated and civilian casualties relatively slight<sup>30</sup>.

The second of these raids, that on La Chapelle on the night of 20/21 April 1944, is also significant in the development of target marking techniques. By April 1944, TALLBOY was nearing operational readiness and the intention was that No 617 squadron would revert to an independent precision bombing unit<sup>31</sup>. The corollary was that No 617 Squadron would not be able to provide marking for No 5 Group. This was one of the factors that led to the transfer of three squadrons - the Lancaster-equipped Nos. 83 and 97 Squadrons and the Mosquito-equipped No 627 Squadron - from the PFF to No 5 Group to provide marking capability for that Group. This would be one of the more controversial episodes of the bombing offensive, and a return to the debate surrounding this is made below. In the interim, it may be noted that the raid on La Chapelle was the first in which No 5 Group used the new marking capability provided by these squadrons albeit, on that occasion, in conjunction with No 617 Squadron.

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<sup>30</sup> TNA AIR14/3411 ORSBC Final Raid Report No 581: Juvisy, 18/19 April 1944, 15 July 1944 and Final Raid Report No 582: La Chapelle, 20/21 April 1944, 23 July 1944.

<sup>31</sup> Robert Owen, *Considered policy or haphazard evolution?*

The execution of the Transportation Plan called upon the resources of Bomber Command as a whole and therefore involved the entire gamut of target marking techniques available at that time. This provided ORSBC with an opportunity to compare the relative effectiveness of a variety of target marking techniques and the subsequent report provides an objective assessment of the effectiveness of the No 5 Group low-level marking technique<sup>32</sup>. This report compared the effectiveness of four target marking techniques, as follows:

A/ *Continuous Oboe*, in which the marking of the target was constantly maintained by TI's dropped by *Oboe* Mosquitoes at intervals throughout the raid. The markers dropped using those *Oboe* channels that were expected to be the most accurate were distinguished by the use of TI's of a distinctive colour, with the Main Force crews briefed to aim at those in preference.

B/ *Musical Newhaven*, in which the target was initially marked with proximity markers by *Oboe* Mosquitoes several minutes before Zero-hour. These markers would be used by illuminating aircraft to drop flares, in the light of which Visual Markers would mark then A/P with distinctive salvoes of TI's. These TI's would be backed-up throughout the duration of the raid with TI's of a different colour. In some raids, a Master Bomber would direct the bombing

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<sup>32</sup> TNA AIR14/4599 ORSBC Report S.154 'A Comparison of the Marking Techniques used on Marshalling Yard attacks', 9 May 1944.

by radio telephone, in which case the technique would be known as '*Controlled Musical Newhaven*'<sup>33</sup>.

C/ *Controlled Oboe*, in which all the *Oboe* Mosquitoes attacked before zero hour, each using a different colour or type of TI according to the accuracy expected using that particular *Oboe* Channel. The target would then be illuminated by flares, in the light of which a Master Bomber would assess the accuracy of the *Oboe* markers and direct the main force to bomb those markers.

D/ *Visual Groundmarking*, in which the target was illuminated before zero hour by lines of flares, either dropped with the aid of proximity markers or by H2S. In the light of those flares, the A/P would be marked visually from low level using Red Spot Fires<sup>34</sup>. The accuracy of the Red Spot Fires would be assessed by a Master Bomber, who would call for the most accurately placed markers to be backed-up with further Red Spot Fires.

The marking for the first three of these techniques was provided by the Pathfinder Force. The latter was the low-level marking technique developed by the No 5 Group, and was only used by that Group.

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<sup>33</sup> This technique was a variation of the standard *Newhaven* technique but, because the small size of the target would be unlikely to be distinctive on the PPI of H2S and were within the range of *Oboe*, the latter was used to drop the proximity markers.

<sup>34</sup> TNA AIR14/2692 ORSBC Report S.167 'The Distribution of Bombs Achieved in *Oboe* Groundmarking attacks on Marshalling Yards by Bomber Command between 6<sup>th</sup> March and 11<sup>th</sup> April 1944', 16 May 1944. In the earlier raids considered in this ORSBC report, the visual marking was carried out using Lancaster aircraft equipped with a MKXIV bombsight but from 18/19 April onwards Spot Fires were dropped by Mosquitoes from a shallow dive using a gunsight.

In order to ensure a common basis for comparison, the ORSBC report assessed effectiveness on the basis of the ratio of the number of hits achieved to the number expected, this being a density of 4 hits per acre at the A/P<sup>35</sup>. In order to take account of the different bomb sizes used, the assessment was made on the basis of 'equivalents' assuming that all bombs were of the same weight<sup>36</sup>. An alternative measure of effectiveness was also used in the report, this being the proportion of attacks that attained or exceeded 70% of expectation, this figure corresponding the expectation that 70% of bomb craters could be plotted<sup>37</sup>. It followed that any raid on which the number of observed hits exceeded 70% of the expected number could be considered successful. The results obtained are summarised in the table below:

Marking Technique	No. of raids	Bombs dispatched as % of estimate	Bombs dropped as % of bombs	Hits achieved as % of hits	% of raids on which achievement exceeded 70%
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<sup>35</sup> Ibid. This report was issued just after ORSBC Report S.154 and provided much of the detailed information absent from the earlier report. The origins of the figure of 4 hits per acre at the A/P are not explained in the ORSBC report, although this appears to relate to the expectation of the accuracy that was possible rather than the figure of 3 hits per acre deemed required to put a marshalling yard out of action.

<sup>36</sup> The bomb loads for these attacks were almost exclusively comprised of 500lb and 1,000lb high explosive bombs, and varied according to the type of aircraft employed (the divided bomb bay of the Stirling precluded the carrying of large numbers of 1,000lb bombs). The destructive power of the 1,000lb was 1.5 times that of the 500lb bomb, such that the assessment was made on the basis that the bomb load was comprised entirely of 500lb bombs, with an equivalence factor built in to allow for the greater destructive power of the larger bomb.

<sup>37</sup> The 30% of bomb craters that could not be plotted comprised of gross errors outside of photographic coverage and bombs within the main distribution that failed to explode.

		required	dispatched	expected	of expectation
Continuous Oboe	15	93	91	57	27
Musical Newhaven	5	131	93	64	40
Controlled Oboe	6	89	94	79	50
Visual Groundmarking	3	110	89	93	100
All Techniques	29	99	92	66	40

Table 9/ Comparison of marking techniques used for attacks on marshalling yards. Source: TNA AIR14/4599 ORSBC Report S.154 *A Comparison of the Marking Techniques used on Marshalling Yard attacks*, dated 9 May 1944.

It is clear from the above that the No 5 Group technique of *Visual Groundmarking* produced considerably better results than the three techniques employed by the Pathfinder Force, both in terms of the number of hits achieved as a percentage of hits expected and the percentage of raids on which achievement exceeded 70% of expectation<sup>38</sup>. Indeed, *Visual Groundmarking* was the only technique in which the number of hits achieved

<sup>38</sup> ORSBC acknowledged that the No 5 Group Visual Groundmarking technique had only been used on 3 occasions, but did not consider that this undermined the overall result.

was not significantly below the percentage of hits expected. The ORSBC report does not consider the reasons for the greater effectiveness of the *Visual Groundmarking* technique and neither does it provide any information about actual bomb distribution: these considerations formed part of a subsequent ORSBC reports discussed below. Nonetheless, this report does confirm that the combination of low-level visual marking and control of the bombing by a Master Bomber was the most effective technique for attacking small targets and provides further evidence that the target marking technique employed was itself determinative of the outcome of a raid.

Before leaving this ORSBC report, the effectiveness of the target marking techniques employed by the Pathfinder Force also requires consideration. Most noteworthy is that the results achieved using the *Controlled Oboe* which, whilst inferior to those achieved with *Visual Groundmarking*, nonetheless demonstrated the efficiency of that technique. This led ORSBC to recommend that *Controlled Oboe* should be used where it was not possible to use *Visual Groundmarking*, this being one of a number of occasions where operational research in relation to target marking techniques led to recommendations being made for future operations<sup>39</sup>. Also noteworthy was the comparative inefficiency of the *Musical Newhaven* technique with which, although the number of bombs dispatched significantly exceeded the percentage estimated to be required, the number of hits achieved as percentage of hits expected was considerably below that achieved by *Visual Groundmarking*. It is accepted that not all of these raids were undertaken as *Controlled Musical*

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<sup>39</sup> The importance of operational research to the development of target marking techniques is discussed in more detail in Chapter 8.



*Newhaven*, and this would suggest that the absence of a Master Bomber resulted in a greater spread in the visual marking, such that the Principle of Cumulative Dispersion resulted in a lower concentration of bombing at the A/P. This supposition is supported by the results achieved using the *Continuous Oboe* technique, which did not employ a Master Bomber, and which were inferior to those achieved by both *Controlled Oboe* and *Musical Newhaven*. The implication was that the use of a Master Bomber was key to maximising the efficiency of target marking techniques, a contention that is examined in detail in Chapter Seven.

As a target set, marshalling yards provided a relatively compact target area within which bomb distribution could be more accurately plotted than in relation to area targets. As a result, it is noticeable that the ORSBC reports of this period take a different form to those relating to area targets and typically include a more mathematical analysis of the bomb distribution. In particular, there is an increasing tendency in these reports to equate bomb distribution to the Gaussian Distribution Function. The ORSBC reports typically show the Gaussian Distribution curves in terms of the distance of bombs plotted in relation to line, range and radial distance from the M.P.I of the markers dropped, expressed as a percentage. The use of the Gaussian Distribution as a measure provides a more accurate picture of bomb distribution although, because the M.P.I. of bombs dropped did not usually equate to the A/P, it should be noted that the Gaussian Distribution curve does not necessarily equate to the bomb distribution around the A/P and therefore accuracy (i.e. the systematic error).

A report produced by ORSBC showed that the bomb distribution in relation to attacks on Marshalling Yards carried out using the *Musical Parramatta* technique closely conformed to Gaussian Distribution curves<sup>40</sup>. No similar analysis has been found in relation to other target marking techniques but, given that the earlier ORSBC report found *Musical Parramatta* to be by some margin the least effective of the four techniques studied, it may be assumed that the Gaussian Distribution curves would at least be similar to (if not better than) those for *Musical Parramatta*. ORSBC found that the bomb distribution pattern resulting from Musical Parramatta attacks to be slightly elliptical, with the longer axis along the line of approach (i.e line error). This partly reflected the use of sticks of bombs rather than individually aimed bombs, but also the greater difficulty generally experienced by bomb aimers of assessing range as opposed to line. The mean Gaussian Distribution curves for the attacks examined by ORSBC are shown in Fig 26/ below, from which it can be seen that the curve in relation to bomb distribution across the line of flight is steeper and with a narrower base than that for bomb distribution along the line of flight, thereby resulting in an elliptical pattern of bomb distribution.

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<sup>40</sup> TNA AIR14/2692 ORSBC Report S.167 'The Distribution of Bombs Achieved in Oboe Groundmarking attacks on Marshalling Yards by Bomber Command between 6<sup>th</sup> March and 11<sup>th</sup> April 1944', 16 May 1944. This report refers to the technique as *Oboe Groundmarking*, but for consistency the description *Musical Parramatta* is used here.

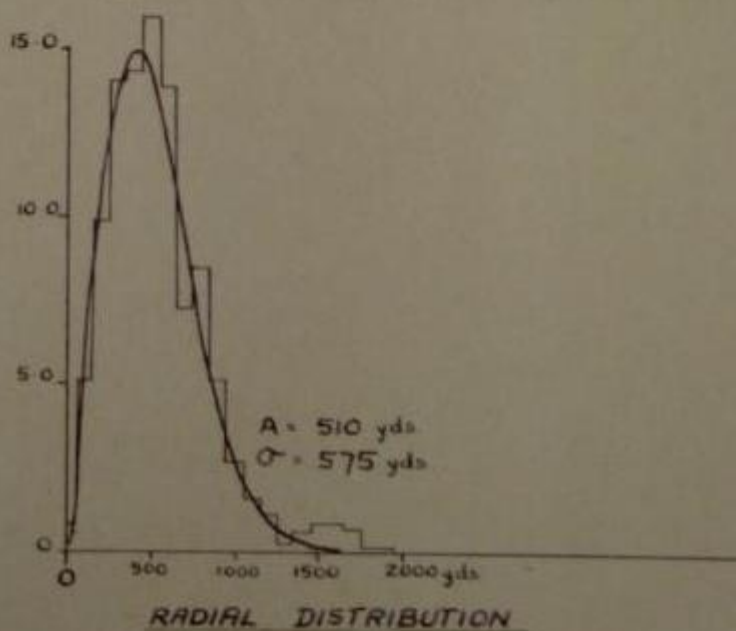
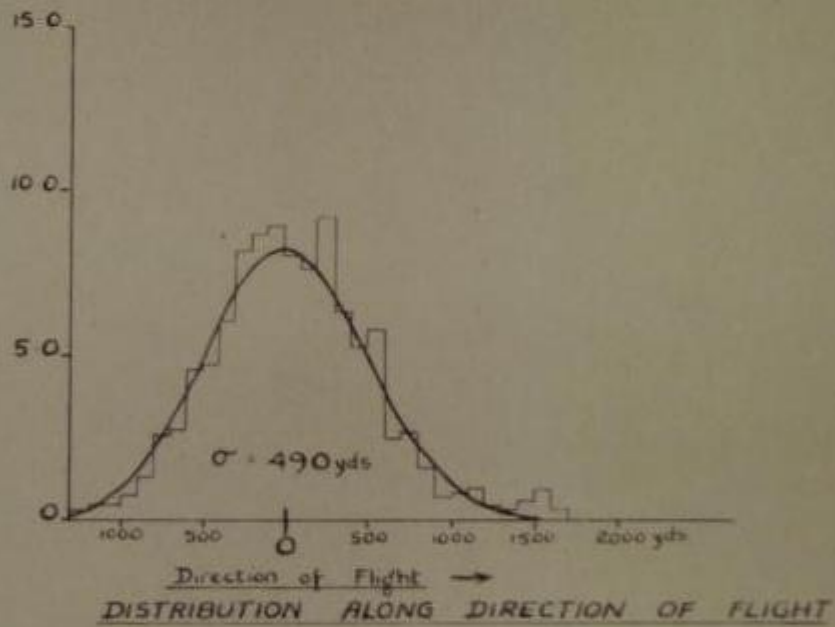
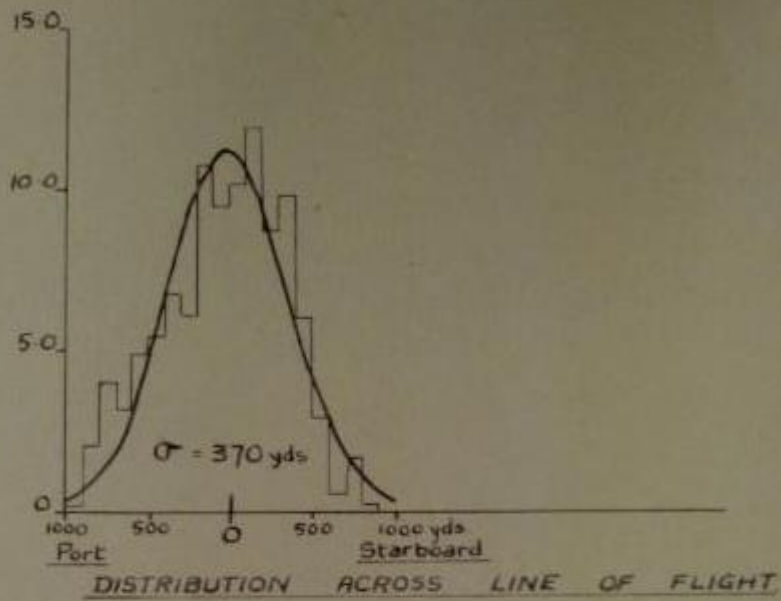


Fig 26/ Mean Gaussian Distribution curves for attacks of Marshalling yards using *Musical Parramatta* Source: TNA AIR14/2692 ORSBC S.167 *The Distribution of Bombs Achieved in Oboe Groundmarking attacks on Marshalling Yards by Bomber Command between 6<sup>th</sup> March and 11<sup>th</sup> April 1944*, dated 16 May 1944.

The other notable feature shown in these diagrams is the actual extent of the range and line errors concerned, these being a mean line error of 370 yards and a mean range error of 490 yards. The average Probable Radial Error was 510 yards. The average Systematic Error was 485 yards, the average Overall Systematic Error was 680 yards and 28% of bombs dropped were more than 1,500 yards from the A/P. These figures are equally remarkable for two very different reasons. Firstly, they are a measure of the progress made since the introduction of the first target marking technique (*Shaker*) a little over two years previously which, at its most effective, only resulted in some 58% of bombs falling within 3 miles of the A/P<sup>41</sup>. Secondly, at the same time the results achieved were an indication of just how inefficient the bombing of the marshalling yards had proven to be<sup>42</sup>. One of the stated objectives of this ORSBC report was to assess the (then) current operational performance against expectations for the campaign against Marshalling Yards, in order to ensure that this important campaign was effectively completed prior to OPERATION OVERLORD. Based upon the bomb distribution and accuracy achieved using *Musical Parramatta*, and in particular the unexpectedly high number of gross errors, ORSBC calculated that the number of aircraft dispatched would need to be increased by 43% if the required density of 4 hits per acre at the A/P was to be achieved. The obvious conclusion was that, notwithstanding the significant improvement in both bombing accuracy and

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<sup>41</sup> See Chapter 3

<sup>42</sup> In this context, the ORSBC accepted that continued improvements in technique would result in increased accuracy and bomb concentration.

concentration resulting from the development and evolution of target marking techniques, in April 1944 Bomber Command was still some way short of being a 'precision' force.

It will be recalled that the target marking technique that came closest to achieving the required degree of efficiency was No 5 Group *Visual Groundmarking*, which had achieved 93% of the hits expected and was the only technique which had exceeded 70% of expectation on every occasion on which it had been used<sup>43</sup>. The technique considered in the ORSBC report was essentially a refinement of that originally employed by No 617 Squadron and, as such, the markers were aimed directly at the A/P. Due to the accuracy of this technique, it was found that the Spot Fires were often obscured during the later stages of the attack by smoke and dust from the first bombs, and as a result it had been observed that bombing was highly concentrated at the start of the attack but became more scattered as the raid progressed. There were also several occasions where the Spot Fires had been extinguished by the blast from bombs bursting close by and this had necessitated the re-marking of the target mid-way through the attack. This raised the spectre that the re-marking or backing-up of earlier markers could lead to confusion, especially if communication between Master Bomber and Main Force was poor. It was also operationally disadvantageous not only to expose the marking aircraft to ground defences for a second time but also to keep part of the Main Force waiting in a target area in which night fighters could be present while the target was re-marked. The solution to these problems resulted in possibly the

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<sup>43</sup> TNA AIR14/4599 ORSBC Report S.154 'A Comparison of the Marking Techniques used on Marshalling Yard attacks', 9 May 1944. See discussion above.

most significant development in the evolution of target marking techniques: 'Offset' marking (also known as 'Vector' marking), in which the markers were placed not at the A/P itself but at a prominent landmark nearby. 'Offset' marking was therefore the first in a series of techniques that fall under the generic term of 'indirect marking'.

'Offset' marking exploited the fact that the trail angle of a bomb is affected by wind speed and that it was therefore always necessary for bomb aimers to set the wind speed into the bombsight. 'Offset' marking was achieved by setting a 'false' wind into the bombsight such that bombs aimed at the markers would fall instead on the A/P. The wind speed in the target area was found by a number of aircraft equipped with H2S and A.P.I., and the average 'found' wind speed transmitted to the Master Bomber. Using the average wind speed, the Master Bomber calculated the 'false' wind speed necessary to achieve the required degree of offset and would transmit this information to the Main Force. The point on the ground on which the markers would be aimed, usually a conspicuous ground feature some 300-400 yards from the A/P and known as the 'Marking Point', would be illuminated with flares (sometimes with a proximity marker dropped by *Oboe*) and marked visually from a low-level with Spot Fires. Once the Master Leader was satisfied with the accuracy of the marking, the Master Bomber would instruct the Main Force to bomb on a designated heading by aiming at the Spot Fires with the false wind set on the bombsight.

The introduction of 'Offset marking' led to an immediate improvement in accuracy, both in relation to the earlier version of the No 5 Group technique but also in terms of the comparative accuracy of other target marking techniques. By the time that 'Offset marking' was introduced<sup>44</sup>, constant practice of and refinement in other target marking techniques had also resulted in an improvement in the accuracy of those methods and the comparative accuracy is shown in the table below<sup>45</sup>.

	Musical Parramatta	All techniques	Offset Marking	
	April	May	May	June
Proportion of Ineffectives, including early returns	44%	17%	19%	-
Average Systematic Error	485 yards	175 yards	110 yards	116 Yards

<sup>44</sup> Offset marking was first used on the night of 8/9 May 1944

<sup>45</sup> TNA AIR14/2692 ORSBC Report S.168 'Bombfall distribution of precision attacks carried out by No 5 Group 19<sup>th</sup> April -31<sup>st</sup> May', 30 June 1944; TNA ORSBC Report S.167 'The Distribution of Bombs Achieved in Oboe Groundmarking attacks on Marshalling Yards by Bomber Command between 6<sup>th</sup> March and 11<sup>th</sup> April 1944', 16 May 1944 *and* TNA AIR14/4599 ORSBC Report S.192. 'Summary of analysis of day and night raids on small targets in occupied territory between March and September 1944', 6 December 1944. This table is a compilation of data contained in these ORSBC reports although, because the parameters used in these reports varied, it has not been possible to provide data for all categories. In the interest of consistency, the terminology used in the table above has been amended from that in the ORSBC report.

Average Probable Radial Error	480 yards	335 yards	265 yards	121 yards
Marking Error	319 yards	-	135 yards	116 yards
Bombing Error	361 yards	-	100 yards	121 yards
Average Overall Systematic Error	680 yards	380 yards	235 yards	237 yards
Density of bombs at A/P per 1000 bombs dropped	2.20	2.86	5.43	5.76
Variability Coefficient	-	73%	-	44%

Table 10/ Comparative accuracy of target marking techniques. Source: TNA AIR14/2692 ORSBC Report S.168 *Bombfall distribution of precision attacks carried out by No 5 Group 19<sup>th</sup> April -31<sup>st</sup> May*, dated 30 June 1944; TNAORSBC S.167 *The Distribution of Bombs Achieved in Oboe Groundmarking attacks on Marshalling Yards by Bomber Command between 6<sup>th</sup> March and 11<sup>th</sup> April 1944* and TNA AIR14/4599 ORSBC Report S.192.

It can be seen from the above that the Offset Marking technique resulted in a significant improvement in accuracy, reducing the Average Systematic Error to 110 yards compared with 175 for all techniques. The Offset Marking technique also resulted in a significant improvement in bombing concentration, reducing the average Probable Radial Error to 265 yards; this



was nearly half that resulting from the *Musical Parramatta* technique in the previous month. The result was a substantial reduction in the Average Overall Systematic Error, which fell from 680 yards with Musical Parramatta to 235 yards when Offset Marking was employed. This latter figure was comprised of a Marking Error of 135 yards and a Bombing Error of 100 yards<sup>46</sup>. Bomb distribution was found to be slightly elliptical, with an average line error of 193 yards and an average range error of 225 yards; this compares with average errors of 250 yards and 285 yards respectively for *Visual Groundmarking* before the introduction of Offset Marking. There was a further improvement in the Marking Error in June but, due to a slight increase in the Bombing Error<sup>47</sup>, the Overall Systematic Error marginally increased, albeit results with *Visual Groundmarking* remained significantly better than with other techniques. In particular, it may be noted that the density of bombs at A/P per 1000 bombs dropped achieved with *Visual Groundmarking* was nearly double that for other techniques, demonstrating the superiority of these technique both in terms of accuracy and concentration at the A/P. The *Visual Groundmarking* technique was also the most consistent of the target marking techniques employed, with a Variability Coefficient of 44% compared with 73% for other techniques

In addition to overcoming the issues associated with the obscuration of markers by smoke from early bombs, ORSBC attributed the improved results

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<sup>46</sup> TNA AIR14/2692 ORSBC Report S.168 'Bombfall distribution of precision attacks carried out by No 5 Group 19<sup>th</sup> April -31<sup>st</sup> May', 30 June 1944. The equivalent results for June 1944 are presented using different parameters in a later ORSBC Report and have not been included in this table.

<sup>47</sup> TNA AIR14/4599 ORSBC Report S.192. 'Summary of analysis of day and night raids on small targets in occupied territory between March and September 1944', 6 December 1944. ORSBC noted that bombing error increased inversely in relation to the strength of defences and that this trend was more pronounced with 'controlled' techniques. This increase in bombing error was noted with all techniques and was largely attributed to increasing night fighter activity in the target area.

obtained by Offset Marking to the use of a Master Bomber to eliminate the influence of incorrectly placed markers and thereby provide a single point of aim. The provision of a single wind speed for input into the bombsight was also considered to reduce the spread of bombs by eliminating the variations that resulted when the wind speed input into the bombsight was calculated by individual crews or at Group level. However, none of this was itself new. It will be recalled that the provision of a single point of aim, essential to minimising the effect of the Principle of Cumulative Dispersion, was an important factor in the comparative concentration achieved using *Oboe* and H2S, and the broadcast of a 'found wind' had become a standard part of Bomber Command attacks during the Battle of Berlin<sup>48</sup>. The improvement resulting from Offset Marking can therefore be attributed primarily to the provision of a distinctive single point of aim that remained visible throughout the duration of the attack and, therefore, achieved the prime objective of any target marking technique.

Nevertheless, in common with all other forms of Visual Groundmarking, Offset Marking was not without disadvantages. The *Visual Groundmarking* techniques employed by No 5 Group were all dependent upon the Marker Leader being satisfied that the Spot Fires were correctly placed. If the Marker Leader and/or Master Bomber were not satisfied, the marking procedure was repeated until the Marking Point was clearly marked<sup>49</sup>. The delay necessitated the Main Force to wait in the target area, thereby negating one of the main benefits offered by Offset Marking in terms of the obviating the delay caused by the necessity to re-mark a target where the initial markers

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<sup>48</sup> Harris, *Despatch on War Operations 23<sup>rd</sup> February 1942 to 8<sup>th</sup> May 1945*, p178.

<sup>49</sup> Additional flare dropping aircraft were made available for this eventuality.

were obscured by smoke or dust from the first bombs. A dramatic demonstration of this drawback occurred during the raid on a military depot at Mailly-le-Camp on the night of 3/4 May 1944 when, although the initial markers were accurately placed, the Master Bomber was unable to transmit instructions to the Main Force due to interference on the designated radio frequency<sup>50</sup>. The attack was eventually initiated by the Deputy Master Bomber but the resultant delay enabled night fighters to reach the target area and 42 Lancasters (11.6% of the force) were lost<sup>51</sup>. It was this risk of heavy losses that led ORSBC to conclude that even though *Visual Groundmarking* resulted in greater bombing success and was the most reliable method, it did not follow that it was always best to employ this technique on defended targets<sup>52</sup>. This facet of the *Visual Groundmarking* technique would later raise questions about its future use against well defended German targets.

The importance of good communication between Master Bomber, Marker Leader and the Main Force had already been realised and had resulted in the introduction of 'Link' aircraft as a standard feature of the Offset Marking techniques. The role of these aircraft, all from the Lancaster-equipped Nos. 83 and 97 Squadrons, was to confirm that the instructions of the Master Bomber could be clearly heard and to re-broadcast the VHF transmissions to the main force in HF. As a failsafe, these aircraft were to transmit the instructions from

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<sup>50</sup> TNA AIR14/3411 ORSBC Final Raid Report No 595: Maily-le-camp, 3/4 May 1944, 29 July 1944.

<sup>51</sup> Middlebrook and Everitt, *The Bomber Command War Diaries*, p505. A detailed account of the Maily-le-Camp raid, including the circumstances surrounding the interference with radio communications, can be found in Jack Currie, *Battle under the Moon: the documented account of Maily-le-Camp, 1944* (Wilmslow: AirData Publications Limited, 1995).

<sup>52</sup> TNA AIR14/4599 ORSBC Report S.192. 'Summary of analysis of day and night raids on small targets in occupied territory between March and September 1944', 6 December 1944.

the Master Bomber in Morse should the HF transmissions not be received by aircraft in the Main Force. The value of these Link aircraft was demonstrated during a raid on Darmsdadt on the 25/26 August 1944, when the Controller's VHF failed and both Deputy Controllers were shot down en route to the target<sup>53</sup>. Control of the raid was assumed by 'Link 3', who recognised that the flares had been dropped too low and too far west. In the event, the Marker Leader could not identify the target and no marking was carried out. The bombing was widely scattered but the presence of the Link aircraft, and the initiative shown by Link 3, negated the need for the Main Force to linger in the target area and potentially prevented a repeat of the losses experienced at Mailly-le-Camp.

However, re-transmission of instructions in HF caused delay and, because it was limited to a few pre-selected code words, the use of Morse code was not as flexible as the spoken word. Consequently, even before the Mailly-le-Camp raid had revealed the full extent of the problem, the AOC of No 5 Group, Air Vice-Marshal Sir Ralph Cochrane, had pressed for all aircraft in the Group to be equipped with VHF<sup>54</sup>. The Deputy C-in-C Bomber Command duly requested the provision of sufficient VHF sets to equip No 5 Group from the Air Ministry<sup>55</sup>. Following the difficulties experienced in controlling the main force in raids on Brunswick and Munich (see below), Cochrane repeated his request, claiming that "...we should have put another 50% of bombs around

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<sup>53</sup> TNA AIR14/2083 Interim Raid Report: Darmsdadt, 25/26 August 1944; TNA AIR14/3411 Final Night Raid Report No 697: Darmsdadt, 25/26 August 1944, 29 January 1945.

<sup>54</sup> TNA AIR14/1255 Memorandum Headquarters No 5 Group to Deputy C-in-C Bomber Command, Headquarters Bomber Command 'Supply of V.H.F. to aircraft in No 5 Group', 17 April 1944.

<sup>55</sup> Ibid Letter from Deputy C-in-C Bomber Command, Headquarters Bomber Command to the Air Ministry, Supply of V.H.F. to aircraft in No 5 Group, dated 24 April 1944.

the aiming point” had the whole Group been fitted within VHF<sup>56</sup>. Notwithstanding that VHF sets were in short supply, Cochrane got his aircraft fitted at the rate of one operational squadron per week and - as shown below - Cochrane made good his claim in terms of the increased percentage of bombs around the A/P<sup>57</sup>.

The other requirement for *Visual Groundmarking* was good visibility at ground level and it was this requirement that resulted in a higher Proportion of Ineffectives with this technique, as shown in the table above. For the purposes of that table, the Proportion of Ineffectives included gross errors, unexploded bombs and early returns<sup>58</sup>. The *Visual Groundmarking* technique resulted in fewer gross errors and it was therefore the early returns that contributed to the higher Proportion of Ineffectives with this technique. In practice, this meant that although the *Visual Groundmarking* technique produced better results than other target marking techniques under suitable conditions, under certain conditions *Visual Groundmarking* could not be employed at all. It follows that the *Visual Groundmarking* technique was not as reliable as other techniques and it was the view of ORSBC that other target marking techniques would continue to be required<sup>59</sup>.

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<sup>56</sup> Ibid Memorandum Headquarters No 5 Group to C-in-C Bomber Command, Headquarters Bomber Command, Supply of V.H.F. to aircraft in No 5 Group, dated 28 April 1944.

<sup>57</sup> TNA AIR14/1255 Letter from the Air Ministry to C-in-C Bomber Command, Headquarters Bomber Command, Supply of V.H.F. to aircraft in No 5 Group, dated 12 May 1944.

<sup>58</sup> The Proportion of Ineffectives is normally defined as the proportions of bombs dropped that for a variety of reasons do not contribute to the normal bomb distribution. Bombs not dropped due to the early return of the aircraft would therefore not normally be included in this figure.

<sup>59</sup> TNA AIR14/4599 ORSBC Report S.231 'A Comparison of high and low-level visual marking on defended German targets', 28 April 1945.

The above analysis shows that the *Visual Groundmarking* technique, particularly when 'Offset marking' was employed, was the most efficient of the target marking techniques available to Bomber Command. However, this success had been achieved only against relatively lightly defended precision targets within *Oboe* range. The question therefore remained whether the technique would translate to heavily defended area targets in Germany beyond *Oboe* range (and therefore deprived of an accurately placed proximity marker to guide the initial illumination of the target area). Setting aside momentarily the question as to whether the low-flying marking aircraft would survive the German defences, the *Visual Groundmarking* technique would itself require some modification for area attacks.

The essence of the technique remained unchanged, but now with the target being marked by low-flying Mosquitoes using a gunsight rather than a bombsight<sup>60</sup>. The second modification was that the dropping of the proximity marker were now undertaken by aircraft equipped with H2S and, from August 1944, with their position confirmed using S.S. LORAN<sup>61</sup>. The illumination of the target was now in two phases, known as Flare Force I and Flare Force II, with the latter only being required if there was a delay in the initial marking procedure. The Marking Point, now some 1,000 to 2,000 yards from the A/P, was marked visually by 'Marker Aircraft' led by a Marker Leader using a T.I. (Red) and backed-up throughout the attack by T.I.s (Green). The accuracy of

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<sup>60</sup> RAFM, Aircraft Movement Cards. The Mosquito Mk BXVI's previously loaned to the squadron were bomber variants and therefore not equipped with gunsights. The low-level marking technique using a gunsight required the use of the fighter-bomber version of the Mosquito, the Mk FBVI, two of which (NS992 and NS993) were supplied to No 617 Squadron as replacements for the bomber variants previously provided.

<sup>61</sup> The two squadrons involved, No 83 Squadron and No 97 Squadron, were those transferred back to No 5 Group from No 8 Group in April 1944.

the initial T.I. (Red) was checked by the Marker Bomber and, if not sufficiently accurate, would be cancelled by placing a T.I. (Yellow) over the errant marker. To assist in this, the Master Bomber controlled the operation (also using a Mosquito aircraft) from a height of some 1,000ft. The Main Force, now operating from a higher altitude of circa 17,000 ft as a concession to the better defended target set, was instructed to bomb on a designated track and to aim for the Marking Point but to release their bombs after a given number of seconds according to the distance of the Marking Point from the A/P. In this respect, the technique was an extension of the 'time & distance' technique that Cochrane had advocated in April 1943 and employed by No 5 Group in the raid on the Peenemünde rocket research facility in August 1943, in which the start datum point was a marker rather than geographical feature (see Chapter Seven).

This technique had in fact been used on two occasions prior to the commencement of the Transportation Plan, the first unsuccessfully against Brunswick on the night of 22/23 April 1944<sup>62</sup>. Although technically an operational failure, this raid is nonetheless of some importance in the development of target marking techniques, in that this was the first occasion on which the *Visual Groundmarking* technique had been used over a heavily defended city. Despite some initial problems with illumination by the flare force, the primary marking was accurate and the failure on this occasion was attributed to faulty communication between the Marker Leader and the Master Bomber. The technique was tried again with more success against Munich on

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<sup>62</sup> TNA AIR14/3411 ORSBC Final Raid Report No 584: Brunswick 22/23 April 1944, 24 July 1944. Further details are provided in Middlebrook and Everitt *The Bomber Command War Diaries*, p499.

the 24/25 April 1944<sup>63</sup>, and then with considerable success on the 18/19 September 1944 in a raid against Bremerhaven using a comparatively small Main Force of 206 Lancasters<sup>64</sup>.

Just as the No 5 Group *Visual Groundmarking* proved to be the most effective target marking technique for precision attacks during the first half of 1944, so it would prove to be most effective in area attacks. An ORSBC report issued in April 1945 compared the high and low-level visual marking on defended targets in relation to accuracy, reliability and loss rates<sup>65</sup>. The principal finding was that the average radial error of the TIs dropped using the No 5 Group *Visual Groundmarking* technique was 299 yards, compared with 1058 yards for high level marking using the Mk XIV bombsight (i.e the *Controlled Newhaven* technique). The low-level technique was found to be less dependent upon clear weather conditions and could often be carried out beneath 10/10 stratus cloud which prevented high level marking: the report found that in conditions of 10/10 cloud cover below 10,000ft it was possible to mark the target on four out of six (66%) occasions using the low-level

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<sup>63</sup> TNA AIR14/3411 ORSBC Final Raid Report No 586: Munich 25/25 April 1944, 20 July 1944. Further details are provided in Middlebrook and Everitt *The Bomber Command War Diaries*, p497.

<sup>64</sup> TNA AIR14/3411 ORSBC Final Raid Report No 718: Bremerhaven, 18/19 September 1944, 1 February 1945. Further details are provided in Middlebrook and Everitt *The Bomber Command War Diaries*, p499.

<sup>65</sup> TNA AIR14/4599 ORSBC Report S.231 'A Comparison of high and low-level visual marking on defended German targets', 28 April 1945. This report acknowledged that marking using the *Parramatta* technique was likely to be significantly less accurate beyond *Oboe* range because of the spread of markers using H2S, and consequently the results using that technique were not considered in the report.



technique but on only one in ten (10%) of occasions when the target was marked from the standard operational altitude<sup>66</sup>.

The findings of this ORSBC report are not in themselves surprising given the unambiguous point of aim provided by the *Visual Groundmarking* technique, but the conclusions of the report are of particular interest. These conclusions highlighted the importance of aligning the concentration of the bombing with the A/P, noting that the (then) current systematic error with high-level marking techniques was of the same order as the random bombing error at about 1,000 yards. The corollary was that a large bombing force was necessary to achieve the required density of bombs at the A/P, thereby resulting in a significant wastage of bombs. A further consequence was that, unless accompanied by a commensurate reduction in the systematic error, any improvement on the standard of bomb-aiming by the Main Force (thereby reducing the random bombing error) would actually result in a reduction in the percentage of bombs falling on the A/P. The report went on to conclude that the principal factor in determining the systematic error was the accuracy with which primary marking was accomplished and that, in the absence of a long range radar device comparable with the accuracy of *Oboe*, the only prospect of improving primary marking was with the *Visual Groundmarking* technique. It was also noted that this technique had the additional benefits of being more reliable than high level marking and, by employing a smaller bombing force, of reducing the wastage of bombs. It was accepted that the technique had been employed by a relatively small force specially trained in the procedures

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<sup>66</sup> This is not the same as low level cloud, which reduced visibility close to the ground and prevented visual marking from a low-level, and which had caused some attacks to be abandoned during the build-up to OPERATION OVERLORD.

involved and acknowledged the difficulties that would be experienced transferring this technique to a larger force comprised of several Groups, although it is not clear whether the difficulty envisaged related to the use of the technique by a single large force or the use by several smaller forces from the various Groups. In any event, ORSBC did not consider the problems insurmountable and, in view of the advantages conferred by the low-level technique, recommended that consideration should be given to using this technique in “any future campaign against long-range targets”<sup>67</sup>.

The ORSBC report is not only a ringing endorsement of the *Visual Groundmarking* technique, it was an indictment of the standard target marking techniques used by the Pathfinder Force and which had served Bomber Command so well during the middle years of the bombing offensive. It is also a testament to the speed of development of target marking techniques that those employed by the Pathfinder Force, which the previous year had been at the forefront of the Bomber Command inventory, were now considered inferior to a technique that had not been devised at that time. There is no record of any views expressed by Bennett or Cochrane about this ORSBC report but the obvious question that this report raises - that is, why the low-level technique was not adopted earlier - is addressed in the conclusion of this thesis.

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<sup>67</sup> Given the timing of this report, April 1945, it must be assumed that this last remark related to the operations in the Far East, and this may have been one of the considerations that led to the selection of No 5 Group to form ‘Tiger Force’ for deployment in the Far East at the end of hostilities in the E.T.O.

However, even before the highly successful use of *Visual Groundmarking* on the Bremerhaven raid of 18/19 September 1944, a further variation of the basic technique had been employed. In this variation, the Main Force was divided into three sections, each of which would bomb the same single Marking Point using a given time overshoot. The innovative aspect of this technique was that each of the three sections would bomb using a different heading, such that the bomb distribution was not centred on an Aiming Point but on an 'Aiming Line', this line being the arc of a circle with the Marking Point at its centre. The size of the arc would be governed by the deviation between the headings on which the sections attacked. Using this technique, the bomb distribution could be varied by adjusting the size of the arc and/or increasing the number of headings employed: the former was achieved by increasing the deviation between the headings on which each section bombed. This technique was known as 'Line Bombing' and was used by No 5 Group until the end of 1944.

Because of the absence of a defined A/P with the Line Bombing technique, the standard measure of accuracy and concentration at that time (the Systematic Error and Probable Radial Error respectively) could not be employed<sup>68</sup>. The previously used measure of the percentage of bombs within 3 miles of the A/P was similarly redundant. The effectiveness of Line Bombing was, however, demonstrated on the very first raid on which it was employed, against Königsberg on the 29/30 August 1944<sup>69</sup>. The initial marking was using

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<sup>68</sup> TNA AIR14/2693 ORSBC Report S.249 'Systematic Errors in Bomber Command Operations', 16 October 1944.

<sup>69</sup> TNA AIR14/3411 ORSBC Final Raid Report No 701: Königsberg, 29/30 August 1944, dated 28 December 1944. Königsberg is now Kaliningrad in Lithuania.

Red Spot Fires but these were assessed by the Controller as being inaccurate and, in accordance with the Marking Plan, a set of Green Spot Fires was dropped. These were assessed as being accurate and Main Force instructed to bomb the centre of the Green Spot Fires on the pre-briefed headings. Accordingly, aircraft of 52 Base bombed the M.P.I. of the Green Spot Fires with a delay of 22 seconds on a heading of 067°; those of 53 Base with a delay of 15 seconds on a heading of 040°; and those of 55 Base with a delay of 8 seconds on a heading of 102°<sup>70</sup>. The result was that 86% of bombs fell within the target area, and 69% of the built-up area was destroyed.

An even more convincing demonstration of the efficiency of Line Bombing was provided on the second occasion on which this technique was used, this being on the night of 11/12 September 1944 during an attack on Darmstadt by 226 Lancasters and 14 Mosquitoes<sup>71</sup>. The Marking Point for the raid was a military exercise yard, a prominent landmark to the south of the town centre. Illumination of the target area began at 23:46 and almost immediately the Marking Point was identified by the low-flying Marker aircraft. The initial marking was accurate, with an average error of 290 yards; the closest TI was just 90 yards from the Marking Point, and no TI was further away than 440

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<sup>70</sup> By 1943, with the rapid growth in the number of bomber airfields, it became apparent that it would be impractical to control up to fifteen airfields from a single Group headquarters and that some intermediate link was required. Bomber Command therefore instituted the 'Base System' in which the administration of up to six bomber squadrons was organised at a 'Base', usually comprised of one parent airfield and two subsidiary airfields. Each base was identified on a numeric basis composed of two characters, in which the first was the Group number and the second the number for the parent station. For example, No 54 Base was station 4 of No 5 Group. No 54 Base was Coningsby, at which the specialist target marking squadrons of No 5 Group were based (Nos. 83 and 97 Squadrons).

<sup>71</sup> TNA AIR14/3411 ORSBC Final Raid Report No 712: Darmsdadt, 11/12 September 1944, 31 December 1944.

yards<sup>72</sup>. At 22:52 hours the Master Bomber declared that Flare Force II was not required and at 23:56 hours the Main Force was instructed to commence bombing along the two pre-briefed headings. The entire raid, from the first flare dropped by Flare Force I to the last bomb load dropped by the Main Force, lasted 51 minutes. The resulting concentration of bombing produced a firestorm in which an estimated 12,300 people were killed and 70,000 made homeless, from a total population of 120,000 people<sup>73</sup>. In his book *Bomber Command*, Max Hastings devotes an entire chapter to the Darmstadt raid and provided a detailed description of the raid, including both the technical aspects and the effects of the bombing on the civilians of Darmstadt. This raid has always been controversial because of the absence of any major industries in Darmstadt. In this context, it is notable that W.J.Lawrence, who in his book *No.5 Group RAF* is prone to lengthy descriptions of precision attacks carried out by No 5 Group, makes only passing reference to the Darmstadt raid and none at all to the civilian casualties<sup>74</sup>. This is surprising given that, in terms of target marking technique employed and the efficiency with which it was implemented, the Darmsdadt raid may be regarded as an exemplar of the efficiency attained by No 5 Group at that time.

It is a testament to the speed of development of target marking techniques by No 5 Group that, within a month of the Darmstadt raid, Line Bombing was itself superseded as the primary form of *Visual Groundmarking* used by that Group. The latest and final development of this technique was a further

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<sup>72</sup> TNA AIR14/4599 ORSBC Report S.231 'A Comparison of high and low-level visual marking on defended German targets', 28 April 1945.

<sup>73</sup> Hastings, *Bomber Command*, Chapter 13.

<sup>74</sup> W.J.Lawrence, *No.5 Group RAF*, p232.

refinement of Line Bombing in which each aircraft was allocated a separate heading on which to attack and a different timed overshoot. The result was a bomb distribution not around a single Aiming Point or an Aiming Line, but a spread of bombs throughout an 'Aiming Area'. The wedge-shape of this Aiming Area was a part of a circle between two lines drawn from the Marking Point, each with a maximum radius of approximately 2,400 yards. This technique was officially known as 'Sector Bombing' but colloquially as the '5 Group Fan'. The timing and organisation required for this technique, and the precision with which it needed to be carried out, was an indication not only of the complexity to which target marking techniques had now evolved but also the standard of proficiency of the Main Force crews that carried it out.

As with Line Bombing, the absence of a defined A/P with the Sector Bombing technique meant that the effectiveness of this technique could not be measured in terms of the Systematic Error or the Probable Radial Error. However, some measure of the effectiveness of Sector Bombing can be gauged from the fact that some of the most devastating attacks carried out by Bomber Command during the entire Bombing Offensive employed this technique. The first occasion on which Sector Bombing was employed was against Brunswick on the night of 14/15 October 1944 by a force of 233 Lancasters with 7 Mosquitoes in the marking role<sup>75</sup>. This relatively small urban area had poor definition on H2S and had hitherto proved to be a difficult target, with four previous major Bomber Command attacks in 1944 causing little damage, including the previous attack by No 5 Group on the 22/23 April

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<sup>75</sup> TNA AIR14/3411 ORSBC Final Raid Report No 741: Brunswick, 14/15 October 1944, 16 February 1945.

1944 using the original *Visual Groundmarking* technique. The use of Sector Bombing in the October raid resulted in 150 hectares of the historic town centre being destroyed, the level of devastation being such that local officials estimated that 1,000 bombers carried out the raid<sup>76</sup>. Similar levels of devastation were achieved against several other targets, including Heilbronn on the 4/5 December 1944 when 82% of the town's built up area was destroyed<sup>77</sup>, although Karlsruhe escaped a similar fate in February 1945 when cloud-cover caused the raid to be a complete failure<sup>78</sup>. This latter raid serves as a reminder that, even with advanced target marking techniques such as Sector Bombing, the weather could still dictate the success or failure of a raid.

However, the most dramatic example of the effectiveness of Sector Bombing was the firestorm raid on Dresden on 13/14 February 1945<sup>79</sup>. The attack on Dresden was in two parts, separated in time by about three hours, a tactic that had been successfully used in a number of Bomber Command raids in the preceding months<sup>80</sup>. Given the previous success of the *Visual*

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<sup>76</sup> Middlebrook and Everitt, *The Bomber Command War Diaries*, p602.

<sup>77</sup> TNA AIR14/3411 ORSBC Final Raid Report No 783: Heilbronn, 4/5 December 1944, dated 5 March 1945, and Middlebrook and Everitt *The Bomber Command War Diaries*, p627. The latter express the opinion that due to level of concentration achieved, some 1,254 tons of bombs in a few minutes, and a reliable death toll of 7,000, this was another raid in which a genuine firestorm developed but is not widely recognised as such.

<sup>78</sup> TNA AIR14/3411 ORSBC Final Raid Report No 826: Karlsruhe, 2/3 February 1945, 14 March 1945.

<sup>79</sup> For the present purpose, it is not necessary to describe the background to this controversial raid. Full descriptions of the Dresden raid and its consequences can be found in, amongst others; Irving, *The Destruction of Dresden*; A. McKee, *The Devil's Tinderbox: Dresden 1945* (London, 1982); Taylor, *Dresden*; Addison, P. and Crane, J. (eds) *Firestorm: the bombing of Dresden, 1945* (Pimlico, London 2006); Jörg Friedrich *The Fire: The bombing of Germany 1940-1945* (Columbia University Press, New York 2006); and Overy *The Bombing War*. See also Peter W. Gray, 'Dresden 1945 – Just Another Raid', *Royal Air Force Power Review*, 4(1) 2001.

<sup>80</sup> TNA AIR14/3411 ORSBC Final Raid Report No 837: Dresden, 13/14 February 1945, dated 3 March 1945. It is interesting to note that all of the other ORSBC Final Raid Reports referred to in this thesis were published some months after the raid took place. By contrast, the Final Raid Report for Dresden was published less than one month after the raid took place and

*Groundmarking* techniques, it was no coincidence that the first raid, tasked with providing an unmistakable conflagration for the second raid, was provided by No 5 Group. The requirement for an unmistakable conflagration was due, in part, because Dresden was close to the Russian front line. The town was beyond the range of GEE and *Oboe*, and was expected to provide a poor response on H2S. The only navigation aid capable of confirming the precise position at that range was S.S. LORAN and No 5 group was the only Group so equipped<sup>81</sup>.

Although successful from the outset, the Sector Bombing technique had undergone several refinements since first used the previous October. The first of these refinements related to the initial illumination of the target area. The flares and the dropping of the proximity marker was still undertaken by Flare Force I with the aid of the Ground Position Indicator (G.P.I.)<sup>82</sup>, but now the later aircraft in Flare Force I were able to drop their flares either blind using H2S and S.S. LORAN or visually in the light of the first flares. Other than the proximity marker (now known as the 'Primary Green'), the use of T.I.'s (Green) was discontinued and the Marking Point was now marked visually exclusively using T.I.'s (Red) at the beginning of the attack. It had also been recognised that one of the consequences of the Master Bomber operating from a low-level was that he was not able to observe the ground marking as it would appear from the higher altitude at which the Main Force was operating

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before that for other raids that had taken place prior to it – for example, Heilbronn on 4/5 December 1944.

<sup>81</sup> The only other aircraft equipped with S.S.LORAN at that time were the Mosquitoes of the Light Night Striking Force (LSNF), part of No 8 Group PFF.

<sup>82</sup> The Ground Position Indicator was a navigation aid based upon the Air Position Indicator, but with the added capability of accepting wind vectors..



and which was potentially above cloud. The final refinement of the Sector Bombing technique was therefore the introduction of 'Check' aircraft, again Lancaster aircraft from Nos. 83 and 97 Squadrons, the role of which was to confirm whether the TI's were visible at the higher altitude before the instruction to commence bombing was given.

The Marking Point for the Dresden attack was a distinctive sports stadium to the west of the town centre, with the Aiming Area containing the whole of the historic 'Old Town'. The initial illumination by Flare Force 1 was on time and the Primary Green was accurately placed over an S-bend in the River Elbe. The first TI's placed by the Marker Leader were within 100 yards of the Marking Point and these were accurately backed-up by TI's Red by two other marker aircraft. The Check aircraft confirmed that the TI's Red were visible from above a thin layer of cloud over Dresden and, six minutes before zero hour, the Master Bomber was satisfied that marking was complete. The Marker Leader and one reserve were instructed to remain in the target area as Long Stops<sup>83</sup>; the remaining five marking aircraft were sent home without having to drop their markers. The instruction for the Main Force to commence bombing was given by the Master Bomber two minutes before Zero-hour and seventeen minutes later the bombing was complete<sup>84</sup>.

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<sup>83</sup> The 'Long Stop' was tasked with placing a ground-marker bomb (usually yellow) to mark the limit of bombing or to cancel stray TI's. The role of the Long Stop is described in more detail in Chapter Seven..

<sup>84</sup> TNA AIR27/767 No 97 Squadron Operational Record Book

There is some debate as to the effectiveness of this first raid; David Irving and Kevin Wilson<sup>85</sup> both describe a very effective attack whereas Martin Middlebrook/Chris Everett<sup>86</sup> describe it as being 'moderately successful' and Richard Overy as being 'not very effective'<sup>87</sup>. However, some indication of its effectiveness may be gauged from the Final Raid Report, which confirms that the fires from the first raid were visible from a distance of 100 miles. Moreover, the second raid had been planned as a *Controlled Newhaven* to be carried out by the Pathfinder Force but, although the Illuminators dropped a succession of flares, the Master Bomber and Deputy Master Bomber were unable to identify the A/P in the light and smoke of the fires below. The Master Bomber therefore directed the TI's Red and TI's Green to be dropped on each side of the conflagration to mark the limits of the new point of aim, and directed successive waves of the Main Force to aim at these. It is impossible to know to what extent this improvised target marking contributed to the firestorm that developed at Dresden, but nonetheless the flexibility demonstrated by the Master Bomber in re-directing the Main Force is a further indication of the value of this technique.

There were many circumstances that combined to result in the firestorm at Dresden, not the least being that the defences were negligible. This enabled the Main Force in both raids to descend to a much lower altitude for bombing than would normally be the case against a heavily defended city and also

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<sup>85</sup> Kevin Wilson, *Journey's End: Bomber Command's Battle from Arnhem to Dresden and Beyond* (London: Weidenfeld and Nicolson, 2010), p.p.159 to 194. This description of the Dresden raid includes several accounts from aircrew of aircraft in the second attack, some of which confirm that the fires from the first wave were visible from a distance of 50 miles.

<sup>86</sup> Middlebrook and Everitt, *The Bomber Command War Diaries*, p663

<sup>87</sup> Overy, *The Bombing War*, p395.

reduced the tendency for the Main Force crews to bomb short of the A/P, thereby minimising 'creepback'. These factors undoubtedly contributed to the good concentration of bombing required for a firestorm to develop. However, there can equally be no doubt that the target marking techniques played a significant part, particularly the conflagration started by the Sector Bombing technique used by No 5 Group in the first raid. Against a target outside *Oboe* range and with a poor response on H2S, and with S.S. Loran not itself being sufficiently accurate for blind ground marking techniques, the only technique which could have achieved the concentration necessary to start a firestorm (or at least provide conditions for the second raid to generate a firestorm) was by confirming the Marking Point visually from a low level. This meant *Visual Groundmarking*, of which Sector Bombing was the most effective version, the irony being that the 5 Group techniques of *visual groundmarking*, which started as a technique employed by No 617 Squadron specifically intended to facilitate attacks on small precision targets such as aircraft factories, turned into the most effective technique for area attacks.

This does, however, raise the obvious question: if the Marking Point was marked with such accuracy, why was *Visual Groundmarking* not used to attack specific points in Dresden rather than as a precursor to an area raid? The attack on Dresden was part of OPERATION THUNDERCLAP, one of the key objectives of which was the bombing of Berlin, Leipzig and Dresden, where heavy attack would cause great confusion in civilian evacuation from the East and hamper movement of reinforcements from other fronts<sup>88</sup>. It is

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<sup>88</sup> Webster and Frankland, *The Strategic Air Offensive against Germany*, p.p. 99 to 109.

apparent that the *Visual Groundmarking* technique was sufficiently accurate to achieve that objective by destroying the extensive marshalling yards to the east of the city centre. In the event, as David Irving points out<sup>89</sup>, the designated Aiming Area for the Dresden raid did not include the marshalling yards. Neither did it include any of the eighteen railway stations in the city or the Marienbrücke railway bridge over the River Elbe, across which the main railway lines all passed. An attack led by *Visual Groundmarking* would have been sufficiently accurate to have included these targets either individually, in relation to the Marshalling yards, or by aligning the Aiming Area to include the key transportation installations. In this respect, the raid on Dresden can be immediately distinguished from the raid on Munich by No 5 Group on 24/25 April 1944, for which the A/P was the marshalling yards, albeit that the A/P was selected in the knowledge that stray bombs would fall in the built-up area of the city<sup>90</sup>. It is not within the remit of this thesis to debate whether OPERATION THUNDERCLAP was necessary or whether an area attack on Dresden was justified on other grounds. The point made here is that target marking techniques, particularly *Visual Groundmarking*, provided an alternative to the area attack that could have secured the objectives of OPERATION THUNDERCLAP without resulting in the destruction of Dresden and thereby avoiding the political fallout that followed. This is a point not widely considered in the extensive literature on the Dresden raid, but provides a further perspective in which the long-standing debate on the Allies' conduct in respect of this raid may be viewed.

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<sup>89</sup> Irving, *The Destruction of Dresden*, p129.

<sup>90</sup> TNA AIR14/3411 ORSBC Final Raid Report No 586; Munich, 24/25 April 1944, 20 July 1944.

The success of the No 5 Group techniques should not be allowed to disguise the improvements that had simultaneously taken place in the techniques employed by No 8 Group. This improvement was not achieved by the introduction of any new techniques, but rather by the refinement of existing techniques<sup>91</sup> and a more efficient execution of those techniques. To a large extent, the latter resulted from factors not related to the target marking techniques employed, including the employment of a smaller Main Force (thereby reducing 'creepback'), lower bombing heights due to weaker defences and an improvement in bomb aiming resulting from greater average operational experience of the Main Force crews as loss rates declined. The degree of accuracy and concentration now possible with these techniques was demonstrated in a series of raids on smaller German towns that took place in the closing months of the bombing offensive. The attack on Pforzheim on the night of 23/24 February 1945 was one of the most effective during this period<sup>92</sup>, with the post-war British Bombing Survey Unit estimating that 83% of the town's built-up area was destroyed and resulting in the third highest death toll in Germany behind the firestorms at Hamburg and Dresden<sup>93</sup>. The results achieved using the high-level target marking techniques of the Pathfinder Force in the closing months of the bombing offensive represent the pinnacle of efficiency capable with those techniques

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<sup>91</sup> The main refinement was the widespread use of a Master Bomber. The role of the Master Bomber is considered in Chapter Seven.

<sup>92</sup> TNA AIR14/3411 ORSBC Final Raid Report No 846: Pforzheim, 23/24 February 1945, 25 March 1945. Details of the raid on Pforzheim are taken from Middlebrook and Everitt *The Bomber Command War Diaries*, p669 and Tony Redding *Bombing Germany: the final phase. The destruction of Pforzheim and the closing months of Bomber Command's war* (Barnsley: Pen & Sword Aviation, 2015).

<sup>93</sup> Cox (ed) *The Strategic Air War Against Germany 1939-1945*. In his Preface, Cox warns that historians should treat the information in the official report with care, taking into account the background and prejudices of those compiling it. However, there is no suggestion that the factual data on which the official report should not be relied upon.

but, as the table above shows, the level of accuracy achieved fell short of that achieved by the low-level techniques developed by No 5 Group.

The development of specialist target marking techniques by No 5 Group, and to a lesser extent those developed by No 1 Group, resulted in a position whereby those Groups were capable of mounting independent raids at Group strength. The possibility of splitting the Main Force into two or more smaller streams had been one of the measures recommended in a report by ORSBC prepared as part of a wider review of tactics in response to an increased loss rate<sup>94</sup>, and had been well received both by Bennett at No 8 Group and Cochrane at No 5 Group<sup>95</sup>. Harris also supported the proposal to split the Main Force but made it clear that the size of the PFF could not be increased<sup>96</sup>. It was this limiting factor, together with the limited availability of navigational aids such as H2S, that in large part dictated the standard tactic employed by Bomber Command of concentrating the Main Force into one large stream. However, following the introduction of *Window*<sup>97</sup>, the German night fighter force had adopted the practice of infiltrating the bomber stream and this had resulted in the significant increase in the overall loss rate<sup>98</sup>. It was also at this time that Bomber Command was beginning to turn its attention away from the Battle of Berlin, and towards precision targets in the

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<sup>94</sup> TNA AIR14/3948 ORSBC Report B197 'Review of Bomber Losses in Relation to Enemy Defensive Tactics in Night Operations', 7 February 1944.

<sup>95</sup> TNA AIR14/1801 Letter AOC 5 Group to A/V/M Walmsley, 8 March 1944 and Letter AOC 8 Group to A/V/M Walmsley, 9 March 1944, respectively.

<sup>96</sup> TNA AIR14/1801 Minute 11, CinC Bomber Command to D/CinC Bomber Command, 25 February 1944.

<sup>97</sup> *Window* was the codename given to metal strips dropped from a bomber aircraft to confuse the German radar. For the history and development of *Window*, see Price, *Instruments of Darkness*, Chapter 5.

<sup>98</sup> TNA AIR14/3948 ORSBC Report B197 'Review of Bomber Losses in Relation to Enemy Defensive Tactics in Night Operations', 7 February 1944. This report noted that the loss rate had increased from 3.7% to 4.9% in November 1943 and to 5.9% by January 1944.

build-up to OPERATION OVERLORD. Clearly, given the number of targets to be attacked and the short period of time in which they must be attacked, the continued practice of a single bomber stream would have been impractical. Bomber Command was therefore obliged to split into smaller forces, each of which would require a target marking component. The success of the low-level target marking techniques devised by No 5 Group from February 1944 provided Harris with an alternative to those provided by the Pathfinder Force and therefore offered one means by which the split of the Main Force could be facilitated.

It was a combination of these factors that led Harris to take one of the more controversial - or, as Hastings<sup>99</sup> termed it, 'one of his more imaginative' - decisions of his tenure as C-in-C Bomber Command: the transfer in April 1944 of the two Lancaster squadrons and one Mosquito squadron from the Pathfinder Force to No 5 Group. The sequence of events leading up to this decision is set out in the Air Historical Branch Narrative<sup>100</sup>, and Bennett himself recounts that he was first advised that the use of the low-level marking technique was under consideration in a telephone conversation with Harris<sup>101</sup>. Bennett had resisted the idea, successfully as he thought at the time, on the basis that a fast, low-flying aircraft could not identify and mark a target in a densely built-up area at night. However, Bennett then found himself being summoned to HQ Bomber Command to receive the "frigid and formal

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<sup>99</sup> Hastings, *Bomber Command*, p364.

<sup>100</sup> Air Historical Branch narrative The RAF in the Bombing Offensive against Germany VOL VI The Final Phase Mar 1944- May 1945, page 34.

<sup>101</sup> Bennett, *Pathfinder*, p175.

notification” from Harris that Nos. 83 and 97 Squadrons (Lancaster) and No 627 Squadron (Mosquito) were being transferred to No 5 Group<sup>102</sup>.

Bennett had gained the impression that the transfer of these squadrons was an experiment and within a couple of weeks made his first attempt to get his squadrons returned. Bennett began by saying that “I naturally do not wish to propose any view as to whether 5 Group are capable of working out correct pathfinder procedures”, surely an intimation that he believed otherwise, and claimed that the detachment had already affected PFF by taking some of the few H2S Mk III aircraft available<sup>103</sup>. Shortly after receiving this letter, Harris requested a note from Cochrane on the marking methods being developed by No 5 Group. In reply, Cochrane sent a detailed summary of the 5 Group technique and stated that the recent success of these methods was down to a well-trained flare force (i.e Nos. 83 and 97 Squadrons) together with the low level marking by No 627 Squadron<sup>104</sup>. Whether Harris was convinced by this is not clear but nonetheless the squadrons remained in No 5 Group. However, Bennett had no intention of letting the matter rest there, and soon afterwards wrote to Harris asking him to re-consider the detachment of the Pathfinder Force Squadrons and urging him to return them as soon as possible<sup>105</sup>. Harris was still not persuaded and so, in a move that on its face held little prospect of success, Bennett visited Cochrane himself to ask for his two Lancaster

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<sup>102</sup> Nos. 83 and 97 Squadrons, both equipped with Lancasters, had both been transferred to the Pathfinder Force from No 5 Group, the former as one of the original founder squadrons in 1942, and in that sense it may be argued that both squadrons were merely being transferred back to their parent Group. No 627 was a Mosquito squadron that had been formed within No 8 Group the previous November.

<sup>103</sup> RAFM Harris Papers H57 Letter Bennett to Harris, 30 April 1944.

<sup>104</sup> Ibid Letter Cochrane to Harris, 15 May 1944

<sup>105</sup> Ibid Letter Bennett to Harris, 31 May 1944.



squadrons back. It would appear that this visit was without the C-in-C's knowledge because, in a letter to Harris describing the meeting, Cochrane explained that the squadrons were gaining experience and "doing good work with the Master Bombers", such that he would not wish to see the organisation broken up<sup>106</sup>. In the event, Cochrane won the day and Harris confirmed that he "had no intention of returning these two squadrons to the Pathfinder Force for the present or, as far as I can see for an indefinite period, if at all"<sup>107</sup>. Bennett finally learned that he would not be getting his squadrons back towards the end of July, when Harris confirmed that the detachment of Nos. 83 and 97 Squadrons should be regarded as "permanent detachments"<sup>108</sup>.

In his autobiography, Bennett describes the decision to transfer part his force to No 5 Group as a ...'tremendous slap in the face to a Force that turned Bomber Command from a wasteful and ineffective force to a mighty and successful one'<sup>109</sup>. Bennett believed that the PFF had "proved to be a vital factor in making the bomber offensive successful. It changed night bombing from something somewhat doubtful into a concrete and most powerful weapon"<sup>110</sup>. Bennett also perceived that the transfer of these squadrons meant that, in the eyes of the rest of Bomber Command, "the pathfinders had apparently failed"<sup>111</sup>. Whilst this may be putting the complaint too high, there

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<sup>106</sup> RAFM Harris Papers H59 Letter Cochrane to Harris, 28 June 1944.

<sup>107</sup> Ibid. Letter Harris to Cochrane, 3 July 1944.

<sup>108</sup> Ibid. Letter Harris to Bennett and Cochrane, 21 July 1944. Harris also made it clear in this letter that the squadrons would not be formally transferred back into No 5 Group so that crews could retain their PFF badge.

<sup>109</sup> Bennett, *Pathfinder*, p176.

<sup>110</sup> RAFM Harris Papers H57 Letter Bennett to Harris, 23 July 1944.

<sup>111</sup> Bennett, *Pathfinder*, p176.

can be no doubt that, as the Official History points out, the predominance and prestige of the Pathfinder Force was much reduced as a result of the transfer of three squadrons to No 5 Group<sup>112</sup>. Indeed, a number of commentators, notably Hastings<sup>113</sup>, point out that the morale of the Pathfinder Force declined as a result of this and the subsequent success of the No 5 Group techniques in the closing months of the bombing offensive albeit, as shown in the improvement in efficiency shown by No 8 Group over this period, this does not appear to have compromised the efficiency of the Pathfinder Force.

The transfer of these three squadrons to No 5 Group also re-ignited the debate that surrounded the formation of the Pathfinder Force. Harris had advised Portal of the transfer of these squadrons on 11 April 1944 and, according to Portal, in so doing had stated that his (Harris) only opposition to the creation of the Pathfinder Force was that it would have been premature at that time. That did not accord with Portal's recollection of events but he offered to check his records before commenting further. Portal replied formally to Harris on the 12 April 1944, confirming that; "I cannot find anything to substantiate your contention that the only opposition in your Headquarters to the formation of the PFF was that it would be premature. On the contrary, the arguments used against the scheme were that it would offer no advantage over the then existing procedure and would have serious disadvantages inseparable from the formation of a *corps d'élite*. It is quite true to say that the opposition in Bomber Command resulted largely from the attitude of the Group Commanders, who were said to be 'utterly, decisively and adamantly

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<sup>112</sup> Webster and Frankland *The Strategic Air Offensive against Germany*, p130.

<sup>113</sup> Hastings, *Bomber Command*, p364. Hastings records that a No 8 Group station Medical Officer had identified a drop in morale for this reason.

opposed to the Air Ministry proposal. I quite realise that the success achieved by the PFF has been greater through the introduction of *Oboe* than it could have been without this particular aid, but this was not the point under discussion'. Portal concluded by saying that 'On reading your letter to Bufton on the 17 April 1942, and his reply of 8 May 1942, I see no reason to modify my opinion as to where the credit lies for the Air Ministry share in what had been achieved. I hope that you will agree to have a talk some time with Bufton'<sup>114</sup>.

If Portal had hoped that this would be the end of the matter, he was to be disappointed. Denying that he had ever claimed that his opposition to the formation of the Pathfinder Force was only one of prematurity, in a reply dated 14 April 1944 Harris also stated that he had personally always maintained an open mind on the subject but that it was his Group Commanders who had been '...utterly opposed to the formation of a *corps d'élite* on Bufton's lines'. Harris re-affirmed that he personally had always favoured a system of pathfinding that did not drain the Groups of their best crews. Recalling his conversation with Portal on the 11 April, Harris firstly conceded that he had regarded the formation of the PFF as being premature in 1942 and that he believed that he had been proved correct by subsequent events. In particular, he asserted that it was only the availability of *Oboe* and H2S in 1943 that had made the PFF worthwhile. Harris then stated that he was not convinced that the formation of the PFF as a single entity had been the best solution for target location and marking and the alternative had always been, and still

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<sup>114</sup> CCL Portal Papers, File 10, 1944, Item 15. Letter Portal to Harris, 12 April 1944.

was, to form a pathfinder element in each Group to meet Bomber Command's requirements without accepting the obvious disadvantages of a *corps d'élite* creaming off the entire Command for one formation. In this context, Harris explained that it was now tactically necessary to split the bomber force in order to confuse and disperse the enemy defence system, and that the preparations for OPERATION OVERLORD required attacking multiple objectives on any one night. In these circumstances, Harris considered, the load of the Pathfinder Force was becoming unsupportable and, with that, it would become impossible for Bennett or any other single commander to keep pace with the inevitable demands placed upon him. In any event, Harris pointed out, "...in Bennett as an individual we have already far too many eggs in one basket" and that this was a problem to which he had already devoted much thought<sup>115</sup>.

In relation to the last point, Harris explained that "After examining it at length with my Staff, with Bennett and Cochrane, I decided some days ago to detach back to 5 Group two Lancaster PFF Squadrons which 5 Group supported in PFF, plus one Mosquito IV (non-Oboe) Squadron for use as 'lowmarkers'. Major reasons for this are that 5 Group is the biggest force and Cochrane is the most progressive and technically and tactically expert of my Group Commanders. His Group can therefore form one effective force, or even two, on its own during a combined attack on multiple objectives. He will also be free to use his own initiative in methods of training, pathfinding and marking, which he has exploited with outstanding success on some of the smaller

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<sup>115</sup> Ibid, Item 15a. Letter Harris to Portal, 14 April 1944

targets in France and Italy in the recent past". Harris concluded this section of his response by indicating that it might prove desirable to extend this principle to other Groups, depending upon the personal ability of individual Group Commanders, and that he already had in mind the intention of making No 3 Group an independent force using the G-H blind bombing device.

Having dealt with issues surrounding the formation of the Pathfinder Force, Harris then went on to launch a scathing attack on Bufton who, it will be recalled, was Director of Bombing Operations and who had been the prime advocate for the formation of a target finding force, and whose methods, Harris complained, "...are rammed down our throats whether we like them or not". Harris then returned to a familiar theme from the Pathfinder debate, restating his view that "... more weight is given to his (Bufton) opinions as a junior officer 2 years out of the Command than to the considered opinion of the Commander's concerned on the spot and responsible for the outcome of events". Although Portal had no intention of interfering with Harris' decision to transfer the squadrons to 5 Group, correspondence on the role played by Bufton carried on for some time and, in the context of the sometimes troubled relationship between Harris and the Air Ministry, it is this aspect of this exchange that has received most coverage in secondary literature<sup>116</sup>. However, in the context of the development of target marking techniques, this exchange reveals much about the reasons behind the transfer of the squadrons from the Pathfinder Force to No 5 Group.

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<sup>116</sup> See Probert, *Bomber Harris*, p.p. 267 to 269 and Saward, *'Bomber' Harris*, p.p. 240 to 244.

With the benefit of hindsight, these reasons appear to be sound. In the event, the transfer of these three squadrons to No 5 Group resulted in operational advantages that outweighed the loss of morale to the crews of the Pathfinder Force. In particular, the development of different target marking techniques by No 5 Group, together with those developed by No 1 Group and the use of the G-H blind bombing device in daylight raids by No 3 Group, resulted in a tactical diversification within Bomber Command that would not have occurred otherwise and became fundamental to the success achieved by Bomber Command in the build-up to OPERATION OVERLORD, as well as against a wide range of precision and area targets in the closing months of the bombing offensive. Thus, as the Official History states, this diversification of target marking techniques greatly increased the operational ability and versatility of Bomber Command, and therefore the prospects of strategic air offensive<sup>117</sup>. Moreover, as Harris pointed out, one of the reasons why he opposed the formation of the Pathfinder Force in 1942 was that he envisaged the benefits that would result if each group had its own target marking capability rather than forming a single *corps d'élite*. In transferring the three squadrons to No 5 Group, Harris was taking the first opportunity to implement a tactical solution that he had long held to be the correct one. In this Harris was proved correct and Bennett was proved to be wrong. Bennett himself always believed that in making this decision Harris was unduly influenced by Cochrane and his loyalty to him as a result of previous service associations<sup>118</sup>, and some commentators have also argued this to be the case<sup>119</sup>. But this does a

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<sup>117</sup> Webster and Frankland *The Strategic Air Offensive against Germany*, p130.

<sup>118</sup> Bennett, *Pathfinder*, p177. See also Jackson, *Pathfinder Bennett*, p.p. 88 and 89.

<sup>119</sup> Bramson, *Master Airman*, p.p. 90 and 91.

disservice to Harris. The final decision to transfer the three squadrons out of the Pathfinder force was unequivocally Harris', and was consistent with his own previously expressed views about each Group having its own target marking capability. Harris has not been afforded due credit in secondary literature for improvement in operational efficiency and performance that resulted from that decision.

The point Harris made in terms of the workload that Bennett personally, and the Pathfinder Force as a whole, would have been under in the build up to OPERATION OVERLORD and the period immediately following was also a valid one. One particular operation demonstrates the point, this being an attack on eight separate coastal batteries involving the marking of eight individual Aiming Points at 20 minute intervals over a period of nearly three hours<sup>120</sup>. The attack was a *Controlled Musical Newhaven* with a Master Bomber for each separate A/P and a 'Long Stop' to cover the entire attack. The planning for this raid, involving the calculation of eight *Oboe* co-ordinates and a marking plan for each A/P, involved a considerable effort by PFF Headquarters and the operation itself, which required eight Master Bombers, eight Deputy Master Bombers as well as eight sets of Primary markers and backers up. This represented a considerable administrative and organisational effort, and left no spare capacity in the Group. The extension of target marking capability to No 5 Group therefore provided Bomber Command

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<sup>120</sup> This operation took place on 10 September 1944 and is described in detail by Sean Feast in *Master Bombers: the Experiences of a Pathfinder Squadron at War 1944-1945* (London: Grub Street, 2008). The eight individual A/P's were each named after cars (Alvis I to IV, Bentley I and II, and Buick I and II).

with enhanced capacity within Bomber Command and eased the burden on the Pathfinder Force.

Harris' indication that it might prove desirable to extend target marking capability to other Groups, depending upon the personal ability of individual Group Commanders, is also an interesting one. In addition to No 5 Group, No 1 Group also acquired its own target marking capability although this did not involve the transfer of a squadron away from the Pathfinder Force<sup>121</sup>. In the case of No 1 Group, this was achieved by forming a Special Duties Flight comprised of one specially selected crew from each squadron in the Group. It is noteworthy that there is no indication that this creaming off of selected crews from the individual squadrons generated the same opposition to the creation of a *corps d'élite* as did the formation of the Pathfinder Force itself or whether, following the success of No 617 Squadron in the target marking role, this was no longer considered as being undesirable. The new unit, officially titled 1 Special Duties Flight (1 SDF) but more usually known as the 'Binbrook Flight', first operated in a successful attack on the Maintenon ammunition dump on the night of 30 April/1 May 1944<sup>122</sup> and thereafter provided target marking for a number of raids in which the entire attacking force was provided by No 1 Group. Similarly, No 3 Group, whilst usually employed in the blind bombing role using G-H, also possessed a target marking capability using that device. These three Groups were all equipped fully equipped with the Avro

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<sup>121</sup> Patrick Otter *1 Group: Swift to Attack: Bomber Command's Unsung Heroes* (Barnsley: Pen & Sword Aviation, 2012), p.p. 162 and 163.

<sup>122</sup> TNA AIR14/3411 Raid Report No 592, 4 September 1944. Details of the raid on Maintenon are taken from Middlebrook and Everitt *The Bomber Command War Diaries*, p503.



Lancaster<sup>123</sup>. It is interesting, therefore, that neither of the remaining two Groups in Bomber Command, No 4 Group fully equipped with the Handley Page Halifax and 6 Group, largely equipped with the Handley Page Halifax but with two squadrons equipped with the Avro Lancaster Mk II<sup>124</sup>, developed their own target marking capability. There is no technical reason why the aircraft with which these groups were equipped could not have performed target marking and, whilst no evidence has been found to prove or disprove the supposition, the comments made by Harris suggest that it was quality of the Group Commanders that prevented these Groups from developing their own target marking capability. Given the success enjoyed by No 5 Group in this respect, and to a more limited extent No 1 Group, this would appear to be the only reason why Harris did not extend the principle of independent target marking capability to these Groups in accordance with his stated preference at the time of the formation of the Pathfinders and as re-asserted in the exchange with Portal in April 1944.

The most interesting aspect of Harris' comments is his contention that the only opposition to the formation of the PFF was that it would be premature. Portal was correct in finding no evidence in earlier correspondence to that effect. This would suggest that Harris' concession that he had regarded the formation of the PFF as being premature in 1942, and that he believed that he been proved correct by subsequent events, was his retrospective assessment

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<sup>123</sup> In all cases, the Lancasters operated by these groups were the Rolls Royce Merlin powered Mk I or Mk III versions.

<sup>124</sup> The Mk II version of the Avro Lancaster was powered by the Bristol Hercules radial engine and, in addition to possessing a lesser performance than the Rolls Royce Merlin powered Mk I and Mk III versions (in particular, a lower operational ceiling and shorter range), could not accommodate H2S because of the bulged bomb bay fitted to this version.

of the achievements secured by the Pathfinder Force. This in itself is not an accurate assessment of the early achievements of the Pathfinder Force, the employment of which had generally resulted in a greater concentration in bombing (see Chapter Five). However, Harris was correct in his assertion that the Pathfinder Force had only become fully effective (or, as Harris termed it, 'worthwhile') with the introduction of H2S and *Oboe*. As shown in Chapter Five of this thesis, it was the introduction of these devices, particularly *Oboe*, and the evolution of target marking techniques in conjunction with them that transformed the performance and destructive capability of Bomber Command. This is not to say that the period of time between the formation of the Pathfinder Force in August 1942 and the introduction of H2S and *Oboe* early in 1943 was entirely redundant; as described in Chapter Five, the early operations led by the Pathfinder Force did generally result a greater concentration of bombing than had been achieved beforehand. Perhaps more importantly, many of the techniques that were employed successfully in conjunction with H2S and *Oboe* were evolved in that period, and many of the lessons learned contributed to the success achieved using those devices. Nevertheless, Harris' retrospective assessment that the Pathfinder Force only became worthwhile once Bomber Command was equipped with suitable navigational aids is an early recognition of the fundamental relationship between the value of target marking techniques and the performance of the navigation aid on which they are based.

The indirect marking techniques evolved by No 5 Group represented a significant divergence in the development of target marking techniques. The

basic techniques used by the Pathfinder Force, in addition to being based on a single and direct A/P, were based upon the application of science and technology to the problem of providing a distinctive point of aim. By contrast, the indirect marking techniques evolved by No 5 Group, particularly those that involved an initial low-level marking phase, relied to a much greater extent on the 'human factor' including, amongst others, the judgement of distance from the A/P and communication skills. However, whilst these human factors were an integral part of the No 5 Group techniques, they were not entirely exclusive to them and could be applied in some measure to the more scientific approach used by the Pathfinder Force. In particular, the use of an experienced 'Master Bomber' to control and direct an attack was a feature not only of all the target-marking techniques employed by No 5 Group, but was also increasingly used by the Pathfinder Force as part of their standard repertoire of target-marking techniques. The following Chapter will trace the introduction of the 'Master Bomber' into target marking techniques and will seek to evaluate the contribution made by this technique to performance achieved by Bomber Command.

## **CHAPTER SEVEN: THE ROLE OF THE MASTER BOMBER**

The low level marking techniques developed by No 5 Group described in the previous Chapter all shared a common element: the marking and main forces were controlled by a 'raid leader' using radio telephony to commentate on the accuracy of marking and bombing, and to issue instructions to either identify the most accurate markers or, if necessary, to correct errors in the marking. The use of radio telephony in this way was not exclusive to No 5 Group, being used extensively by No 8 Group and, to a lesser extent, No 1 Group. The technique was developed and refined over time, and was known by a variety of different names, including 'Raid Leader', 'Raid Commentator', 'Raid Controller' and 'Master of Ceremonies': for present purposes and in the interests of clarity, the technique will be referred to here using the generic term of 'Master Bomber'. However, despite frequent reference to Master Bombers in secondary literature, nowhere in that extensive body of literature has an attempt been made to quantify or critically assess the role played by Master Bombers in the outcome of the bombing offensive. This Chapter will examine the introduction and development of the Master Bomber as a component of target marking techniques, and will evaluate the contribution made by the use of a Master Bomber to the accuracy and efficiency of those techniques as the bombing offensive progressed. As such, it will seek to rectify a glaring omission in the secondary literature of the bombing offensive.

As with the formation of the Pathfinder Force, there is some debate over the first use of the Master Bomber technique. The first reference to a Master Bomber found is in the autobiography of Wing Commander Bill Anderson, who was one of the original staff on the formation of the PFF<sup>1</sup>. In his autobiography, Anderson indicates that he first proposed the concept of a Master Bomber as a Staff Officer at Bomber Command HQ in 1941 but the idea had been firmly rejected<sup>2</sup>. Anderson resurrected the idea when a Staff Officer at PFF HQ although, according to his autobiography, his idea was not intended to improve accuracy but was “almost entirely about morale raising” through the use of encouragement for less experienced crews. Anderson recalls that his idea was tried on the second raid mounted by the Pathfinder Force (against Frankfurt on the night of 24/25 August 1942), in which Wing Commander Pat Daniels acted as ‘Master of Ceremonies’. However, although Daniels believed the bombing to be south of the target, he was unsuccessful in diverting the bombing onto the correct A/P<sup>3</sup>. Anderson explains in his autobiography that the concept of the Master Bomber was shelved until suitable equipment was received and, whilst Sean Feast suggests that Wing Commander Daniels was authorised to make a further attempt during a raid against Munich in March 1943, this was thwarted by the weather conditions<sup>4</sup>.

As described in Chapter Six, the employment of a Master Bomber was one of the suggestions made at a conference to discuss the performance of the then

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<sup>1</sup> Anderson *Pathfinders*, page 57.

<sup>2</sup> No copy of the minute Anderson claims to have written on this subject has been found.

<sup>3</sup> ‘Master of Ceremonies’ was one of the several alternative names for a Master Bomber. The Master of Ceremonies on the Frankfurt raid was Wing Commander Pat Daniels, who would later become one of the most able and experienced of the Master Bombers.

<sup>4</sup> Feast *The Pathfinder Companion*, p57.

nascent Pathfinder Force in November 1942<sup>5</sup>. The suggestion, which was put forward by No 5 Group, was that one or two aircraft should be detailed to control the PFF and re-direct its effort if required. The minutes of this conference do not record whether those attending were made aware of the apparent failure of the 'Master of Ceremonies' to re-direct bombing during the raid on Frankfurt a few months previously and there is no evidence to show that the suggestion made by No 5 Group was acted upon. Nonetheless, as will be evident from the following, No 5 Group became one of the leading exponents of the use of a Master Bomber to direct raids.

There is therefore a general acknowledgement that the first occasion on which a bombing force was controlled by radio telephony was the Dams Raid on 16/17 May 1943, and this leads some commentators to attribute the first use of the Master Bombing technique to this operation<sup>6</sup>. However, on that occasion Wing Commander Guy Gibson used radio telephony primarily to order the crews taking part to begin their individual attacks on to a single, previously specified target for which the small force had been specifically trained<sup>7</sup>. This was a significantly different exercise to the direction of a large bomber force for the purposes of bombing an ever-changing pattern of markers on the ground. Consequently, whilst the Dams Raid may have initiated the use of radio telephony to direct a bomber force, it can not be

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<sup>5</sup> TNA AIR14/3062 Minutes of Conference of Group Officers and BQD Commanders held at Wyton on the 28<sup>th</sup> November 1942 at 11:00 hours. See Chapter Five.

<sup>6</sup> Feast *The Pathfinder Companion*, p57. Sean Feast is amongst those that have expressed this view.

<sup>7</sup> There are numerous published accounts of the Dams Raid and the use made of radio telephony during that operation. The sources referred to here were: James Holland *Dam Busters; The race to smash the Dams 1943* (London: Bantam Press, 2012); Lawrence, *No.5 Group RAF*; John Sweetman *The Dambusters Raid*: (London: Arms and Armour Press, revised paperback edition 2003); and Colin Ward et al. *Dambusters: the definitive history of 617 Squadron at war 1943-1945* (Walton-on-Thames: Red Kite Publishing, 2003).

considered to be the first use of a Master Bomber in the generally recognised sense.

The first occasion on which a Master Bomber was used to control a main force raid took place shortly after the Dams Raid on the night of 20/21 June 1943, when a force of 60 Lancasters of No 5 Group attacked the former Zeppelin works at Friedrichshafen, on the shores of Lake Constance. It is significant that this first use of a Master Bomber was made by No 5 Group and not, as perhaps might have been expected, by the PFF. This is further evidence of the development of precision night bombing by No 5 Group and that it was the use of radio telephony in the Dams Raid, which was a 5 Group operation, led directly led to the first employment of a Master Bomber to control a main force raid.

The former Zeppelin works at Friedrichshafen was by that time engaged in the production of components for radar sets and was considered to be a genuine bottleneck in the production of these sets. However, the factory presented a very small target deep into Germany and a daylight raid would have incurred prohibitive losses. Precision bombing at night would therefore be necessary. This presented a number of particular operational difficulties and a special plan of attack, codenamed 'OPERATION BELLICOSE', was evolved to tackle them<sup>8</sup>. The attack was to be in two parts. The early aircraft would bomb TIs placed by a small number of aircraft provided by No 8 Group, the accuracy of which was first to be checked by the Master Bomber. It was, however,

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<sup>8</sup> TNA AIR20/782. This file, titled 'Operation Bellicose', contains records relating to the preparation and operational orders for the raid.

recognised that such a small target would quickly be obscured by the smoke and dust generated by the early bombing. When that point was reached, the later arrivals would be instructed by the Master Bomber to undertake 'time & distance' runs from a prominent landmark on Lake Constance, to be identified by the light of flares dropped by one of the pathfinder aircraft.

The 'time & distance' technique, which it will be recalled had been attempted with limited success by No 4 Group as early as June 1940, was included at the behest of Cochrane of No 5 Group. Cochrane had first proposed the idea to Harris in January 1943 when AOC No 3 Group, suggesting a timed run from a distinctive landmark some 10 miles from the A/P<sup>9</sup>. Harris was not initially receptive, indicating that he wanted to determine whether markers laid down by scientific methods would give better results than bomb aiming by visual recognition of the A/P<sup>10</sup>. However, as AOC No 5 Group, Cochrane continued to refine his ideas and proposed low-level marking to provide the start point for the timed run where there was no distinctive landmark, this on the basis that it was easier to mark a point from low level outside the defended target area than the A/P itself<sup>11</sup>. OPERATION BELLICOSE would be the first significant use of the time & distance method, and to ensure accuracy the bombing at Friedrichshafen was to take place at the unusually low heights of between 5,000ft and 10,000ft.

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<sup>9</sup> TNA AIR14/3522 Letter from Air-Vice Marshal R.A.C. Cochrane, AOC No 3 Group, to C-in-C Bomber Command, 12 January 1943.

<sup>10</sup> TNA AIR14/3522 Letter from C-in-C Bomber Command to Air-Vice Marshal R.A.C. Cochrane, AOC No 3 Group, 5 March 1943

<sup>11</sup> RAFM Harris Papers, H59 Letter Cochrane to Harris, 28 April 1943.



OPERATION BELLICOSE suffered an early set back when the Master Bomber's aircraft developed engine trouble before reaching the target area and control was handed over to the Deputy Master Bomber. Further problems arose when the active defences caused the Deputy Master Bomber to order an increase in the altitude from which bombing was to take place by some 5,000ft above the heights originally allocated. Unbeknown to the Deputy Master Bomber, the wind speed was significantly greater at the new bombing altitude than that stated in the Operation Order. The increased wind speed caused the TIs dropped by the first two pathfinder aircraft to fall short of the target but the third set of markers were accurately placed and, having checked them, the Deputy Master Bomber ordered bombing to commence. The bombing was accurate and, as expected, the accurately placed markers were soon obscured. The Deputy Master Bomber therefore ordered the switch to the time & distance method for the remainder of the attack. Post-raid reconnaissance revealed that some 10% of bombs dropped hit the small factory and much damage was caused<sup>12</sup>.

The success achieved by OPERATION BELLICOSE would not have been possible without the presence of a Master Bomber (or, in that case, the Deputy Master Bomber). The complexities of the attack, including the assessment of the initial marking of a small target and the switch in bombing technique whilst the raid was in progress, necessitated an element of control that would not have existed if individual crews were reliant upon instructions

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<sup>12</sup> Middlebrook and Everitt *The Bomber Command War Diaries*, p 399. Middlebrook also suggests that, although not known to the Allies at the time, the factory had been selected as one of two locations for the production of components for the V2 rocket and this caused some disruption to that programme. See Middlebrook *The Peenemunde Raid*, p51.

issued at the initial briefing for the raid. The increase in bombing altitude was a real-time decision made in direct response to unexpectedly strong defences, and could not have been pre-planned. Similarly, although the change in bombing altitude itself caused some difficulties, these were overcome by the ability of the Master Bomber to assess the initial marking and initiate the necessary adjustments. The obvious lesson was that the increasing complexity of target marking techniques in turn demanded a greater degree of control than had previously been employed if they were to be successful.

It was this degree of control that led to the Master Bomber technique being employed in one of the most important raids of the bombing offensive: the attack on the rocket research establishment at Peenemünde, on the Baltic coast, known as 'OPERATION HYDRA'<sup>13</sup>. The Peenemünde site was of such importance as a target that special tactics would be needed, similar in concept to those used in the Friedrichshafen raid. However, that raid had been carried out by a relatively small force, comprising only about 10% of the average Main Force raid at that time. OPERATION HYDRA would involve the entire Main Force and control of a force of this size presented its own difficulties, not least in terms of the duration of a main raid and the risk to the Master Bomber in terms of being in the target area for that period of time.

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<sup>13</sup> TNA AIR20/4040 Although the attack on Peenemünde was allocated the codename 'OPERATION HYDRA', unlike other operations of this period the records for this raid are not referenced under that codename. It is also noteworthy that there is no copy of the Operation Order for the Peenemünde raid in the TNA files. Some of the detail of the attack referred to in this Chapter is taken from the copy of the original Operation Order reproduced as Appendix 1 in Middlebrook, *The Peenemunde Raid*.

It is therefore unsurprising that the first use of a Master Bomber in a full scale Main Force attack was a rehearsal for OPERATION HYDRA against the relatively 'soft' target of Turin. This raid took place on the night of 7/8 August 1943, the Master Bomber chosen being Group Captain J.H.Searby, then commanding No 83 Squadron, one of the founder squadrons of the Pathfinder Force<sup>14</sup>. Notwithstanding that the most recent operational use of a Master Bomber was by No 5 Group, and that the only attempt by the Pathfinders to employ a Master Bomber was the abortive attempt of a year previously, this choice of No 8 Group officer was deliberate because OPERATION HYDRA would involve the whole of the Main Force. The ORSBC report for the Turin raid refers to the use of a 'Raid Commentator', commenting that this appeared to give the Main Force crews "great confidence" and successfully directed aircraft to bomb the correct markers<sup>15</sup>.

In his autobiography *Everlasting Arms*, Searby recalls that the idea of a 'Master of Ceremonies' had been postulated by Bennett as a means of gaining tighter control over bombing performance in normal Main Force raids in terms of improved concentration and fewer wasted bombs<sup>16</sup>. The use of a Master Bomber is another example of the tension between No 5 Group and No 8 Group and clearly rankled with Bennett who, in his own autobiography, complains that No 5 Group had been allowed to use a Master Bomber on the

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<sup>14</sup> Searby, *The Everlasting Arms*, p139. Searby was not aware that he was taking part in a trial run for the Peenemünde raid and recalled that his only contribution over Turin was to seek to correct the 'creep-back' that had developed

<sup>15</sup> TNA AIR14/3410 ORSBC Final raid Report No 396: Turin, 7/8 August 1943, 4 October 1943.

<sup>16</sup> Searby, *The Everlasting Arms*, p139.

“easy undefended target of Friedrichshafen”, apparently forgetting that his own group had employed the technique without success a year previously<sup>17</sup>.

The experiment was not repeated and a Master Bomber would not be used again until the Peenemünde raid itself on the 17/18 August 1943<sup>18</sup>. The rocket research establishment at Peenemünde was situated on a peninsula formed by the River Peene and the Baltic, and was located south of the large and distinctively shaped Rügen Island. At the tip of the Peenemünde peninsula was a small island, Ruden Island. The combination of the distinctive land shapes and areas of water was expected to present a good image on the P.P.I. of the H2S-equipped Pathfinder aircraft<sup>19</sup>. The operation required attacks on three separate parts of the rocket research establishment: the Experimental Works; the V2 Production Works; and the housing estate. These three targets were broadly aligned on a north-south axis, such that an approach down the distinctive east coast of Rügen Island would take the bombers directly over Ruden Island and all three targets. The marking plan was a complicated one, in three consecutive but separate phases, but was essentially a *Controlled Newhaven* attack.

Blind Markers would initially drop Red Spot fires at the northern tip of Ruden Island to provide a start point for the approach to the target; these would be refreshed at regular intervals throughout the raid. The Blind Markers of the

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<sup>17</sup> Bennett *Pathfinder*, p171.

<sup>18</sup> TNA AIR14/3410 ORSBC Final Raid Report No 404: Peenemünde, 17/18 August 1943, 20 October 1943. A detailed description of the Peenemünde raid may be found in Middlebrook, *The Peenemunde Raid 17/18*.

<sup>19</sup> At that time, all Pathfinder aircraft were fitted with the MkII version of H2S.

First Wave were then to drop a combination of TIs Red to serve as proximity markers to identify the general target area for the Visual Markers and flares to illuminate the A/P for the Visual Markers, this being the housing estate and the southernmost of the three target areas. The Visual Markers were to mark the exact A/P with the Primary Markers (TIs Yellow), to be backed up by Secondary Markers (TIs Green). The instructions to the main force were to aim at the TIs Yellow if visible, and the M.P.I. of the TIs Green if not.

The novel element of this raid was that, at the completion of the First Phase of bombing, the A/P had to be shifted from the housing estate to the V2 Production Works for the Second Phase. The shifting of the A/P whilst the attack was in progress had never been attempted before and was to be undertaken at a pre-specified time by the most experienced crews in each Pathfinder squadron, specially selected as designated 'Shifters'. The technique used was a variation of what would later become known as 'Offset marking' (see Chapter Six) whereby a deliberate and precisely calculated false wind vector was set on the bomb sight<sup>20</sup>. By aiming at the M.P.I. of the Secondary Markers of the First Phase, the TIs Red of the Shifters would fall on the A/P for the Second Phase, this being one mile further back along the line of approach than the A/P for the First Phase. These would then be backed-up with TIs (Green) which, because the A/P was a mile short of the A/P for the First Phase, should appear as a separate and distinct pattern.

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<sup>20</sup> Setting a height on the bombsight lower than the height at which the aircraft was actually flying would result in an undershoot. Conversely, setting a height on the bombsight higher than the height at which the aircraft was actually flying would result in an overshoot.

The process was then to be repeated again for the Third Phase, the A/P for which the target was the Experimental Works. In addition, the aircraft of No 5 Group would use the time & distance technique, starting from the northern tip of Rügen Island and using the landmarks on the east coast of the island to check time and heading. The timed run would start from Ruden Island, which would be marked by Red Spot fires. However, this was not to be a purely time & distance attack. The No 5 Group crews were instructed that, at the end of their time & distance run, they should aim for the Pathfinder TIs unless these were obviously misplaced. If the crews were unsure about the accuracy of these markers, they were to be guided by the instructions of the Master Bomber and only if no markers were visible, or the Master Bomber advised that the markers were misplaced, was the time & distance method to be used alone.

The accuracy of marking and bombing in each phase was to be checked by the Master Bomber or, if for any reason the Master Bomber was not able to communicate with the Main Force, by the Deputy Master Bomber. This complicated plan, if successful, would result in the bombing migrating northwards over three separate A/Ps, each one mile part, over a time period of 40 minutes.

As with the Friedrichshafen raid, the attack on Peenemünde started badly when the Blind Markers failed to place the Red Spot Fires accurately on the northern tip of Ruden Island. The difficulty was caused by the unexpectedly poor return presented by Ruden Island on the P.P.I. of the H2S sets, which

caused the Blind Markers to mistake the Peenemünde peninsula for Ruden Island, an error of some two miles. The result was that the majority of the proximity markers and flares dropped by the Blind Markers were displaced by a similar distance to the south of the target for the First Phase (the housing estate) where, by coincidence, they fell on a labour camp exactly two miles further south. This error was compounded by at least one of the Visual Markers, although two of the five Visual Markers did place their T.I.s (Yellow) on the correct A/P. The result was two distinct groups of markers, the larger being the inaccurately placed markers two miles south of the correct A/P. The error was quickly spotted by the Master Bomber, who broadcast instructions to the Main Force to ignore the incorrectly placed T.I.s (Red), but this took time and some of the early arrivals bombed the inaccurately placed markers before the instructions could be broadcast.

After the initial confusion, the Backing-up proceeded normally and the A/P remained marked throughout the 15 minutes of the Main Force bombing of the First Phase. This was crucial for the next phase of the attack, because the TIs Green of the Backers-up would provide the reference point for the 'shifting' of the marking onto the target for Phase Two of the attack. However, despite the accuracy of the Backing-up, only one of the marker-loads dropped by the Shifters was accurately placed, the other five either undershooting or overshooting by nearly a mile. As before, the error was quickly spotted by the Master Bomber, who instructed Main Force to aim for the accurately placed marker. At this stage, another problem became apparent, in that an unexpectedly strong crosswind at ground level was drifting the cascading

markers to the east. The Master Bomber had detected this towards the end of the first wave but his efforts to instruct Main Force to take account of the drift in the markers met with only limited success.

The dilution of the marking effort due to the crosswind was to present difficulties for the Third Phase, and the shifting of the marking at the end of Phase Two was even less effective than with the first phase. Two of the marker loads overshot the target by some 1,000 yards but the other three overshot by a considerable distance, some landing as far south as the A/P for the First Phase. The situation was exacerbated by the fact that the Master Bomber was focusing on the drift of the markers in the preceding phase and failed to notice the error in the marking, and issued no instructions to correct the error. This is significant, in that the No 5 Group crews in the Third Phase were only to rely upon their time & distance run if no markers were visible, or the Master Bomber advised that the markers were misplaced. The approach along the east coast of Rügen Island had provided good checks and most crews were able to make accurately timed runs. However, presented with the sight of the Pathfinder Markers, and with no indication from the Master Bomber that these were misplaced, many No 5 Group crews aimed at the misplaced markers instead of relying upon their time & distance runs. Later analysis would show that those No 5 Group crews that did rely on their time & distance runs were more accurate than those that relied upon the Pathfinders markers<sup>21</sup>.

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<sup>21</sup> Middlebrook *The Peenemunde Raid*. In his book, Middlebrook suggests that Air Vice-Marshal Cochrane, AOC of No 5 Group, was annoyed that his Group had not been allowed to attack Peenemünde on its own using just the time & distance technique. According to Middlebrook, Cochrane had been convinced that Peenemünde would have been totally



The Friedrichshafen and Peenemünde raids have been set out in some detail here because they both demonstrate the benefits and problems associated with the control of large bomber forces by a Master Bomber. In both raids, the Master Bomber was able to detect initial errors in the target marking to correct those errors through instructions to the later marking crews and the Main Force. In the Peenemünde raid, the Master Bomber was also able to detect the error in the first 'shift' in the A/P and to correct that error also. In relation to such small targets, it may be reasonably concluded that the attacks would have substantially failed had a Master Bomber not been employed. In both raids, the Master Bomber was able to detect changes in wind strength and direction and, at least to some extent, to compensate by issuing instructions to the Main Force and thereby improve both the accuracy and concentration of the bombing.

The other benefit concerns one of the reasons why a Master Bomber was first proposed by Wing Commander Anderson in 1942: the effect on morale. In his book *The Peenemunde Raid 17/18 August 1943*<sup>22</sup>, Martin Middlebrook includes a number of quotes from aircrew that took part in the Peenemünde raid, all of which refer to the boost in morale provided by hearing 'a calm, authoritative English voice encouraging the crews and providing guidance on the markers to aim for'. It is impossible to quantify the effect this may have had on the overall bombing performance, although it is a reasonable assumption that this effect was a positive one.

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destroyed by using of that technique, rather than just damaged. This was an early example of the differences between Cochrane and Bennett.

<sup>22</sup> Ibid. p.p. 128 and 129.

The main problems arose from the work load imposed upon a single Master Bomber in controlling a large bomber force in an ever-changing tactical situation. In the Peenemünde raid, for example, by focusing upon the drift of the markers due to the crosswind, the Master Bomber failed to spot the error in the marking for the Third Phase. It is clear that the Master Bomber for the Peenemünde raid did lose control over the Main Force towards the end of the raid, although any consequences of that must be weighed against the benefits gained by the positive control achieved in the initial phases. The clear indication, however, is that attempting to control a large bomber force was not a viable proposition and that, rather than seek to 'control', the role of the Master Bomber was more properly one of guiding or directing the attack.

The common denominator linking the Friedrichshafen and Peenemünde raids was that they were small scale precision targets. Although a Master Bomber had been employed on an area attack on Turin, that was primarily a trial for OPERATION HYDRA and it remained to be seen if the Master Bomber technique was suitable for full scale Main Force raids on the German area targets that were the main focus of Bomber Command at this time.

The primary reason for using a Master Bomber in area raids was to reduce the 'creepback' of the Main Force bombing. There were three causes of creepback. The first was derived from the characteristics of the Target Indicator itself; in terms of its position on the ground and the assessment by

the bomb aimer<sup>23</sup>. The second was the practice of some crews faced with the defences in the target area to release their bomb load on the first markers visible, and therefore not necessarily at the M.P.I. of the marking pattern. The third, related reason, was a function of searchlight activity over the target area, the presence of which denied bomb aimers clear sighting of the pattern of markers. The M.P.I. of the marking pattern was therefore not always apparent and, in many cases, this led bomb aimers to focus on the most prominent TI visible. This would typically be the closest, and hence bombing and marking would tend to move progressively along the line of approach.

As related in Chapter Five, the initial response to the phenomenon of creepback was the introduction of 'Recenterers'. These were experienced Pathfinder crews detailed to re-mark the A/P and would typically drop markers with a slight overshoot in order to bring bombing back onto the A/P, a technique which, in isolation, met with only limited success. The introduction of the Master Bomber in area attacks was intended to add a further dimension to this technique by instructing the Main Force crews which markers to aim for and to encourage crews to continue over the target area until the most accurately placed markers were observed.

The use of a Master Bomber in a raid on an area target was first tried on a raid on Berlin on the night of 23/24 August 1943<sup>24</sup>. The Master Bomber on

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<sup>23</sup> See Chapter Five.

<sup>24</sup> TNA AIR14/3012 ORSBC Final Raid Report; Berlin, 23/24 August 1943.

that occasion was again provided by No 8 Group<sup>25</sup> and the marking plan was a *Controlled Parramatta*. Perhaps learning from the experience at Peenemünde, the Master Bomber was only to control the first ten minutes of the raid and, in particular, to comment on the accuracy of the TI's dropped by the Blind Markers. In the event, the raid was only partially successful and, despite the corrections issued by the Master Bomber, the majority of the markers and bombing fell to the south-east of the A/P. The ORSBC Interim Raid Report noted that weather conditions prevented visual identification of ground features and considered the Master Bomber to have been completely ineffective. This led ORSBC to recommend that the Master Bomber technique should only be used as part of the *Newhaven* technique where ground detail was visible.

A Master Bomber was again employed on the next major raid, against Nuremburg on the night of 27/28 August 1943, but with no more success than in the Berlin raid a few days previously<sup>26</sup>. The initial Pathfinder marking was accurate but an extensive creepback developed, and much of the bombing fell in open countryside. The Master Bomber had detected the creepback but was unable to persuade crews to move the bombing forward, partly because only about one quarter of the crews could hear his instructions.

The use of a Master Bomber in these two raids can only be judged to have had little success, but the next raid on which a Master Bomber was employed,

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<sup>25</sup> The Master Bomber on this occasion was Group Captain Johnny Fauquier, at that time commanding No 405 Squadron, and who would later lead No 617 Squadron on precision attacks. Fauquier had been one of two Deputy Master Bombers on the Peenemünde raid

<sup>26</sup> TNA AIR14/3012. The Master Bomber on this occasion was Wing Commander Ken Burns, who had been the Deputy Master Bomber on the previous Berlin raid.

against the Dunlop rubber factory at Montluçon in Central France, was entirely successful<sup>27</sup>. The raid, carried out in good visibility and bright moonlight, was carried out from an altitude of 5,000ft. The defences were light, and the initial marking was generally accurate. However, one TI (yellow) was dropped very wide in error and the backing-up with TI (Red) was widely scattered. The success of the raid was therefore attributed to the Master Bomber, who noticed the errors and directed the Main Force bombing onto the accurate markers. Nevertheless, ORSBC estimated that the damage to the factory, which was completely destroyed, was caused by just 2% of the aircraft taking part.

No formal analysis of the role of the Master Bomber in these attacks has been found. However, in his book *The Berlin Raids: R.A.F. Bomber Command Winter 1943-44*, Martin Middlebrook quotes two of the Master Bombers who took part in these raids<sup>28</sup>. Both express the opinion that the main difference between precision targets such as Peenemünde and large city targets such as Berlin lies in the extent to which ground features were visible. This was partly due to the weather conditions. The precision attacks all took place in conditions of bright moonlight, whereas the area attacks took place in the non-moon period. The bombing altitude was also a factor, in that individual ground features are generally not visible from above 4,000ft even in conditions of bright moonlight and that no ground features are discernable above

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<sup>27</sup> TNA AIR14/3012 ORSBC Report B.165, 29 September 1943.

<sup>28</sup> Martin Middlebrook *The Berlin Raids: R.A.F. Bomber Command Winter 1943-44* (Penguin Books, 1990), page 95. The two Master Bombers quoted are Group Captain John Searby, Master Bomber for the Turin and Peenemünde raids, and Wing Commander Ken Burns, who had been the Master Bomber for the Nuremberg raid and Deputy Master Bombers on the Berlin raid.

12,000ft<sup>29</sup>. At that time, operational heights of circa 20,000 feet were typical for area attacks and it follows that the Master Bomber operating at that height would not be able to discern individual ground features. A further factor was the intensity of the defences, particularly searchlight activity, which hindered visibility of the ground. A combination of these factors reduced the ability of a Master Bomber to assess the accuracy of the marking in area attacks, which in turn reduced the extent to which corrections could be made.

There is plenty of anecdotal evidence in personal accounts of the bombing offensive to suggest that the use of a Master Bomber did assist in encouraging crews to press on to the A/P in the face of strong defences in the target area. Martin Middlebrook quotes the navigator of a Lancaster crew taking part in the Berlin raid of 23/24 August 1943 who, speaking of the Master Bomber on that occasion, Group Captain Fauquier, said that: "He had an excellent R/T voice that came over loud and clear to all we later talked with. It no doubt helped to calm jittery nerves and, I believe, it helped produce a better concentration of bombs on the Aiming Point"<sup>30</sup>. The similar comments cited above in relation to the Peenemünde raid tend to support that view.

There is, however, no empirical evidence to counter the conclusion of the two Master Bombers quoted by Middlebrook that the role was a refinement that made little difference, simply because the ground could not be seen. Indeed, this is supported by the facts. The most successful large-scale Main Force

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<sup>29</sup> See Chapter 1 for a discussion on the visibility of ground features at night.

<sup>30</sup> Middlebrook, *The Berlin Raids*, p65. The abbreviation 'R/T' in this quote refers to 'radio telephone'. Group Captain 'Johnny' Fauquier had been the Deputy Master Bomber on the Peenemünde raid and would later lead No 617 Squadron during the period was equipped with the 'Tallboy' and 'Grand Slam' bombs.

raids of the period, including the substantial destruction of the main Ruhr towns<sup>31</sup> and the firestorms raids on Hamburg and Kassel<sup>32</sup>, were achieved without the presence of a Master Bomber. The success of these raids all resulted from accurate primary marking, combined with effective backing-up by secondary marking, all achieved without assistance from a Master Bomber. Where raids failed, the main reason was the spread of the primary marking and the inability of the Pathfinders to create a distinctive point of aim. In those cases, the Principle of Cumulative Dispersion ensured that the raid was not concentrated and that creepback developed. The limited evidence from the two failed attempts to control a large Main Force with a Master Bomber suggests that, due to the inability of the latter to see ground detail at the operational heights employed, no substantial benefit resulted from the technique. Although no formal decision to discontinue the employment of Master Bombers has been found in documentation, the small-scale Montluçon raid would be last occasion on which a Master Bomber was used until the reversion to tactical targets in the build-up to OPERATION OVERLORD six months later.

The build-up to OPERATION OVERLORD and in the months following involved an entirely different target set to the area attacks Bomber Command had focused upon previously. Beginning in March 1944, Bomber Command switched to tactical targets in support of the planned invasion, these being

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<sup>31</sup> TNA AIR14/3011 Final raid Reports Report No 340 Wuppertal 29/30 May 1943 12 August 1943 and No 389: Remscheid, 30/31 July 1943, 26 September 1943. See also Middlebrook and Everitt, *The Bomber Command War Diaries*, p394 and p415 respectively. These raids were regarded as the outstanding successes of the Battle of the Ruhr.

<sup>32</sup> TNA AIR14/3411 Final Raid Report No 451 Kassel 22/23 October 1943, 6 January 1944. See also Middlebrook and Everitt, *The Bomber Command War Diaries*, p440. The raid on Kassel (569 aircraft) resulted in the second firestorm of the bombing offensive.

small precision targets such as marshalling yards, storage depots, V-weapon sites and, occasionally, synthetic oil plants<sup>33</sup>. The operations at this time generally involved smaller bomber forces, typically between 100 and 350 in strength<sup>34</sup>. In order to ensure efficiency and accuracy, and to minimise civilian casualties in occupied countries, these attacks were generally conducted at lower bombing altitudes than the area attacks (typically 8,000 to 10,000ft). The attacks on these target sets therefore had many similarities with the precision attacks at Friedrichshafen, Peenemünde and Montluçon in which the use of a Master Bomber had proved beneficial.

The target marking used in these operations encompassed the whole range of techniques developed until that point but, because the typical bomber strength allocated to individual targets was reduced, there was an increasing tendency for some of the Bomber Groups to act independently, especially Nos. 1 and 5 Groups, both of which possessed their own target marking capability<sup>35</sup>. This enabled a direct comparison of the various target marking techniques to be made, including the difference, if any, made by the employment of a Master Bomber<sup>36</sup>. The following table is a summary of the results.

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<sup>33</sup> Although in support of the planned invasion, these operations were not in direct support of land forces on the ground and, in the strictest sense, these targets were therefore 'strategic' rather than 'tactical' targets. However, the term 'tactical' is used here to differentiate from the strategic bombing that Bomber Command had been largely conducting up until that time

<sup>34</sup> Middlebrook and Everitt *The Bomber Command War Diaries*.. This figure had been calculated by averaging the size of the raids listed in this work, which itself is based on the Final Raid Reports held in The National Archives and may therefore be considered to be reliable.

<sup>35</sup> Otter, *1 Group: Swift to Attack*, p162. In the case of No 1 Group, this was provided by the 1 Group Marking Flight, based at Binbrook.

<sup>36</sup> TNA AIR14/2692 Operational Research Section Report S184 'Bombing Accuracy of Bomber Command against lightly defended targets', 20 September 1944. The table reproduced above is based upon that in this report, although information in that table not directly relevant to the point under discussion has been omitted for clarity.



Target marking technique	Proportion of Ineffectives	Systematic Error	Random Error
Musical Parramatta	17%	330 yards	320 yards
Controlled Musical Parramatta	16%	230 yards	420 yards
Controlled Newhaven	18%	355 yards	455 yards
5 Group Visual Groundmarking	16%	205 yards	370 yards
5 Group Offset	19%	370 yards	365 yards

Table 12/ Comparison of target marking techniques against lightly defended targets. Source: TNA AIR14/2692 ORSBC Report S184 'Bombing Accuracy of Bomber Command against lightly defended targets', 20 September 1944.

Comparison of the results achieved with these various techniques provides an interesting insight into the value of the Master Bomber. The first observation relates to the *Musical Parramatta* technique of ground marking with and without the use of a Master Bomber. The constant in all these attacks was that the use of TIs dropped blind using *Oboe* and it may be noted that the Systematic Error of the initial *Oboe* ground marking was 330 yards (i.e. that for *Musical Parramatta*). Because the target sets for all these raids were of a

similar range and at a similar angle of cut in relation to the *Oboe* ground stations, it is reasonable to assume that the accuracy of the initial marking in the *Controlled Musical Parramatta* raids was of the same order. The reduction in the Systematic Error of 100 yards, or nearly one third, for the *Controlled Musical Parramatta* attacks can therefore only be attributed to the presence of a Master Bomber. The most likely explanation for this improvement in accuracy is the ability of the Master Bomber to assess the accuracy of the initial *Oboe* Marking and to direct the Main Force onto the most accurate marker, and to ignore obviously misplaced markers.

It is, however, interesting to note that whereas the Systematic Error in attacks based on *Oboe* ground marking was reduced by the use of a Master Bomber, the Random Error increased. The Random Error was the measure of bomb scatter about the M.P.I. or, in other words, the measure of concentration. The increase in the Random Error is counter-intuitive, in that the role of a Master Bomber was to direct the Main Force onto the most accurate markers and thereby provide a single point of aim for the Main Force. In theory, this should have reduced the effect of the Principle of Cumulative Dispersion and thus the Random Error, thereby resulting in greater concentration. The answer to this apparent discrepancy lies in the practice of some Master Bombers of marking the A/P visually in addition to the initial *Oboe* marking. ORSBC calculated that the prospect of visually aimed markers being closer to the A/P than a group of four or more *Oboe* dropped markers was slight, and that this practice led to some scatter of the bomb distribution. This later led to the recommendation that the primary role of the Master Bomber should be to direct the bombing

onto the most accurate marker and that visual marking should only be attempted when there was a failure in the *Oboe* marking<sup>37</sup>.

A second observation arising from the above table concerns the *Controlled Newhaven* and the 5 Group Visual techniques. In most respects these techniques were similar, relying on Target Indicators aimed visually in the light of flares dropped blind using H2S<sup>38</sup>. The main difference was in the height from which the markers were dropped and the accuracy of the marking assessed by the Master Bomber. In the *Controlled Newhaven*, in which the marking was provided by No 8 Group, the Primary Visual Markers and the Master Bomber operated at a similar altitude to the Main Force bombing. In the 5 Group *Visual Groundmarking* technique, the marking was carried out at low level, as was the assessment of the marking by the Master Bomber. The result was that the Systematic Error and the Random Error were significantly lower for the *Visual Groundmarking* technique compared to the *Controlled Newhaven* technique used by No 8 Group.

The reason for this improved accuracy and concentration is the now familiar one: the lower altitude at which the Master Bomber flew in the *Visual Groundmarking* technique enabled a more precise assessment of the accuracy of the Primary Markers to be made and corrections to be issued to Backers-up. The resulting accuracy and concentration of the marking

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<sup>37</sup> TNA AIR14/2692 Operational Research Section Report S193 'The accuracy of visual marking on lightly defended targets', 12 December 1944.

<sup>38</sup> In the standard *Newhaven technique*, the flares were usually by H2S and this was the also case with this particular target set. However, because of the poor response given by the relatively small targets on the PPI of the H2S sets, and given the relatively short range, in some of the attacks on this target set the flares were dropped using GEE.

provided, if not a single point of aim for the Main Force, at least a more compact pattern of markers from which the M.P.I. had to be estimated. This reduced the effect of the Principle of Cumulative Dispersion and thus the Random Error, thereby resulting in improved initial accuracy. The smaller Main Force used in these raids enabled the Master Bomber to retain control over the Main Force bombing, thereby achieving greater concentration.

The final observation to be made in relation this table is that the Proportion of Ineffectives tended to be lower when a Master Bomber was used. The Proportion of Ineffectives is the proportion of bombs dropped that for a variety of reasons do not contribute to the normal bomb distribution. This included bombs dropped so far outside of the main bomb distribution that they were classed as Gross Errors<sup>39</sup>. One of the main causes of Gross Errors was bombs aimed at misplaced markers. The reduction in Gross Errors in 'Controlled' attacks was a direct result of the ability of a Master Bomber to detect misplaced markers and to issue instructions to Main Force crews to ignore them. The reduction in the Proportion of Ineffectives, and the consequent increase in the efficiency of Bomber Command attacks, was one of the most important benefits derived from the Master Bomber technique.

The role of correcting gross errors was formally incorporated into target marking techniques with the introduction of the 'Long Stop'. The 'Long Stop' was both the name given to a TI dropped to indicate the limit of the bombing area and the title given to the crew specifically detailed to drop that marker.

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<sup>39</sup> The other main contributor the Proportion of Ineffectives was 'dud' bombs that failed to explode on impact.

The technique was introduced following a bombing error made in the direct support of ground forces in the Normandy battle area when, on 14 August 1944, part of the bombing fell amongst positions held by Canadian Forces<sup>40</sup>. The Long Stop technique was to drop a line of TI's Yellow, beyond which the main force must not bomb, or to cancel gross errors by placing a TI Yellow over them. In addition to dropping these markers, the Long Stop would monitor the bombing and, if necessary, could stop the raid (in which eventuality, the instructions of the Long Stop would be in addition to and take precedence over those of the Master Bomber). The technique was first used on 10 September 1944 during a remarkable raid in which eight individual coastal gun batteries were targeted, each with an individual A/P and Long Stop<sup>41</sup>. It was a testament to the degree of control possible using the combination of a Master Bomber and Long Stop that Bomber Command was able to attack a series of targets in such proximity to each other and to the British ground forces. These raids against smaller targets highlight the true value of a Master Bomber, particularly those against precision targets such as oil refineries and marshalling yards, in which the control exercised by the Master Bomber in terms of eliminating gross errors and directing the bombing onto the most accurately placed markers made a significant difference to the effectiveness of the raid.

In summary, it can safely be stated that the inclusion of a Master Bomber could optimise the effectiveness of a raid. This was particularly the case

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<sup>40</sup> Middlebrook and Everitt, *The Bomber Command War Diaries*, p562.

<sup>41</sup> Feast *The Pathfinder Companion*, p.p. 153 and 154. This raid was carried out by 992 aircraft in total, with each individual A/P being allocated codenames after makes of cars (Alvis I to IV, Bentley I and II, and Buick I and II).

where both the target and the bomber force were relatively small, such that the Master Bomber could evaluate the progress of the raid and exercise control over the Main Force. As Bomber Command increasingly shifted away from large scale area attacks on major conurbations towards attacks by smaller forces on lesser towns and precision targets, the role of the Master Bomber would assume increasing importance and made a significant contribution to the effectiveness of Bomber Command in the last year of the bombing offensive.

It would, however, be erroneous to assume that the role of the Master Bomber was a pre-requisite to effectiveness or a guarantee that a raid would be successful. If the initial target marking was inaccurate or the markers widely spaced, there were limits to the extent to which a Master Bomber could recover the situation. It was, therefore, the accuracy and concentration of the primary marking that ultimately dictated the effectiveness of a raid. An effective Master Bomber could maximise the concentration of bombing on that primary marking and reduce the wasted effort due to gross errors. But it was beyond the scope of the Master Bomber to direct the bombing when the ground was obscured by cloud or smoke, or the bombing area too large or the spread of bombing too scattered to direct bombing to any single part of it. There was also the fact that, as shown by ORSBC, the presence of a Master Bomber could itself result in an increase in the Random Error at the A/P due to inaccurate visual marking the A/P in addition to the primary blind marking. The contribution made by the introduction of Master Bombers therefore must be viewed in this context, and against the inability of a Master Bomber to

control the larger bomber forces used against the area targets that occupied Bomber Command throughout a large period of the bombing offensive. Looked at in this way, the role of Master Bomber can at best be described as a qualified success.

## CONCLUSION

At the end of the bombing offensive, the Operational Research Section at Bomber Command (ORSBC) produced a report on the effect of the development of navigational and blind bombing techniques on the efficiency of bombing operations during the Second World War<sup>1</sup>. The report was largely descriptive, and charted the improvement in bombing efficiency throughout that part of the bombing offensive for which data was available<sup>2</sup>. The report defined 'efficiency' as being the number of bombs dropped within 3 miles of the Aiming Point (A/P) and included a graph to show the improvement in efficiency over the course of the offensive. That graph is reproduced below as Fig 27/. It can be seen from this graph that the efficiency of Bomber Command night attacks - the term 'efficiency' is readily transposable with the term 'accuracy' - improved from a total of 24% in August 1942 to 96% in April 1945, the latter date being effectively the end of the bombing offensive<sup>3</sup>. This significant improvement in accuracy was one of the main factors that turned Bomber Command from the ineffective instrument of the early war years into a formidable striking force capable of devastating a substantial proportion of an urban area in a single night or attacking precision targets such as oil refineries.

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<sup>1</sup> TNA AIR14/2693 ORSBC Report S252 'The effect of the development of navigational and blind bombing techniques on the efficiency of bombing operations during World War II (Aug 1941-May1945), 15 October 1945.

<sup>2</sup> Ibid. For the purposes of the ORSBC report, the data was derived from night bombing photographs taken from August 1942. Night bombing photographs had been available since the summer of 1941, but no explanation is given in the ORSBC report as to why the analysis did not include data from that year.

<sup>3</sup> The last operation carried out by Bomber Command was on the night of 2/3 May 1945, although this was a one-off operation and bombing offensive effectively ceased a week beforehand, on the night of 26/27 April 1945. The figures in the OSBC report represent the first and last months of the bombing offensive for which data was available.



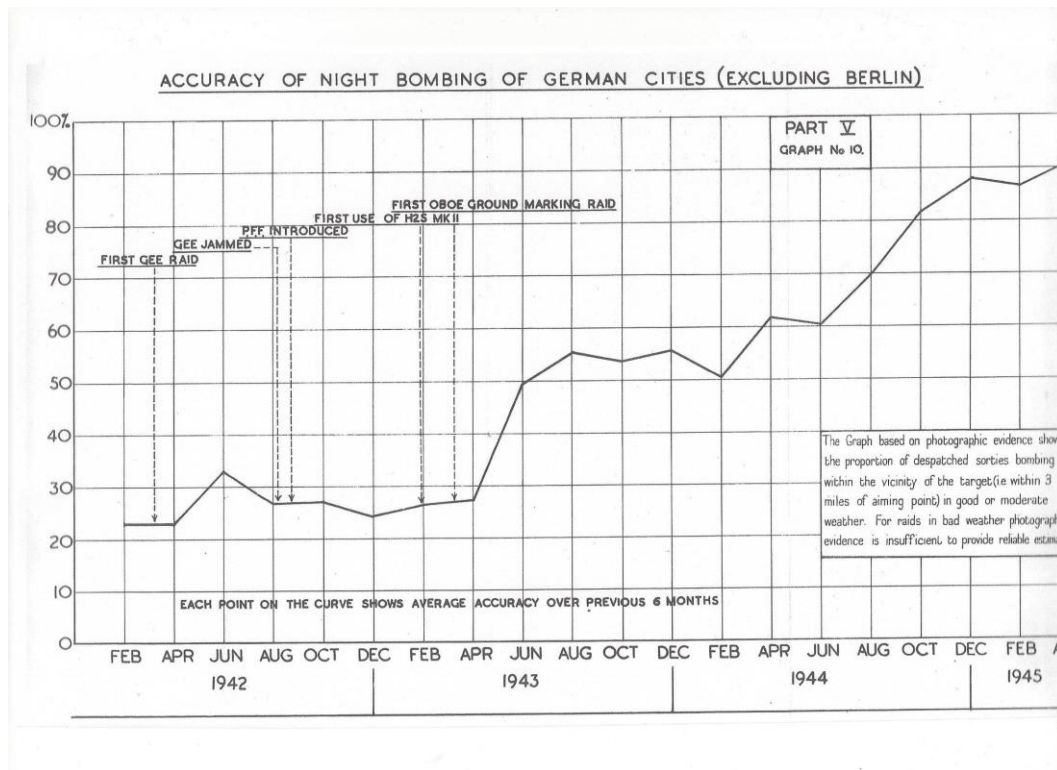


Fig 27/ Improvement in efficiency (accuracy) of Bomber Command night attacks August 1942 to April 1945.

It may be noted that the graph in Fig 27/ is annotated with reference to the first use of the main navigation and blind bombing aids used by Bomber Command - GEE, Oboe and H2S. The ORSBC report focuses upon these aids and, whilst it makes reference to target marking techniques throughout, it does not seek to relate the aids used to the development of target marking techniques. This graph does, however, provide a convenient vehicle for exploring the question that underpins this thesis: to what extent did the development of target marking techniques contribute to the improvement made in the accuracy of Bomber Command night raids?

This thesis has demonstrated that the improvement in the accuracy of Bomber Command shown in Fig 27/ was the result of the introduction of target

marking techniques. Two key points may immediately be drawn from the improvement in accuracy shown on this graph. The first is that the improvement in accuracy was neither progressive nor linear. There are a number of points throughout the bombing offensive where there were step changes and reverses in the improvement in accuracy. The second key point is that these step changes and reverses can all be directly related not to the introduction of a particular navigation aid or blind bombing device *per se*, but rather to the target marking technique that was associated with it. Thus, the step change from April 1942 to June 1942 corresponded to the introduction of GEE and the *Shaker* technique (see Chapter Three of this thesis), whereas the significant step change that occurred between April 1943 and June 1943 corresponds to the Battle of the Ruhr and the introduction of *Oboe* in conjunction with the *Musical Parramatta* technique (see Chapter Five of this thesis). The step change that occurred between February 1944 and April 1944 corresponds with the introduction of the improved H2S Mk III and the consequent improvements in the *Newhaven* and *Parramatta* techniques in association with it (see also Chapter Five). The sustained improvement that took place from June 1944 onwards was to a large extent predicated upon the introduction of the improved *Oboe Mk II* and the provision of mobile *Oboe* ground stations advancing into Europe following OPERATION OVERLORD, with the consequent increase in *Oboe* coverage and the more widespread use of the *Musical Parramatta* technique. In addition, the improvement in accuracy during this period resulted in part from the introduction of the indirect bombing techniques introduced by No 5 Group (see Chapter Six of this thesis). Although not associated with a particular navigation aid or blind bombing

device, the improvement in accuracy achieved using indirect bombing was nonetheless a direct result of the application of a target marking technique.

Similarly, the period in the bombing offensive during which accuracy stagnated, and even declined, can be explained by reference to the use of navigation aids and the associated target marking technique. The period of stagnation between August 1942 and April 1943 corresponds to that between the jamming of GEE, and therefore the effective cessation of the *Shaker* technique, and the introduction of *Oboe* and *Musical Parramatta*. This was therefore a period during which there no navigation aids or blind bombing devices to provide an initial indication of the A/P. As described in Chapter Five, it was also during this period that the Pathfinder Force came into being and the use of target markers first became a standard feature of target marking, and thus the first time during the offensive in which crews were instructed to aim at a marker rather than a point on the ground that they had identified themselves. The dip in accuracy between October and December 1942 therefore corresponds with the first occurrence of the 'Systematic Error' which displaced the M.P.I. of the bomb distribution from the A/P and which, until the use of target markers, had not been a feature of Bomber Command attacks.

In parallel with the improvement in accuracy, there was a commensurate increase in concentration. The latter may be measured in two ways: absolute density, this being the tons per square mile at the A/P and therefore a measure of the scale of the attack: and relative density at the A/P, this being

the absolute density per 1,000 tons dropped. Relative density is therefore independent of the scale of attack, and is a measure of both accuracy and concentration. It is therefore the relative density at the A/P that is of primary interest here.

From 1943 onwards, ORSBC monitored both the absolute and relative density achieved in Bomber Command attacks on major German towns<sup>4</sup>. The headline figures showed a relative density at the A/P of 33.4 tons per square mile per 1,000 tons dropped in 1943, rising to 173.5 tons per square mile per 1,000 tons dropped in 1944. This represents an increase in relative density at the A/P of 140.1 tons per square mile per 1,000 tons dropped, a 5.2 fold increase.

The improvement in accuracy and concentration achieved by Bomber Command throughout the bombing offensive may be attributed directly to the introduction of target marking techniques in conjunction with navigation aids or blind bombing devices. Moreover, as the graph shows, there was a causal relationship between the degree of accuracy achieved and the navigation aid or blind bombing device employed and the target marking device associated with it. The development of target marking is in essence the story of the use of technology in conjunction with human actions to address, as Air Commodore Coningham termed it as early as December 1939, the never ending struggle to circumvent the law that human beings cannot see in the dark.

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<sup>4</sup> Air Ministry (Air Historical Branch monograph), *Operational Research in Bomber Command* (1949), Table 1, p.110

Most of the principal techniques for target marking approached this problem with the application of science. It was the technical characteristics of the particular navigation/blind bombing aid employed that dictated the target marking technique associated with it. These characteristics resulted in considerable differences in the profile of the target marking technique. In turn, the target marking techniques associated with these various devices resulted in significant differences in the amount of human interaction required and, therefore, the potential for the introduction of gross errors.

The blind bombing aids that were sufficiently accurate to place a primary marker in close proximity of the A/P, specifically those based on signals from ground stations and particularly *Oboe*, provided a distinctive and unmistakable point of aim. As pointed out by ORSBC, the success achieved by *Oboe* ground-marking raids was directly attributable to the certainty with which primary markers could be placed within a Probable Radial Error of ½ mile of the A/P<sup>5</sup>. This incurred an immediate advantage in that both the backers-up and Main Force aircraft could be categorically instructed to focus on a single point of aim rather than at the M.P.I. of several markers, and immediately minimised the effect of the Principle of Cumulative Dispersion.

However, when used to provide primary marking, *Oboe* required the initial primary marker(s) to be backed up at regular intervals by secondary markers dropped visually (this was the *Musical Parramatta* technique). The drawback of the *Musical Parramatta* technique was that the secondary marking was not

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<sup>5</sup> TNA AIR14/1574 ORSBC Report S.102, 'The Operational Use of *Oboe* Mk1A: December 1942 to June 1943', 31 August 1943.

carried out by *Oboe* aircraft and that the secondary marking necessary to maintain a continuity of marking for the Main Force was carried out visually. The accuracy of the secondary marking was considerably less than that achieved with the primary marking by *Oboe* aircraft and it was this lesser accuracy in secondary marking, together with the effect of the Principle of Cumulative Dispersion with the Main Force bombing, that resulted in the overall figure of 54% of bombs falling within 3 miles of the A/P. The potential for gross error in attacks led by *Oboe* was therefore largely confined to errors generated by the assessment of the M.P.I. of the T.I.s by Backers-up and the Main Force crews. However, because of the initial accuracy of the primary marking the influence of the Principle of Cumulative Dispersion was minimised. As a result, attacks led by *Oboe* groundmarking were consistently accurate and concentrated, and were consistently amongst the most successful attempted by Bomber Command.

The importance of removing the potential for gross error due to human action is best demonstrated by the successive improvement in results achieved throughout the Battle of the Ruhr using the *Musical Parramatta* technique where, following the introduction of a third *Oboe* Channel, an attack on Remscheid became the first during which continuous primary marking had been maintained throughout the entire raid. The primary marking was exceptionally accurate, with the result that 83% of the town was devastated. The importance of providing a single point of aim was reinforced by the subsequent development of a variation of *Musical Parramatta* known as *Continuous Oboe Marking*, in which the only markers dropped were primary

markers using *Oboe*, and which was the only groundmarking technique where the dropping of every marker was fully automated<sup>6</sup>. *Continuous Oboe Marking* was therefore the only target marking technique in which the estimation of the M.P.I. of the marking was not required, and which therefore entirely removed the human error factor and avoided the effects of the Principle of Cumulative Dispersion during the marking phase.

By contrast, those navigation aids that were based on the principles of hyperbolic navigation (principally, in the context of target marking, GEE) and the H2S airborne radar were not sufficiently accurate to place a T.I. in close proximity of the A/P. The use of these devices therefore required a different target marking technique in which the A/P was either first illuminated with the use of flares dropped blind (*Shaker* and *Newhaven*)<sup>7</sup> or T.I.'s were dropped blind to form a pattern around the A/P (*Parramatta*)<sup>8</sup>. The *Shaker*, *Newhaven* and *Parramatta* techniques all required considerably more human interaction than the *Musical Parramatta* technique using *Oboe*. In relation to the *Newhaven* technique, this human interaction first occurred at the critical initial identification of the A/P and the dropping of the primary markers. Consequently, in addition to being considerably less accurate than *Oboe* in terms of placing the initial primary markers, the target marking techniques that relied upon GEE or H2S provided greater opportunity for the introduction of gross errors through human interaction as the raid progressed. In accordance

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<sup>6</sup> The only other target marking technique that was fully automated was *Musical Wanganui*. This was a sky-marking technique in which the flares were dropped using *Oboe* but, as with all skymarking techniques, was in inherently less accurate than ground-marking techniques.

<sup>7</sup> TNA AIR14/3293 ORSBC Report S30 'The operational use of Gee III: The use of flares in conjunction with GEE', 24 January 1942

<sup>8</sup> TNA AIR14/3025 ORSBC Report B.151, 'Review of H2S Groundmarking raids on Germany: February – April 1943', 1 July 1943.

with the Principle of Cumulative Dispersion, the initial wide spread of primary markers was compounded at each stage of marking and Main Force bombing. As a result, these techniques were inherently less accurate than *Musical Parramatta* directly because of the characteristics of the navigation/blind bombing aid upon which they were based and the consequent extent of the human interaction required to implement those techniques.

The target marking techniques described above all approached the problem of providing a single and unmistakable point of aim with the application of science in the first instance followed to a greater or lesser degree by human interaction to mark the A/P. The most successful of these techniques, *Musical Parramatta*, minimised the extent of human interaction and in some versions eliminated it entirely. It may therefore appear paradoxical that the most effective target marking techniques developed during the bombing offensive - those generically known as 'indirect bombing' - not only deliberately marked a position away from the A/P but also relied exclusively upon human action to provide the primary marking (see Chapter Six). In these techniques, the role of science was generally confined to providing illumination of the target area through the use of flares in order that the Marking Point (as opposed to the Aiming Point) could be accurately marked. The subsequent actions, including the calculation of the 'false wind' for setting of the bombsights of the Main Force aircraft, involved a significant human input that, in theory, should have introduced the potential for significant gross errors.



In practice, the reason why indirect bombing was successful was that it provided a single and unmistakable point of aim for the Main Force and, consequently, minimised the effects of the Principle of Cumulative Dispersion from the very outset. This was in part due to the benefit resulting from the markers not being obscured by smoke and dust from the bombing, but was principally due to the fact that the Marking Point was clearly visible from the low level at which the marking was carried out. Indirect bombing was, simply put, an effective means of circumventing the law that humans cannot see in the dark by the simple expedient of initial target marking from an altitude at which ground detail was visible.

It is noteworthy that in all its forms indirect bombing relied upon communication between a Master Bomber, the marker aircraft and the Main Force. This was a fundamental component of the technique and required a number of human inputs, including matters of judgement in terms of assessing the accuracy of the primary marker in relation to the Marking Point. On the face of it, the reliance of the technique on human judgement may be considered to introduce the potential for gross errors and therefore be susceptible to the Principle of Cumulative Dispersion. However, the principal benefit of the Master Bomber in these techniques was to direct the Main Force bombing on to the most accurately placed markers, this therefore being an example where human interaction worked positively in conjunction with the technology rather than negatively. This was only possible because the Master Bomber was operating at an altitude at which ground detail was visible and was therefore in a better position to judge accuracy than the Main Force

operating at altitudes from which no ground detail was visible. The transmission of this information to the Main Force therefore obviated the need for the Main Force crews to make a similar judgement on an individual basis. By these means, the number of individual actions by the Main Force crews was significantly reduced and this had the effect of reducing the effects of the Principle of Cumulative Dispersion. This was one of the factors that underpinned the success of the indirect bombing techniques.

The foregoing demonstrates that it was the accuracy and concentration of the primary marking that ultimately dictated the effectiveness of a raid and that was primarily a function of the science and technology involved in the primary marking. It was for this reason that target marking techniques were constantly refined and improved throughout the course of the bombing offensive in an attempt to provide an unmistakable point of aim as close to the Aiming Point (or Marking Point) as possible. Due to the technologies involved, groundmarking techniques developed during the course of the bombing offensive fell into two broad categories: those in which the primary markers were dropped blind (*Parramatta* and *Musical Parramatta*) and those in which the primary markers were dropped visually in the light of flares dropped blind (*Shaker*, *Newhaven* and indirect bombing). This in turn dictated the methods by which these techniques were developed over the course of the bombing offensive.

In relation to those techniques in which the primary markers were dropped blind, the development tended to concentrate upon the objective of providing

continuous primary marking throughout the duration of the attack. This was achieved primarily by increasing the number of *Oboe* Channels that were available to ensure that the primary markers dropped by *Oboe* were replenished before the original markers burnt out, the ultimate iteration being *Continuous Oboe Marking*. For all other versions of *Musical Parramatta*, the improvements made were secured by improvements in the timing of the backing-up and the disposition of the Main Force throughout the duration of the raid. The only other significant refinement to the *Parramatta* and *Musical Parramatta* techniques was the use of a Master Bomber which, as described above, improved concentration of the primary markers by directing the Main Force to the most accurate of the primary markers.

Those techniques in which the primary markers were dropped visually in the light of flares dropped blind, in this context *Shaker* and *Newhaven*, were dependent upon the timing of the initial illumination, the primary marking and the secondary marking. Refinements to these techniques therefore tended to concentrate upon the timing of these key elements, particularly the time between the illumination of the target area and the dropping of primary markers. This was particularly true of the *Shaker* technique (see Chapter Three), in which the main focus for experimentation was the duration of 'flare period', albeit that the short lifespan of GEE restricted the extent to which this flare period was varied<sup>9</sup>. This experimentation was continued in the early raids led by the PFF, in which the use of a marker bomb was also first employed<sup>10</sup>.

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<sup>9</sup> TNA AIR14/1769 Operational Research Section, 'Note on attacks on Essen March 8/9<sup>th</sup> – June 8<sup>th</sup>/9<sup>th</sup>', 24 July 1942.

<sup>10</sup> Middlebrook and Everitt. *The Bomber Command War Diaries*, p304; Feast. *The Pathfinder Companion*, p19; and Musgrove *Pathfinder Force*, p16.

The *Newhaven* technique was used over an extended period of the bombing offensive, and the refinements in this technique included the provision of blind marking continued throughout the raid rather than just at the opening and the use of a Master Bomber (see Chapter Five).

There was also a further imperative to the development of target marking techniques, this being the need to reduce the spectre of the Systematic Error. The proportion of bombs falling on or close to the A/P was a function of the extent of the Systematic Error and the degree of concentration achieved. A key objective of the development of target marking techniques was therefore to maintain the maximum concentration in the bomb distribution whilst at the same time minimising the Systematic Error by aligning the M.P.I. of the bomb distribution with the A/P. The concentration of the bomb distribution was itself a function of the Principle of Cumulative Dispersion, such that any technique which reduced the effect of the Principle of Cumulative Dispersion also reduced the base of the Gaussian Distribution Function curve and increased the steepness of that curve. This in turn increased the importance of minimising the Systematic Error to ensure that Gaussian Distribution Function curve overlapped the A/P to the greatest possible extent. Consequently there was an important counter-working relationship between the Principle of Cumulative Dispersion and the Systematic Error. This was a paradox that persisted throughout the bombing offensive and it was this paradox that the development of target marking techniques sought to reconcile.

There are two themes that emerge from the development of target marking techniques as the bombing offensive progressed. The first is that the overall profile of the techniques remained fundamentally unaltered from the inception of target marking, albeit that there was an early realisation that more than one target marking technique was usually required on any one raid (i.e. the 'Berlin method'). The basic profile of the *Parramatta* technique remained that of primary marking undertaken automatically by *Oboe* or H2S, interspersed by secondary marking as necessary. It was only late in the bombing offensive, when more *Oboe* Channels became available, that secondary marking was phased out in favour of continuous primary marking. This is a classic example of improvements in technology facilitating a change in the profile of the target marking technique associated with it. In relation to techniques based upon the illumination of the ground by flares, the basic profile of 'illuminators', 'target markers' and 'followers' remained present right from the *Shaker* technique to the complex 'Berlin Method' of 1943/44. The technique was refined over time with the inclusion of specific roles, including 'Primary and Secondary Visual Markers', 'Supporters' and 'Visual Centerers', but the overall profile remained unaltered.

This point also held true for the development of the indirect bombing techniques developed by No 5 Group. These techniques shared the common element of a 'Marking Point' away from the target itself but only with 'Offset Marking' was this in relation to a precise Aiming Point. The later variations of indirect bombing involved firstly an Aiming Line ('Line Bombing') and then an Aiming Area ('Sector Bombing'), both fundamentally different concepts to

marking a precise Aiming Point that underpinned the techniques used by the Pathfinder Force (see Chapter Six). The profile of the technique did not itself alter significantly between these techniques, being essentially illumination from high level followed by marking of the target at a low-level, all under the control of a Master Bomber. It was therefore in the application of a timed overshoots and the allocation of separate headings that these techniques were evolved. The significant factor, and the one which distinguishes the development of these techniques from those developed by the PFF, was the extent to which the technique evolved within the overall profile. Each subsequent variation of the basic technique, from Offset Marking to Line Bombing and then to Sector Bombing, represented a significant advancement over the previous one, both in terms of complexity and effectiveness. Moreover, not only were these techniques evolved to become the most effective used by Bomber Command, they were developed over a remarkably short time period.

This 'root and branch' approach to the development of target marking techniques serves to highlight the disparity between the innovative approach of No 5 Group, in which the individual skill and judgement of the crews was at the forefront, with the successive application of minor refinements to an established technique adopted by the PFF. It also highlights the potential of a different approach to the relationship between the application of technology and human actions in target marking techniques. The profile of the techniques developed by the PFF, in this context primarily *Newhaven* and *Parramatta*, was dictated by the navigation or blind bombing aid used. It followed that

apart from minor refinements, the causal relationship between the navigation or blind bombing aid used and the associated target marking technique determined that the overall profile of the technique was effectively fixed. The use of technology required a fixed A/P that could, initially at least, either be input into the *Oboe* system or which provided a distinctive feature for H2S. Moreover, at the altitude at which the PFF typically operated, the role of the Master Bomber was limited by the fact the ground detail was not visible. By contrast, although the use of either GEE or S.S. Loran was required to fix the location of the marker aircraft before commencing the individual marking runs, indirect bombing techniques developed by No 5 Group were not dependent upon technology to provide the initial marking. This allowed for considerably more flexibility and initiative on the part of individual marking crews, and also enabled the Master Bomber to ensure that the Marking Point had been accurately marked. Without this degree of certainty of the initial Marking Point, the deviation between the headings on which each section bombed and the allocation of different time overshoots to aircraft within each section would not have been effective. This degree of certainty in relation to the accuracy of the primary marking was considered by ORSBC to be the primary reason behind the success of the low-level technique<sup>11</sup>, and the flexibility provided by the low-level technique to the individual marking crews to achieve this could not have been replicated by the greater reliance placed upon science with the techniques employed by the PFF.

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<sup>11</sup> TNA AIR14/4599 ORSBC Report S.231 'A Comparison of high and low-level visual marking on defended German targets', 8 April 1945.

The other theme that emerges from the development of target marking techniques is that comparatively little of the evolution of these techniques arose from trials and experimentation. The basic profile of what eventually became to be known as *Newhaven* was established by the two 'CRACKERS' exercises in February 1942 (see Chapter Three). However, from that point on, the evolution of the technique for using flares to illuminate the target area for primary marking was evolved by experimentation at unit level on actual operations, notably in relation to the length of the 'flare period', both in terms of the use of *Shaker* and refinement of that basic technique without GEE that took place in Phase 1 of operations by the PFF. The technique was further refined for use with the H2S system, but the technique employed was to a large extent that originally suggested by ORSBC. Similarly, the profile of primary and secondary marking for use with *Oboe* was the result of a recommendation by ORSBC. There is no evidence to suggest that the basic target marking techniques were evolved as a result of trials undertaken specifically devised for that purpose, for example by the Bomber Development Unit, or that the subsequent refinement of those techniques arose from anything other than operational experience by the PFF. Moreover, there is no evidence of any formal structure within the PFF to develop target marking techniques.

This absence of any formal structure for the development of target marking techniques is one of the most surprising outcomes from this thesis. In part, this may be explained by the need to constantly refine target marking techniques in response to rapidly changing operational circumstances and



technical developments. There is also the question of accurately recreating the conditions of a live target area under practice conditions in order to conduct realistic tests. It is, however, debatable as to whether the lack of structured testing made any difference to the development of target marking techniques. Aside from perhaps determining the optimum 'flare period', which was the original purpose of the two 'CRACKERS' exercises, and the frequency of secondary marking, it is difficult to envisage what other benefits structured testing of target marking techniques would have achieved. It is therefore possible that learning from operational experience, with the benefit of scientific analysis provided by operational research, was the best and indeed only way in which target marking techniques could be developed. In this respect, the development of target marking techniques is an example of what Tizard considered to be far the greatest contribution that scientists could make in wartime, in terms of doing everything possible to improve the operational efficiency of equipment and methods then in use<sup>12</sup>.

It was the improvement in accuracy through the application of target marking techniques that underpinned the main achievements of Bomber Command. The first 'Thousand Bomber Raid' on Cologne in May 1942, which was one of the main turning points in the bombing offensive, was initiated by a small GEE-equipped force to drop incendiaries to start fires for the following aircraft. The Battle of the Ruhr, which culminated in some of the most accurate and destructive raids of the entire offensive, was predicated on the use of the *Musical Parramatta* technique. The firestorm at Hamburg was the result of a

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<sup>12</sup> IWM Tizard Papers, HTT 298.

complicated *Parramatta* technique in association with H2S, and the attack on the rocket-research establishment at Peenemünde was achieved using a complicated attack profile in which the A/P was shifted under the control of a Master Bomber and re-marked on three occasions. The significant contribution of Bomber Command in the build-up to OPERATION OVERLORD in terms of hindering the movement of troops through the Transportation Plan and the bombing of coastal batteries, arguably one of the most important aspects of the bombing offensive, was based on the application of variations of the *Musical Parramatta* technique and the use of indirect bombing by No 5 Group. Similarly, setting aside the debate surrounding the extent of Bomber Command's contribution to the oil offensive, those attacks on oil installations that did take place were relatively successful and this was due to the application of the suite of target marking techniques available to Bomber Command by that stage of the offensive. Finally, the high level of destructive power of which Bomber Command was capable at the close of the offensive, as exemplified by the firestorm raid at Dresden and the destruction of a sizeable proportion of smaller towns such as Pforzheim, was founded upon the effectiveness and efficiency of the target marking techniques available. This thesis has shown that none of these achievements would have been possible without the advent and development of target marking techniques.

Moreover, the contribution made by the development of target marking techniques was not confined to the main achievements identified above. During the majority of the bombing offensive, specifically from 1942 onwards,

target marking was an ever-present feature of Bomber Command night raids. This applied equally to the overall objective of undermining the morale of the enemy civil population, and in particular that of the industrial workers, that underpinned much of the bombing offensive. One of the main advantages conferred by the introduction of target marking techniques was the ability of Bomber Command to operate in weather conditions that would otherwise have prevented bombing operations taking place or which, if they did take place, would have been largely ineffective. This applied mainly to the *Parramatta* technique of blind groundmarking which, provided that the ground was visible, allowed effective attacks to take place in conditions of poor visibility that would otherwise have yielded poor results. This was particularly important in the main industrial centres of Germany, notably the Ruhr, which were prone to industrial haze. As revealed by the Butt Report of 1941, prior to the introduction of target marking the presence of thick industrial haze resulted in only one aircraft in every fifteen getting within 5 miles of the target. The development of target marking techniques, in the form of *Musical Parramatta*, allowed these areas to be attacked with up to 80% of bombs falling within 3 miles of the target and resulting in considerable levels of destruction within the target area during the Battle of the Ruhr.

This principle was taken even further with the advent of the *Wanganui* skymarking technique, which enabled raids to take place even in conditions where all ground detail was obscured by 10/10ths cloud cover. Bombing accuracy and concentration never equalled that achieved in conditions where the ground was visible, although on occasions the *Musical Wanganui*

technique achieved a Radial Standard Error of 910 yards and an Average Systematic Error of 950 yards<sup>13</sup>. This was sufficient to inflict useful damage on urban areas. There were also occasions during the bombing offensive, such as the raid on Wilhelmshaven on 11/12 February 1943, where the standard *Wanganui* technique with flares dropped blind using H2S achieved significant results<sup>14</sup>. The development of the *Wanganui* skymarking technique therefore enabled the bombing offensive to continue on a greater number of nights than would otherwise have been possible, and in so doing to exert greater pressure on the German defences and the morale of the civil population. Considering also that the effectiveness of the German defences effectively prevented operations during the moon period, and that this reduced the number of nights on which Bomber Command could operate, the extension of the capability of Bomber Command to operations against cloud covered targets was an important contribution to the effectiveness of bombing offensive.

It should also be recognised that the tactic of the 'bomber stream' could not have functioned without target marking. The bomber stream was initially conceived as a means of mutual defence for the bombers in passing through the 'Kammhuber Line', the German defence system whereby night fighters were individually controlled within geographically defined 'boxes'. By passing as many bombers as possible through one 'box' in the Kammhuber Line in the shortest possible time, the opportunity for night fighters to intercept individual

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<sup>13</sup> TNA AIR14/2693 ORSBC Report S.251 'Bombfall distribution in attacks on German Targets through 10/10ths cloud', 23 November 1945.

<sup>14</sup> TNA AIR14/3410 Final Raid Report No 264: Wilhelmshaven, 11/12 February 1943, 21 April 1943. See also Middlebrook and Everitt *The Bomber Command War Diaries*, p353.

bombers was much reduced. A large number of aircraft passing over the target in a short period of time also had the advantage of overwhelming the defences in the target area and reduced losses to anti-aircraft fire, as well as overwhelming the civil defences and allowing the fires started to take hold. The benefits resulting from compacting aircraft into a bomber stream resulted in a progressive shortening of the duration of the attack, from approximately 1½ hours in the first of the 1,000 bomber raids on Cologne in May 1942 to less than 20 minutes in an attack on the same city in October 1944 involving 905 aircraft<sup>15</sup>. The corollary of this was that the crews within the bomber stream were denied the opportunity to search for the A/P on an individual basis, not only in terms of the disintegration of the bomber stream that would have resulted but also in the interest of minimising the risk of collisions. It was therefore essential that crews within the bomber stream were able to identify the A/P as quickly as possible and without having to make any significant deviation in heading. The only way in which this could be achieved was through the provision of an unmistakable point of aim, visible from a sufficient distance for the bomb aimer to track onto the A/P within the limitations of the bomb sight being used, through target marking. It follows that the tactic of the bomber stream, which enabled Bomber Command to reduce losses to within acceptable rates for the majority of the bombing offensive and which was essential to achieve the concentration of bombing required, would not have been possible without the development of target marking techniques.

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<sup>15</sup> TNA AIR14/3408 Final Raid Report No 74 Cologne 30/31 May 1942, 15 July 1942; TNA AIR14/3410 Final Raid Report No 755 Cologne 30/31 October 1944, 17 February 1945; See also Middlebrook and Everitt *The Bomber Command War Diaries*. The 1,000 bomber raid in May 1942 is recorded at page 271, the attack on Cologne on the 30/31 October 1944 is recorded on page 611.

There was one further contribution made by target marking techniques that arose directly from the causal relationship between the navigation aid or blind bombing device employed and the outcome achieved. This was the ability to calculate the likely outcome of a raid by reference to the anticipated number of bombs that would fall on the A/P depending upon the target marking technique employed. This was achieved by applying a 'Comprehensive Planning Factor' to establish the weight of attack to be despatched in a single raid in order to achieve a 50% chance of securing not less than one unit density at the A/P. For precision attacks, the unit required was usually expressed as bombs per acre; for area attacks, the unit required was expressed as tons of bombs per square mile. The Comprehensive Planning Factor, based upon analysis of target photographs, varied according to the target marking technique. Thus, for example, for precision attacks the Comprehensive Planning Factor for *Musical Parramatta* was 948 bombs per acre, for *Controlled Oboe* it was 244 bombs per acre and for *Visual Groundmarking* it was 190 bombs per acre. The equivalent Comprehensive Planning Factors for area attacks was 1.469 tons per square mile, 0.366 per square mile and 0.297 per square mile respectively<sup>16</sup>. The technique was equally applicable to individual raids and a series of raids where the A/P remained the same throughout.

The presence of a Comprehensive Planning Factor associated with particular target marking techniques conferred two advantages in terms of the forward planning of bombing operations. Firstly, if it was known that a particular target

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<sup>16</sup> TNA AIR14/2693 ORSBC Report S.227 'Practical Methods used in forward planning of bombing operations', undated.

marking technique was to be employed because of the characteristics of the target (for example, it was within *Oboe* range or, as in the case of Hamburg, was particularly suited to H2S), then the precise bomb load required to achieve the required unit density at the A/P could be accurately calculated. This enabled those commanding the bombing force to make informed decisions on the number of aircraft that needed to be despatched, taking into account the bomb lift required and the bomb lift capacity of the aircraft types to be used, which in turn informed decisions about the weight of the fuel necessary and/or the route to be taken to the target. Secondly, if the characteristics of a target were such that the bomber commander had a choice of target marking methods available, such as the attacks on marshalling yards as part of the Transportation Plan in the build-up to OPERATION OVERLORD (*Controlled Oboe* or *Visual Groundmarking*), the Comprehensive Planning Factor informed which of those target marking techniques was the most efficient in terms of the resources at disposal. The value of the forward planning capability conferred by the Comprehensive Planning Factor in these respects is explicitly acknowledged by Harris in his *Despatch on War Operations*<sup>17</sup>. These advantages would not have presented themselves if the Comprehensive Planning Factor used in this raid planning was not dictated by the causal relationship between the navigation aid employed and the associated target marking technique.

There has been much debate by historians as to the contribution made by the bombing offensive to the outcome of the Second World War, with some

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<sup>17</sup> Harris, *Despatch on War Operations*, p88.

authors taking the view that the air offensive (including the contribution made by the American Eighth Air Force) was a decisive element in explaining Allied victory<sup>18</sup> and contributed much to the pacific foreign policy of post-war Germany<sup>19</sup>. It is not within the remit of this thesis to enter that debate. However, the point made here is that the contribution made by Bomber Command to the air offensive, whatever that may have been, would not have materialised without the development of target marking techniques. This is a factor in determining the contribution made by Bomber Command that has not received the recognition deserved in subsequent analysis of the air offensive, primarily on the grounds that secondary literature has tended to attribute the improvement in bombing accuracy purely to the introduction of navigation aid and has consistently failed to identify and recognise the causal link between the navigation aid and target marking.

There is, however, a certain irony in attributing credit to target marking for the contribution made to the night offensive mounted by Bomber Command. The formation of a dedicated Pathfinder Force specifically for the purpose of target marking originated, in the minds of the Air Ministry at least, as a method of eventually moving away from area attacks towards precision targets (see Chapter Four). In the event, for much of the bombing offensive target marking techniques were used exclusively in relation to area attacks and, by the close of the conflict, had assumed the optimum level of proficiency in relation to such attacks. The development of target marking was in effect hijacked by Bomber Command as a means of perfecting the technique for area attacks

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<sup>18</sup> Overy, *Why the Allies Won*, p163.

<sup>19</sup> Andrew Roberts *The Storm of War: a new history of the Second World War* (London: Allen Lane, 2009), p460.



rather than moving towards attacks on precision targets originally envisaged by the Air Ministry, and it was not until Bomber Command was forced to do so with the change to tactical targets in the build-up to OPERATION OVERLORD that it eventually turned its attention to precision targets<sup>20</sup>.

This raises the obvious question: why did Bomber Command continue with area attacks when it possessed the capability to carry out precision attacks? Indeed, there were those involved in the prosecution of the bombing offensive who considered that Bomber Command possessed the capability of precision attack, notably Bufton, who believed that Bomber Command "...could have done so had they wished.." and "...given to the PFF the enthusiastic support and the overriding priority to the selection of crews that they later gave to 617 Squadron" <sup>21</sup>. Bufton also believed that Bomber Command could have developed a low-level marking technique in 1942 had they had the vision - he possibly had the very successful attack on the Renault factory at Boulogne-Billancourt in March 1942 in mind (see Chapter Three) - and goes on to lament that the PFF was formed "over the dead body' of the Commander-in-Chief, and its activities were directed not to the attack of precise targets but to the attack of cities".

The same conclusion was reached by the British Bombing Survey Unit (BBSU) post-war which, in the context of a discussion on navigational and bombing accuracy as a prelude to the presentation on the effects of the Combined Bomber Offensive, questioned whether the lessons learned by the

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<sup>20</sup> Setting aside, for this purpose, the occasional precision attacks that took place throughout the bombing offensive, notably those conducted by No 617 Squadron.

<sup>21</sup> CCAC Bufton Papers, File 5/13 Letter Bufton to Martin Middlebrook, 7 September 1972.

precision attacks in the build-up to OPERATION OVERLORD could have led to precision attacks earlier had there been a different priority of target set been adopted<sup>22</sup>. The BBSU suggested that the answer to this question should be answered in the positive<sup>23</sup>.

The views expressed by Bufton and the BBSU must, however, be treated with some caution. Bufton was a committed advocate of precision bombing and, throughout his tenure as Deputy Director (then Director) of Bomber Operations at the Air Ministry, had harboured the belief that area attack was only a temporary phase through which Bomber Command would have to pass before it could revert to precision attack once the tactical problems of doing so had been solved. This was evident in the papers that he prepared in relation to the formation of a Target Finding Force, in which he opined that a system of flare dropping “.....might have a far reaching effect on our planning and enable us to undertake effectively the complete destruction of vital factories, synthetic oil plants, and to attack at night such targets as the battleships at Brest, which at present we find ourselves incapable of doing”<sup>24</sup>. It is therefore not surprising that Bufton considered that Bomber Command could have embarked on precision attacks earlier than it did.

The BBSU did not, as Sebastian Cox termed it, have an easy birth<sup>25</sup>. When it eventually came into existence, the two leading appointments were Air

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<sup>22</sup> TNA AIR10/3866 Report of British Bombing Survey Unit ‘The Strategic Air War against Germany 1939-1945’

<sup>23</sup> Cox (ed) *The Strategic Air War Against Germany*, p47.

<sup>24</sup> Bufton Papers, 3/6, ‘Increase of Striking Power by Application of Tactics’, 29 November 1941, page 3, para 22 (underlining is as in the original).

<sup>25</sup> Cox (ed) *The Strategic Air War Against Germany*, Introduction, page xvii

Commodore Pelly as its Head and Professor Zolly Zuckerman as Scientific Advisor. As Cox points out, both had a background in the Supreme Headquarters Allied Expeditionary Force (SHAEF) in the build up to OPERATION OVERLORD and that it was hardly surprising that the final report of BBSU strongly reflected the favourable view held within SHAEF of the importance of transportation as a target system in the bombing offensive<sup>26</sup>. As a target system, transportation required precision bombing and hence the belief that Bomber Command could have turned its attention to precision bombing sooner is consistent with the support by the BBSU for that target set. The final report of the BBSU was not subject to independent review or objective scrutiny, and the support given by the BBSU in relation to precision bombing must be viewed in this context.

The answer to the question why Bomber Command continued with area attacks when it possessed the capability to carry out precision attacks is, essentially, two-fold. Firstly, there was an element of tactical capability driving strategic direction in that, for a significant part of this period, Bomber Command was simply not technically capable of successfully attacking precision targets in Germany. Indeed, it was the growing realisation during 1941 that Bomber Command was incapable of attacking precision targets at night that led to a switch to area targets. However, once navigation and blind bombing aids became available, it was the causal relationship between these aids and the associated target marking techniques that dictated the degree of precision of which Bomber Command was capable. The *Shaker* technique

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<sup>26</sup> Ibid, page xxi

using GEE was simply not capable of achieving the accuracy necessary to attack precision targets. Insofar as the question relates to targets within *Oboe* range, the accuracy and concentration achieved in preparation for OPERATION OVERLORD was predicated upon continuous primary marking, which in turn required three *Oboe* Channels. This did not become available until June 1943, but there is no reason why the refinements to the basic target marking techniques based on *Oboe* that were made in 1944, including *Continuous Oboe Marking* and *Controlled Oboe*, could not have been introduced considerably earlier if attention had been turned to precision targets. The situation is equally clear cut in relation to techniques based upon H2S. The best version of H2S to see widespread operational use was the Mk III, which did not become available until November 1943. But even with this version, the average Probable Radial Error achieved was 2.0 miles and it follows that at no point was H2S sufficiently accurate for precision attack.

Different considerations apply in relation to the indirect bombing techniques developed by No 5 Group. These techniques arose from the development at unit level (specifically No 617 Squadron) of low-level marking. Although much of the credit for the subsequent expansion of this technique into more widely applicable forms must rest with the Air Vice-Marshal Cochrane, AOC of No 5 Group, it was an accident of timing that the opportunity to do so arose when it did. Moreover, a significant element of the low level marking technique relied upon the marking crews being able to positively fix their location at high altitude before making a rapid descent to low level for the marking phase. This could have been achieved using GEE for short range targets but it was not

until S.S. Loran became available that this was possible over Germany. Consequently, low level marking was never a viable proposition against the target sets specified in the Casablanca and Pointblank Directives, even if the PFF had the vision to develop it, and only became viable towards the end of the bombing offensive. Consequently, there is no reason to suggest that these techniques and the significant improvements that resulted in terms of accuracy and efficiency could have been applied to precision targets earlier than was the case.

The second reason why Bomber Command did not switch to precision attack sooner relates to the strategic direction of bombing offensive. The Butt Report of August 1941 had confirmed the extent to which Bomber Command was failing to reach even area targets, and this cemented the policy of area bombing. From February 1942, this policy was then pursued enthusiastically, to the point of obsession, by Harris as C-in-C of Bomber Command. Whilst Portal and the Air Staff were responsible for the strategic direction of the bombing offensive, tactical decisions were made by Bomber Command. The Casablanca Directive of January 1943 specified a number of primary objectives, the priority being German submarine yards but also including oil plants and the German aircraft industry, although in each case these objectives had been placed in the context of "...undermining the morale of the German people"<sup>27</sup>. However, in a letter to Portal dated 6 March 1943, Harris stated his interpretation of the Casablanca Directive as it applied to Bomber Command as being "...the progressive destruction and dislocation of

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<sup>27</sup> Webster and Frankland *The Strategic Air Offensive against Germany*, p153.

the German military, industrial and economic system aimed at the undermining the morale of the German people”<sup>28</sup>. The Official History points out that this minor but significant amendment had fundamentally changed the meaning of the Directive, such that undermining the morale of the German people became the primary objective<sup>29</sup>. The Air Staff do not appear to have realised the implications of this wording, which entitled Harris to pursue his policy of area bombing. Moreover, whilst the Pointblank Directive of June 1943 had sought to focus on the aircraft industry as a prelude to the forthcoming invasion of Europe<sup>30</sup>, as Gray and others have pointed out Portal was singularly ineffective in forcing Harris to comply with primary objective of that Directive<sup>31</sup>. However, that Harris chose to ignore the Pointblank Directive by focusing on Berlin and other cities unconnected with the aircraft industry, and that the Air Staff failed to control Harris in this regard, is a different point. For the purposes of this discussion, the relevant point is that many of the target sets specified in the Casablanca and Pointblank Directives were beyond *Oboe* range and within the ‘zone of relative inefficiency’ for Bomber Command<sup>32</sup>. Consequently, although by 1943 there was a growing opinion within the Air Staff that selective and precise night attack could be more effective, in practice the development of target marking techniques during this period took place in the context of a strategical direction of the bombing offensive predicated upon area bombing as a means undermining the morale

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<sup>28</sup> TNA AIR41/57 AHB Narrative Vol VII, ‘The Planning of the Bombing Offensive and its contribution to German Collapse’, p108.

<sup>29</sup> Webster and Frankland *The Strategic Air Offensive against Germany*, Vol II, p14.

<sup>30</sup> *Ibid.* Vol IV, p158.

<sup>31</sup> Gray’ *The Leadership, Direction and Legitimacy of the RAF Bomber Offensive*, p.p. 246-254.

<sup>32</sup> Webster and Frankland *The Strategic Air Offensive against Germany*, Vol II, p161.

of the German people and which underpinned the Directives issued during that period.

There is also a further point that should be considered in relation this question: even if target marking techniques could have been employed against precision targets earlier in the bombing offensive, it does not follow that the results achieved would have equalled or even approached those achieved in the last year of the conflict. The reason for this is that target marking did not take place in a vacuum. There were a multitude of factors that also contributed to the accuracy of attacks and which did not remain constant over the duration of the bombing offensive. Two of the more important factors were the altitude at which bombing took place and the experience of the crews involved. Research conducted by ORSBC established that the most significant reduction in bomb aiming errors by operational crews using the Mk XIV bombsight occurred between 16,000 feet and 12,000ft, reducing from 191 yards at an altitude of 20,000ft to 155 yards from 12,000 feet<sup>33</sup>. Research also established that bombing accuracy improved significantly with the operational experience of the crews, although the average bomb aiming error made by operational aircrew remained some 50% worse than that of 'skilled personnel'<sup>34</sup>. Both of these variables improved converse to the strength of the defences. It must therefore be recognised that the sustained improvement in accuracy from June 1944 onwards was in part due to a weakening in the German defences that occurred at that time, a point that is conceded by the British Bombing Survey Unit in reaching its conclusion that a switch to

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<sup>33</sup> TNA AIR14/2690 ORSBC Report S.220 'Bombing accuracy using the Mk XIV bombsight', 20 April 1945

<sup>34</sup> Ibid.

precision bombing could have been made earlier than it was<sup>35</sup>. Similarly, it must also be recognised that the targets during this period were, on the whole, less well defended than the major cities attacked during the area offensive of 1943 and early 1944. This enabled the altitude at which Main Force bombing took place to be progressively lowered to an average of 12,000 feet, with the commensurate improvement in bombing accuracy. At the same time, the loss rate of heavy bombers fell sharply from between a range of 3% and 5% that had persisted since 1942 to below 1% in October 1944, and thereafter remained between 1% and 2% for the remainder of the offensive<sup>36</sup>. This significant reduction in the loss rate of bombers resulted in an overall improvement in average operational experience of bomber crews in the last year of the bombing offensive. These two factors, both individually and cumulatively, contributed to the improvement in bombing accuracy in the last year of the bombing offensive. This is not to say that the importance of target marking was in any way diminished by the improvement in accuracy resulting from these factors. At no stage in the bombing offensive did the typical altitude at which Main Force bombing took place descend to the height at which ground detail is visible at night. It follows that the improvement in accuracy resulting from the decrease in bombing altitude and increase in operational experience would not have occurred to the same extent in the absence of target marking. In that sense, the improvement in accuracy resulting from those factors built upon the benefit of target marking but would not have taken place without it. The answer, then, to the question as to why Bomber Command continued with area attacks when it possessed the

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<sup>35</sup> Cox (ed) *The Strategic Air War Against Germany*, p47.

<sup>36</sup> Harris, *Despatch on War Operations*, Part V, p48, Graph No 5A.



capability to carry out precision attacks is the combination of these three factors.

A related, and in some respects a more prescient question, is whether target marking techniques would have ever been employed in precision attacks had Bomber Command not been tasked with attacking precision targets in the build up to OPERATION OVERLORD. There is no evidence to suggest that it would<sup>37</sup>. Although this is an *ex post facto* conclusion, the development of target marking techniques up to that point had been based on the application of science to the marking of area targets from a high altitude. The target marking techniques themselves had evolved since the introduction of the basic *Newhaven* and *Parramatta* techniques, but even the most advanced form of these techniques - the complex 'Berlin method' - was directed towards area targets. In proposing the formation a Target Finding Force in late 1941/early 1942, the Air Ministry had accepted area bombing as an interim measure pending the development of techniques for precision bombing. However, apart from the occasional attack on specific targets of particular importance, such as rocket research facility at Peenemünde in August 1943 and the former Zeppelin works at Friedrichshafen (see Chapter 8), which were special cases, there were few attempts to use target marking technique for precision targets. There is no indication that, prior to the tactical necessity for bombing precision targets in the build up the OPERATION OVERLORD, the application of target marking techniques was moving Bomber Command away from bombing of area targets towards precision targets.

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<sup>37</sup> Other than the self-contained specialist No 617 Squadron.

This is perhaps best demonstrated by the obstinate refusal of Harris to attack the ball bearing works at Schweinfurt. Some indication of the importance attached by the Air Staff to these ball-bearing works may be gleaned from the fact that, despite being well beyond GEE range, the town of Schweinfurt was included in the February 1942 Directive as alternative target for area attack<sup>38</sup>. There followed sustained pressure from the Air Staff to attack this town, all of which Harris resisted, partly on the grounds that Schweinfurt was a small town with no distinctive navigation features and therefore difficult to locate with the navigation aids then available<sup>39</sup>. This led Harris to conclude that the destruction of Schweinfurt by night - and in this context it is important to note that Harris was referring to the whole town and not just the ball-bearing works - was "tactically impracticable"<sup>40</sup>. This exchange culminated in an exasperated Bufton expressing the opinion that Bomber Command "...is operating a policy of its own and is disregarding both the policy and precise instructions for its implementation...."<sup>41</sup>. The ball-bearing works at Schweinfurt were exactly the type of 'vital factory' that Bufton and the Air Ministry had in mind when proposing the formation of a Target Finding Force but Harris' continued refusal to attack it was typical of his approach to precision targets and, in the face of considerable pressure to do so, Harris was disinclined to attack it. Consequently, with Bomber Command adopting this position and Portal lacking the ability to enforce the Air Ministry policy, there is nothing to suggest that the development of target marking techniques would have

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<sup>38</sup> Webster and Frankland *The Strategic Air Offensive against Germany*, Vol IV, p143.

<sup>39</sup> TNA AIR2/4477 Letter Harris to Bottomley, 9 January 1944.

<sup>40</sup> Ibid

<sup>41</sup> TNA AIR20/8148 Letter Bufton to Coryton, 22 January 1944.

developed for use against precision targets without the tactical necessity brought about by OPERATION OVERLORD and therefore fulfil one of the *raison d'être* advanced by the Air Ministry for the formation of a specialist target finding force in the first instance.

In the interest of balance, it must also be recognised that the navigation and blind bombing aids on which the principal target marking techniques were based were not the only technologies that influenced the efficiency and effectiveness of those techniques. The success of the principal target marking techniques was to a large extent dependent upon accurate timing, not only by the various marking components but also the prompt arrival of the Main Force at the point in time at which the marking most effective. The timing chart for a raid on Kassel in October 1943 (see Fig 28/ below) illustrates this point and demonstrates the complexity of timing over the course of a typical Bomber Command night raid at that time<sup>42</sup>. In particular, it may be noted that the distribution of the Main Force aircraft within that raid corresponded closely not only with the primary marking but also with secondary marking provided by the 'backers-up' throughout the planned duration of attack. This required a high standard of time keeping, both by the Pathfinder Force and the crews of the Main Force.

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<sup>42</sup> TNA AIR14/4597 ORSBC Report S115 'The use of H2S as an aid to navigation', 4 December 1943

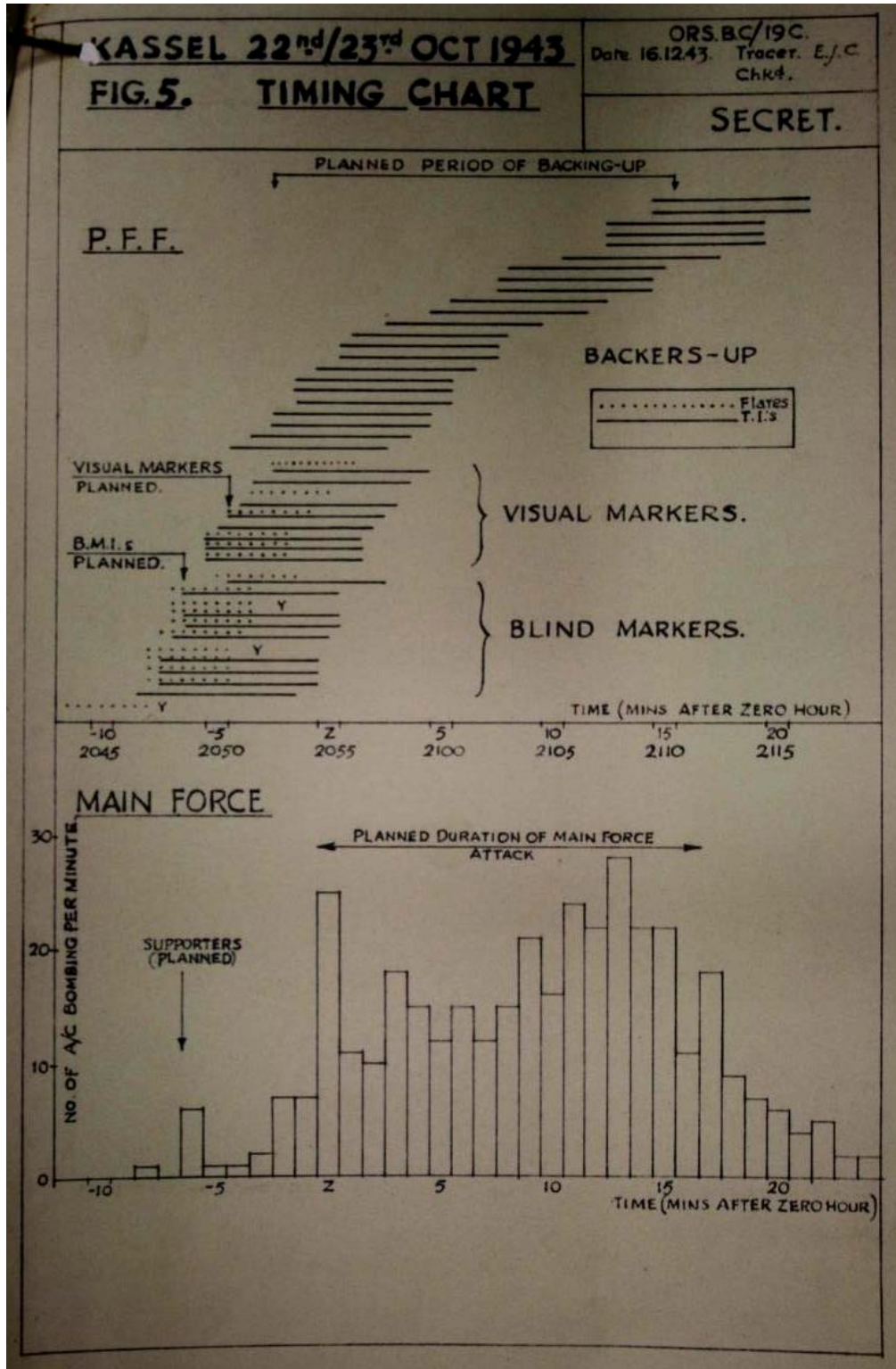


Fig 28/ Timing chart for the raid on Kassel, 22/23 October 1943. The marking technique for this raid was planned as a combination *Parramatta* and *Newhaven*, but the Visual Markers were able to identify the A/P and the raid progressed as a *Newhaven*. Note that the timing of the 'Backers-up' was staggered to ensure that T.I.s were burning throughout the planned duration of the Main Force attack. The 'Y' denotes aircraft fitted with H2S. Source: TNA AIR14/4597 ORSBC Report S115 'The use of H2S as an aid to navigation', 4 December 1943.

This timing was largely achieved through the use of a number of electronic and other devices that became available to assist in navigation. These included the Air Position Indicator (A.P.I) and the Ground Position Indicator (G.P.I.), both of which not only provided an indication of the position of the aircraft but also facilitated the accurate calculation of wind speed. The latter was a vital component in navigation and an essential input into the bombsight, as well as being necessary for the calculation of the 'false wind' as part of the indirect bombing techniques evolved by No 5 Group. The timing of raids was also facilitated by the navigation functions of GEE, S.S.LORAN and H2S. Indeed, ORSBC concluded that, used correctly, the Main Force squadrons were capable of using H2S to provide accurate fixes of inland towns on more than 80% of occasions and of coastal features on 95% of occasions<sup>43</sup>. Although the majority of heavy bombers in Bomber Command were not equipped with H2S until late 1944, this device was nonetheless of considerable and increasing value as a navigation aid as the bombing offensive progressed, with concentration achieved over the target compared to planned concentration improving from 48% in 1943 to 70% in April 1945<sup>44</sup> . Furthermore, the indirect bombing techniques of No 5 Group would not have been possible if the marking aircraft had not been fitted with S.S.LORAN in order to establish their position at their cruising altitude before descending to low level for the marking runs. The expansion of the Continental Gee Chain into Europe post D-Day also facilitated accurate time keeping over a large part of Germany in the closing months of the bombing offensive in areas

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<sup>43</sup> Ibid. The ORSBC report found that there was not appreciable difference between the ability of the Main Force H2S operators and the operators in the Pathfinder Force in this respect.

<sup>44</sup> TNA AIR14/2693 ORSBC Report S252 'The effect of the development of navigational and blind bombing techniques on the efficiency of bombing operations during World War II (Aug 1941-May 1945)', 15 October 1945.

where the use of GEE had been denied to Bomber Command since 1942 by jamming of the signals from home-based ground stations.

There was, however, one form of technology without which target marking could not have functioned: that generically known as the marker bomb. The objective of target marking was to provide an unmistakable point of aim. There can be no doubt that the development of an effective marker bomb was fundamental to the contribution made by target marking techniques to the bombing offensive. In particular, the advent of the Target Indicator, coincidentally simultaneous with the first operational use of *Oboe* and H2S, transformed the efficiency of target marking. The development of the Target Indicator, including the more accurate 'low-bursting' version and the 'short-tailed' version for fitting in the bomb bay of the *Oboe* Mosquito, were some of the more important advances in the target marking techniques. The development of the Spot Fire for use in the low-level marking techniques practised by No 5 Group was also an important innovation in terms of target marking techniques. Similarly, the development of the reconnaissance flare, particularly the 'Hooded Flare' to reduce glare from above, was essential to the *Newhaven* technique. The importance of the reconnaissance flare and the marker bomb in its various forms to target marking techniques cannot be overstated but, conversely, these technologies would have been ineffective, and indeed counter-productive, without the development of target marking techniques to exploit their ability to provide an unmistakable point of aim.

It must therefore be recognised that these various technologies combined to improve the accuracy of bombing and the efficiency of target marking techniques. The key point, however, is that these technologies were not by themselves capable of fulfilling the role played by target marking and therefore do not detract from the vital contribution made by target marking techniques to the outcome of the bombing offensive. Rather, these technologies worked in conjunction with the principal technologies on which target marking techniques were based to optimise the contribution that those techniques made to the bombing offensive. In that respect, the application of these technologies to target marking highlights the point made by authors such as David Edgerton, Guy Hartcup, Phillips O'Brien and Richard Overy about the importance of technology to the outcome of the Second World War in terms of a numerical advantage in trained manpower and industrial output not being sufficient in itself, with the science lead held by the Allies being critical.

Whilst acknowledging the importance of a range of technologies employed by Bomber Command, this thesis has shown that it was the development of target marking techniques that enabled Bomber Command to circumvent the law that human beings cannot see in the dark. As this thesis has demonstrated, the function of any target marking technique in this respect was to provide an unmistakable point of aim whilst overcoming the combined effects of the Principle of Cumulative Dispersion and Systematic Error. The ability of any target marking technique to fulfil this function was itself in turn inextricably linked to the particular characteristics of the navigation or blind

bombing aid employed and with which it was associated. The development of target marking techniques was to a large extent the development of this causal relationship. This thesis is the first work to precisely define that causal relationship by detailed reference to the technical characteristics of each navigation aid, there being no equivalent definition or analysis of that relationship in published material. It has also shown that the improvement in bombing accuracy and concentration was a result of the application of target marking techniques in conjunction with those navigation aids. This is in itself represents a departure from the views normally expressed in secondary literature which tend to suggest that the improvement in accuracy and concentration resulted from the introduction of the navigation aid *per se*, and in that respect also this thesis breaks new ground.

However, the extent to which the application of the various technologies used in target marking required human interaction should not be underestimated. The balance between technology and human action could vary significantly, as shown by the contrasting scientific approach of the techniques used by the PFF and those adopted by No 5 Group based primarily on the individual judgement and skill of the crews involved. The development of target marking techniques is therefore not only concerned with the use of technology to solve the problem of providing an unmistakable point of aim: it is the story of the interaction between technology and human action to produce results that underpinned the outcome of the entire bombing offensive.



In order to arrive at this conclusion, this thesis has descended into layers of detail in relation to target marking that sit below that found in the hierarchy of published literature on the subject. It has considered concepts that are not addressed in this secondary literature, but which are fundamental to a complete understanding of the role played by target marking in the outcomes of the bombing offensive. Thus, for the first time, concepts such as the Systematic Error, Gaussian Distribution, Probable Radial Error and the Principle of Cumulative Dispersion have been considered alongside operational factors such as the visibility of Target Indicators, the visual acuity of bomb aimers, the ability of bomb aimers to assess the Mean Point of Impact of a rapidly changing pattern of markers and the role of the Master Bomber. This thesis has drawn these factors together, in a way not be found in any existing literature on the bombing offensive, and has assessed how they relate to the causal relationship between the particular characteristics of the navigation or blind bombing aid employed and with which it was associated.

The key question asked posed at the outset of thesis was: what difference did the introduction of target marking techniques make to the performance and efficacy of Bomber Command? In answer to that question, this thesis has shown that the improvement in bombing accuracy over the course of the bombing offensive was not, as frequently alluded to in secondary literature, the result of the introduction of navigation aids such as *Oboe* and H2S. There was an additional component required to bridge the gap between the law that human beings cannot see in the dark and the ability of blind bombing to fulfil

the tactical and strategic objectives of Bomber Command, this being the provision of an unmistakable point of aim for those crews that did not have the benefit of navigation aids. Target marking provided that additional component, and the fundamental importance of that to explaining the achievements of the bombing offensive has not received the recognition that it deserves. This thesis has corrected that omission and, in so doing, has ploughed its own furrow to provide a valuable new perspective on the outcome of the bombing offensive.

## GLOSSARY

Aiming Area	The bomb distribution resulting from Sector Bombing, the shape of which was a part of a circle between two lines drawn from the Marking Point.
Aiming Line	The bomb distribution resulting from the Line Bombing technique, being the arc of a circle with the Marking Point at its centre.
Aiming Point	The point on the ground that is the briefed target for the raid. Usually abbreviated to A/P.
Air Position Indicator	Navigation aid based upon the Distant Reading Compass. Usually abbreviated to API.
Air Speed	The speed of the aircraft relative to air in which it is flying i.e the speed at which the air meets the aircraft. Note that due to the effect of the wind this may not be the same as the ground speed of aircraft. Air speed can be measured as Indicated Air Speed (IAS), this being the speed shown on the Air Speed Indicator (see below), or True Air Speed (TAS), this being the Indicated Air Speed corrected for difference in air pressure and/or temperature. The latter is required for accurate navigation.
Air Speed Indicator	Basic flight instrument that shows the air speed of the aircraft. Usually abbreviated to ASI.
Altitude	The height of an aircraft above sea level or ground level.
Attitude	The inclination of an aircraft in relation to the horizontal. The attitude of bomber aircraft would, within limits relative to the centre of gravity, vary according to the weight of bombs carried and the weight/distribution of fuel remaining.
Average Radial Error	The average radial distance of all variates, measured either in relation to the Aiming Point or the Mean Point of Impact. Sometimes referred to as the Average Probable Error.
Azimuth	The position around the horizon.
Backers-Up	Pathfinder crews detailed to replenish or reinforce Target Indicators placed by the Primary Markers.

Baillie Beam	Lorenz-type directional navigational beam generated by ground stations, along which aircraft could track.
Ballistic Errors	Distance of variates from the Aiming Point caused by the miscalculation of the ballistic properties of bombs or markers, or by interference with the bomb or marker during fall.
BENITO	British code name for the German Y Verfahren navigation system.
Berlin Method	Target marking technique in which the Pathfinders marked the target using by Parramatta ground marking and Wanganui sky marking simultaneously. Main force crews were briefed to aim at the Parramatta ground markers if visible and the Wanganui skymarkers if the ground markers were not visible.
Blind Bombing	Release of bombs without visually identifying the target, using navigation aids to determine position.
Blind Bombing Cherbourg	Series of bombing operations in late 1940/early 1941 against the RUFFIAN transmitters located on the Cherbourg peninsular, using the German beams as a guide to the target and (in some cases) an early variant of OBOE for blind bombing. Usually abbreviated to B.B.C.
Blind Marker-Illuminators	Blind Illuminators that also dropped TI's (usually TI Yellow) to identify the target area for the Visual Markers
Blind Marking	Release of Target Indicators or Flares without visually identifying the target, using navigation aids to determine position.
Bomb Density	Actual tons of bombs per square mile falling within any given area. N.B. this should not be confused with "Density of Bombing" (see below)
Bomb Distribution	The scatter of bombs around the Mean Point of Impact
Bombing Error	The systematic error of the bombs dropped (as distinct from the Markers dropped).
Bradshaw navigation	Derogatory RAF slang for poor navigation, in which crews were derided for following railway lines to find their target or destination. Derived from the inventor of railway timetables, George Bradshaw.

Broadcast Winds	A system introduced in mid-1943 where wind vectors were calculated by experienced navigators during the course of an operation, and relayed to Group headquarters as "found winds". The found winds from a number of navigators were then collated and averaged, and then re-broadcast to the Main Force as "Group" winds.
Broody Hen	Early form of receiver used in experimental versions of OBOE.
Check aircraft	Pathfinder aircraft tasked with reporting on the visibility of markers from the altitude at which the Main Force bombed.
Concentration given time limit.	The number of aircraft bombing within a
Continuous Oboe Marking	A variation of Musical Parramatta involving the continuous dropping of Target Indicators over a period of approximately 8 minutes, in which those Target Indicators would be the only markers dropped.
Controlled	A prefix applied to any target marking technique when a Master Bomber was employed; e.g Controlled Newhaven.
Cope	A successful sortie involving GEE, G-H, H2S, or OBOE. Crew were said to have 'coped' if bombs or markers were dropped blind using this equipment.
Creepback	The tendency for the bomb distribution to fall progressively shorter of the Aiming Point towards the direction of the bombers' approach as a raid progressed.
Cross Trail	Path taken by a bomb or marker through the air, taking into account the effect of cross wind.
Cross Wind	Any wind that is not a head wind or tail wind.
Dead (or Deduced) Reckoning	Navigation using three vectors. The first vector is the course and airspeed of the aircraft, thus giving the theoretical position of the aircraft in conditions of zero wind. This is known as the air position vector. The second vector is the direction and speed of the wind, this being known as the wind vector. These two vectors were computed to produce a third vector, this being the track and ground speed of the aircraft. It was this third vector that dictated the progress of the aircraft over the ground. Usually abbreviated to D.R.

Delta OBOE	OBOE navigation aid with the facility to automatically guide aircraft onto the required course.
Density of Bombing	Percentage of all aircraft claiming to have attacked a given area which actually bombed within that area. N.B. this should not be confused with "Bomb Density" (see above)
Directional Stability	The tendency of an aircraft to align itself with the direction of the airflow.
Distant Reading Compass	A gyroscopically stabilised magnetic compass in which the compass sensor unit, known as the Master Compass, was positioned in the aircraft so as to be unaffected by the magnetic effect of the bomb load. The compass instrument(s) used by the aircrew to indicate the heading of the aircraft, known as the Repeater Compass, being located remotely from the sensor unit and were synchronised with the Master Compass. Usually abbreviated to D/R Compass or D.R.C.
Drift	The extent to which an aircraft, bomb or flare is deviated from its original course due to the effect of the wind.
Effective Weight of Attack	The weight of bombs delivered to the vulnerable area of a target.
Error Ellipse	A regular oval shape, the shape being that resulting when a cone is cut by an oblique plane that does not intersect the base, within which any given percentage of the bombs fall. Usually depicted as an oval within a percentage of 50% of bombs fell, and therefore known as the 50% ellipse.
Estimated Weight of Attack	The minimum weight of attack necessary to destroy the social and industrial structure within selected areas (towns), measured in tons of bombs per square mile or tons of bombs per population number.
Finders	Pathfinder crews briefed to drop long sticks of flares at the opening of a raid for the purpose of identifying the general target area for the Illuminators.
Flying Errors	Distance of variation from the Aiming Point caused by inaccurate flying of the aircraft.
Followers	Pathfinder crews with no target marking duties but taking part in a raid as part of the Main Force. New Pathfinder crews were usually detailed as Followers for their first few sorties in order that their navigation and time-keeping abilities could be assessed.

Found Winds	The wind vectors obtained during an operation by experienced navigators and relayed to Group Headquarters as part of the Broadcast winds system or the Master Bomber in the Visual Groundmarking technique.
Gaussian Distribution	A measure of probability of a single event occurring applicable where there are a large number of events. The Gaussian Distribution Function provides that 68% of all events will be within one standard deviation of the mean of all events. The Gaussian Distribution Function is shown graphically as bell-shaped curve, in which the steepness of the curve reflects the number of events occurring close to the mean: - a large number of events occurring close to the mean results in a steep curve. Commonly known as 'normal distribution'
GEE	Electronic navigation aid, based on the principle of hyperbolic navigation. Commonly referred to in contemporary reports as TR1335 or Gee.
G-H	Radar navigation aid that used transmissions made from equipment carried in the aircraft and re-radiated by two ground stations. Sometimes referred to as GEE-H or Gee-H.
Gross Error	An error in bomb fall that is significantly greater than the main concentration of bombs, and as such readily identified as an error and non-typical of the average bomb fall.
Ground Marking	The placing of pyrotechnics on or close to ground level for the purpose of marking a target.
Ground Position Indicator	Navigation aid based upon the Air Position Indicator. Usually abbreviated to GPI.
Ground Speed	The speed of the aircraft over the ground, taking into account the effect of wind.
Group Winds	The wind vectors broadcast by Group Headquarters as part of the Broadcast winds system.
'H'	An early electronic navigation aid involving two ground stations, each consisting of a transmitter and receiver, with a transmitter and a receiver in the aircraft.

H2S	Radar navigation aid, employing ground facing centimetric radar housed in a cupola beneath the aircraft.
HEADACHE	British code name for the German Knickebein navigation system.
Heading	Direction in which the aircraft is pointing, measured as a compass bearing.
Head Wind	A wind in the opposite direction to the heading of the aircraft.
Hooded Flare	A flare designed not to cause glare when viewed from above.
Illuminators	Pathfinder crews briefed to drop short sticks of flares for the purpose of illuminating the Aiming Point in order to assist Primary Markers in locating the Aiming point visually.
Indirect Marking	A generic term used to describe the target marking techniques employed by No 5 Group in which a point some distance from the Aiming Point was marked from which the Main Force would make a time and distance bombing run to the target.
Ineffectives	Bombs dropped that for a variety of reasons do not contribute to the normal bomb distribution.
Initial Equipment	The number of pieces of equipment, usually in relation to aircraft but also applying to bombing and navigation aids, with which a Group, Squadron or Unit was equipped upon formation (or, in relation to bombing and navigation aids, first supply). Usually abbreviated to I.E.
Instrumental Errors	Distance of variates from the Aiming Point caused by faults in the navigation or bombing system, or by faulty calibration of that equipment.
“J” Beams	Spurious Baillie Beam transmissions used by the British in an attempt to deceive the Germans about the true nature and purpose of the GEE navigation system.
Kammhuber Line	The German defence system whereby night fighters were individually controlled within geographically defined ‘boxes’
Knickebein	German blind navigation system using two intersecting radio beams.
Lateral Stability	Stability of an aircraft in the rolling plane.



Line Bombing	Bombing technique where aircraft of the Main Force were detailed to aim at an offset marker on a given heading.
Line Error	The distance of the Mean Point of Impact of the bombs or markers from the Aiming Point, measured as a line perpendicular to the briefed heading for bombing.
Link aircraft	Aircraft tasked with checking that VHF communication from the Master Bomber to the Main Force were received.
Longitudinal Stability	The stability of an aircraft in the pitching plane.
Long Stop	A ground-marker bomb (usually yellow) dropped to mark the limit of bombing or to cancel stray T.I's. The term was also applied to Pathfinder crews detailed to perform these tasks.
Loran (S.S.Loran)	Electronic navigation aid that used simultaneous pulsed systems from two ground stations, one Master and one Slave, with the time difference between the pulsed signals being measured by equipment carried in the aircraft.
Lorenz beam	Blind approach system using two adjacent radio beams directed on slightly diverging paths, one transmitting Morse 'dots' and the other Morse 'dashes', arranged such that the two beams slightly overlapped. Where the two beams overlapped, the dots and dashes combined to produce a steady note zone (the 'equisignal') that progressively narrowed towards the source of the transmissions. Aircraft navigated by flying down the steady note zone until they reached the transmitter.
Main Force	The numerically superior element of the bombing force guided to the target by the Pathfinders
Marker Leader	Experienced bomber pilot tasked with placing Spot Fires and assessing the accuracy of all Spot Fires placed as part of the Visual Groundmarking technique.
Marking Error	The systematic error of the markers dropped (as distinct from the bombs dropped)
Marking Point	A point on the ground away from the Aiming Point on which the markers would be aimed as part of the No 5 Group Visual Groundmarking technique.

Master Bomber	Experienced Pathfinder whose role was to direct the Main Force whilst a raid when in progress
Master of Ceremonies	Unofficial term used by the Main Force crews referring to the Master Bomber.
Mean Point of Impact	The mathematical centre of the bomb distribution. Usually abbreviated to MPI.
Meteorological Errors	Distance of variates from the Aiming Point caused by the miscalculation of the wind vector.
Musical	A prefix applied to any target marking technique in which the OBOE precision bombing aid was used; e.g Musical Parramatta
NEWHAVEN	Target marking technique using ground markers aimed visually using illumination from flares dropped by H2S. The prefix 'Musical' was applied when used in conjunction with Oboe.
Nil Wind	A weather condition in which wind speed was zero. Nil Wind is the only condition in which the heading and track of the aircraft are the same, and in which the actual ballistic profile of a projectile is achieved Also known as Still Air.
Normal Distribution	See Gaussian Distribution.
OBOE	Generic term for a variety of ground-controlled precision bombing systems.
Offset Marking	Target marking technique employed by No 5 Group in which a point some distance from the Aiming Point was marked (known as the 'Marking Point') rather than the Aiming Point itself.
Overall Systematic Error	The combination of the Marking Error and the Bombing Error
OVERTURE	The code name given to OBOE sorties in which only high explosive bombs were dropped.
PARRAMATTA	Ground marking technique using H2S or OBOE employed when visibility was not adequate for the Aiming Point to be identified visually. The prefix 'Musical' was applied when used in conjunction with Oboe.
Pathfinder	Crew detailed to mark the target for the Main Force.

Point of Aim	A point on the ground, marker or pattern of markers on which the Main Force crews were briefed to aim. Note: this should not be confused with the Aiming Point.
Point Release Flares	Parachute flares, usually primarily red or green and projecting stars of the contrasting colour (i.e. red with green stars, green with red stars). Also known as Skymarkers.
Preliminary Oboe Marking	A variation of Musical Parramatta in which not less than 4 Mosquito aircraft would each drop between 1 and 4 Target Indicators Is to provide an indication of the A/P, either as the sole target marking or as a basis for full PFF marking.
Primary Green	Alternative name given to the Proximity Marker
Primary Visual Marker	The most experienced and able Pathfinder crews detailed to ground mark the target visually, usually including a highly specialist bomb aimer. Sometimes referred to as Primary Markers.
Principle of Cumulative Dispersion	A principle whereby if successive aircraft aimed at the M.P.I. of all the markers visible, the aggregate M.P.I. was itself subject to a cumulative error which rapidly became greater than that of the individual attempts.
Probable Radial Error	Radius of a circle about the Aiming Point or the Mean Point of Impact within which 50% of the plotted bomb distribution are located. Sometimes referred to as the "50% Zone" or the "50% circle".
Proportion of Ineffectives	The proportions of bombs dropped that for a variety of reasons do not contribute to the normal bomb distribution.
Proximity Marker	A TI, usually green, dropped blind by H2S or Oboe to guide the Primary Visual Markers or a Marker Leader to the general vicinity of the Aiming Point.
Radial Standard Error	The square root of the mean of the square of the radial distance. Otherwise known as the square root mean error or the standard deviation.
Random Error	The measure of bomb scatter about the Mean Point of Impact.
Range Error	The distance of the Mean Point of Impact of the bombs or markers from the Aiming Point, measured along the briefed heading for bombing.

Rate One Turn	A turn which completes 180° in one minute and therefore a complete 360° turn in two minutes. Also known as a Standard Rate Turn.
Re-centerers	Pathfinder crews detailed to re-mark the Aiming Point if the pattern of bombing goes astray during a raid.
Release Errors	Distance of variates from the Aiming Point caused by the delay in the release of a bomb or marker from the aircraft release mechanism.
Release Point	Point at which Main Force crews released their bombs when the sky marking technique was employed. Also the term used for the point at which bombs were automatically dropped using OBOE or G-H.
RUFFIAN	British code name for the German X-Verfahren navigation system.
Salvo(es)	The practice of dropping two or more bombs, Target Indicators or flares at the same time.
SAMPSON	Technique for blind bombing using the GEE navigational aid.
Sector Bombing	Variation of Line Bombing, where aircraft of the Main Force were detailed to bomb on different overshoot times.
Service Ceiling	The maximum altitude that an aircraft could reach in normal operating conditions (i.e aircraft in clean configuration; engines operating at normal power; full petrol and bomb load).
SHAKER	Target marking technique in which incendiary bombs were dropped using the GEE navigational aid to guide following aircraft not so equipped.
Sky Markers	Parachute flares, usually primarily red or green and projecting stars of the contrasting colour (i.e. red with green stars, green with red stars). Also known as Point Release Flares.
Sky Marking	Marking technique used when cloud cover obscured the ground, involving the placing of parachute flares released at a position ascertained with the H2S or OBOE navigation aids, at which the Main Force aimed. Also known by the codename WANGANUI.
Spot Fire	A type of Target Indicator that provided a single spot of red or green light.

Standard Blind (later Beam) Approach	Lorenz-type approach system used at Bomber Command airfields. Usually abbreviated to S.B.A.
Standard Deviation	A measure of variability used in statistics and probability theory, which shows how much variation or dispersion there is from the average and upon which the Gaussian Distribution Function is based. In relation to target marking, Standard Deviation is used as a measure of the scatter of bombs around the Mean Point of Impact, and therefore as a measure of the concentration of bombing.
Stick (of bombs)	The practice of dropping two or more bombs, Target Indicators or flares at pre-set intervals, typically of one quarter of a second, thereby producing a line of equally spaced strikes on the ground or a line of flares in the sky.
Still Air	A condition where the wind speed is zero. 'Still Air' is the only condition in which the heading and track of the aircraft are the same, and in which the actual ballistic profile of a projectile is achieved. Also known as Nil Wind.
Supporters	Pathfinder crews detailed to bomb the target at the same time as the Primary Markers to reduce the conspicuity of the latter to the defences
Systematic Error	A function of target marking, the Systematic Error is the distance of the Mean Point of Impact from the Aiming Point, measured as a direct line.
Systematic Errors	Errors that are inherent within a system and are therefore constantly repeated.
Tail Wind	A wind in the same direction as the heading of the aircraft.
Target Indicator	A bomb that ejected a number of pyrotechnic candles for the ground marking of targets. Usually abbreviated to T.I.
Terminal Velocity marker during its fall to the ground.	Maximum speed reached by a bomb or
Time and Distance	The release of bombs or markers based on flight time from a well defined landmark or a Target Indicator placed for that purpose, calculated using groundspeed, wind direction and distance to the target.
Track	Direction of travel of an aircraft over the ground.

Trail (or Trail Angle) air after release.	Path taken by a bomb or marker through the
TRINITY	Code name for a series of attacks on the German battleships <i>Scharnhorst</i> and <i>Gneisenau</i> when at anchorage at Brest in late 1941/early 1942 using an experimental version of OBOE.
Turn and Slip Indicator	A basic flight instrument which recorded the rate at which the aircraft was turning and the amount a 'slip' or yawing movement in the turn.
UNISON	Code name for a series of bombing raids in 1942 featuring a high proportion of incendiaries.
Variates	The term used in the calculation of bomb distribution for the individual bombs or bomb loads that comprise the bomb distribution.
Vector Marking	Alternative name for Offset Marking
Visual Centerer	A Backer-up tasked with reducing the spread of marking or correcting gross errors in the placement of markers.
Visual Centring	The judgment made by bomb aimers in estimating the M.P.I. of the pattern of markers.
Visual Groundmarking	Technique devised by No 5 Group for marking targets visually from a low level.
Visual Marker	Experienced Pathfinder crews detailed to ground mark the target visually. Later termed Primary Markers or Primary Visual Markers.
WANGANUI	Target marking technique using sky markers released at a position ascertained with the H2S or OBOE navigation aids. The prefix 'Musical' was applied when used in conjunction with Oboe.
WINDOW from a bomber aircraft to confuse the German radar	Codename given to metal strips dropped
Wind Vector direction of the wind.	Variable composed of the strength and
X Gerät with the X Verfahren navigation system	Instrument carried in the aircraft associated
X Verfahren	German automatic blind navigation system comprising one master beam transmission to provide approach guidance to the target, intersected by three beam transmissions at fixed intervals to the target.

Y-aircraft	Any aircraft fitted with the H2S navigation aid.
Yaw(ing)	Movement of an aircraft such it is not aligned with the direction of the airflow.
Y Verfahren	German blind navigation system comprising two separate beam transmissions from the same ground station to measure the aircraft's bearing and range.

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