

Design Process and Technology Implementation for  
Wheelchair Accessible Vehicles

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Signature:

A handwritten signature in black ink, appearing to read 'P Cullingham', written in a cursive style.

## Acknowledgements

I would like to dedicate this thesis to my father, Michael. It was his encouragement and enthusiasm that motivated me to apply and take the KTP placement with GM Coachwork and Exeter University.

Other individuals I would like to express my appreciation for are my supervisors at Exeter University. Prof Ken Evans, Dr Julian Wright and Mike Felstead. Their support and advice in my first years in industry has been invaluable to me and something that I will look to apply throughout my career.

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Finally I would like to thank my mother, Diana, for having to put up with the ordeal of proof reading and correcting the majority of my written work throughout my education.

## **Abstract**

This thesis follows the design process of a safety restraint for a wheelchair occupant travelling in a passenger vehicle. The introduction of design processes and technologies that are new to the GM Coachwork they were established into the company is also documented.

Seven design concepts were created for the wheelchair occupant safety system. These underwent varying levels of development, from 3D CAD models to physical mock-ups and included a number of FEA studies. These concepts were then evaluated against each other and a concept chosen to take forward for further development and physical testing.

3D CAD technology was introduced to GM Coachwork by demonstrating its capabilities by a number of case studies. These showed where and how the technology could be used specifically for GM Coachworks requirements. The wheelchair occupant safety restraint project followed closely the development of the design process. A Products Design Specification was introduced and used with this project, 3D CAD and FEA was an integral part to the products development and evaluation techniques such as matrix analysis was used at various places within the design process.

By the end of the project a final product had been finalised, physical testing had been completed and the product presented to the staff within GM Coachwork. The design process had been tested and some recommendations and changes suggested and put in place to better suit GM Coachworks requirements.

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## Glossary

BPR	- Business Process Reengineering
CAD	- Computer Aided Design
CSI	- Chest Severity Index
DfT	- Department for Transport
FCZ	- Front Clear Zone
FEA	- Finite Element Analysis
FMEA	- Failure Mode and Effects Analysis
HHT	- Seated Head Height
HIC	- Head Injury Criterion
HIS	- Head Severity Index
HNB	- Half Neck Breadth
HSW	- Half Shoulder Width
ISO	- International Standard Organisation
M1 Vehicles	- Vehicles with less than or equal to 8 seats in addition to the driver's seat.
M2 Vehicles	- Vehicles with more than 8 seats in addition to the driver's seat and a maximum mass of less than or equal to 5 tonnes.
M3 Vehicles	- Vehicles with more than 8 seats in addition to the driver's seat and maximum mass of greater than 5 tonnes.
OEM	- Original Equipment Manufacturer
QFD	- Quality Function Deployment
ShHt	- Shoulder Height
STATUS	- Specialist Transport Advisory and Testing Utility Society
StHt	- Sternum Height
TQM	- Total Quality Management
WAV	- Wheelchair Accessible Vehicle
WTORS	- Wheelchair Tie-down and Occupant Restraint Systems

## **1. Introduction**

This MPhil has been carried out as part of a Knowledge Transfer Partnership (KTP) in association with GM Coachwork (Company Partner), Exeter University (Academic Partner) and Peter Cullingham (Graduate). The main MPhil project closely followed the regular activities of the graduate engineer with some aspects being investigated more thoroughly than would usually happen for purely commercial purposes.

### **1.1 Aims and Objectives**

The MPhil project was split into two distinct sections. To bring in technologies and processes that are new to GM Coachwork to allow them to refine their product development plans.

While doing this, the second half of the MPhil will be a design project intended on increasing wheelchair users safety when travelling in a vehicle.

Therefore the aims of the MPhil are:

#### **1.1.1 Aims**

1. Design and Develop a product intended to increase the safety of a wheelchair passenger travelling in a passenger vehicle.
2. Introduce a formal design process to GM Coachwork.
3. Introduce technologies to aid GM Coachworks product development.

These aims will be completed when the following objectives have been achieved.

#### **1.1.2 Objectives**

Aim one will be considered achieved when the following objectives are met:

1. To produce a number of design concepts for a product which increases the safety of a wheelchair occupant travelling in a passenger vehicle.
2. Further develop one of these products and produce a final design
3. Present the final design to the staff of GM Coachwork

Aims two and three will be considered achieved when:

4. 3D CAD has been established in GM Coachwork, ensuring other engineers are capable of using the program.
5. A formal product design specification is set before a design project is started.
6. Concepts are developed using the 3D CAD technologies without the need for physical testing.

## **1.2 Motivation**

With increasing quality of life, longevity and changing cultural attitudes there is an increasing demand for Wheelchair Accessible Vehicles (WAVs). Hence there is both an increasing number of WAVs using the roads and an increasing demand for variety in the range of available vehicles. Vehicle conversions are the most cost effective and customer orientated solutions so it is important to consider the safety of the wheel-chaired occupant whilst they are using such vehicles. For many the wheelchair takes the role of the car seat when they are travelling in a vehicle. Standard fixed car seats have to undergo many rigorous tests to ensure that they are strong enough and that they do not deform too much or fail in a way that can cause injury to the occupant or anyone else in the vehicle. These tests range from M3 vehicle loads for larger buses to smaller M1 (1) vehicles where the loading is much higher.

For a wheelchair to be transported in a vehicle, only the restraints holding the wheelchair into position and the belt supporting the passenger are tested (2).

This does not take into account how the wheelchair behaves or any rearward back, neck and head support for the passenger. This thesis considers the design of a device to provide additional support for the wheelchair occupant giving them back and head support. The aim of this design is to significantly reduce or prevent back, neck and head injuries that may occur during an accident and bring the level of safety for a wheelchair passenger up to the same level as it is for a passenger travelling in motor vehicle seats. The device is to be designed to protect against the rebound force during a frontal collision and against an impact from the rear, and needs to conform to ISO10542 regulations (2) for Wheelchair Tie-down and Occupant Restraint Systems (WTORS).

### **1.3 Technology Implementation**

As well as the design and development of a wheelchair back restraint the objectives of the MPhil were to implement new design techniques, methods and processes into GM Coachwork. (3) This process involved consideration of 3D Computer Aided Design (CAD) software, such as SolidWorks, and Finite Element Analysis (FEA), for example SolidWorks Simulator or ANSYS. (4) and methods and business case evaluation, using methods such as Business Process Reengineering, Six Sigma and Total Quality Management.

Before the start of the MPhil, GM Coachwork had no systematic method for creating technical drawings of parts that needed to be manufactured. When components were needed to be made they were often fabricated on site, using the facilities available and then sent to a local manufacturing company to recreate what they had provided. This led to inaccurate parts being produced with huge tolerances involved and often changing from one batch to the next. This also meant there was no record of parts and where a modification may have occurred in the model range.

3D design enables drawings to be produced accurately and in multiple formats. Assemblies will be able to be tested on here before components are

produced. Most CAD packages on the market also provide the facility to run FEA studies to check the strength of components and whether they can take the forces that will be inflicted upon them.

As well as this technology different design techniques and working practices will be integrated to GM Coachworks design process. This is to allow for more open working patterns between each member of the design team to ensure that each member is working towards the same objective.

The final product had to be within the production cost limits set out at the start of the design process. It was essential that the design met the technical requirements of the crash test but also be affordable for the end users to purchase.

## **1.4 Thesis Structure**

At the start of the MPhil, GM Coachworks position within the market place was assessed. The processes that are currently employed analysed and the objectives that were needed to be achieved were established. This followed a literature review which assesses the importance of technology in a design process and how best to manage the change process of introducing this new design methodology.

Smaller introductory projects are presented (Chapter 4) that demonstrated the capabilities of the CAD software, recommended by the University, to the staff at GM Coachwork.

A second literature review examines the need for a device that will increase the safety of wheelchair occupants while they are travelling in a wheelchair. The literature review also covers the regulations surrounding vehicle seats and wheelchairs that are transported in vehicles.

Current devices that are already on the market will be evaluated using Pugh's matrix comparison, to find the features that the device should include and sizes of occupants and wheelchairs will be assessed.

The back restraint brief is then created taking into account company factors and those that have become clear from the literature review. A Product Design Specification (Chapter 6.2) has been created to cover every part of the design process.

The concept designs were reviewed and their development followed as well as FEA studies carried out where appropriate. This followed physical testing of the concept chosen by Matrix analysis (Chapter 8.2) which led to further optimisation of this idea.

The final solution for the back restraint is then evaluated. Its performance was then compared it against the Product Design Specification (PDS). The new techniques and processes taken on in the project are reviewed in the evaluation of technology implementation chapter. This reviews how well the technology established itself, the costing factors that were involved and what has been saved by virtual prototyping and testing. Finally GM Coachworks business case and position in the industry and how it has reacted to these changes is evaluated.

## **2. Company Information**

As this thesis follows the changes and improvements introduced in by the MPhil, the effect these had on the company as a whole will be assessed and evaluated. This chapter looks at the company's position at the start of the MPhil and what processes and improvements are to be considered.

### **2.1 Company Position**

At the beginning of the MPhil, September 2008, GM Coachwork was in a good position in the wheelchair accessible vehicle industry. It was considered one of the midfield converters with good reliable conversions but it did not have the same manufacturing capabilities of some of the larger converters such as Gowrings (5) or Allied Mobility (6). The company had an annual turnover of £7.5 million and employed 65 people.

GM Coachwork had a good base of minibus sales with a range of vehicles consisting of the Fiat Doblo 'Aspen', Peugeot Expert 'Montana' VW Caravelle 'Colorado' and 'Vermont' and the Citroën C8 'Sirus'.

### **2.2 Planned Improvements**

The MPhil consists of two parts. The introduction of a formal design process and methodologies and the design of a wheelchair user back restraint device.

The processes that were introduced to the design process were an amalgamation of the engineers at GM Coachwork into a single design team with the intention of working together on projects rather than each engineer having an individual design project. A formal design brief and specification process was introduced as a way of considering the requirements needed from the product and then evaluating the finished result. The use of

Peter Cullingham

Computer Aided design will be implemented which allowed 3D design and Finite Element Analysis.

In addition to processes applied by the MPhil, other new production philosophies such as a production line and lean manufacturing were implemented over the course of the project. These were introduced in order to increase production of the existing models of vehicles that GM Coachwork currently converts.

### **3. Business Case Literature Review**

The advantages of having a formal design methodology are considered as well as factors that may affect how these changes are implemented within the company. Managing the reaction to the change was an important factor to consider, how the company was viewed from within by its own staff and also seen externally by customers, suppliers and competition.

#### **3.1 Process Implementation**

A technology cannot be introduced into a company without the appropriate systems and processes in place to maximise the full potential of the technology. It is important to do this to make sure the company is getting as much from it as it can and it is running efficiently. As with the example of GM Coachwork, it is to make sure the adoption of the CAD system is as simple as possible.

It was not possible to introduce full vehicle models to GM Coachworks CAD system straight away. The processing power of the CAD software was not be cable of running such a model and the skills within the company were not there to manipulate and work with the design. Instead introducing the software slowly by parts and then subsystems was an appropriate way of demonstrating the potential of the software.

GM Coachwork Ltd had no formal design software at the beginning of the KTP. Previously if drawings were required they were drawn on Microsoft Word, or if parts were sent to subcontractors to fabricate then an example was sent for them to reproduce. The KTP provided a good opportunity to introduce CAD software as part of a new design methodology for the company.

For a company specialising in the design and development of products it is essential that the demands, both external and internal, of the company are known. These include its customers, resellers and company directors (7). The Back Restraint Project will introduce GM Coachwork to a PDS (Chapter 6) which considers 32 different characteristics of the product.

There are different processes already developed and functioning in some companies to constantly monitor the design and manufacturing procedure. These include Business Process Reengineering (BRM) (8), Six Sigma (9) and Total Quality Management (TQM) (10). These are often used in larger companies where different departments are spread out with large numbers of employees. It is important to have regular reviews to ensure that the targets are still met. The techniques can still apply to smaller companies but it is more likely for a single person or a handful of people to be over-seeing and doing the work. Progress on the project is therefore easier to track. Such methods can involve costly training and upkeep that is sometimes not beneficial for the company, distracting valuable resources with process management rather than the core business activities. The concepts of these processes can be scaled down and implemented in a smaller company without all the administrative work that comes with them in larger organisations.

Implementing such processes can be costly as it is important to up skill staff in how to carry out the work required. It is also important not to only up-skill managers or senior personnel. TQM (10) applies this, as it is a management system that considers that every employee in the organisation is responsible for keeping up the highest standards in every aspect of the companies work. This is only achievable if each employee is kept current with methodologies and the companies' targets and goals. This includes regular reviews of the internal and external influences.

An overall design process is the most relevant to this project. Evidence exists (11) to show that process focused design organisations can result in superior overall organisational performance. It shows that if the design processes is

completed and passed to 'process complete' departments in the company, such as marketing and sales, then it creates a collective sense of responsibility and enthusiasm for the product resulting in faster cycle times and more motivated workers. (11) Therefore it is important to make this process as effective and efficient as possible.

### **3.2 Factors Affecting Implementation**

As a technology is introduced to a company it can be a challenging time for those involved in the adoption of the new process. In the example of introducing CAD to GM Coachwork expectations and assumptions (12) have to be managed in order to show effectively what can be achieved. To fully implement the technology into the design process a fundamental change in the assumption and way of thinking of the members of the design team is needed. (13)

When the Chief Executive was originally introduced to the idea of bringing 3D Design technology into the company he was extremely enthusiastic. His expectations were that the software would be the standard of the major players in the automotive industry and GM Coachwork would be able to share information back and forth with the manufacturers that it deals with, for example Fiat and Volkswagon. It was important to manage his expectations with a series of case studies into what the software was capable of.

Examples were shown of what the chosen software, SolidWorks, (14) was capable of and the time constraints involved in doing certain things. The overall reaction to the proposal of introducing CAD to the companies design process was positive. Engineers had seen the capabilities advanced CAD software (For example Catia V5) in the mainstream automotive industry and were keen to see some of these processes being implemented at GM Coachwork using SolidWorks. There were also concerns over data management, storage issues and communication between the design and

purchasing departments. This is something that was addressed in the introduction of the software.

The undertaking of getting the members' of the design team to accept the changes and new processes introduced can sometimes be difficult as it can result in a change of the culture of the company (15). As a company introduces a new process is it essential that there is a clear action plan and understanding of how it is going to be implemented.

When introducing the technology or process it is important to take into account a number of issues (7).

- The key phases in the process.
- Design and modelling approach to the technology.
- Process management and monitoring.
- Technical capabilities of the company.
- Information flow management throughout the company.

The key phases of introducing the software to the company were the purchase of the software and hardware. It is important to ensure that the correct choice of software for the company has been purchased, by demonstrating to staff case studies of the software's capabilities (Chapter 4), and that the computer hardware is available so that the software can be run to its full potential. The next stage of the implementation was to consist of showing the capabilities of the software, which will take the form of a number of smaller mini projects. These were intended to show the variety of things the software can be used for and also calculate time-wise and financially how the software would benefit the company. This was done by measuring the time and materials saved using the CAD software as compared with what the engineers would have done before they had access to CAD. The users of the software will have to be decided upon. This decision has to take into account any training required and other responsibilities for the members of staff involved. How the software fits into other members of the company with

regards to suppliers and customers is something that will have to be considered. One aspects of this were not foreseen so would be addressed as issues arose during implementation. Finally monitoring and maintenance of the software will have to planned and carried out.

### **3.3 Managing Change**

It is not just engineering based industries that have to adapt to changes to processes within the company or adopt new technologies. Ensuring that the transition period is as smooth as possible is essential to the success to the business. For a successful business to handle the ups and downs it will inevitably encounter over the years of its existence it needs to be able to handle change in an efficient and sustainable way (16)

When faced with changes the thought of moving from the familiar to the unknown is often instantly labelled as too difficult. It is therefore the duty of the manager to demonstrate a convincing argument to justify the change that is about to be implemented. This can be illustrated using figures to show how the change may make financially sense or drawn up in diagrams or graphs to show how a new structure may prove more efficient (17). Setting realistic targets and milestones to meet these changes is often a good way of keeping up moral and performance during this period.

Implementing change requires both capability and the capacity to manage it effectively (17) to achieve the outcomes that are desired. Having an effective plan of implementation is needed to prove that the company is capable of adopting these changes. While carrying out the capability plan it require a resource assessment which will then outline the companies capacity to take on the transition to change. This will look into the financial situation of the company as well as the skills of the personnel involved, whether the company will have to employ other people more skilled in the new technology or

processes. If the company is missing one of these then unforeseen problems are more likely to arise.

There are three common reasons for failure when implementing change (17). Firstly is that the people directly involved in the change are not involved in the planning the details of the change. They may see some of the unforeseen problems that some of the managers or human resources planners may not have seen. The second common reason for failure is that different parts of the company are not communicating well enough so that when the change is implemented misunderstandings occur. This can happen in large and complex organisations and can have the opposite effect by making the process slower and producing more errors than before the change was implemented.

The most common reason for change implementation failure is that people feel threatened by it, believing that it could be a structural change and it could result in their positions being threatened. This can lead to hostile attitudes and general mistrust of the change. People's natural instincts are to shy away from change. It is the fear of the unknown and can often lead people to be resistant to anything that disrupt their normal routine (16). This leads to having to deal with the attitudes of people towards the change. Good leadership is essential for this and it is important that the manager or leader is ahead of the change transition and able to answer questions of personnel effectively in order to inspire confidence to the people involved.

A good leader will be able to understand the factors that cause people to shy away from change and can anticipate them and then harness them to work in favour of change rather than against it. The role of human resources and come into play here by being able to look at the bigger long term picture and answer questions when managers in departments are often busy dealing with the day to day issues (17).

It is not only down to the managers and leaders to make the change process work. It comes down to the people affected by the change and they have just

as important a job to play as well. By winning them over and making them work positively and constructively with the change it can be taken on quickly and efficiently and any problems overcome quickly (16). If the staff are working with the change they are more likely to engage with it and contribute their own suggestions and ideas and may prevent any of the unforeseen problems arising.

The human factors of change come down to two major factors that must be carefully managed (16). The leaders on all levels who must positively engage with the change and keep their employees informed and motivated and the employees, who have the skills and positive attitude to engage constructively and work with the change rather than against it.

## **4. Action Research Projects**

As part of the process of change, several smaller projects were carried out during the course of the MPhil. These helped implement the CAD technology that was being brought in and also had other benefits for the company such as time savings, material cost savings and improving the companies' image amongst potential customers. These are described in this chapter and the lessons learnt indicated.

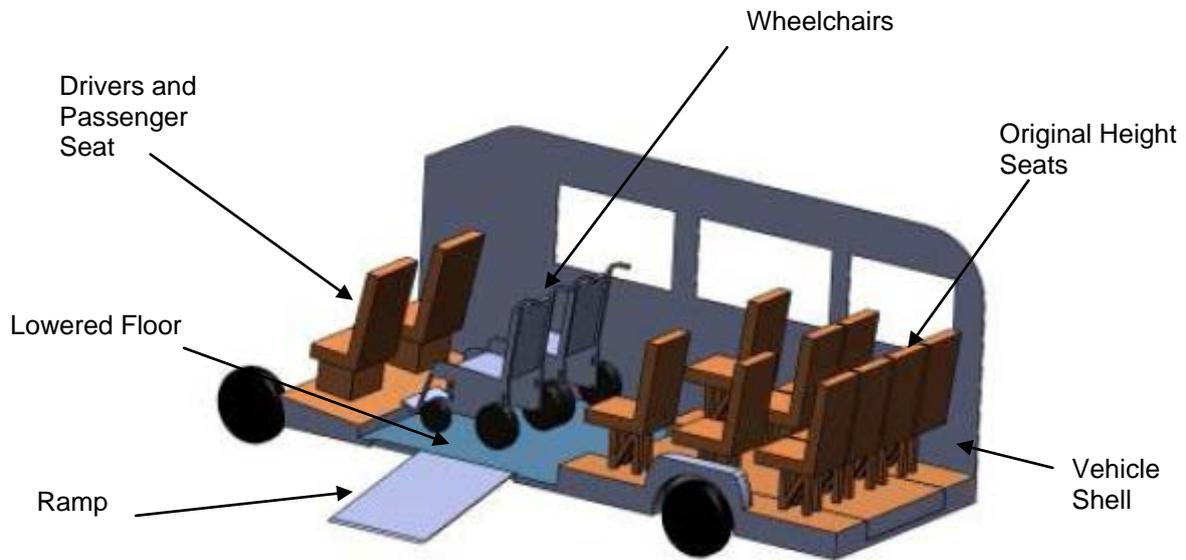
### **4.1 Minibus Seat Layout Configurator**

Bath and North East Somerset Council (18) were placing a large order of minibuses from GM Coachwork. As part of the negotiations it was requested that ramp angle of no more than 13° would be desirable. This would reduce the need for a winch to help pull the wheelchair into the vehicle. This can be done in 2 ways. Either the ramp is extended in order to reduce the angle, or the vehicle floor is lowered which will reduce the height the ramp has to reach and reduce the angle.

Increasing the length of the ramp would be impractical as it would extend too far out the back or side of the vehicle. A proposal was made to lower the floor of the minibus by 200mm, that combined with lowering suspension and a slightly extended ramp would achieve the desired ramp angle.

As this would be a new vehicle for GM Coachwork a demonstrator vehicle was not available to show the potential customers. In order to give a visual representation of what was planned for this vehicle, a basic 3D CAD model was produced. This had to be drawn up from measurements made on the vehicle as CAD files from the OEM (in this case Peugeot) were not available within the time scale involved in the project. The model was kept simple to key dimensions to avoid complicating the model and risk introducing measurement errors. The modifications were then made to the floor of the

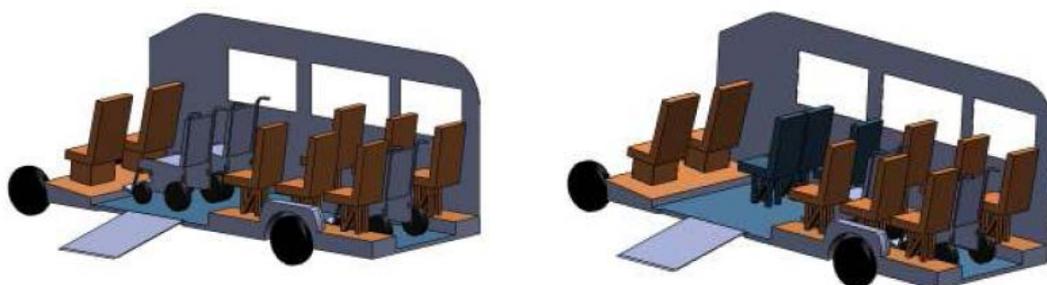
vehicle. To get a representation of the scale of the vehicle the seats and wheelchair were also modelled and put into the assembly.



**Fig 1. - Minibus with Lowered front area and seats fitted**

Figure 1 shows the original plan for the vehicle. It illustrates a side access ramp with a lowered section at the front of the passenger compartment for wheelchair occupants to use. It was decided to produce a 3D CAD illustration of the bus rather than technical drawings as these would be shown to non-technical staff from potential customers.

The model was then adapted to lower the centre section of the floor all the way to the back of the bus. This is to provide access for wheelchair users from the rear of the vehicle via a lift or ramp. The seats passenger compartment were then fitted down each side of the vehicle.



**Fig 2. - Different lowered floor, seats and wheelchair configurations**

Figure 2 shows some of the different configurations that were prepared to the customer. It provided a scale image of how the minibus was set up and how much room there was around each wheelchair and in between seats.

While this particular vehicle was not appropriate for the needs, an order was placed for a regular bus, in keeping with the products GM Coachwork normally produces. Despite this, being able to produce these illustrations and adapt the configurations to their needs really showed off GM Coachworks technical capabilities and showed them that as a company, they were willing to invest in advanced technologies in order to improve products and the design process.

## 4.2 CAD Assembly Simulations

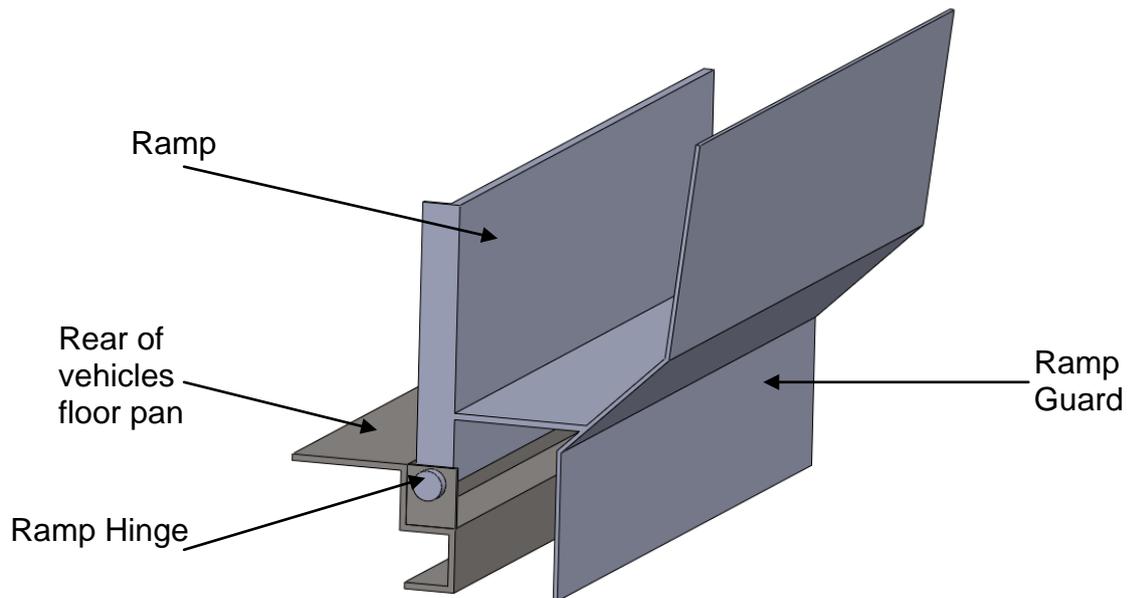
When designing parts that interact or move around each other, the engineers at GM Coachwork often created a 'mock up' out of wood or metal. This ensures that the movement of the part is correct and does not come into contact with any components that it should not. These mock ups would often take 2-3 hours to make and use up material.

An example of this can be found in the development of the VW Nevada Vehicle. This is a vehicle based on the VW T5 Caravelle which has a lowered floor and is accessed via a ramp at the back of the vehicle.



**Fig 3 - Rear view of GM Coachwork T5 Nevada vehicle (3)**

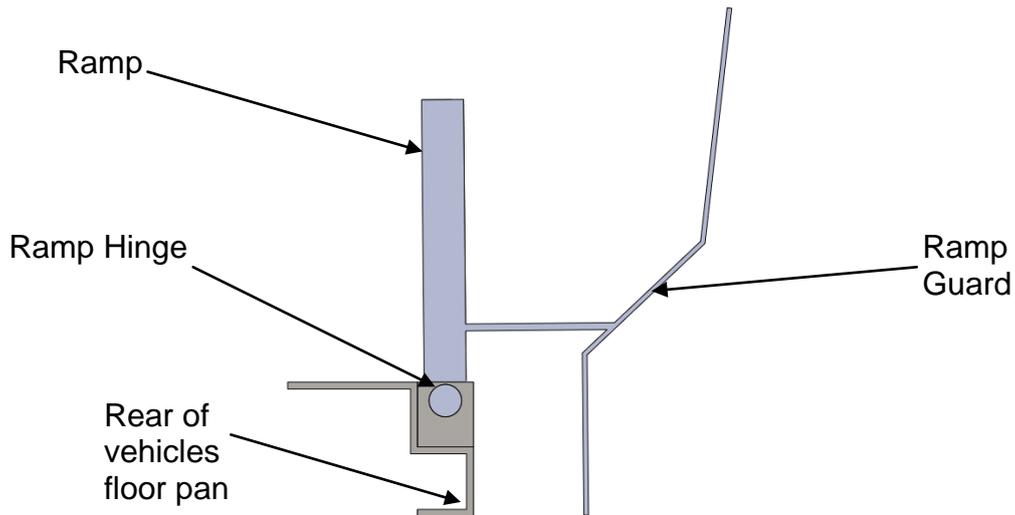
A guard needed to be fitted to the underside of the ramp to ensure that it fitted flush with the rear bumper of the vehicle. This can be seen in Figure 4. This improved the looks of the vehicle, hiding the cut floor. It is this attachment that is in danger of coming into contact with the rear of the vehicle as the ramp is deployed.



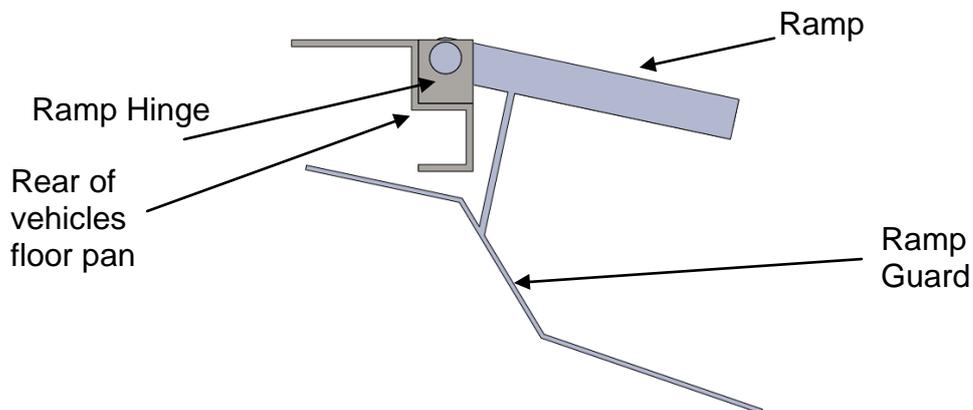
**Fig 4. - CAD Model of the back of the vehicle, ramp and ramp guard.**

A CAD model was created using the dimensions of the floor pan and ramp. The ramp guard was then modelled and added to the assembly.

Using this model the ramp can be lowered into its deployed position and the assembly will show if there is any points where the guard comes into contact with the edge of the vehicles floor pan.



**Fig 5. – Sectional view of assembly with the ramp in its stowed position**



**Fig 6. – Sectional view of ramp assembly in the deployed position**

As can be seen from Figures 5 and 6, the ramp can be deployed without contacting any part of the vehicle. From this, the dimensions can be taken and the part can be drawn up for manufacture and then produced. This method only took 1 hour to carry out on SolidWorks and did not use any materials. If the simulation had shown that the guard did foul a part of the vehicle then the dimensions could be changed in a matter of minutes. If a physical mock up had been produced, it would have taken longer, and any changes that would have to be made would mean making the part again which would use more material and take much longer.

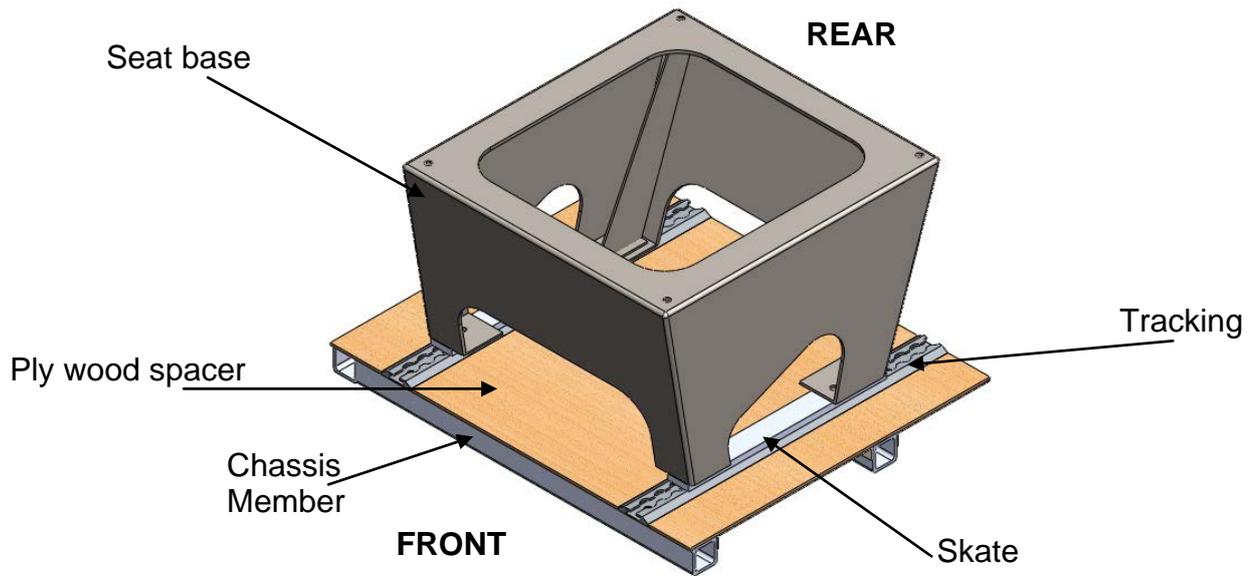
This was a successful demonstration of how 3D CAD can save labour hours and material costs on creating parts and ensuring that they are correct the first time they are produced.

### **4.3 VW Seat Base FEA**

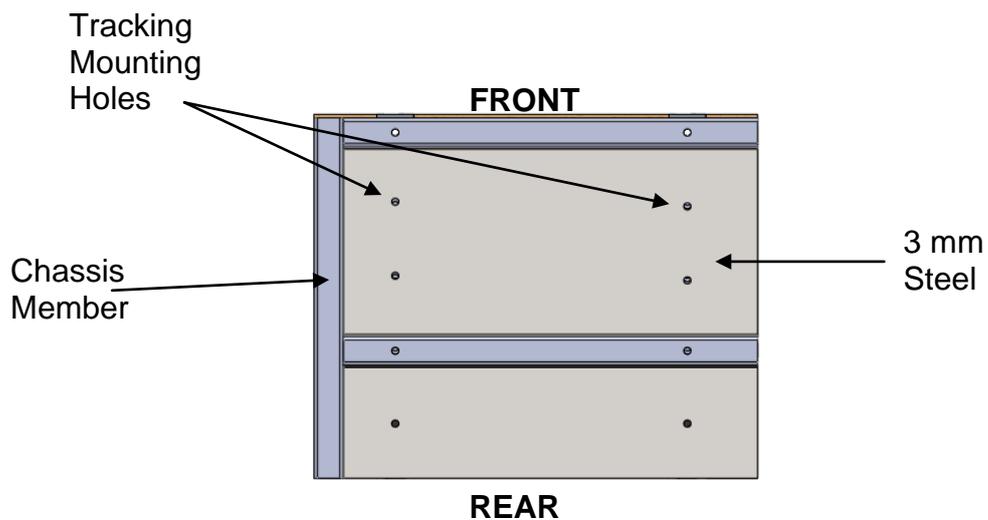
This case study demonstrated how Finite Element Analysis used in conjunction with the 3D CAD tool can provide confidence in a design and reduce the need for extensive physical testing that is both costly and takes up valuable time bringing a product to market.

The Nevada wheelchair accessible vehicle has a floor that is 100mm lower than the original vehicle. This is to provide the additional seating height for a wheelchair user, who sits higher than a standard car seat. Due to the lowering of the floor, the existing seats need to be raised so they return to their original height. The new taller seat base was modelled on the CAD software along with a detailed section of flooring. Once this has been modelled the forces that the structure has to withstand during physical crash testing will be applied to see if the structure can withstand them.

The flooring that is used in the vehicle is 6mm sheet steel, fitted onto a cross member chassis that supports the frame of the vehicle. The seat base itself is then fitted to the flooring using a set of Unwin (26) lockable fixtures into tracking. This is tracking to allow the seats to be removed and wheelchair secured into position. The flooring is then levelled up to the top of the tracking with ply wood.



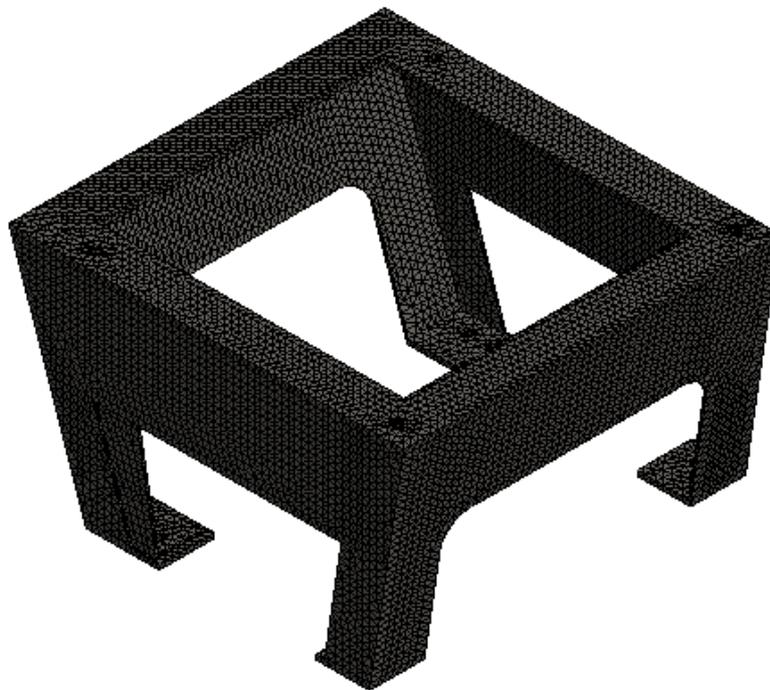
**Fig 7. - Isometric View of Seat Base and Flooring Assembly**



**Fig 8. – Bottom View of Vehicle Flooring**

The assembly model was restrained in the simulation on the ends of the cross members. This accurately recreates how the chassis is supported into the vehicle. The forces that are applied to the system (Stated in A1.1.2 M1 Seating Regulations) are then applied to the fixing holes in the top of the seat base. This is where the original vehicle seat is attached.

The entire model was meshed (Figure 9) using a solid mesh which was carried out using a no penetration boundary condition with the components attached using bonded connections where the corresponding joints would be. This assumes a perfect joint where the parts overlap. Setting the boundary condition to this allows the components of the assembly to move if the joints fail or large deflections occur during the simulation. Each part of the assembly was then meshed individually in order to speed up the meshing process and simplify the calculation as much as possible.



**Fig 9. – Image of Mesh used in FEA Study.**

The mesh was concentrated in areas where the model is restrained and load applied. By concentrating the mesh around these spots it provides more detailed results while the rest of the model can have a larger, coarser mesh where the changes to the forces are going to be slighter. The areas of fine mesh are those of the fixing points, connection between parts and the areas where the loading has been applied. This allows for an accurate simulation that includes the fine detail in the key areas while keeping total element count low, which in turn speeds up the running time of the analysis.

Static tests were that were carried out using SolidWorks Simulator on the model demonstrated that there are large areas of concentrated stresses that exceed the yield strength of the material, illustrated in the figures below. This would cause excessive deformation in the parts.

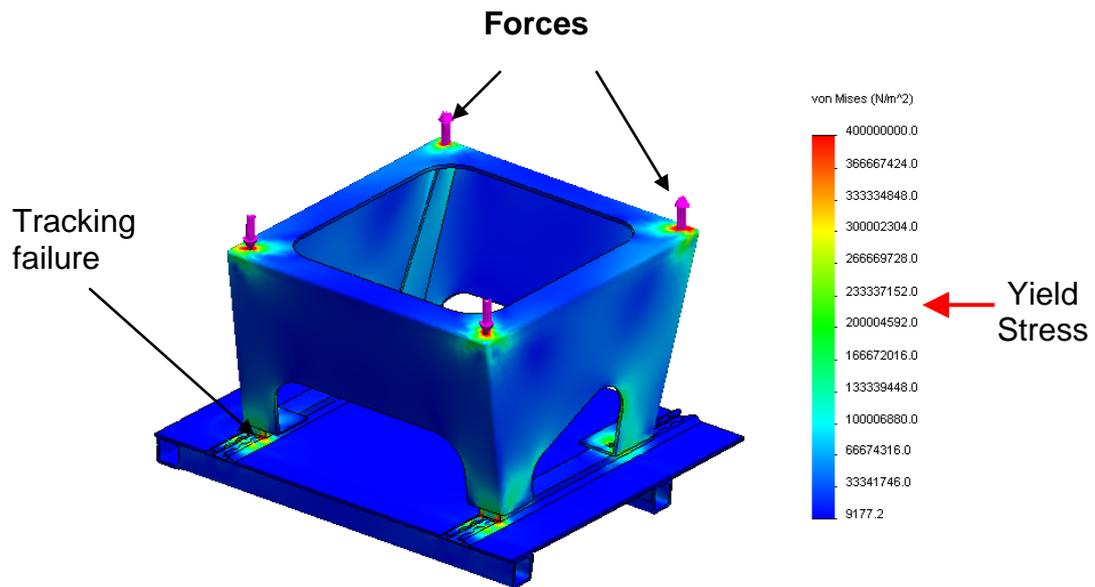


Fig 10. – Isometric view of the initial computer simulation results

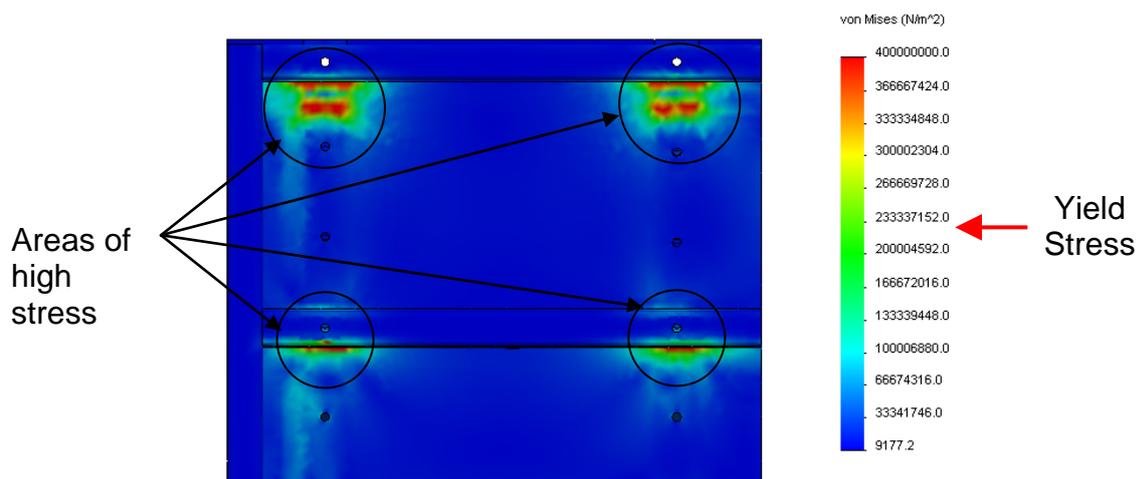
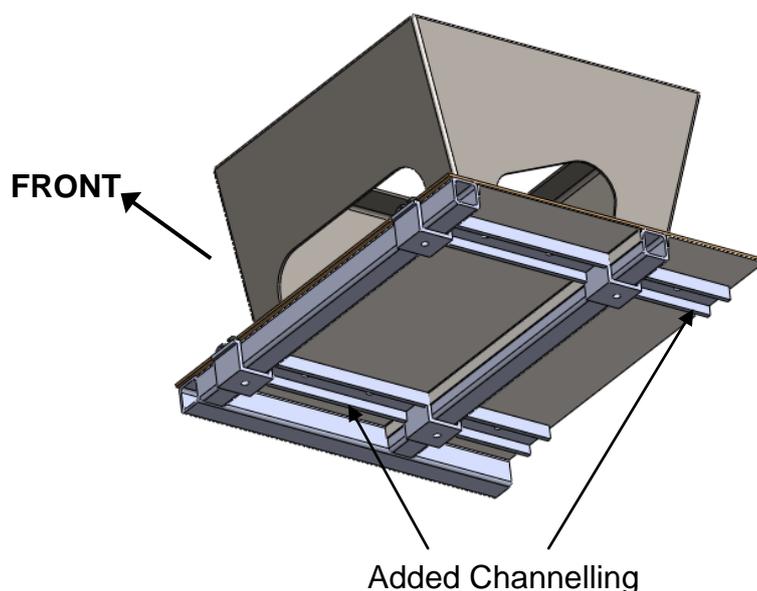


Fig 11. – Bottom view of the initial computer simulation results

The results from the initial simulation served as a warning system for GM Coachwork as it indicated that the seating system would not withstand the forces inflicted on it during the physical testing. Due to the design of the tracking, once deformation has started it is very easy for the tooth which holds the lockable fixture to become displaced. Once this has happened to one tooth the loads are transferred to the other, which also becomes displaced. It starts an 'unzipping' action along the length of the fixture and the seat base free from the floor. Therefore it was from these results that a decision was made not to carry out the physical testing of this model in order to save costs in time, labour and material.

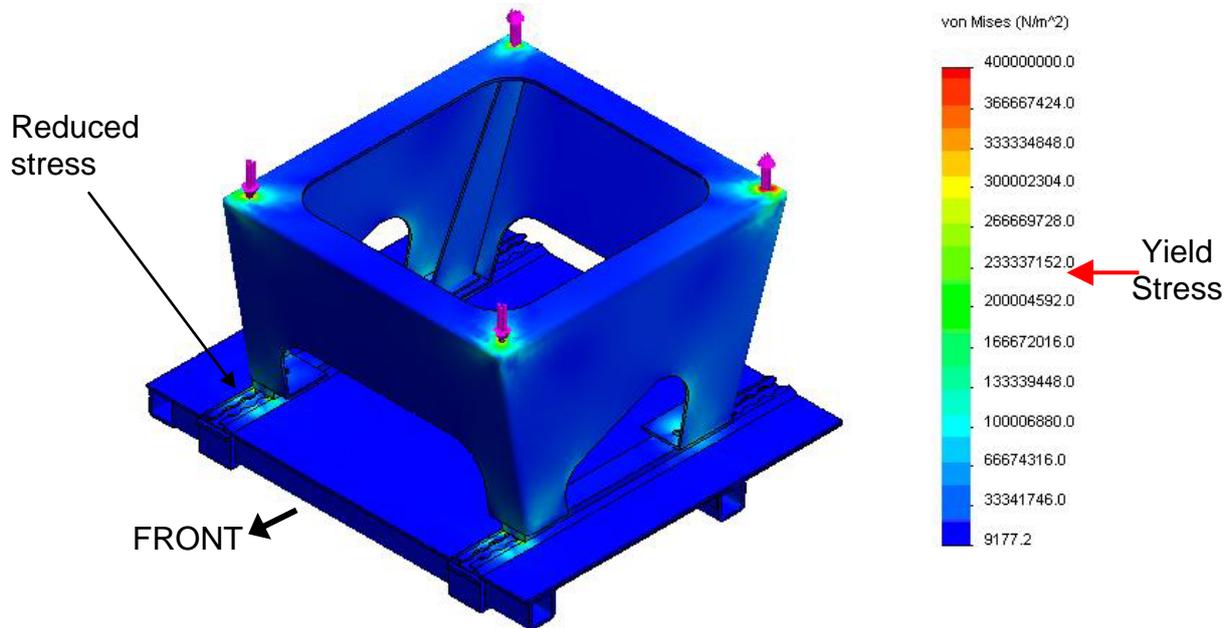
A solution was developed using engineering experience and then the computer modelling to support it. This solution consisted of two channels that ran the length of the Unwin tracking on the underside of the flooring. These held the tracking down to the floor and prevent them from deforming which was the main cause of failure during the test.



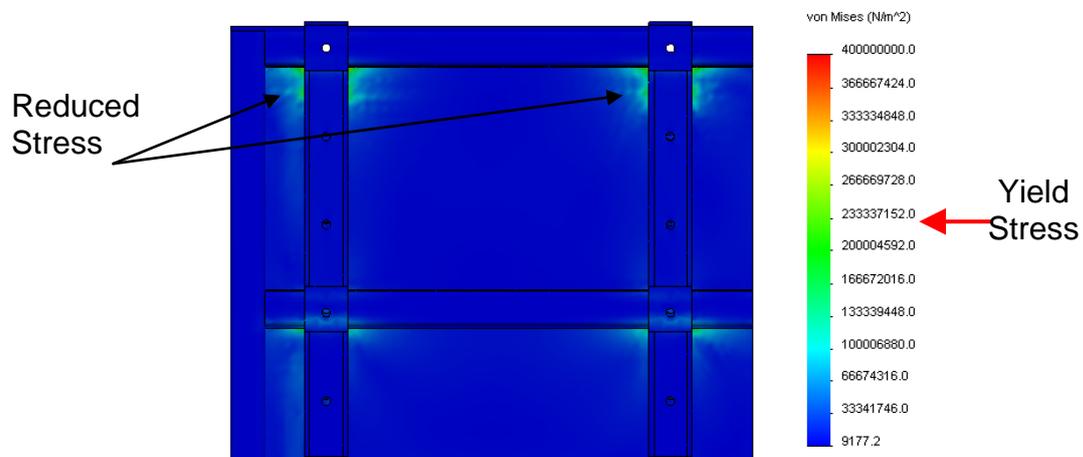
**Fig 12. – Bottom view of additional channelling**

This analysis was carried out on the revised model in order to establish what effect the addition of the channelling has made. As can be seen from figures

13 and 14 below the stresses have been greatly reduced and there are no longer excessive forces built up in the key areas of the assembly.

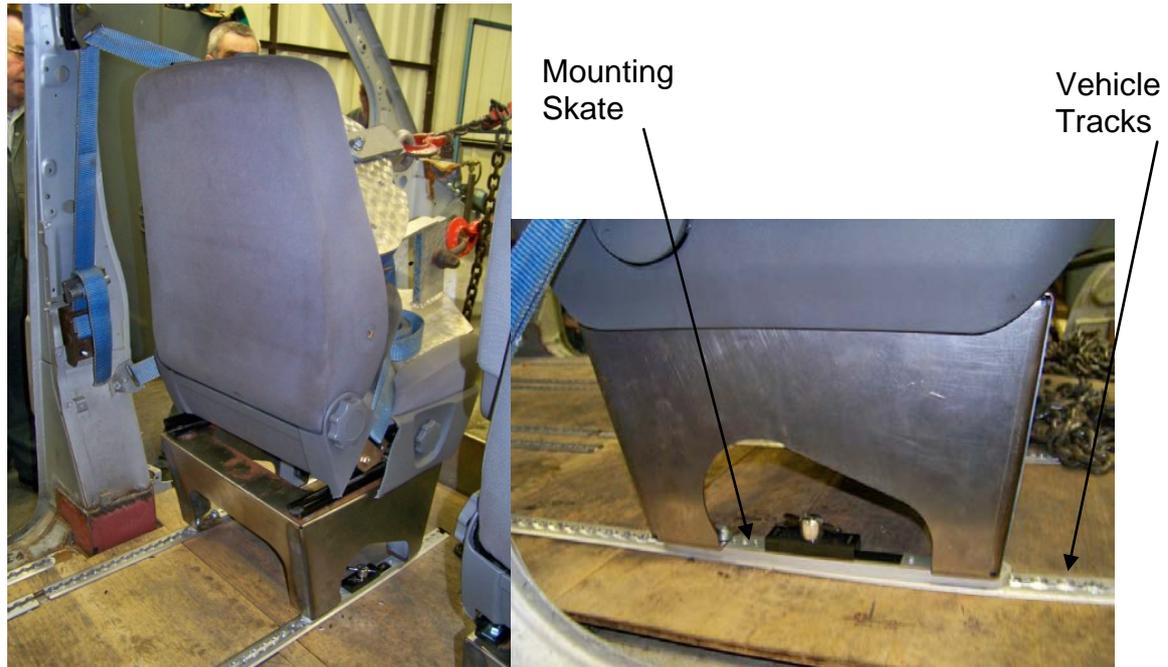


**Fig 13. – Isometric view of the second computer simulation results**



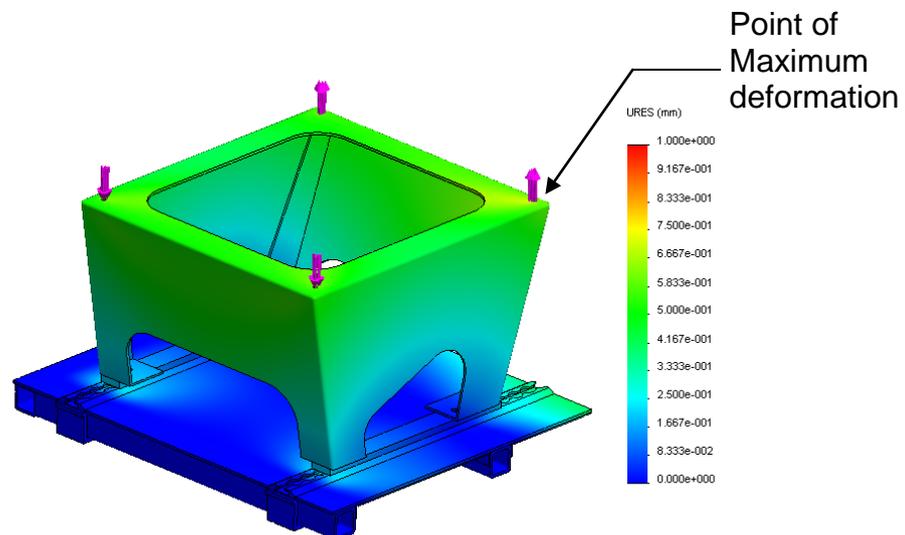
**Fig 14. – Bottom view of the second computer simulation results**

The results of the analysis allowed GM Coachwork to go into the physical testing with enough confidence that the model will pass. The physical testing was carried out and the components passed and behaved as predicted by the simulation.



**Fig 15. – Photographs of flooring and seat base after physical testing**

The results from the physical testing prove the accuracy of the computer simulated model. The deformation of the seat base and tracking, which can be seen in Figure 16, were predicted from the computer model.



**Fig 16. – Isometric view of second model deformation results**

Being able to directly compare the results of the FEA to the physical testing provided a great boost in confidence GM Coachwork had on the computer simulations. It means that components and assemblies can be modelled on the computer and have the forces applied to them to see if they can take the

loads. This can then lead to the design being refined on screen rather than having to be physically made up then changed. It can reduce the number of physical tests carried out; enabling GM Coachwork to taking on version that they are confident will pass to the physical testing.

The above examples (Sections 4.1, 4.2 and 4.3) show how 3D CAD and FEA software can be a benefit to GM Coachwork and how it is being used to integrate it into the design process. It has been used to reduce the need for physical mock ups, allowing designs to be refined and corrected on screen instead of having to do it physically, reducing the amount of labour hours and material costs. FEA can also reduce the need for extensive physical testing, giving GM Coachwork the confidence in a single design instead of carrying out multiple tests on different versions of a component. The CAD abilities have also been to show potential customers the technical ability GM Coachwork has, boosting their image within the industry.

## **5. Back Restraint Literature Review**

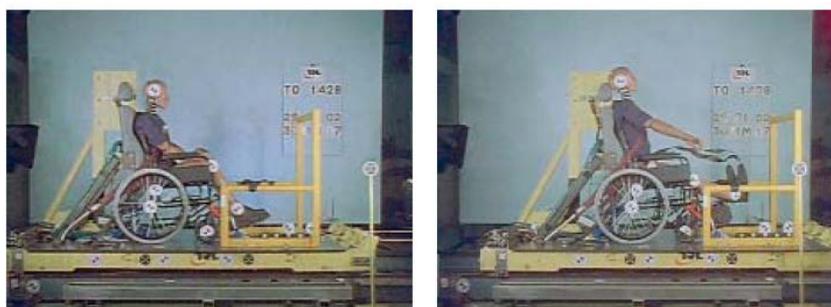
### **5.1 Wheelchairs in Passenger Road Vehicles**

Motability is a not for profit government supported charity that provides vehicles for disabled users in the UK. They provide up to 140,000 vehicles a year which make up standard cars, fitted with adaptation to aid driving, and cars suitable for wheelchair transportation.

There is continuing social pressure by Motability and WAV manufacturers to bring the safety level for a wheelchair occupant travelling in a vehicle up to the same standard as those occupants travelling in a M1 vehicle seat (1). A large factor that currently has no mandatory regulations surrounding it is the back and head restraint. The regulations for the surrogate wheelchair used when testing the Wheelchair Tie-downs and Occupant Restraints (WTORS) has a seat back height that only goes up 550mm (2). This does not give adequate protection for the upper back, neck and head. Work has been carried out on behalf of the Department for Transport (DfT) with the primary objective of establishing the occupant's safety while travelling in vehicles while seated in a wheelchair (19). Part of this study focuses on head, neck and back protection. Three experiments are carried out each setting different scenarios and forces inflicted on the passenger. The test was carried out using a standard manual chair, a heavy duty electric wheelchair with the manikin right up against the back rest and head restraint, the third was with the heavy duty wheelchair but the manikin starting 222mm away from the back rest and head restraint.



**Fig 17. - Test 1 Wheelchair occupant during sled test in manual wheelchair with no extra back or head restraint. (19)**



**Fig 18. - Test 2 Wheelchair occupant during sled test in heavy during electric wheelchair sat up against the back and head restraint. (19)**



**Fig 19. – Test 3 Wheelchair occupant during sled test in heavy duty electric wheelchair with 222mm gap between themselves and back and head restraint. (19)**

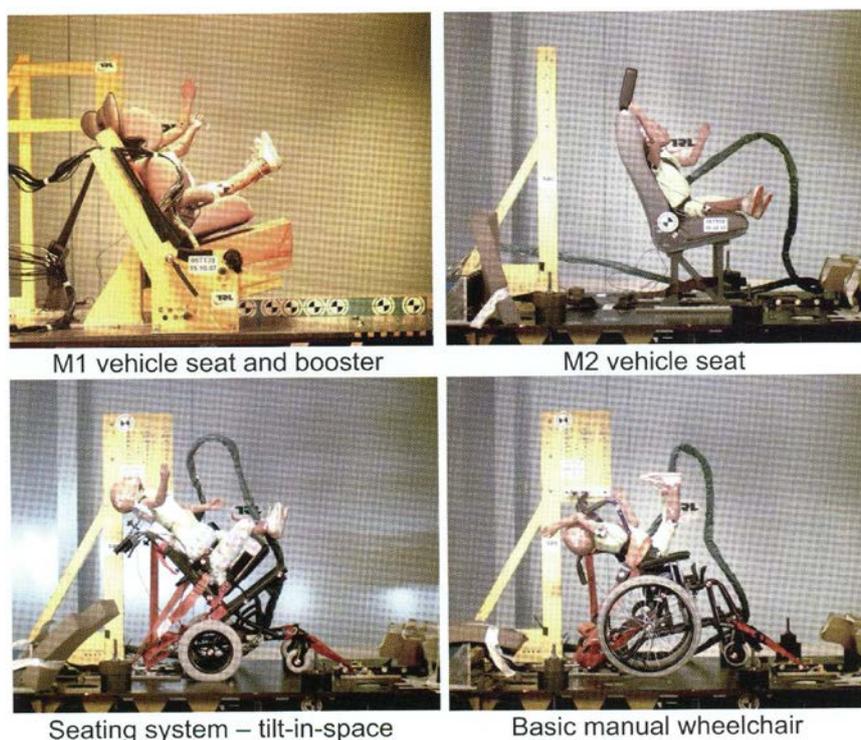
The test 1 (Figure 17) proves the need for sufficient occupant restraints. The occupant rises up out of the wheelchair and the neck over extends. In test 2 (Figure 18) the occupant does not rise up out of the wheelchair and the movement of the head and neck is much more controlled. This is in stark contrast to the test 3 (Figure 19) where there is a space in-between the occupant and the back and head restraint. In this test the occupants head rotates before it makes contact with the head rest which results in high head and neck extension and loading.

This indicated that a high backed back and head restraint goes a big step further towards bringing the wheelchair occupant safety levels up closer to those levels of a fixed vehicle seat (20). In order for this to be effective the occupant must be sat right up against the back restraint and with no gap which allows the head to rotate before it comes into contact with it. In an ideal world it would only be these heavier duty wheelchairs with substantial back and head rests that would be used in vehicles, but due to user preference, needs and practicality reasons this is not always possible and the lighter weight manual chairs will be used to transport wheelchair users in vehicles. It is these wheelchairs that will be targeted for an additional safety device as they are not providing efficient protection.

## **5.2 Child Wheelchair Occupants**

The current standards and regulations only account for an adult, the size of the 50 percentile male and being a mass of 75kg. There are no standards that are directed at the protection of children during an accident. As the WTORS are expected to be in the same location whether it is an adult or child occupant it is clear that they are not going to offer adequate support for each. A similar report to that above was issued by the DfT which compared the level of protection provided for a child travelling in a wheelchair as compared to a child travelling in a fitted car seat. (21) During this, the behaviour of children of the ages of 3, 6 and 10 years old were simulated in crash simulations in a number of seats including standard M1 car seats, manual and electric wheelchairs.

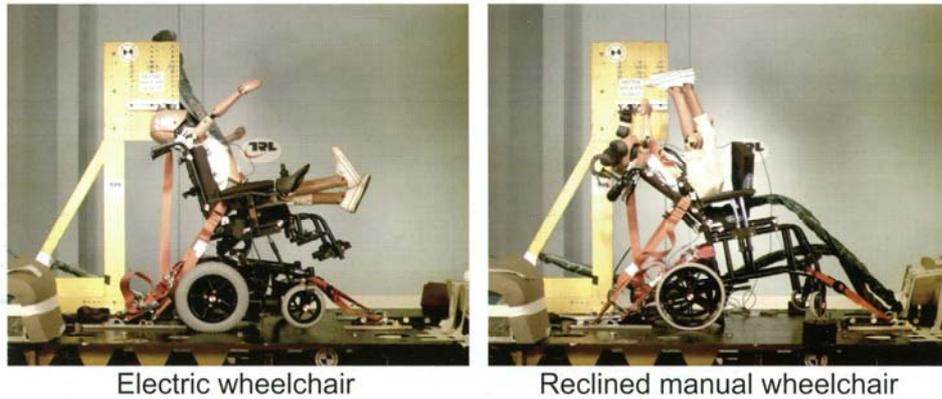
The first study was of children aged three years old. Figure 20 shows that when a child is seated in a standard car seat the dummy experiences minimal neck extension during a collision and is fully restrained so there is no danger of coming into contact with any part of the vehicle.



**Figure 20. – Crash test of a three year old dummy in various chairs (21)**

In a system with a tilt-in-space wheelchair there was a large displacement of the occupant. The head rose above the 'top of head' position and the back and head rest of the chair extended rearwards on the rebound. Due to the poor belt geometry due to no fixed upper anchorage position and seat angle the dummy ramps up the back rest during the rebound forces. While the dummy stays within the footprint of the wheelchair this does increase the risk of coming into contact with the side of the vehicle.

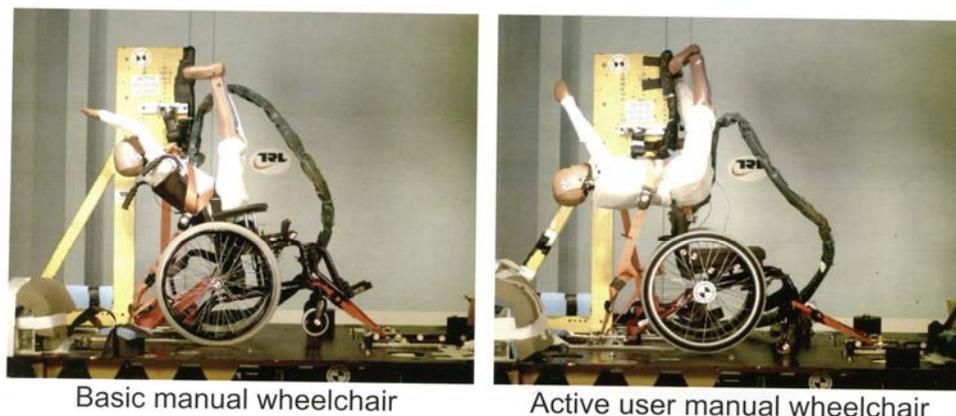
Similarly in the manual wheelchair the folding mechanism of the backrest fails causing the occupant to fall rearward giving a high neck extension and head movement and which can risk soft tissue neck injury and contact with the side of the vehicle. During the initial frontal force the occupant is thrown forward and pulled to the left as this is the side that the upper anchorage point is located.



**Fig 21. – Crash test of a six year old dummy in different wheelchairs (21)**

Figure 21 shows a series of crash tests with a 6 year old occupant during a frontal collision travelling in an electric wheelchair and a manual recliner wheelchair. As with the previous seats the occupant travelling in the car seat experienced minimal neck and head extension and remained fully restrained. In the electric wheelchair the folding mechanism of the seat withstood the force of the crash but during the rebound impact the dummy rode up the backrest, creating a large neck extension and head displacement. While still in the footprint of the wheelchair, this increases the chance of neck injury and contact with the edges of the vehicle.

The manual reclining wheelchair was fitted with a headrest which proved to offer little protection during the impact. Figure 21 shows that the headrest is easily pushed away as the dummy reclines up the backrest which offers little support. There is a high level of neck extension and head movement and a high chance of injury during the collision.



**Fig 22. – Crash tests with a ten year old dummy in different wheelchairs  
(21)**

The experiment was then carried out for a child of 10 years of age. Figure 22 shows the behaviour of the occupant in a basic manual wheelchair and an active user manual wheelchair. The former illustrates that the push handle of the backrest fails causing a large amount of ramping up of the backrest while it moves backwards. This greatly increases the risk of coming into contact with the vehicle as well as giving a high level of rearward neck extension.

An active user manual wheelchair was used to view its behaviour in an accident. While this does not meet the standards for a wheelchair that can be used for transportation in a vehicle, how it behaved in an accident is important. The backrest immediately broke; this was too low to offer any protection for the user. The user was not contained at all during the rebound phase and left the foot print of the wheelchair. This means that there is an extremely high chance of further injury from coming into contact with the sides or roof of the vehicle.

The study concludes that the strength of the backrest and folding mechanism is crucial. If either of these should fail then the child could be thrown backwards. When the backrest stays in position the rear head displacement and risk of vehicle contact is greatly reduced. It is still possible for there to be a large neck extension and uncontrolled movement of the head. Soft tissue neck injuries are likely to result from this.

The head rests that come on wheelchairs are currently not designed to be used as head restraints. In some cases the dummy ramping up the wheelchair backrest missed the head rest altogether. On the other occasions the headrest was just pushed aside and played no real part in protection of the user.

The test proves that the children in wheelchairs do not receive a comparable level of safety as those travelling in a vehicle seat or using child restraints such as booster seats. The document advises provision of a head and back restraint for wheelchair users in vehicles. This is justification for a product in the marketplace that provides this kind of additional head and back protection.

The strength of the back rest on a vehicle transportation worthy wheelchair is essential to the level of safety that it provides. A study (22) has been carried out to determine the level of back support provided by a standard manual wheelchair with nothing more than cushioning for support of the passenger. This study addresses the issue that standard wheelchairs are not designed for the role of in vehicle transportation of a passenger. While the testing is carried out for the loadings to the WTORS this is carried out with a surrogate wheelchair in position. This test does not take into account for the deformation of a standard wheelchair. Although the surrogate wheelchair is of the correct dimensions, it is of a different level of strength and often much stronger than a standard wheelchair would be.

The weight of the surrogate wheelchair prohibits its use by a wheelchair user and makes pushing by a carer difficult. The testing carried out in this investigation uses five wheelchairs that are currently on the market. It establishes that the main loadings on the wheelchair are the rebound loads associated with frontal impacts and the loads encountered during rear impacts. It chooses to test to the worst case of these, which is the rear impact loads. The testing was carried out using a sled test.

The results were that all of the back supports on the wheelchairs failed under loading, with failures that included severe metal deformation of components

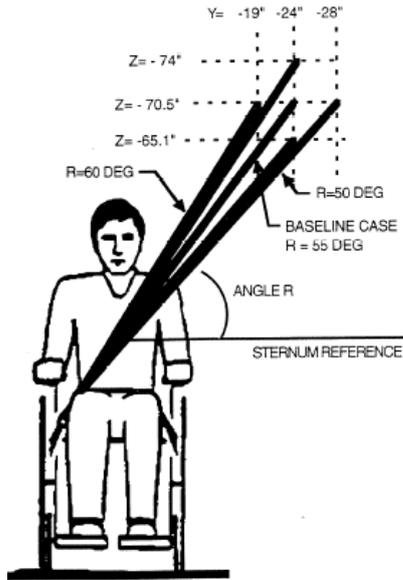
and the fracturing of plastic components. On all but one of the wheelchairs the back support systems failed at less than 50% of the load which may be experienced during a rebound or rear impact.

The article then goes on to assess the advantages and disadvantages of having a backrest designed to yield and deform at certain loads and of backrests designed to remain as rigid as possible and hold the occupant in set position. There are arguments for and against each approach to seat design. A study entitled 'The influence of seatback characteristics on cervical injury risk in severe rear impacts' (23) carried out by R. Burnett. This article shows that current trends in automotive seat design are heading towards stiffer and stronger seats.

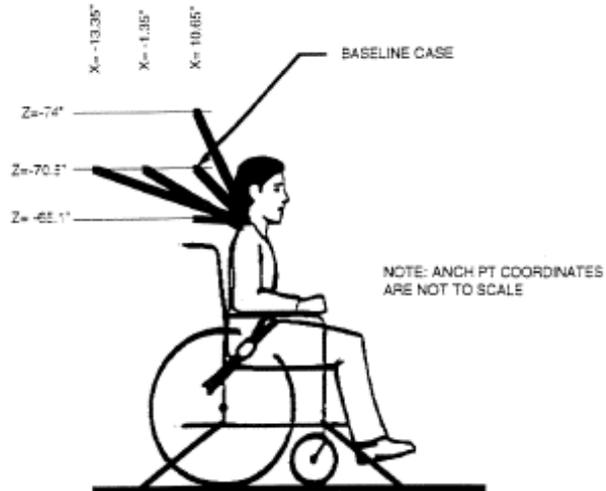
### **5.3 Seatbelt Anchorage Point Locations**

The trend with most car manufacturers today is to construct seats with the belts inclusive to them instead of being mounted to the body of the vehicle. This means that all of the loading that is going through the seatbelts is transmitted to the seats themselves rather than being applied to the shell of the vehicle. While this provides a sleeker more compact design it does mean that the seats are undergoing much higher loads during an accident (20).

When a vehicle is made capable of carrying a wheelchair, the seatbelts that provide support for the user have anchorage points on the sides, floor or roof of the vehicle. These positions are often a compromise between practicality, ease of fitting and strength of the anchorage point. In particular, it is the position of the upper anchorage point that has a large effect on how the body acts in an accident. Previous work examined the effect of differing upper anchorage points (24). This uses ISO10542 (2) which provides an approved area for the location of the upper anchorage restraint. This range of locations means that there is a varying angle in the route which the seatbelt takes across the occupant's torso. The experiment carried out will be using five different locations within the ISO10542 approved area.



**Fig 23. - Different upper anchorage locations in the frontal plane. (24)**



**Fig 24. - Different upper anchorage locations in the longitudinal plane. (24)**

For each test the deceleration profiles for the head and upper torso will be calculated and from this the Head Severity Index (HSI) Head Injury Criterion (HIC) and Chest Severity Index (CSI). These will enable the determination of the different characteristics, trend and maximum values for each upper anchorage position. From the experiment results it can be established that the further back from the occupants shoulder that the coupling between seatbelt and vehicle is, the less the chance of injury.

Reducing the angle of the seatbelt after the shoulder decreases the amount of linear and angular acceleration of the head, which in turn reduces the HIC level and severity of injury in a crash. This is because by moving the anchorage position further back, the contact between the belt and the shoulder is increased, which improves the contact between the occupant and the seat. This closely simulates the anchoring position for an integrated seat seatbelt. It means that during a collision the occupant will 'ride down the crash' at the same rate as the vehicles structure which in turn reduces the amplitude of the crash.

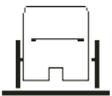
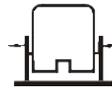
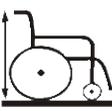
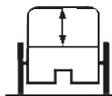
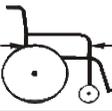
When moving the seatbelt in a direction perpendicular to the line of travel, closer towards the centre line of the passenger provides the best protection. As the anchor point is moved outwards the belt is moved more over to the edge of the shoulder, which in turns means that the belt no longer passes over the collar bone. This means that there is an increase in movement of the head during an accident. Despite the acceleration levels on the head being reduced, the increase in movement of the head also helps to reduce the peak loads on the neck and shoulder during the accident. Varying the angle of travel of the seatbelt across the torso, bringing the seatbelt up to pass closer to the neck, increases the level of acceleration of the head and the HIC level.

From this the report concludes that a seatbelt which has shallow angle over the shoulder is preferable, as it simulates the effect of a seat with integrated seatbelts as well as a shallow torso angle and a position which enables to belt to pass near the edge but not over the occupants shoulder.

## **5.4 Transport Wheelchair Sizes**

Although there is the ISO10542 (2) wheelchair which has dimensions set, in reality all wheelchairs are different in order to suit somebody's size, use or for practicality reasons. As with designing a device to suit an individual's body size, the device shall be able to fit within a range of wheelchair sizes.

Below is a table of wheelchair sizes that are currently on the market and may be used when transporting somebody in a vehicle.

		Karma KM-1500 Standard	Roma Medical Standard Car Transit Wheelchair	Sunrise Medical Breezy range	Invacare Atlas Lite	Days Healthcare Transit Wheelchair	Remploy Aurora	ISO10542 Surrogate Chair
Between Handles		395-455	380	380-600	380-480	450	380-480	405
Overall Width		620-680	620	470-790	575-685	630	468-666	698
Overall Height		870	910	900-950	890-915	910	930	1020
Seat Back		370	400	410-460	460	400	440	430
Seat Height		500	510	375-505	440-470	510	500	460
Seat Depth		410	400	410-480	420	400	390-465	520

All measurements in mm

**Table 1. – Transport Wheelchair Size Range compared with an ISO10542 wheelchair.**

As can be seen in Table 1, the ISO chair has far bigger overall dimensions than that of the normal manual wheelchairs. This could be that the ISO10542 chair is taking an average from all wheelchairs, including electric wheelchairs which are much larger than the standard manual chairs. As these electric chairs have more substantial back rests, they are better suited to take the crash loads. The manual chairs, which are smaller, are the type of chair that the back restraint device is designed for.

## **5.5 Competition Analysis**

There are a number of products in the market place that have a similar function to that of the back rest that is being designed in this project. They are produced by suppliers of floor tracking and safety tie down devices for the wheelchair accessible vehicle market. To help assess the features and functions that GM Coachwork's product has to include, a comparison of these existing products has been carried out. Each function is given a rating to be able to assess its importance.

The current products on the market place are:

- Easilok 3 (Product Number 1) from Unwin Safety Systems (26), this is a back rest support for wheelchair occupants which folds down to become a regular chair.
- Future Safe (Product Number 2) from AMF Bruns (27), which is a side mounted back and head support which folds out from the side of the vehicle.
- Millennium Removable Seat Back (Product Number 3) from NMI Safety Systems (28) which is a back rest which also acts as the rear tie downs for the wheelchair securement.



**Fig 25. - Unwin Safety Systems Easilok (26)**



**Fig 26. - AMF Bruns Future Safe (27)**



**Fig 27. - NMI Safety Systems Millennium Removable Seat Back (28)**

A table of features has been created by the between the design team by discussing what key features affected the function and usability of the products. These could then be compared to see how each device performs against the others.

No.	Feature	Product		
		Unwin	AMF	NMI
1	Weight (kg)	32	N/A	24
2	ISO10542 Tested	Yes	No	Yes
3	Tested to:	M1	M1	M2
4	3 Point Belt	Yes	Upper Only	No
5	Height Adjustable	No	Yes	No
6	Incline Adjustable	No	Yes	No
7	Fitted to tracking	Yes	Yes - Additional needed	Yes
8	Max W/C Weight (kg)	85	85	85
9	Removable to use	Yes	Yes - Twists to side	Yes
10	Behind user	Yes	Yes	Yes
11	Can act as regular seat	No	No	No

**Table 2. - Specification of Competition**

## 5.6 Competition Matrix Analysis

A matrix analysis has been carried out to compare the three competitors designs against each other. Eleven different features have been selected to compare the products against.

The initial comparison (Table 3) will compare the products against each other with each function being given the same importance. After this has been carried out, a Quality Function Deployment (QFD) comparison will be completed (Table 4). A QFD weights each function according to its importance to the design.

The Product from AMF was set as the Datum. This is the product which the others are compared directly against.

No.	Feature	Product Rating ±1		
		Unwin	AMF	NMI
1	Weight	-1	Datum	+1
2	ISO10542 Tested	+1	Datum	+1
3	Tested to M1	0	Datum	-1
4	3 Point Belt	+1	Datum	+1
5	Height Adjustable	-1	Datum	-1
6	Incline Adjustable	-1	Datum	-1
7	Fitted to tracking	+1	Datum	+1
8	Max W/C Weight	0	Datum	0
9	Can act as regular seat	+1	Datum	0
	<b>Score</b>	<b>1</b>	<b>0</b>	<b>1</b>

**Table 3. – Matrix analysis Stage 1**

The features have been chosen because they are important to the function of the product GM Coachwork are set out to design.

#### Weight – Weighting 8

As this product is being removed and installed into a vehicle it is important that the weight is below the maximum handling limit (25kg)

#### ISO10542 Tested – Weighting 10

Test criteria for the product to meet safety requirements.

#### Tested to M1 - Weighting 10

Test criteria the product must meet in order to be installed into an M1 passenger vehicle.

### 3 Point Belt – Weighting 8

To be at the equivalent safety level of an able bodied passenger travelling in a regular vehicle seat a 3 point seatbelt is important.

### Height Adjustable – Weighting 7

For increased comfort level for a wheelchair user travelling in a passenger vehicle height adjustment is preferable.

### Incline Adjustable - Weighting 7

For increased comfort level for a wheelchair user travelling in a passenger vehicle incline adjustment of the backrest is preferable.

### Fitted to tracking – Weighting 7

For fitting in the majority of wheelchair converted vehicles the back restraint should be compatible with vehicle tracking.

### Max W/C Weight – Weighting 8

To take into account electric wheelchairs and combined wheelchair and occupant weights larger than those set out in the ISO10542 the maximum weight the product can take. This is an additional selling feature for products.

### Can act as a regular seat – Weighting 1

When not in use, is the product capable of being used as an additional seat for an able bodied passenger. This is a low weighting because it is envisaged that the product is removed from the vehicle when not in use.

No.	Feature	Product Rating $\pm 1$			Weighting (1 = minimum 10 = maximum)
		Unwin	AMF	NMI	
1	Weight	-1	Datum	+1	8
2	ISO10542 Tested	+1	Datum	+1	10
3	Tested to M1	0	Datum	-1	10
4	3 Point Belt	+1	Datum	+1	8
5	Height Adjustable	-1	Datum	-1	7
6	Incline Adjustable	-1	Datum	-1	7
7	Fitted to tracking	+1	Datum	+1	7
8	Max W/C Weight	0	Datum	0	8
9	Can act as regular seat	+1	Datum	0	1
	<b>Score</b>	<b>4</b>	<b>0</b>	<b>9</b>	

**Table 4. – Matrix Analysis Stage 2 including QFD.**

From the QFD analysis (Table 4) the NMI Safety Systems Millennium Removable Seat Back is judged to be the better product on the market today. The main advantage of this is that it is tested to ISO10542 and includes a 3 point seat belt restraint. It is also capable of being fitted into the tracking that will already be in place in the vehicle. The disadvantage product is that it is not tested to M1 vehicle standards, despite this being a top weighted factor this product still came highest in the analysis. The lack of adjustability in its height and incline may also limit which users and wheelchairs are able to use it.

From looking at the results of the literature review and other products currently on the market that carry out a similar function a design brief can be created. This is to ensure that everyone knows the project is set out to achieve.

## **6. Back Restraint Design Brief and PDS Development**

This chapter is going to review the design brief and product design specification for the back restraint project.

### **6.1 Design Brief**

Peter Cullingham created the design brief with input and approval from the Chief Executive.

To design and develop a back and head rest that when installed in a vehicle will fit behind the wheelchair. It must provide extra back, neck and head protection for the wheelchair user during an accident as well as added comfort.

The design must be manageable as it is to be moved and replaced behind the wheelchair in the vehicle. For the mini bus market the people removing/fitting the device will be carers or drivers but the design must also account for the less able private WAV users. It must have a universal fitting system which will allow it to be easily installed in any vehicle. During the early stages of this product it will be aimed at the mini bus market so compatibility with the UNWIN tracking must be provided. The design must fit in with the aesthetics of the vehicle and not take up too much space when storing. There are current designs on the market that are very bulky and do not fit in with the aesthetics of the vehicles.

The restraint must be M1 classified (20) and be able to take the loads of the seatbelt anchorages as well as the rear wheelchair tie downs. It also must provide a 3 point seatbelt system.

The back and head restraint must be cushioned to give the user extra comfort. Here the different sizes and positions of people will need to be considered for

the shape of the cushioning. Also how the backrest fits to different sizes of wheelchairs. It must be designed to fit the majority of standard manual wheelchairs and possible electric wheel chairs of similar shapes.

## 6.2 Product Design Specification

To ensure that every aspect of the product was considered before any design work started a Product Design Specification (PDS) was created. This has been created using the 32 steps Pugh (creator of 'Total Design methodology) (29), which is a template of different possible aspects of the product that could be a variable or influence the design.

Not only does this ensure that as much as possible has been thought about and decided upon before the design work starts, it also helps everyone involved in the project fully understand the function of what the product has to do. This helps save time and money on designs later on in the process as they don't have to be changed because of people misinterpreting the design brief.

A PDS is an extremely useful checklist to see if design concepts comply with the original specification.

This is the PDS for the GM Coachwork Back Restraint:

### 1. Performance

- 1.1. Provide comparative protection to an M1 vehicle seat for a wheelchair occupant for front and rear collision. (Not side impact) (20)
- 1.2. To minimise the chances of whiplash
- 1.3. Make travelling in a vehicle more comfortable by providing back and head support
- 1.4. The unit must fit in behind the wheelchair and be completely removable when the wheelchair user is entering and exiting the vehicle

- 1.5. To fit into Unwin (26) rails (Most common 330mm apart) range of 270-350mm including bespoke design
  - 1.6. To be within Unwin (26) Innotrax max loadings
  - 1.7. Can not be installed incorrectly in the vehicle
  - 1.8. Must be removable and have the ability to be stored neatly out of the way in the vehicle when not in use
  - 1.9. When installed in the vehicle whether it's in or use or not there must not be any squeaks and rattles.
2. Environment
    - 2.1. Corrosion resistant to maintain car manufacturers warranty or cover the life of Motability contract
    - 2.2. Drop / Fall over proof. No fragile items that may fall off when hit
3. Life in Service (Performance)
    - 3.1. To be able to be removed and replaced by an elderly person (70 year old arthritic lady) when wheel chair is in position
    - 3.2. Behave as an M1 vehicle seat in accidents
    - 3.3. Give comfort levels of an M1 seat in the form of a back and head restraint
4. Maintenance
    - 4.1. No different to seatbelt and wheelchair tie down checks
5. Target Production Cost
    - 5.1. £600-£850 (Inc wheelchair tie downs and seatbelt)
6. Competition
    - 6.1. Unwin Easilok 3 (26)
    - 6.2. AMF Back and Headrest Restraint (27)
    - 6.3. NMI Backrest (28)

*See Competition Matrix*
7. Shipping
    - 7.1. Sold with vehicle
    - 7.2. After sold items
8. Packing
    - 8.1. Sold with vehicle

8.2. Must be shippable

9. Quantity

9.1. GM Coachwork's own vehicles – 200 per annum

9.2. Other manufacturer's vehicles – potential 1800 per annum

10. Manufacturing facility

10.1. Subcontracted to manufacturer to produce

10.2. Possibly assembled at GM Coachwork

10.3. Design rights sold to other company

11. Size

11.1. To fit a range of wheel chair sizes (5 percentile to 95 percentile)

11.2. Tested with ISO10542 surrogate wheelchair

12. Weight

12.1. Ideally  $\approx$  15kg

12.2. Max Limit 25kg (Manual handling weight limit)

13. Aesthetics

13.1. Fit in with vehicle aesthetics (similar looks to child seats, pushchairs and bicycles)

14. Materials

14.1. Standard engineering materials

15. Product Life Span

15.1. 5 years – Length of Motability contract

16. Standards and specification

16.1. ISO10542 (2) - Wheelchair tie down and restraints

16.2. M1 Class Seat

16.3. European Classification (20)

16.4. ISO7176 Part 5 - Wheel chair size standard

16.5. ISO7176 Part 19 - Wheel chair standard for use in motor vehicles

16.6. Comply to Motability and WAVCA standards

17. Ergonomics

17.1. Secure into the vehicle to ensure there are no squeaks or rattles

17.2. Provide the comfort levels of an M1 seat

17.3. Easy to use for elderly user

17.4. No longer than current wheelchair tie downs and seat restraints

18. Customer

18.1. Mini bus services – hospitals, nursing homes, schools

18.2. Wheelchair Accessible Vehicles

19. Quality and Reliability

19.1. High quality, no squeaks or rattles over time

19.2. Linkages to be reliable over time

19.3. Can not be installed incorrectly in the vehicle

20. Shelf Life

N/A

21. Processes

N/A

22. Time-Scales

22.1. Retail launch May 2010

23. Testing

23.1. To correspond with GM new production model testing program

23.2. Wheelchair/Seatbelt anchorage points to be tested to ISO10542

23.3. M1 Vehicle Testing. Head rest impact test, adjusting mechanism  
pull

24. Safety

24.1. Comply To M1 vehicle seat regulations (20)

24.2. No protruding sharp edges

24.3. All edges must have a minimum radius of 3.5mm

24.4. After forces tested there must be no sharp edges

25. Company Constraints

25.1. Must not effect other projects/staffs workloads

26. Market Constraints

N/A

27. Patents, Literature and Product Data

27.1. Design to have some intellectual property protection.

27.2. Be aware of AMF product holds existing patent

28. Political and Social Implications

28.1. Prompt Motability/WAVCA to create a regulation enforcing back  
and head support for wheelchair users.

- 28.2. Product should create an awareness in the market and the need for something that provides whiplash protection

#### 29. Legal

- 29.1. Conform to M1 seating regulations
- 29.2. ISO10542 (2)
- 29.3. Type Approval as a M1 Seat (including belts) (20)
- 29.4. Define as Seat or Wheelchair Restraint – Depends on type approval or testing requirements

#### 30. Installation

- 30.1. Full guide to installation produced
- 30.2. Must be suitable for elderly users

#### 31. Documentation

- 31.1. Proof of testing required
- 31.2. Full project documentation, development and production books in order to conform to ISO9001
- 31.3. Final product must include user manual

#### 32. Disposal

- 32.1. Must conform to end of vehicle life (EVL) standards

David Vooght

Chief Executive – GM Coachwork

Signed off: 15/10/2009

The PDS was circulated amongst members of the design team which includes 3 engineers, 2 sales men and the company Chief Executive, to ensure that it is specific enough and that everyone understands it. The head of the project then signs it off and this is dated and set. In the case of this project it was signed off by the Chief Executive.

This PDS went through three different iterations during its development. Some of the specific functions of the product needed to be set as the initial statements were too general. An example of this is specifying the user that would be handling this device. Originally the PDS stated that it should be 'easy to remove and replace in the vehicle' without stating who it must be

easy for. The addition of a user was then added so it read 'To be able to be removed and replaced by an elderly person (70 year old arthritic lady) when wheel chair is in position.' (PDS Point 3.1)

An example of how the PDS influences the design is the adaptability of the design to suit different widths of the Unwin (26) vehicle tracking. There is a common size which the majority of seats are set up to (330mm) but there are also a number of other combinations that the product must be able to adapt to. To account for this the PDS states that the product must fit a range of sizes. (270-350mm PDS Point 1.5)

The engineers at GM Coachwork have vast experience in using box, tube and sheet metals from which the components for the current vehicle conversions and additional products are constructed. The workshop facilities are well equipped to produce components made up from these materials. The CEO did not want to restrict the design of the back restraint to these traditional materials. For this reason the PDS did not state a specific material.

The PDS is a key part in the evaluation of the design concepts while they are being developed. It will be a constant point of referral to ensure that that design is meeting the correct criteria and it is not going away from the original intended function. It will become a benchmark to compare different designs against.

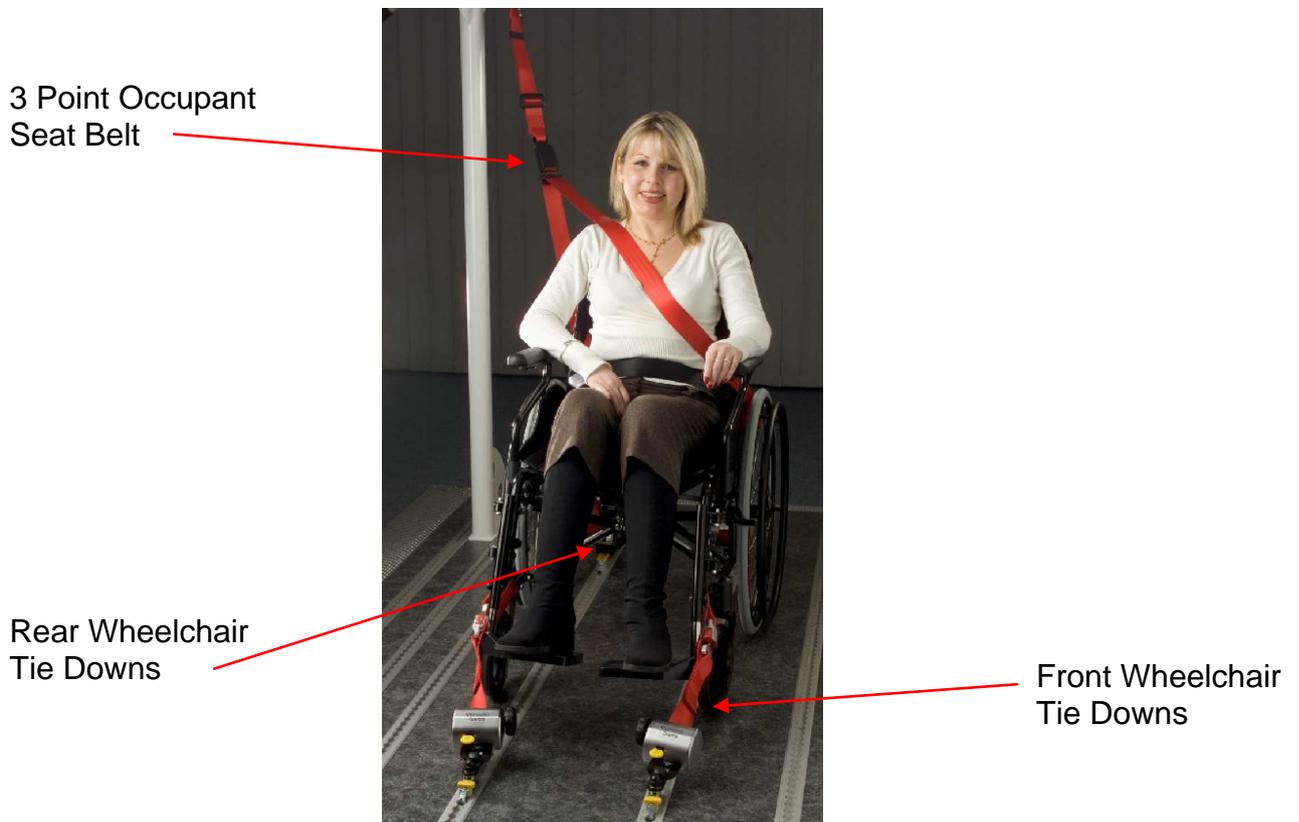
This is a newly introduced technique to the design process at GM Coachwork. Whilst it took a number of permutations to produce the above article it forced the design team to think clearly about each aspect of the product, forcing into consideration some parts of the product life cycle that would previously not be considered until it was ready to market. For example, product life span and environmental disposal considerations.

Examples of this are maintenance considerations, storage when in use or not in the vehicle, aesthetics and product life span.

Since creating a PDS for this product, a number of other design projects have been completed and have used this technique before any parts were designed. A GANTT chart specifying timescales for each major part of the design process (see Appendix 4) was also used for the first time in the company for this project and has since been applied to other projects.

## 7. Back Restraint Design Concepts

The aim was to develop a number of different design concepts and the first stage was to set the constraints of the design, namely the geometry of points that needed to be connected. The physical dimensions were dictated by the anthropometric data and wheelchair sizes reviewed in the previous chapter and the fixings to the floor of the vehicle, occupant restraints which includes the upper anchorage point and two lower anchorage points and the rear wheelchair tie downs.



**Figure 28. – Occupant using the 3 point seat belt and wheelchair tie down straps (26)**

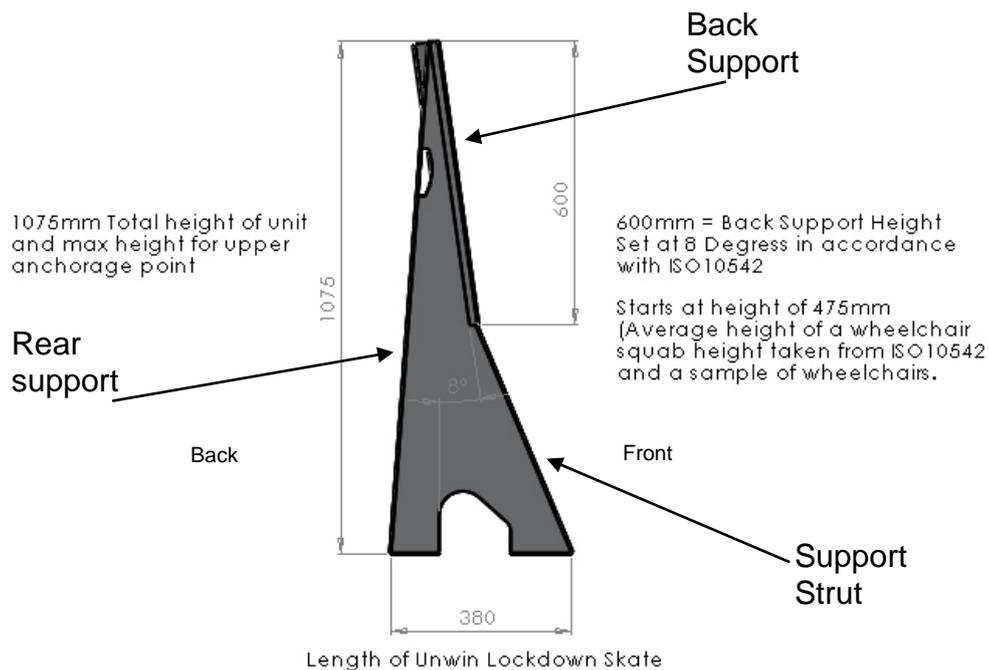
Once these points were established a structure had to be produced that could tie all of these points together.

The approach for producing designs was to take into consideration different materials and manufacturing techniques and attempt to produce different designs which made use of these.

The initial model of each concept was created on the CAD software in order to clearly demonstrate what the concept was aiming to achieve. This was a benefit of the software that it portrayed a clear image of the concept to all members of the design team before any materials had been used to produce physical mock-ups. It was a new process to GM Coachwork and allowed staff to see the benefit of being able to follow up ideas that would not normally be developed due to time and material constraints.

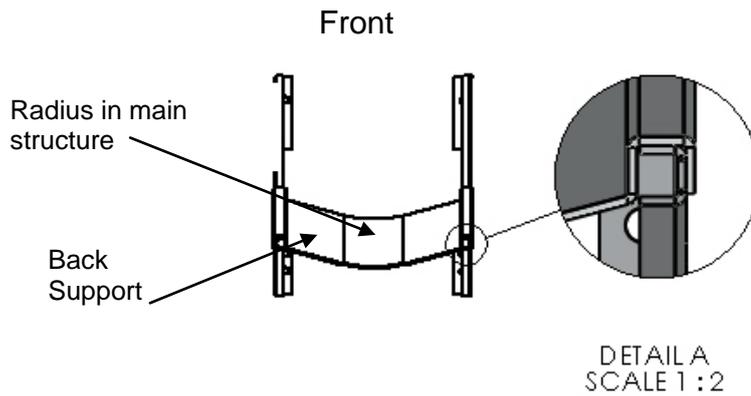
## 7.1 Concept 1 (Sheet Aluminium Concept)

The first concept idea was constructed out of sheet metal. Aluminium was initially chosen in the interest of reducing the weight as much as possible. Different techniques were used to make up the strength difference between aluminium and steel in the design and shape of the model.



**Fig 29. - Dimensions of Concept 1 (Sheet Aluminium Concept)**

The total structure height will be 1075mm, this is taking into account the overall back support dimensions and seat squab height of a range of wheelchairs used for transportation in vehicles as well as the ISO10542 surrogate wheelchair.

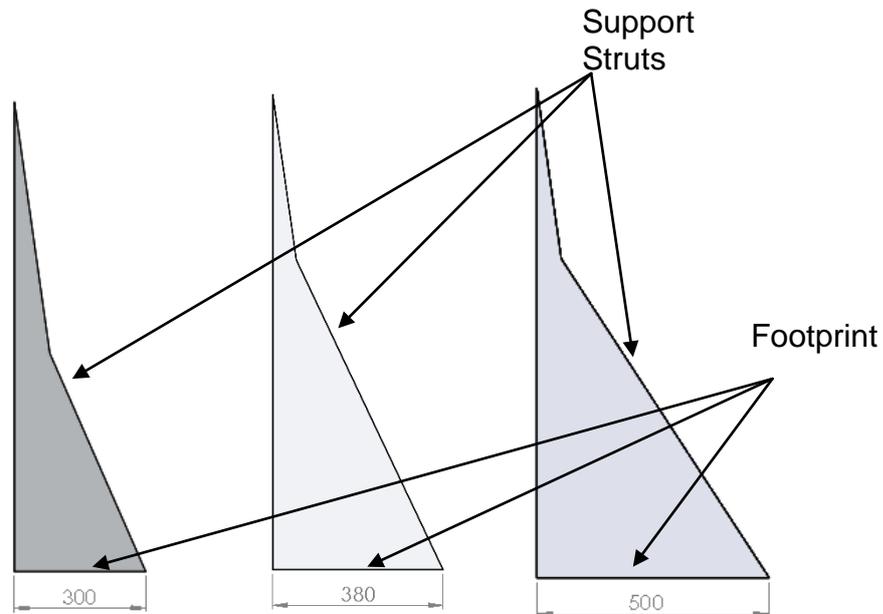


**Fig 30. - Top View of Sheet Aluminium Concept**

As can be seen in Figure 30 the main structure of the back support has a radius, not only is this intended to provide extra comfort for the user, it allows the restraint to get closer to their back and against the wheelchair. It also provides extra strength that a flat support would not.

The close up in Detail A (Figure 30) illustrates an attempt to increase the strength into the main beam support beams of both side panels and the back support component. This is done by including extra folds in the joint of the two components to increase the rigidity of the structure.

The 'foot print' of the structure is currently set as it is designed to be attached to the Unwin tracking in the vehicle using the Unwin lockdown skates. These are set at a length of 380mm. This current design could benefit from a longer foot print that would stretch further under the wheelchair utilising the 'dead space' that is under there. There is also the structural leg that comes up at the front of the design. This meets the 8° angle of the back support and extends down.



**Figure 31. – Labelled image of different ‘footprints’**

There is a possibility of a large area of concentrated stress around this area and as it is there is already a bend in it which means it is the most likely place that the structure will buckle. By raising the height of this support leg the load is decreased and reduces the chance of failure in this area. An FEA study was undertaken to investigate the effect of changing the support angle and footprint length.

### **7.1.1 Sheet Metal FEA**

A number of FEA studies were carried out on the design concepts to see how the designs perform under the full test loading. The first test was carried out on the initial sheet metal design.

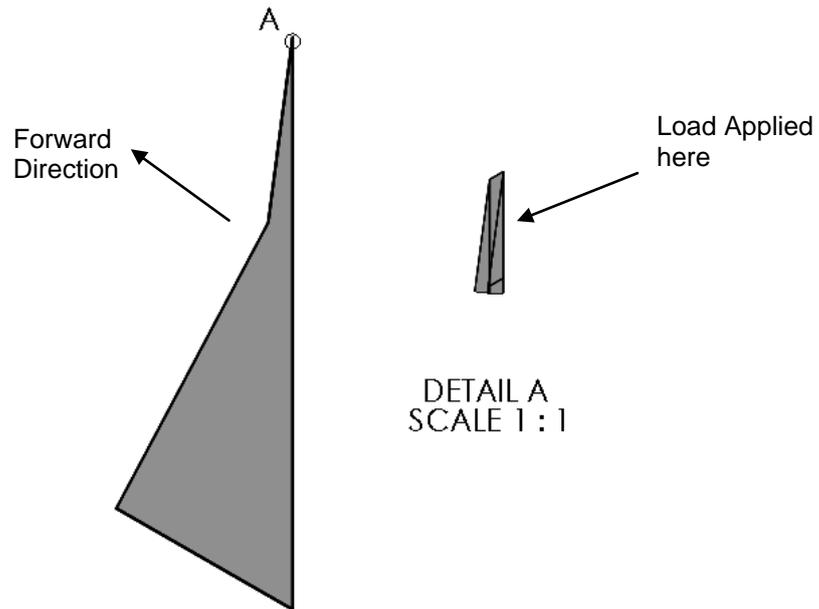
In order to run multiple tests in a short time frame, an initial 2D FEA investigation has been carried out to see the effect of the support height and see which layout is the best compromise that does not interfere with the back support for the wheelchair user. The test also includes different ‘foot print’ sizes to see which the optimum size to be using is.

A Design Table (Table 5) was produced to speed up the modelling of the different components. Three different foot print sizes (300, 380 and 500mm) and different support beam heights (Ranging from 300 – 1075mm) will be used for the analysis.

<b>Design Name</b>	<b>Support Height</b>	<b>Base Length</b>	<b>Thickness</b>
300a	500	300	3
300b	600	300	3
300c	700	300	3
300d	800	300	3
300e	900	300	3
300f	400	300	3
300g	300	300	3
380a	500	380	3
380b	600	380	3
380c	700	380	3
380d	800	380	3
380e	900	380	3
380f	400	380	3
380g	300	380	3
500a	500	500	3
500b	600	500	3
500c	700	500	3
500d	800	500	3
500e	900	500	3
500f	400	500	3
500g	300	500	3

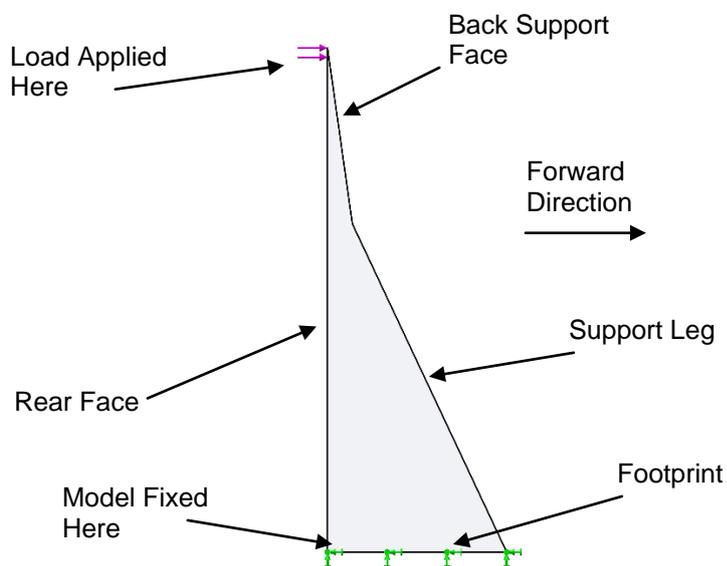
**Table 5 - Design Table of different models and varying dimensions (mm)**

The models were all produced in 3mm thick 1350 Aluminium Alloy, restrained in all dimensions along the bottom face which ran the entire length of the components.



**Fig 32. - Location of loading point for FEA study**

There is a 20mm pad at the top of the vertical edge of the component where a load of 60N was applied in the horizontal forward dimension.



**Fig 33. - Fixture and Loading positions on Model 380d**

The loading is much lower than the completed structure has to cope with for a number of reasons. Firstly this is only a 2 dimensional model so it has not got the width in order to dissipate the forces over. In addition, some of the

simulations for the lower support angles (300mm) can not run a higher loading because the deflection that occurs is larger than the software is designed to simulate. This is due to limitations in the software. It is designed for small deflections and to pick up stress levels rather than large deformation failures. If the study was to be carried out on a more advanced FEA package then the force could be increased. To illustrate the effects had by adjusting these dimensions a lower force is sufficient. Because of this some of the deflections and stresses in the more supportive structures are very small, this was necessary in order to produce a direct comparison. A value 60N has been established through trial and error as it is the largest force value the small foot print, low support angle model simulation will run at.

<b>Design Name</b>	<b>Displacement (mm)</b>	<b>Von Mises Stress (N/m<sup>2</sup>)</b>
300a	4.451	1.70E+08
300b	4.285	1.66E+08
300c	4.063	1.65E+08
300d	3.761	1.63E+08
300e	3.311	1.61E+08
300f	4.552	1.71E+08
300g	4.682	1.69E+08
300h	0.665	4.15E+07
380a	4.368	1.63E+08
380b	4.155	1.61E+08
380c	3.874	1.57E+08
380d	3.543	1.54E+08
380e	3.052	1.51E+08
380f	4.541	1.66E+08
380g	4.682	1.70E+08
380h	0.342	2.71E+07
500a	4.248	1.54E+08
500b	3.994	1.45E+08
500c	3.711	1.44E+08
500d	3.339	1.45E+08
500e	2.992	1.58E+08
500f	4.470	1.61E+08
500g	4.654	1.64E+08
500h	0.162	1.77E+07

**Table 6 - Results from 2D FEA of Sheel Aluminium Concept**

These results were then compared to see how the deflection and stresses in the model vary with different geometries. The following graphs illustrate this and from these the most suitable support strut height can be chosen.

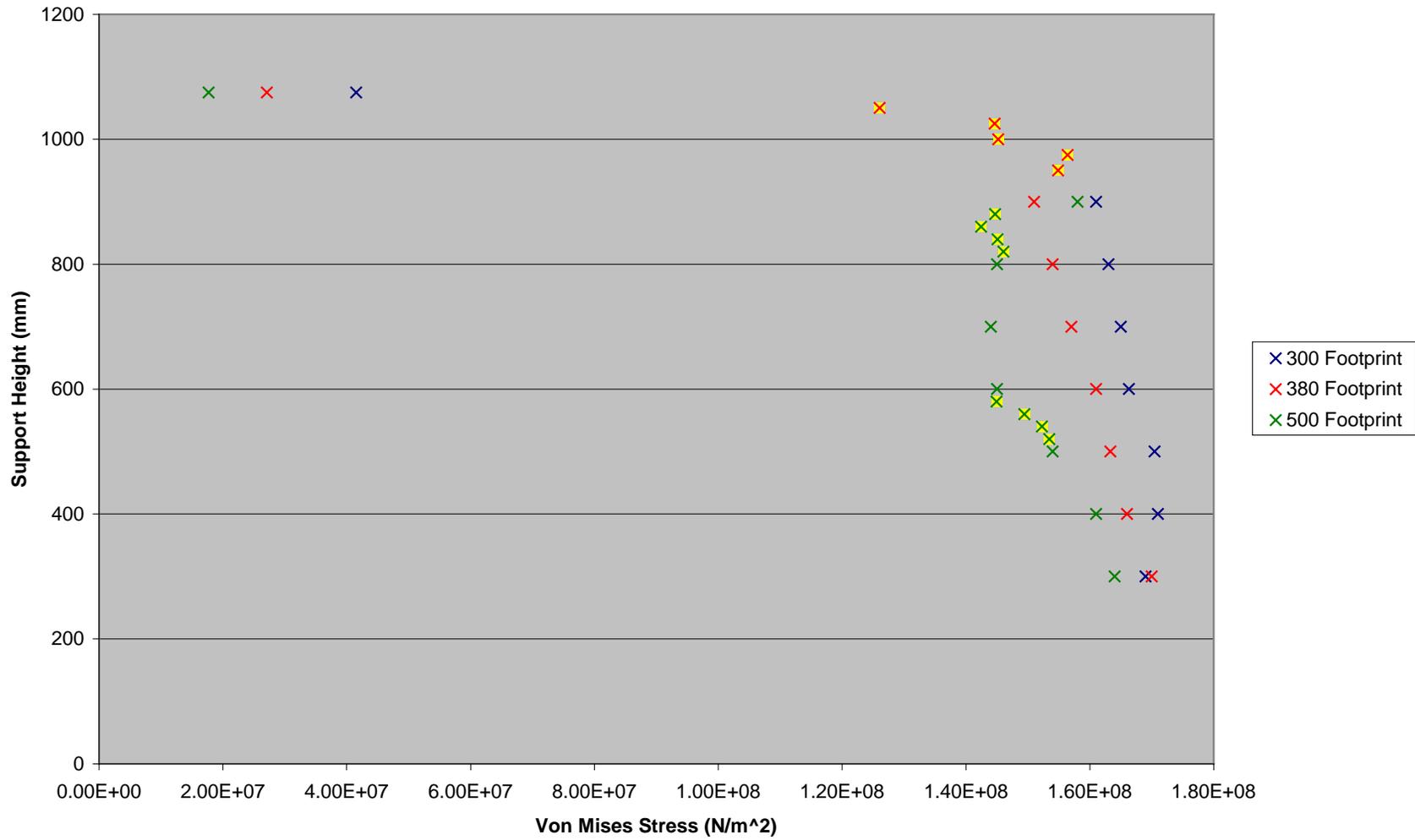


Figure 34. - Total Stress of the side panel with varying height of support leg

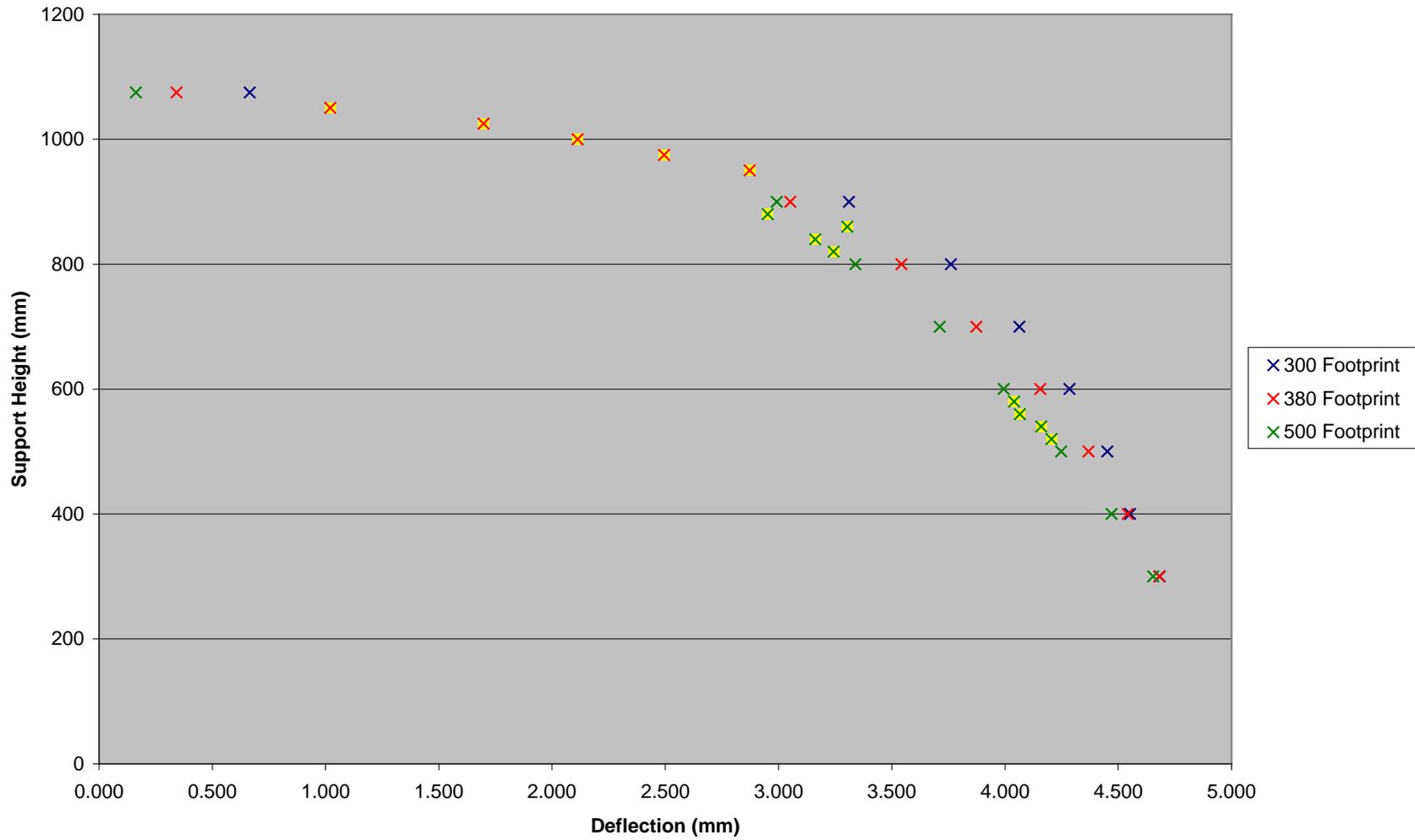


Figure 35. - Total Deflection of the side panel with varying height of support leg

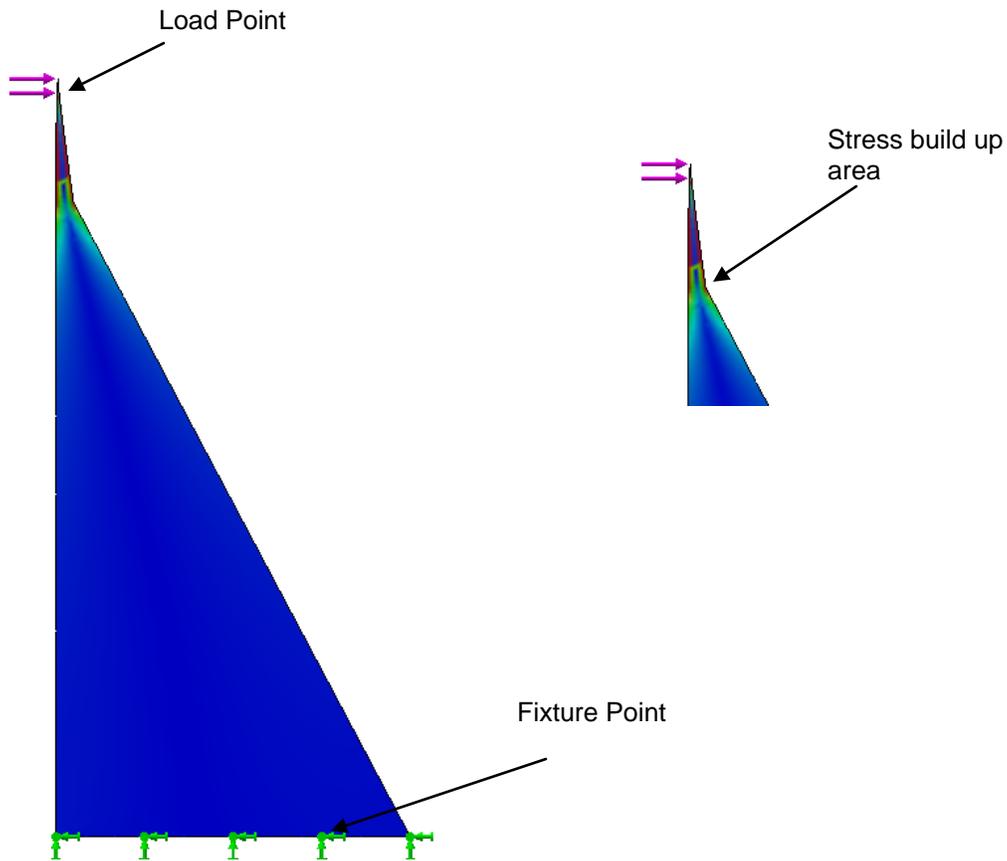
The graphs (Figures 34 and 35) show that as soon as the support strut is moved from the top most position there is a rapid increase in deflection and stress in the model. Due to this sudden increase in the deflection and stresses, further iterations of the 380mm model were carried out in order to fill in the gaps in the results and check that there is a continuous trend to the results. The results of the extra simulations (Figures 34 and 35) confirmed that there was a steady increase in deflection and stress as the support strut angle was lowered from the topmost position.

Between the support heights of 1070mm and 1000mm there is an initial increase in deflection of approximately 2mm on each footprint size, after this the stress and deflections rate of increase reduces as the support height gets lower. Due to the position of the wheelchair seat squab (the horizontal part of a seat that the user sits on) the practical support strut height is approximately 500mm. (Figure A1.1 Dimensions of the surrogate test wheelchair.) This gives a deflection of 4.5mm at the upper anchorage point. Even by raising this up to 800mm there is only a saving of 1mm on deflection. But doing this would increase the material needed for the structure and increase its weight and manoeuvrability.

The difference in foot print size also reduced as the support beam height was lowered. See Figures 34 and 35. When it is reduced down to 300mm there is minimal difference in the 3 different lengths. Overall the increased foot print of 500mm does reduce deflection and stresses in the model. As expected, the trend in the graphs is that the difference in von Mises stress and the amount of deflection is greater when the support height is higher up on the model. At its highest point (1075mm) the range of the deflection values is 0.513mm whereas at the lowest support height position (300mm) the difference in deflection is only 0.028mm. The trend is also apparent in the stress levels with the differences being  $2.38e7 \text{ N/m}^2$  at the highest support height and  $5.0e6 \text{ N/m}^2$ .

On the 500mm foot base, as the support height increases to the top most positions the overall stress of the model increases. The stresses around the support beam joint build

up. In the case of models with an 900mm and 800mm support height, the stresses at this point are higher than those on the point where the load was applied.



**Figure 36. – Stress build up around support height angle**

Footprint 500mm, support height 900mm shows a change in trend in the graph where the von Mises stress is higher than that of the 380mm footprint model of the same support height. The difference in deflection is also less significant than in other lower support height models. This is caused by the build up of stresses around the joint of the support beam and the 8° angle of the back board section.

As can be seen in the results in figures (Figures 34 and 35) of the analysis the strongest structure is a complete triangle with the support leg going up all the way to the upper anchorage point. As this is not possible due to space restrictions, the required length and angle of the back support and the push for the restraint to tuck in under the

wheelchair a compromise must be come to as to what height the support is going to go to.

The results have made it clear that the ideal position for the support strut to go up to is the very top of the structure. The only way this can be achieved is by having the struts go out behind the wheelchair instead of fitting in under the chair and the 8° angle of the back support should continue down to the base of the unit.

This led to a key design decision being made for the sheet metal design as can be seen in the 2nd sheet metal mock up (Concept 2, Figure 40) that has had a folding mechanism incorporated.

As this was the first design concept and it is using a material and production methods that are familiar to GM Coachwork a 'mock up' was produced. The dimensions of this were taken from standard wheelchair sizes which dictated the height of the support

height, back board height and width of the design. This was to give an idea of how easy to use the design would be, whether it was able to carry out its designed function and where different attachments would be included to the design.



**Fig 37. - Sheet aluminium concept mock up**

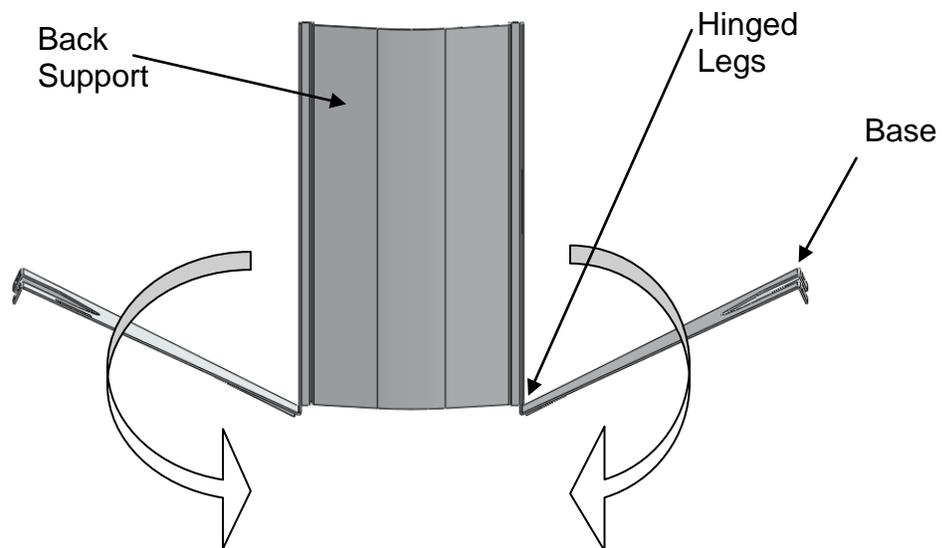
By handling the mock up, fitting it against a wheelchair and moving in and out of a vehicle it was apparent there were a few parts of the design that would need refining and changing.

At a weight of 5.2kg before any fixing skates, seatbelts or wheelchair restraints were added it was felt by all members of the design team that there was some weight to be saved.

There are large areas where material could be removed in order to reduce the weight. Examples of this can be seen in Figure 39.

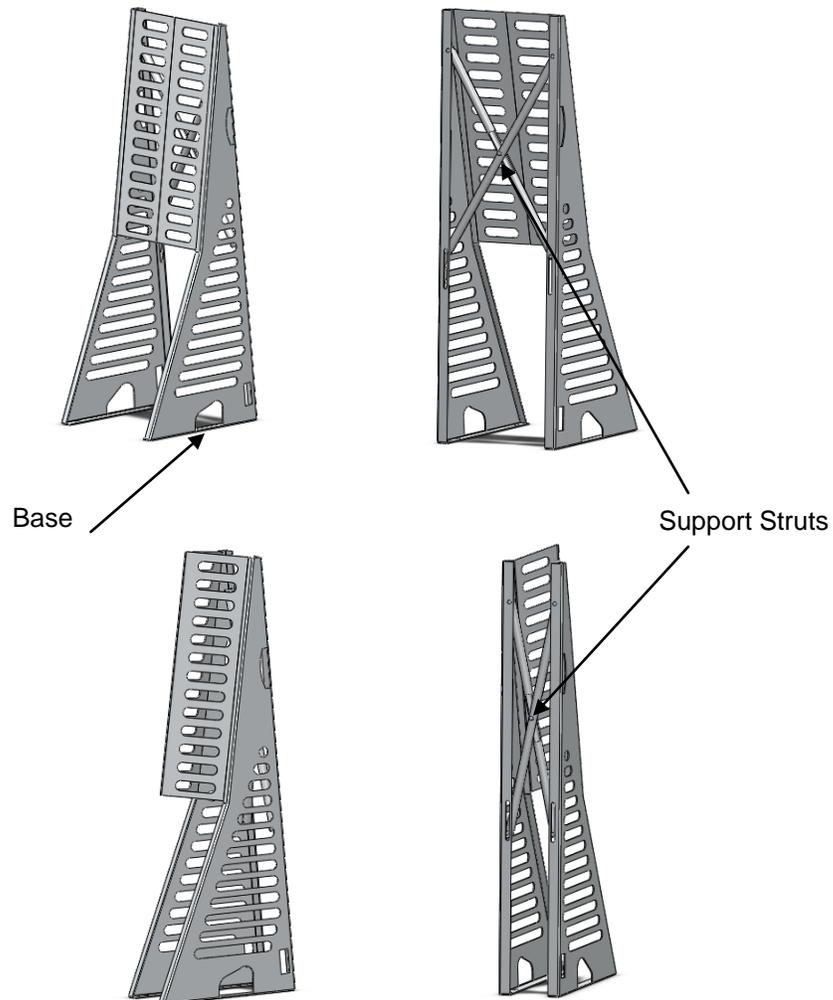
## 7.2 Concept 2 (Folded Sheet Aluminium Concept)

The need for the design to fold away or reduce in size to enable it to be stored when not in use (PDS Point 1.8) was required to be incorporated into the design. There are a number of locations in which this could be incorporated into the design. The most obvious was at the structures legs. If these could fold up to become part of the back support structure then it would nearly halve the product in size and make it much easier to store when not in use.



**Fig 38. - Sheet metal with horizontal hinges on legs.**

Another solution was to create a fold in the back support structure so that the product folds vertically. CAD models of a solution were produced (Figure 39 below) to provide an illustration of how the product would fold. Holes were added to the design in order to show how weight saving could be achieved. A more efficient way of carrying this out would have to be carried out to see whether the shape and direction of these could be refined to maximise weight loss without compromising on the structures strength.



**Fig 39. - CAD model of the development of the folded aluminium back restraint**

As the back support structure now has a hinge in the centre of it there is nothing to support it horizontally; it has become loose at the top. Support struts (Figure 39) have been added along the back part face of the structure to provide the extra support that will be needed. This design has the ability to fold up to a very thin structure. Having the fold going in this direction also enables the design to fit a lot of different tracking widths. This allows the design to be able to adapt to individual vehicles track set up.

A mock up the folding design was produced and the advantages of being able to fold up completely soon became clear. This means that when the restraint is not being used, it can be stored out of the way and not take up the same amount of space that it does

when in use. This is even more advantageous when carrying multiple restraints, as in the case of the minibuses.

As can be seen in Figure 40 the panels that rest up against the back of the wheelchair have had corrugations added to them in order to increase the stiffness of the panels without increasing the weight of the structure.



**Fig 40. – Concept 2 (Folded Sheet Aluminium Back Restraint)**

The physical mock up exposed an additional problem with the folding device. It was difficult to deploy and ensure that the skates were kept even in the tracks. This means that there is a larger chance of error when setting up the device which could lead to uneven loading on the restraint causing the occupant belt to behave in an unpredictable way.

### 7.3 Concept 3 ('Suitcase' Back Restraint Concept)

The need for the design to fold up so it was able to be stored neatly to the side of the vehicle or in a user's house or garage was the idea that led to this design.

The main framework of this concept follows closely to the sheet aluminium concept. It has the same forward support strut heights. In this design the rear face is working vertically. This is a disadvantage as the standard wheelchair dimensions state the back rest angle is approximately 8°. When not in use the back restraint will completely fold away leaving only something the side of the back support frame. (600 x 360 x 50(mm)).

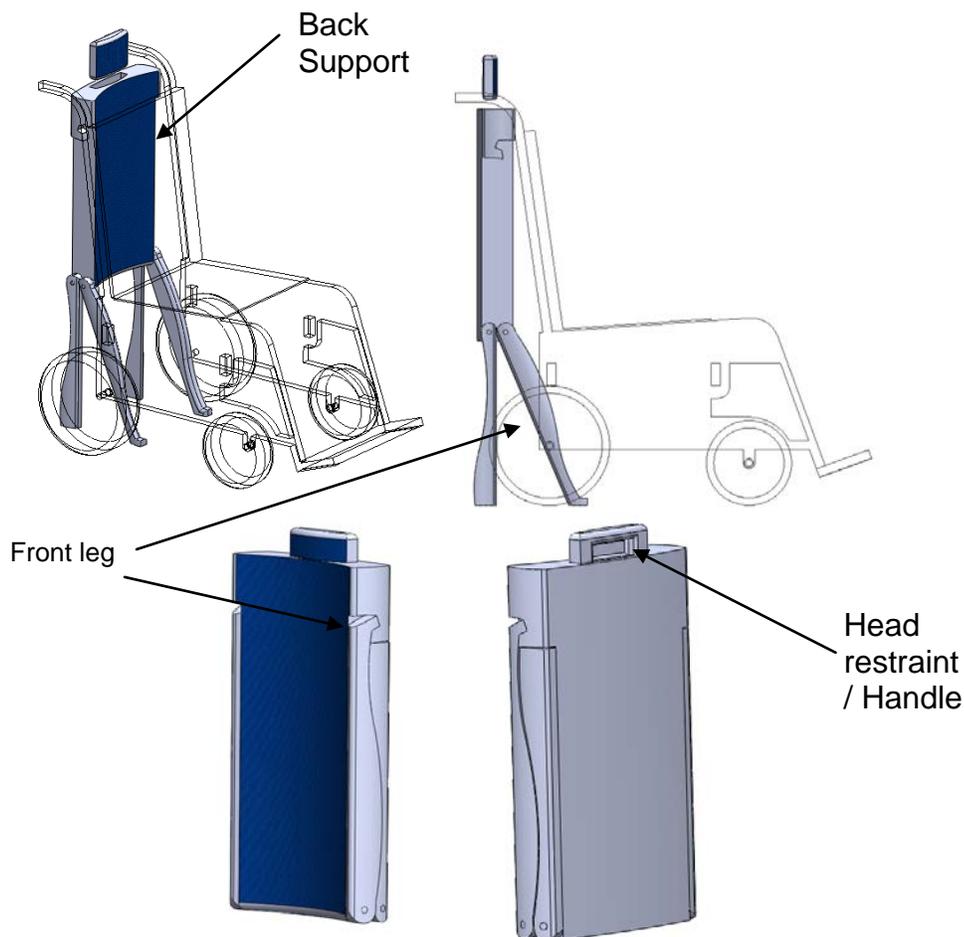


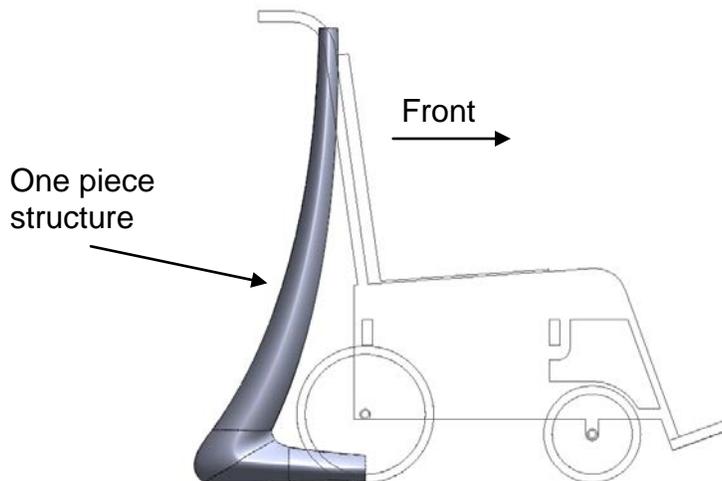
Fig 41. – Concept 3 (Suitcase Back Restraint Concept)

The front leg of the device pivots forward from the hinge position, then position itself in the back board structure. The fixing skate then pivots up from the end of the back leg which will slide up inside the back support structure. The head rest folds down into the support leaving a small handle moulding free to either carry away or wheel using the wheels that are attached to the fixing skates.

The structure of the back support would have a metal framework that lies beneath a plastic moulded covering that conceals it all and provides the product with aesthetic appeal. This structure will have to be lightweight (PDS Point 12.1.) and strong enough to take to loadings involved. The hinging area around the legs is a big concern as there is force of 12.5kN being applied from the upper anchorage point (20) that will focus around this area.

## 7.4 Concept 4 (Composite Model)

When the initial solutions for this product were being considered the chief executive, who has overall design authority over the project, had been shown the advantages of using composite material for its weight saving and high strength properties. It soon became a push to investigate this material and to include it in the design.



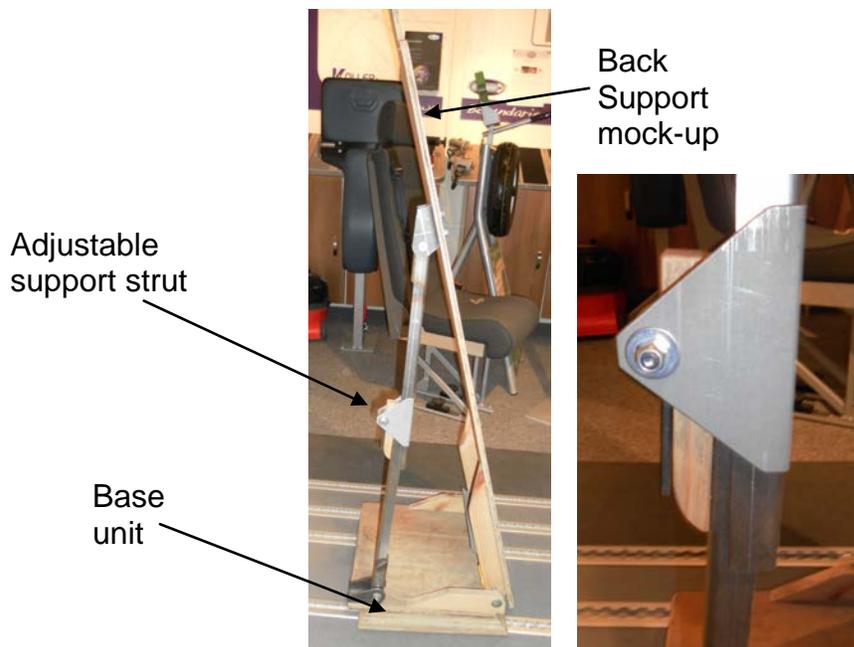
**Fig 42. - Initial CAD images of an entirely composite model**

After initial discussions with the Managing Director of GM Coachwork, a brief shape was developed to work towards. This had the curved shape that was considered by the sales staff at GM Coachwork to have a great market appeal and progressed from the straight edges and angles of the sheet metal designs. This shape was essentially cheap to manufacture in a single piece unit with a foam core. The layers and direction of the carbon fibre sheets would have to be calculated further into the design process in order to ensure the structure was capable of taking the loads involved in the crash test.

As GM Coachwork had no experience designing or manufacturing carbon fibre components, Carbonyte, a bespoke vehicle and carbon fibre specialist, was brought in at this stage of the design process in order to advise in the designing of and possibly manufacture the restraint.

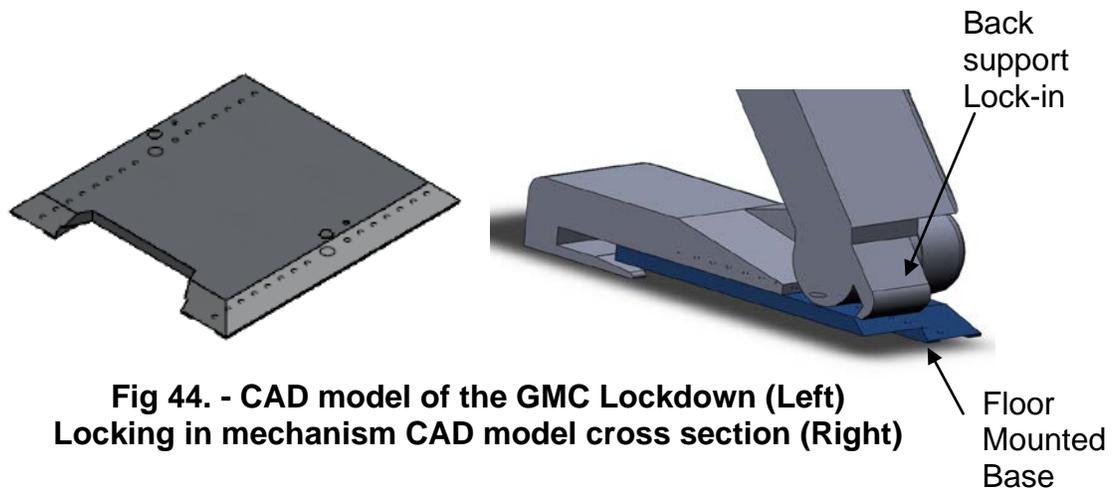
The initial carbon fibre design concepts were shown to Carbonyte along with the PDS and examples of the fixings that would have to be used. The design was then modified to suit the manufacturing requirements and to suit the function of the PDS. Regular meetings and conversations were held with CAD models being exchanged to incorporate the changes that were made to the original sketches.

The design team at GM Coachwork reviewed the PDS and concluded that the design of the back restraint had to differ from the original composite sketches. An essential part of the design is its ability to fold down and reduce in size for storage purposes (PDS Point 1.8). This resulted in the main composite body of the restraint being split into two pieces and a hinging mechanism added to it. This hinging mechanism had to be adjustable in order to provide different back angles. This and the addition of the seat belt attachment points had to be considered and the positions decided upon in the design of the composite body as it could not be changed afterwards due to moulds being produced as part of the manufacturing process.



**Fig 43. - A mock up of the composite restraint (left) and close up on the adjusting mechanism latch (right)**

The interface with the vehicle flooring is also an issue with this design. To remove the need for skates an additional lockdown system was being worked on that could be combined with the back restraint. This consisted of a locator slot at the rear of the base unit and a movable front lip (Figure 44 Right) that, when the back rest was put in position and raised to the correct angle, clamped onto the front of the lock down holding it in place during the rebound crash forces.



The addition of these components increased the cost of the device further. The lockdown unit alone would cost approximately £130 per unit (as quoted by a local manufacturer). This is a price for a sand cast base with the holes machined in afterwards. The price of a 100% machined component was also received but a sand cast component was 15% cheaper. The mechanical fixings also increased the weight of the structure by 4kg, negating the advantages of using carbon fibre. In a vehicle impact the forces would travel through the mechanical components making up the folding and adjusting mechanism. As these components will be taking the majority of the force the need for using the strength of the carbon fibre to increase strength of the back board is reduced. Additionally, a joint between metallic and composite materials is going to introduce areas of high stress around in these areas.



**Fig 45. - Mock up of the composite model with mechanical fixing and lock down mechanism in place**

The addition of mechanical parts to the composite model made the design of the composite components more complicated which increased the cost to manufacture these parts. This brought the costs up to approximately £600 for the composite parts alone (Price estimate provided by Carbynte). When the PDS states that the retail price is targeted at a maximum of £850 (PDS Section 5) this does not leave enough mark up for GM Coachwork, which has a maximum targeted retail price of £1000. It became clear that, while lightweight solution could be produced using composite material it would be at a cost that the market could not withstand. It is also a design that GM Coachwork would be able to produce themselves without relying on another companies manufacturing facilities. While this is not a problem it has to be ensured that steps can

Peter Cullingham

be taken to ensure there will not be delays with meeting orders and consistency in manufacturing.

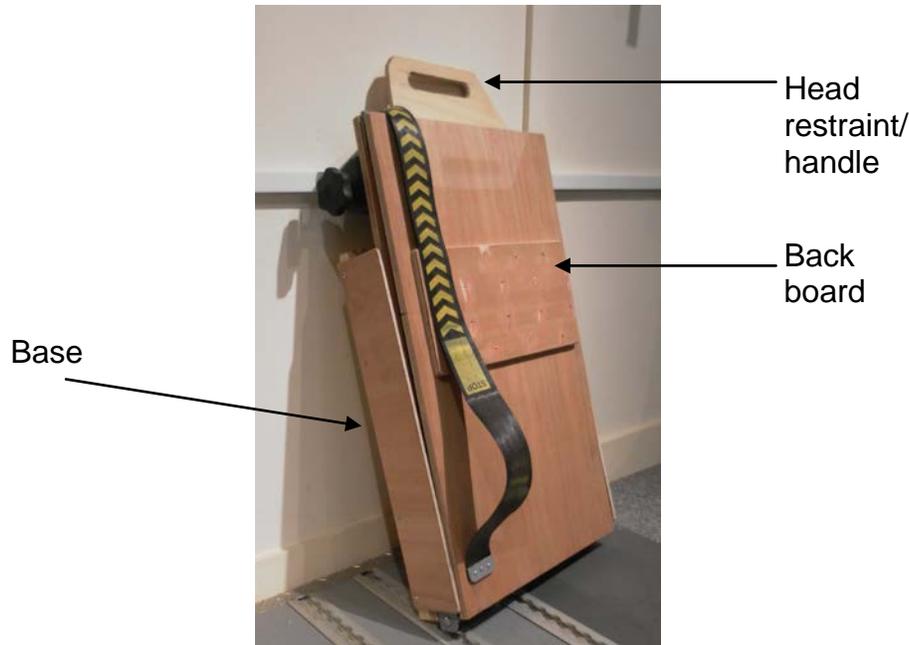
## 7.5 Concept 5 (Webbing Folding Design)

Reducing the strength in the design while keeping the weight as low as possible was the idea behind this solution. The webbing used in seat belts has already been tested to be able to take the loads involved in the crash test as they are already being used to restrain the occupant. The webbing was used as the support straps, running from the top of the back restraint, where the upper anchorage point is, to the back of the base unit. There are two of these support straps, due to limitations on material the mock up pictured below (Figure 46) only uses one. This would then take the main loadings of the crash test. The whole structure will be able to fold down to a portable unit with a carrying handle to aid carrying and movement of the restraint. When in the unfolded position the structure can be fixed in place by another belt around the front of the restraint that tightened using a ratchet mechanism. This would also be in place to take the rebound crash loads.



**Fig 46. – Concept 5 (Webbing folding design) in its deployed position**

The main body of the restraint would have to deal with compressive forces during the test as the support strap tries to reduce the angle between itself and the vehicle floor. In order to keep the structure as light weight as possible, a metal tubular framework has been designed that will be filled in with a light weight foam/polymer sandwiched sheet. This acts as a stiffener to help prevent the structure from twisting as the uneven load of the upper anchorage point is applied to one side.



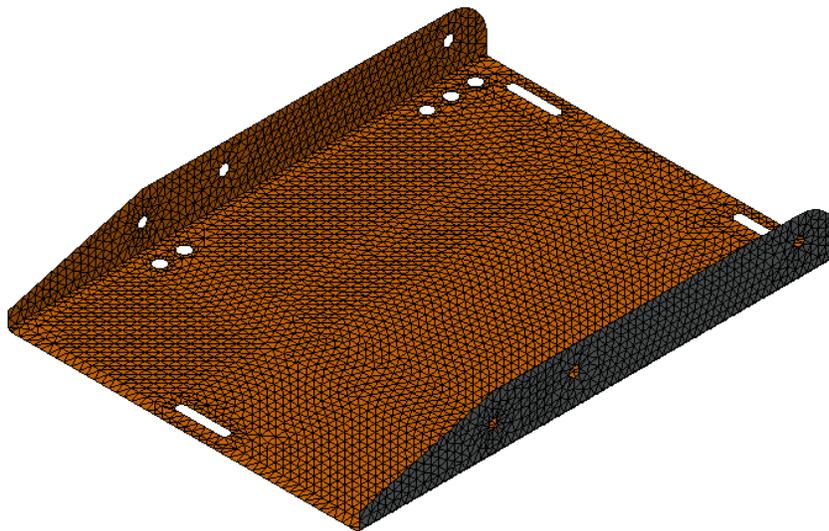
**Fig 47. – Concept 5 (webbing folding design) in its folded state**

### **7.5.1 Base Unit FEA for the Webbing Concept**

As the base unit of this design had all of the load taking straps attached to it, the inertia reel, lower anchorage points and rear wheelchair tie down straps, it was essential that it is able to withstand the loads that would be inflicted on it during the crash test (20). For the benefit of the user and to make it easy to use it must be light enough to place in position behind the wheelchair (PDS Point 12.1).

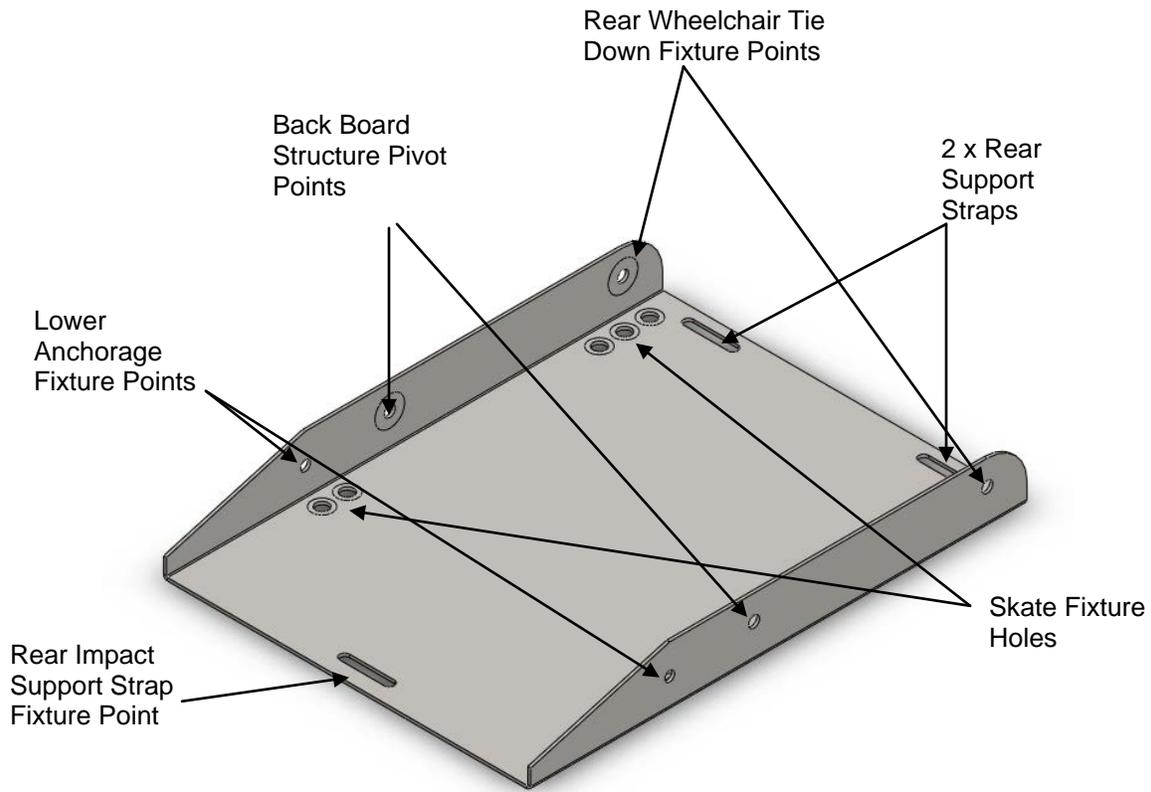
A FEA study has been carried out on different configurations of the seat base to establish an optimum design in order to reduce weight but maintain the strength in order to pass the physical testing.

The FEA study was carried out using SolidWorks Simulator to investigate the stress build up in the base unit. The forces from the crash test would be transmitted through the webbing into the base plate. The webbing is attached through the slots (Figure 48), 2 rear support straps and one front strap. Similarly to the previous 2D study, a shell mesh was used on the model. See Figure 48. This was in order to provide fast meshing and analysis run time.



**Fig 48. – Base Plate Mesh**

As the mesh becomes more complicated, using a 3D mesh, it will create more elements to be calculated. This extends the run time of the analysis. As the study was investigating the effects of changing the shape and structure of the base unit, this involved re-meshing the model after each change then running the analysis again. To do this repeatedly on a complicated mesh would take a lot longer and with very little improvement in accuracy.



**Fig 49. – Webbing Concept Base unit**

The base unit, constructed from 3mm mild steel will be attached to the floor using lockable fixtures that are bolted through the holes along the folded edges of the base unit. These bolts are modelled in the simulation as the fixed points, located on the model using 'split lines' around each of the mounting holes. The loading will be applied around the slots (2 x at the rear, 1 x at the front) of the base unit where the seatbelt webbing will be attached.

The loads applied will be 12.5kN split between the two rear slots, 12.5kN split between the two lower anchorage points and 22.5N split between the two rear wheelchair tie down mounting holes. These loads will be applied through split lines surrounding the holes in order to simulate the mounting bolts and washers that will be used to fix the attachments. As the model was a single piece, sheet metal component it was possible to carry out the simulation using a shell element type with a mesh size of 8mm. Shell

elements work in 2D along the mid-plane of the component. It enables the simulation to run quicker than solid elements which work in 3D. This means a number of iterations of a design can be tested in a short amount of time.

The base plate was modified after each test in order to improve the strength of the component and then reduce its overall weight. The initial test was on the component pictured above in Figure 49.

<b>FEA Study Model</b>	<b>Changes</b>
Model 1	Original FEA Model (Fig 57)
Model 2	Folds on the front and rear of the plate added.
Model 3	The centre section of the base lowered down to the vehicle make contact with the vehicle floor. Folded ends remain although they have been slit due to centre section modification.
Model 4	The end model has had the folds removed and end plates fitted to make solid lips on each end of the base
Model 5	Shape the same as Model 4 but material thickness reduced from 3mm to 2mm

**Table 7. - Description of Base unit models used in FEA study.  
Photos below in Figure 50**

The purpose of these modifications was to increase the rigidity of the base unit to reduce the amount of deflection that occurs during the crash test. This was done by adding bends into the component structure.

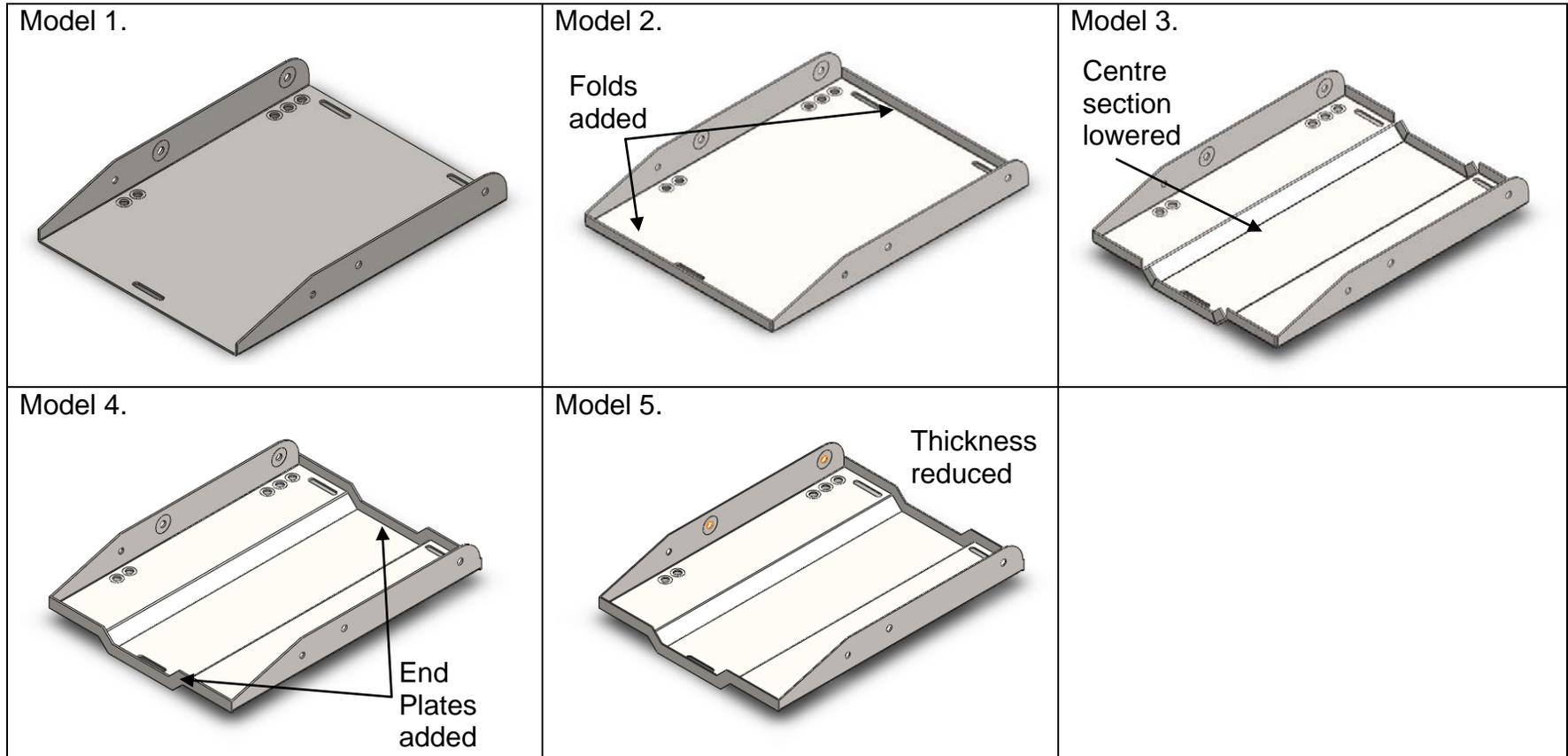


Fig 50. - Variations of the base plate models used in the FEA Study

Model No.	Weight (kg)	Forward Pull		Rearwards Pull	
		Stress (N/m <sup>2</sup> )	Deflection (mm)	Stress (N/m <sup>2</sup> )	Deflection (mm)
1	5.41	2.80E9	5.53	2.51E9	19.37
2	5.73	2.01E9	1.89	1.30E9	6.22
3	5.59	2.30E9	2.22	1.64E9	4.53
4	5.96	1.80E9	1.49	9.39E8	3.39
5	3.99	3.49E9	3.69	2.13E9	8.3

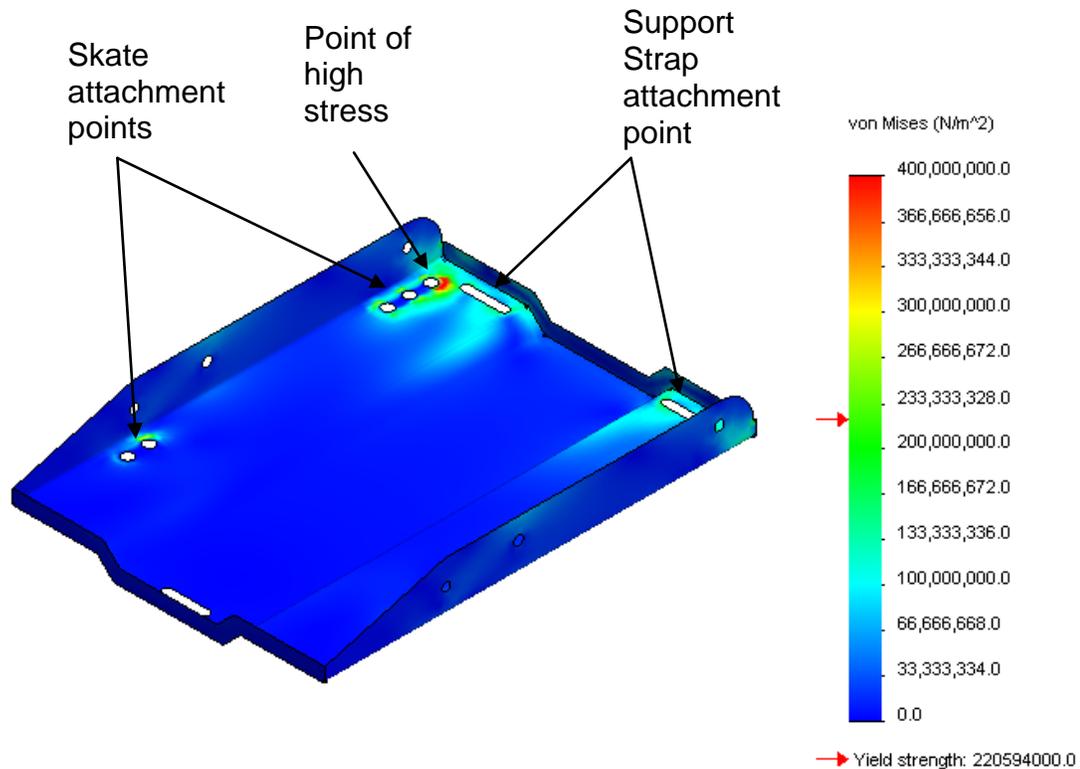
**Table 8. - Results from the base plate FEA study**

The results show that by adding the additional bends into the material the structural rigidity is increased resulting in a smaller amount of deformation. By adding the flanges on the front and rear of the base, deformation is reduced by 67.8%. However in doing so this increased the amount of material used in the base leading to a weight increase of 0.32kg. Again, as the additional folds running in parallel to the length of the base unit were added the amount of deflection was reduced again. By Model 4, the deflection had reduced from 19.37mm to 3.39mm (82.5%) but the weight had increased 0.55kg.

As a result of this, Model 4 was changed by reducing the thickness of the material from 3mm to 2mm. The shape and orientation of the design remained unchanged. By doing this the weight of the base unit was reduced to 3.99kg which is 1.42kg lower than the original model and also has a deflection of 8.3mm, still 57.2% lower than the original.

The overall stresses in the model are very high, the maximum stress of the original model is 2.51E9 N/m<sup>2</sup>. This is far in excess of the stated tensile strength of the material, which is stated as 3.99x10<sup>8</sup>. Although the deflection of the model is said to be 19.37mm, the stresses involved in the loading is so high that material failure can be expected around the mounting holes before then and a true measure of deflection can not be predicted.

In model 4, when the stresses in the model are most reduced, the stresses are still over the maximum tensile strength of the material. Increasing the material thickness would provide extra strength, Model 6 demonstrates the material thickness (in the orientation of model 4) would be required to stay within the maximum tensile strength of the material.



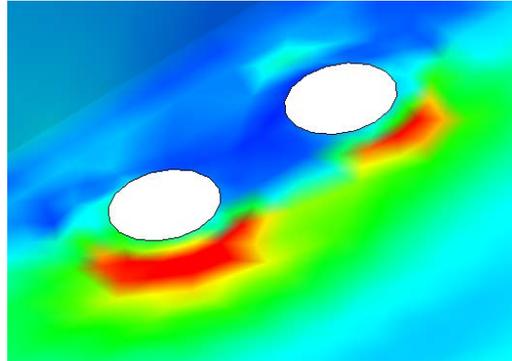
**Fig 51. - FEA Screenshot of Model 6 showing von Mises stress**

Model No.	Weight (kg)	Forward Pull		Rearwards Pull	
		Stress ( $N/m^2$ )	Deflection (mm)	Stress ( $N/m^2$ )	Deflection (mm)
6	9.84	7.6E8	0.45	4.36E8	1.1

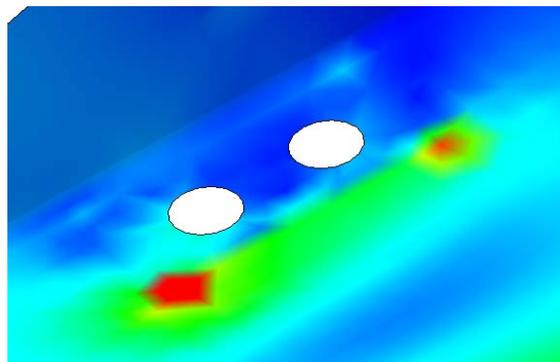
**Table 9. - FEA Results for Model 6**

As can be seen from the results, the maximum stress does still exceed the tensile strength of the material but it is only in a concentrated area around the rear fixing hole.

This is something that can be managed with a large washer or backing plate in order to disperse the load. Figures 52 and 53 show how the load can be spread over a larger area by increasing the 'split line' size on the model.



**Fig 52. - Skate fixture holes with 20mm washer fitted**



**Fig 53. - Skate fixture holes with a 28mm x 55mm plate fitted**

By doing this it will not cause a failure in the part however the material thickness has increased. The material thickness used in this test is 5mm, 2mm increase from original. The deflection is reduced to 0.45mm.

The total weight of the base unit is 9.84kg. This is too heavy to be used in the back restraint as it will not be able to be lifted or moved by the target user (PDS 3.1). This is yet to have the back board structure included to it, which CAD models suggest is going to weigh 5.8kg, and with the addition of the trim and restraint straps rules out this design as an option.

The lack of rigid adjusting bars on this design gave it the ability to fold up to a very compact size which is ideal for storage in the vehicle when it is not being used.

The design does not allow for adjustability of the back angle in use due to the straps running from the upper anchorage point to the base unit having a fixed length. There is potential for having the back angle set to customers need when the product is being manufactured by setting the length of the rear support straps; however this would be a one-time fitment and allows for no adjustment once the product is in service.

After a couple of installation tests into the vehicle tracking the mock up, with the main structure constructed out of wood for demonstration purposes, started showing some signs of stress around the lower fixing point. This is the strap that has the ratchet mechanism in place and tightens the restraint in the deployed position. Around the strap path there was splintering of the wood where the tension in the strap was causing areas of high stress.

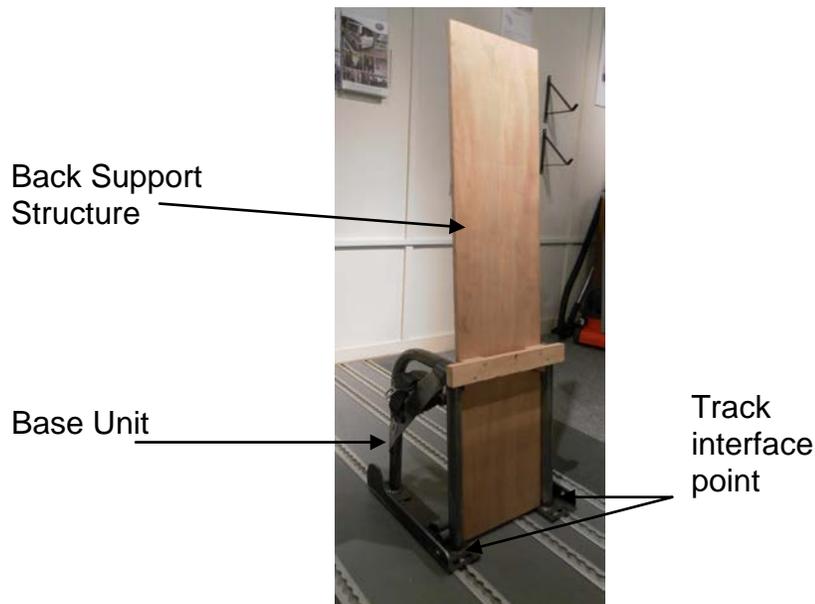
This method of holding the restraint in its position was pre-stressing the structure which would then need to be able to withstand the additional crash forces. The constant tension on the straps would also lead them to stretch and get frayed over time.

Not enough information about the behaviour of the straps under crash conditions is known. Under further investigation while the mock up was being produced, manufacturers state that the belts can stretch between 5 to 18%. This large range of stretch is unacceptable for the back restraint. While 5% would be acceptable, to reduce the maximum forces on the occupant and help dissipate the loading, 18% would cause the back restraint to move too far forward, creating the danger that the occupant may be forced off the wheelchair or allow them to move too much so they come in contact with the seat in front or vehicle around them.

It was because of the pre-stressing of the structure and the effects that it had on the prototype mock up it was decided not to continue the development of this design.

## 7.6 Concept 6 (Two Piece Back Restraint Design)

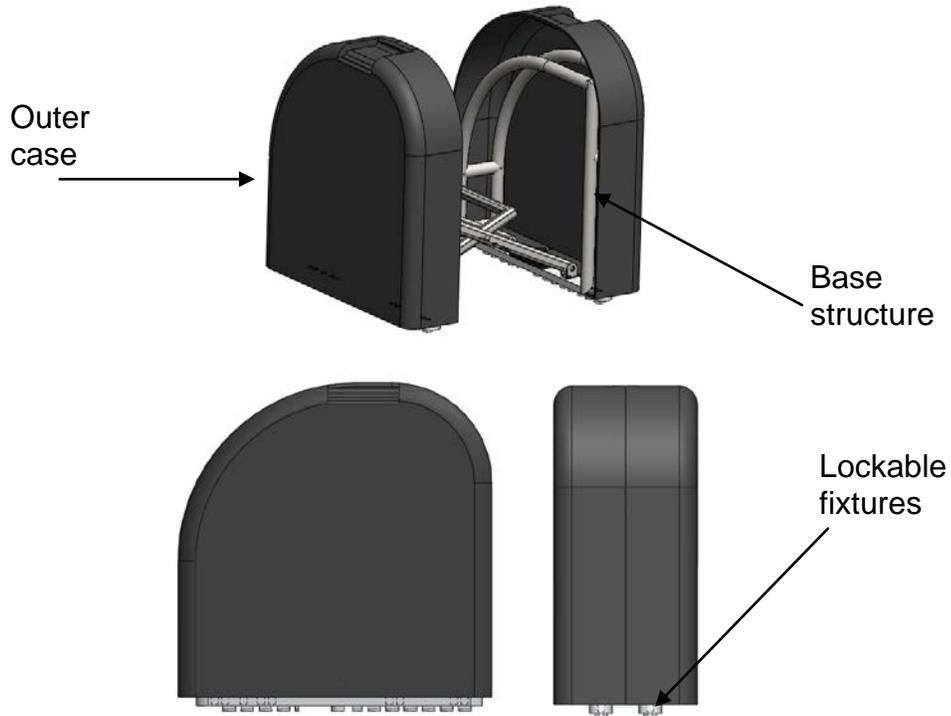
This concept comes in two different units. The first is the base structure that sits 400mm high and fits in behind the wheelchair into the tracking. This structure contains the wheelchair tie downs and occupant belts that are mounted onto it.



**Fig 54. – Concept 6 (Two Piece restraint) mock up**

The second part comprises of the back support structure. Once the wheelchair is in position and the base unit in place this comes in and creates the connection point between the base, wheelchair and occupant. By having the design in two parts it means that they will be able to reduce down to a small size and be easier to store.

This may include a base unit designed and developed for this purpose. Initial CAD models show (Figure 55) that it could look tidy and compact when folded and also include a carrying handle. This design can cope with a range of track widths, 270 – 350mm (PDS Point 1.5.) The webbing attachments can also be stored away inside the centre of the framework where there is free space.



**Fig 55. - Base Unit for 'Two Part Concept' in its folded and unfolded position**

Another option of this is to adapt a product already being used for a similar purpose that is being produced by one of GM Coachworks suppliers (Koller (30) Figure 56). This is a system that is made up of a tubular frame that fits up against the back of the tracking and holds the wheelchair against it.

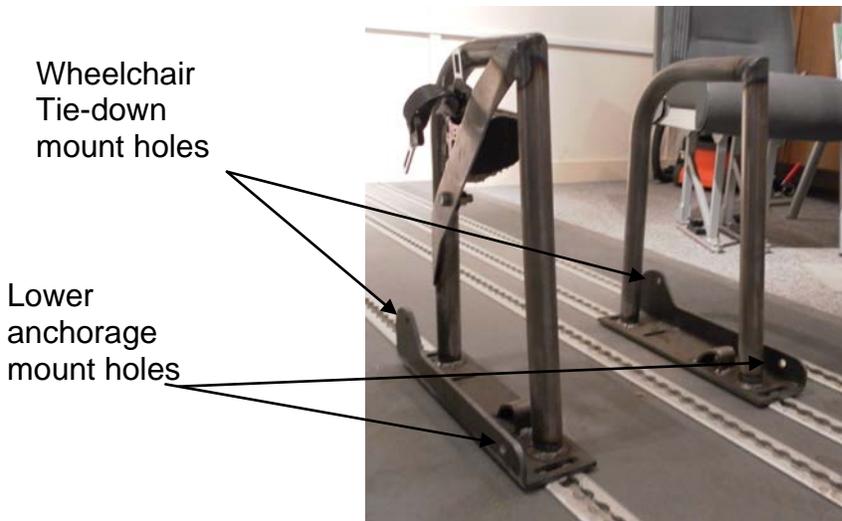


**Fig 56. – Koller Wheelchair Restraint (30)**

The base unit has all of the belts required attached to it. There is limited adjustability (25mm) to account for different widths of tracking. It would require an extra tube attached to the framework then a simple back restraint could be added to provide the additional support and comfort to the wheelchair user.

The back support that goes into either device will have to be thin and light weight (PDS Point 12.1.) so that it is easily removable and able to be stored out of the way. It will have a slot in the top where the upper anchorage point will be. The belt will run from the base unit through this slot and then around the vehicle occupant and back down to the buckle at the lower anchorage point. This means that the back support does not have to take the full loading from the upper anchorage point during the pull test, although it does have to be strong enough to withstand the compressive forces (6.25kN downwards) that this set up will put on it. As the strap is running from the vehicle floor, up over the back support and down to the lower anchorage belt buckle the belt is trying to straighten out. This puts a lot of force acting downwards on the back support. The support should also be strong enough to withstand the rebound forces from the frontal impact and the crash forces involved in a rear impact collision. To conform to M1 Standards (20) the loadings for the rebound static pull test are 6.25kN from the upper anchorage point and 6.25kN from the lower anchorage points.

Two 'D' shape frames were constructed out of 1.5 inch mild steel and fitted to a base plate (Figure 57). This plate is where the lockable fixtures, lower anchorage points, inertia reel seatbelt and rear wheelchair tie downs will be fixed to. The ridges on the bottom of the unit are there to support the removable back board.



**Fig 57. - Two base sides of the base unit framework and base plates**

The fixing slots for the lockable fixtures have been elongated along the width of the base plates. This is to take into account the varying width of the recesses tracking in the vehicles (270-350mm as stated in PDS Point 1.5.). (Technical Drawing for this in Appendix 2) The hole at the front of the base plate is to take the lower anchorage point on one side and the end of the seat belt strap on the other. The rear, raised hole is to take the wheelchair tie down straps. These have been put in this position to give clearance for the reel and provide the correct strap length and strap angle (2).

The inertia reel for the occupant restraint strap is mounted in the enclosed space in one of the 'D' frames (Figure 58). This allows the buckles to exit out the top of the housing that will clad the frames. When the wheelchair, base unit and back board are in position the seatbelt strap will travel up over the shoulder of the occupant and clip into the seatbelt buckles fixed to the lower anchorage point locations.

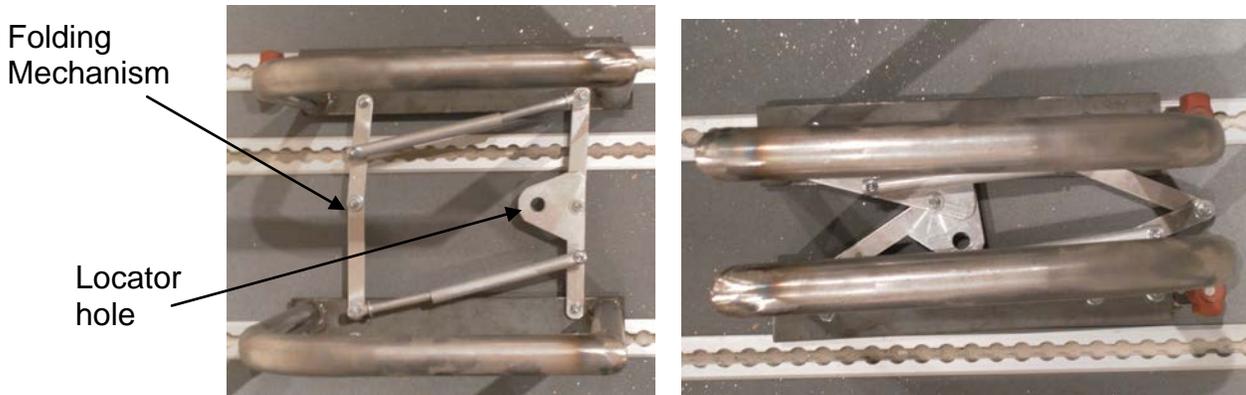


**Fig 58. - The back board fitted into the base unit**

The method of fitting the back board into the base unit is required to be simple to carry out and reliable, so there is no chance of fitting the unit incorrectly so that it could be displaced while it is being used. Figure 58 shows a design that was used in the mock up of this prototype. The unit is moved into position at 45° to the horizontal plane of the vehicle. When the rear two bars are in position behind the front horizontal bar of the 'D' frame the back board is straightened up. The back board is then lowered into position behind the raised notch on the base plate of the base unit. There is a beam along the front of the back board which holds the board steady, taking the rebound loads of the crash tests and providing a position for the wheelchair to rest against so it is not putting the entire load on the length of the back board.

The two sections of the base unit have to be linked together and close up to create a compact case (Figure 59), so that it can be stored in the vehicle when it is not in use. It is essential that the mechanism does not interfere with the other components that are in use in the base unit. The back board locking system, wheelchair tie downs and occupant restraint are all fitted to the base unit.

A number of systems were developed; the first was a method that fitted flat to the base plate to give as much room to manoeuvre the back board in above it.

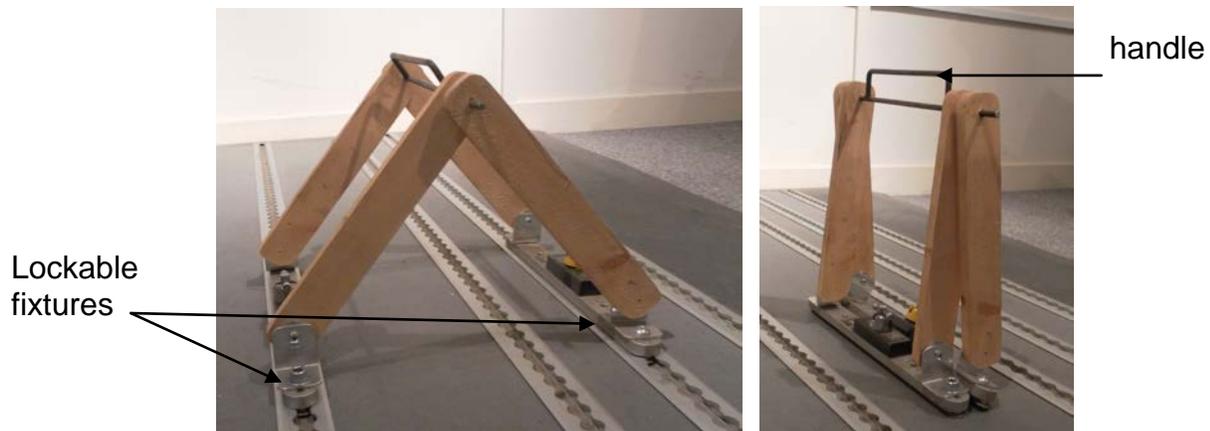


**Fig 59. - First folding mechanism for base unit**

This method incorporates two expandable struts which flick over centre when the base unit is in the expanded position so that it is held open. Once these are in their fully extended position it aligns two holes at the front of the unit. This acts as a locator unit for the back board and also locks the unit open. The mechanism can then be fully folded up onto itself linking the two base plates together. A latch will be fitted on the base units cladding to hold these pieces together.

The mock up of this design (Figure 59) demonstrated that without any form of vertical adjustment the base plates move forward and backwards as well as in an out. This produced a possibility that the unit could be misaligned in the track. It is important that the two base plates are level with each other and by having the adjustability backwards and forwards it would be easy for them to be positioned incorrectly.

The solution to overcome this was a scissor action acting with a hinge that runs the length of the base unit. The two scissor actions have to be spread out over this length because it limits the potential twisting action that could misalign the two halves of the base unit, which was the problem with the previous design seen in Figure 59 above.



**Fig 60. - Scissor action folding mechanism**

As the base unit is deployed, the pivot moves downwards leaving the space above it clear for the back board to clip into the framework. By fitting a handle on the hinge point, when the base unit needs to be folded up the user can pick it up using this, the unit will then fold up and the handle will protrude out of the cladding providing a method of carrying the unit.

As this design progressed it soon became apparent that the folding mechanism was making the design increasingly complex and interfering with the method of attaching the back board to the base unit. The decision was taken to keep the base unit as two different parts, which would then clip together manually using the fasteners on the casing. Because the base unit would have to be made up of two separate pieces the whole design will comprise of 3 pieces increasing the complexity of the design, it was soon discounted for a more favourable, single piece solution.

## 7.7. Concept 7 (Front Pivot Tubular Design)

As an alternative method of construction and with possible weight advantages a design was considered constructed out of tubular steel. As with the initial sheet metal solutions it is based around the similar geometry, but instead of pushing the support leg forward and utilising the space under the wheelchair, the main struts stretched backwards. This makes the back rest stick out slightly more from the back of the wheelchair but allows the strut to go all the way up to the height of the main loading point of the upper anchorage point. This, as proved by the 2D FEA studies on the sheet metal restraint (Paragraph 7.1.1), is the most efficient design in reducing the amount of deflection and stress levels during the crash testing.



**Fig 61. – Concept 7 (Front Pivot design)**

The advantage of using tubes over the sheet metal was that it could be made to reduce down in size, ensuring it took up less room when it was not being used. This design folds down on itself by a pivot located at the bottom, front of the structure. The lockable

fixtures are pivoted upwards and the rear support struts fold down towards the front framework.

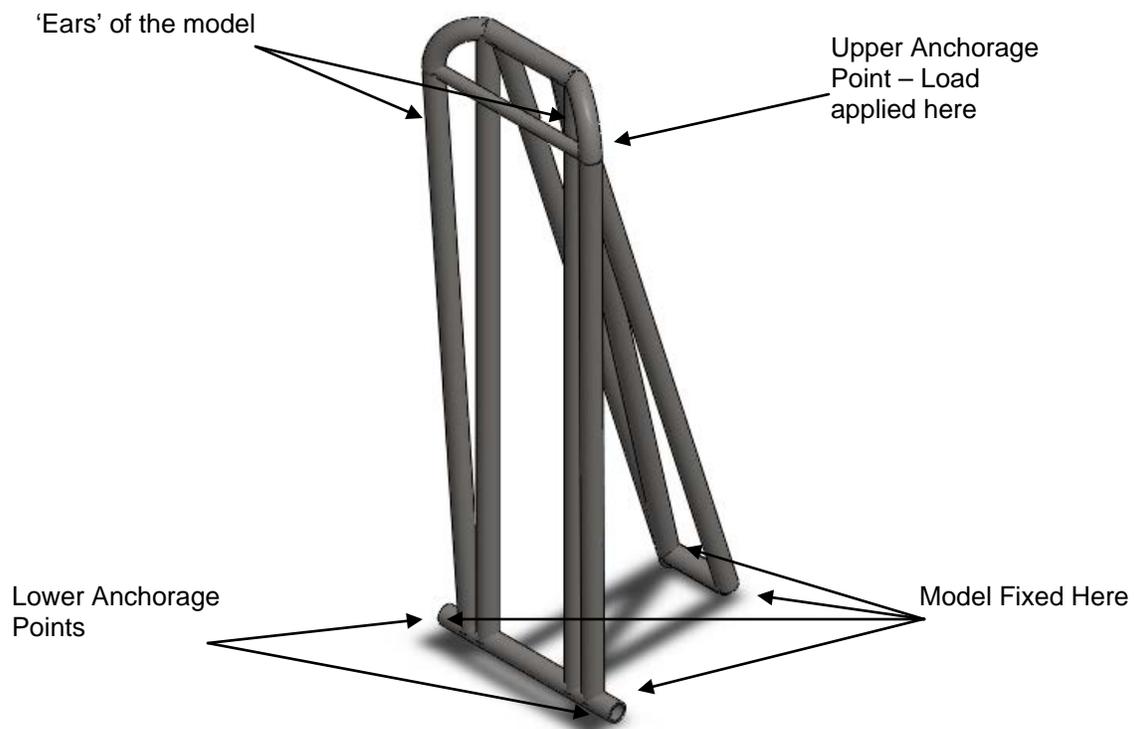
The structure is prevented from moving by a bar which runs along the rear of the lockable fixtures and holds the rear support in position. As can be seen in Figure 61, the lower anchorage points are taken from the front pivot point, into the end of the tube. The wheelchair tie downs are taken off the rear of the lockable fixtures, this ensures that the minimum strap length and strap angles (2) are adhered to. The upper anchorage point is located on the main structure. Just down from the positioning hoop where it will then go around the occupant. This is to clear some space on the lockable fixtures so that the design can fold up as compactly as possible. The mounting point of the inertia reel at the upper anchorage point is level with the rear support strut.

### **7.7.1 Tubular Structure Orientation and Weight Reduction FEA**

The principle for the movement and shape of the structure had been decided. In order to make the design as efficient as possible and ensure there is no excess weight, an FEA study was carried out to test different combinations of tube layout for the structure.

The study that was carried out was a simplified single part model constructed of tubes using the weldment function in SolidWorks. This enabled the design to be quickly modified and a beam element mesh to be used in order to speed up. Each design was modelled using Plain Carbon Steel in 1 inch (25.4mm) outer diameter tube with a wall thickness of 1.5mm.

This material and tube size was chosen because it is what GM Coachwork has available and the facilities to bend in house. The study was carried out using the same material for each model in order to directly compare the performance of each model.



**Fig 62. - Labelled Image of Tested Back Restraint Model**

A load of 12.5kN was applied in the forward direction and 6.25kN in the downward direction. This is applied to one of the joints at the outer side of one of the 'ears' of the model. This is to simulate where the forces around the upper anchorage position and where inertia reel seatbelt is mounted.

Six different combination of tube layout were designed, these differed in locations of support struts, side bars and the rear support struts. The different layouts of the tested back restraints can be seen in Figure 63. In order to keep the model simple to reduce simulation time, no headrest is has been modelled. This is because for the final design a standard OEM head rest will be fitted to the structure so will have already undergone the necessary testing.

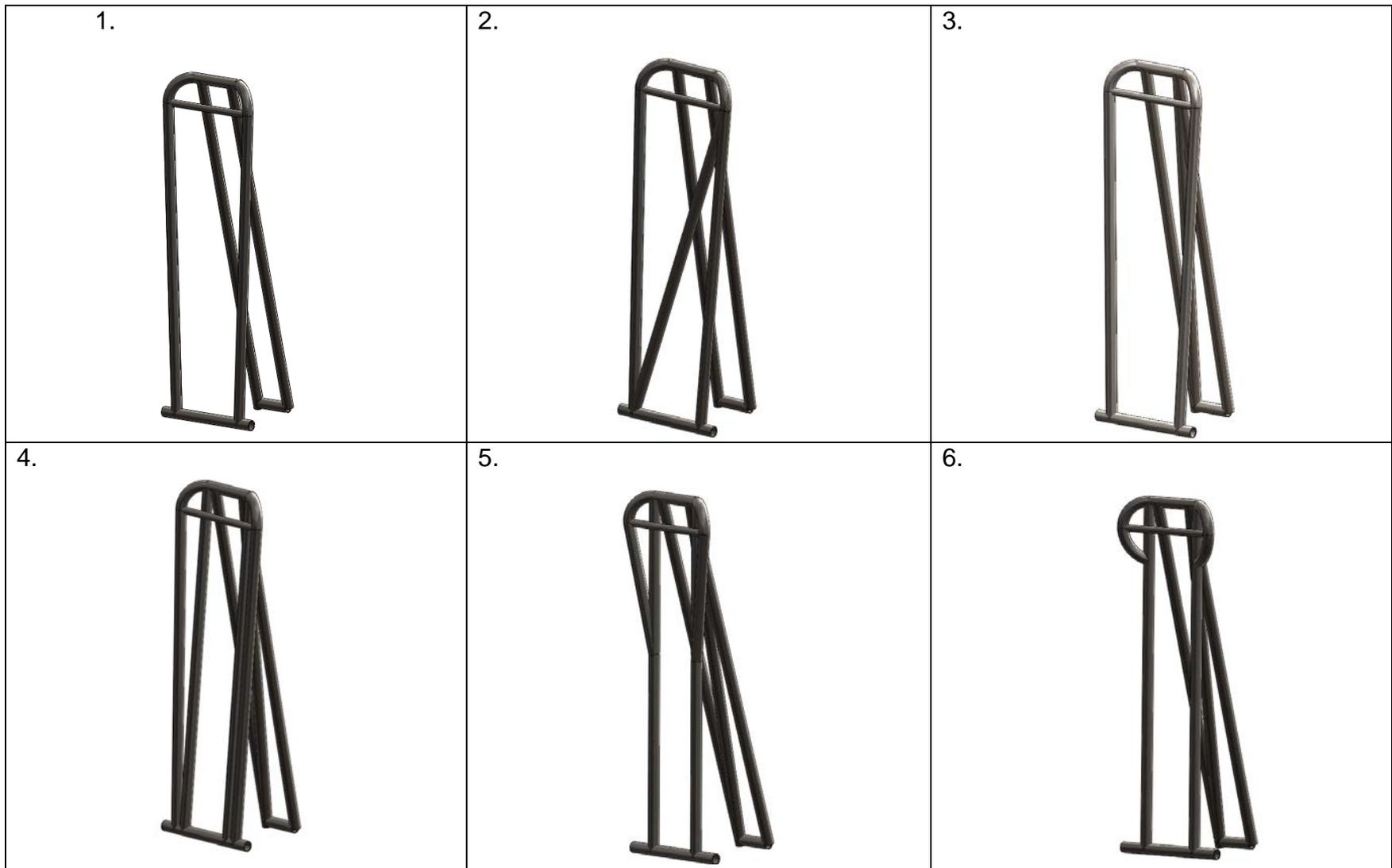
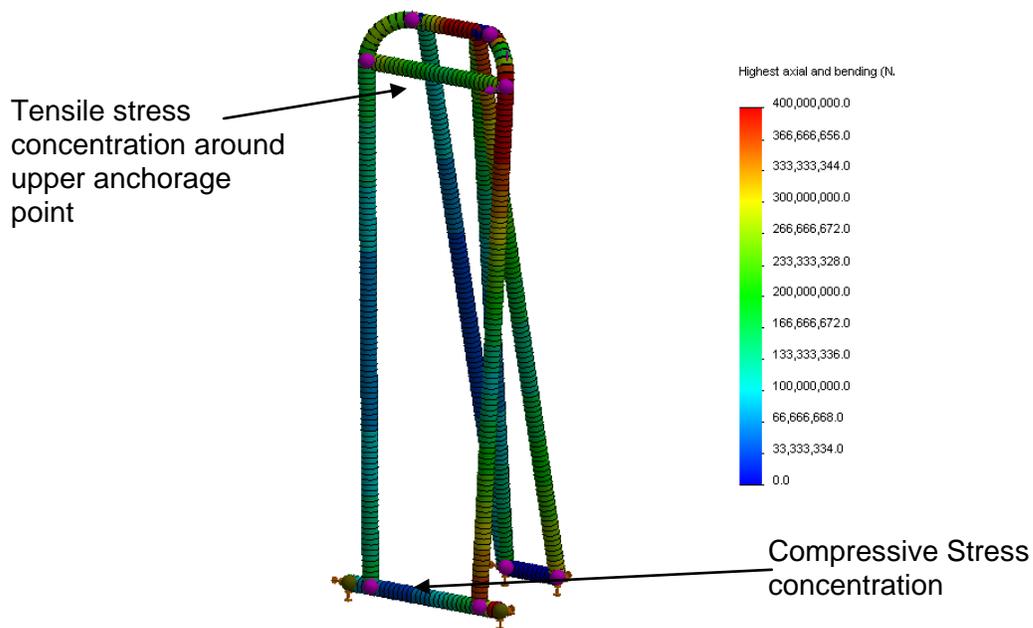


Fig 63. - The 6 different models tested in the FEA study

The simulations were carried out on all six models. The results show that the areas of stress concentration are the upper anchorage point, where the load is applied that is in tension, and the base bar at the front of the model. This is a compressive force as the back restraint is being pushed forward and into the ground.



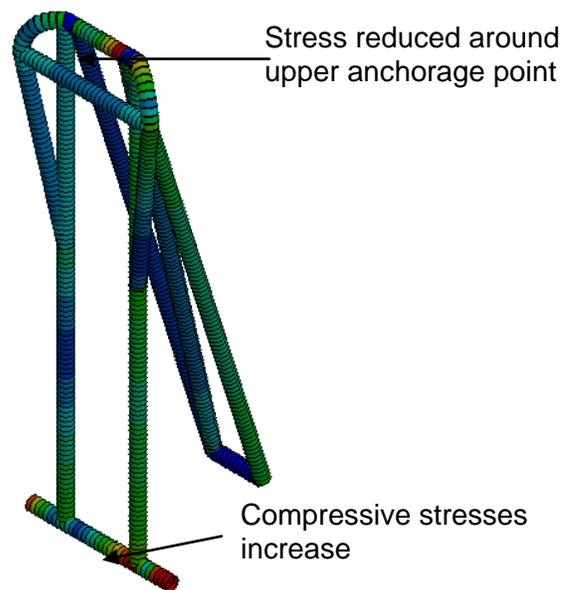
**Fig 64. - Von Mises Stress Plot for Model 4**

Model Name	Weight (kg)	Displacement (mm)	Max Von Mises Stress (N/m <sup>2</sup> )
1	13.3	16.5	7.89x10 <sup>8</sup>
2	15.9	15.7	6.61x10 <sup>8</sup>
3	16.1	15.8	7.43x10 <sup>8</sup>
4	21.5	9.8	7.11x10 <sup>8</sup>
5	18.6	10.3	8.04x10 <sup>8</sup>
6	17.2	12.9	8.54x10 <sup>8</sup>

**Table 10. - Model Weights, Deflection and Stress values.**

As can be seen from the results in Table 10, when the central struts are added the deflection reduces approximately 6mm.

Model 5 uses the central struts as the sole frontal structure leading to the ground. The side 'ears' where on one side the upper anchorage point will be located have been reduced in length to end approximately 500mm from the ground. This is to reduce the amount of material that is being used in order to save weight. The results in Table 10 show that while the deflection has increased by 0.5mm the weight has reduced by 2.9kg (13.4%) from that of model 4. As the 'ear' tubes are reduced even further, as in model 6, the stress concentration increases around the upper anchorage point. This increases the maximum stress of the model and the deflection by 2.6mm from the previous model.

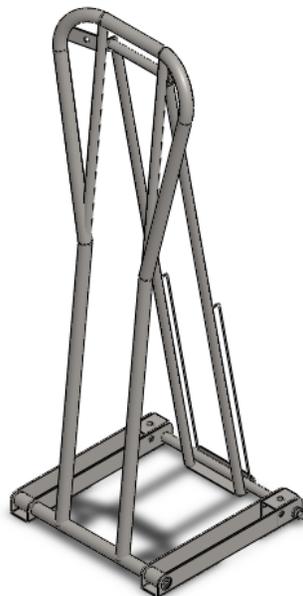


**Fig 65. - Model 5 shows narrower struts**

When the model has had the outer struts shortened, the stress build up is reduced around the upper anchorage point but increased around the lower front base bar. This is because the supports are 70mm narrower than the 'ear' struts so there is more room for the bottom bar to move. The simulations show that there is a 0.7mm deflection in models 5 and 6 where as there is a 0.05mm deflection in model 1-3. This would account for the greater stress concentration.

Model 5 was the best compromise between structural stiffness and reduced weight. It had the 2<sup>nd</sup> lowest deflection (10.3mm) and the weight was 18.6kg. This is 5.3kg rise from the first model tested but the deflection is 37.6% less.

After FEA studies were carried out on the effect of changing the orientation and adding or removing struts a solution was decided upon and two prototypes were fabricated (Figure 66). The first was constructed out of 1 inch, 2mm mild steel tube. The second was made out of 1 inch, 1.5mm stainless steel.



**Fig 66. - CAD model of tested design**

Different materials were used because these prototypes were being used for the preliminary physical testing. It was a good chance to prove the FEA results on this concept and a good comparison between materials.

## 8. Comparison of Designs and Selection of Prototype

The design concepts were reviewed in order to establish which to develop further and then take forward to the prototype phase and then onto physical testing. This chapter will provide a summary of each design concept. The concepts will then be evaluated and the rationale behind which design is taken on to the prototype stage explained.

### 8.1 Design Concept Summary

Figure 67 below provides a summary of all seven design concepts. These will be evaluated in Chapter 8.2.

Concept 1 – Sheet Aluminium Concept: Created from folded sheet aluminium. The curved back is designed to provide increased strength for minimal added material.

Concept 2 – Folded Sheet Aluminium Concept: Using flat aluminium as with concept 1 shape is added to increase strength. This concept includes a folding mechanism to allow for storage in the vehicle when the product is not in use.

Concept 3 - 'Suitcase' concept - A compact design with retractable legs, intended to be easily stored in the vehicle when not in use.

Concept 4 - Composite concept: A design made from composite materials. The addition of mechanical components for locking mechanism and adjustability increases the complexity of this design.

Concept 5 – Webbing concept: Utilising the strength of seat belt occupant restraints this design can fold away when not in use. The main forces of the crash tests are directed through the seat belt webbing.

Concept 6 - 'Two Piece' concept: Designed to direct the main forces to the base unit with a lightweight back board that clips into the case.

Concept 7 - Front Pivot Concept: A tubular construction similar to the folded aluminium of concepts 1 and 2. The crash forces act in tension on the rear struts rather than compressing the front as they do in concept 1 and 2.



Fig 67. – Summary of Concepts

## 8.2 Design Concepts Matrix Analysis

A matrix analysis was used in order to establish which best fulfils the original criteria set out in the PDS (Chapter 6.2).

Concept Numbers:

<b>Concept</b>	<b>Number</b>	<b>Description</b>
1	Concept 1	Sheet Aluminium concept
2	Concept 2	Folding sheet aluminium concept
3	Concept 3	'Suitcase' concept
4	Concept 4	Composite concept
5	Concept 5	Webbing concept
6	Concept 6	'Two Piece' concept
7	Concept 7	Front Pivot Concept

**Table 11 - List of Concepts**

The features that the concepts were compared against were not identical to those in the competition analysis (Chapter 5.7). This was because the concepts were designed to comply with specific features such as 3 point seat belts, ISO10542 and to fit into floor tracking.

The features took into account the designs from the users point of view ensure that the design team considered the end use rather than solely concentrating on the technical aspect of the project.

<b>Feature</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>Weighting</b>
Weight	Datum	+1	0	+1	+1	+1	+1	10
Storage / Folding	Datum	+1	+1	+1	0	0	+1	8
Adjustability	Datum	0	0	+1	+1	0	0	6
Ease of Deployment	Datum	-1	-1	-1	0	-1	0	9
Cost	Datum	0	-1	-1	0	0	0	10
<b>Total</b>	<b>0</b>	<b>9</b>	<b>-11</b>	<b>5</b>	<b>16</b>	<b>1</b>	<b>18</b>	

**Table 12 - Concept QFD Analysis**

Carrying out this analysis showed that Concept 5 and Concept 7 met the criteria better than the others.

While Concept 5 (Webbing concept) met the user criteria used in the concept matrix analysis (Table 12), it was not a suitable concept for further development. As discussed in Chapter 7.4, the webbing strap, which provides the main support for the back restraint and takes the full force of the crash loading can stretch up to 5-18%. This kind of stretch provides too much deflection for the wheelchair occupant to remain contained in the wheelchair. From this, and supported by the QFD analysis the Front Pivot design was progressed to the working prototype and testing stage of the design process.

## **9.1 Prototype Testing and Development**

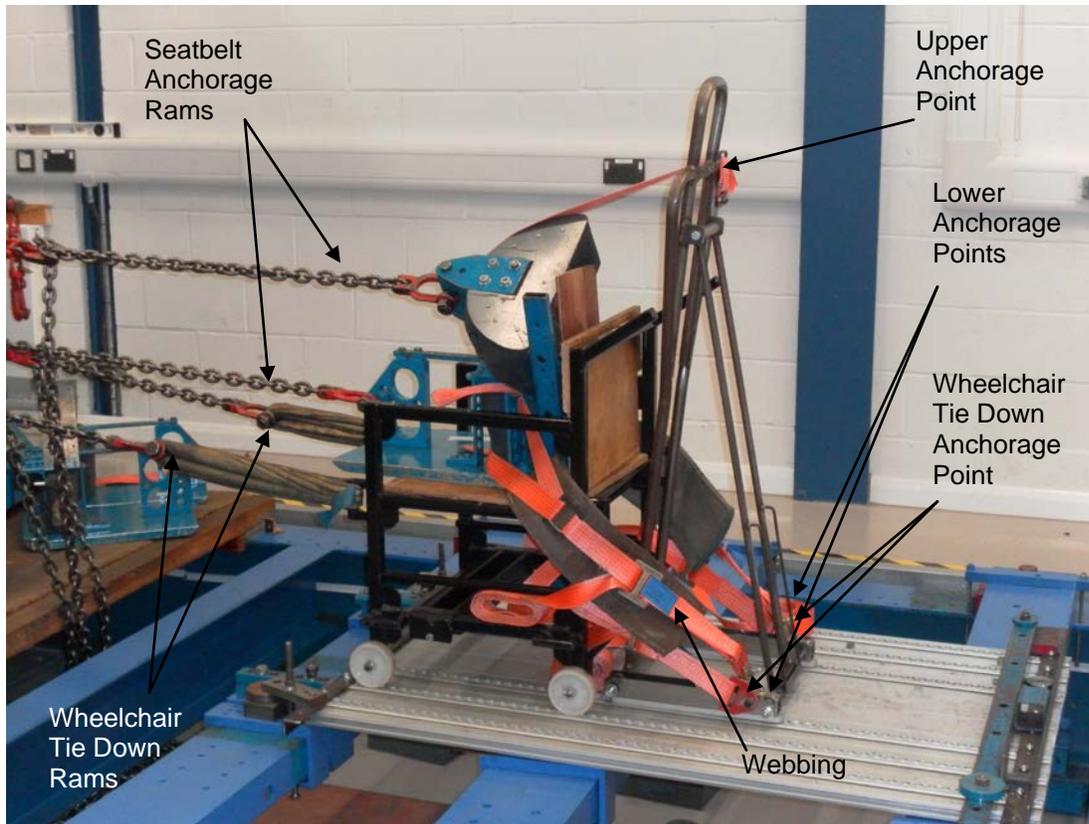
A fully functioning prototype design was then produced and made based on Concept 7 (Front Pivot Concept). The prototype was designed taking into consideration that it had to be suitable to for manufacturing. Using CAD software, it is possible to draw any shape regardless of whether it manufacturing considerations. This part of the development process is where the details of the design are established. Designing the product for manufacture meant it was important to suppliers tooling, for example the radius of their tube bending tooling and how the seatbelt and wheelchair straps would be assembled on the final tool. It had to be ensured that bolt holes and locations gave enough clearance to be easily and quickly assembled.

From this three prototype models were produced and taken for physical testing to prove the results from the FEA study.

### **9.1 Physical Testing**

The physical testing was carried out at STATUS (31), a specialised vehicle testing company based at Manchester Metropolitan University. They have the facilities to test the seatbelt anchorage locations to M1 standards (20) and wheelchair tie down and occupant restraint (ISO10542 (2)).

The test is carried out by hydraulic rams that are connected to the back restraint via straps which simulate the seat belt path and be attached at the seat belt anchorage point.



**Fig 68. - Physical Testing set up**

The load for the seat belt anchorage points are linked to weights that simulate an occupant. The upper and lower anchorage points are connected with webbing running the path of the seat belt around the wheelchair that is placed in front of the back restraint. The total load is 22.25kN and is accumulated over a 5 second period. The second set of rams are used to load the wheelchair tie down restraints. This is loaded to 27kN and applied over the same time period. The ram is attached to the front tie down locations and the rear wheelchair tie down straps are fixed to the base of the back restraint.

### Test 1

The first test carried out was on the Mild Steel back restraint. This was set to reach M2 values, half of those of the M1 test (20) hold for 0.2seconds to achieve a pass on this load then increase the loads to the M1 test as stated above.

The test was carried out and the loading achieved 4/5<sup>th</sup> the loads of M2 before failure occurred. The failure happened in the skate, a third party component that links the channelling of the back restraint to the floor of the vehicle. It occurred at the locking pin of the skate that sheared with the forward force being applied to the skate.



**Fig 69. - Failure of the skate fitted to the back restraint**



**Fig 70. - The sheered locator pin on the skate.**

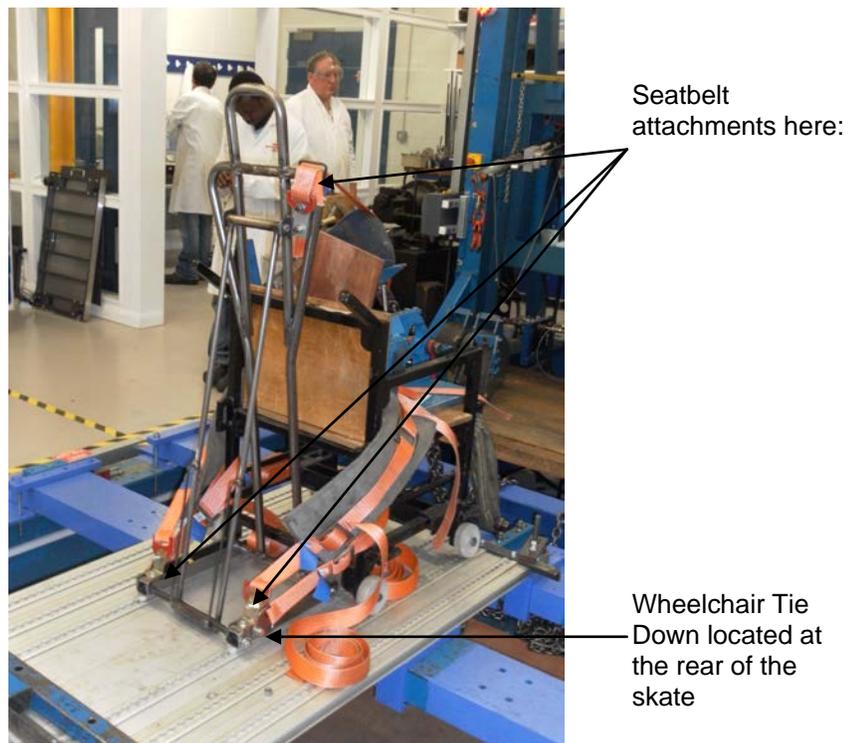
This could have been because the loading had been changed from what was normal for the skate. Normally the loading points are at the rear of the skate which causes the rear to be pulled up and the front of the skate to be pushed down. However the wheelchair tie down restraints had been attached to the front of the skate. This means that the

front and rear of the skate are being pulled upwards during the test which could lead to the forward directional force of the skate having more effect than the skate can tolerate.

To account for this, in the second test the wheelchair tie down straps were fixed to the rear of the skate, in the same location to the lower anchorage points of the occupant seat belt. The back restraint structure was unharmed during this test so could be used for further tests.

### Test 2

The second test was carried out using the stainless steel back restraint. In order to speed up testing, while this test was being carried out the skates were replaced on the first prototype back restraint.



**Fig 71. - Rear wheelchair tie down strap changed location**

The test was carried out under the same conditions as the first test. The only change was the different location of the wheelchair tie down anchorage point location.



**Fig 72. - Showing the back restraint and wheelchair pulled out of the floor**

The failure occurred in the same location as the first test. The layout of the skate was inspected and it was observed that the centre pin of the locking mechanism was removed in order to fit around the channelling of the back restraint base. In its place was a wire to provide the ability to turn the pin and lock the skate in position. This thin wire in place of the centre pin made the locking mechanism sit lower in the skate than it originally would. This made the narrower bore of the pin exposed at the bottom of the skate body. This meant that a sheer force was being applied to the narrower diameter part of the pin causing it to shear.

### Test 3

The centre pin was put into position but cut short in order to fit into the channelling of the back restraint. This meant that the narrow section of the locking pin was not exposed under the body of the skate.



**Fig 73. - Image showing the turning pin located to raise the locking pin to its original position**

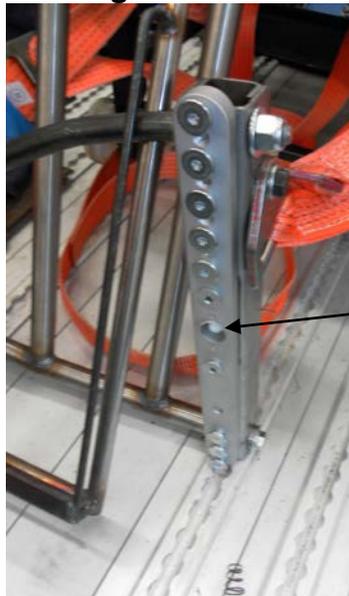
This failed in the same manner as the previous tests but at a much higher load. The loading achieved approximately 5/6<sup>th</sup> of M1 loading. This time only 1 skate failed. This caused failure of the channelling of the skate that was still in position as the structure was pulled forward.



**Fig 74. - Image after test 3**



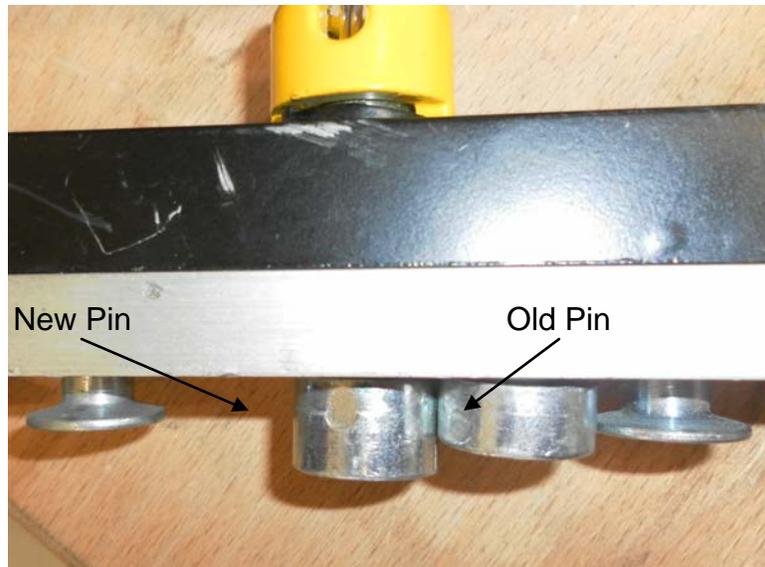
**Fig 75. - The deformed channelling of the skate that remained in the tracking**



Sheered pin in  
lockable fixture

**Fig 76. - The failed skate**

The main structure of the back restraint was undamaged in the test. The skates appeared to have a difference in the locking pin. The failed skate was a new model which, when compared to the older skate had a different locking pin. The larger diameter bore of the older model skate was 3mm longer than that of the newer model. This meant that it was more securely inside the skate during the test so that the shear loads were acting on the large diameter part instead of the narrower part further up. This explains the older skate withstanding the force loads which the newer model did not.

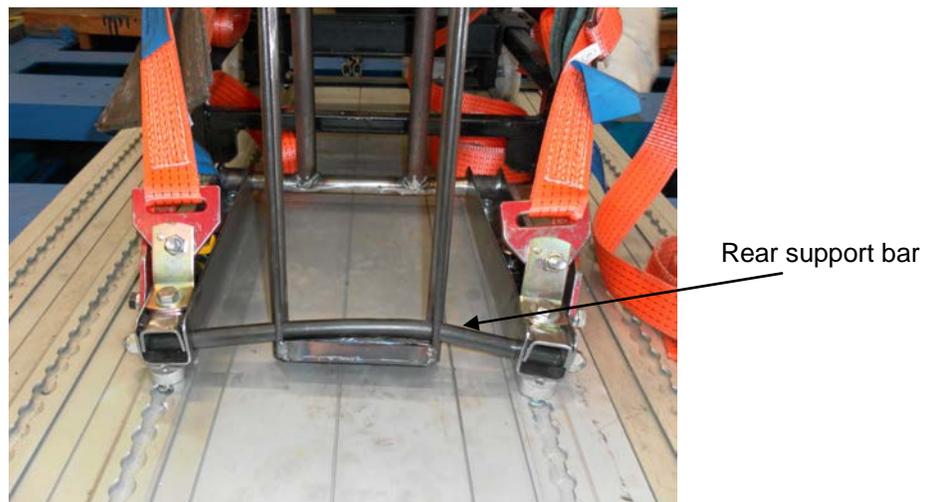


**Fig 77. - The locking pin of the new skate compared to an old model skate**

#### Test 4

This test was carried out using the Mild Steel model; it was also done using old model skates with the larger locking pin.

The test was carried out increasing the load to M1 in 5 seconds. The test was successful and was achieved with little deformation of the back restraint structure.



**Fig 78. - Deformation of the rear support bar after test**

The main effect on the structure after the test was the deformation of the rear support bar. It had been pulled up, mainly on the side of the upper anchorage point by approximately 35mm. The channels had also been pulled inwards towards the centre of the back restraint.

There was slight deformation of the rear bar; it had been pushed down towards the ground. This was at maximum deformed 1mm.



**Fig 79. - Back restraint and wheelchair after passed test**

The prototype passed the physical testing, proving that the overall concept and orientation of the design was correct. The testing did produce a number of failures of the lockable fixtures. These are a third party product that has been incorporated into the design. A new set of lockable fixtures (Unwin HAL (26)) have now been introduced.

### 9.1.1 Summary of Physical tests

Test Number	Summary
1	Mild steel back restraint tested. Backrest achieved 4/5 M2 loading. Failure occurred in both lockable skate fixtures.
2	Stainless steel back restraint tested. Failure in both lockable skate fixtures (As seen in test 1).
3	Stainless steel back restraint tested. 5/6 M1 loading achieved before failure. Failure in one lockable skate fixture. Deformation to back restraint base channel.
4	Mild Steel back restraint tested. Difference in lockable fixtures identified. (Old and New versions), Back restraint past test. Slight deformation to rear support bar.

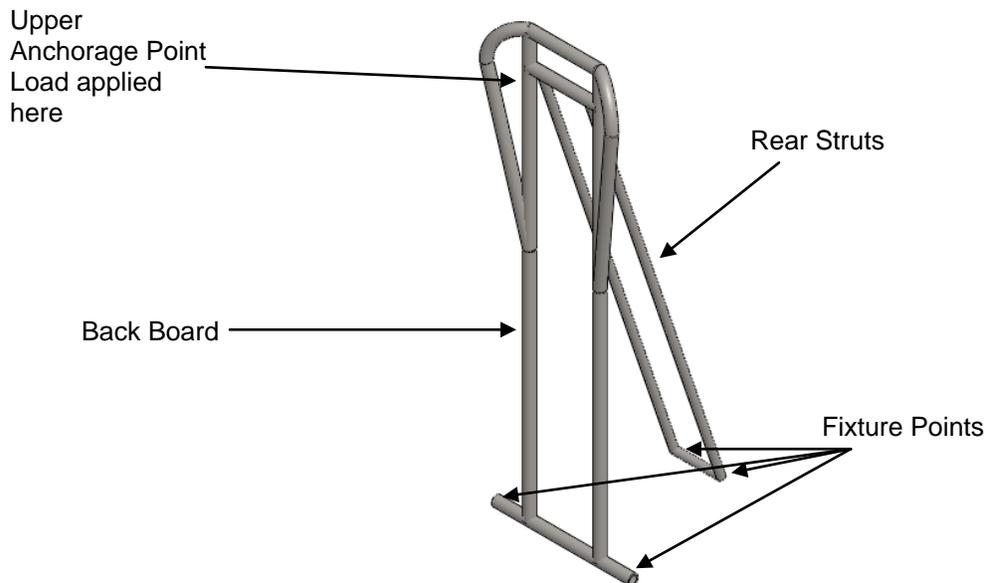
**Table 13 - Physical Testing Summary**

## 9.2 Refining the Design

Weight also needed to be considered. The weight of the tested design is approximately 11kg, 4kg under the target value stated in the PDS (Point 12.1). From handling the devices this weight has to be reduced and the device made easier to manoeuvre. It became apparent that there are points in the PDS that were incorrect and should have been tested before sign off. This will be discussed further in the Evaluation chapter.

### 9.2.1 Alternative Material FEA Study

The purpose of this study is to ensure that the FEA testing is carried out on the exact lay out that was previously used. In previous tests the tube model was created in a basic form to test the theory of the design. For this study, the rear struts will now stretch up to a point that is level with the upper anchorage point, rather than the top of the structure. This duplicates the model that was tested on the test rig.



**Fig 80. - Tested Model Tube Configuration**

Aluminium is only commercially available in imperial sizes (Steel or stainless steel which is available in metric sizes.) The material dimensions of the model were changed to aluminium tube in the tube sizes that are available for manufacture.

<b>Model No.</b>	<b>Back Board Material</b>	<b>Rear Strut Material</b>
1	25.4mm (O/D) Mild Steel Thickness = 3mm	18mm (O/D) Mild Steel Thickness = 1.5mm
2	25.4mm (O/D) 1060 Aluminium Thickness = 3mm	18mm (O/D) 1060 Aluminium Thickness = 1.5mm
3	38.1mm (O/D) Aluminium Thickness = 2mm	38.1mm (O/D) Aluminium Thickness = 2mm
4	38.1mm (O/D) Aluminium Thickness = 3.25mm (Gauge 10)	38.1mm (O/D) Aluminium Thickness = 3.25mm (Gauge 10)
5	25.4mm (O/D) Aluminium Thickness = 3.25mm (Gauge 10)	38.1mm (O/D) Aluminium Thickness = 1.63mm (Gauge 16)

**Table 14. - List of models tested and material and tube thickness**

The force applied to the model is the same as the previous study, simulating the upper anchorage force. 12.5kN acts in the forwards direction and 6.25kN will act in the vertical downwards direction. The model was meshed with beam elements; this provided an accurate result with a much faster simulation than the solid component.

<b>Model</b>	<b>Weight (kg)</b>	<b>Von Mises Stress (N/m<sup>2</sup>)</b>	<b>Deflection (mm)</b>
1	7.87	9.29E8	28.66
2	2.72	9.19E8	86.14
3	3.79	4.24E8	29.96
4	5.95	2.87E8	19.73
5	4.52	5.72E8	35.76

**Table 15. - Results from the alternative material FEA study**

The first model is made using mild steel; this is the same that was physically tested. The second model is a direct comparison to the first model, it is the same tube size and thickness but that material has been changed to aluminium. As can be seen in Table 15 the weight has reduced from 7.87kg to 2.72 kg (65.4%). The overall stress levels are similar due to the geometry being the same but the deflection has increased from 28.66mm to 86.14mm. While this is still within the allowed deformation of the standard for M1 seating (20), previous experience from testing has found when the deformation is this large, it causes uneven loading on the lockdown fixtures and tracking which leads to a failure.

Model 3 (See Table 15) has the tube size increased to 1.5inch (38.1mm) tube with a thickness of 2mm. This is 1.07kg heavier than model 2 but the deformation has been reduced to 29.96mm. This would be acceptable for the physical testing and the stress levels are 64% of the maximum tensile strength (Maximum tensile strength of 1060 Aluminium Alloy = 680,000,000 N/m<sup>2</sup>). This would be a suitable material and tube size for construction of the back restraint. However, this size tube is not available on the market. The tube sizes available are 1 inch (25.4mm) and 1.5 inch (38.1mm) outer diameter with a thickness of gauge 10 (3.25mm) or 16 (1.63mm). The following tests will be carried out taking this into account.

In model 4 (See Table 15), all the tubes used are 1.5inch gauge 10. The weight of this is 5.95kg, 24.4% less than the original steel model. The stress has been reduced throughout the model to 2.87E8 N/m<sup>2</sup>. This is 57.8% lower than the maximum tensile strength and only 0.17E8 N/m<sup>2</sup> above the maximum yield stress.

Model 5 (See Table 15) has the back board constructed out of 1 inch gauge 10 aluminium tube and the rear struts made up of 1.5inch 16 gauge. From the results this appears to be a compromise between model 3 and 4. It weighs 4.52kg, 42.6% less than the original steel model and 24% less than model 3. The deformation is 35.76mm which is greater than model 3 and 4 but still enables the model to pass the physical testing. The stress levels are elevated slightly from the previous models but due to the

increased tube sizes and thickness is 38.4% less than the original steel model. This is 15.8% less than the maximum tensile strength of the material.

By changing the material to aluminium the weight can be reduced. This does have an effect on the strength of the structure, so the thickness of the front panel has been increased to gauge 10 (3.25mm). The rear support struts have been increased to 1.5 inch (38.1mm) outer diameter with a thickness of 16 gauge (1.63mm). This size increase is to make up some of the strength lost by changing the material to aluminium and also an aesthetic decision as these parts will be on display. The front board will be clad in a seat cushion and backing cover.

## **10. Back Restraint Final Design**

The design had been decided upon using the results gathered from the physical testing and FEA studies. This was then constructed ensuring all the detail and components are included. This chapter includes the final designs for the back restraint as well as material choices and level of trim. It also includes the final FEA study used to check the design.

### **10.1 Material and Finish Specification**

The finish of the back restraint is important, the PDS (Point 13.1) states that it must be in- keeping with the aesthetics of the vehicles that it will be used in. The original plan was to get the tubular structure polished to a high level, which would provide a chrome effect. A clear powder coat would be used to protect it from any fingerprint marks and scratching. This would help maintain the high standard and professional look of the product.

When sourcing quotes for getting the framework polished, it soon became apparent that it could not be done as cheaply as other methods that were available. For the polishing alone the quotes were £80 per frame. This with the powder coat added to it (approximately £5 for a batch of 100 frames) was too costly to add on to each unit. Due to the complex shape of the framework around the bends and joints, each unit would have to be hand polished which is an expensive process.

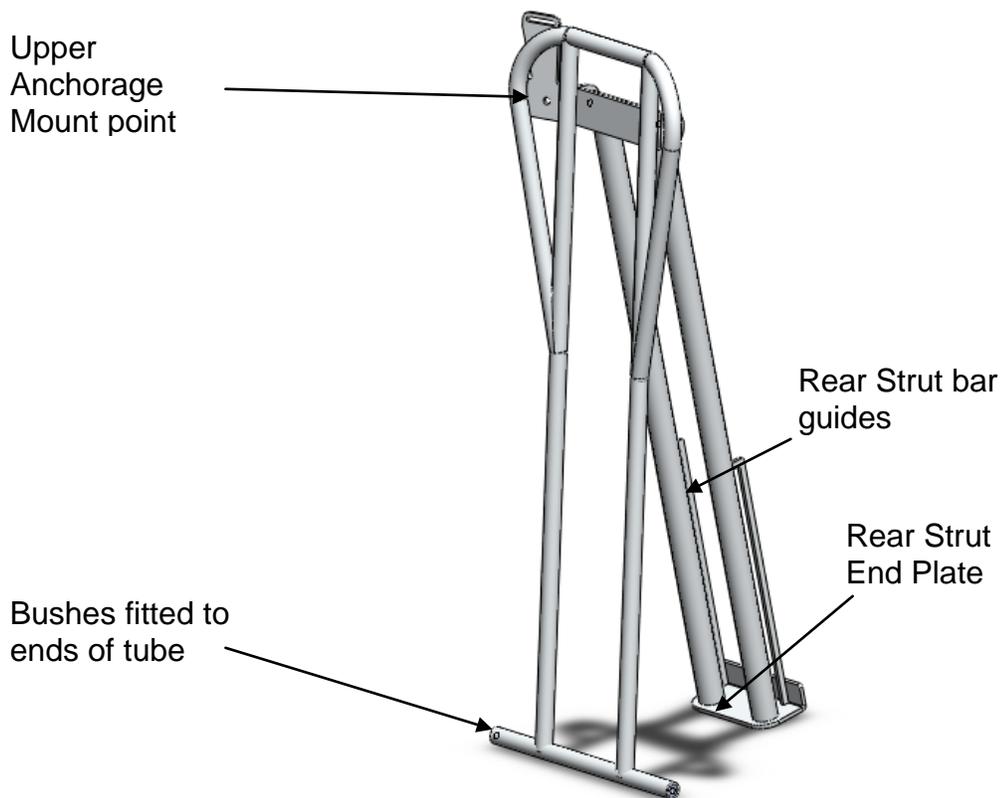
Other alternative finishes were investigated. The two most appropriate were anodising and coloured powder coating. While anodising could provide a good finish and protection, due to the aluminium welds containing silicon, this could not be used. The silicon in the welds discolours when anodised resulting in all of the welds in the framework being a different colour from the rest of the tubes.

Powder coating was chosen as a cost effective finish for the back restraint. A light grey colour was picked as it matched interior trim of many of the vehicles produced by GM Coachwork Ltd. The channels that are fixed onto the lockable fixtures were also powder coated in the same colour.

The cushioned part of the back restraint that will provide the support (for the user) will be constructed from a sheet of ply with foam and trim applied. The trim will be made up of automotive seat material in order to match the interior of the vehicle.

## **10.2 Final Model**

The prototype model that had been drawn up from the quotes was then adjusted to make it more suitable for manufacturing. The radius of the 'ears' were made to a uniform tooling. The pipework in the model was adjusted from metric to imperial grades to take into account it would be made out of aluminium. (Aluminium tube is only readily available in imperial rather than the metric used in mild steel.)



**Fig 81. - The Final CAD Model**

An additional plate has been mounted next to the pivot of the rear struts, which is on the side where the seat belt reel will be mounted. It will move up and go through a positioning slot which will hold it in the correct position so that the belt is over the occupants shoulder. This will be the upper anchorage point.

At the end of the rear struts, the end plate size has been increased so that it overlaps the ends of the tube by 10mm. This modification was necessary due to changing the material to aluminium. The weld bead when welding aluminium is larger than that of steel so it will need a larger surface area to get a sufficient bond.

The bars on the back of the rear struts have been changed for slots made out of 6mm sheet aluminium. The single 3mm bar, made out of steel, used in the physical test was

strong enough but in order for the aluminium to be strong enough, and simplify manufacture the decision was made to make this component from sheet material.

The ends of the tubes on the front section are fitted with solid bushes' in order to provide a fixing point for the lower anchorage points. It is on these sections that the channels are fitted.

The skates that were present in the physical testing (which were not FEA tested due to the complexity of the mesh and time constraints) can be seen in Figure 82. These are complex to build and have been made up from a number of components welded together.

Once the CAD model had been produced and changes made, 3 units were ordered to be manufactured. These would be the first fully trimmed prototypes. They would be presented to staff at GM Coachwork and a select group of wheelchair users and carers. Figures 82 and 83 shows the first completed trimmed product.

A full technical drawing package can be found in Appendix 5.

It was at this point that the final prototype was given a product name for presentation to industry and potential customers. Artemis was chosen, as the Greek goddess of light and protector of the vulnerable (32) it seemed an appropriate name for the product.



**Fig 82. – The Artemis fitted into tracks**

Rear Wheelchair  
Tie Downs

3 Point Seatbelt  
Occupant  
Restraint



**Fig 83. – The Artemis fitted with wheelchair in place**

Figure 83 shows the Artemis located in the Unwin tracking that is fitted into all minibuses and most cars. It also shows a wheelchair in position and tied down using the back restraints wheelchair tie down straps. The 3 point seat belt occupant restraint is also in position around the wheelchair.

## 11. Back Restraint Evaluation

This chapter will go look back to the original specification for the back restraint set out in the PDS as well as evaluating its overall performance in its designed function. The accuracy of the FEA tests when compared to the results from the physical testing will also be evaluated.

The design tool that was used for studying potential structural weaknesses of the designs was FEA, this was chosen for a number of reasons. It aided with establishing the 3D CAD software (SolidWorks) into GM Coachwork as it demonstrated that design could go from sketch to computer model and then tested in a very short time period. The resources were available to this process, SolidWorks was already being set up in the company and a graduate engineer was trained in using it. There were also support resources available at the university. The company Chief Executive was also in favour of FEA as it gave a definitive answer of what areas were weak and in need of additional design attention.

Further design tools were considered, FMEA (Failure Mode and Effect Analysis) was considered for including into the design process. It is a useful tool for implementing into a design process and minimises the likelihood of failures, it is also a useful method of analysing risk within a design and reducing this to a suitable level it was discounted because senior members of the design team felt looking for potential failures and ranking these to calculate severity was unnecessary. It was considered that there was more risk in using FMEA as a design tool as potential failure points could be neglected whereas weak areas would be more likely to show up when looking at the results of FEA studies.

## 11.1 Performance of design in FEA and Physical Tests

The result of the FEA studies on The Artemis showed that the main area of deformation was around the 'ear' section (locating the upper anchorage point). This is due to the large bending moment that is acting on it as it is fixed into the ground. The largest proportion of the force is being applied to this area.

The deformation of the back restraint is predicted to be 35mm, occurring in the 'ear' section. The maximum stress that occurs in the model is  $7.5 \times 10^8 \text{ N/m}^2$ . This is 10% over that of the maximum tensile strength of the material which is  $6.8 \times 10^8 \text{ N/m}^2$ . While this load exceeds that of the maximum of the material, the assumptions and simplifications that were made while setting the conditions of the study must be taken into account. The tubes are fixed by points on the model. There are additional brackets that will be fitted to the physical model to allow it to fold. The framework is taking the full load rather than being able to transfer it to the fixings and floor of the vehicle that the back restraint will be fitted in.

The Artemis passed the physical testing. There was a large area of deformation on the rear bar which moved upwards and the channels moved in towards the centre. It is this area that was not modelled in the FEA tests. The 'ear' section on the side that the upper anchorage point is located showed some signs of deformation although not the amount that the FEA tests predicted.

## 11.2 Comparison of physical tests and FEA

FEA allowed the development of the designs while still in the concept phase. This is a very cost effective way of carrying out design refinement, as it did not involve having to physically make or test any components.

The initial concepts were modelled on the computer using the CAD software. The ideas were then discussed and evaluated and certain concepts were taken forward to the next level. This would include putting extra details into the initial CAD models such as fixing points for restraints and mounting brackets for the moving components. It was at this stage where weight was looked at as the CAD software could give an accurate figure of how much the model weighed.

With this information the initial FEA tests were carried out. If the tests proved that the model needed more strength added, an extra flange or enforcing plate could be added and the FEA test re-run very quickly. 3-4 iterations of design could be run in the space of 3 hours whereas if the design was being physically built it would take 2-3 days and up resources in material. Physical testing of each iteration would not have been possible as GM Coachwork Ltd does not have the facilities to do so and each physical test can cost £1500.

The same method was used when changing the layout of tubes for Concept 7 (the front pivot model) which went on to become the final product. This gave a number of options of models which could be used and allowed the design team to choose the best compromise between high strength and reduced weight by looking at the results of the FEA.

The FEA tests of Concept 7 that was recreated in the physical test. Being able to directly compare the results of the FEA to those of the physical testing gave a direct indicator of how accurate the computer simulations are.

The FEA testing showed that the back restraint would be able to sustain the load applied to it. It demonstrated the areas of high stress and where there would be deformation in the model. Although simplified, the FEA did not take into account the rear bar or channels. The results show that it would pass the physical test.

The physical testing that was carried out was a dynamic test. The load was applied and took 3 seconds to reach maximum load. This is different to the FEA test situation where the full load was applied instantaneously. This was chosen for a number of reasons. The time taken to run the simulation would have been increased by at least 5 times. As the project ran a large number of smaller studies there were not the resources available to run these as a dynamic simulation. Software limitation also meant that static simulations were the preferred option for testing. GM Coachwork only had access to SolidWorks Simulator software which could not run a dynamic simulation therefore any additional testing would have to have been carried out elsewhere. An operator of a more advanced software would also have to have been resourced.

The simulations were run with this limitation in mind. Simplified assemblies were run concentrating on the key areas of interest, the mesh of the model was kept simple in order to speed up simulation time and the joints between components were assumed to be perfect. In the case of the VW Seat base FEA (Chapter 4.3) the simulation was advanced to model the weld joints while still using the static simulation.

FEA studies that test materials above their yield stress do require a dynamic FEA study as it predicts the deformation of the material more accurately than a static simulation. Due to hardware and resources available for the project a fully dynamic study could not be ran. With additional resources a dynamic FEA study of the completed back restraint should have been carried out. This would have provided a direct comparison between FEA and physical testing.

The effects on The Artemis during the physical test are discussed above. These differences in the results could be because of the addition of the rear bar and channels in the physical test. By deforming they would have dissipated a lot of the load that was in the model before the deformation occurred at the upper anchorage point. The total deformation in the FEA model was 35mm and this was the distance that the upper anchorage point had moved forward after the physical test.

FEA will never replace the need for physical testing. There are too many assumptions and compromises to be made. For example, software and hardware capabilities and time constraints means that dynamic simulation tests cannot be run. Static FEA tests proved informative when evaluating the difference design changes made to a concept. A combination of the FEA and real life experience of the GM Coachwork engineers must be applied in the future.

### 11.3 Costing

The bill of materials consists of the aluminium framework, channels, (Technical drawings can be seen in Data CD Appendix 5) lockable fixtures, seat belt and wheelchair lock down restraints, and trim and labour costs.

The costs for these are calculated for an order of 100 units.

<b>Part Description</b>	<b>Cost (£)</b>
Aluminium Framework	98
Channels	60
Lockable Fixtures	30
Seatbelt and Wheelchair Restraints	160
Trim + Labour	200
<b>Total</b>	<b>538</b>

**Table 16. – Bill of Materials**

The total of £538 is under that of the initial target production cost stated in point 5.1 of the PDS.

## 11.4 Final Product compared to PDS

The completed product will now be compared against the PDS that was created at the start of the design project. This will enable the design team to see how it conforms to the original specification.

- 1.1 The Artemis meets the requirements of an M1 (20) seat and successfully passed the appropriate physical testing.
- 1.2 The addition of a standard car seat head rest reduces the chance of whiplash during an accident. The literature review states the differences a head rest can make during an accident.
- 1.3 The Artemis provides additional back support and a head rest for wheelchair users and positions the seat belt in the appropriate position making travelling in a vehicle a much more comfortable experience.
- 1.4 The Artemis is removable from the tracking fitted into vehicles and locks in behind the wheelchair when it is its travelling position.
- 1.5 Designed to use the Unwin (20) HAL lockable fixtures, the back restraint fits into the tracking fitted into vehicles. There is adjustment on the width to allow it to fit into the 270-350mm range stated in the original PDS.
- 1.6 The Artemis does not exceed the maximum loading and the tracking. This was proven in the physical tests.
- 1.7 As the Artemis fits into the tracking, it is difficult to install it incorrectly. As long as the lockable fixtures are in the tracking then the device is secure.
- 1.8 The ability to fold up when not being used means that the Artemis can be stored compactly. This will be most convenient for minibuses with multiple back restraints as they can be stacked.
- 1.9 The Artemis is of a quality build. There are some rattles coming from the third part lockable fixtures but these are reduced when the restraints are put in place and is tightened up.

- 2.1 The Artemis have a service parts and are set to last the length of the Motability contract. (5 years).
- 2.2 There are no fragile parts to the product. This means that it is not in danger of damage if it is knocked over or dropped.
  
- 3.1 The weight of 16kg is under the manual handling limit for people in the work place. However, moving the Artemis around shows that it may still be too heavy for the target elderly group.
- 3.2 The physical tests prove that the product can behave like an M1 seat during an accident
- 3.3 The Artemis has a similar back and the same head rest as a standard M1 seat so comfort levels are similar.
  
- 4.1 The same seat belts and wheelchair tie downs are incorporated to the Artemis that are currently used to hold wheelchairs in place. This means that maintenance remains the same.
  
- 5.1 The production cost is £538 for an order of 100 units. This comes in under the target production cost of £600-850.
  
6. Competition Matrix Comparison

Using the same feature comparison and QFD analysis as used in the Literature Review Competition Matrix (Chapter 5), GM Coachworks 'Artemis' will be compared against the other similar products on the market.

No.	Feature	Product			
		Unwin	AMF	NMI	<b>Artemis</b>
1	Weight (kg)	32	N/A	24	16
2	ISO10542 Tested	Yes	No	Yes	Yes
3	Tested to:	M1	M1	M2	M1
4	3 Point Belt	Yes	Upper Only	No	Yes
5	Height Adjustable	No	Yes	No	Yes
6	Incline Adjustable	No	Yes	No	No
7	Fitted to tracking	Yes	Yes – Additiona I needed	Yes	Yes
8	Max W/C Weight (kg)	85	85	85	85
9	Removable to use	Yes	Yes – Twists to side	Yes	Yes
10	Behind user	Yes	Yes	Yes	Yes
11	Can act as regular seat	No	No	No	No

**Table 17. Feature Comparison between GM Coachworks ‘Artemis’ and competitors’ products**

No.	Feature	Product Number			
		Unwin	AMF	NMI	<b>Artemis</b>
1	Weight	-1	Datum	+1	+1
2	ISO10542 Tested	+1	Datum	+1	+1
3	Tested to M1	0	Datum	-1	0
4	3 Point Belt	+1	Datum	+1	+1
5	Height Adjustable	-1	Datum	-1	0
6	Incline Adjustable	-1	Datum	-1	-1
7	Fitted to tracking	+1	Datum	+1	+1
8	Max W/C Weight	0	Datum	0	0
9	Can act as regular seat	+1	Datum	0	-1
	<b>Score</b>	<b>1</b>	<b>0</b>	<b>1</b>	<b>2</b>

**Table 18. – Stage 1 Matrix analysis of QFD features compared to GM Coachworks ‘Artemis’**

The QFD weightings will now be applied and the back restraints compared.

No.	Feature	Product Number				Weighting (1 = minimum 10 = maximum)
		Unwin	AMF	NMI	<b>Artemis</b>	
1	Weight	-1	Datum	+1	+1	8
2	ISO10542 Tested	+1	Datum	+1	+1	10
3	Tested to M1	0	Datum	-1	+1	10
4	3 Point Belt	+1	Datum	+1	+1	8
5	Height Adjustable	-1	Datum	-1	+1	7
6	Incline Adjustable	-1	Datum	-1	-1	7
7	Fitted to tracking	+1	Datum	+1	+1	7
8	Max W/C Weight	0	Datum	0	+1	8
9	Can act as regular seat	+1	Datum	0	-1	1
	<b>Score</b>	<b>4</b>	<b>0</b>	<b>9</b>	<b>0</b>	<b>25</b>

**Table 19 - Stage 2 Matrix analysis including QFD**

The results (Tables 18 and 19) clearly show that the GM Coachworks design successfully meets more requirements than any of the similar products which are already on the market.

7. These will not differ to standard GM Coachwork products being sold.
8. These will not differ to standard GM Coachwork products being sold.
9. The target of 200 per annum is realistic. The pricing and design for manufacture has been carried out accordingly.
10. The Artemis is intended to be subcontracted out with little to no final assembly at GM Coachwork.  
The Artemis royalties could also be sold to a seat restraint company to produce and sell.

- 11.1 Having been tested on a number of wheelchairs at GM Coachwork, the Artemis is able to fit each of them with no problem.
- 11.2 The physical testing was carried out to ISO10542 (2) and the restraint locations comply to this standard.
  
- 12.1 The Artemis exceeds the ideal weight of 15kg by 1kg. There are potentially more weight savings available.
- 12.2 The Artemis weighs 16kg so is under the maximum limit of 25kg.
  
- 13.1 The automotive finish is good and the metal work matches those of the majority of vehicles.
  
- 14.1 Standard engineering materials were used throughout the product.
  
- 15.1 The Artemis is intended to last the 5 years of a standard Motability contract.
  
- 16. The Artemis meets the standard it was set out to. ISO10542 (2), M1 Class Seat, European Classifications (20) and Motability are all met.  
WAVCA Standards were being written as the back restraint was being designed and the back restraint does not infringe on any of these.
  
- 17.1 The Artemis secures into the vehicle and rattles only come from a third party component. These are reduced when the straps are applied.
- 17.2 Comfort levels are comparable to an M1 level seat.
- 17.3 The weight is currently too much for an elderly person.
- 17.4 The combination of wheelchair and back restraint is less than the previous combination of wheelchair and tie down straps. This is because the Artemis fits in closer behind the wheelchair than the current tie down straps were fitted.
  
- 18. The target customer market remains the same as initially intended.

19. Further tests will need to be carried out to see how the Artemis wears over a longer period of time and use.
22. The Artemis was delayed past the initial retail launch. The product was presented to sales staff at GM Coachwork in January 2011.
- 23.1 The Artemis underwent the usual GM Coachwork tests for products as well as initial FEA testing.
- 23.2 The seat belts and wheelchair ties down straps meet the ISO10542 standards.
- 23.3 The Artemis meets the M1 seat pull test. The head rest impact test has not been carried out yet but a standard OEM head rest is used so this should not prove an issue.
24. The safety tests have been carried out during the physical testing which was passed. No protruding edges were present after the test.
- 25.1 The back restraint design project fitted in around other projects that were being carried out at GM Coachwork without delaying any of them.
- 27.1 While not patentable, GM Coachwork has a full design record of the development of the Artemis and holds the design rights to the product.  
The name 'Artemis' is not trademarked, this will need to be considered when bringing the product onto the market.
- 27.2 The Artemis does not infringe on any existing patents for products that are currently on the market.
28. The introduction to the Artemis to the market may have many social and political implications. This will be discussed in the conclusion.

29. The Artemis meets the legal testing it has to undergo for ISO10542 and an M1 seating regulation.  
It is classed as an occupant restraint and wheelchair tie down device.
- 30.1 Full documentation will be available instructing users how to correctly use the device.
- 30.2 The weight of the Artemis needs to be reduced to make it suitable to elderly users.
- 31.1 The physical testing has been documented by both GM Coachwork and STATUS (30).
- 31.2 The project has been completely documented in log books and all CAD models kept on GM Coachworks server.
- 31.3 A full user guide will be produced to be included with each back restraint
32. As standard engineering materials have been used the back restraint is disposable and conforms to end of life vehicle standards.

The finished design conforms to many of the specification points originally set out at the start of the project. The main specification point that it does not meet is the use for the target user (Point 3.1). This is due to the weight. The target weight (Point 12.1) may still have been too high for the user. This is an issue that can be addressed as discussed in the conclusion.

## **12. Business Case Evaluation**

The position of GM Coachwork as a company and how the process has improved the design and development process are reviewed in this chapter. The effect of the technology that has been implemented in the company during the course of the MPhil are discussed.

### **12.1 Evaluation of Process Implementation**

There were a number of different processes used over the course of the back restraint project. Primarily a formal, fixed design brief and PDS had never before been established before commencing work on a design. The need for a product was traditionally brought to the attention of the design team by the Chief Executive. The requirements would then be listed and communicated to the designers left to it. Once built the Chief Executive would then review the design then often list additional requirements and the design process would start again.

On the back restraint project the design brief and PDS forced the design team leader, to thoroughly think through the requirements of the product and set out exactly what needed to be achieved before any designs began. This meant that all the designs produced were to one specification and not changed during the project. By having the PDS signed off it meant that it was less likely to change during the implementation of the project.

While not using the exact method used in back restraint project, (32 steps of Pugh (29)) the design team have adopted the practice of creating a detailed brief and specification for products before a design is started. An example of this is the two new vehicles the Citroën Berlingo 'Blaze' and Peugeot Expert 'Flare'.

Another difference to previous design projects was a formal combination of all design engineers at GM Coachwork working together. This resulted in monthly 'design team meetings' which were chaired by the Chief Executive and design team leader. Before these meetings it had generally been one designer per project with very little cross over. By bringing together the team it allowed the engineers to share ideas and discuss solutions for problems that had arisen.

This worked not only on the back restraint project but on other projects such as the VW Caravelle 'Monterey' and 'Minibus Lite' vehicles.

The biggest change to the design process at GM Coachwork was the introduction and successful use of the 3D Design Software.

The Managing Director introduced changes based, on his own experience, aimed at speeding up the conversion time and increasing the manufacturing capabilities of GM Coachwork without directly having to increase the facility size or employ more staff.

A production line was brought in for the VW Caravelle 'Colorado' and 'Nevada' range. This split the conversion into 4 stages where each fitter would carry out a set stage repeatedly. The vehicle would then travel down the line and the next stage of the conversion would be carried out. Times of the conversion were reduced as each fitter perfected his particular stage of the conversion. The conversion time reduced from 240 hours per vehicle to 160 hours and 6 vehicles a month were being produced. This is set to increase to 8 by the end of 2011.

Another change to the smaller, less complicated conversions, involving 1 person per vehicle, was to reduce the time the vehicle was in the work bay. This was done by splitting as many of the components that could be made up as subassemblies off the vehicles beforehand and having them made in batches. This was done in batches of 10 at a time so there was a constant supply of sub-assemblies ready to be put onto the vehicles. Through repetition this reduced the time each sub assembly took to put

together. When the vehicles went for the conversion the sub-assemblies could be put straight on the vehicle instead of having to be built while the vehicle was in the work bay.

A new vehicle assembly technique was introduced by the Managing Director. Instead of welding the lowered floor pans into the vehicles, which can be a lengthy and messy process, as much welding was taken out of the conversion process as possible. Instead, the floor pans were riveted and bonded in place. This effectively 'deskilled' the conversion and made it a much simpler and quicker process.

The conversion time for the Fiat Doblo 'Aspen' came in at approximately 60 hours. With the culmination of subassembly components and a bonded and riveted floor pan the replacement model, the Citroën Berlingo 'Blaze', had a conversion time of 26 hours.

## **12.2 Evaluation of Technology Implementation**

Computer Aided Design had never been used at GM Coachwork and was introduced initially with a number of mini projects discussed in a previous chapter. The back restraint project was the first time that the software would be used from initial design concept through to testing and design completion.

The ability to produce design ideas on the computer screen allowed all of the design team to visually see the concepts instead of deciphering them from rough sketches. It also allowed an initial weight and dimensions calculated easily. This made selecting concepts that were worth following up or discarding a quick and efficient process.

Once a design was taken to the next level initial CAD models could be adjusted to get in more detail that was required or make structural changes. This would not be possible if producing 'mock ups' for each iteration. The lack of material costs and time saving potentially saved weeks on the design process

The staff at GM Coachwork were keen to learn the software and a training programme of 2 hours per week for each of the 3 engineers was started.

Once the engineers had time and some guidance to use the software as well as seeing the mini projects as examples of what could be done they became increasingly enthusiastic. They began to see more and more examples that the software could be used for. Their abilities increased quickly and were carrying out more advanced modelling and drawing projects. By the end of the project they were able to create parts and drawings to be sent to manufacturers with little or no assistance.

An example of this is an engineer who also had little interest in using the software for himself. When asked about training he stated that he would be happy with using the software to get access to existing drawings but that was it. After a couple of training sessions his ability to use the software increased and he got more enthusiastic, even coming in early and staying in late to have time training on the software and became the most capable of the original engineering staff in the company.

The ability to produce high level technical drawings in a number of different formats to send to suppliers increased GM Coachworks image within the industry and other suppliers. It even produced access to suppliers further afield who previously would not deal with the company due to the lack of technical drawings.

An example of this was the Fiat Doblo 'Aspen' conversion kit technical drawing package was produced. The components of the conversion was modelled in 3D CAD and then the technical drawings were produced. A supplier in the midlands who previously would not have dealt with GM Coachwork due to lack of technical drawing information for parts then provided a quote which worked out considerably less than was currently being paid by local suppliers (see costing below). When the kits were supplied the quality was much improved on the previous supplier and the quantities could be increased.

The technical drawings also increased the accuracy of the parts that were produced. Giving set dimensions to work to instead of copying an example from a previous batch of components greatly increased the consistency of the parts that were being ordered. The technical drawings also produced a trail of revisions when a design was changed which could be traced back if there was ever a warranty issue or problem with older vehicles.

There were issues with the implementation of CAD. It became clear that creating technical drawings from existing parts proved inaccurate and some parts were manufactured without being checked by another engineer. This resulted in some parts being incorrectly made. A change to the technical drawing process was established and the drawing template was modified to incorporate a signed off section to ensure that each drawing was verified by a separate engineer who had checked the drawing. See Appendix 2.

Data management was another issue that had to be overcome. Any drawings that were sent to suppliers were held on a paper copy in a folder by the stores man. He would fax the drawings to suppliers for production or for a quotation. With the ability to produce technical drawings in different electronic formats the drawings could now be emailed, providing a better quality of drawing in the preferred format of the supplier. Due to only having one license of SolidWorks in the design office the stores could not open the SolidWorks drawing themselves. All the drawings were then saved in 3 formats on a separate hard drive which belonged to stores. These were the SolidWorks drawing (.sldprt) a PDF (.pdf) and DXF (.dxf) format.

Each time a drawing was updated on the design office computer the stores external hard drive was updated. This ensured both systems were always up to date with the latest revision and also served as an additional backup in case of any problems which resulted in a loss of information on the design computer or server.

The ability to produce 3D CAD models and high quality technical drawings improved GM Coachworks reputation when dealing with the major vehicle manufacturers such as VW, Peugeot-Citroën and Renault. Having the ability to accept CAD models also meant that conversions could be preassembled on the computer before a new vehicle was delivered to GM Coachwork. This technical ability helped improve the relationship with these suppliers and contributed to the technical accreditation and vehicle approvals from VW and Peugeot-Citroën and lead to Renault accreditation in April 2011.

Finite Element Analysis was something that GM Coachwork originally believed to be far too advanced or expensive for their use. The Simulator software built into SolidWorks was used for the FEA studies used in this design process. The initial weight reduction and max stress location tests provided by the FEA will be valuable to GM Coachwork on future projects and could save considerable amounts of money on physical testing if a failure is prevented.

The FEA results for the final design also allowed GM Coachwork to enter the physical testing with the confidence that the design would pass.

This was quite an advanced practice for GM Coachwork and with no engineers who are trained in the FEA software in the company it is unlikely to use it often in future projects.

The use of it in the back restraint project served as a demonstration to the benefits of using it and what the software was capable of. For larger design projects where prototyping and testing may be of importance GM Coachwork may know what they want from an FEA study and be able to subcontract the skills in from a specialist company.

The costs to take on these changes were initially the CAD software and the hardware needed to run it. These were £6500 for the software with annual subscription payments of £1500. The hardware required cost £1100.

The savings are difficult to calculate in time but for examples such as the Fiat Doblo conversion kit mentioned above, by having the ability to find another supplier who could produce the parts at 35% (£300) less per vehicle provided an annual saving of £2,700 based on 6 vehicles per month. This saving could then be applied to other vehicles as the process is repeated.

Another example of savings provided by 3D modelling is the sub-assembly mini project. This would have saved 2-3 hours of labour time (up to £105 based on GM Coachworks rate of £35 per hour labour charge) and up to £50 on materials. These sub-assemblies would be carried out 3-4 times per month.

### **12.3 Company's Position**

During the time of this project, the company has increased its ranking in the wheelchair accessible vehicle industry. It won the 'Motability Partner of the Year Award' in 2009 and again was 'Commended' at the same awards in 2010. It has risen above the mid field players in the industry to ranking among the top members. The turnover has increased to £14 million since the start of the MPhil and number of staff employed by the company has risen from 60 to 85.

There have been a number of new vehicles added to GM Coachworks range. The Citroen Berlingo 'Blaze' has replaced the outgoing Fiat Doblo 'Aspen'. A new 'up front passenger' version of the Peugeot Expert has been launched labelled 'Flare' and the VW Caravelle has had a number of new models introduced called the 'Nevada' and 'Monterey'. The Citroen C8 'Sirus' has stopped production due to Citroen discontinuing the model. The range of minibuses remains the same with the addition of the new light weight bus called 'Minibus Lite'.

Manufacturing capabilities have been increased primarily thanks to newer faster build conversions and changes brought in by the Managing Director as discussed above.

## **13. Conclusion**

Overall the project has been successful. A working product has been produced. It met the criteria set out at the start of the project and was carried out using processes and technology that were new to the company.

New CAD and FEA processes were introduced during the course of this project and the level of success can be shown that it was also adapted and applied to other projects being carried out over the course of the KTP placement. In addition to technology take on, the adoption of new design processes and the collaboration of the design engineers to a formal design team for the project was a significant achievement of the project.

### **13.1 Back Restraint Design Project**

The back restraint design project was successful and the Aim (Aim 1 Paragraph 1.1.1) set out at the beginning of the MPhil has been achieved. After conceiving 7 different concepts (Objective 1 Paragraph 1.1.2), a working product was produced and tested to the necessary requirements to be put into the market place. When compared to competitors' products GM Coachworks design proved stronger in nearly each category showing that it was designed specifically to be the most practical of the products available (Objective 2 Paragraph 1.1.2).

There are still possible improvements that can be made to the design. The steel channels that fix to the lockable fixtures could potentially be revised. Preliminary drawings for a machined or cast aluminium block were created for this. It would take the place of both the channels and the lockable fixtures, attaching straight to the tracking. This would reduce the need for a complicated fabricated assembly in the current channels and also the need for a 3<sup>rd</sup> party component, the lockable fixtures, which proved to be the problem in the physical tests.

The motivation to do this is both cost and weight saving. Quotes from suppliers for a machined aluminium block were £60 for the pair, which would reduce the production cost of the total product by £30. The weight saving would also be greatly beneficial, the weight would be reduced by 2kg per fixtures reducing the total weight by 4kg.

The finished designed was delayed from the original intended finishing date. This was mainly due to other influences within the company. A number of new vehicles were designed and launched during the time the back restraint was being designed. There was also the process of vehicle type approvals and inspections that demanded a lot of labour time to be spent on them. The back restraint was always the project was affected by these other factors. The PDS stated under the company constraints (Point 25.1) that the back restraint should not have an adverse effect on any other projects that are running at the same time. While this was kept to, there were serious effects to the back restraint project development and timescale. Labour resources were not available until 4 months before the completion of the finished product.

Further testing would ideally be carried out to confirm the results of the finished product. This could also act as a marketing tool. By carrying out a dynamic sled test, which would have a manikin fitted in the wheelchair and be recorded on a high speed video camera, the effects on a human body could be recorded and shown as part of the promotional material for the product. This test could be carried out with just a wheelchair and occupant installed in a vehicle and then a wheelchair and occupant using the Artemis in a vehicle. The footage of the two videos would then be compared against each other.

When presenting the product to the sales staff and other key members of GM Coachwork (Objective 3 Paragraph 1.1.2) it soon became apparent that there may be social implications introducing such a product to the market.

The literature review shows that there are obvious dangers to the way wheelchair occupants are currently travelling in vehicles but unless there is a suitable alternative,

available to all then it is a belief that, even with the risks, enabling wheelchair occupants to get out in vehicles improves their quality of life immeasurably and by introducing stricter regulations on how they are able to travel my stop some people travelling at all.

An option that was suggested was to introduce the product to the market through Motability (30). Having the Artemis available on the Motability scheme would mean huge subsidies and funding to allow them to be sold with each new vehicle. Although this would provide a potentially huge market the product must first be proved in service to ensure that it is the best available and to be the forefront at such a radical change to the safety of the industry.

The decision has been made to continue to refine the model and be ready to present it to an external company, who specialises in making wheelchair and occupant restraint straps. That may sell the product on behalf of GM Coachwork, or present it to Motability to be sold via their scheme.

## **13.2 Design Process and Technology Implementation**

GM Coachwork had a positive reaction to all of the changes that were introduced over the course of the MPhil. The engineers felt they had more of a focus than before and enjoyed working with each other on designs instead of having their own exclusive projects. Until the amalgamation of the design team, the engineers each had individual projects and felt almost like they were played off against each other to see who would come up with the better design. With the introduction of the design team, it allowed the engineers to exchange more ideas with each other and the designs became a culmination of their ideas. This method often showed up problems with certain ideas that one engineer had not thought of before the design had progresses too far.

The aim of introducing a formal design process (Aim 2 Paragraph 1.1.1) has been achieved, as discussed in the evaluation, while the company has not adopted the PDS method used in the back restraint project (32 Steps of Pugh (29)), the concept has been

taken on (Objective 5 Paragraph 1.1.2). This initial design specification takes the form of a 'work instruction' produced on GM Coachworks internal IT system. This is a sheet which states the requirement that the design must meet in a simpler form. The design is then issued with a job number, to which materials and labour time can be booked to and all the documentation is stored under this number.

There was also a positive reaction to the introduction of 3D CAD. (Aim 3 Paragraph 1.1.1) After the engineers saw what it was capable of in the mini projects they were keen to learn how to use it and make the most of its potential. They also saw it as a way to increase their own personal capabilities and treated it as professional development. While the engineers, who were actively using the software and aware of its capabilities and what the limitations of the software were, the CEO's expectations were harder to manage. He had seen software being used in the automotive industry by the major manufactures and believed that GM Coachwork should be able to carry out the same tasks. How the FEA worked and its limitations were not often considered when he requested tasks to be complete. The mini projects helped to an extent for him to see what was realistic. Timescales involved in modelling and running analysis was an expectation that constantly had to be managed, when other smaller jobs that took longer than originally predicted resources were repeatedly taken away from the back restraint project.

Up skilling the engineers to be able to use CAD independently was a major milestone for the MPhil. The introduction of the software would have been pointless if it was to be made redundant after my time at the company had come to an end. It was essential that the engineers were trained to a level where they could use the software to produce component and assembly drawings to be sent to manufacturers unaided. I believe that this was achieved and for the last 2 months of my time at the company the engineers had taken over the majority of the modelling and drawing work that had to be done. (Objective 4 Paragraph 1.1.2)

As discussed in the previous chapter, FEA was not adopted by the existing engineers. This would have required more resources and the engineers labour time than was available for training. It is also something that David Vooght could not see the advantage of investing time and staff into for the few projects that it would be used in. The members of the design team are aware of the uses of FEA, its capabilities and limitations and may seek to use it through outside contractors for specific projects in the future. (Objective 6 Paragraph 1.1.2)

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## **Appendix 1**

This appendix will review the standards and regulations surrounding the transportation of a wheelchair user in a motor vehicle. It will look at the ISO Standard and the European Union directives surrounding passenger vehicle occupant safety.

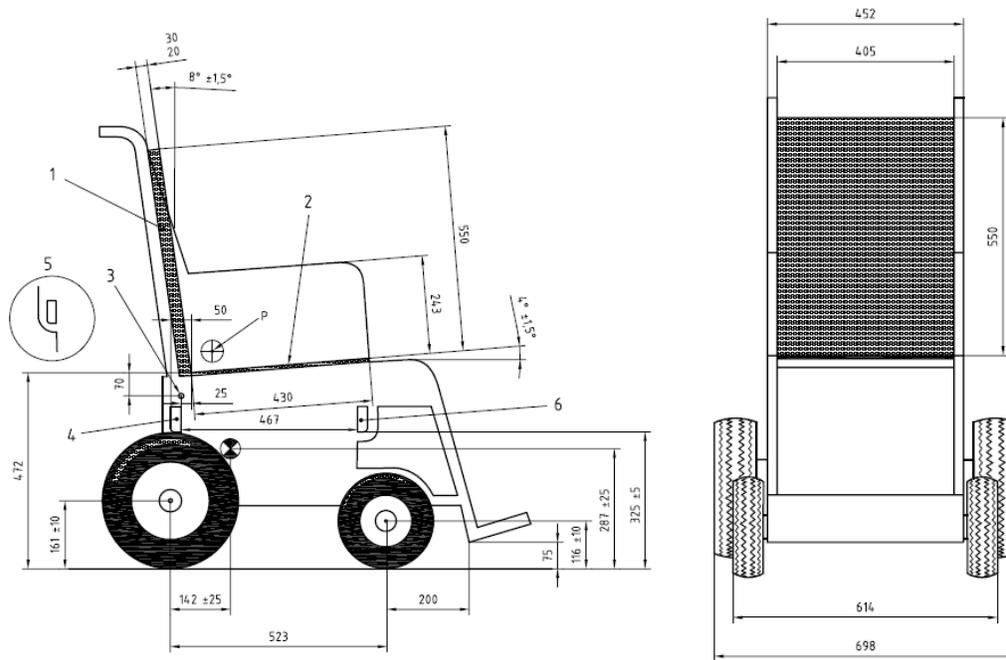
This appendix also includes a summary of the anthropometric data used in the designs.

### **A1.1 Standards and Legislation**

#### **A1.1.1 ISO10542**

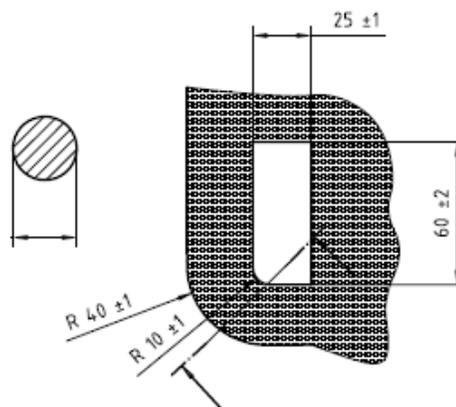
ISO10542 (2) is the standard for the wheelchair tiedown and occupant restraint systems. It provides the guidelines for the location of the wheelchair restraints and occupant safety belts on the vehicle and the wheelchair, as well as the path that the seatbelt should take across the occupant's torso.

As part of the standard, it also provides the measurements for a surrogate wheelchair. It is this chair that the WTORS are designed against and what are used and tested with when the WAV is being developed. The dimensions of the surrogate wheelchair are essential for the development of any restraint system, as it is the benchmark for the wheelchair that is tested with it.



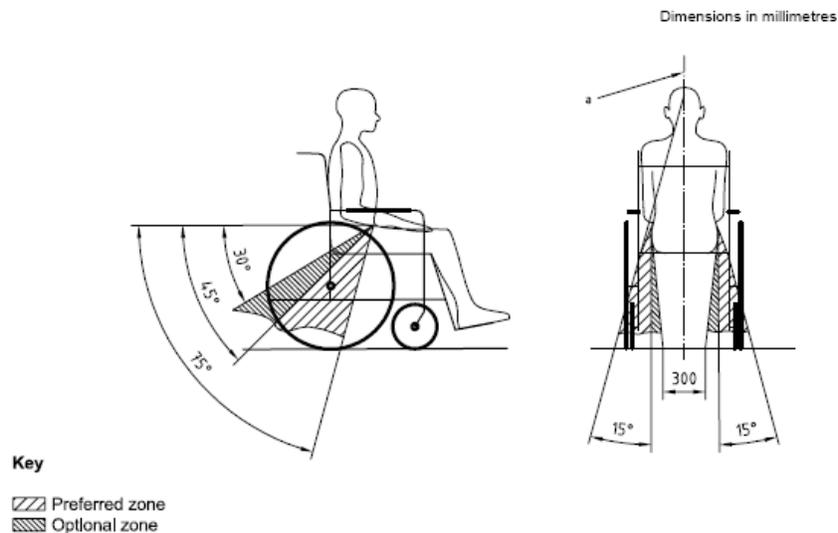
**Fig A1.1. - Dimensions of the surrogate test wheelchair. (2)**  
**(All dimensions are ±5mm unless otherwise stated)**

As can be seen in Figure A1.1 there are specified locations for the securement points. These are the points where the strapping is attached to the wheelchair that is then fixed to the tracking or anchor point on the vehicle. They also have a set of dimensions to which the surrogate wheelchair must comply.



**Fig A1.2. - Wheelchair securement size. (2)**  
**(All dimensions in mm)**

The tie down locations for the occupant restraint must be in a certain range of positions. These positions control the travel of the seatbelt across the occupant's torso and at what angles the pelvic belt comes up from the floor. The pelvic belt must go inside the arm rests of the wheelchair and properly support the occupant. It must not just travel over the arms of the chair.



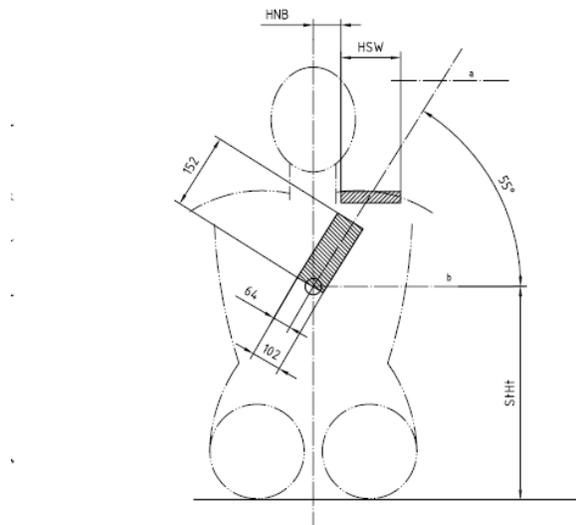
**Fig A1.3. - Occupant Restraint position range. Also showing preferred zone. (2)**

The wheelchair occupant sits facing the front of the vehicle. In the wheelchairs side plane the occupant restraints are allowed to come back from the pelvis position in between the angles of 30° and 75° from the horizontal. From Figure A1.3 it can be seen that the preferred angles range from 45° to 75° from the horizontal.

In the rearward plane, the restraints are allowed to come in towards the centre line of the vehicle but must keep a minimum distance of 150mm from the centre line. They are then allowed to move outwards to a maximum of 15° from the centre point of the occupants head.

For the torso belt there is a set angle in which it should pass across the torso. This is to ensure sufficient restraint of the occupants' upper body to support them during an accident.

Dimensions in millimetres



See Table F.1 for typical values of HNB, HSW and StHt.

a Belt angle

b Sternum reference plane

**Fig A1.4. - Preferred zones for location of shoulder belt (2)**

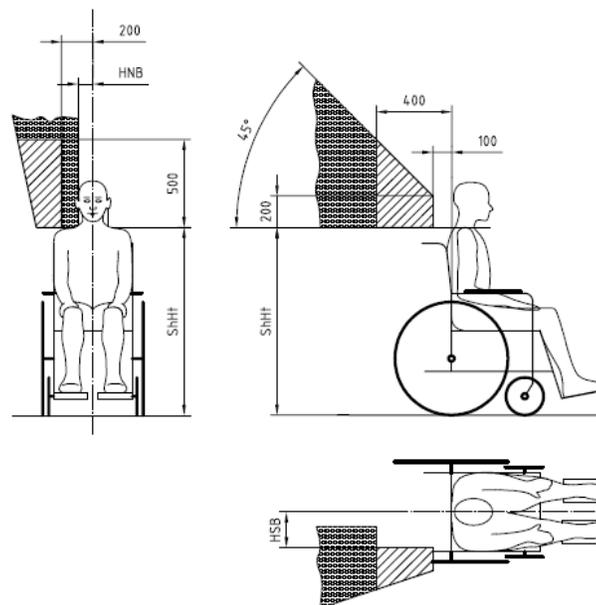
Occupant Size	Half neck breadth HNB	Half Shoulder Width HSW	Sternum Height StHt
Small Female	66	109	353
Average Male	76	127	406
Large Male	81	135	432

**Table A1.1. - Recommended Belt fit values. (2)  
(Dimensions in mm)**

Figure A1.4 shows the Sternum Height (StHt) is the centre part of the torso where the seatbelt should cross. It should be running along here at an angle of 55° from the horizontal. The area on the shoulder in which the seatbelt should pass over and make contact with all depends on the Half Neck Breadth (HNB) and the Half Shoulder Width (HSW) which all depends on the size of the occupant. Table A1.1 above shows the anthropometric data for the range of sizes that the ISO standard caters for.

Once the path of the torso belt has been decided upon across the occupant's body it has to be fastened to the upper anchorage point. As the previous studies have demonstrated it is essential this is in the correct place to ensure that the occupant is properly restrained. Figure A1.5 below shows the regions in which the upper anchorage point is allowed to be located.

Dimensions in millimetres



**Key**

-  Preferred zone
-  Optional zone

**Fig A1.5. - Zones for upper anchorage point of upper torso restraint.  
(Can be either side of the wheelchair) (2)  
(All dimensions in mm)**

The frontal view in Figure A1.5 shows the height and how far out the upper anchorage point should be located. It is preferred that it should range from the Shoulder Height (ShHt) to 500mm above the ShHt and be located from a minimum of 200mm from the centre of the passenger, although an allowed region starts from the maximum HNB.

The side plane view shows where the restraint can be located out from behind the occupant. This region starts 100mm from the rear of the occupants head and extends outwards at an angle of 45° from the occupants head. The preferred zone for this point is in the distance from 100-400mm from the rear of the occupants head and 200mm up from the ShHt.

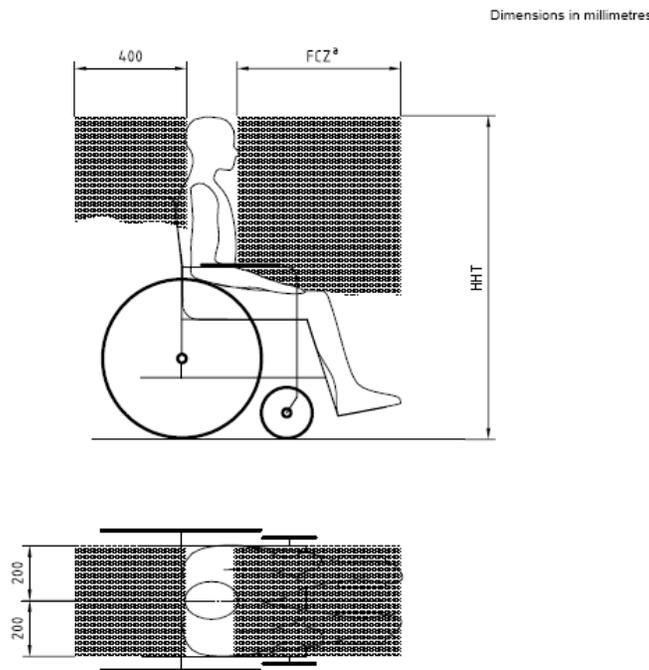
The downward view in Figure A1.5 of the occupant seated in the wheelchair shows that the preferred region for the upper anchorage point starts after the HSB unless it is 400mm behind the rear of the drivers head and then it has the option of coming in up to the HNB.

Occupant Size	Shoulder Height ShHt	Half Shoulder Breadth HSB	Half Neck Breadth HNB	Seat Height
Small Female	1000	175	66	450
Average Male	1100	200	76	500
Large Male	1200	210	81	550

**Table A1.2. - Typical Values for ShHt, HSB, HNB and Seat Height (2)  
(All dimensions in mm)**

The above Table A1.2 shows the different anthropometric data for the range of adults that the standard covered. The positioning of the anchorage points should account for the individual size variation.

Once the wheelchair is positioned in the vehicle there are certain zones that should be kept clear. These 'clear zones' are to ensure that if the vehicle is in an accident and the occupant is thrown around forwards or backwards in their wheelchair then they are not going to come into contact with anything sticking up or out of the vehicle.



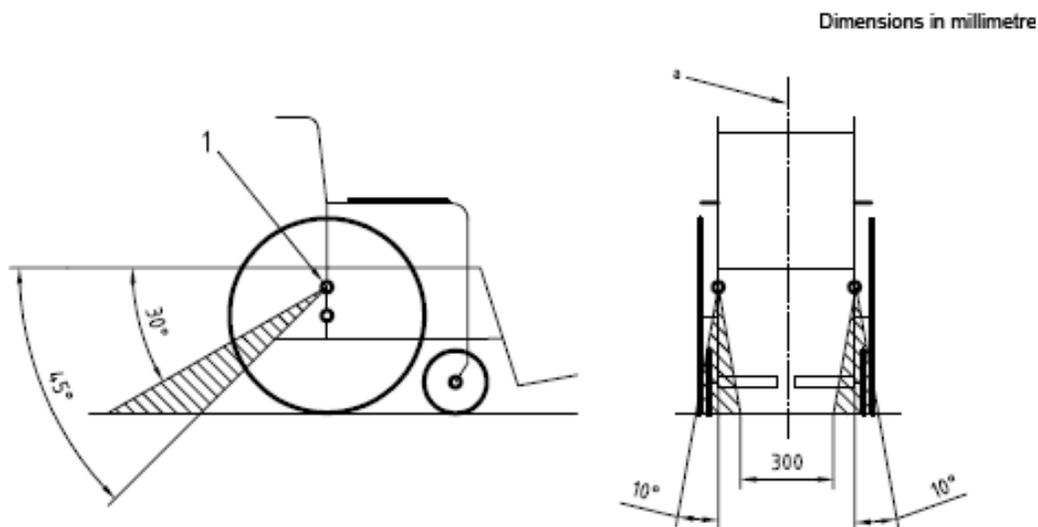
**Fig A1.6. - Clear Zones (2)  
(All dimensions in mm)**

Figure A1.6 shows that in the frontal plane, 200mm either side of the centre line of the occupant should be kept clear. There should be 400mm clear from the back of the occupants head. Forward of the drivers head the Front Clear Zone (FCZ) depends on

the type of occupant restraint being used. If an upper torso restraint is being used, then the FCZ should be at least 650mm. If only a pelvic restraint is being used then the FCZ should be extended up to 950mm. The height of the clear zone should be up to the Seated Head Height (HHT) of the occupant. This ranges from 1200mm for a small adult female to 1550 for a tall adult male.

Part 2 of ISO10542 is applied to the method in which the wheelchair itself is tied down to the vehicle. The wheelchair is restrained using front and rear tie downs which are attached to the wheelchair at the restraint points and then into the vehicle floor either using tracking or solo mounting points.

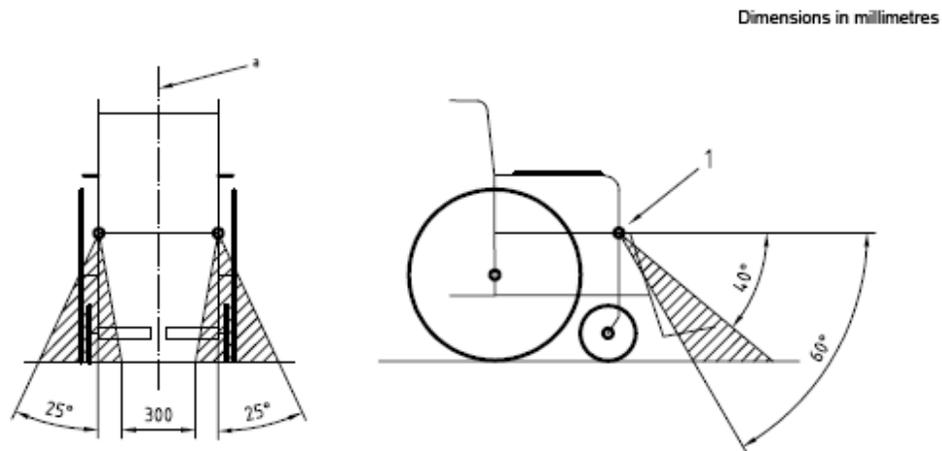
The rear wheelchair restraints (Figure A1.7) extend outwards behind the wheelchair. They are permitted to be within the angles of  $30^{\circ}$  to  $45^{\circ}$  from the horizontal. The restraints are allowed to come in behind the wheelchair to a minimum distance of 150mm from the centre line and outwards to  $10^{\circ}$  from the vertical from the wheelchair restraint mounting point.



**Fig A1.7. - Angles for rear wheelchair-tiedown straps and locations of anchorage points (2)**

Figure A1.8 shows the front wheelchair tiedown restraints. These have a fitting zone which extends out from the front of the wheelchair between the angles of  $40^{\circ}$  to  $60^{\circ}$  degrees from the horizontal. They are permitted to go inwards to within 150mm from

the centre line of the wheelchair and then outwards to a maximum of 25° from the vertical plane from the wheelchair restraint mounting points.



**Fig A1.8. - Angles for front wheelchair-tiedown straps and locations for anchorage points. (2)**

Along with the recommended angles and positions for the wheelchair restraint ISO10542 also sets the maximum and minimum strap length for the restraints, shown in Table A1.3. These lengths are based on the minimum lengths considered to be reasonable to achieve the anchorage and securement locations as well as the adjustment and tensioning of the strapping. The maximum lengths are recommendations based on the maximum strap lengths that will not be too impractical in real world situations.

Strap	Lower Length Recommendation	Upper Length Recommendation
Rear	485	740
Front	410	710

**Table A1.3. ISO10542 Upper and Lower Length recommendation for tiedown straps. (2)**  
(All dimensions in mm)

### **A1.1.2 M1 Seating Regulations**

This section of Appendix 1 reviews the legislation and EU directive that surrounds the test of seatbelt anchorages used in passenger vehicles. Values and forces given are dictated by the regulation.

As the back and head restraint for the wheelchair occupant is targeted at providing protection at the same level as a passenger travelling in a fixed car seat, it is important to test the device up to the same level. The regulations surrounding this are 74/408/EEC as amended by 2005/39/EC (20).

This dictates the standards that the seat must comply to. If the seat/back restraint has an adjustable part on it, the adjustable mechanism must be lockable, with the exception of luxury comfort items like arm rests. Any of these locking items should be on the door side of the seat so it can be accessed from the door and from the passenger behind.

The rear of the seat back rest and head restraint must be suitable and ensure that there are no dangerous or sharp edges that can cause injury to anyone sat behind it. There must not be radii of less than 2.5mm on the back of the seat base and head restraint. In order to test the energy dissipation of the seat back to protect objects or people hitting the seat from the rear, a pendulum test is applied. During this test the deceleration of the sphere must not be greater than 80g for more than 3ms. Should permanent deformation occur during this test there must be no ruptures or failures that cause sharp edges, which could cause further injury. This test is also testing the locking devices on the seat. There must be no release of the locking system during the test and afterwards all locking systems allowing access for occupants should still be in working order. Any other displacement systems or adjusting systems are not required to be in working order after the test.

In order to test the strength of the seat back and its adjustment systems a force of 530Nm in relation to the R point shall be applied longitudinally and rearwards to the upper part of the seat back through a manikin.

For seats with head rests fitted it must be ensured that they do not cause any additional risk to the occupant. There must be no sharp edges or roughness or in a position that could cause injury. There is an energy dissipation test which is carried out using a spherical head form 165mm in diameter which produces an initial moment of 333Nm around the R Point. This is targeted to make contact 65mm below the top of the head restraint. To further test the effectiveness of the head rest the loading is increased to 890N unless breakage of the seat or seat back occurs earlier. If the head rest is adjustable for the purposes of the test it should be positioned in its most unfavourable position which is generally it's highest. The head restraint and its anchorages must be supportive enough to limit the backwards head deformation to a maximum of 102mm.

There are set limits for the height of the head restraints. For seats with adjustable head restraints the height should be no less than 800mm for the front seats and 750mm for any others. For the rear seats if there is an adjusting mechanism that allows the head restraint to go below 750mm, it must be ensured that it is clear there is no use position below these limits.

For front seats, the head restraints can be automatically displaced to a height of less than 750mm when the seat is not occupied providing that it is automatically returned to the position of use as soon as the seat becomes in use. The maximum width of the headrest must not be more than 85mm from either side of the centre line of the seat.

Once the seat has been fitted into the vehicle it must be ensured that there is adequate clearance between the head restraint and the interior surface of the roof, windows or any part of the vehicle structure. This clearance should intrude no less than 25mm from the head restraint.

## A1.2 Anthropometric Data

It is essential that the dimensions of the back restraint suit as many people as possible. There dimensions of the most common sizes of people so in order to fit the 5 – 95 percentile person.

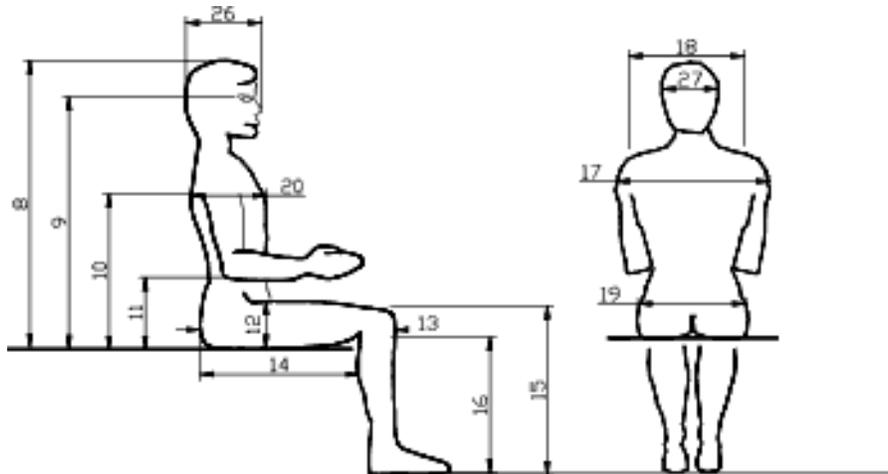


Fig A1.9. – Anthropometric Data (25)

Number	5%	50%	95%	Range	From average
8	795	880	965	170	±85
9	685	765	845	160	±80
10	505	575	645	140	±70
17	355	430	510	155	+80 - 75
18	325	375	430	105	+55 - 50
19	310	365	435	125	+70 - 55
20	135	150	165	30	±15

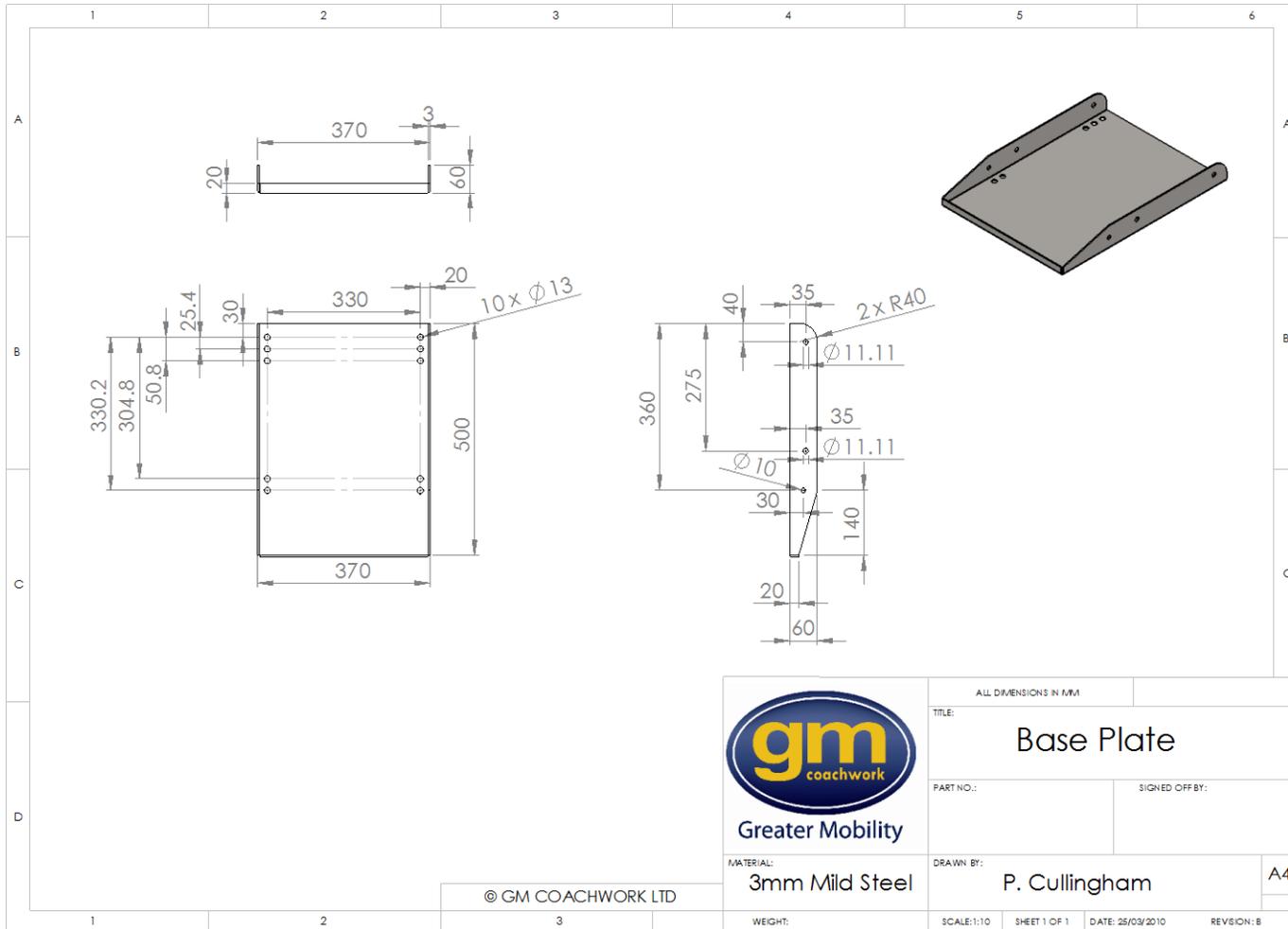
Table A1.4. – Anthropometric Data (25)

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This covers the average sizes of people not taking into account the extreme ranges of the results. This means that if the back restraint is built to fit people in these sizes it will cover 90% of the population.

## Appendix 2

### Base Plate Technical Drawing



# Appendix 3

## Technical Drawing Sheet Template

	1	2	3	4	5	6	7	8	
A									A
B									B
C									C
D									D
E									E
F									F
	1	2	3	4	5	6	7	8	
					© GM COACHWORK LTD				
 Greater Mobility		ALL DIMENSIONS IN MM		TITLE:		PART NO.:		DRAWN BY:	
MATERIAL:		SCALE: 1:1		SHEET 1 OF 1		DATE:		REVISION:	
								A3	

## Appendix 4

### Project GANTT Chart

	2009																	
	May				June					July				August				
	4th	11th	18th	25th	1st	8th	15th	22nd	29th	6th	13th	20th	27th	3rd	10th	17th	24th	
Literature Review	█																	
Design Brief									█									
Requirements and Regulations										█								
Final Specification																		
Concept Designs																		
Concept Evaluation and Selection																		
Prototype Testing																		
Detailed Final Design																		
Evaluation of Final Design																		
Design Manufacture																		

	2009																
	September				October				November				December				
	7th	14th	21st	28th	5th	12th	19th	26th	2nd	9th	16th	23rd	30th	7th	14th	21st	28th
Literature Review																	
Design Brief																	
Requirements and Regulations	█																
Final Specification			█														
Concept Designs								█									
Concept Evaluation and Selection																	
Prototype Testing																	
Detailed Final Design																	
Evaluation of Final Design																	
Design Manufacture																	

	2010																
	January				February				March				April				
	4th	11th	18th	25th	1st	8th	15th	22nd	1st	8th	15th	22nd	29th	5th	12th	19th	26th
Literature Review																	
Design Brief																	
Requirements and Regulations																	
Final Specification																	
Concept Designs																	
Concept Evaluation and Selection																	
Prototype Testing																	
Detailed Final Design																	
Evaluation of Final Design																	
Design Manufacture																	

	2010																	
	May					June				July				August				
	3rd	10th	17th	24th	31st	7th	14th	21st	28th	5th	12th	19th	26th	2nd	9th	16th	23rd	30th
Literature Review																		
Design Brief																		
Requirements and Regulations																		
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Concept Evaluation and Selection																		
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Evaluation of Final Design																		
Design Manufacture																		

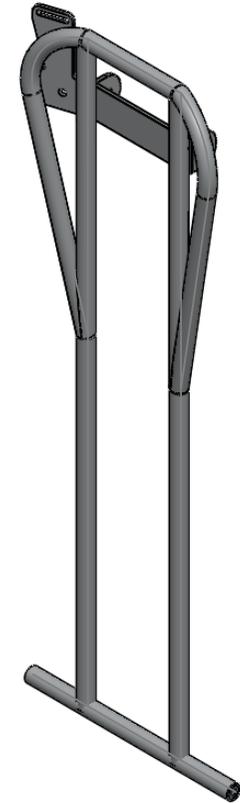
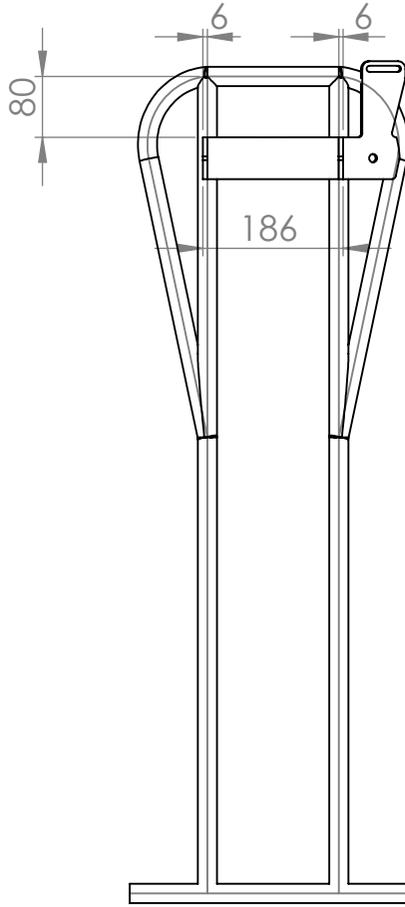
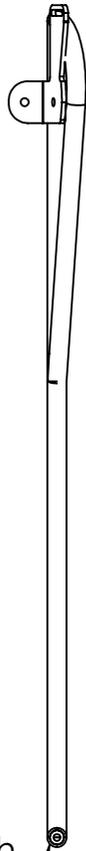
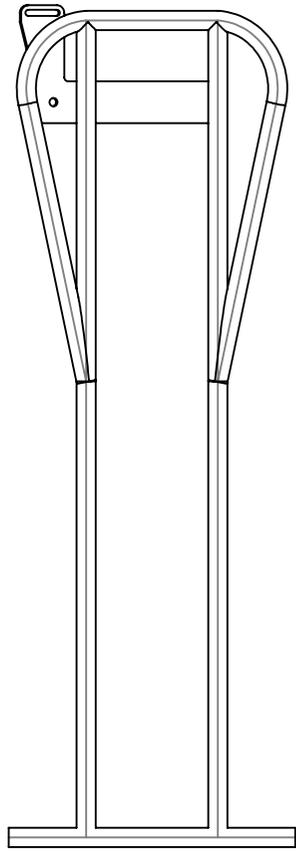
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	September				October			
	6th	13th	20th	27th	4th	11th	18th	25th
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Design Brief								
Requirements and Regulations								
Final Specification								
Concept Designs								
Concept Evaluation and Selection								
Prototype Testing								
Detailed Final Design								
Evaluation of Final Design								
Design Manufacture								

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## **Appendix 5**

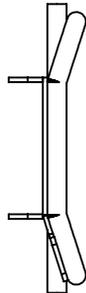
### **The Artemis Technical Drawing Package**





18.9mm Bush fitted in either end

ITEM NO.	PART NUMBER	QTY.
1	Back Board Structure	1
2	Seatbelt Mount Plate	1
3	Hinge Point	2
4	18.9mm Bush	2



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Greater Mobility

MATERIAL:  
See Part Drawings

WEIGHT:

ALL DIMENSIONS IN MM

TITLE:  
**Front Board Assembly**

PART NO.:

SIGNED OFF BY:

DRAWN BY:

**P. Cullingham**

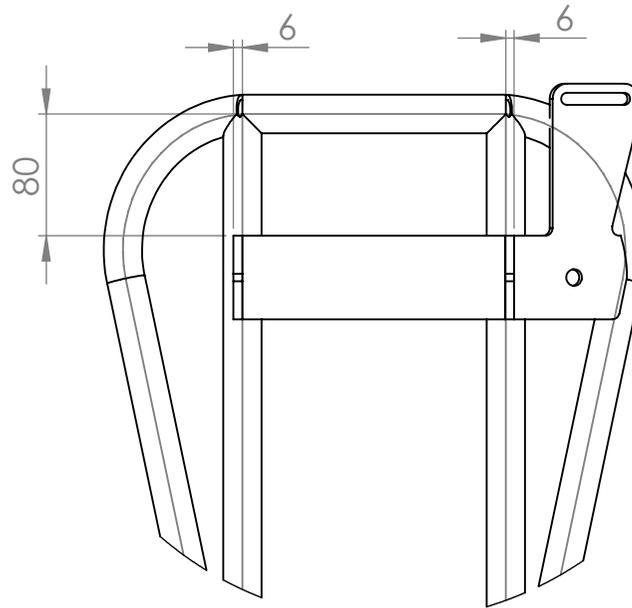
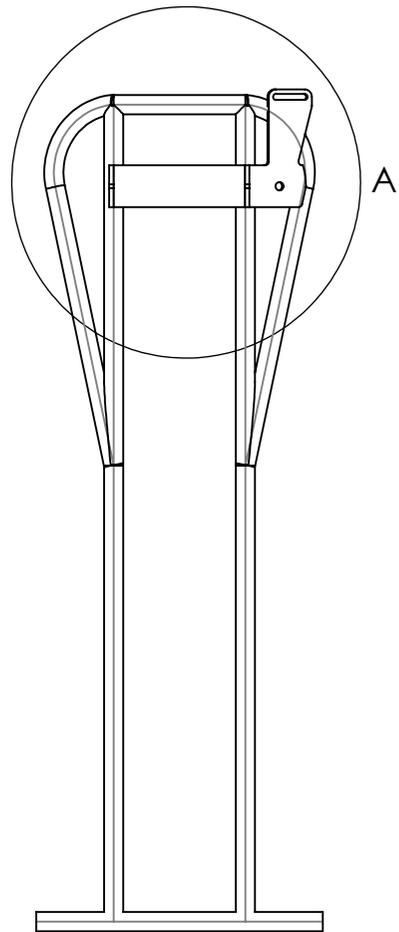
A4

SCALE: 1:10

SHEET 1 OF 2

DATE: 04/11/2010

REVISION: A



DETAIL A  
SCALE 1 : 5



MATERIAL:  
See Part Drawings

ALL DIMENSIONS IN MM

TITLE:  
**Front Board Assembly**

PART NO.:

SIGNED OFF BY:

DRAWN BY:

**P. Cullingham**

A4

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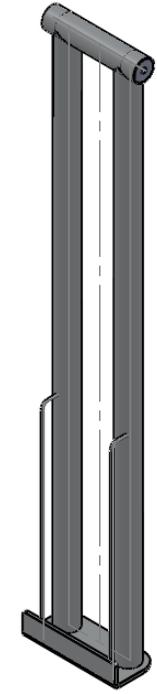
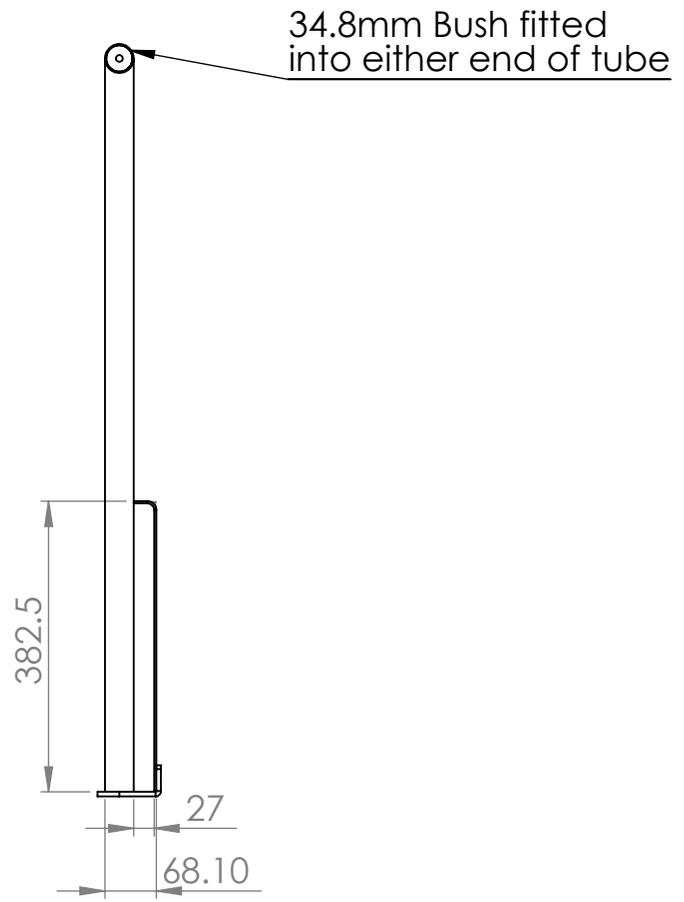
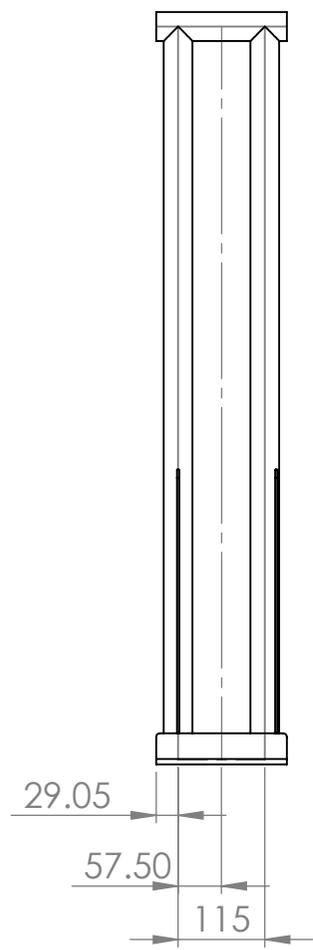
WEIGHT:

SCALE: 1:10

SHEET 2 OF 2

DATE: 04/11/2010

REVISION: A



ITEM NO.	PART NUMBER	QTY.
1	Rear Support Struts	1
2	Strut End Plate	1
3	Guide Bar	2
4	34.8mm Threaded Bush	2



MATERIAL:  
See Part Drawings

ALL DIMENSIONS IN MM

TITLE:  
**Rear Struts Assembly**

PART NO.: \_\_\_\_\_ SIGNED OFF BY: \_\_\_\_\_

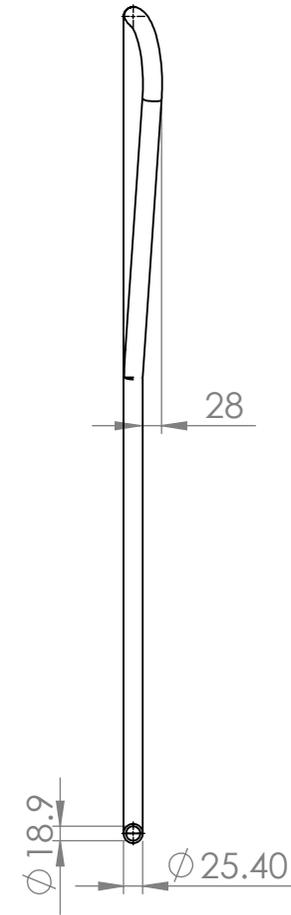
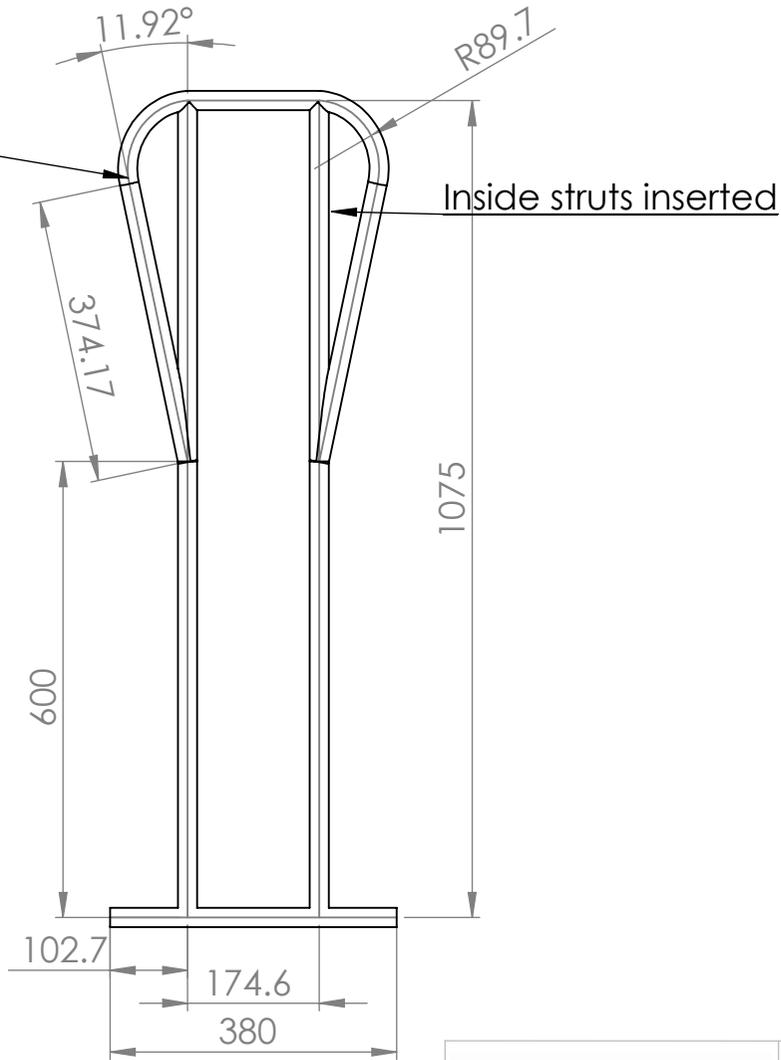
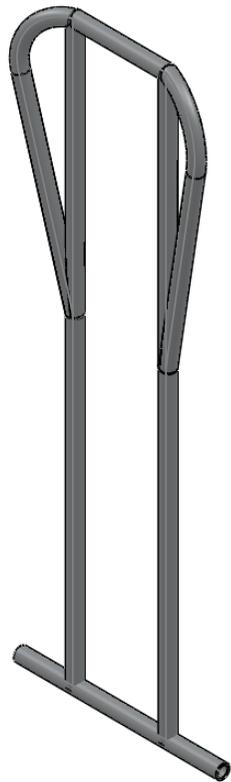
DRAWN BY:  
**P. Cullingham**

SCALE: 1:10 SHEET 1 OF 1 DATE: 04/11/2010 REVISION: A

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A4

Outer Frame constructed from 1 piece



Greater Mobility

MATERIAL: 1050A H16  
Aluminium Tube  
O/D 1 inch, Gauge 10

ALL DIMENSIONS IN MM

TITLE: **Back Board Structure**

PART NO.: SIGNED OFF BY:

DRAWN BY: **P. Cullingham**

A4

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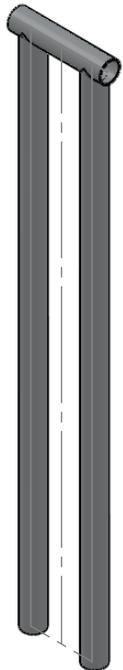
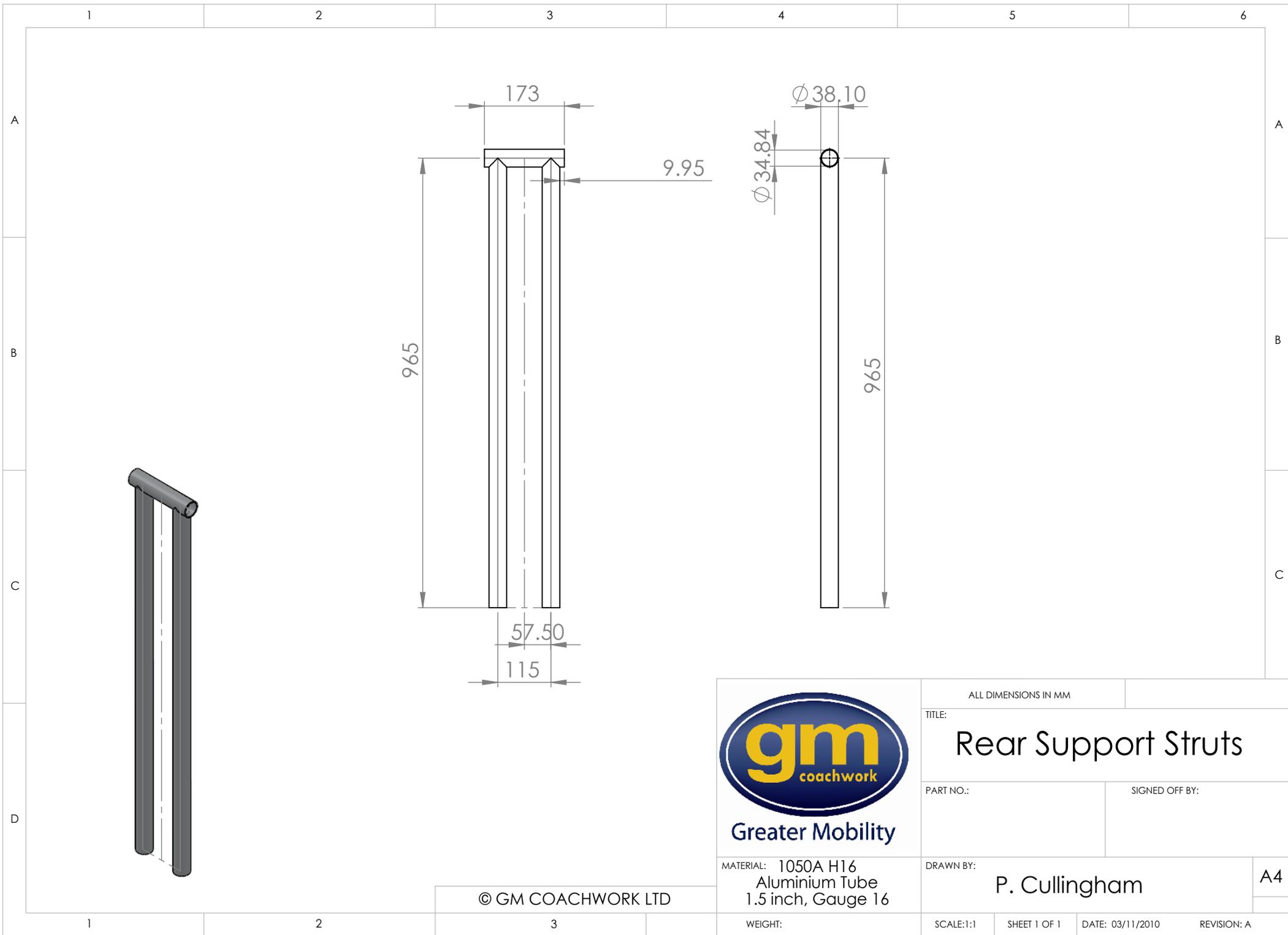
WEIGHT:

SCALE: 1:10

SHEET 1 OF 1

DATE: 03/11/2010

REVISION: A



Greater Mobility

MATERIAL: 1050A H16  
Aluminium Tube  
1.5 inch, Gauge 16

ALL DIMENSIONS IN MM

TITLE: Rear Support Struts

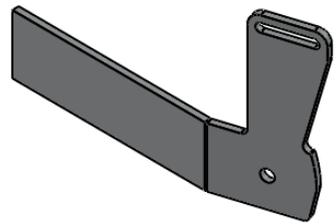
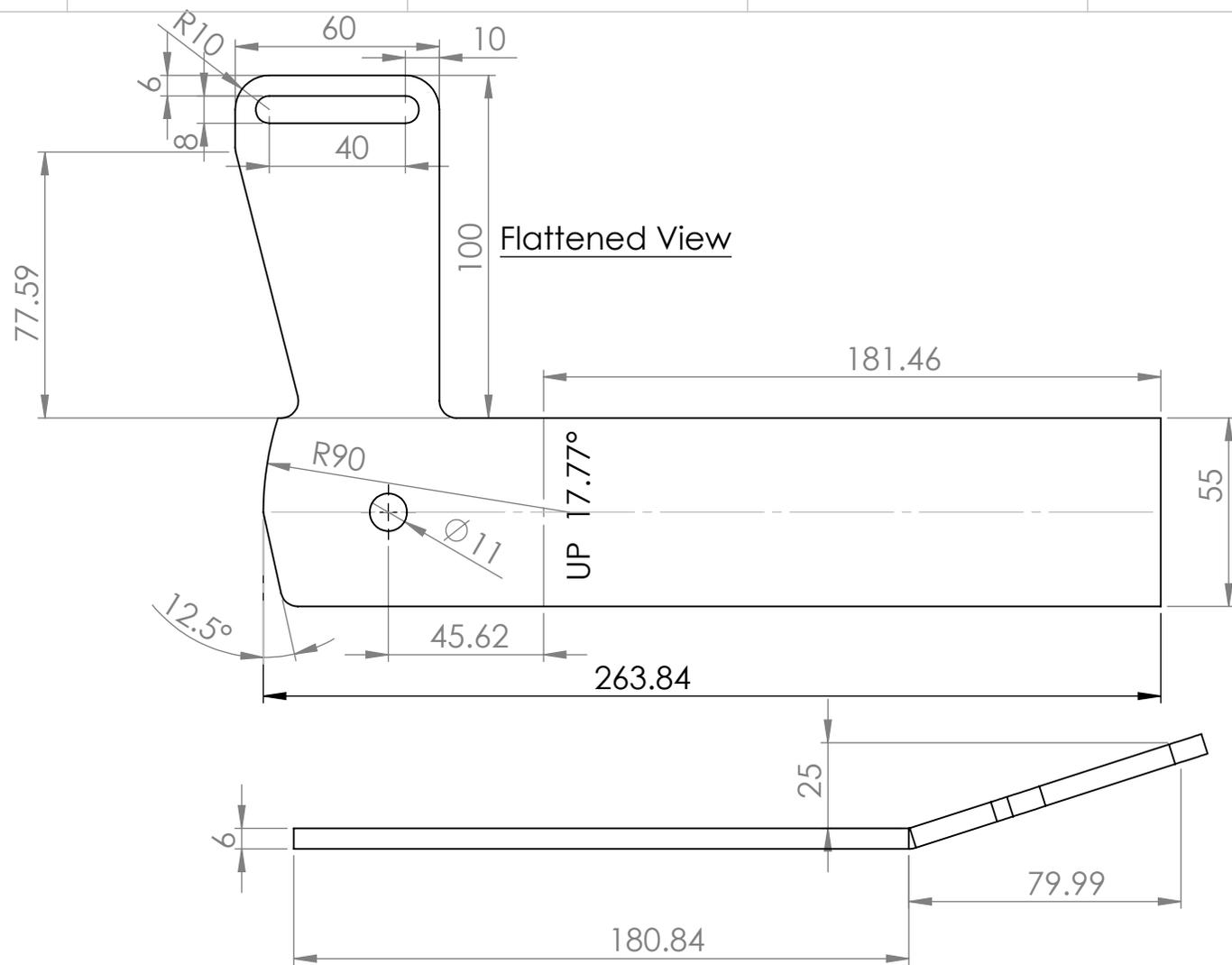
PART NO.:

SIGNED OFF BY:

DRAWN BY: P. Cullingham

A4

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Greater Mobility

MATERIAL:  
6mm Aluminium

WEIGHT:

ALL DIMENSIONS IN MM

TITLE:  
**Seatbelt Mount Plate**

PART NO.:

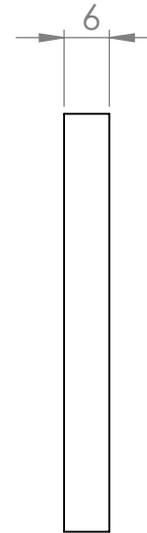
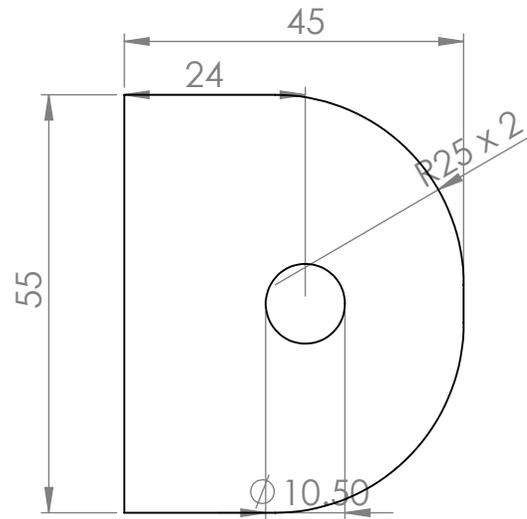
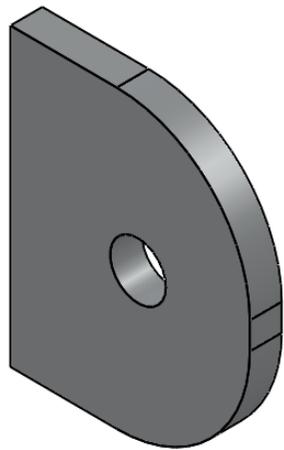
SIGNED OFF BY:

DRAWN BY:  
**P. Cullingham**

A4

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SCALE: 1:2    SHEET 1 OF 1    DATE: 03/11/2010    REVISION: A



Greater Mobility

MATERIAL:  
6mm Aluminium

WEIGHT:

ALL DIMENSIONS IN MM

TITLE:

Hinge Point

PART NO.:

SIGNED OFF BY:

DRAWN BY:

P. Cullingham

A4

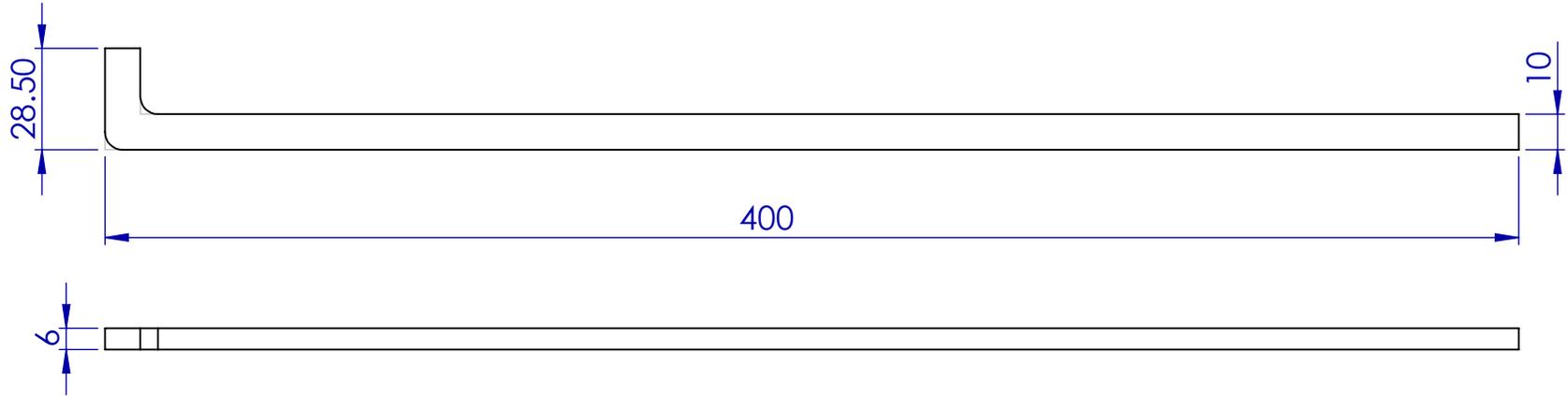
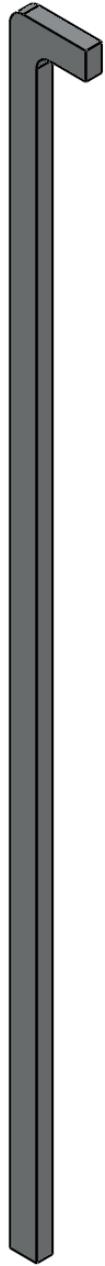
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SCALE: 1:1

SHEET 1 OF 1

DATE: 03/11/2010

REVISION: A



Greater Mobility

MATERIAL:  
6mm Aluminium  
Sheet

ALL DIMENSIONS IN MM

TITLE:

Guide Bar

PART NO.:

SIGNED OFF BY:

DRAWN BY:

P. Cullingham

A4

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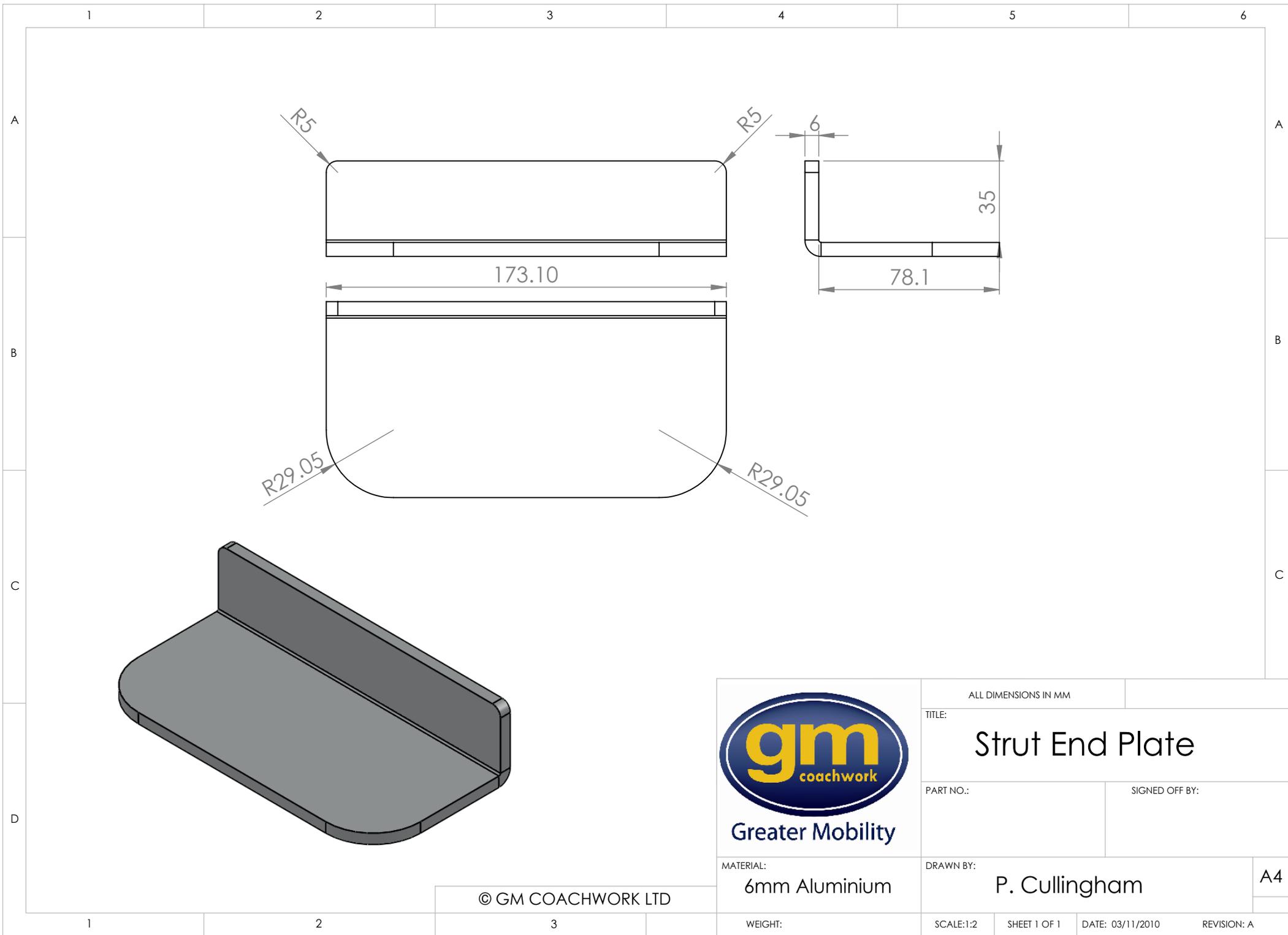
WEIGHT:

SCALE:1:2

SHEET 1 OF 1

DATE: 04/11/2010

REVISION: A



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Greater Mobility

MATERIAL:  
6mm Aluminium

WEIGHT:

ALL DIMENSIONS IN MM

TITLE:

Strut End Plate

PART NO.:

SIGNED OFF BY:

DRAWN BY:

P. Cullingham

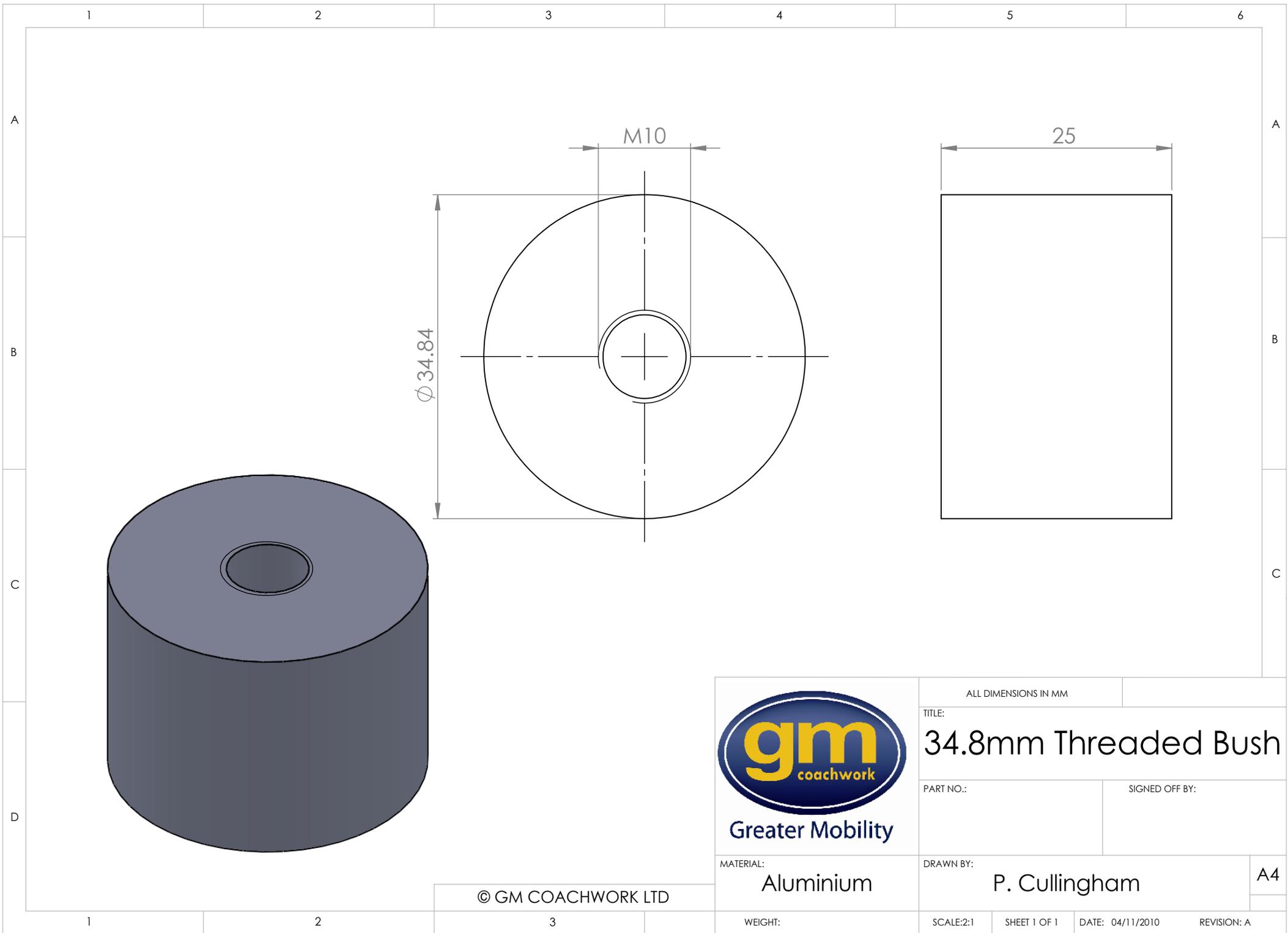
A4

SCALE: 1:2

SHEET 1 OF 1

DATE: 03/11/2010

REVISION: A



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Greater Mobility

MATERIAL: Aluminium

WEIGHT:

ALL DIMENSIONS IN MM

TITLE:  
34.8mm Threaded Bush

PART NO.:

SIGNED OFF BY:

DRAWN BY:  
P. Cullingham

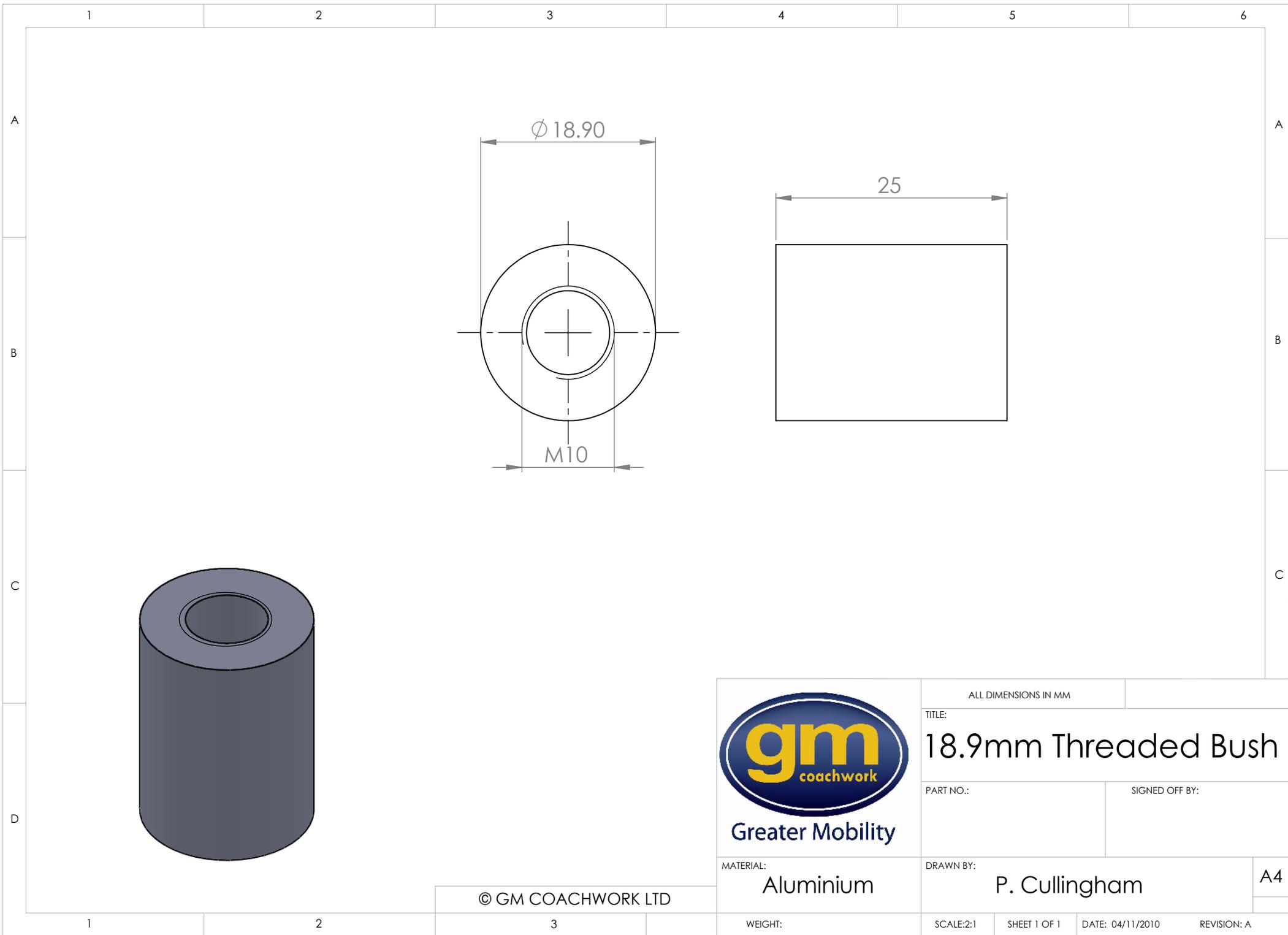
A4

SCALE:2:1

SHEET 1 OF 1

DATE: 04/11/2010

REVISION: A



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Greater Mobility

MATERIAL: Aluminium

WEIGHT:

ALL DIMENSIONS IN MM

TITLE:

18.9mm Threaded Bush

PART NO.:

SIGNED OFF BY:

DRAWN BY:

P. Cullingham

A4

SCALE:2:1

SHEET 1 OF 1

DATE: 04/11/2010

REVISION: A