F-SAE Race Car Seat Design

- *A user-centred concept development project*

Hampus Bergstrand

3221082

University of Newcastle, NSW, Australia

2015 - 2nd Semester

GENG 6000 - Engineering Project

*The rendered version of the seat model on the title page is not an accurate representation of the finished concept, variations for some details apply. Refer to final concept chapter for accurate representation of the final concept.

Abstract

University student from all over Australasia are every year challenged by the Society of Automotive Engineers Australasia (SEA-A) to design, manufacture and compete with a small formula race car.

The purpose of this project has been to, during one academic semester, develop a seat concept for the University of Newcastle' 2015 year formula race car team; and the primary goal during the project has been to put the user in the centre of the design, by incorporating human factors engineering aspects to the design process. A secondary goal has been to facilitate for knowledge transfer by explicitly and accurately describing the process and adequate ergonomic principles for formula student race car seat design.

Even though the design process is limited to the seat; many aspect have been necessary to consider and the project started at the highest systemic level; to progressively work its way down to the main element for the study: the seat. Due to the working progress at the time and a fair amount of SEA-A rules concerning the seat, many constraints were already set when the project started; this fact has had a considerable influenced on the project process and result.

Due to the products proximity and inseparable relation to the user; for obvious safety reasons, many of the SAE-A rules concern the seat and its immediate proximity, which inevitably has led to a large amount of contradictions and necessary compromises. Through a thorough research study on ergonomic consideration in regards to race car seat design; specific guides have been developed, which have then made up the base for the subsequent concept development study.

Through an iterative process of idea generation, synthesis and evaluation, supported by state of the art product development theory, methodology and practice; needs and requirements have been translated into ideas and finally into viable concept solutions and combined to a final concept.

Throughout the whole concept development process contradictory demands and requirements have occurred, which continuously have been necessary to consider and dealt with. According to a final theoretical evaluation process, the final concept has proven to satisfy the defined success indicators and requirements to a high extent and show high potential to, once produced, become a high quality product; unique in its category for its ambition to not only accommodate for, but also to fully satisfy the ergonomic needs for a wide range of different users.

Acknowledgements

There are many people to thank for their contribution to this project. First of all I want to express my sincere gratitude to the whole NU racing team of 2015; it has been a great pleasure to work with you all! Special thanks to the Chief engineer Luke Murphy, Aero leader Harley Braddick, Team leader Francis Conroy and Project manager Thomas Steigler for your support, and for a very rewarding experience. I would also like to thank supervisor William McBride, the composites sponsors from MW supplies in Newcastle and UoN Engineering workshop staff; who all have an played an important role for the final result.

Thank you!

Table of Contents

Introduction

Background

In the end of every academic year, Society of Automotive Engineers of Australasia (SAE-A) challenges Universities around the world to engage a team of students in the ultimate engineering test; to bring knowledge and skills in various disciplines, from business and management to engineering and workshop practise together and design and fabricate a small formula style race car. The 2015 main even, organized by SAE-A, is held during three days in the beginning of December in Melbourne.

Since the beginning of the academic year of 2015, NU Racing, University of Newcastle's Formula Automotive Engineers Team has been engaged in the development process of an internal combustion engine formula race car; set to compete with number 3 in 2015 year's main event. Over the past year, the team has moved from concept, through construction design and finally into the manufacturing and assembly stages.

As a part the master's degree in Industrial design engineering at Chalmers University of Technology in Gothenburg, Sweden it is required to carry out a product development project, relevant for the field of study. The opportunity to participate in the design stage of a real world project like the NU Formula Racing project was well-received and the challenge was accepted with enthusiasm.

To develop a concept for the formula race car seat was considered an appropriate task; both because its relevance for the education, the expected size of such project in relation to course specifics and the team's working progress at the time.

Through a design process recommended by Chalmers's industrial design program and adapted for the particular project, the work has been carried out as half-time university studies for one semester; together with the NU Racing Team of 2015. During the concept development process the ambition has been to constantly incorporate the user perspective, as a complement to the predominantly technical engineering process. Human Factors Engineering (HFE) and Human Factors Integration (HFI) theory offers a range of methods and techniques, which some of which have been used throughout the development process. The Human factors engineering development process is characterized by its constant focus on the user and the user interaction; and can in general terms be described as a continuously iterative process aiming to identify and transform user needs to a solution. Whether that is redesigning a workplace, designing a service, developing a new product or redesigning an existing one; all might fit within the fields of HF; as long as the user's needs and abilities remain in focus (Bligard, 2011).

When I am finishing the project and leaving the team with only about one month left to the competition, it is with a backpack full of new experiences and knowledge; and I am very grateful to have had the opportunity to work with this project and together with a great team. Now let us hope that all the hard work the team has put in (and still are) will be rewarded with a great result in Melbourne.

Project purpose and goal

The project's main purpose is to, when considered appropriate, incorporate human factors engineering theories and methodology for the concept development process of the race car seating for the NU formula team's contribution to the 2015 year's competition. Another important purpose is to facilitate for, and encourage student in future projects to acknowledge the value of and to incorporate human factors aspects to a higher extent, if applicable.

The project goal is to, by incorporating state of the art human factors research with a particular focus on ergonomics; design a concept for the 2015 year's formula race car seat and mounts, in line with the SAE-A regulations and the NU team working progress. And also to support knowledge transfer to subsequent projects of similar character; through continuous documentation and a final report describing the user centred development process and presents principles for user centred design of a SAE formula race car seat.

Project boundaries

The project is limited to the conceptual design of seat; complete with head restrain and a solution that enables the seat to be attached to the frame.

Project process

Very simplified the user centred development process as a whole can be described as a continuously iterating path; from the basic user need, research and define relevant considerations and use them to generate possible solutions which are evaluated and combined into a final concept that can respond to the user's need.

The actual design process used in the project is best described as three interrelated parts; largely following the previously mentioned structure. The aim of the initial part is first to establish latent conditions and an overall project goal; and ultimately to establish the product properties required for the final result to be considered successful. The next part; the synthesis, is aiming to transform the requirements into possible design solutions; and through iterations evaluate and refine to a concrete design concept. In the third phase, the design concept will be embodied; through modelling and the production of manufacturing documentation and finally follows a theoretic evaluation of the final concept.

Report organization

When appropriate the chapter start with a subchapter called "*introduction*", which aim to, if applicable, supply the reader with a brief background to the chapter, the process, the theory and the methodology that is essential for the reader's comprehension. After the introduction follows the chapter's main text with findings, result, result reflection and conclusions; to what extents each of these are represented in each chapter varies, depending on the character of the individual chapter. After the six chapters that the main text constitutes of, follows a discussion and recommendations. And lastly references and appendices are presented.

Project Process and Result

1 Project initiation and planning

Prior to project definition and planning process commencement, a sufficient fact base must be established, in order to be able to define and plan the project as accurate as possible. The accuracy is essential for the project to run efficiently; and might, even though quite time consuming, end up saving a sufficient amount of time, due to a more efficient process, with lesser risk for unexpected events to influence the process and the quality of the result negatively (Larson & Gray, 2011).

1.1 Project definition

The purpose of the initial project definition process is to establish and communicate the initial project goal, objectives, boundaries and possible constraints (Larson & Gray, 2011). Goals and objectives are initially expressed in quite vague terms and will become more specific as new information appears along the process. Expressing goals and objectives at a very specific level already at an early stage might be harmful to the creative process; since this is likely to limit both width and depth of the range of possible solutions. This project, with a large amount of predefined constraints and dependencies forced a slightly different approach than described; with goals and objectives that had to be rather unambiguously defined already at an early stage.

1.2 Planning and administration

The planning process is meant to create an overall structure and facilitate monitoring and managing the project. For any project to be successful, it is essential for the project plan to be defined as accurate as possible (Larson & Gray, 2011). The initial planning includes creating a timeline, setting up milestones, and plan processes and their relative order etc. In the next section the planning process for the particular project will be described more in depth.

1.2.1 WBS - Work breakdown structure

Prior to the process of fitting the project processes into the calendar, the project is divided into smaller sub process and further down on a task level through a WBS. WBS, Work Breakdown Structure, is an important tool to arrange and overlook the project as a whole (Larson & Gray, 2011). For comprehension and to facilitate communication, the WBS is presented as a visual presentation; a hierarchical diagram of processes and tasks in chronological order, complemented with a document describing the different work packages more in detail. WBS diagram and detailed explanation for the project are presented in ***appendix 1*** and ***2***.

1.2.2 Gantt

The next step in the planning process is to actually define the project and the processes in relation to the timeline. This can be achieved with the help of a Gantt chart. The Gantt chart is an important tool, both for analysing the project in regards to process relations and possible dependencies and also throughout the project; by overlooks processes and progress in relation to plan (Larson & Gray, 2011). During the project, the Gantt chart is continuously re-evaluated and updated if required. The project Gantt chart is presented in.

1.2.3 Continuous activities

According to studied product development project theory, the success of the project very much relies on continuous monitoring and adaptations to the inevitably dynamic context. In order to sufficiently overlook and manage this type of project there are four recommended continuous process and associated tools described in theory and which have been used during the project (Bligard, 2011).

Planning

The planning process consists of continuous re-evaluations of the initial plan and to update the Gantt with the current progress. For the particular project it also included planning work ahead more in detail, prior to entering a new work package. This is required since new information is constantly coming up which the plan need to relate to as the project abstraction level decreased; and goals and boundaries are becoming less ambiguously defined.

Research/ data collection

Data collection is another essential process that is more or less continuous throughout the project; even though more concentrated to the first half of the project. In general, the broader knowledge base that can be sustained, the better are the chances for satisfying results and sufficient goal fulfilment.

Documentation

To continuously document work and thought processes is essential in order to avoid replicated work, remember decisions and the background to the decision making. Continuous documentations might also stimulate to reflections; which can help to understand and potentially improve the process. Tools that were used for documentation during the process were a working diary, a time log and the report draft. The working diary, consisting of notes written after most work sessions, was used during the project to record processes and reflections. Apart from previously mentioned reasons, the diary was also kept in order to facilitate the writing of the report. The time log that was used consisted of a short summary of work carried out, when, and the duration spent on the task. The work log ensured that sufficient amount of time was spent each week (+20 hours), thus also helped to avoid unbalanced workload. In addition, continuously adding information to a report draft, collecting reports and references and taking process pictures was also frequently used tools for documentation throughout most of the project.

Revaluation of project goal and project definition

Continuous iterations of goals and project definition are essential aspects in managing the project; and are necessary if to be able to plan and incorporate the required measures to achieve a result that satisfies all of the relevant stakeholders' needs and wants. With the support of the three previously mentioned continuous processes, the current project state is assessed in relation to the current project definition and current goals. Redefining or increasing the precision of the goals and objectives are often necessary measures when the level of abstraction is narrowed down along the path. During this project the goal was re-evaluated and specified several times; which resulted in the goal presented in the introduction to be slightly different from the initial goal that was defined prior to the project initiation. The reasons for the redefinitions were, as mentioned, the continuously increasing level of understanding, the change of demands from external environment and the occurrence of unexpected events and more.

2. Research study

The purpose of the initial research study is to build a solid fact base; to understand and be able to analyse relations between system components, the product (or the artefact/machine), the user and the context. The knowledge gained through this process is important if the product development will be able to consider most of the relevant aspects and thereby avoid contradictory elements in the final design.

2.1 System Analysis

2.1.1 Introduction

The purpose of systemic theory, originated in biology research, is to define a foundation for the analysis and modelling and to facilitate comprehension of internal and external relations (Bligard, 2011). The systemic view is a necessary tool to understand the particular system; for which the combination of the parts is more than the sum of the individual parts and for which the relationship between subsystems and system elements is complex and dynamic i.e. when a slight change to one element might affect the design or performance of a related components; the relation is not always obvious, necessarily even possible to record. System boundaries are used to limit system and subsystems to only the essential parts and to indicate membership among elements. Setting up system boundaries often facilitates the comprehension; both for the individual and in the group. Flow of matter, energy and information might occur both over and within the defined system boundaries. The individual elements and subsystem relations, boundaries, flow of matter, energy and information are often visualized in a system model, in order to facilitate comprehension.

In order for the seat design to sufficiently take surrounding aspects into consideration, the system analysis zooms out and looks at the larger system(the whole car) and the subsystem (the cockpit), of which the seat is only one part. The system analysis start with a very general description of the main system and the environment on the top level, which primarily aims to create an overview and a general understanding of the systems and its relations; and also to ensure that the subsystems that potentially influences the main system are taken into consideration. As the analysis narrows down to subsystem level and further down to the actual product, the level of detail and the accuracy in the descriptions increases.

Seat <-> Cockpit <-> Car <-> Surrounding

The system analysis have been an essential part of the particular development process since it has facilitated the understanding of the system and internal and external relations between system components and subsystems, just as it is intended to. In order ensure all aspects were captured, as well as limiting the analysed system to only the relevant parts, system boundaries were defined. The boundaries are best described in the visual illustration of the system and subsystems; the systemic model presented in ***figure 1***. To further describe internal relations and the external relation to the surrounding, the systemic model is also complemented with arrows describing the exchange of matter, information and energy throughout the system. Another important aspect when analysing the particular system was to define the system and subsystem goals (Bligard, 2011). This process can be rather complicated since the goals for the same system often varies between different stakeholders or users; the system goal that was formulated by the designer might not even be that same as the goal defined by the user. The same applies for the use; referred to as intended and actual use. The different types of use, (primary, secondary, co- and side-use) will be further declared for when user types are discussed in the next subchapter.

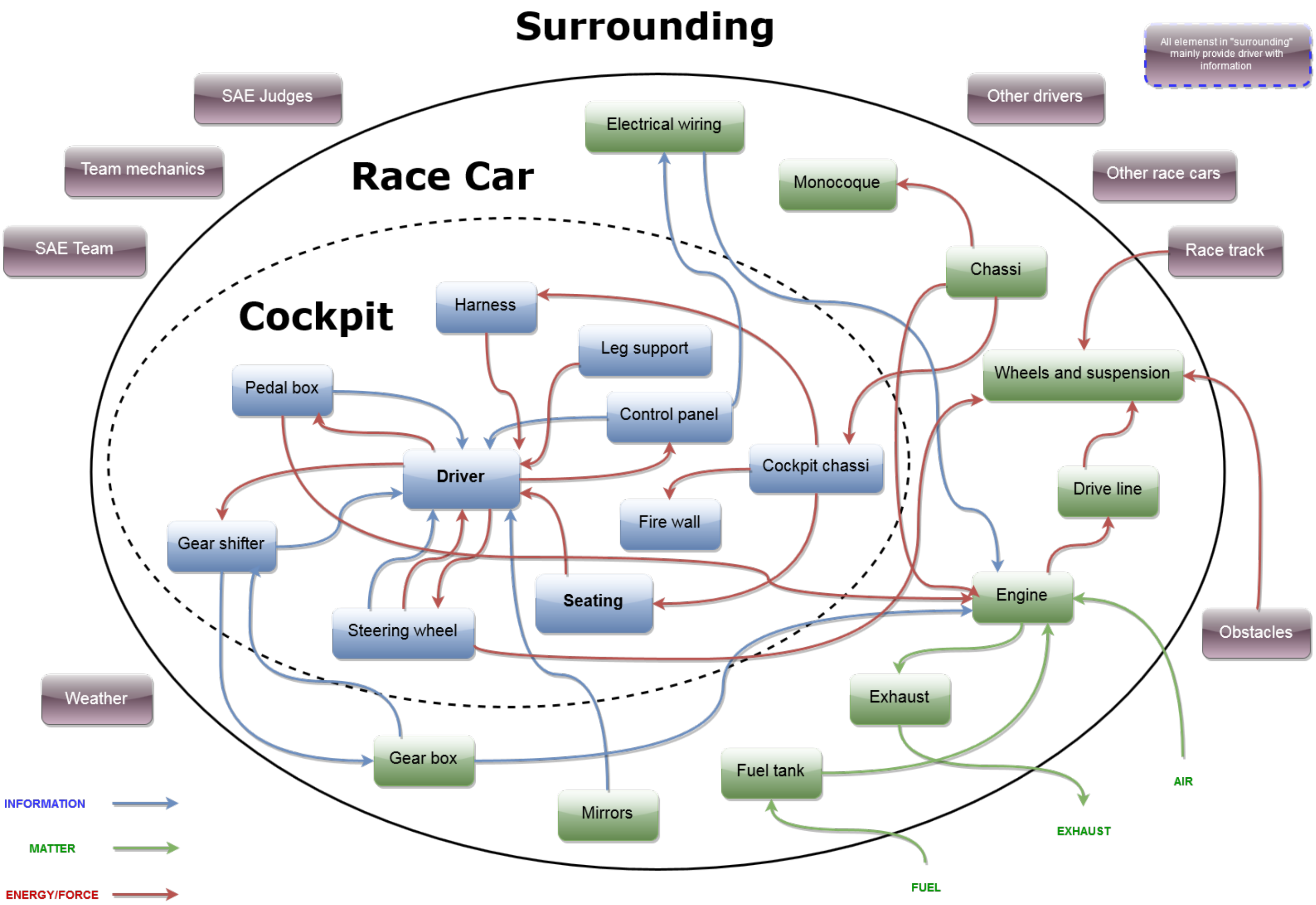


Figure 1 *– Systemic model*

2.1.2 Surrounding /environment

The external environment is defined as surrounding factors that influence the system, but over which the system has little control (Bligard, 2011). The system surrounding is of major importance to the studied system's performance and goal fulfilment. However, the surrounding has slightly less impact on the subsystem and the main elements for this particular study; the seat, thus described only in brief terms in the next section.

The race track and its properties; such as condition, obstacles, opponents etc. obviously has a big impact on the car and the driver's ability to perform. The same goes for weather conditions during the event; rainfall and air temperature affecting car, driver and the track etc. and the sunshine causing glares are all factors which are affecting the system's overall goal fulfilment. Other surrounding factors relevant for the studied system are for instance other participating teams;

vehicles and drivers and also the competition administration; SAE personnel, judges, safety personnel etc. The NU team can be located on the boundary between external and internal environment; since the driver, unlike the rest of the system, actually is able to control the team to some extent.

2.1.3 Main System – The Race car

As seen in the system illustration, the main system is constituted out of the actual formula student race car, with the car body as outer boundaries as illustrated by ***figure 2***.

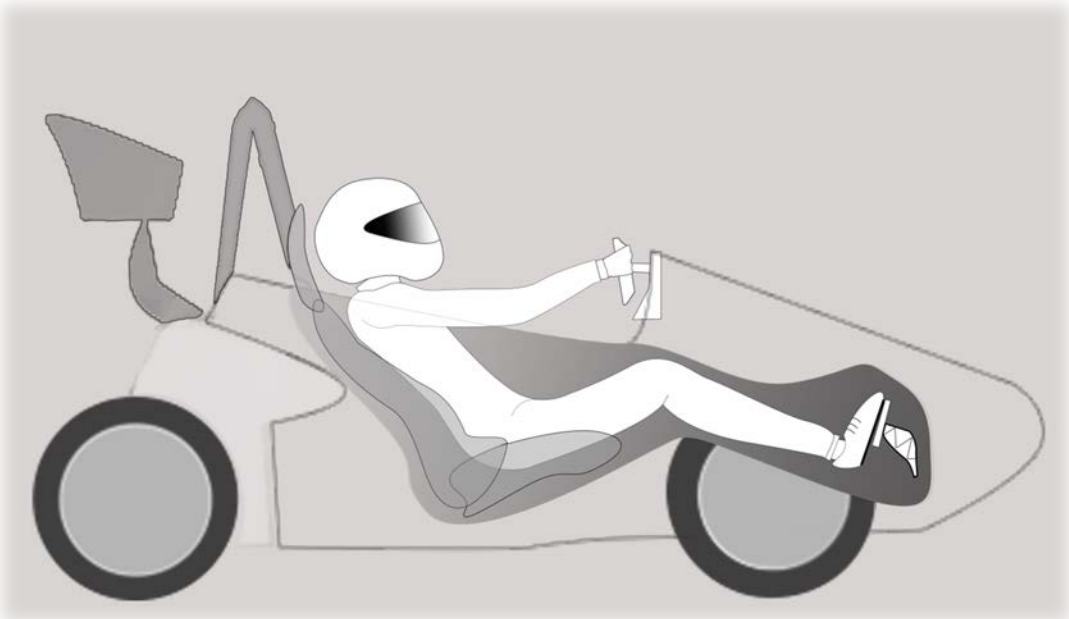


Figure 2 *– The main system*

Goals

Relevant system goals for the main system can be derived from the result of the initial research study and are presented for the different areas respectively. The goals on the top level are rather vague; the level of precision and accuracy will however increase when moving down towards the main element.

Regulations - Meet the SAE Formula Student regulations

Design (technical and aesthetic) - Be of outstanding technical and aesthetic design

Innovation - Show innovation in solutions

Safety - Keep the driver safe during driving and in case of an accident.

Reliability - Perform according to expectations during the events.

Performance - Allow the driver to safely manoeuvre the car through the race track in the shortest possible total time in the main event. Allow high manoeuvrability to complete the technical event.

2.1.4 Subsystem - The Cockpit

The natural subsystem, in which the seat is a vital element, is identified as the driver's cockpit, illustrated in ***figure 3***. Most elements in the cockpit are related; primarily through their placement relative to each other and the driver. Of all cockpit elements, the driver and seat has the closest relationship; which implies seat design is bound to the user goals declared for in following subchapters.

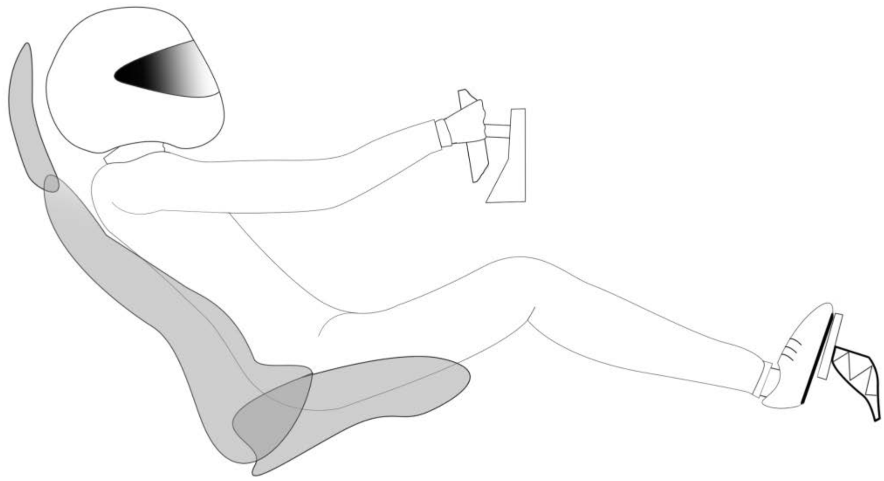


Figure 3 *– The subsystem*

Goals

The subsystem goals can be obtained after analysing and breaking apart the main goals; however is still kept relatively unspecific, in order not to limit or exclude possible solution paths.

Regulations - Meet SAE formula student regulations

Safety - Protect driver from external force, heat, fire etc.

Manoeuvrability - Allow driver to manoeuvre the vehicle

Ergonomics - Support the driver's posture. And by the relative placement of components ensure little negative stress on driver's body.

Relevant Element relations in the subsystem

The subsystem elements that were considered relevant for the seat design is presented together with an explanation of initial relationship assessment in ***table 1***.

Element	Affect main element?	Is affected by main element?	Importance to design	Specifics
Primary - Directly in contact with or affect/ is affected by main element				
The User	Body shape and size decide design. Heat, sweat, transfer	Is supported and protected by seat	Very high	Strongest connection: head feet, hands, eye and buttocks placement
Driver's suit	Friction	-	Some	
Driver's Harness	-	The seat might limit placement and harness setup	High	6 attaching points in frame
Driver's Helmet	-	Might rest against seat (be supported?)	High	
Chassis	Limits the size and placement	-	High	
Firewall	Limits the size and placement	Designed to fit together with seat	Some	Might need insulation
Pedal box	The relative placement of the seat vs. the pedals must ensure sufficient manoeuvrability.		High	Pedal box is offset + linearly adjustable 120 mm
Steering wheel	The relative placement of the seat and the steering wheel must ensure sufficient manoeuvrability and restricts space		High	Not yet constrained longitudinally
Gear shift	The relative placement of the gear shift vs. the steering wheel must ensure sufficient manoeuvrability		High	Pads on steering wheel
Control panel	The relative placement of the seat vs. the Control panel must ensure sufficient manoeuvrability		High	
Handbrake	The relative placement of the seat vs. the handbrake must ensure sufficient manoeuvrability + restricts space		Some	
Seat brackets	In direct contact between seat and frame; placement will be dependent on seat location		High	Where and how to attach to seat and frame. Adjustable?
Secondary - Not directly in contact with or affect/ is affected by main element				
Car body	Might limit the size and placement	-	Some	
Leg rest	The seat position, thus the driver's position in relation to the leg rest must ensure sufficient body support.		Some	
Mirrors	The seat position, thus the driver's position in relation to the mirrors must ensure sufficient visibility		Some	
Steering column	Restricts space		High	About 100mm above chassis bottom

***Table 1** – Subsystem elements*

2.1.5 Main element – The Seat

The main element is obviously the seat, and due to its inseparable relationship to the user also depicted and analysed together.

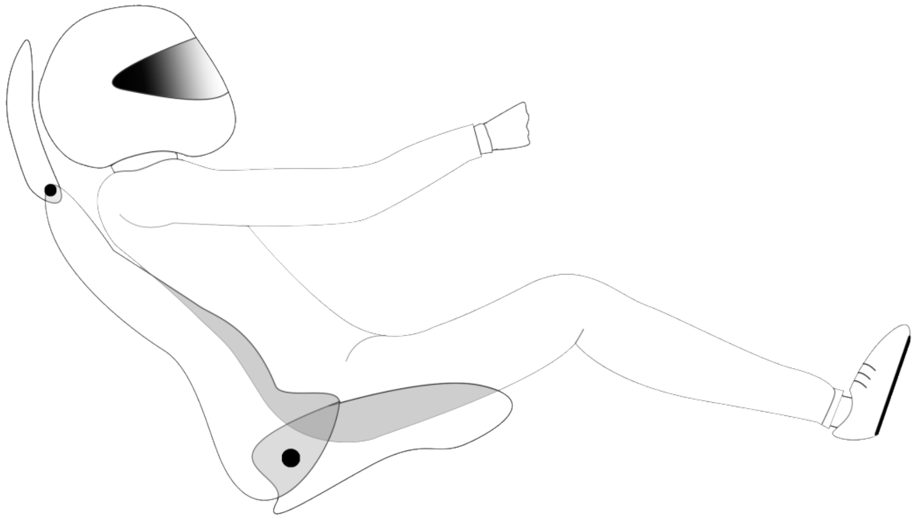


Figure 4 *– The main element*

Goals

Main - Allow range of drivers, specified by SAE-A, to manoeuvre the vehicle; i.e. reach and manipulate steering wheel, control panel and pedals. And in addition prevent unwanted body movements.

Regulations - Meet SEA formula student regulations

Performance - Maintain low weight distribution COG - centre of gravity

Ergonomics - Sufficiently support driver's body to minimize negative ergonomic load from harmful postures or unnecessary movement.

Safety - Protect driver and allow the driver to stay securely in place while manoeuvring the race car, and also allow driver to quickly exit, in case of an emergency.

Design/Innovation - Be somewhat innovative in technical and aesthetic design.

2.2 User Profile and User Analysis

2.2.1 Introduction

According to Janhager's theoretical framework (2005), in order for the product to sufficiently satisfy the user goals; the different users, their intentions and their unique preferences and properties must be researched and defined prior to listing required product attributes. This is the background to the user description and the user analysis presented in this subchapter.

For the design of the seat the human body dimensions are obviously the most important user attribute. To facilitate design of user centred products, among other purposes, a field of study referred to as anthropometrics has developed. Anthropometrics are human body dimensions for a specific population collected through empirical studies. The data is then statistically processed and compiled, in relevance to the area where it will be used. For the adult population the anthropometrics are often divided into men and women and depending on the purpose of the study, different measurements are collected. From general measurements such as weight, stature, BMI etc.; to very detailed dimension, such as most hand and foot dimensions, hip breadth, head circumference and much more (The open design lab, 2015). Percentiles describe a sub-range of anthropometric values within the full anthropometric range. Often reference anthropometrics from 1st to 5th percentile woman is used to represent the smallest person that is likely to use the product and 95th to 99th percentile man is used to represent a large possible user.

The general anthropometric presented in this report are collected from The National Health and Nutrition Examination Survey, NHANES (NHANES, 2006). NHANES is an ongoing anthropometrics study that is updated every other year, performed for the US national centre for health and statistics. Due to its purposes, NHANES is relatively general; only supplying gross anthropometrics such as BMI, stature, mass and a couple of other general key dimensions. According to *open lab*, NHANES is the anthropometric database used by SAE international (The open design lab, 2015). Detailed dimensions are collected from ANSUR 1988 (ANSUR, 1988); which is the widest study of its kind, but unfortunately it is also fairly outdated and not completely representative, since its limited to military recruits in the US.

2.2.2 User types and relevant considerations

In general a product has got more than one user; also the designer's intended use often differs from the actual use. The definition of a user described by Bligaard (2011), is very wide and obviously includes more than what we commonly would refer to as the primary or intended user.

"The user is a human that directly or indirectly exchange energy, information

and/or matter with the product"

There are different aspects to consider for the different users, most users have different intentions and needs in relation to the product; which will be defined in short terms in the following section (Janhager, 2005). However, for the particular project the primary user (the driver), will obviously have a particular influence on the seat design; thus will be the main focus in the following user needs and requirement research study. A complete stakeholder analysis was not considered necessary for the quite narrow scope of the project. However, some of the users that will be described could also have been described in stakeholder terms.

Primary User

"The individual who uses the product for its primary intended use." (Janhager, 2005)

The Driver - The *driver** of the car, no matter anthropological properties, must be able to fit in the seat and be sufficiently supported and protected.

For this particular case the definition of the* ***driver* *is extended to, not only include the actual drivers but also a presumed user; which is defined as an individual within the anthropometrical range from 5th percentile woman to 95th percentile man.*

Secondary user(s)

"An individual who is in contact with the product without using it for its primary intended use." (Janhager, 2005)

NU Team Engineers - Design intent and experience and knowledge provided by the team will affect the final design.

Manufacturer/workshop personnel - Will be part in producing the part, need clear specifics, drawings and a highly manufacturable design.

Fitter/Mechanics - Have to be able understand the product and to reach certain parts and fasteners for maintenance, repairs, adjusting position etc.

SAE judges - Need to be able to perform inspections according to supplied regulations. Seat needs to meet regulations and specifications. Judges will also be assessing both technical and aesthetic design.

Race track safety personnel - Need to be able to safely bring driver out of danger in case of an accident.

Opponents - Are driving other vehicles and might pose a threat to driver and vice versa.

Co-user

"An individual who is collaborating with the primary user." (Janhager, 2005)

NU Team - Can help the user to assess the performance of the car, give advice, instructions and communicate tactics etc.

Other team drivers - Several drivers will be driving during the event; previous drivers can supply vital information to the next driver on conditions, appropriate tactics, adjustments and configurations etc.

Side user

"An individual who is affected by the system, without actively influencing the system goal fulfilment." (Janhager, 2005)

University of Newcastle - The university of Newcastle is an important stakeholder, both as contributor and beneficiary; contributing as a sponsor and will obtain promotional gains from the team's achievement.

Sponsors - Sponsors have a monetary influence over the system goal, however very little influence over the design and are considered more interested in the promotional value and the relations that the sponsorship will provide them; and for this particular case, therefore considered to be side-users (the university and sponsors would have been more accurately represented in a stakeholder analysis).

Spectators - People from the public and/or from other teams will perceive, and are potentially affected by the design and performance of the product.

2.2.3 User description - Primary User (Driver)

The general user characteristics often used in design are for instance gender, age and ethnicity; however, due to the very heterogeneous populations these divisions have often proved to be quite useless. It is often more valuable to characterise the user by defining attributes specific to the product, e.g. anthropometrics, muscular strength, experience, training, attitude etc. (Janhager, 2005).

General user characteristics

Use characteristics that are considered relevant for the design of the seat are, except for physical characteristics, quite few. However, the drivers experience and training might influence how the seat is used and perceived. User training and experience aspects identified during the research that might be relevant for the seat design are as follows. The user (driver) has high knowledge about the car and the use. He or she has been practicing driving, hence developed manoeuvring skills and muscle memory in a seat in a similar car, which must be considered in the design of the new seat.

Physical attributes (anthropometrics)

The most important driver characteristics for the design of a racing seat are obviously the physical properties. According to the regulations, the car must allow human measurements between ***5th percentile woman*** up to ***95th percentile man*** to fit in the cockpit and to be able to drive the car. However the cockpit and the seating are going to be optimized for the intended drivers selected for the actual competition. The seated position is characterised by a number of reference points; which with their relative location to each other will define the driver's posture in the three dimensional coordination system; these are head, eyes, feet, hands, buttocks and knees position.

Anthropometric data for the actual drivers is collected by measuring relevant dimensions, according the recording principles described in the ANSUR data collection from 1988 (ANSUR, 1988). A wide range of anthropometrical measurements were collected; mainly for two reasons. First, due to the early stage of the process, hence the high level of uncertainty; it is only possible to assume what dimensions might become useful at this stage. And secondly, if not for the design of the Seat, the anthropometric data that is collected is likely to be useful for the design and placement of other subsystem components, such as pedal box, steering wheel, control panel, switches etc. Another factor that influenced which dimensions to measure was the range of anthropometric dimensions available in the existing databases, ANSUR and NHANES. Even though some complementary dimensions, outside the existing range were considered relevant for the seat design; hence recorded. The data collected from the two databases and from measuring three of the potential drivers is compiled in ***table 2***. To facilitate the collection of data the online tool *Opelab toolbox* (The open design lab, 2015) have been used rather than scanning and writing of the analogue (and digital) copies of the ANSUR and NHANES reports.

Dimension	5th percentile woman ANSUR (NHANES)	50th percentile man ANSUR (NHANES)	95th percentile man ANSUR (NHANES)	Actual driver #1 - Tall	Actual driver #2 - Tall	Actual driver #3 - Short
Buttock-knee length sitting (front of knee)	543	615	668	670	700	570
Buttock-knee length sitting (back of knee)	440	500	546	530	565	480
Eye-height sitting	685	792	848			
Foot breadth (with racing shoes)	82	100	110			
Foot length (with racing shoes)	224	269	292			
Head breadth (with helmet)	137	152	161	275	275	275
Head circumference (with helmet)	523(525)	567(578)	593(607)			
Head length (with helmet)				340	340	340
Knee height sitting (under knee)	352	433	476	510	475	435
Knee height sitting (over knee)	474(461)	557(558)	605(607)	630	620	555
Hip breadth sitting	(349)	(386)	(459)	430	390	345
Hip breadth standing	308	341	376			
Shoulder breadth	397	491	534	470	515	420
Shoulder height sitting	510	598	646	695	705	545
Shoulder height standing				1605	1690	1360
Sitting height (with helmet)	795(795)	914(919)	972(987)	970	1070	930
Shoulder-elbow length	307	368	399	410	425	350
Elbow-fingertip length	407(398)	483(488)	523(528)	520	540	440
Hand length	165	193	210			
Stature	1529(1507)	1756(1763)	1868(1883)	1895	1990	1670
Body mass	(50.31)	(86.19)	(124.19)	86	86	60
BMI				23.95	21.72	21.51
Lumbar height (from sitting, approx.)	114	131	135			
Lumbar curve depth (approx.)	15		50			

Table 2 *– Anthropometric measurements*

Another human body property that was considered important for the design and the positioning of the seat is possible joint movement; minimum and maximum (contraction, flexion, rotation). This data is not supplied by the anthropometric databases and was therefore captured for a 50th percentile man from within the (human modelling software) ergonomic simulations software JACK from Siemens. No research could be found about how the joints movement relates to other body anthropometrics, which further disqualifies these values as accurate representations. However, the reason to why this 50th percentile figures could be used to represent the full anthropometric scale is because the absolute values for joint angles are not particularly interesting, but will rather be used as a rough guide; since the bodies for all percentiles are likely to be positioned in postures with joint angles with a significant margin to the extremes. One exception to this might be ankle and wrist angles, since the flexion rage for these are more limited than the rest of the represented guides. The collected data is compiled in ***table 3*** with support from the illustration of angles in ***figure 5.***

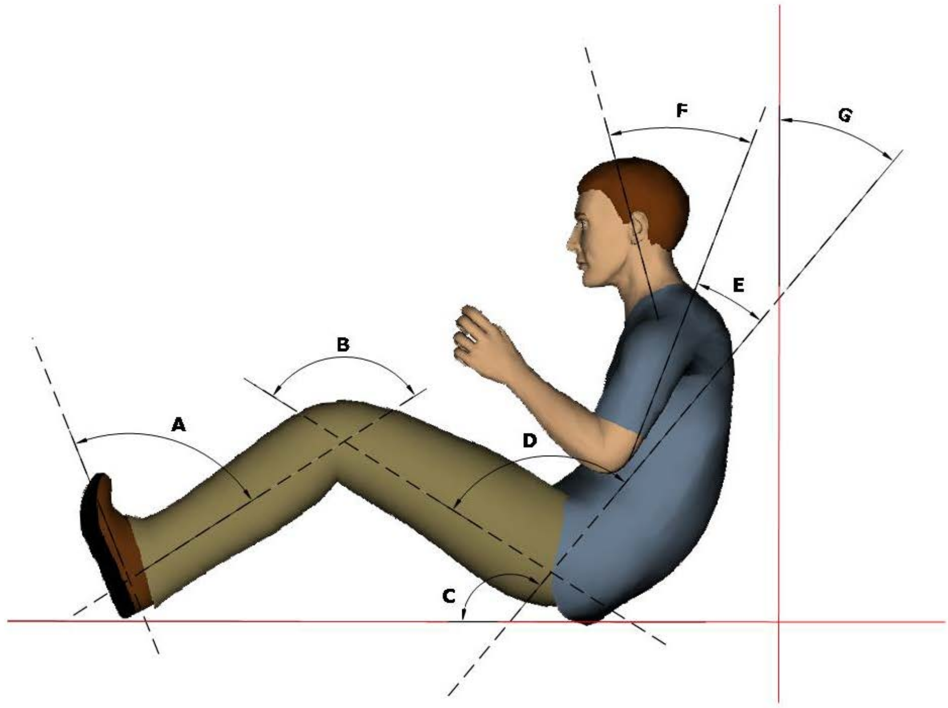


Figure 5 *– Reference model for human joint angles*

No.	Dimension	Max - Min (flexion)	Optimal posture (max - min)
A	Ankle	168° - 67°	≈ 90°
B	Knee	183° - 20°	160° - 120°
C	Hip - Horizontal axis (Inclination)	-	130° - 100°
D	Hip	(-197)° - 63°	
E	Torso	84° - (-52)°	
F	Neck	45° - (-51)°	≈ 0°
G	Hip - Vertical axis	-	

Table 3 *– Human joint angles*

2.2.4 Adequate Performance shaping factors

The system and its elements are constantly influenced by numerous factors that alone or in combination will influence the overall system performance (Bohgard et.al, 2011). The factors can be divided into internal factors such as user attributes; both mental and physical. And also external factors; which can be further separated into latent external factors (built-in attributes of the product and the surrounding) and operational external factors (procedural factors). Due to the analogue characteristics of the seat and the very limited amount of interaction, the internal factors and in particular the user anthropometrics will be the primary influencing factors for the seat design. The complete list of identified factors is presented in ***table 4.***

Performance shaping factor	Importance to performance	Importance to seat design
Internal		
Arm length (above/below elbow)	Medium	High
Leg length (above/below knee)	Medium	High
Shoe/foot length	Low	Low
Feet breadth (foot +separation+ foot)	Low	High
Knee breadth (knee +separation +knee)	Low	High
Thigh breadth (thigh + separation + thigh)	Low	High
Hand size	Low	Low
Hip breadth	Low	Very High
Hip circumference	Low	Very High
Shoulder breadth	Low	Very High
Head breadth (with helmet)	Low	Medium
Head width - from side view (with helmet)	Low	Medium
Head height (with helmet)	Medium	High
Body mass	High	High
Eye height	Medium	High
Stature	Medium	High
Shoulder height	Medium	Very High
Flexibility (overall, joints)	Medium	Medium
Vision	High	Low
Endurance	High	Low
Strength	Medium	Low
Mental capacity	Medium	Low
Experience	Very High	Medium
Training	Very High	Medium
Attitude	High	Medium
External		
Rain	Very High	Medium
Sunlight	High	Medium
Temperature	High	Medium
Moisture	Medium	Medium
Car	Very High	High
Operational - SAE regulations	Very High	High

Table 4 – *Performance shaping factors*

2.3 Relevant ergonomic considerations

2.3.1 Introduction

One of the main considerations when designing the seat has been to incorporate ergonomic principles as a complementary approach to the traditional technical perspective, already in the early stages of concept development. In order to achieve this, a quite extensive research study has been carried out, with the aim to identify the ergonomic principles that might be relevant to the design of a race car seat.

Before the identified ergonomic considerations are presented, a brief background to the concept and terminology is appropriate. In the field of ergonomics, researchers often divide the concept into the two subareas, cognitive ergonomics and physical ergonomics (Bohgard et.al, 2011). Depending on the definition, the concept sometimes also includes surrounding factors that affects well-being and behaviour; such as noise, light conditions, mental/psychological stressors, vibrations etc. For this project, the physical aspects will obviously be the main consideration, hence the focus of the research study that is presented in the chapter.

2.3.2 Ergonomic principles for race car seat design

The following section is a compilation of state of the art ergonomic research on topics that has been considered relevant to the highly specific topic of race car seat design. The compilation of research in the subchapter *general principles* is based on general ergonomics theory, general ergonomic seating design, ergonomic car seat design for professional drivers and ergonomic car seat design for private drivers The specific principles have been much harder to find; presented information however is derived from webpages, online blogs and forums and from discussions with experienced drivers. The compilation aims to summarize aspects that may have an influence on the ergonomic stress that the driver is exposed to. The main justification to why such extensive research study and compilation was considered necessary is that no information of this character, for the design of this particular type of a racing car seat was to be found. However, it is also due to the very specific project characteristics; as being highly customized and limited to a single-series. The ergonomic considerations presented below are divided into categories according to the main area of relevance.

General principles

Ergonomic load - To fully understand the concept of physical ergonomics, some aspects related to the human anatomy needs to be clarified; however, in very brief terms in order to keep it relevant to the field of study. Internal forces in the human body, referred to as stress, reacts on external load in order to keep the body in balance (Bohgard et.al, 2011). The external load can be static, dynamic and/or transient (impulse). The external load and the counteracting stress affects muscles, joints, ligaments, heart and blood circulation etc. It is this load's effect on the body that is often referred to when ergonomics is discussed; a product that is ergonomically adapted strive to either minimize the load or the negative effects of the load that is causing excessive stress levels to the user, which might lead to both long and short term damages to the body structures; such as joint, muscles, nerves, ligaments, discs, bone structure etc. The development of medical issues might occur instantly or due to loads under an extended period and whether or not damages occur and whether symptoms show depend on several aspects; such as if the load is dynamic or static, load exposure and frequency, load angle and direction, physical properties of the human, surrounding temperature, the amount and quality of rest etc. It is also important to remember that not all loads are bad; load that is applied ergonomically correct is essential for the body functions and structures to stay healthy and to develop.

Body posture - From an ergonomic point of view, the desirable body posture when driving is a neutral posture. An erected position often leads to over tensioned muscles and is likely to increase the risk of premature fatigue. Whereas, a slumped posture causes an unfavourable pelvis rotation/position, thus is likely to cause discomfort and pain. The pressure on the discs and overall stress on the body decreases with a more reclined posture. However, according to Reynolds (2012) research an angle between seat and backrest of around 120 -130 degrees is a desired inclination for general driving. Also, load should be symmetrically applied if possible.

The human spine's natural inverted S-shape changes with the disc rotation that occurs when sitting down; a seated posture is in general an unfavourable position and ergonomic theories and tools is an important element for reducing some of the negative stress that the body is exposed to (MacLeod, 2015 and Gkikas 2013).

A built in shape that supports the lower region of the back; called the lumbar region after the name of the lower vertebrae, is an efficient tool to relieve some of the stress. The idea with such support is to push the spine into a curve shape that causes a pelvic to rotation into a position better adapted for taking up load. The depth of the lumbar curve is between 15 and 50 mm, depending on body anthropometrics and the optimal support is characterized by an even pressure from lower back to shoulders (Gkikas, 2013).

The shoulders should be relaxed and kept back against backrest; forward leaning shoulders compress blood vessels and cause impingements, which will influence muscle capability and blood circulation negatively (Bohgard et.al, 2011).

A forward bent (flexion) neck causes an increased pressure on discs and might be harmful for extended periods. However, a head position behind the vertical axis is direct harmful and must be prevented. Sideways head translation (and rotation) is also a potential risk (MacLeod, 2015 and Gkikas 2013).

Comfort - Comfort is defined as absence of discomfort (Bohgard et.al, 2011).

Pressure zones - Pressure zones occur when high amount of load is applied to a small area (sometimes due to asymmetrically applied load); the negative effects might also be reinforced due to hard contact surfaces. Pressure zones can lead to disrupted blood circulation; hence reduced muscular ability and it might also affect the nerve functionality, which might be perceived as discomfort or pain (Cornell, 2015). Through maximized surface contact and by avoiding high load on especially sensitive areas, pressure zones can be reduced and negative effects can be avoided.

Vibrations - Relevant aspect of vibrations connected to the seat design might be that the vibrations that inevitably will reach the body through the car body and the mounts might affect the driver's sensitivity negatively, since vibrations might cause reduced nerve functions. Also the combination of vibrations and load is potentially a combination which increases the risk for premature driver fatigue and even damage to body structures (Bohgard et.al, 2011).

Joints - The first general rule of thumb when it comes to joints is to stay away from extremes when it comes to flexions (Bohgard et al., 2011and Steenbekkers, 1998). If it is necessary to operate close to maximum flexion however, it should only be for short periods and additional load should be avoided. The next principal is to ensure that load is not applied in directions other than what the joints are capable to handle. Torsional moment applied to a single directional joint for instance, is very likely to cause damage to joint and ligaments.

Maximal Voluntary Contraction - MVC, Maximal Voluntary Contraction is the maximum level of self-controlled force that can be measured in a (human) muscle and is obviously unique for each individual (Bohgard et.al, 2011). Muscular load (%MVC) is defined as percentage of the MVC value. Human factors research has come up with a set of values that are supposed to work as a recommendation when designing for different types of muscular load. Even though the values are developed in a context of workplace and work task design they can still be considered relevant as general guides even in this high performance context.

> *For static load during consecutive periods of over one (1) hour, the muscular work is not to be exceeding 2-5% of MVC.*
>
> *For a combination of dynamic and static muscular work; the maximum recommended level is at 10- %MVC*
>
> *Peaks of muscular load are not to exceed 50-70 % of MVC.*

Safety principles - The human body can sustain high levels of external G loads; however, also has some weak points that are highly relevant to be aware of and consider when the race car seat is being designed (Gartner, 1999). Particularly susceptible to trauma is the brain and the neck, hence the importance of a head restraint that prevent potentially harmful head movement. Another critical weak point is the spine; which if exposed to rapid accelerations or impact from certain angles might impose life threatening risks. As for the rest of the body, bones are due to their flexibility highly resistant to stress applied lengthwise, but a lot more susceptible to breakage when exposed to shear or bending stress.

Specific ergonomic principles for race car seat

Leg support - An extended seat surface can help take some load of the buttock and reduce the risk for concentrated pressure zones (Bohgard et al., 2011 and Cornell, 2015).

To get sufficient support for the knee position by appropriately angled and sized seat surface might also imply that less muscular effort is required to maintain the driving posture, hence reduced risk for premature fatigue.

View - It is desirable for the driver to be able to maintain sufficient line of sight without having to change body posture; move or stretch the body. The focal point of the driver's vision field when positioned in the natural position in the cockpit is preferably a couple of meters in front of car (Turnfast, 2015).

Reach controls - The driver must be able to reach and manipulate controls that need to be used while driving, without having to change body posture (move or stretch the body).

Feedback - The driver should preferably be able to receive sufficient (visual, haptic, tactile, auditory) feedback from controls and indicators (gauges) without having to change body posture (move or stretch the body) (Turnfast, 2015).

Such instruments are preferably located in the direct line of sight of the driver, without interfering with the view of the track. The design must also allow the driver to receive haptic feedback when manipulating controls as well as about the cars relative movement through transfer of forces and vibrations through the seat.

Steering wheel - The seating position in relation to the steering wheels is best positioned so that the centre of the steering wheel is horizontally aligned with the driver's shoulders (Turnfast, 2015).

The seat-to-steering wheel position should also position the driver's wrists to rest on the top edge of the steering wheel, when arms fully stretched forward and shoulders are tight against back rest; this will allow the driver to execute a full arm crossover without arms being over extended (with shoulders kept in initial position against back rest), hence increasing the risk for premature fatigue in shoulders and arms and loss of fine handling and the ability to pick up essential tactile feedback from the steering wheel (vibrations and resistance). The elbow angle in optimal seat to steering wheel setup is around 90 to 100 degrees (Obutto, 2015).

Pedal box - The pedal box placement in relation to the seat and vice versa must allow the driver to fully depress pedals without having to change body posture (move or stretch the body) (Obutto, 2015). This is achieved by slightly bent knees when pedals are disengaged (no more than 120 degrees; around 175 degrees is fully stretched knee) (Turnfast, 2015).

Over extended legs won't provide sufficient control. A correct knee angle will decrease the risk of premature fatigue. The legs (knees in particular) should have enough room to move freely in cockpit to prevent sores due to wearing or injuries in the event of a collision.

2.4 User tests

2.4.1 Introduction

Computer simulations

Digital human modelling is a tool widely used in industry to perform ergonomic simulations (Gkikas, 2013). The simulations are commonly used to, already at an early stage of the design process, evaluate a product's or a workplace's design, from an ergonomic point of view. This is achieved by importing CAD models of products or workplaces into a digital 3D environment, digital representations of humans scaled according to desired percentiles can then be moved within the limits of a human body in order to assess for instance ergonomic load when using a certain product, or assess human reach and/or field of view when working at a certain workstation. The method is preferred since it produces a large amount of objective data without having to perform physical user tests; which is generally a very tedious and expensive process; including the construction of product and workspace mock-ups, selecting and coordinating test subjects, plan and carry out tests, document and analyse results etc. Physical user tests, which for some purposes have been replaced by digital human modelling, were the only approach that traditionally could be used to collect the type of data previously described. However, for product development purpose, digital human modelling is at a later stage of the process preferably combined with physical user tests, in order to complement the analysis base with subjective data from the real user experience. The digital human modelling software used for this project is Siemens JACK. JACK, which seem to be used frequently in car industry, is primarily chosen because of its appropriateness for the particular purpose (Blanchonette, 2009), and secondly because of its availability and due to personal preference and competence.

Physical user tests

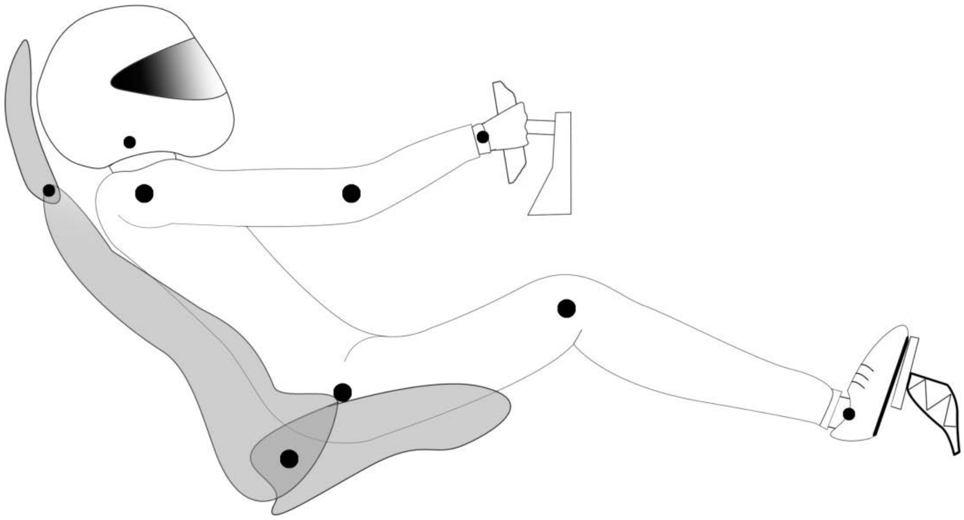
The main purpose of the user test is to gather subjective data i.e. how a potential driver experience different postures (Rexfeldt, 2013). User tests are a valuable contribution to the objective data gathered through traditional research and frequency analysis etc., especially for use-intense products. For products with less user-product integration, such as the seat, subjective user data might also benefit the design, even though it is probably not crucial for a successful end result.

For the user tests to produce useful data, preparations are essential. First of all the purpose and the questions that needs to be answered must be as explicitly as possible defined (Rexfeldt, 2013). The second step is to select test subject; this is a crucial step if the results are supposed to representative for a particular user group; which means that demographic as well as cultural and geographic aspects etc. need to be considered. Since the particular project deal with a highly customized product however, this fact does not apply to the same level and the user group is obviously selected from actual and potential drivers, within the specified range. The next step is to plan the procedure; how to perform the test? What data will be recorded and at what time? If using mediating object might be appropriate, and in that case how to design and build the object? etc. Mediating objects are representations of the product and are commonly used in user trials to stimulate the communication about how the test subjects experience certain aspects of the item and the use; for the seat, for instance possible strains, pain, general discomfort, view and reach for different seat angles and positions. The mediating object is designed and built according to what is essential to test and does obviously not have all functions or even look like the final object, as long as these biases are considered when analysing the result. After the tests are performed, the data need to be compiled and analysed for patterns. Another important step during the analysis is to analyse and possibly adjust for biases. The next step is to prepare the result for presentation to clearly capture conclusive relationships and trends and just as important, conclusive non-relationships. And finally to critically analyse and discuss the test process and result by considering reliability in terms of biases, replicability and validity.

2.4.2 Computer simulations

The main purpose with the computer simulations is to investigate positioning and design of the seat in relation to known parameters and parts, which are already finished (designed and fully constrained in the CAD assembly; but not necessarily manufactured). The approach used was to place the computer mannequin within the frame CAD model, in such way that it enabled the mannequin to sufficiently reach and manoeuvre controls in an ergonomically desirable way and at the same time remain within the safety boundary defined by SAE. The same procedure is carried out for different scaled mannequins; from 5th percentile woman to the body size that represented the biggest of the potential drivers (slightly bigger than 95th percentile man).

Figure 6 describes the driver body's degrees of freedom relevant for the seat positioning and design, The key parameters that the simulations is meant to decide an approximate position of the black dots and the angle of the joint in every black dot within a certain a range. The joints at each dot can be manipulated in the simulation software and are, as a starting point, adjusted to optimal



angles for driving. The position of the dots and the joints angles are then manipulated to respond to the considerations that will be declared for in one of the following subchapters.

Figure 6 *– Relevant human body (and seat) joints*

Mannequin scaling

Anthropometrics for different body parts are not directly dependent; hence not proportionally scalable. Therefore the first step is to decide which anthropometrics that are relevant for the design and individually scale them according to the anthropometrics of the potential drivers. For known percentiles the software automatically scale all body parts individually according to the entered percentile. For the anthropometrics of the actual drivers on the other side, each of the separate body parts requires manually scaling. The scaling can be made in the *advanced scaling panel* in the fully licenced Siemens JACK version (the student trial version does not allow this). Due to licence issues the mannequins used were scaled and downloaded free from the Open lab's ergonomic toolbox (The open design lab, 2015). The webpage allowed individual scaling for most of the body anthropometrics that were considered relevant and the models are considered an acceptable representation of the actual drivers.

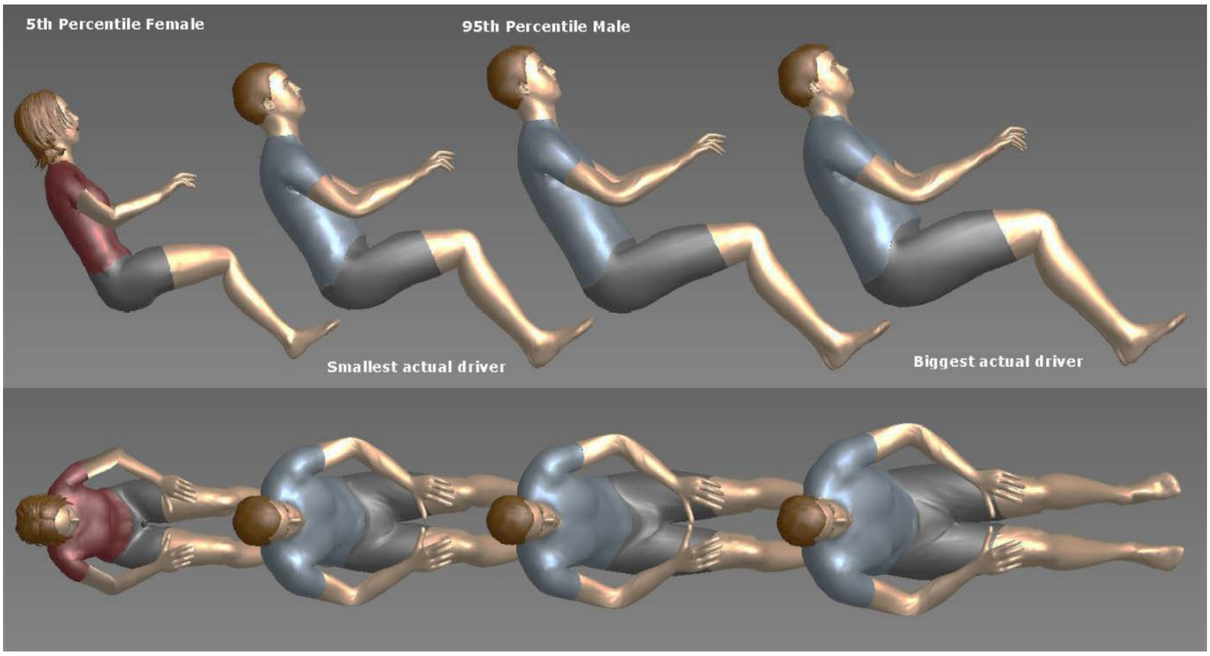


***Figure 7** – Downloaded mannequins of adequate percentile variation*

Creating the virtual world

Parts which were considered relevant for the placement and design of the seat, previously declared for in the subsystem description, were placed in the frame assembly. For those parts not represented by CAD models, digital volume representations were created and positioned in the assembly where they were assumed to go in the final design. A volume representation was also created for the cockpit safety zone boundary, defined by SAE and illustrated in the ergonomic mock-up assembly in ***figure 8.***

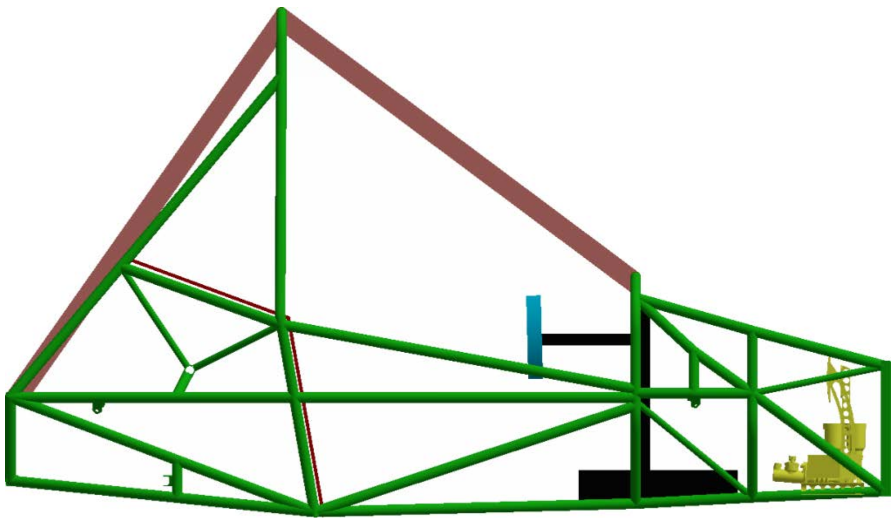


***Figure 8** – Ergonomic mock-up with helmet clearance constraints (red)*

Considerations for the mannequin positioning

The full licence of Siemens JACK allow the user to import CAD assemblies to the environment and then constrain (lock) the mannequins' body parts to the different structures of the CAD model; for instance the feet to the pedals and the hands to the steering wheel etc. This tool is obviously is very useful when assessing reach zones and similar aspects, for different percentiles. However, the student version of the software is very limited compared to the full version, which meant that a very time consuming, manual process had to be used instead. Where downloaded mannequins and the ones created in the JACK software had to be manually manipulated in JACK, saved in the fixed position as CAD-files (.stp) and then imported into the ergonomic mock-up assembly in Autodesk Inventor, where the mannequin could be sufficiently positioned in relation to relevant elements. The large amount of joints (8+, ***figure 6***) that was adjusted in order to sufficiently place the body in relation to the surrounding elements obviously caused a large amount of iterations. By adjusting the mannequins' joints and move them around in the inventor mock-up, the four mannequins could be positioned to sufficiently respond to the following aspects. These guides and demands are based on the result of the initial research; SAE-A rules, ergonomic considerations, driver's properties, existing parts and constraint etc.

Pedal box - Feet reach the pedal box; with pedals from disengaged to fully engaged. And pedal box linearly adjusted to furthest away position for biggest anthropometrics mannequin and closest position for smallest.

> *With a knee angle within defined min and max values (optimal, or close to optimal angle if applicable)*
>
> *Keeping knees clear of steering wheel, steering column and steering rack*
>
> *With an ankle angle within defined min and max values; (optimal, or close to optimal angle if applicable)*

Steering wheel - Hands reach the steering wheel and manage to perform a full steering movement with a fixed hand position.

> *With an elbow angle within defined min and max values (optimal, or close to optimal angle if applicable)*
>
> *If, applicable with shoulders leaned back in a neutral position.*
>
> *If, applicable with over arms in a relaxed, vertical position when steering straight.*

Eye position - The eye position in the neutral body position is at a height that allow for a sufficient visual field.

With a head angle that directs the visual field to an appropriate distance in front of the car, when eyes are in their neutral position.

With a neck angle within defined min and max values (optimal, or close to optimal angle if applicable)

With a neck angle that meet the SAE requirements for a near vertical head position.

Centre of gravity - If applicable trying to keep driver's CoG as low as possible. Hip angle and placement of buttocks are main parameter for this aspect, see ***figure 9***.

With the lowest buttocks placement above lowest edge of the lower frame according to SAE rules (with at least 10 mm margin for seat's material thickness etc.).

With a hip angle within defined min and max values (optimal, or close to optimal angle if applicable). And which allows for a head position and neck angle that is ergonomically preferable and that meet the SAE requirements for a near vertical head position.

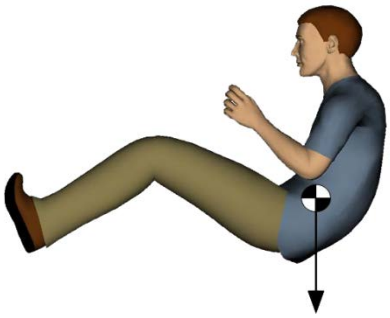


Figure 9 *– Approximate location for human centre of gravity*

Frame - Placing mannequin in relation to the pre-set frame specifics.

Ensure body remain within the safety boundaries defined by the SAE rules for helmet clearance viewed in previous ***figure 8.***

The furthest back body position does not go past the intended firewall position (with at least 30 mm margin for seat's material thickness, potential mounts etc.).

Simulation outcome

When the different sized mannequins has been sufficiently positioned in the digital mock-up (see ***figure 10***), and joint angles adjusted according to the previous considerations the JACK mannequins are saved in their respective frozen posture as digital shells (.wire files) that can be used as 3 dimensional templates in the digital modelling process of the seat in the surface modelling software Autodesk Alias.

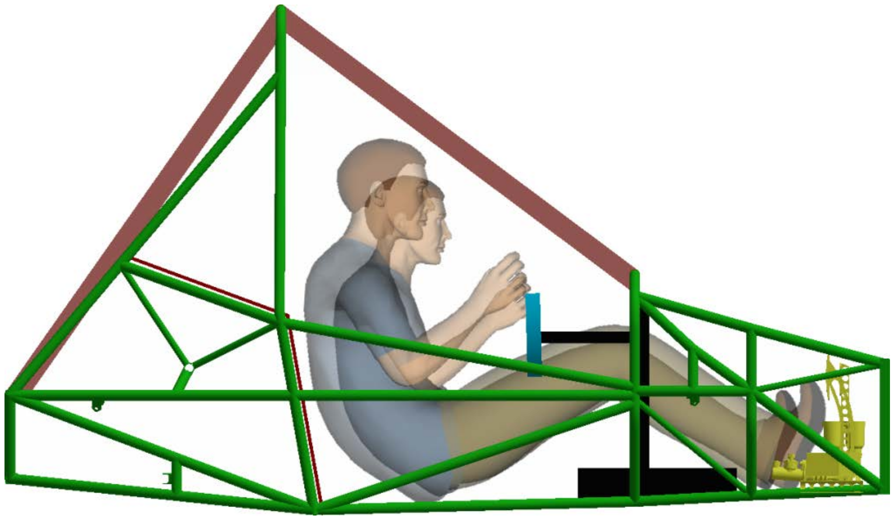


Figure 10 *– Mannequins (actual drivers) positioned in ergonomic mock-up assembly.*

2.4.3 Physical tests

In order to make up for some of the time lost, due to software issues and the time consuming preparation for the ergonomic tests the physical tests were only carried out partially. However, the decision was also made on the basis that most of the essential information was captured already during the computer simulations. The small amount information that could be expected from such test, in relation to the large amount of work that was required to get it done made it unjustifiable.

Useful information that could be expected from a complete user test would for instance have been the subjective data on how the drivers experience different positioning, supports and their visual field etc.

For future purposes, the planning for a complete user test (physical and computer simulation) and image of a timber mock-up that was planned to be used as mediating object for the interviews is attached to the report (***appendix 3***).

2.5 SAE-A framework and regulations

2.5.1 Introduction

The car will be assessed in several categories from performance, reliability, safety, ergonomics and cost to aesthetics and innovation etc. In order for the vehicle to be allowed to compete in the main event it is first required to pass an inspection carried out by the SAE judges. During the inspection the car will be tested against the technical requirements in the rule book (SAE-A, 2015); which all teams should have been supplied with a copy of before project initiation. The purpose of this chapter is to condense the SAE which are or might possibly become relevant for the design of the seat and related parts.

One of the first steps in the research study was to thoroughly and repeatedly go through the SAE rules; first at a general level and then in depth for areas relevant for the seat design. Relevant paragraphs were extracted and gathered in a separate document for further analysis and during the following step in the process translated into actual requirements.

2.5.2 Regulations/rules compilation

The SAE regulations considered relevant for the project are compiled and categorized in ***appendix 4***, in order to ensure all relevant paragraphs were covered and to facilitate overlooking and referencing to particular guides or rules. The compilation is sorted according to the following system:

- ***General considerations***
  - ***Modifications***
  - ***Materials***
  - ***Cockpit***
  - ***Firewall***
  - ***Driver***
- ***Specific considerations***
  - ***Seat***
  - ***Head restraint***
  - ***Harness and belt***

2.7 Manufacturing possibilities

2.7.1 Introduction

In order to ensure the final product is manufacturable, and well adapted to the required processed it is important to incorporate design for manufacturing DFM aspects and project specific manufacturing constraints into the development process, already at a quite early stage. However, explicitly defined manufacturing constraints are potentially an element that might repress the early creative processes.

2.7.2 Seat body

Already when the seat design started the materials and the manufacturing process was more or less set; the reason for this is a combination of many factors such as internal (in-house) knowledge (team and workshop), contacts (external knowledge), sponsors, facilities and workshop machinery/tools, budget and already stored materials. However material use and manufacturing process that was chosen on these premises are all very much applicable for the purpose and also what seems to be the most common method for the particular type of product; even though some variations in manufacturing methods have been identified during the research study (literature, expertise knowledge (composite sponsors) and online descriptions and tutorials). Variations that occurred in the researched material were for instance negative instead of positive mould, other materials for the mould, other ways to manufacture the mould etc.

The material selected for the seat body is layers carbon fibre, due to its superior weight to stiffness and strength ratio (Savage, 2009 and Demerchant, 2015)

Laminated carbon fibre is also highly appropriate for the type of complex shapes represented in a race car seat. Another material that was considered is glass fibre; the weight ratio between a glass fibre and a carbon fibre product with otherwise the same structural properties are on the other hand up to four times if stiffness is considered and double if strength is the decisive factor. Price wise however, Carbon fibre is around three times the price of glass fibre. Due to the sponsor contracts with composites supplier (MW Supplies) the price becomes lesser of a factor. The stiffness to weight ratio weighed over to the carbon fibres advantage, hence decided that carbon fibre was the material to use for the seat shell.

The manufacturing method selected for the carbon fibre body is to layer the fibres on a positive mould that is CNC milled from a polystyrene foam workpiece and coated with several layers of protective coat, which is then polished and waxed before the woven carbon sheets and the resin is applied alternately. The workshop’s CNC mill constraints and specifics were researched prior to further design work. Some of the relevant aspects were for instance number of degrees of freedom, maximum workpiece size, workpiece mounting specific, tool clearance, available tools, spindle and feed speed etc.

The foam type was picked because it was already in the team’s possession from earlier years’ mould manufacturing. From the team’s previous experience the particular type of foam was proved to be appropriate for the intended purpose, as it is relatively easy to join together to larger work pieces, to process and it is also non-reactive to the sealing coat that will have to be used to achieve a resistant, impenetrable and smooth surface to lay the carbon on. The dimensions of the foam sheets in stock are 600x1200x75.

2.7.3 Mounting

For the brackets; the material selection and manufacturing method was quite open. Possible alternatives are sheet metal (steel or aluminium) or composites (reinforced carbon fibre). The design, the expected properties and the attachment to the seat and to the chassis will be some of the factors that will decide the material, and thereby the manufacturing method.

2.7.4 Head restraint

According to the SAE rules, the general structure for the head restraint is left to the designer, as long as it meets certain requirements regarding size and force resistance; however is required to be padded with: "an energy absorbing material such as Ethafoam® or Ensolite®" (SAE-A, 2015).

2.8 Initial research conclusions

To facilitate the requirements generating process the research material is reduced to what is considered essential factors. These considerations are arranged and presented as bullet points below.

2.8.1 Primary considerations

A slightly reclined seat reduces disc pressure

Upright head position is preferable.

If head needs to be bent; rather slightly leaning forward then backwards

Allow room for the shoulders to be brought back against backrest to natural position.

Lock driver in position (especially sideways) to enable sufficient feedback transfer, on the cars condition, movement etc. and to facilitate manoeuvring. Especially important for the hip area.

Smallest and biggest anthropometrics is for most aspects considered fulfilling needs for every percentile in between; and can therefore be used as templates in seat shape design.

Strive for symmetrical positioning and loads.

Minimize load at extreme joint flexion and from unnatural directions.

Avoid excessive load on small areas (pressure zones)

2.8.2 Secondary considerations

Optimize steering power and accuracy by relative seat-to-steering wheel position (elbow + wrist angle). Approximately 90-110 degrees bend at elbow.

Optimize pedal accuracy by relative seat-to-pedal box position and knee and ankle angle. Approximately 120 - 160 degrees bend at knee (with pedals disengaged).

Optimize driver's view.

Minimize driver fatigue.

Support driver's legs/thighs for all percentiles.

Prevent lateral movement at shoulders.

Achieve/increase driver comfort by considering pressure zones (material hardness, shape, contact area, load amount and relative frequency)

Support the lumbar curve.

Absorb vibrations

2.8.3 Design Challenges

Optimize for the wide anthropometric range of possible drivers - one size fit all!?

Prevent neck from bending sideways.

Avoid asymmetrical load (a challenge, since pedal box is slightly offset and pedals have different properties and use frequency etc.)

Restricted space in cockpit

Many parameters already set.

2.8 Concept requirements, constraints and specifications

2.8.1 Introduction

As a final outcome of the research study, derived from the result of the initial research study from the different areas: systemic analysis, user analysis, ergonomic considerations, and SAE regulations and manufacturing possibilities, initial requirements and constraints for the concept can be defined.

The initial requirements can, when compiled be analysed in order to detect and possibly manage contradictory requirements. Or eliminate requirements that are irrelevant for a potential solution or which are impossible to meet etc. The requirements are also valuable for the continuous evaluation of ideas and solutions and concepts, when translated to performance indicators in the next development stage.

According to Bligaard (2011), requirements need to well defined and explicitly described; and if applicable, quantifiable and measureable. However, for the initial requirements developed in this early stage of the process, requirements might, if explicitly described repress the design process and reduce the chance of truly innovative ideas to occur and evolve; thus is for this project's concept development purpose better expressed inexplicitly in the form of guides. According to the same theories, requirements (or guides) are neither to be expressed in terms of particular solutions at this stage of the process.

2.8.2 Initial requirements

Since the design process of the car was close to finished when the seat design started and because of the explicitly described SAE rules, many of the requirements for this particular development projects needed to be quite explicitly expressed already at this early stage and does therefore have a major impact on the seat design. The initial requirements in ***table 5*** are divided into the area it has the strongest relationship to.

No.	Requirement	Specifics
1	**Technical requirements**	
1.1	Attach to the chassi	
1.2	Allow for attachment of harness	At 6 attachment points(from 5 angles)
1.3	Handle forces that may apply;	Provide sufficient structural stability and stiffness
1.4	Allow for (complete) removal of seat	
1.5	Allow for padding/inserts	
2	**Human factors requirements**	
2.1	Allow use by 5th percentile woman to 95th percentile man	See anthropometrics table
2.2	Allow use by actual drivers according to measured anthropometric data	See anthropometrics table
2.3	Follow principles for ergonomic seat design according research	See ergonomic consideration
2.4	Avoid/Minimize discomfort	

2.5	Minimize driver's fatigue	
2.6	Minimize vibrations	
3	**Performance/use**	
3.1	Prevent lateral body movement	
3.2	Allow haptic feedback to driver	
3.3	Allow for efficient steering	
3.4	Allow for efficient use of pedals	
3.5	Optimize body weight distribution (low COG)	
3.6	Allow for sufficient field of vision	
3.7	Allow for efficient use of controls and indicators	Reach controls and read indicators
4	**SAE regulations**	
4.1	Allow for quick exit of the vehicle	5 sec
4.2	Ensure head clearance	50 mm clearance, for all drivers (see head clearance figure)
4.3	Ensure adequate visibility	200 degrees vertical field of vision
4.4	Seat Position; the lowest point of the seat must be no lower than the bottom surface of the lower frame rails	
4.5	While seated, driver cannot be in contact with any part that might be heated.	60 degrees or more
4.6	Head restraint; must be provided and follow regulations according to specifics.	Min req. : 38 mm thick, 150 mm wide, area 235 sq.cms, height 280 mm No more than 25 mm away from head. Head no shorter than 50 mm from edge Withstand min. 900 Newtons force
5	**Economical**	
	Price for material and manufacturing must not exceed budget and should aim to keep prices at a minimum.	
6	**Manufacturing**	
	The design must allow and facilitate for manufacturing	
7	**Aestethic**	
	The design expression must align with the racing context and the team's aesthetic intentions.	

Table 5 – Concept requirements

2.8.3 Requirements Analysis - Contradictory requirements and demands

In most product development processes contradictions between demands and/or requirements are very likely to occur. Sometimes they are easy to manage by simple prioritizations; but sometimes the contradictions are more complex and might have close connections to other requirements which might force design compromises (Bligard, 2011).

A few contradictions worthy of discussion have occurred for the seat design. First the demand for sufficient tactile/haptic feedback of the car's behaviour that is transferred to the driver through the seat is somewhat a contradiction to the wish for a shock and vibration absorbing seat to protect the driver from transient external load and by extension prevent premature driver fatigue. This contradiction can possibly be managed by ensuring the vibration absorption only filters out the non-essential haptic feedback.

Another inevitable contradiction of similar character is regarding the drivers need to be securely in place in the seat, without letting any movement of the car negatively affect the driver's ability to manoeuvre the car and on the other side, the absolute necessity to enable the driver to quickly escape the car in case of an emergency. Since unwanted movement in this case primarily concern lateral movement (seat, harness and gravity prevent movement in the other two directions) the problem is managed by making sure the seat shape has got sufficient shoulder and hip support to prevent the lateral body movement; alteration which is likely to have little or no influence over the driver's ability to escape the car.

Another contradiction is between, on one side the importance of a stiff seat for safety reasons, for sufficient feedback transfer and for increased driver control; in opposition to the risk for development of decreased performance because of pressure zones due to hard surfaces. However; these two factors are not completely contradictory since there is most likely a possible solution for avoiding distinct pressure zones by smooth, large surfaces adapted to the body shape and possibly also by using glue-on foam pads to make the surface softer etc.

For the particular type of project, resulting in a high performance product; product component weight and weight distribution will always be a necessary consideration for optimizations. Weight reductions however, will contradict many of the other aspects that have been mentioned as important for the overall success of the project and compromises are necessary. For the seat design, weight will directly stand in relation to the stiffness and strength of the product. In order to fulfil ergonomic goals and ensure sufficient support to the driver, the part weight is inevitably affected. There are also safety aspects connected to the seats weight, both strength wise for seat and mount; but also material thickness and distribution will affect the seats ability to serve as a shield to protect the driver from objects, heat and possible compressions in case of an accident.

3. Concept development

3.1 General success factors

3.1.1 Introduction

Before ideas and solutions can be generated a baseline for the success of a solution must be established, to ensure quality and relevance for each solution, in relation to purpose and each other. What theory might refer to as either success factors, performance indicators, evaluation criteria etc. is a useful tool when evaluating possible solutions at an early stage and later when individually assessing, or comparing concepts (Stevensen et Al., 1993). The indicators are, as the name implies, generally just a list of specifications, divided according to the area of relevance; and which are considered relevant for determining how well solutions respond to the defined problem. To allow for, and to make evaluation meaningful it is important for these factors to be explicitly described; and might even be weighted in order to facilitate comparison of solutions or concepts.

3.1.2 Identified performance indicators

The identified indicators that will be used for later concept evaluation are the following:

SAE regulations fulfilment; to what degree the concept meet SAE requirements and to what extent it facilitate for related artefacts to do so.

Sufficient reach; how well the concept let the driver reach manoeuvring and control devices such as pedals, steering wheel and other controls. Factors that might influence this indicator might for instance be the ability to adjust product or to complement with inserts to accommodate for the wide range of body sizes etc.

Sufficient visual field; to what extent the solution allow the driver to sufficiently view track, relevant surrounding and indicators. Relevant factors for this indicator might for instance be eye position and angle of view in neutral position etc.

Fixed body position; to what degree the seat and related items prevent unwanted body movement; primarily lateral movement, and in particular at the hip, but also in other directions and areas. The main parameter to evaluate this criterion is obviously the relative movement in multiple directions and it might be managed by built-in supports, inserts, belts, friction, structural stiffness etc.

Avoid/minimize fatigue; the extent to which the solution help to reduce negative ergonomic load; static, dynamic and/or transient. And support the body when performing necessary manoeuvring; turning and adjusting pedals. Relevant parameter for this factor might be the product's ability to absorb vibration, allow for and support preferable postures and joint angles and to what extent the solution allow the musculature to rest when not activated. This might be achieved by helping the driver avoiding unnecessary muscle use and static load by for instance eliminating the need to push shoulders forward, and/or lift over arm to reach. Or by supporting for instance thigh, buttocks and head in their position, hence reducing the amount of additional muscular activity required only to keep them statically in place.

Avoid/minimize discomfort; the level to which the product is likely to cause little driver discomfort amongst the wide range of drivers. Parameters to assess this criteria might for instance be ratio and location of pressure zones, surface hardness etc.

Weight; an ultra-low weight product is desired for the high performance purpose.

Low driver CoG; to what extent the solution allows for the driver to maintain a low centre of gravity; another factor that influences the overall performance, through improved manoeuvrability, and stability. Since the CoG for humans is located slightly above the waist in general (see ***figure 9***), relevant parameters for this particular performance indicator is mainly the buttocks position and the seat inclination (and theoretically also kneecap position).

Structural integrity; evaluate the extent to which the seat and mounts can withstand external forces during driving and in the case of a potential collision.

Manufacturability; this criteria will investigate how well the product's design, material selection etc. is adapted to the possible or suggested manufacturing strategies. Both price and time will be taken into consideration.

3.1.3 Weighted performance indicators

The indicators and requirements previously established are not all equally important for the success of the design; hence require internal weighing. A simple requirement weighing method suggested by Johannesson et al., (2004) is comparing requirements internally, resulting in each of the requirement receiving a quantitative value, which then can be used in various evaluative matrixes to compare solutions internally between concepts or externally with existing solutions (benchmarking) etc. It is also valuable to weight requirements to communicate intentions within a design team or even to facilitate the individual's selection process. The weighted requirement method cross-compare the requirement in the row with the requirement in the column and if the row requirement is considered more important than the corresponding column requirement the cell located in the intersection will receive an "X", and if not, an "O". X's and O's are then summarized for each row, to receive the weighted value. The type of specific indicators that have been picked together with the weighing, gives a clear indication of the designers intensions and prioritizations. For use in later evaluations, the performance indicators are weighted and presented in ***table 6.***

	Low weight	**Low CG**	**Fixed pos.**	**Suf. reach**	**Suf. vis.**	**Min disc.**	**Min fat.**	**High Man.**	**Struct.**	**X**	**O**	**Weight**
SAE regulations fulfillment	X	X	X	X	X	X	X	X	X	9	0	**9**
Low weight		X	O	O	O	X	O	X	O	3	0	**3**
Low CG			O	O	O	O	O	O	O	0	0	**0**
Fixed position				O	O	X	X	X	X	4	2	**6**
Sufficient reach					X	X	X	X	X	4	3	**7**
Sufficient visual field						X	X	X	X	4	3	**7**
Avoid/minimize discomfort							O	O	O	0	1	**1**
Avoid/minimize fatigue								X	O	1	3	**4**
Manufacturability									O	0	2	**2**
Structural Integrity										0	5	**5**

Table 6 – Weighing of Performance Indicators

3.2 Generation process

3.2.1 Introduction

The basic idea of the synthesis is to produce solutions through a three stage process; where the first step is to state the need or the problem which the solution is going to address (Bligard, 2011 Osterlin, 2003 and Johannesson et Al., 2004). To keep the solution space open it is important that the needs and problems are not expressed in terms of a solutions (rather express the need to seal a wine bottle than describing the cork). The next step is to produce a range of potential solutions that solve the problem or meet the need and finally select one solution, by comparing solutions relative to each other or existing solutions (benchmarking) and also against pre-defined performance indicators. To facilitate comprehension and since the generation process has been fairly straightforward, with relatively simple solutions, the following sections describes the whole generation process at once; from the identification of a need or problem through an iterative idea generation and evaluation process to the suggested conceptual solution for the different problems, needs and areas.

Before selecting any solution the alternatives had to undergo an evaluation process against the key success factors previously described and be assesses against how well each solution relates to other solutions. Such iterative and integrated generation process can help to avoid contradictions between solutions. In following chapters the conceptual solutions that are suggested will then be combined and further refined to the final concept.

For the particular type of project, project parameters obviously changes and unexpected events occur, which will require adaptations or completely new solutions; therefore a continuous adaptive problem solution approach needs to be practiced, to complement the initial generation process.

There is a large variety of different methods suggested for different stages of the idea/solution generation process. A commonly used method when the needs are relatively well defined and require feasible solutions is to scan catalogues, web pages etc. for similar solutions to similar problems (Osterlin, 2003 and Johannesson et Al., 2004). Sometimes, often earlier in the process, it can also be valuable to look for solutions in totally different areas, but with similar needs. Apart from this sketching and rapid digital prototyping has been used as important tools to visualize and concretize needs and to generate a variety of solutions. Another method that was used to support the generation process was something that can be referred to as "solution trees" (Johannesson et Al., 2004); a fairly straight forward method which is forcing the designer to keep on asking "In what possible ways?" until the problem or need is fully broken down. The need or the problem is specified at the root of the tree and solutions are defined as branches; and possible solutions keeps growing out from previous solutions as long as it stays relevant to the initial need. The result of the full solution three processes is presented in full in ***appendix 5.***

3.2.2 Needs identification, idea generations, selection process and proposed solutions

Head restraint

The very first decision that had to be made regarding the overall seat design was whether or not the head restraint was going to be included as one component or whether the seat and the head restraint were better divided in two separate pieces. The thought process is briefly illustrated in the solution three in ***figure 11.*** An integrated solution was chosen; since it allows accommodation of wider spectra of anthropometrics. A two part solution would more or less have forced the head restraint, hence the head, to remain at a static position, same for all drivers; which obviously would force compromises of seat design and placement between high and low percentiles. And due to this fact induce harmful postures and insufficient support as well as possibly making drivers with smaller anthropometrics unable to reach or taller driver's unable to fit in the cockpit.

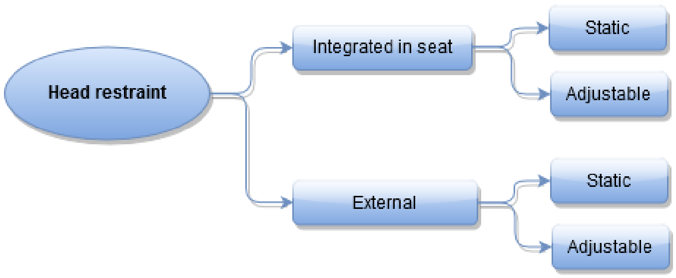


Figure 11 *– Solution Tree; Head restraint*

Basic shape and dimensions

For the seat to sufficiently accommodate for a driver from the 5th percentile woman to the 95th percentile man and slightly above; a series of needs and problems must be considered; for which the first is addressing the seat shell size and shape. Some of the considerations are displayed in ***figure 12.***

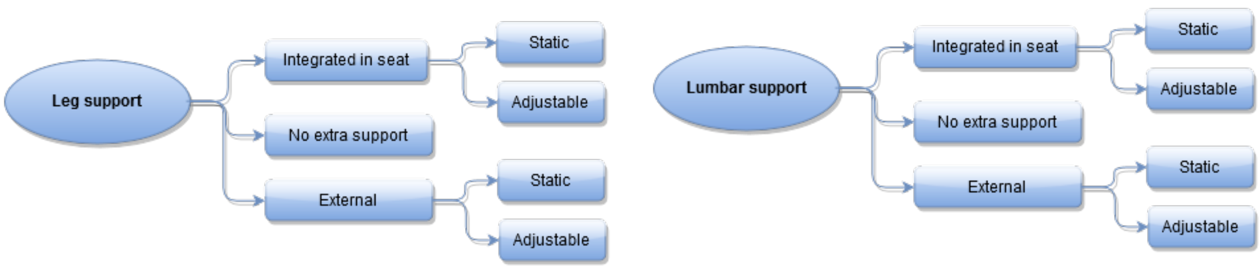


Figure 12 – Solution Trees over various support solution

To decide the seat shape; in regards to the angle at the hip, torso and neck and also the shape of the lumbar curve, the first step was to consider the ergonomic principles and arranging the mannequins in a range of ergonomically satisfying postures as described in the previous chapter. Setting up postures also included several other parameters than previously mentioned, which are relevant for other areas than the specific seat shape; such as angle at the ankles, knees, elbows and wrist and also the distance between feet, kneecaps, elbows and palms. All of which are parameters that were decided, as a range, during the digital ergonomics testing. The finished mannequins could then be used, together with the added thickness of the foam head restraint, as guides for shaping the main outline, from top of the head, down to the back of the knee.

For the seat shell size however, only the biggest driver template will be used; since no feasible alternatives to alter the actual shell size were found; even though this approach will require additional modifications to sufficiently support the smaller bodies. The template will decide overall width, shoulder height, head height etc. The only dimension which smaller percentiles affected in regards to the overall size of the basic shape was where the seat ends before the driver's knee. The reason is to allow drivers with shorter buttocks to knee distance to sufficiently move the leg and to avoid pressure zones that potentially may cause discomfort and sores in the region on the back of the driver's knees.

Reach - Adjustability

The second aspect to address in regards to the design of the seat is the reach. The solution's thought process is illustrated by ***figure 13*** and ***14.*** The possible solutions that were considered feasible were to either make the seat adjustable for different anthropometrics or to complement with inserts to alter the position of the driver in that way. An adjustable solutions was considered superior to inserts, mainly for two reasons; first, since it is more universal both for present and future purposes and secondly because an adjustable solution offer a much better possibility to position the body in ergonomically satisfying postures. Other influencing aspects regard safety and time and material savings, if manufacturing individual inserts can be avoided.

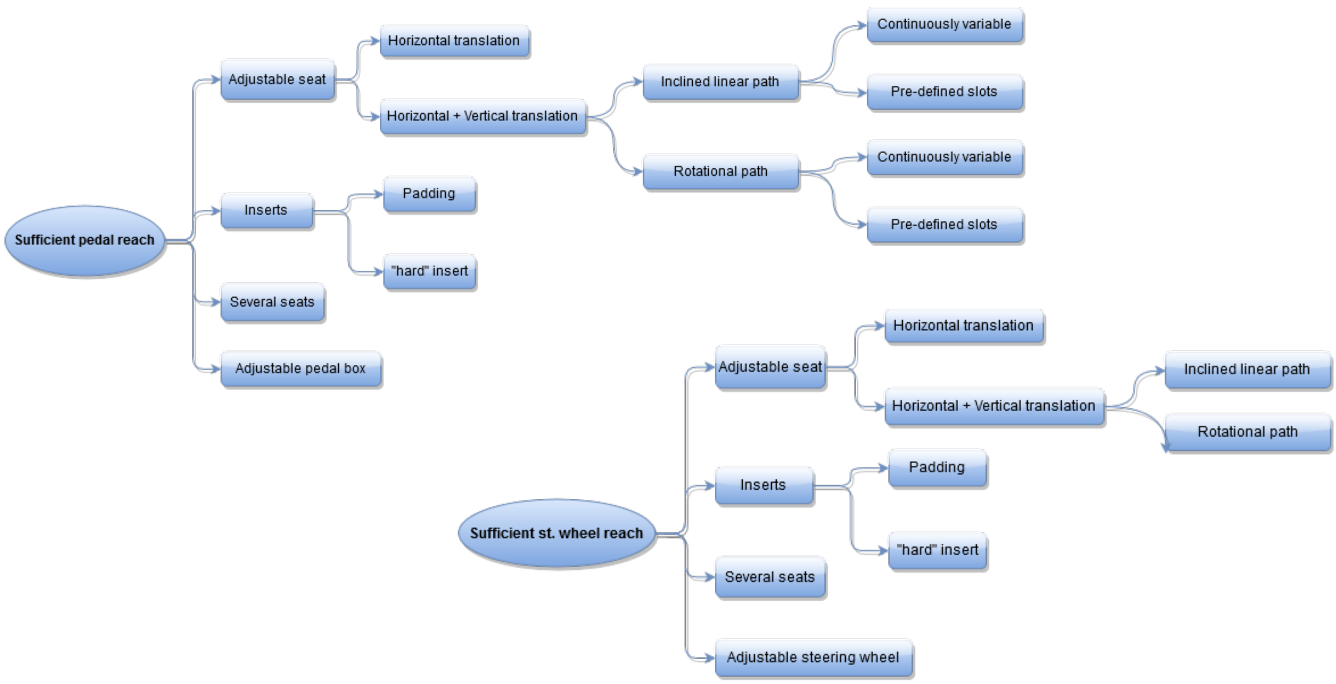


Figure 13 and 14 *– Solution trees for achieving pedal and steering wheel reach*

After it was decided that the seat required to be adjustable, a couple of new questions arose that need to be addressed before moving on to actually generating ideas for solutions. How much body translation is required to meet the needs of the different user percentiles and what kind of translation is required? From the values gathered in the ergonomically simulations with frame, pedals and steering wheels etc. it was evident that both angular and horizontal translation (forward and backwards) was required. From the data, a range for the required translation and rotation could be defined. Angular adjustability up to around 10 degrees and horizontal adjustability at around 100 mm was concluded appropriate reference values for the overall adjustability.

With the base in previously mentioned constraints and requirements a solution for adjusting the seat's angle and horizontal position can be designed. For both linear and rotational adjustment there is no need to allow for quick adjustments; which will allow for simple solutions with bolts and nuts for instance.

For both angular and linear translation there would be an option to either use a curved slot to slide or using holes at set distances or angles. Using a slot for the angular adjustment was considered inappropriate for two reasons. First due to a safety issue; it would be a risk that the considerable amount of force that is applied to the fasteners might cause the seat to unintentionally slide off angle. And secondly, that it is not essential for the seat to allow for very accurate angular positioning. Therefore the type of adjustment solution chosen is an angular rotation in four steps, of a total 9 degrees; four holes, with 3 degrees increments.

The requirements for the linear transition are slightly different however; which resulted in a different solution. The sliding solution was considered appropriate for part; primarily because being positioned at the correct distance from the steering wheel is considered very important to be able to sufficiently manoeuvre the car. The space to loosen bolts to adjust the seat will be very limited underneath the seat; however, the sliding solution offer an additional bonus on this point, since the particular solution, unlike several separate holes, not require complete removal of nut and bold in order to adjust the seat.

Body Support

The overall seat shape was very much design to give good support to the driver and prevent unintended movement. The research study revealed, as mentioned, some of the principles for supporting the body in regards to what is important both from a racing performance perspective and from an ergonomics point of view.

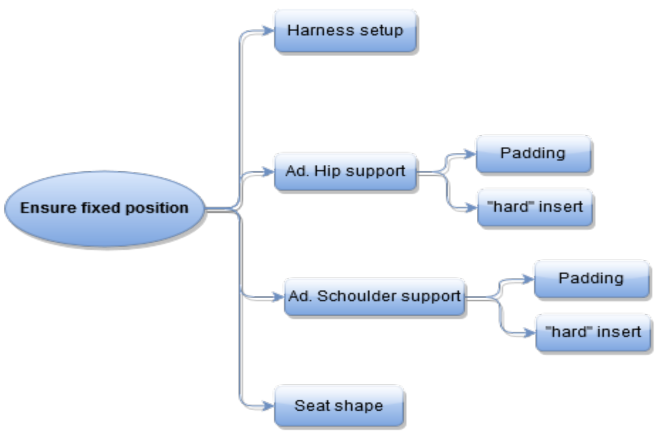


Figure 15 – *Solution tree over the need to fixate body*

Prevent Lateral movement in the hip and thigh is one of the most important objectives for the racing seat. This need is obviously very hard to meet for a wide range of hip breadths. The suggested solution to this need is to design the seat with a supporting structure, along the full length of the smallest percentile thigh and with a height according to the largest percentiles thigh height in profile (displayed in ***figure 16 (B)*** *and* ***17 (A)***). To ensure larger anthropometrics to fit in the seat, the largest hip breadth among the potential drivers will be used as primary driving dimension. And because of this fact, the solution need to be complemented with inserts to support the hips of the lower percentiles. To further prevent hip and thigh movement, and also to keep the knees apart, in a preferred, natural position, a ridge is added in the space between the legs as shown in ***figure 16 (A).***

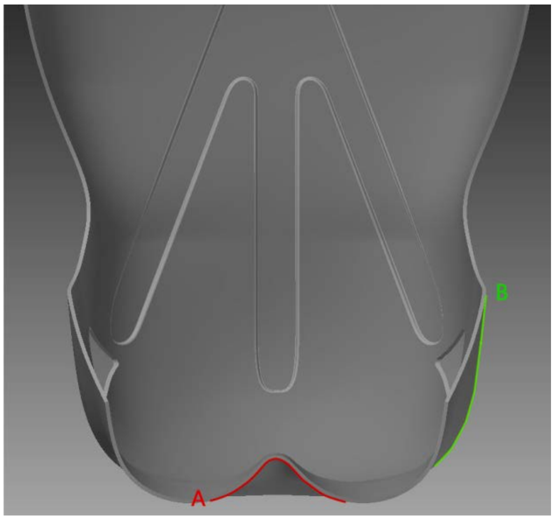


Figure 16 *– Show possible support solution for thigh and hip.*

The second most important area for lateral support is at the shoulder level. And the suggested solution to this need is similar to previously mentioned for the hips. The seat shell wraps around the side of the shoulders of the driver as seen in ***figure 17***. With this solution, new problems arise. The difference in shoulder breadth is obviously quite big between lowest and highest percentile. The shoulder breadth however, is a more or less a linear function of the height; information that is used to make the lateral shoulder support cone shaped to support both extremes, displayed in ***figure 18***.

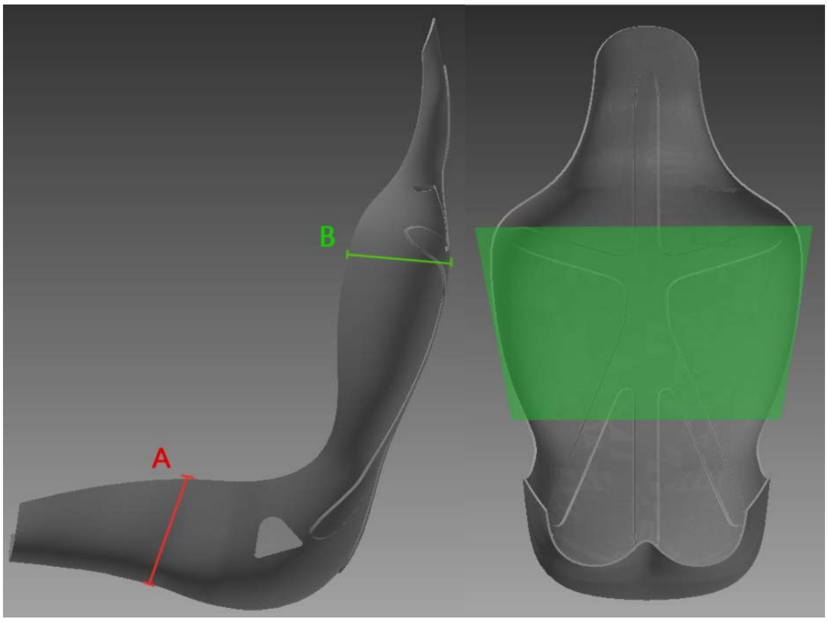


Figure 17 and 18 *– Show possible support solution for thigh/hip and the cone shaped shoulder support*

Head restraint

Except for whether it is integrated or not, most constraints are already defined for the design of the head restraint. However, how to sufficiently support the head of drivers of various heights is yet to be worked out. The two possible solutions that remained after a general screening were to either design a smaller foam cushion and make it vertically adjustable or by designing a larger version that could be allowed to remain static.

The latter solution was picked for a combination of reasons; it is a simple solution that in contrast to an adjustable version would not risk to slide out of position. Also, since it is larger, it would not risk being in any conflict with the regulations for size and area. The foam cushion will be glued to the seat.

The only concern with a static restraint is that the large cushion might extend too far down and for some of the taller drivers, possibly causing discomfort in the higher back region and also not allowing them the intended support for shoulders and higher back. There might also be consequences for the very shortest drivers; such as an undesired neck angle. However, the latter can likely be avoided with the help of inserts for low percentiles.

Belt and harness setup

As for the head restraint, rules and guides for the belt and harness setup is quite well defined in the SAE-A rules. The main consideration for the seat design in regards to belt and harness is how to ensure a tight fit around the driver's body when seated. The belt is attached to the frame at 5 (6) positions (***figure 19***) and merge together in one lock, just over the driver's waist. The belt runs from frame attachment point to the lock; preferably without wrapping around seat corners; to, when put under heavy load not giving the appropriate support to the driver or risk damaging or dispositioning the seat.

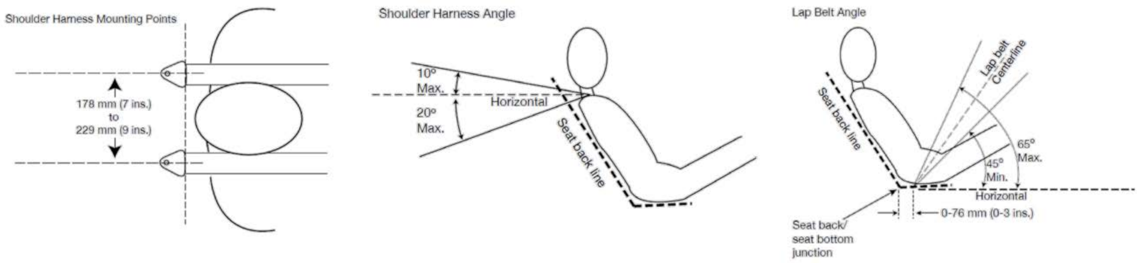


Figure 19 *– Illustrating the SAE-A rules regarding harness setup*

After screening, two solutions remained (see ***figure 20***). Either to lower the side profile of the seat to let belt wrap around the edge; and thereby only giving support halfway up the thigh, or making holes or slots in the actual seat structure, where the belt can be allowed to pass through.

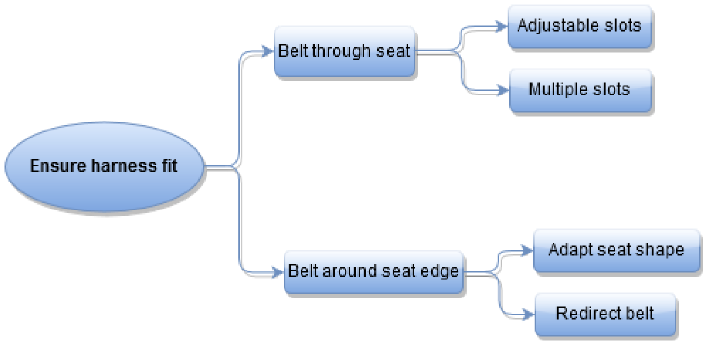


Figure 20 – *Solution Tree with possible harness setup solutions*

When researching existing solutions on the current online market; the two solutions is estimated to be equally common; however the latter seem to be more applicable to the thin composite single shell types, and especially so if the seat is inclined. The difference between the solutions is illustrated in ***figure 21***. A slot was selected for the hip belt; primarily because removing the supportive structure that is connecting seat and backrest will seriously affect the amount of force the seat can withstand in the hip section. Especially so when force is applied to the back and headrest, as the main attachment points are located in the seat part and the forces therefore need to be transferred through this region. Which is a potential cause of failures and thereby an unacceptable risk to the driver.

Figure 21 – *Illustrates the difference between slots or lowered profile for harness.*

In order to maintain sufficient structural integrity, a slot solution was chosen also for the belt with its attachment point(s) between the driver's legs. However, since the position of the thighs is very similar for all percentiles, this slot can be kept rather small. The minimum size will be decided by the maximum size of the harness that is intended to pass through the slot when seat is mounted or removed.

As far as the shoulder belt is concerned the only feasible alternative is to use slots, in order to get sufficient structural integrity in the transition between the back and head regions. The next problem regarding the slots, and in particular the shoulder slots, is how to make them wrap tightly around the driver's shoulder for all represented percentiles. The two solutions generated for this problem, were either to have several slots in a vertical fork shape (typically used in car seats for babies to accommodate for varying body sizes), or to have a larger cut-out to fit all percentiles in one. The latter was selected due to higher level of flexibility and manufacturability and due to the simple process of removing the seat that this solution provides (the solution does not require disassembly of the harness). However, this solution will lead to more material being removed, hence negatively affecting the structural integrity; and will thereby make the implementation of structural changes and additional support structures necessary in the region, which are described in following section.

Structural profiles for stiffness and strength

Unlike a static seat, or a seat in two parts this year's version need to have the structural integrity to withstand load during race and a potential crash on its own. According to expert knowledge from the composites sponsors and from carbon fibre research reports (Savage, 2009) a few alternatives were discovered for how to achieve the required strength. Composite wise, it is possible to strengthen sensitive areas or the whole piece with combinations of different types of fibre sheets (thickness, material composition, weave type and direction etc.), with the relative layering direction, resin type and mixture etc. Another efficient way to obtain sufficient strength, that was discovered, is to use structural surface profiles; 3D patterns in the surfaces, such as ridges and flanges increases the both torsional stiffness and flexural rigidity. Lastly, the actual shape of the piece in itself is very important for the overall strength. See ***figure 21*** for brief idea generation process.

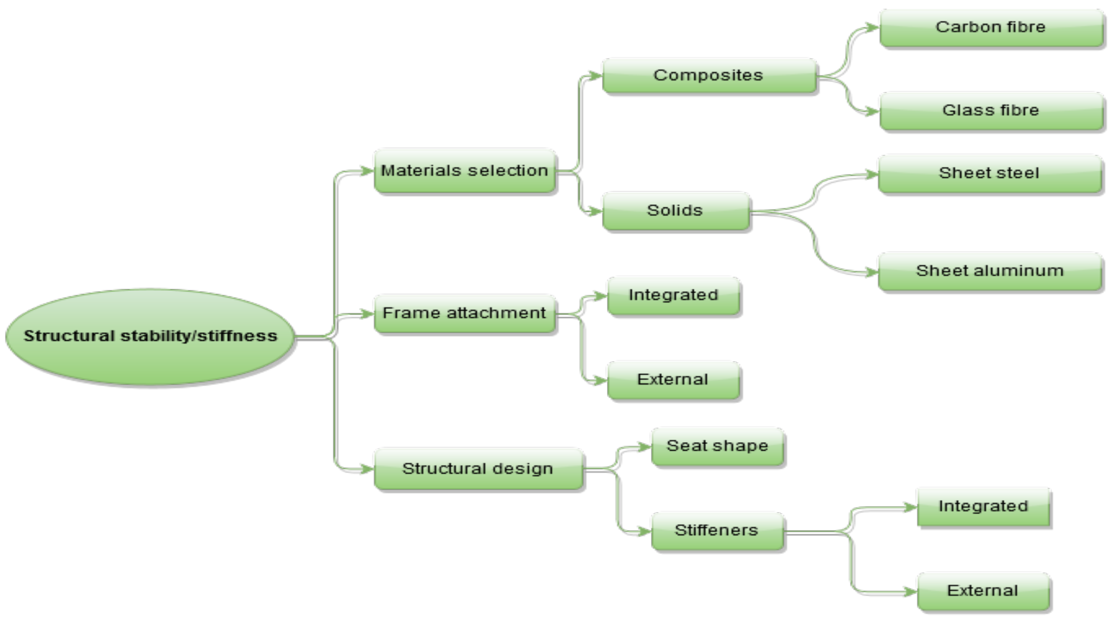


***Figure 21** – Solution tree for maintained and improved structural capacity*

For the final concept, several of the above mentioned principles have been used to give the seat sufficient strength to resist predicted stress. However, due to the difficulty of estimating the actual forces that might occur during the actual event, the seat it is far from optimized when it comes to weight-to-stiffness/strength ratio. The only data available is the minimum forces supplied by the SAE rule book, which means that in the absence or real data, quite significant safety margins have instead been used for the stress analysis, to ensure sufficient strength.

Due to lack of experience and knowledge and since it is hard to estimate the effects of and to simulate, the principles related to the actual carbon layering, weaves and directions, is not going to be actively considered during the design process. But will on the other hand be considered through expertise knowledge, when the manufacturing is planned in detail. Structural profiles and the shape on the other hand, will be important aspects to continuously consider throughout the design process and manufacturing. First of all, the shape will be adapted to transfer load from the point where force is applied, to where it's transferred over to the frame. An especially sensitive region, also discussed in regards to the harness slots, is where the sitting surface meets the backrest in a near perpendicular angle. The predicted stress in this region can both be caused by a twisting moment, around horizontal axis, when force is applied asymmetrically to the backrest. And also due to a bending moment, around the axis running widthways, from all forces applied to back and head region of the seat shell. To achieve the needed strength in the region, extra material will be kept to connect backrest and the sitting part. In addition to this conscious design alteration, the primary strengthening feature in regards to the overall shape is probably the naturally occurring curvatures throughout the entire part; with surfaces almost exclusively bending and often so in multiple directions.

A rounded rectangular profiled ridge will be added to the back of the seat, from head to buttocks, with four symmetrical branches extending out from the central ridge to increase the torsional stiffness. In addition to the ridges, a flange running along the edge all around the seat's outer profile will be added. The flange will most likely be an important addition to significantly increase the strength. However, the flange also contributes to the appearance and protects the driver from potentially harmful edges.

Design for manufacturing

The aspects that were considered regarding manufacturing was first of all to make sure the draft angle on the intended plug allows removal of the piece once hardened. This was achieved by making not designing the shell angle of the deeper sections, especially around the hip area and the shoulder section at least having a 3 degrees angle difference to an imaginary horizontal plane and also by considering the ridge depth and angles (see ***figure 22***). Secondly manufacturing consideration in regards to the shape was ensuring ridge depths and angles, as well as flanges and general surface curvatures and fillets are not within a minimum radius that allows both for mould processing and for composite layering.

Figure 22 – *Illustration of minimal draft angle for deepest section*

Attach to frame

The seat obviously needs to be attached to the frame somehow. The solution need to take the requirements for adjustability as previously mentioned into consideration and also be light and adapted to frame and surrounding parts. In order to achieve that linear adjustability through sliding, the most appropriate solution seems to be a bracket holding the seat sliding on a base plate attached to the frame. Different options were considered, where the sliding surfaces were, vertical, horizontal or at an angle. Since most of the load will be vertical however, the surface areas were maximized by making the attaching faces horizontal. The next problem to be considered was how the baseplate was going to be attached to the frame; fasteners (bolts, screws or rivet) or if to be welded. Welding was chosen, since drilling in the frame in this area might risk weakening the frame.

The next consideration was whether the base plate was going to be welded on top of the frame or notched between the frame bars. The second alternative was selected, since it does not add to the mounting height of the seat and will therefore maintain the low profile and the low centre of gravity.

The final issue regarding the attachment of the seat to the frame is the actual connection between carbon and the mount. The needs and constraints regarding the adjustability that have been mentioned previously will obviously dictate the design of the bracket; four holes will allow for the angular adjustment and slots will be used to allow for the linear translation. The brackets need to be designed and placed so that the seat position can be as low as possible. For all this needs a pair of side mounted parallel brackets was considered appropriate. Parallel mounted to allow for both angular and linear translation and side mounted to allow for the angular adjustment and to maintain a low seat placement. Since the sides of the seat are curved, the brackets need to be placed at a distance from the seat, in order not to hit the side of the seat when set at the lowest angle. A displacer, which is static to the seat, must therefore be used to make up for the varying distances between bracket and seat surface. Another measure that is necessary for avoiding clashes is to design the bracket so it stays clear of the seat for all four adjustments; this will be achieved by reducing the material in between the pivot hole and the lowest of the four holes at the front, and also by a bracket cross section profile that is bent to be tangent to the seat when it is set to the lowest angle.

4. Concept Modelling

Even though the modelling process can appear pragmatic and fairly less creative than earlier processes; problems that requires solutions will appear and also, even though parameters seem to be well defined there is often room for interpretations, which opens up a great opportunity for the designer to add personal touch to the design. The embodiment and visualization of the concepts during the modelling process enables constant evaluations. But it might also stimulate creativity and additional idea generation.

4.1 Surface modelling process

4.1.1 Introduction

To sufficiently represent the seat design digitally, required use of complex surfaces, many of which had double curvatures (curve around two axes simultaneously). The available parametric 3D solid modelling softwares steadily improve their surface modelling capacity; after trials however did still proved to be insufficient for the particular purpose. For the solid modelling process, Autodesk Inventor was used. For the surface modelling process, Autodesk offer better adapted tools however; for this process Autodesk Alias was used, due to its superior ability to generate complex surfaces. Other contributing factors to the choice of software was due to previous experience and also and due to the expected smooth transitions between surface and solid modelling; since the two softwares nowadays are in the same suite.

The first step in a surface modelling process is often to import some kind of representation of the analogue world; often sketches, photos, 3D reference model or similar, often from several views if 2D representations are used. From outlines of the objects, depicted in different views, surfaces can be created.

The modelling approach for creating complex multi curved surfaces in computer aided design softwares is to create curves in 3-dimensional space, which will then define the surfaces. There are several different tools to create different types of surfaces with different properties and different quality. A common approach is also to create surfaces which are bigger than intended and then either project curves from a certain direction or intersect shapes which results in curves-on-surface. These types of curves can then be used to trim away undesired region of the surface.

The degree of the surface will decide the smoothness (as for curves). Another relevant concept is surface continuity; the continuity is commonly either: point, tangent or G3 curvature (G4) type and is describing the relationship between the two surfaces (or curves) that are bound together. The most commonly used curve type for this project is CV curves; CV curves have got CV points along the curve defining the curve. The curve shape is altered by manipulation of the CV point in 3D space.

4.1.2 Surface modelling in Autodesk Alias

Create primary 2D rail curve

The different sized mannequins are imported into the software as surface models to be used as 3D templates, around which the seat surface will be modelled. As mentioned; the biggest mannequin representing the biggest potential driver will be used as the main template.

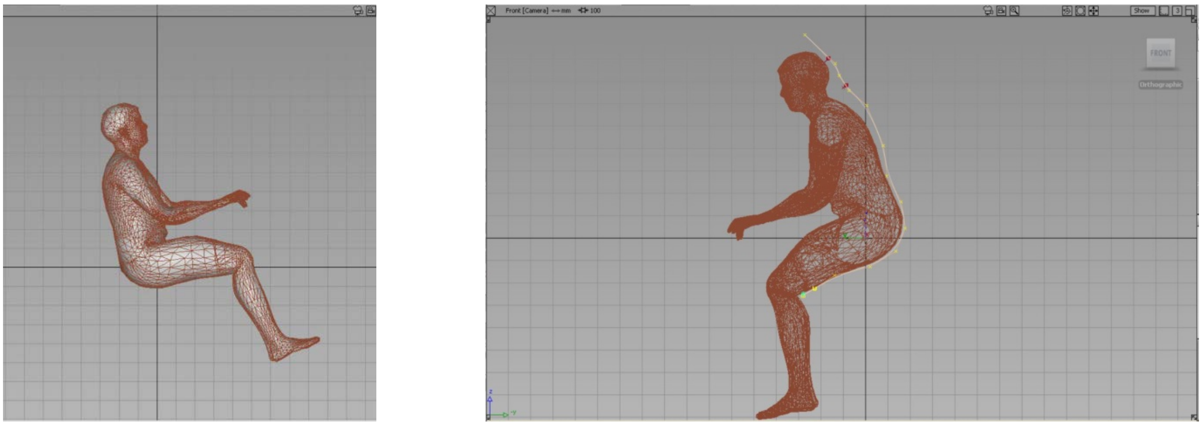


Figure 23 *– Importing mannequin and creating main rail curve*

The first curve that is created is the primary rail curve; this curve goes all the way from the top of the head down to the back of the knee and defines the shape of the spine and the thigh. This curve is the most important curve since it will be the base of all other curves and since it defines the angle between seat and backrest (***figure 23***).

Create construction planes

In order to improve the chances of achieving high quality 3D surfaces when combining rail and generation curves and to achieve high level of continuity between the different patches in the next stage it is from experience a good idea to combine curves which have only a two dimensional relationship between CV points. In order to achieve this, 19 construction planes are created along the primary rail curve (***figure 24***); and are made perpendicular to the curve tangent in the plane's origin. By toggling between each of the construction planes, individual 2D generation curves can be created on each plane.

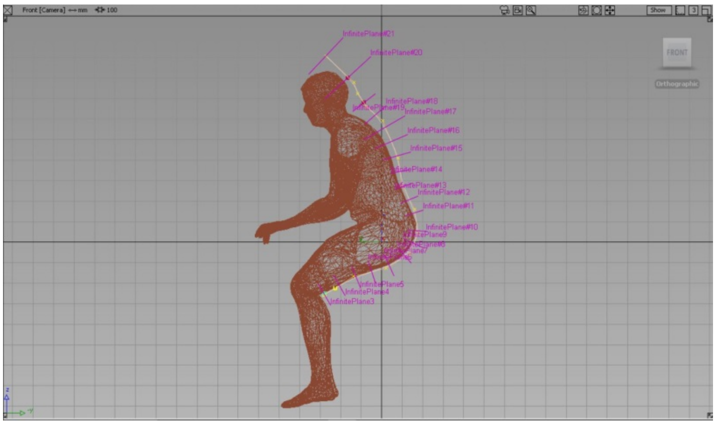


Figure 24 *– Construction planes, tangent to curve curvature*

Create 2D generation curves

Each of the 19 2D generation curves along the rail curve is tracing the 3D contour of the template at that particular section (***figure 25***). To make the modelling more efficient, generation curves are only created in one direction from the rail curve with the intention to simply mirror the final surfaces in the end.

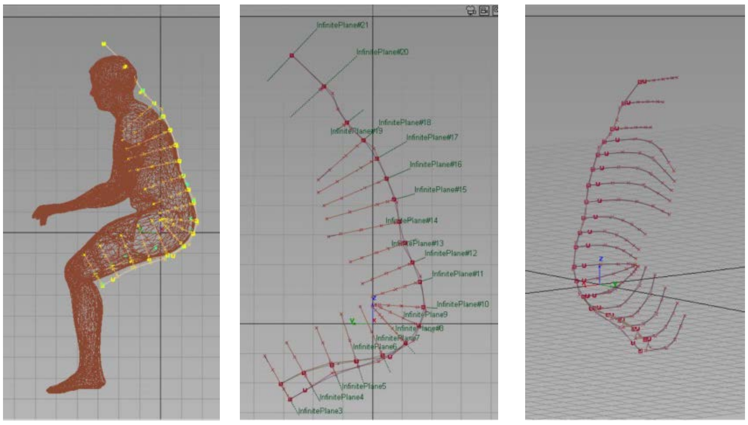


Figure 25 *– 2D Generation curves displayed in three dimensions*

Create secondary 3D rail curve

When all 2D generation curves are created and modified to fit the template, a 3D rail curve is created to bind the second edge of the generation curves together (***figure 26***) and thereby defining the last boundary for each of the surface patches. Using this approach will obviously result in a secondary rail curve which expand in three dimensions and might cause problems when surfaces are to be created later. However, was chosen because it was probably the quickest method, since it also shapes the template outline both from the front view and the top view simultaneously. An alternative approach; which most likely would have resulted in just as good surfaces or better, would have been to instead divide the process into two parts by extending the generation curves beyond the point where the surfaces are intended to end and afterwards project an outline of the body shape onto the oversized surfaces and trim away excess surfaces outside the projected *curves-on-surface*.

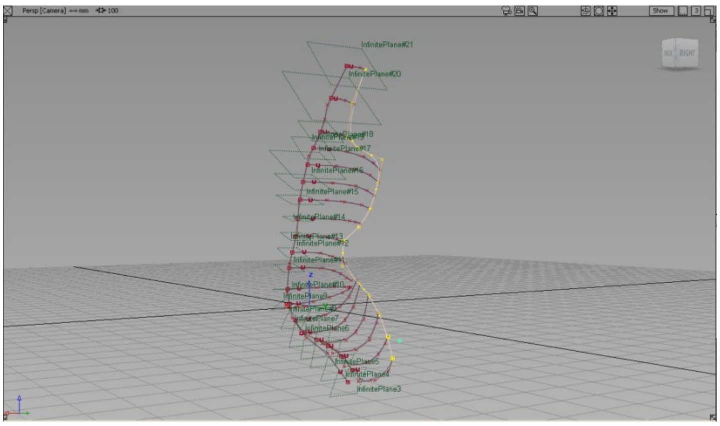


Figure 26 – *3D rail curve*

Create 3D surfaces

Creating the surfaces is probably the most critical moment; experience show that the result is highly dependent on the work that has been done up to this point; the planning and the quality of curves are essential factors for successful surface modelling. The initial idea was to create a single surface running all the way along the primary rail curve; by using the rail curve tool with two rail curves and 19 generation curves. If this approach would have worked, the mono-surface would have had perfect continuity and smoothness. However, such surface was too complex to build for the program and a slightly altered approach had to be used, where only 2 or 3 generation curves were used at once (patches seen in ***figure 27***). The surface continuity is evaluated with the zebra pattern diagnostic shade and can be improved with various alignment tools in order to achieve the desired result. All transitions except at the major angular deviation, where backrest meet seat reached curvature continuity.

Figure 27 – *Surfaces patches; analysed with various continuity analysis tools*

Mirror surface

The software has a built in symmetry option which will continuously update a visual mirror of all objects in a certain layer without actually creating the geometry. However, when the model is ready the geometry can simply be created and then loses the connection to the parent object (***figure 28***). If modelling with the intention for a model to be mirrored already from the beginning, this is obviously a very efficient method and it ensures complete symmetric objects. To mirror height surfaces require some additional preparation; a curve align tool was used for the 19 generation curves to make them normal to the symmetry plane; which will at least result in tangent continuity between parent and mirrored surface. There is also a tool, called symmetry align, that achieve the same thing after the surfaces have been created, however was not appropriate for this purpose, since it might alter the surface shape to achieve higher continuity; which obviously is not something we want.

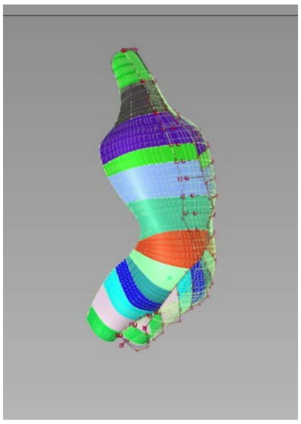


Figure 28 *– Mirrored surface*

Create structural profile (ridge)

To achieve extra structural stability and stiffness a 5 mm deep structural surface profile is running along the back rest and splits up in four branches to add additional torsional stiffness (***figure 29***). Several methods were tried and there are most likely several more that might have worked to achieve the ridges. The modelling approach that finally proved to work was to create a construction plane, tangent to the backrest on which the curves were created to shape the outline of the ridges. The curves were then projected in the normal direction to the plane onto both an offset copy of the seat surface, 5 mm behind the original previously created and onto the original. For the original the ridge shape was trimmed away and for the offset surface the shape was kept and the rest was trimmed away. The two surfaces were then connected with surfaces to complete the profile with sides.

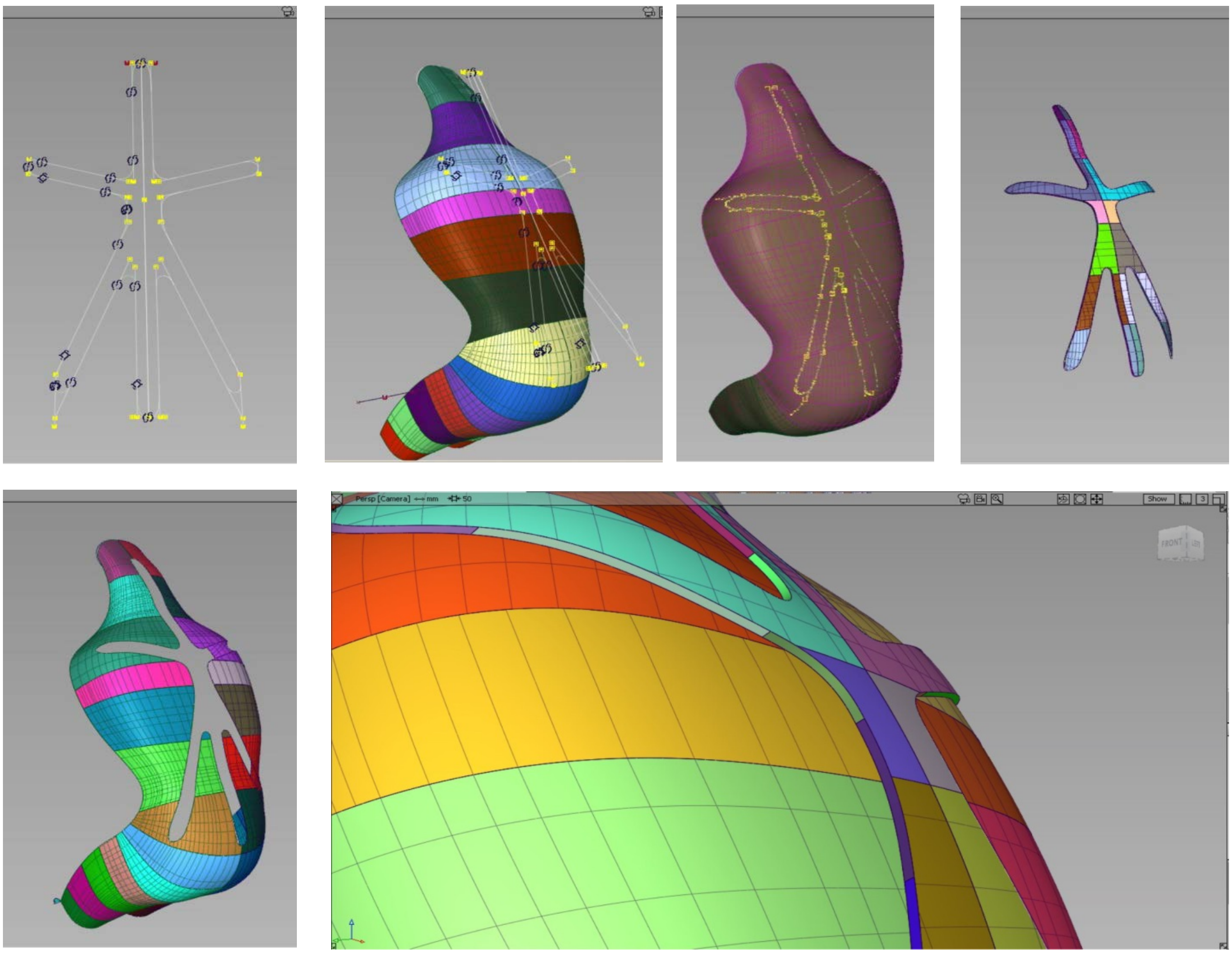


***Figure 29 –** Ridge modelling process; projection, trim, offset and combining surfaces.*

Create edge flange

A flange is added along the outer edge of the seat; primarily to add to the structural stability and stiffness, but also to achieve a soft, round edge which will reduce the risk of cuts, sores and general discomfort to the driver. The flange tool is quite easy to use; an edge or a curve is picked as the rail along which the flange will run (***figure 30***). Then the flange parameters are defined in a pop-up menu, such as flange length, radius, shape and angle of rounded surface connecting flange and edge etc. However, the tool does not work around sharp edged corners; such surfaces have to be created manually (***figure 31***).

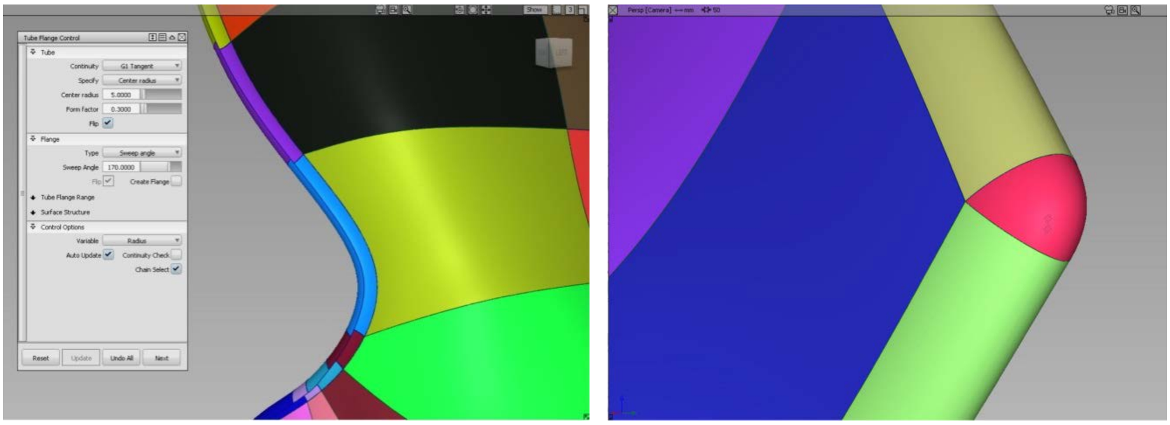


Figure 30 and 31 – *Edge flange toll and manually connecting flanges in sharp corners*

Evaluate and improve surfaces (continuity)

The software supplies various tools that can be used to improved surface quality. For instance simplifying or making them more complex by altering the degree, curvature, number of sections etc. Also before stitching the surfaces, it is preferable to make sure all surfaces have the same direction. Where blue normally is outside and yellow inside, if applicable (***figure 32***).

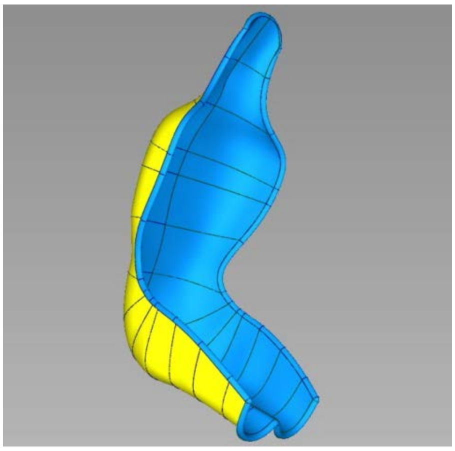


Figure 32 – *Surface direction visualisation*

Stitch surfaces and exportation preparation

When the surface model is considered finished, it needs to be prepared for parametric CAD software. The first step in this process is made prior to the modelling; in a menu where preferred CAD software can be selected and the Alias software will automatically adjust modelling parameters, such as scale, tolerances etc. The next step is to select all the surfaces that are going to be transferred into solid modelling and stitch them together with the stitch tool which creates a single shell. The shell can then be exported to a number of different formats. .IGES (.igs) or .step (.stp) files are preferred formats for this purpose (***figure 33***). .IGS was chosen since it is appropriate for non-solid surfaces. Later was found that Inventor actually can read the surface files created by Alias (.wire), which on the other hand perhaps could have been expected, since the two softwares are in the same suite.

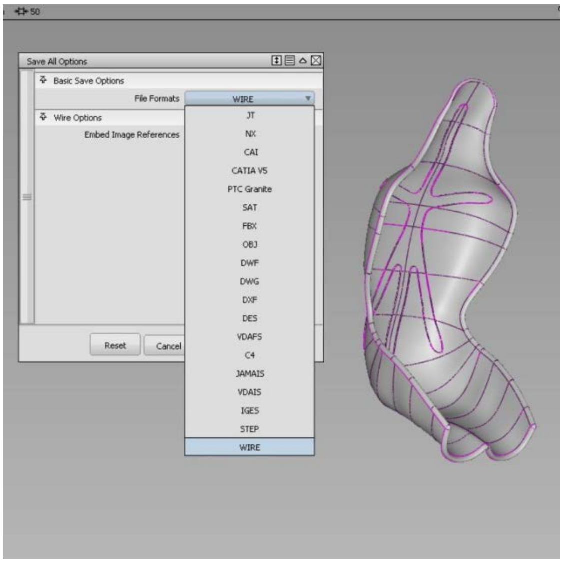


Figure 33 – *Stitch and export surfaces*

4.2 Solid modelling process

4.2.1 Introduction

Since the Nu team is using Autodesk Inventor, it was considered more efficient to learn Inventor than working with the softwares that have been used in previous projects. Autodesk Inventor is parametric CAD software...

4.2.2 Solid Modelling in Autodesk Inventor

Import object and heal errors

When the IGES-file was imported, the Inventor software detected a few errors which were resolved through the "heal error panel". And the surfaces could eventually be stitched, which make them recognizable as surfaces according to Inventor's definition; which is necessary before any operations can be performed.

Apply thickness

Since the surface is a direct outline of the mannequin's body, the surface thickness had to be applied in the direction facing away from the body shape. This fact caused a lot of problems with the tubular flanges around the outer edge; and which in the end forced an extra iteration; going back to Alias, removing the flanges, stitch the surface again and perform necessary Inventor operations.

Create (new) edge flange

Unlike Alias, Inventor does not have the kind of automatic flange tool. The approach that had to be used instead was to use the sweep tool to sweep a profile curve along the edge. The profile curve had an outer radius of 10 mm and was curved back 180 degrees (***figure 34***).

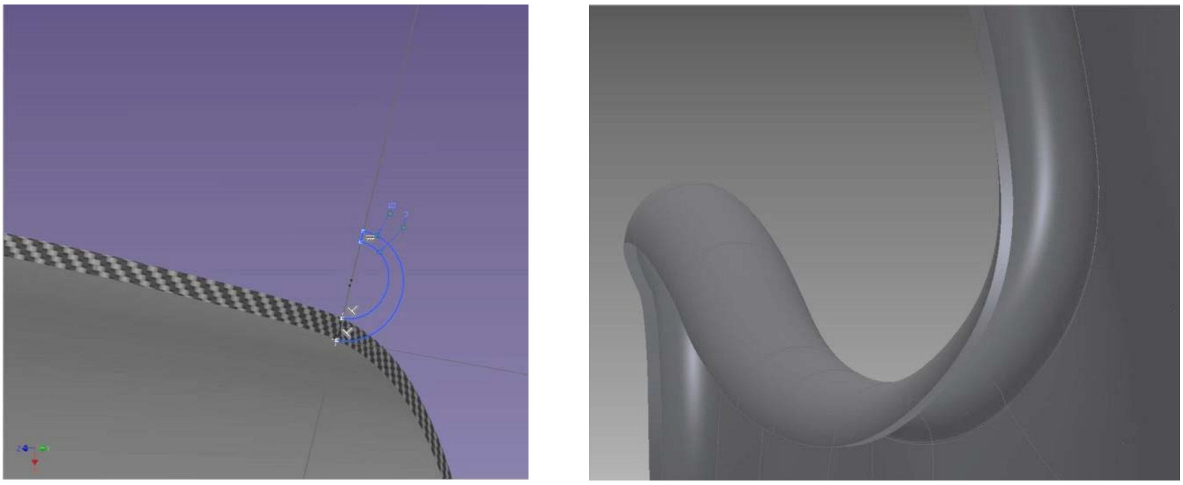


***Figure 34 –** Sweep tool to create flange from sketch*

Create slots for belt

From the anthropometric information and the SAE rules regarding belt and harness the position and the size of the slots for the belts. The slots over the shoulders were made by simply sketching the outline and create cut-extrusion; after completed with fillets, the extrusion was mirrored. The same approach was used for the two hip slots; with the only difference that it was sketched on an extra construction plane, tangent to the surface where the slot was going to be placed. An Existing plane could however be used for the slot between the legs (***figure 35***).

Figure 33 – *Slots at shoulder, hip and between legs*

Apply fillets

A 1 to 2 mm fillet is applied for most edges; for added realism. This was considered extra important to illustrate for the slots, since the rounded edge is necessary in the final design to prevent tearing of the belt.

Continuous stress analysis

A static stress analysis was performed on the model to identify weak points/areas; which might require special considerations or redesign. Force was applied to the head restraint, which according to rules is required to withstand a minimum of 900 Newtons (***figure 36***).

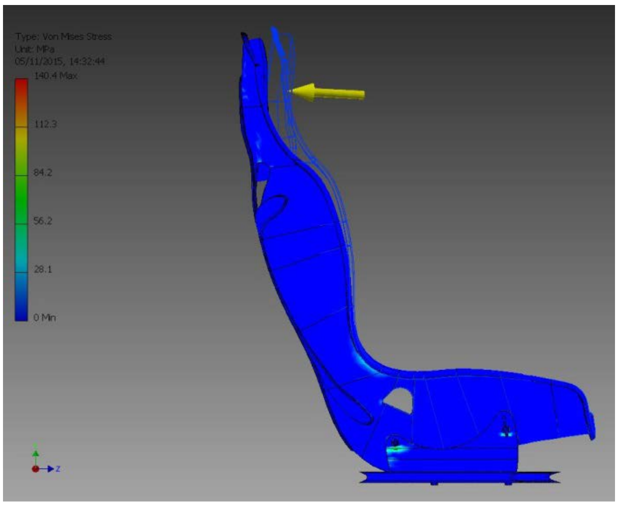


Figure 36 – *von Mises stress test as modelling reference*

Model head restraint

The head restraint was modelled in several steps according to the previously mentioned regulation but also to match the shape and look of the seat. The first step was to create an oval shaped sketch matching the head part of the seat and that was sufficiently sized in regards to the SAE rules for height, width and surface area (***figure 37***). The sketch was then extruded as a "new solid" up to the next surface, i.e. the seat surface. The next step was aiming to achieve the right thickness and shape and was therefore divided into another two steps. Where a sketched profile from the top view was swept with the cut-sweep tool along a curve created in side view. The sweep curve was a projected edge from the seat profile in side view, and was then offset 40 mm to achieve the required thickness.

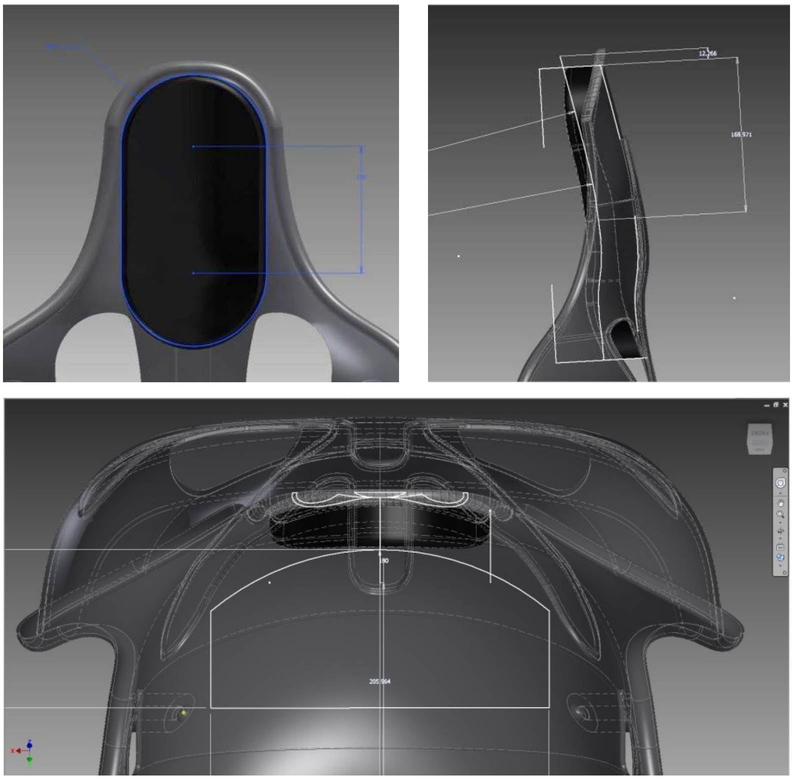


Figure 37 – *Head rest modelling; solid extrusion and sweep cut.*

Model Brackets and displacers

When the seat model was finished and the assembly angle and position was fully decided in the full car assembly the brackets could be designed. The folded sheet metal profile was sketched as a section cut in the seat assembly mode to get heights and angles adequate for the seat placement. The initial plan was to have the horizontal fold that is going to be attached to the frame folded outwards to facilitate assembly and possible adjustments; due to lack of space however the plate was folded inwards, underneath the seat instead.

The profile of the bracket marking out the two attachment point was then sketched from a perpendicular view (side view) and cut-extruded out from the folded sheet metal profile. In a similar cut operation the holes was created; the four holes for angular adjustments are constrained with 3 degree increments between each other and obviously all at the same distance from the static, rearmost hole. A sketch with two slots C-C 100 x D 8 mm, and 168 mm apart (C-C) the horizontal face of the bracket that will slide on a base plate welded to the frame is placed and cut-extruded (***figure 38***).

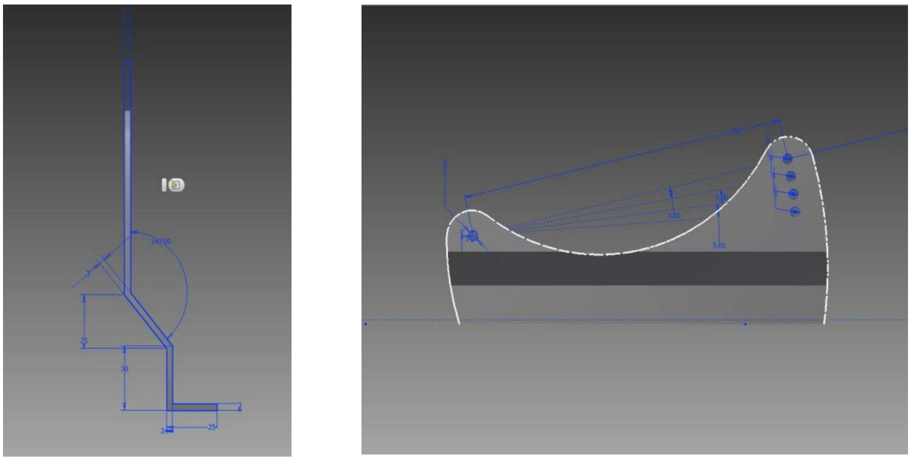


Figure 38 – *Bracket; profile extrusion, cut extrude shape and cut extrude for holes*

The displacers were then created by referencing the holes from the bracket over to the seat and extrude a circular shape as “new solid” up to the seat’s outer surface. And the same reference axis was used to make the holes in the seat for the bolts; holes were countersunk with the hole-tool to ensure bolt heads does not cut into the driver’s thighs (***figure 39***).

Figure 39 – *Displacers and countersunk hole in seat*

Seat assembly

The seat assembly is simple with only three parts; the seat, and the two brackets, which are only mirrored copies of one another (***figure 40***). The brackets are constrained first to the ground plane and then to the seat through aligning the rearmost holes and then constraining the displace surface to the bracket's touching surface. With these constraints in place the last constraint required is to set the angle by constraining to either of the four holes (or all, by the use of driven dimensions), depending on the desired seat inclination. Bolts, washers and nuts are added to the assembly from the library.

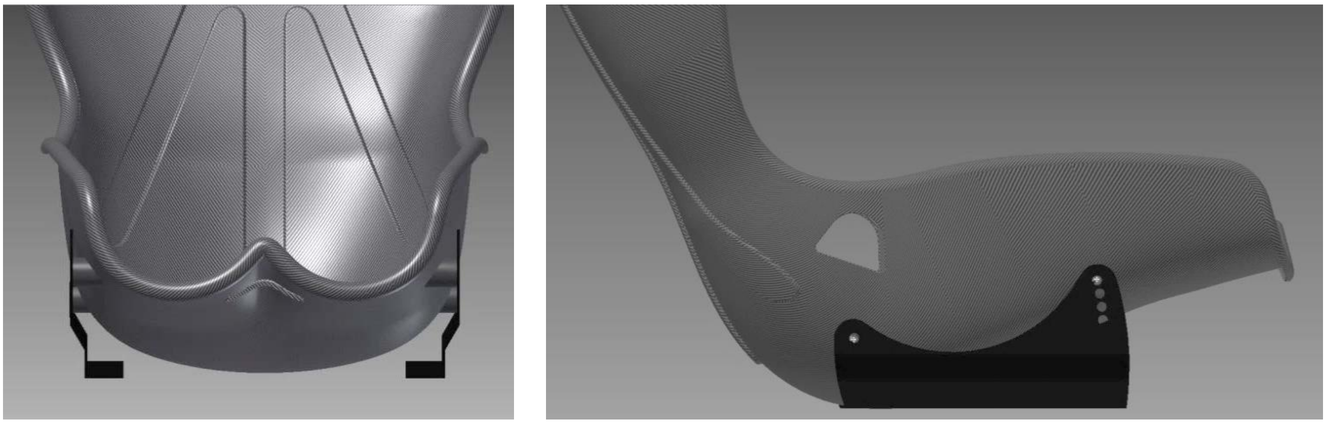


Figure 40 ***–*** *Assembly of seat and brackets: parallel and constrained to ground plane*

Frame attachment plate

The seat is, as previously described, meant to be attached to the frame through the bracket, sliding on a welded base plate, and fixed in the appropriate position for each driver. In order to design the baseplate, the seat and backrest assembly is temporarily placed in the rearmost position in the full car assembly. At this stage most components are represented in the assembly and other parts must be considered when designing the base plate. It was considered appropriate to manufacture the base plate out of a 25.4 x 25.4 mm (square), 1.25 mm thick walled, hollow steel bar. The most appropriate design strategy for a frame component was to use Inventors frame insert toolbox (***figure 41***). The 25.4 x 25.4 mm bar was used because it will supply the strength required and because it matches the diameter of the frame's round bars, hence relatively easy to notch according to the round profile, when later attached to the frame. Also the planar, attaching surface of the bracket was altered to match the width of the 25 mm square bar.

The first step in this procedure is to open the frame skeleton file that consist of a 3D line sketch of all frame components; add a 3D line between the lines where the baseplate was going to be located, according to the constrained seat assembly reference. From the 3D sketch, the insert frame tool can be used; a desired tubing type can be selected from the Autodesk library. The 25 mm square hollow profile was selected. When the bar was created, the notch tool was used for both sides of the bar to notch it to the round profiled main frame. Then two holes were created on the part, where the bolts that attach the bracket to the base plate and allow the sliding are going. A copy of the square profile bar was mirrored to the opposite side of the frame assembly. Bolts, lock-washers and nuts were then added from the library to lock the sliding bracket to the base plate in the assembly.

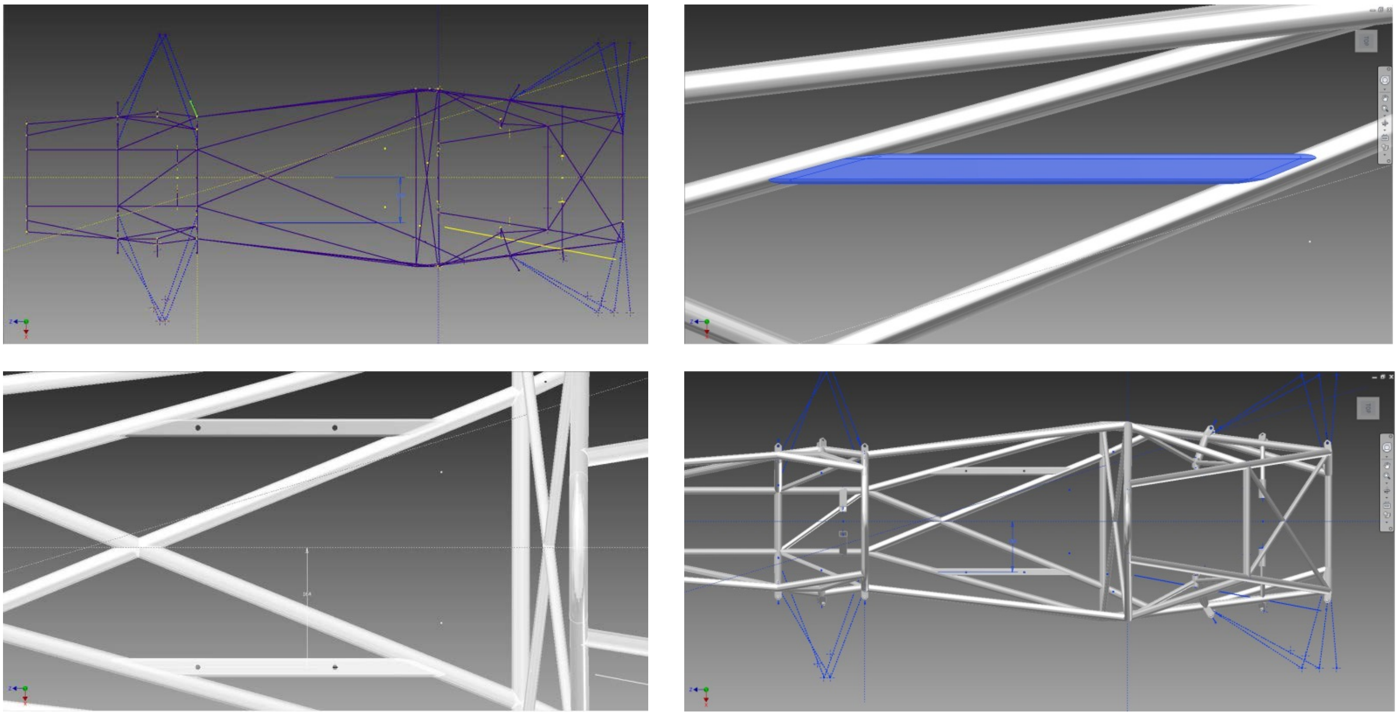


***Figure 41 –** Frame component modelling process through skeleton file.*

This was the final step in the modelling process and thereby, the concept development process for the 2015 year's edition of NU's formula racing car seat.

5. Concept presentation and evaluation

5.1 Digital Concept Presentation

5.1.1 Introduction

Through the previous development process description all individual elements of the conceptual seat have been accounted for in depth; what is left in order to remove all of the remaining ambiguousness surrounding the product, is to bring all of the individual pieced together in a final, distinct concept. By doing this the end of the concept development process is clearly distinguished; and this statement is also establishing the very essential reference on which the evaluations are based and very much depend on.

5.1.1 Final concept

Accurate representation

The following renders (***figure 42***) show the finished concept fully assembled; with materials put on as specified and also with the team logo added to the head restraint. These images; in absence of actual 3D models will be represent the base for the evaluation.

Figure 42 *– Accurate representation of the final concept*

Render versions

The next figures (***figure 43***) show possible graphical alternatives. These renders are mainly represented to view possibilities and as a base for the aesthetic evaluation process.

Figure 43 *– Version optimized for render with (not accurate representation of final concept)*

5.2 Theoretical evaluation and validation of final concept

5.2.1 Introduction

The evaluation of the final concept will obviously be purely theoretical since there is not yet a physical product to test. The evaluations will be based on a combination of final specifics, the digital representation of the final concept and on digital simulations. The first step of the evaluation process will be to consider how well the concept responds to the initial performance indicators. Secondly, by comparing the concept to a reference object and finally to consider the product in relation to some of the more implicit and subjective performance indicators.

A modified version of Pugh's concept evaluation matrix is used to compare the concept to a reference object. For each aspect where the concept is expected to perform better than the reference it receives a plus and when the reference performs better, the concept receive a minus. For cases where the reference and the concept are expected to perform equally good, both are assigned a zero. The sum of the weighted value is then calculated and the concept(s) performance can be compared. The method is originally designed to compare several concepts, by individually comparing each concept to the reference object and then compare the weighted results among the concepts to declare a winner. This modified version however, lay more weight on how well the concept respond to the performance indicators, and unlike the first evaluation method, also take the importance (weight) of the indicators into consideration.

5.2.2 Evaluation according to Key performance indicators

SAE regulations fulfilment; the design does most likely not in itself or by the influence of related components deviate from any of the SAE guides, or violates any of the stated regulations.

Sufficient reach; the design meet the requirements for reach to a high extent for most potential drivers and with additional inserts as suggested, for all drivers within the defined range.

Sufficient visual field; the design does not in any way reduce the driver's view when used as intended.

Fixed body position; the design of the seat is most likely giving the adequate support for most drivers, provided harness is well fitted and inserts are used for the smaller percentiles as suggested.

Avoid/minimize fatigue; as the seat is adjustable to a high extent, allows the driver to position the body at a relative distance from steering wheel and pedals which is ergonomically preferable according to the principles described in previous chapters; hence reducing additional stress from deficient positioning and allow for sufficient levels of muscular work when it is required.

Avoid/minimize discomfort; this evaluation criterion is obviously very hard to assess theoretically; however, the seat has been designed with the principles of ergonomics and comfort since the initiation stage and is likely to be considered quite comfortable in relation to the product category it belongs to.

Weight and centre of gravity; when intended materials have been applied to the inventor model, the seat will weigh 4.837 kg and the whole assembly 10.588 kg, with backrest, fasteners, head restraint and the frame mounted base plates included. These values are obviously just a guide for the final weight. The real carbon layer density might deviate from the software's suggested density; for instance depending on carbon-resin ratio and also to a high extent the final thickness of the part, which is obviously not likely to be as uniform as the model.

The low seat position, with the seat close to the lowest point allowed by the rules, with side-mounted, low profile brackets and with the slightly inclined body posture, the centre of gravity will be located relatively low. The 2015 year's seat however, is unfortunately not as light and low profiled as previous year's seats. As discussed in the requirements contradiction chapter; the low weight requirement has been prioritized slightly lower than some of the other requirements, which unfortunately have led to the weight going up in the compromise against improved support, stiffness, ergonomics and the seat's capability to sufficiently accommodate for the full range of potential drivers.

Structural integrity; theoretical frameworks and expert knowledge have to a high extent been used as the base for the structural design of the seat. However, continuous stress analysis in the CAD software has been used as guide; however, with the only reference figures supplied by the rules (headrest to withstand a force of 900 Newton). With the same procedure, a static stress analysis was performed also on the final product assembly with the result presented in ***figure 44.*** The complete analysis result can be view in ***appendix 6.***

As seen in the figures, critical zones around slots and at attachment points show some deformation and areas with elevated stress levels, just as predicted. However, is still well within the safety zones for the applied forces. A significant deformation of the head and backrest can also be observed; which according to the result is something that the flexible but strong material properties of the carbon fibre apparently are able to handle. It is also possible to conclude that such deformation actually can be desirable in case of an impact; since head and neck (still supported) are allowed to decelerate less quickly than if the head restraint was completely compact and static, hence reduce the risk of brain damage.

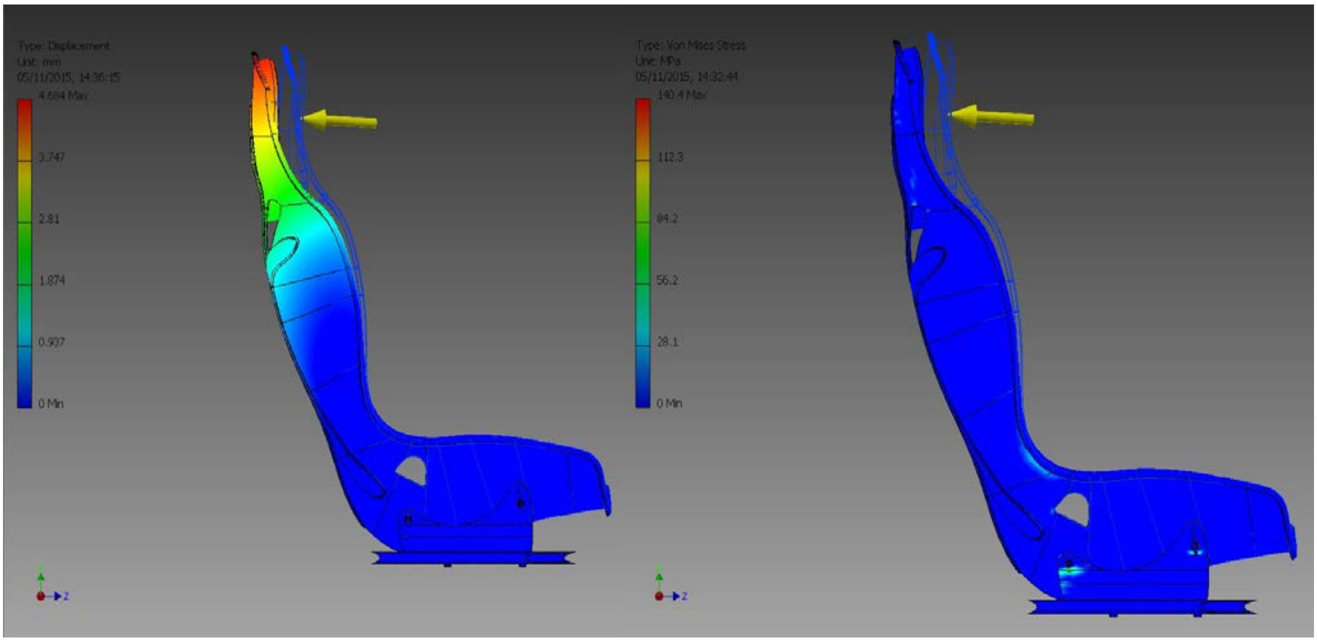


Figure 44 *– Stress analysis result from Inventor: L: Displacement analysis; where a substantial distortion can be noticed. R: von Mises stress analysis; identifies sensitive areas around fasteners and the expected weak point where backrest and seat surface connect.*

With a different project focus; the influence from more of the parameters (profile depth, length, shape and direction as well as advanced layering techniques for the carbon etc.) that affect the seat's structural integrity could have been investigated through the collection of forces during real driving and continuous FEA simulations. Through such process, weight and shape could most likely have been further optimized.

Manufacturability; as DFM-principles and simulations have been used throughout the design process all parts; such as mould, seat and associated objects are likely to be highly manufacturable. However, the lack of experience on the area of composites layering might imply that some aspects regarding the manufacturability of the carbon fibre shell has not been considered.

5.2.3 Weighted evaluation

The weighted evaluation is performed with a modified version of Pugh's evaluation matrix, and presented in ***table 7.***

	Weight	Reference object: 2014 year's seat	**Evaluations object: 2015 year's seat concept**
SAE regulations fulfillment	9	0	**0**
Low weight	3	+	**-**
Low CG	0	+	**-**
Fixed position	6	-	**+**
Sufficient reach	7	-	**+**
Sufficient visual field	7	-	**+**
Avoid/minimize discomfort	1	-	**+**
Avoid/minimize fatigue	4	-	**+**
Manufacturability	2	+	**-**
Structural Integrity	5	0	**0**
Sum (+ + (-))	44	-2	**2**
Weighted result	0 + 3 + 0 +6 +7 + 7 + 1 + 4 + 2 +0 =30	0 + 3 + 0 - 6 - 7 - 7 - 1 - 4 + 2 + 0 = -20	**0 - 3 - 0 + 6 + 7 + 7 + 1 + 4 - 2 - 0** **= 20**

Table 7 – Weighted Evaluation Matrix

The result clearly weighs over to the concept's advantage. However, this can only be used to support the conclusion that the concept responds well to most predefined performance indicators and requirements. And not to discard the reference, since this year's concept unlike last year's seat, obviously is designed explicitly to respond to these ten evaluation aspects. The result is also an indication of the different priorities between the two years, which is further elaborated in the final discussion. For the modified version of the matrix it might be more interesting to compare how well the concept perform in relation to the maximum weighted value; 20 points on the weighted scale between -30 and 30 further support the concept's success in relation to chosen indicators.

5.2.4 Additional evaluation aspects

In this section follows an evaluation of some of the factors that cannot be estimated through a completely objective assessment process, but which are still factors that can be considered to have a significant influence over the design's overall perception of success. Unlike many of the factors described in the last section; the following aspects are, through the support of digital representations, already at this stage more or less ready to be evaluated.

Innovation

The definition of an innovative design is that it must both possess the properties of novelty and functionality. The overall seat design cannot claim to be very innovative, neither are any of the solutions. However, the way the seat accommodate for an unusually large spectra of different percentiles, must be considered fairly unique for the particular type of product; and thereby, to some extent also innovative.

Aesthetic design

The aesthetic design can at this stage be subjectively assessed through renders; to what level the actual product will look anything like the rendered images however, is yet to be seen. From the renders it can be argued that the visual expression manage to capture most of what have been considered important; in order to define the product in its context. The seat with its characteristic outline implies the connection to the human body and together with the mechanical details the overall impression land in what very much can be described as the definition of human factors engineering. In addition, the shape, materials and some of the details and colour themes relates to the formula racing context and in particular to the 2015 year's NU formula team.

6. Manufacturing preparations and initial manufacturing

This chapter describes a process taken several steps further than what was initially planned for the project and the report to include. The following text describes detailed manufacturing preparations, simulations and some workshop practice etc., processes that stretches beyond the industrial design engineer's expected proficiency, however was seen as a great opportunity to develop new knowledge and experience.

With background in the manufacturing preparation performed during the late research study, with all parts modelled and assembled in the final assembly model and after some complementary research, the manufacturing preparations and the initial manufacturing could start.

6.1 Manufacturing preparations

6.1.1 Mould design

When the overall manufacturing method was decided, the mould could be prepared. The positive seat mould, onto which the carbon layers are supposed to go was created as a solid CAD part-file by projecting the outline of the initial surface on a working plane and extrude the sketch back up to next surface (***figure 45***).

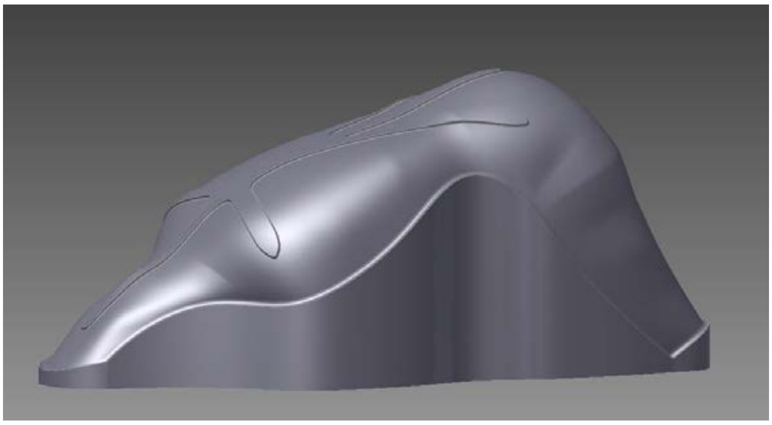


Figure 45 *– Mould model*

Due to CNC constraints the workpiece model was then divided into four separate pieces (***figure 46***). In order to bring stability to the workpieces, save foam and foremost to be able to attach the four pieces together again after milling; a structural skeleton was used. This internal frame consisted out of four different sized and angled boxes, onto which the foam sheets were later glued.

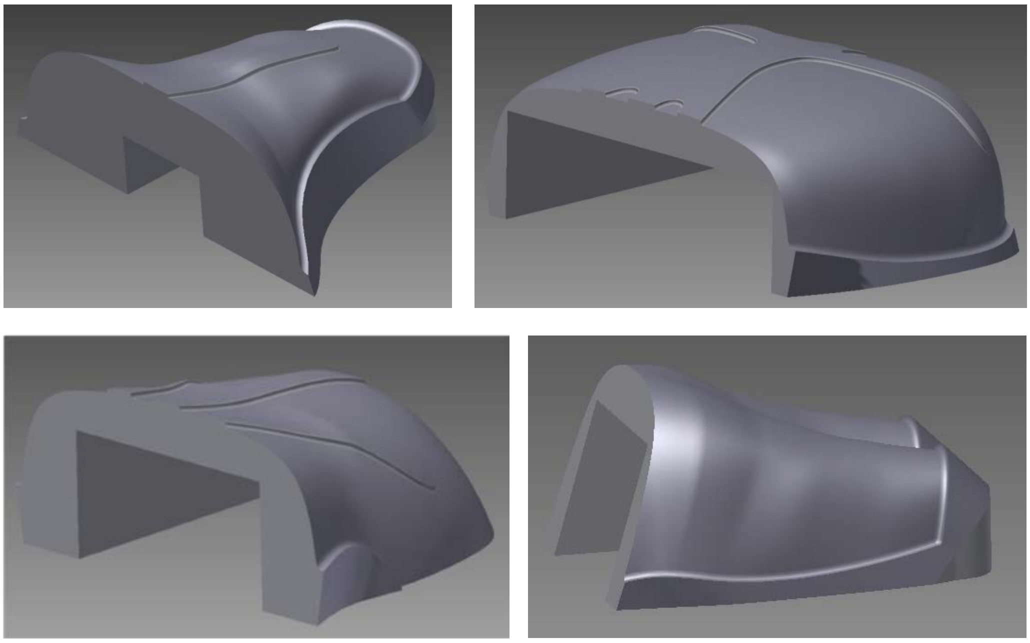


***Figure 46** – Mould model; split up in machinable pieces*

6.1.2 Design and manufacture a support frame

After it was decided to construct the boxes out of 12 mm MDF board, Inventor was used to model the boxes. The MDF pieces were then cut out and glued and nailed together (***figure 47***). Also MDF base plates for the boxes were cut out and marked out according to workshop's specifications for clamping the workpieces in the CNC mill.

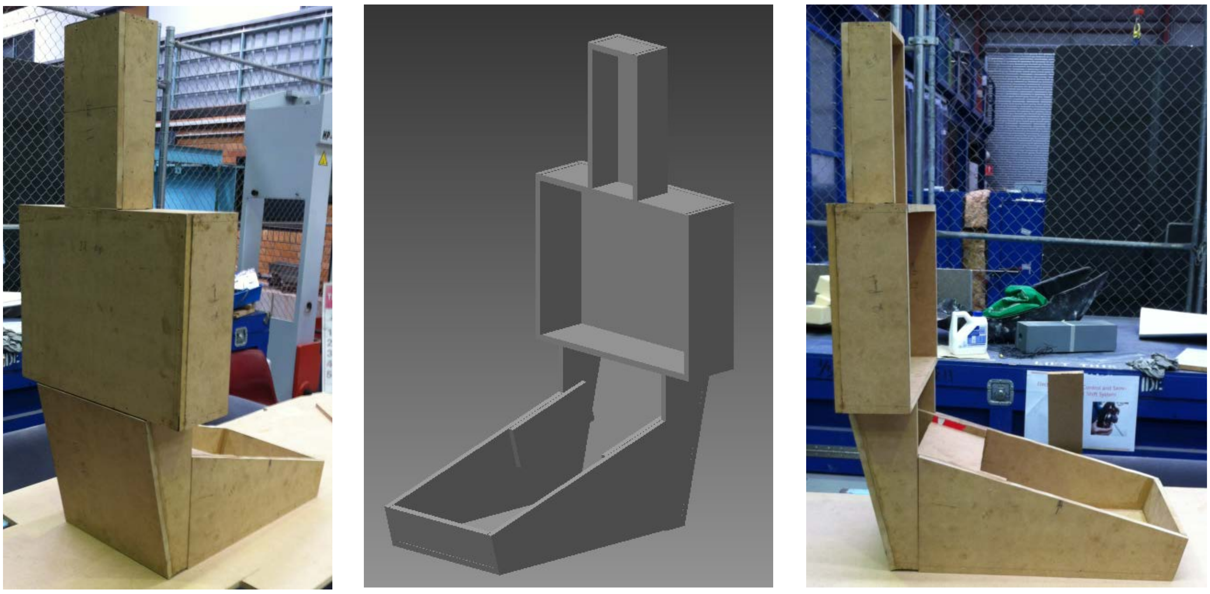


***Figure 47** – Frame model and actual MDF-frame*

6.1.3 Design and manufacture foam workpieces

The workpieces were manufactured through a series of processes. The initial step was to plan the process in order to make efficient use of the foam sheets and to ensure best result possible during CNC processing. The latter was achieved by considering the joining of the foam sheets; making sure joining surfaces are square and neatly fitted together, that joints are avoided in sensitive areas (where the moulds corners will be etc.) and that the glue used to keep the sheets together is sparingly applied in the milling path. The latter is a necessary precaution, in order to avoid potential rips due to the difference in material properties between the glue and the foam (tough glue and fragile foam).

6.1.4 Tool path programing in CREO Manufacturing

From the custom foam workpieces and the constraints and machining parameters from the workshop CNC, the work paths were created for each of the separate pieces. Working parameters for the particular pieces were worked out together with workshop staff and NU team member Aidan Fluit. The three axes CNC obviously require a modified process for the steep curved surfaces in order to get sufficient surface quality and to make sure the chuck would have enough clearance when processing surfaces at maximum depth. Modifications that were done to achieve sufficient surface quality include changing the route type to cut along, rather than across. Also, the steep surfaces were dealt with by decreasing the step-over value (only 4 mm, with the 16 mm tool head).

CREO Manufacturing was used for the tool path programming and milling simulation and for the material removal simulation. The first step was to set up the CREO Manufacturing tool library, according to specifications from current workshop equipment, according to the data (***figure 48***).

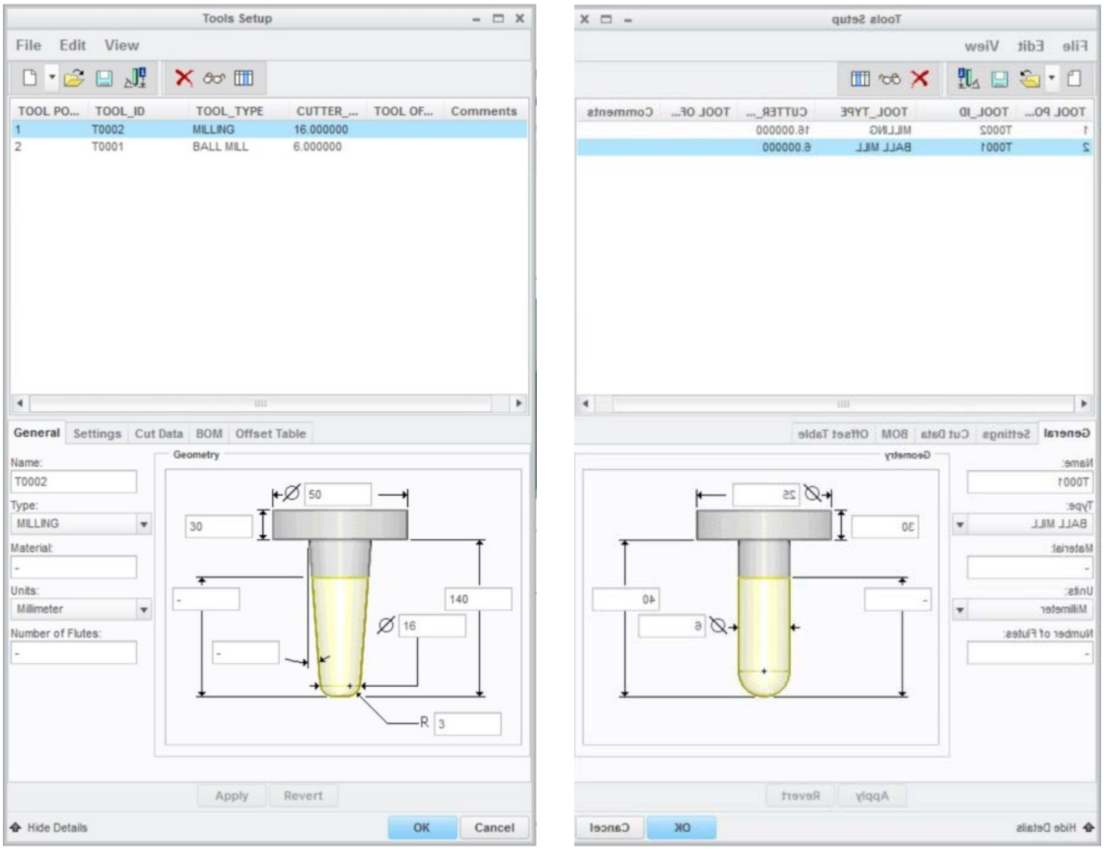


Figure 48 *– Tool library with tool parameters for used tools*

Secondly, the custom workpieces were created according to inventor model specifications (***figure 49***). When the reference model was imported and fully constrained to workpiece and coordination system the mill window was created.

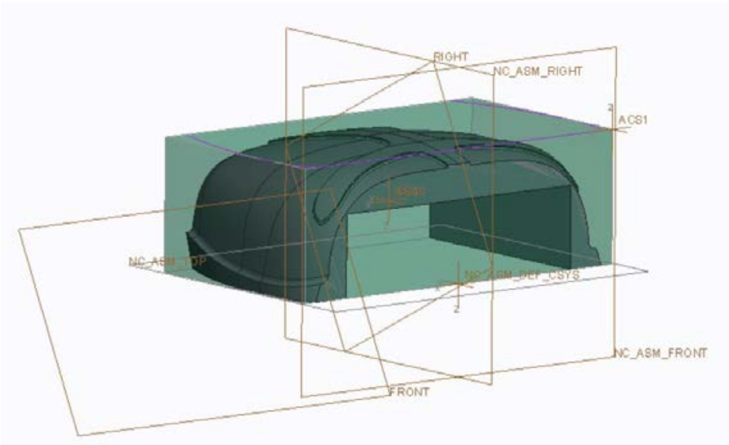


Figure 49 *– Workpiece example*

The milling process consisted of a set of three passes with separate operations (***figure 50***); first a roughing operation to relatively quickly remove excessive material and reveal a rough surface contour of the model. Next passing was a surface mill to refine surface quality over the entire piece. And finally a trajectory mill was programmed in order to refine some of the edges, where the surface mill was not able to achieve good enough accuracy; such as along the three dimensional ridge and the negative surface in the tubular flanges.

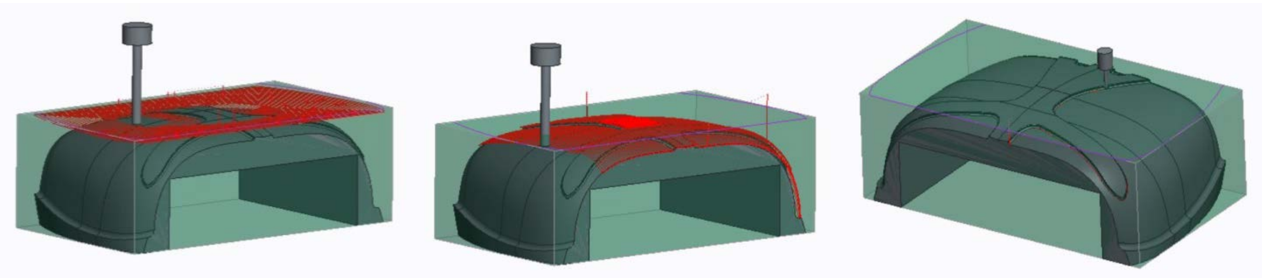


Figure 50 *– Path simultion for the different operations.*

The preprogramed scan types available were tested to minimize milling time for each of the passes; "*maintain cut direction"* was proven to be the most efficient scan type for all four parts. Largely the same the same sequences and processes were used for all four parts, except from one less trajectory mill for the lower seat part, since it has no structural ridge. The milling data for the parts are presented in ***table 8*** and table ***9*** below. The last part of the programing process was to evaluate material removal, with the material removal simulation to ensure excessive pieces of material will not interfere with the process.

Operation	Roughing	Surface mill	Trajectory mill (flange/edge)
Cut feed [mm/min]	3000	2400	2400
Step-over [mm]	7	4	-
Step depth [mm]	5	-	-
Scan type	Maintain cut direction	-	-
Spindle speed [rpm]	3000	3000	3000
Tool	Tool 1 (16 mm)	Tool 1 (16 mm)	Tool 1 (16 mm)

Table 8 – CNC operation details for part 11, 12 and 13

Operation	Roughing	Surface mill	Trajectory mill (flange/edge)	Trajectory mill (ridge)
Cut feed [mm/min]	3000	2400	2400	2400
Step-over [mm]	7	4	-	-
Step depth [mm]	5	-	-	-
Scan type	Maintain cut direction	-	-	-
Spindle speed [rpm]	3000	3000	3000	3000
Tool	Tool 1 (16 mm)	Tool 1 (16 mm)	Tool 1 (16 mm)	Tool 2 (6 mm)

Table 9 – CNC operation details for part 2

6.1.5 Order mould

With Support boxes manufactured and foam pieces cut according to dimensions and most of them glued together, the workshop informs that there will be a hold-up for three weeks before the foam pieces could be processes. An estimated additional week to perform the actual milling of the seat and nose cone moulds; and after that approximately two more week for surface finishing and applying the protective and sealing coat layer before the mould is ready for carbon layering. This would have caused a delay that would have been impossible to make up for; an alternative route therefore had to be chosen as soon as possible.

The CAD model of the plug was sent to Industrial Carving Services Pty. in Melbourne for a quote. The company had been hired by the team before to do similar jobs, and the team had good experiences from previous collaborations. According to the quote, the company could offer the carved piece with surface treatment and delivery for a total of 1199 $AUS (GST included and with "young engineers" discount applied). According to quote specifics, the pieces were going to be cut out of medium density expanded polystyrene foam ($620, ex-GST), surfaces filled with acrylic filler, sanded to shape if necessary and coated with an Polyurethane hard coating ($375, ex-GST) and delivered to Newcastle within two weeks($95, ex-GST). The quote was accepted.

6.2 Initial Manufacturing

6.2.1 Baseplate manufacturing

Since the frame is being painted, the bracket base plates that was going to be welded to the frame needed to be manufactured and welded before the manufacturing of the seat could start. The hollow square profiled bars were cut to length and then the notches were marked out on the bars, from a flattened template (.dxf) of the 3D-object, created in Inventor's sheet metal plug-in. After preparing the notched surfaces, the two bars were fitted in relative to reference point in the frame and then tacked and welded to the frame. The two 8mm holes were marked out on each of the mirror identical pieces, to ensure correct relative location. The holes being square to frame and each other were considered critical aspects for the fitting. The corresponding holes were then drilled to fit the "nutserts" for the fastening bolts. The welds were ground with an angle grinder and then cleaned as the last step before the frame with attached base plates was ready for the paint job. Manufacturing and welding the base plate will be the last process covered by the report as it is the last process executed before project and report completion date.

6.2.2 Post project manufacturing plan

The plan is for the ordered foam mould to be ready for the carbon layering, right at arrival. Since the process not yet has been carried out; and thereby not been possible to evaluate, the following section will just briefly present the steps according to what the plan looks like. The process has been taught during workshops with the composites sponsor and through theory. For in depth description of the process and evaluation from a job of similar character, see Harley Braddick's report on the nose cone design and manufacturing.

The description assumes the surface quality of the ordered mould to be ready for layering without any further measures. The mould surface will first be waxed in several layers with drying time in between. The base layer will then be evenly applied; according to the experts preferably with an air brush. Before the carbon layering can start; the fibre layers needs to be roughly cut to shape and enough resin to cover one pass needs to be mixed. The different fibre weaves are layered according to the predefined list. The plan is to achieve the flanges by bending the carbon sheets around a garden hose or a tube of similar characteristics and diameter. When layered and cured, the slots will be cut out and edges will be ground.

The head restraint will be cut from Ethafoam or Ensolite according to specified dimensions (and potentially covered in fabric). The plan is to let the workshop manufacture the brackets; cut the shape and slots, bend the profile and drill holes.

The manufacturing of the displacers are not yet confirmed; the considered alternatives are to cut the displacers from a solid tube of high density rubber or plastic, or to 3D-print or cast the parts in plastic. The displacers will be manufactured after the seat is finished to ensure a good fit between bracket and seat surface; the reason to why this is necessary because the final seat shape is likely to differ slightly from the CAD model, for various reason connected to the manufacturing of the mould, the layering of the carbon and the curing process etc. The four displacers will then be glued to the outer surface of the seat; which will be the last step before the seat is ready to be assembled, with fasteners specified in the assembly drawing files.

Discussion and Recommendations

Discussion

Methodology

Methodology - Some of the method used; such as an in depth systemic analysis and user description are suited for more complex system with a higher degree of user-product interaction. However, was still proved to be useful since working with defining elements, subsystems and boundaries really raised awareness about many of the detailed system elements and processes; which without the systemic perspective most likely never would have been identified and considered in the design. The systemic view has also been an important tool when communicating system elements and relations, both internally and externally. Externally, also to potential readers of the report who are new to the systemic thinking; these will receive an early introduction and supported with graphical content to stimulate the new perspective and facilitate comprehension.

Physical user tests – If the physical user test would have been carried out, the subjective data recorded could have made an important complementation to the objective dataset. This would have been essential aspects for a product with high levels of interaction or if it would have been completely customized, as many racing seat are; however, is probably a bit less importance for this particular product since the seat offers little interaction and is supposed fit a range of individuals.

Tools

Software – The human modelling software JACK was planned to play an important role during the project; bot for design and evaluation. However, that assumed that the fully licenced version could be used, as for earlier projects. This was not the case however; a very limited student version had to be used; which caused lot of extra work for manual scaling of models and foremost due to the fact that the student version does not allow CAD models to be imported over a certain size (very low). The latter resulted in that the placing of the mannequin in relation to subsystem elements had to be done manually thus required several iterations for each mannequin to get it right. Also some of the analysis tools that was planned to be used for the evaluation were not included in the limited version. Even though all limitations the software still had some importance during the design stage.

FEA - The final result would most likely have benefited from a proper FEA stress analysis for early CAD models. FEA would have allowed optimizations of shapes, varying surface thicknesses, fibre directions and structural ridges and flanges etc. (The methods used to decide on these specifics was instead a combination of information gained from literature studies, comparisons (benchmarking) with similar product on the market and by the use of safety margins, but primarily based on the expertise and experience of the composites sponsor. The reason to why FEA was not used to a large extent is due to lack of competency for analysis of complex surfaces and the problem of estimating forces that is affecting the seat and the effects of factors such as how much load the harness is taking and what forces may apply during a crash etc.

Theory

Ergonomics - In engineering product development, ergonomic considerations often seems to be subordinate the technical requirements. To incorporate ergonomic design principles in the design of a racing car seat however must be seen as highly relevant. Even though lap times are short and the overall load might be small compared to for instance an office chair (the typical object for representing the implications of ergonomics). However; an ergonomically satisfying design when it comes to supporting the driver's body and accommodating for ergonomically favourable postures will most likely have a significant effect on reducing driver fatigue, ensure sufficient transfer of muscular power MVC. Also these measures are likely to improve the supply of sufficient external response/stimuli to the driver (not getting numb; avoid sensory loss; by avoiding excessive load on certain pressure zones); which are all considered vital aspects for the driver’s ability to make accurate and fast decisions and respond accordingly.

Validity and Reliability

Due to the very narrow area of research; race car seat design principles and due to the very high level of customizations that is generally connected to the area , very little specific information could be found on the topic. Furthermore, the information that actually could be obtained was not possible to verify by several independent sources, since it often originated in subjective forums and similar. This data could due of these reasons only be used as guides, rather than a base for the complete design; which would have been possible if a reliable and verifiable fact base for these specific topics could have been obtained.

According to the theoretical evaluations the product seem to very successful; however, that is the major problem with theoretical evaluations; we do not yet know whether the theoretical success criteria are completely relevant to the actual performance. However, the broad research study has definitely made sure the chances for the success indicators to be relevant for the real world equivalent.

General Discussion

Generic knowledge – One problem that was encountered when the report started to take shape was how to estimate which Information can be considered generic knowledge. Since the report is not written for the department of human factors, which is where most of the previous experience has been developed there is a risk that theories and processes used either has been under or over explained; where the latter is more likely due to the uncertainty of the potential readers knowledge spectra within the field of human factors engineering. However, it was never intended to disqualify the reader's ability to understand, but rather to facilitate for a wider range of readers by sometimes over explaining and repeating.

Quality/Manufacturing- Carbon fibre layering is a quite complicated process; more practice or outsourcing the manufacturing to experts would most likely provided better quality and ensured a consistent result, free from, or with only minor deficiencies. Such quality insurance would also mean more predictable structural properties, hence lesser risks for failure. Experienced composites layer personnel would most likely also be able to optimize weight and structural properties by altering layering directions and thicknesses etc.

Compromises/Sacrifices - In retrospective reflection; it is possible to argue that ergonomic factors have been slightly overestimated during the project. When deciding success criteria for instance ergonomically satisfying design was considered more important than many of the performance aspects. The optimal compromise between both worlds would most like have come from a team project; where several individuals with different background and competencies get to have a say in the design. According to personal experience, the best, most innovative and substantiated ideas evolves in such team climate; since ideas are constantly questioned and only the strongest ideas are allowed to follow through to the final concept.

Learning outcomes - Since the involvement of the industrial design engineers for most projects seldom even stretches to modelling the final designs in CAD; taking this project further than before has given a lot of valuable knowledge and experience; which will most likely be valuable also for coming projects. As for most team members the most valuable outcome probably lies in understanding and considering options from a wider perspective and in improved communication.

Recommendations

The most important personal recommendation is for future engineering students to take the opportunity to learn about, practice and maybe acknowledge the value of a user focus in engineering and to approach a problem or need from a human factors point of view, or at least with the principles described in this report in mind.

Second recommendations is for future students to take the opportunity and to continue from where this project ends; proposedly with a focus on simulating the effects of support structure profiles, shape and different layering configurations (type, direction, number of layers, extra layers in exposed regions) on overall structural integrity and stiffness of the seat and in relation to dependent aspects such as cost, weight, manufacturability etc. It would presumably be achieved with support from FEA analysis tools for complex surfaces and possibly also by empirical evaluations. An important and very interesting area that this report only briefly touch, due to a combination of insufficient knowledge and the limited time frame.

References

Literature

ANSUR, Athropometric data set (1988). *Anthropometric Survey of US army Personnel*, US Government

Blanchonette, P. (2009). *Jack Human Modelling Tool: A Review*, Air Operations Division Defence Science and Technology Organisation, commonwealth of Australia

Bligård, L. (2011) *Utvecklingsprocessen ur ett människa-maskinperspektiv*. : Chalmers University of Technology (Research series from Chalmers University of Technology, Department of Product and Production Development)

Bohgard, M., Karlsson, Stig., Lovén, E., Mikaelsson, L-Å., Mårtensson, L., Osvalder, A-L., Rose, L. och Ulfvengren, P. (2011) *Arbete och teknik på människans villkor*

Gkikas, N. (2013*). Automotive Ergonomics*, Autonomics UK

Janhager, J. (2005). *User Consideration in Early Stages of Product Development – Theories and Methods*. Stockholm, The Royal Institute of Technology. Ph.D.

Johannesson, H., Persson, J. & Pettersson, D. 2004, *Produktutveckling: effektiva metoder för konstruktion och design,* 1. uppl. edn, Liber, Stockholm.

Larson, E.W. & Gray, C.F. 2011, *Project management: the managerial process.* McGraw-Hill, New York.

NHANES, Anthropometric data set (2006). *Anthropometric reference data for children and adults: United states 2003-2006,* US Department of health and human services

Osterlin, K. (2003). *Design i focus for produktutveckling*, Kenneth Osterlin och Liber

SAE-A (2015). *2015 Formula SAE Rules*, SAE International

Rexfeldt, O. (2013). *Lecture on Usability and empirical methods for user test design, and analysis*. Chalmers, Gothenburg

Savage, G. (2009) .*Formula 1 Composites Engineering*, Brawn GP Formula 1 Team, Brackley, Northants, UK

Steenbekkers L. P. A., (1998). Ranges of movement of joints. In L. P. A Steenbekkers and C. E. M Van Beijsterveldt, (eds.) *Design-Revelevant Characteristics of Ageing Users.* Delft: Delft University Press, pp. 60–68.

Stevens, F., Lawrenz, F., & Sharp, L. (1993). *User friendly handbook for project management: Science, Mathematics, Engineering and Technology Education.* Washington DC: National Science Foundation.

Online References

Cornell University Ergonomics Web. Sitting and chair design, http://ergo.human.cornell.edu/DEA3250Flipbook/DEA3250notes/sitting (2015-08-09)

Demerchant, C. Carbon fibre characteristics http://www.christinedemerchant.com/carboncharacteristics (2015-09-20)

Ergonomics simplified. Driving ergonomics, http://www.ergonomicssimplified.com/tips/driving (2015-08-10)

Gartner, M. Build your own race car, tips safety and ergonomics, http://www.gmecca.com/byorc/dtipssafetyergo (2015-08-10)

MacLeod, D. 90-90-90 and all that, http://www.danmacleod.com/Articles/rightangles (2015-08-10)

MacReynolds, (2011). Auto seat design and sitting comfort, http://www.slideshare.net/MacReynolds/auto-seat-design-and-sitting-comfort-7286294

Obutto, Europe. Race car seats for gaming https://www.obutto.eu/store/proper-race-driving-position (2015-08-10)

The Open Design Lab at Penn State. Anthropometric database, http://openlab.psu.edu (2015-08-10)

Turnfast!. Articles about driving techniques, http://www.turnfast.com/tech_driving/driving, (2015-08-15)

List of appendices

1. **Work Breakdown structure – Chart**

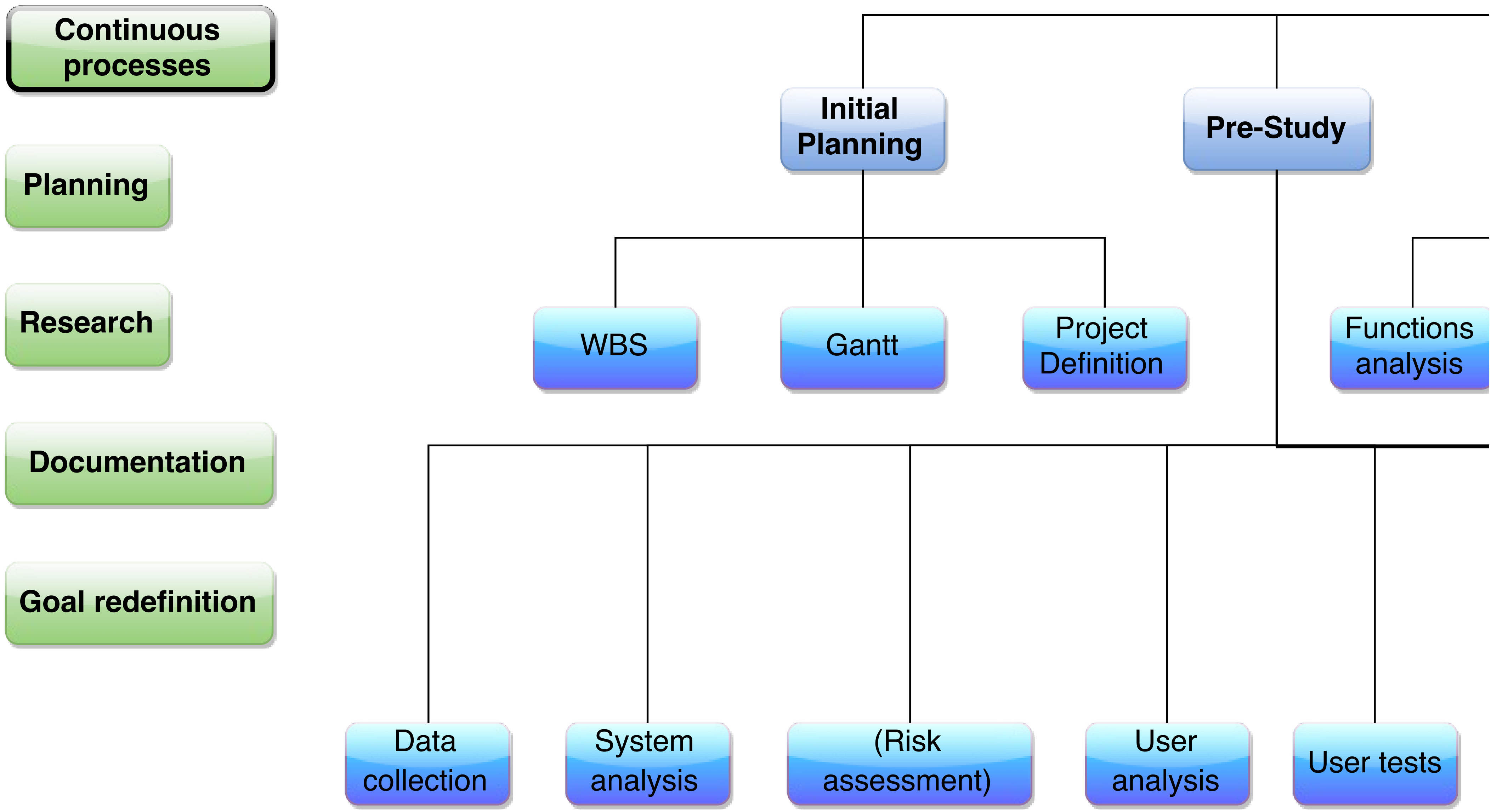
2. **Work Breakdown structure – Work package description**

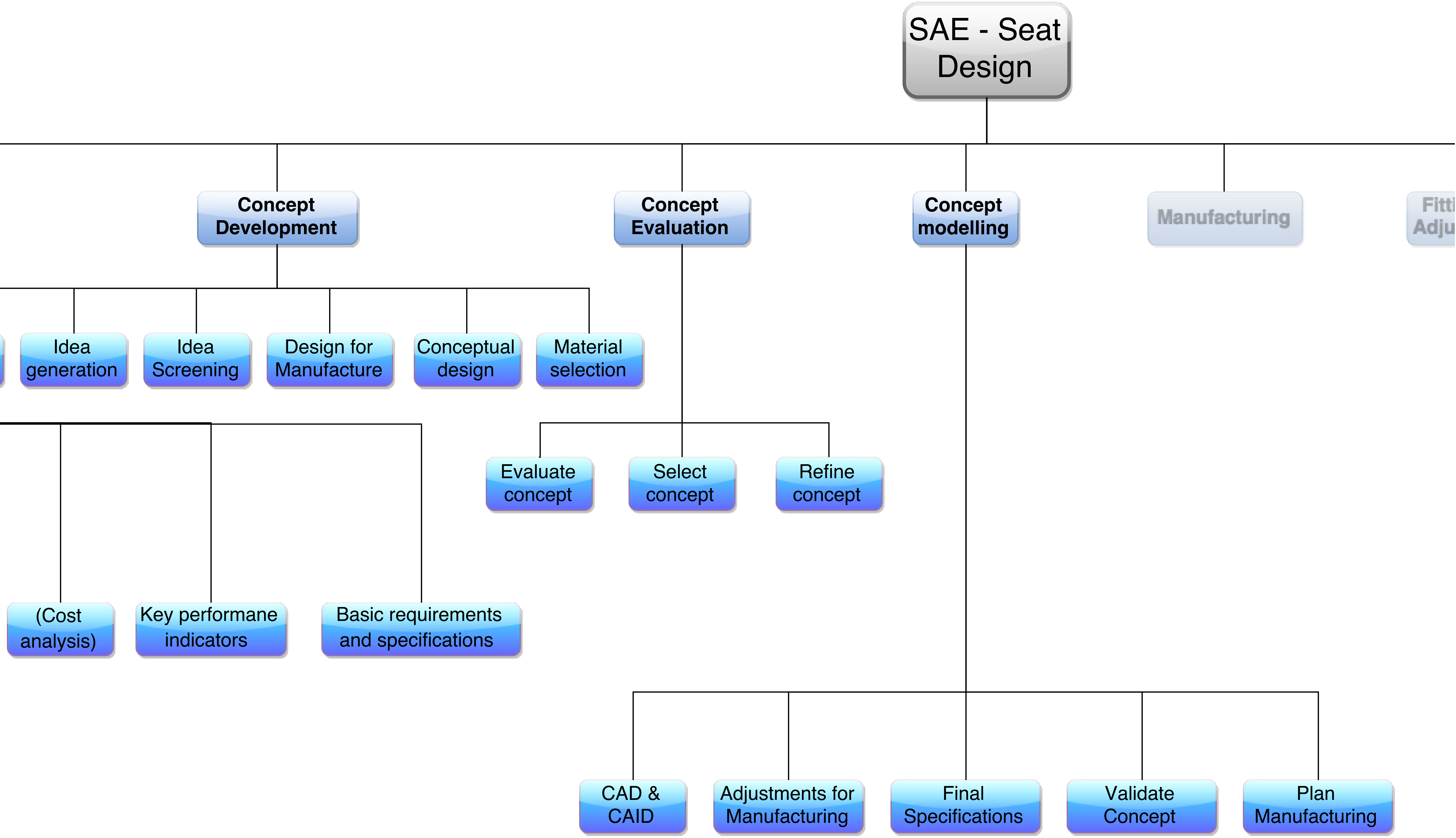
3. **Ergonomic tests**

4. **SAE rule compilation**

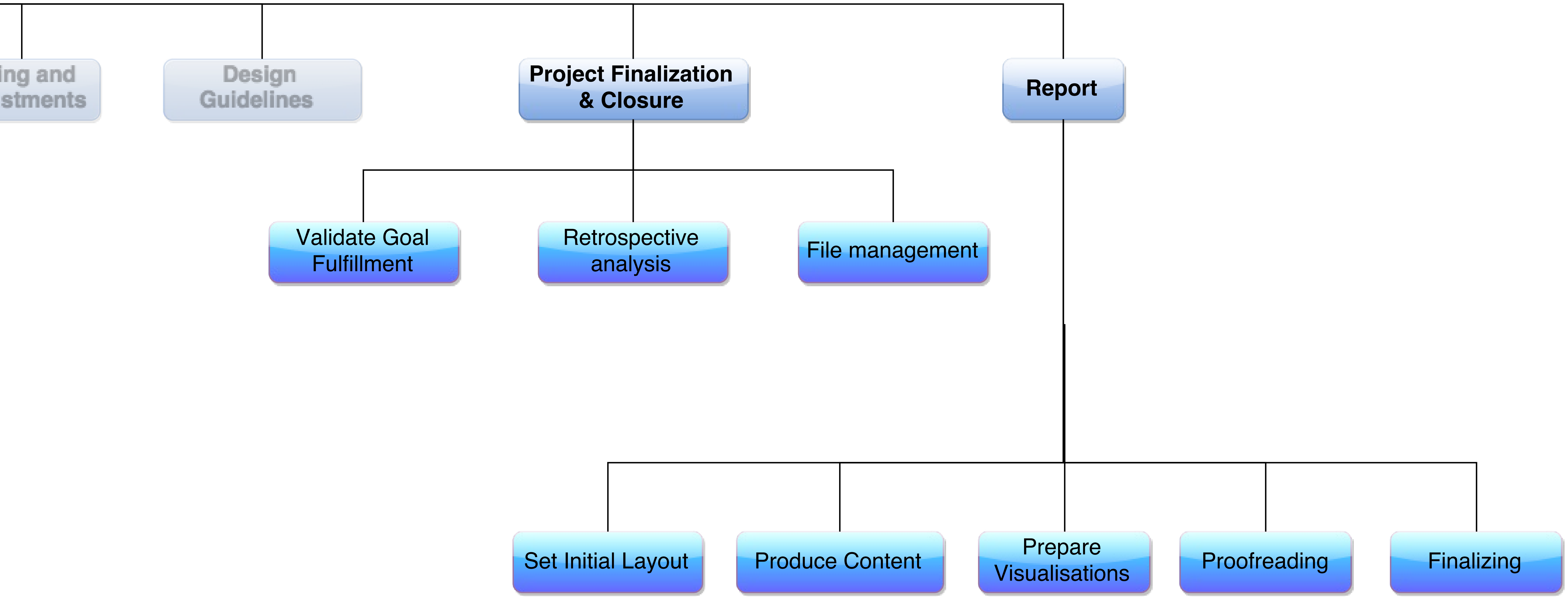
5. **Solution tree**

6. **FEA analysis images**


Continuous processes
Planning
Research
Documentation
Goal redefinition
Initial Planning
Pre-Study
WBS
Gantt
Project Definition
Functions analysis
Data collection
System analysis
(Risk assessment)
User analysis
User tests



SAE - Seat Design
Concept Development
Concept Evaluation
Concept modelling
Manufacturing
Idea generation
Idea Screening
Design for Manufacture
Conceptual design
Material selection
Evaluate concept
Select concept
Refine concept
(Cost analysis)
Key performane indicators
Basic requirements and specifications
CAD & CAID
Adjustments for Manufacturing
Final Specifications
Validate Concept
Plan Manufacturing


ing and
stments
Design
Guidelines
Project Finalization
& Closure
Report
Validate Goal
Fulfillment
Retrospective
analysis
File management
Set Initial Layout
Produce Content
Prepare
Visualisations
Proofreading
Finalizing

Appendix 1 - Work Breakdown Structure

Continuous processes

Planning
- Update Calendar with dates
- Plan processes in detail before a new stage/work package is entered
- Control progress in relation to Gantt and update if necessary

Documentation
- Update diary and work log.
- Housekeeping; File and document management

Research
- Interviews
- Literature studies
- Database search
- Online scanning

Goal/definition revaluation
- Evaluate goal in relation to progress, and new information
- Update project definition and goal description if necessary

Initial planning

Work Breakdown Structure
Gantt-chart planning; Schedule work packages and set baseline
Project Definition (project plan); aim, goal, objectives, deliverables, resources, time frame

Research study

Data collection
- Interviews
- Lit. Review
- Tests

Workshop introduction and progress update
System analysis/description; user, artifact, context etc. (Man-machine model/ functional model)
(**Cost analysis**)
(**Risk assessment;** SWAT) LEAN PD - page 193
User analysis
- Antropometric measurements
- User type (acc. Janhager)
- Performance influencing factors

User tests
- Physical (ergonomic and antropometric) REBA, RULA, OVAKO
- Simulations (JACK) digital human modeling DHM

Rapid Prototyping
Key performance indicators (for concept evaluation)

Basic requirements and specifications (Technical and HF)
Investigate the manufacturing possibilities

Concept development

Idea generation
Idea screening
Function analysis
Initial designs; (1-3 concepts)
Material selection; Evaluations (tests)
Design for manufacture.

Concept evaluation

Evaluate Design Concepts; according to KPI
- Conjoint analysis (metodappendix)
- Pugh's matrix
- Benchmarking (through Pugh)
- Simulations (Jack, FEM?)
- Ergonomics REBA, RULA, OVAKO

Concept selection; Choose one or combine concepts to final concept
Refine concept

Concept modelling

CAD and CAID
- Surface model
- Solid model
- Drawings for manufacture

Final specifications/requirements
Adjustments for manufacturing
Plan manufacturing
- Necessary competencies
- Equipment and tools (Carbon layers and directions)
- Order parts?

(Cost estimate)
Validation of final concept

Project Finalization and Closure

Validate Goal Fulfilment
Retrospective analysis
- Individual work
- The "organisation's" work
- Theories and methods
- Summarize Learning outcomes

File Management
- Organize files and documents

- Get rid of excessive documentation

Report

Initial layout and referencing system
Write report
Prepare visualizations; Figures, sketches and drawings
Proofreading
Finalizing report

Appendix 4 - Ergonomic tests

Questions to be answered

Seat position - Vertical and horizontal

Seat angle - Between seating and backrest and backrest and head restraint

Seat dimensions - Height, width, shape, head/leg rest

Posture - Knee angle to reach pedals, arm position to reach and manoeuvre steering wheel, eye position to overview track etc.

1 Computer simulations

Create virtual world

With known constraints and digital mock-ups of relevant elements

Scale manikins

According to driver dimensions and percentiles;.

Smallest driver

Biggest driver

5th Percentile woman

95th Percentile man

Test ergonomic position and movability

Adjust all mannequins' joints close to desirable positions. Let software perform ergonomic analysis and assess uneven loads. Save mannequins in a posture that meet all requirements listed in "considerations for mannequin positioning"

Analyse results and compile

Analyse outcome in relation to previous data and possible solution. Summarize outcomes

2 Physical tests step-by-step

Decide on relevant aspects/key data point to measure

Test 1

Use timber mock-up to try out different settings and ask the test subject to explain how the different postures feels and compared different settings.

Height - View

Backrest Angle

Head Angle/height

Knee angle

Leg support length

Test 2

10-12 wires separated on an even distance along back and buttock, from shoulder to knee, bound together with 1-3 spine shaped wires, to form a mesh of user's back that can be photographed and transferred into curves and "patched" together accordingly.

Choose test subjects

What characteristics matters?

Test 1

Tallest

Shortest

Test 2

Tallest

Shortest

Widest shoulders and waist

Narrowest shoulders and waist

Anthropometric measurements questionnaire

Measure anthropometric data according to "relevant anthropometrics for seat design" data sheet. For biggest and smallest driver (stature, hip circumference etc.)

Build Test model (mock-up)

Test 1

Building mock-up out of studs, parts of a chair etc. According to supplied drawings.

Test 2

10-12 wires separated on even distance along back and buttock from shoulder to knee, bound together with 1-3 spine shaped wires. Use masking tape on each wire to mark up number, to be able to keep track of position.

Test 3

Measure and compare existing seats in the workshop, and evaluate. Interview previous years drivers;

What was good vs bad?

How does it feel?

-Support

-Stiffness

-Angle

-Surface structure etc.

Perform test and measure

Put people in ergonomically satisfying positions. Neutral body posture (according what is described in ergonomic considerations chapter and result of computer simulations and anthropometric joint angles data sheet).

Place wrists on steering wheel, steering wheel mid neck high, elbow angle 90-110 degrees. Head upright. Knee bent up to 120 degrees.

- Measure position, angle, dimensions etc acc. to drawing sheet
- Photos, all angles (reference, 1 meter ruler in photo)

Analyse results and compile

REBA and RULA theoretical frameworks for ergonomic testing.

Consider possible bias, test sample, replicability etc.

Summarize outcomes

Appendix 5 - SAE-A Regulations compilation for seat design

General rules

Modifications

T1.2.2 Once the vehicle is approved to compete in the dynamic events, the ONLY modifications permitted to the vehicle are those listed below. They are also referred to in Part S of the Formula SAE Rules – Static Event Regulations.

a. Adjustment of belts, chains and clutches

b. Adjustment of brake bias

c. Adjustment of the driver restraint system, head restraint, seat and pedal assembly

d. Substitution of the head restraint or seat insert for different drivers

Materials

T3.8 Composite Materials
T3.8.1 If any composite or other material is used, the team must present documentation of material type, e.g. purchase receipt, shipping document or letter of donation, and of the material properties. Details of the composite lay-up technique as well as the structural material used (cloth type, weight, and resin type, number of layers, core material, and skin material if metal) must also be submitted. The team must submit calculations demonstrating equivalence of their composite structure to one of similar geometry made to the minimum requirements found in Section T3.4.1. Equivalency calculations must be submitted for energy dissipation, yield and ultimate strengths in bending, buckling, and tension. Submit the completed “Structural Equivalency Spreadsheet” per Section T3.9.

Cockpit

T4.1 Cockpit Opening

T4.1.1 In order to ensure that the opening giving access to the cockpit is of adequate size, a template shown in Figure 8 will be inserted into the cockpit opening. It will be held horizontally and inserted vertically until it has passed below the top bar of the Side Impact Structure (or until it is 350 mm (13.8 inches) above the ground for monocoque cars). Fore and aft translation of the template will be permitted during insertion.

T4.1.2 During this test, the steering wheel, steering column, seat and all padding may be removed. The shifter or shift mechanism may not be removed unless it is integral with the steering wheel and is removed with the steering wheel. The firewall may not be moved or removed.

HELMET CLEARANCE

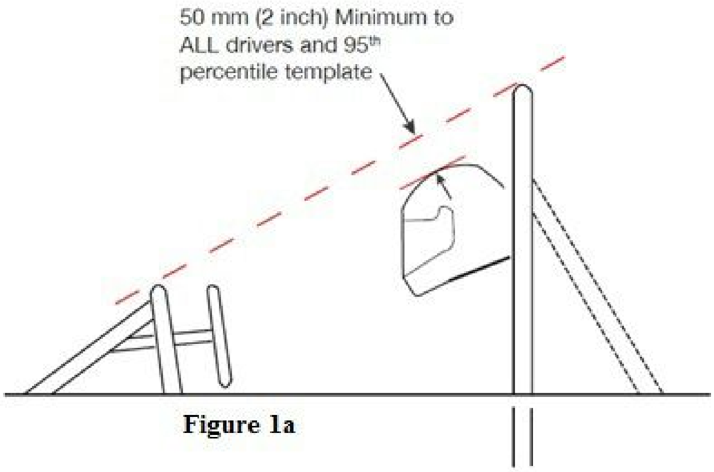


Figure 1a

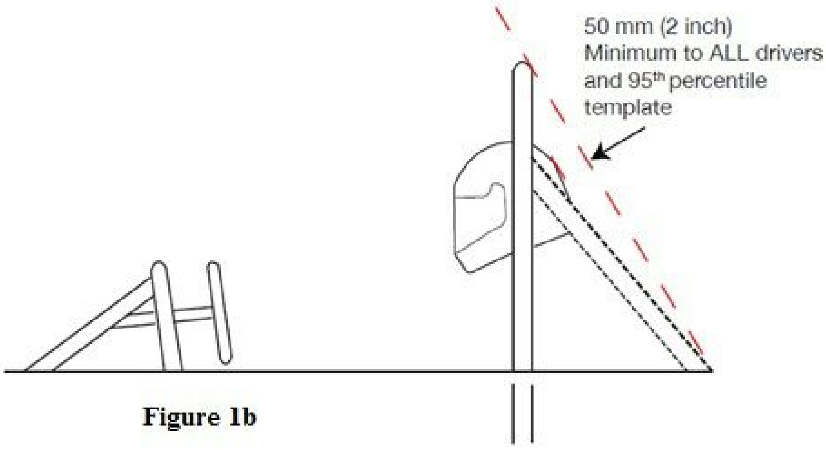


Figure 1b

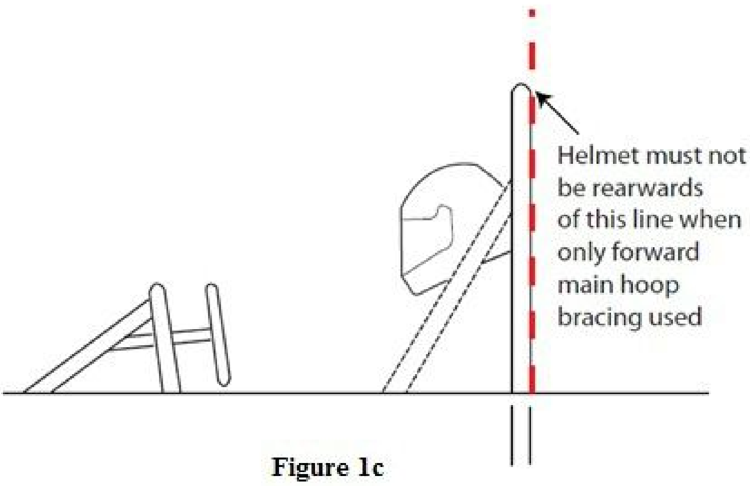


Figure 1c

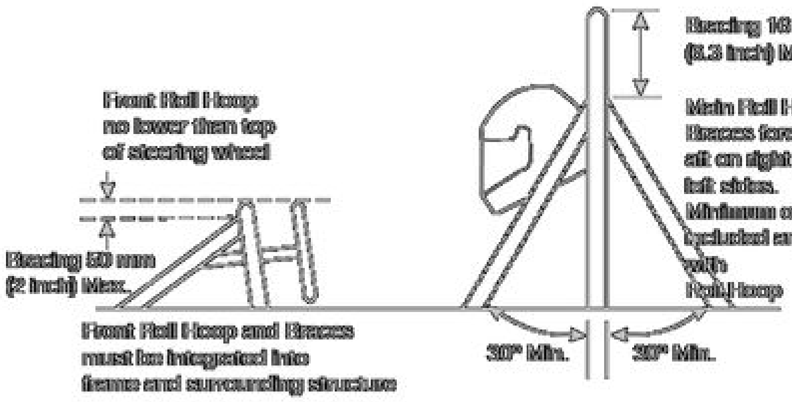


FIGURE 3

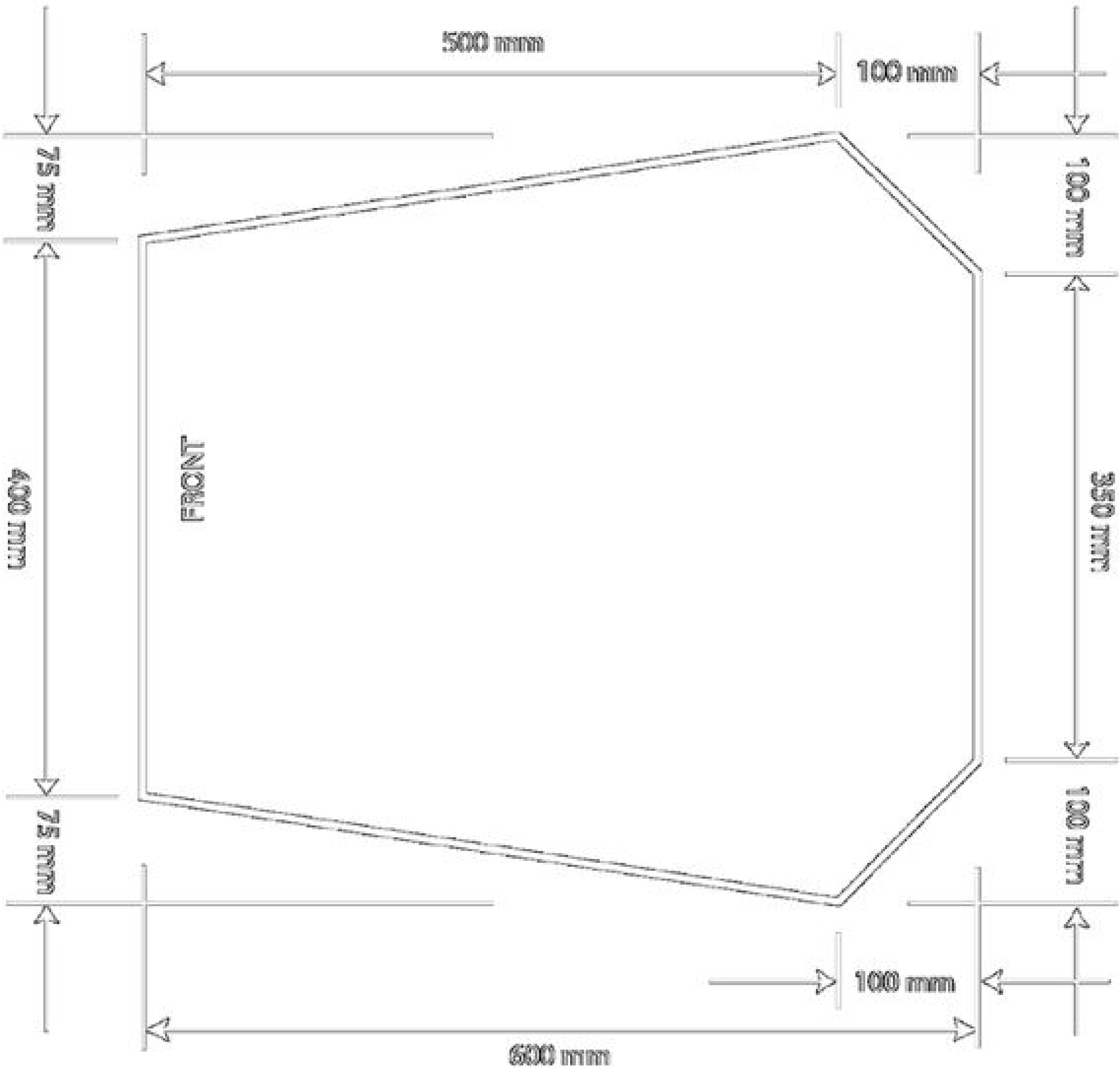


FIGURE 8

NOTE: As a practical matter, for the checks, the steering column will not be removed. The technical inspectors will maneuver the template around the steering column shaft, but not the steering column supports.

T4.2 Cockpit Internal Cross Section:

T4.2.1 A free vertical cross section, which allows the template shown in Figure 9 to be passed horizontally through the cockpit to a point 100 mm (4 inches) rearwards of the face of the rearmost pedal when in the inoperative position, must be maintained over its entire length. If the pedals are adjustable, they will be put in their most forward position.

50

T4.2.2 The template, with maximum thickness of 7mm (0.275 inch), will be held vertically and inserted into the cockpit opening rearward of the Front Roll Hoop, as close to the Front Roll Hoop as the car's design will allow.

T4.2.3 The only items that may be removed for this test are the steering wheel, and any padding required by Rule T5.8 "Driver's Leg Protection" that can be easily removed without the use of tools with the driver in the seat. The seat may NOT be removed.

T4.2.4 Teams whose cars do not comply with T4.1.1 or T4.2.1will not be given a Technical Inspection Sticker and will NOT be allowed to compete in the dynamic events.

NOTE: Cables, wires, hoses, tubes, etc. must not impede the passage of the templates required by T4.1.1 and T4.2.

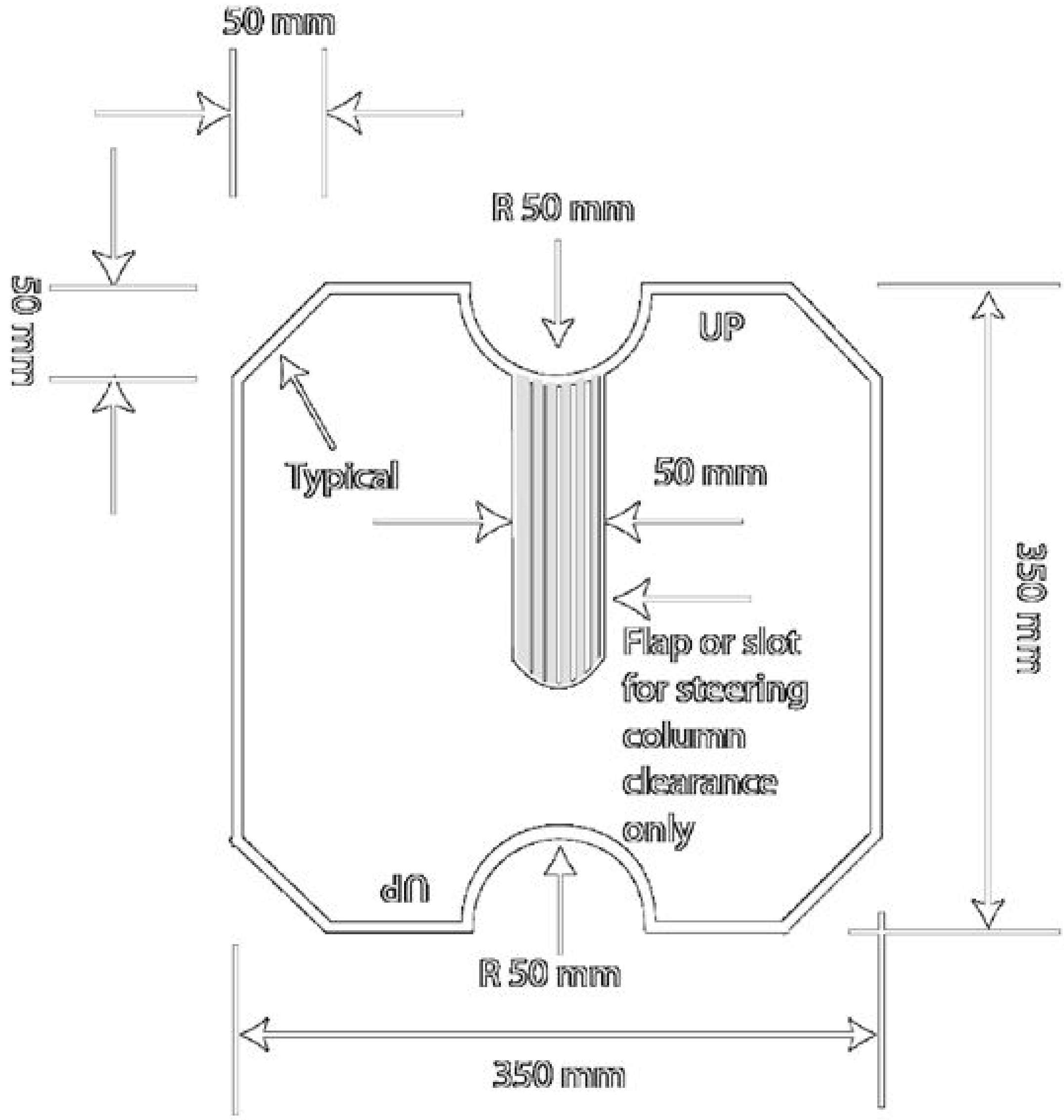


FIGURE 9

Firewall

T4.5 Firewall

T4.5.1 A firewall must separate the driver compartment from all components of the fuel supply, the engine oil, the liquid cooling systems and any high voltage system (PART EV - EV1.1). It must protect the neck of the tallest driver. It must extend sufficiently far upwards and/or rearwards such that any point less than 100 mm (4 ins.) above the bottom of the helmet of the tallest driver shall not be in direct line of sight with any part of the fuel system, the cooling system or the engine oil system.

T4.5.2 The firewall must be a non-permeable surface made from a rigid, fire resistant material.

T4.5.3 Any firewall must seal completely against the passage of fluids, especially at the sides and the floor of the cockpit, i.e. there can be no holes in a firewall through which seat belts pass.

T4.5.4 Pass-through for wiring, cables, etc. are allowable if grommets are used to seal the pass-through. Also, multiple panels may be used to form the firewall but must be sealed at the joints.

Driver

95th Percentile Male Template Dimensions
A two dimensional template used to represent the 95th percentile male is made to the following dimensions:

• A circle of diameter 200 mm (7.87 inch) will represent the hips and buttocks.
• A circle of diameter 200 mm (7.87 inch) will represent the shoulder/cervical region.
• A circle of diameter 300 mm (11.81 inch) will represent the head (with helmet).
• A straight line measuring 490 mm (19.29 inch) will connect the centers of the two 200 mm circles.
• A straight line measuring 280 mm (11.02 inch) will connect the centers of the upper 200 mm circle and the 300 mm head circle.

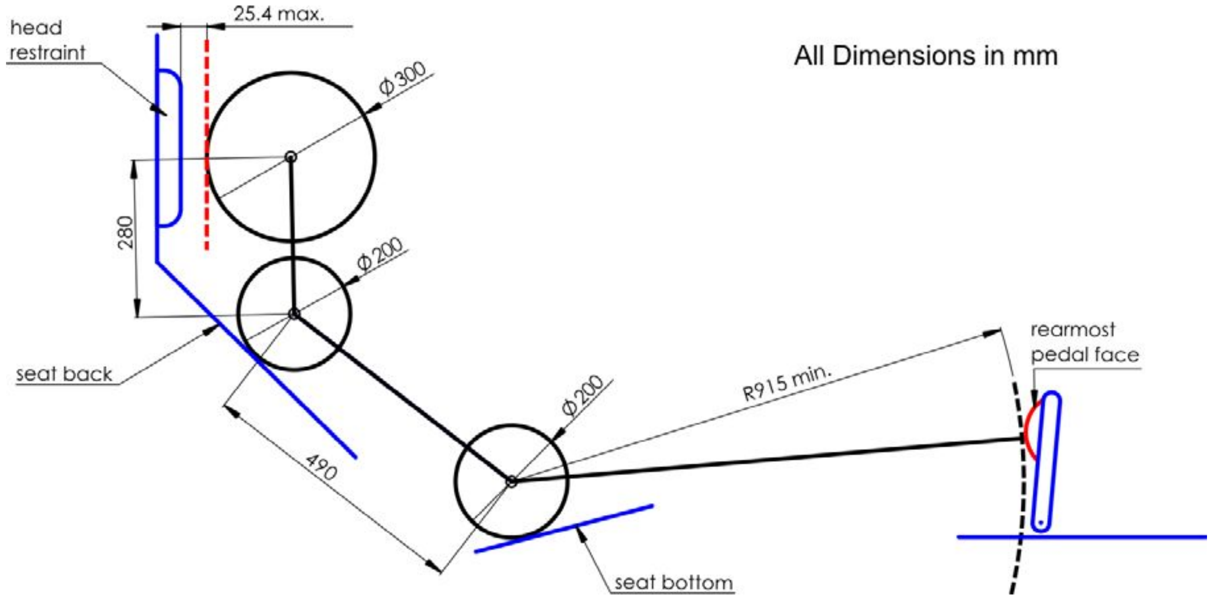
T3.10.4 The 95th percentile male template will be positioned as follows: (See Figure 2.)
a. The seat will be adjusted to the rearmost position,

b. The pedals will be placed in the most forward position.

c. The bottom 200 mm circle will be placed on the seat bottom such that the distance between the center of this circle and the rearmost face of the pedals is no less than 915 mm (36 inches).

d. The middle 200 mm circle, representing the shoulders, will be positioned on the seat back.

e. The upper 300 mm circle will be positioned no more than 25.4 mm (1 inch) away from the head restraint (i.e. where the driver’s helmet would normally be located while driving).



T4.7 Driver Visibility
T4.7.1 General Requirement
The driver must have adequate visibility to the front and sides of the car. With the driver seated in a normal driving position he/she must have a minimum field of vision of two hundred degrees (200°) (a minimum one hundred degrees (100°) to either side of the driver). The required visibility may be obtained by the driver turning his/her head and/or the use of mirrors.

T4.7.2 Mirrors
If mirrors are required to meet Rule T4.7.1, they must remain in place and adjusted to enable the required visibility throughout all dynamic events.

T4.8 Driver Egress
All drivers must be able to exit to the side of the vehicle in no more than 5 seconds. Egress time begins with the driver in the fully seated position, hands in driving position on the connected steering wheel and wearing the required driver equipment. Egress time will stop when the driver has both feet on the pavement.

Specific rules

Driver’s seat

T4.3 Driver’s Seat

T4.3.1 The lowest point of the driver's seat must be no lower than the bottom surface of the lower frame rails or by having a longitudinal tube (or tubes) that meets the requirements for Side Impact tubing, passing underneath the lowest point of the seat.

T4.3.2 When seated in the normal driving position, adequate heat insulation must be provided to ensure that the driver will not contact any metal or other materials which may become heated to a surface temperature above sixty degrees C (60°C). The insulation may be external to the cockpit or incorporated with the driver's seat or firewall. The design must show evidence of addressing all three (3) types of heat transfer, namely conduction, convection and radiation, with the following between the heat source, e.g. an exhaust pipe or coolant hose/tube and the panel that the driver could contact, e.g. the seat or floor:

a. Conduction Isolation by:
i. No direct contact between the heat source and the panel, or
ii. A heat resistant, conduction isolation material with a minimum thickness of 8 mm (0.3 in) between the heat source and the panel.

b. Convection Isolation by a minimum air gap of 25 mm (1 inch) between the heat source and the panel

c. Radiation Isolation by:
i. A solid metal heat shield with a minimum thickness of 0.4 mm (0.015 in) or
ii. Reflective foil or tape when combined with T4.3.2.a.ii above.

Head restraint

T5.6 Head Restraint
T5.6.1 A head restraint must be provided on the car to limit the rearward motion of the driver's head.

T5.6.2 The restraint must:
a. Be vertical or near vertical in side view.

b. Be padded with an energy absorbing material such as Ethafoam® or Ensolite® with a minimum thickness of 38 mm (1.5 inches).

c. Have a minimum width of 15 cms (6 inches).

d. Have a minimum area of 235 sq. cms (36 sq. inches) AND have a minimum height adjustment of 17.5 cms (7 inches), OR have a minimum height of 28 cms (11 inches).

e. Be located so that for each driver:
i. The restraint is no more than 25 mm (1 inch) away from the back of the driver's helmet, with the driver in their normal driving position.
ii. The contact point of the back of the driver's helmet on the head restraint is no less than 50 mm (2 inch) from any edge of the head restraint.

NOTE 1: Head restraints may be changed to accommodate different drivers (See T1.2.2).
NOTE 2: The above requirements must be met for all drivers.
NOTE 3: Approximately 100mm (4") longitudinal adjustment is required to accommodate 5th to 95th Percentile drivers. This is not a specific rules requirement, but teams must have sufficient

Driver's harness and belt

T5.1 Belts - General
T5.1.1 Definitions
a. A 5-point system – consists of a 76 mm (3 inch) wide lap belt, approximately 76 mm (3 inch) wide shoulder straps and a single approximately 51 mm (2 inch) wide anti-submarine strap. The single anti-submarine strap must have a metal-to-metal connection with the single release common to the lap belt and shoulder harness.

b. A 6-point system – consists of a 76 mm (3 inch) wide lap belt, approximately 76 mm (3 inch) wide shoulder straps and two (2) approximately 51 mm (2 inch) wide leg or anti-submarine straps.

c. A 7-point system – system is the same as the 6-point except it has three (3) anti-submarine straps, two (2) from the 6-point system and one (1) from the 5-point system.
NOTE: 6 and 7-point harnesses to FIA specification 8853/98 and/or SFI Specification 16.5 with approximately 51 mm (2 inch) lap belts are acceptable.

d. An "upright driving position" is defined as one with a seat back angled at thirty degrees (30°) or less from the vertical as measured along the line joining the two 200 mm circles of the template of the 95th percentile male as defined in Rule T3.10.3 and positioned per T3.10.4.

e. A “reclined driving position” is defined as one with a seat back angled at more than thirty degrees (30°) from the vertical as measured along the line joining the two 200 mm circles of the template of the 95th percentile male as defined in Rule T3.10.3 and positioned per T3.10.4.

f. The “chest-groin line” is the straight line that in side view follows the line of the

T5.1.2 Harness Requirements
All drivers must use a 5, 6 or 7 point restraint harness meeting the following specifications:
a. All driver restraint systems must meet SFI Specification 16.1, SFI Specification 16.5, or FIA specification 8853/98.

b. The belts must bear the appropriate dated labels.

c. The material of all straps must be in perfect condition.

d. There must be a single release common to the lap belt and shoulder harness using a metal-to-metal quick release type latch.

e. To accommodate drivers of differing builds, all lap belts must incorporate a tilt lock adjuster (“quick adjuster”). A tilt lock adjuster in each portion of the lap belt is highly recommended. Lap belts with “pull-up” adjusters are recommended over “pull-down” adjusters.

f. Cars with a “reclined driving position” (see 5.1.1.e above) must have either a 6 point or 7-point harness, AND have either anti-submarine belts with tilt lock adjusters (“quick adjusters”) or have two (2) sets of anti-submarine belts installed.

g. The shoulder harness must be the over-the-shoulder type. Only separate shoulder straps are permitted (i.e. “y”-type shoulder straps are not allowed). The “H”-type configuration is allowed.

h. It is mandatory that the shoulder harness, where it passes over the shoulders, be 76 mm (3 inch) wide, except as noted below. The shoulder harness straps must be threaded through the three bar adjusters in accordance with manufacturer’s instructions.

i. When the HANS device is used by the driver, FIA certified 51 mm (2 inch) wide shoulder harnesses are allowed. Should a driver, at any time not utilize the HANS device, then 76 mm (3 inch) wide shoulder harnesses are required.

T5.1.3 Harness Replacement
SFI spec harnesses must be replaced following December 31st of the 2nd year after the date of manufacture as indicated by the label. FIA spec harnesses must be replaced following December 31st of the year marked on the label.
NOTE: FIA belts are normally certified for five (5) years from the date of manufacture.

T5.1.4 The restraint system must be worn tightly at all times.

T5.2 Belt, Strap and Harness Installation - General
T5.2.1 The lap belt, shoulder harness and anti-submarine strap(s) must be securely mounted to the Primary Structure. Such structure and any guide or support for the belts must meet the minimum requirements of T3.4.1.
NOTE: Rule T3.5.5 applies to these tubes as well so a non-straight shoulder harness bar would require support per T3.5.5

T5.2.2 The tab or bracket to which any harness is attached must have:
a. A minimum cross sectional area of 60 sq. mm (0.093 sq. in) of steel to be sheared or failed in tension at any point of the tab, and

b. A minimum thickness of 1.6 mm (0.063 inch).

c. Where lap belts and anti-submarine belts use the same attachment point, a minimum cross sectional area of 90 sq. mm (0.140 sq. in) of steel to be sheared if failed in tension at any point of the tab.

d. Where brackets are fastened to the chassis, two fasteners of 6mm Metric Grade 8.8 (1/4 inch SAE Grade 5) fasteners or stronger must be used.
NOTE: Double shear mounting is preferred.

T5.2.3 Harnesses, belts and straps must not pass through a firewall, i.e. all harness attachment points must be on the driver’s side of any firewall.

T5.2.4 The attachment of the Driver’s Restraint System to a monocoque structure requires an approved Structural Equivalency Spreadsheet per Rule T3.9.

T5.2.5 The restraint system installation is subject to approval of the Chief Technical Inspector.

T5.3 Lap Belt Mounting

T5.3.1 The lap belt must pass around the pelvic area below the Anterior Superior Iliac Spines (the hip bones).

T5.3.2 The lap belts should not be routed over the sides of the seat. The lap belts should come through the seat at the bottom of the sides of the seat to maximize the wrap of the pelvic surface and continue in a straight line to the anchorage point.

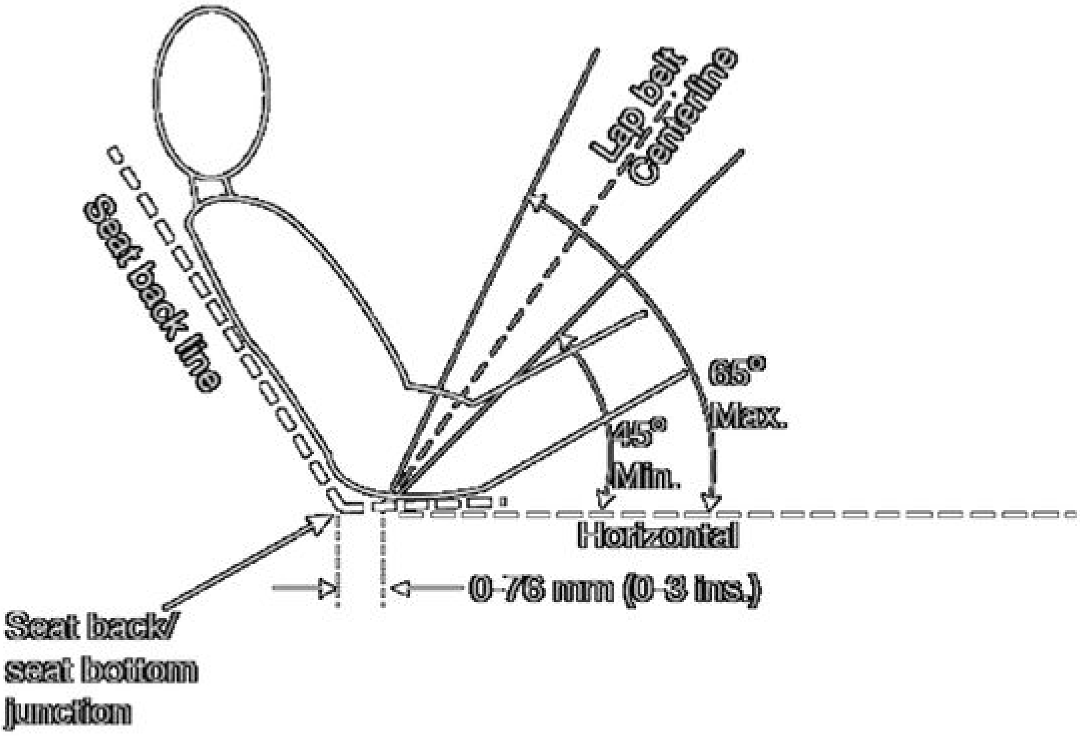
T5.3.3 Where the belts or harness pass through a hole in the seat, the seat must be rolled or grommeted to prevent chafing of the belts.
‘

T5.3.4 To fit drivers of differing statures correctly, in side view, the lap belt must be capable of pivoting freely by using either a shouldered bolt or an eye bolt attachment, i.e. mounting lap belts by wrapping them around frame tubes is no longer acceptable.

T5.3.5 With an “upright driving position”, in side view the lap belt must be at an angle of between forty-five degrees (45°) and sixty-five degrees (65°) to the horizontal. This means that the centerline of the lap belt at the seat bottom should be between 0 – 76 mm (0 – 3 inches) forward of the seat back to seat bottom junction. (See Figure 10)

FIGURE 10

Lap Belt Angle



T5.3.6 With a “reclined driving position”, in side view the lap belt must be between an angle of sixty degrees (60°) and eighty degrees (80°) to the horizontal.

T5.4 Shoulder Harness

T5.4.1 The shoulder harness must be mounted behind the driver to structure that meets the requirements of T3.4.1. However, it cannot be mounted to the Main Roll Hoop Bracing or attendant structure without additional bracing to prevent loads being transferred into the Main Hoop Bracing.

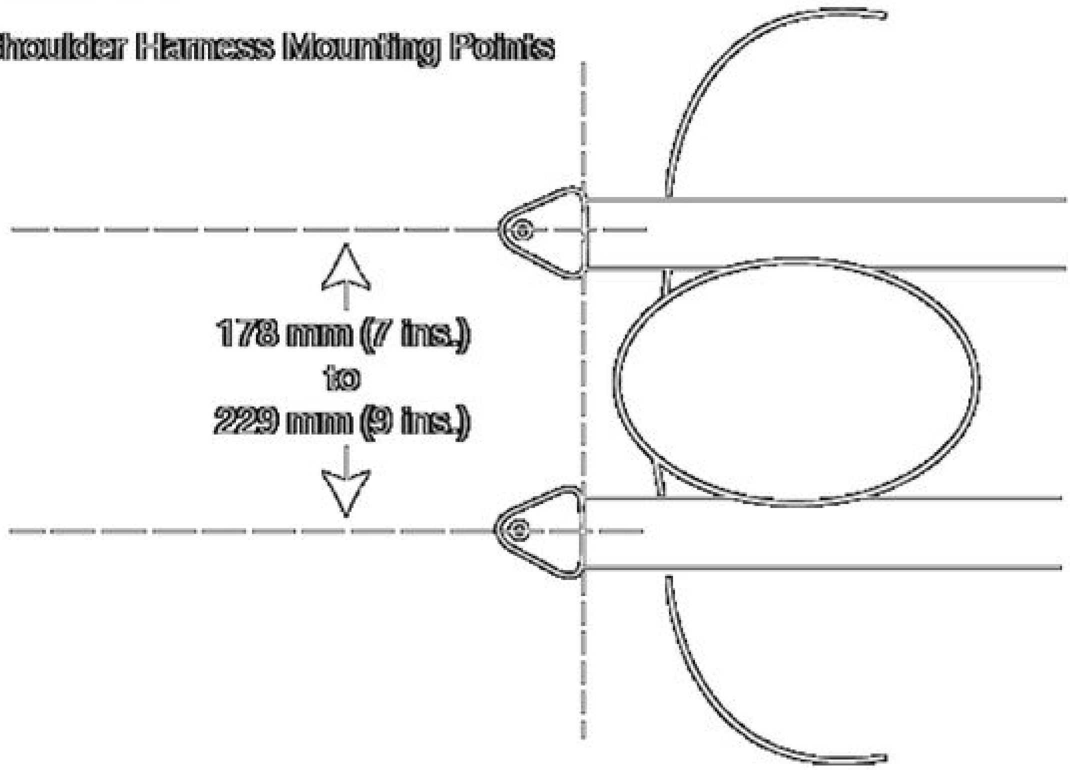
T5.4.2 If the harness is mounted to a tube that is not straight, the joints between this tube and the structure to which it is mounted must be reinforced in side view by triangulation tubes to prevent torsional rotation of the harness mounting tube. Supporting calculations are required. Analysis Method: Use 7kN load per attachment and the range of angles in T5.4.4 calculate that the bent Shoulder Harness Bar triangulation stresses are less than As Welded Yield Strength (T3.4.1 note 4) for combined bending and shear and does not fail in column buckling. If the team chooses not to perform the strength analysis rule T3.5.5 will apply.

T5.4.3 The strength of any shoulder harness bar bracing tubes must be proved in the relevant tab of the team's SES submission.

T5.4.4 The shoulder harness mounting points must be between 178 mm (7 inches) and 229 mm (9 inches) apart. (See Figure 11)

FIGURE 11

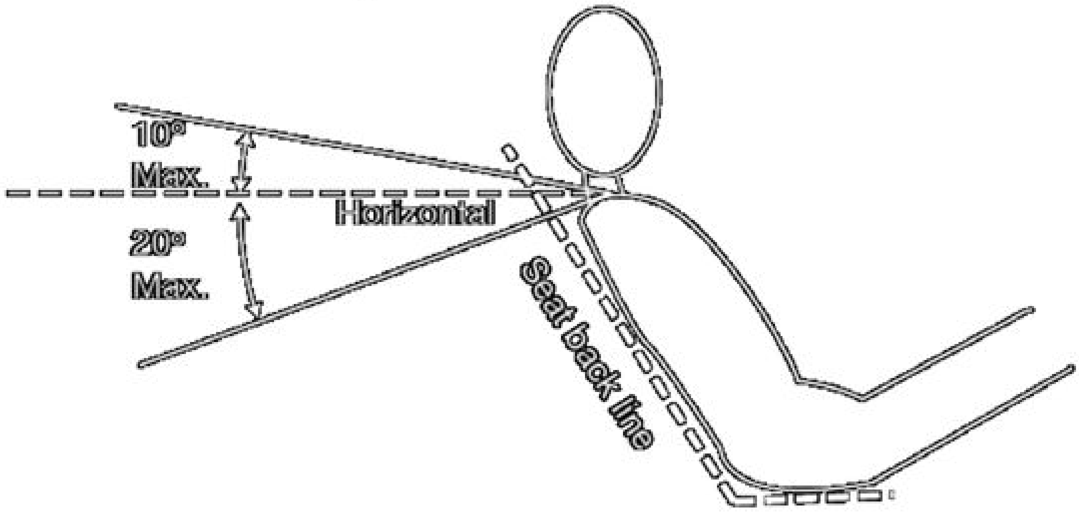
Shoulder Harness Mounting Points



T5.4.5 From the driver's shoulders rearwards to the mounting point or structural guide, the shoulder harness must be between ten degrees (10°) above the horizontal and twenty degrees (20°) below the horizontal. (See Figure 12).

FIGURE 12

Shoulder Harness Angle



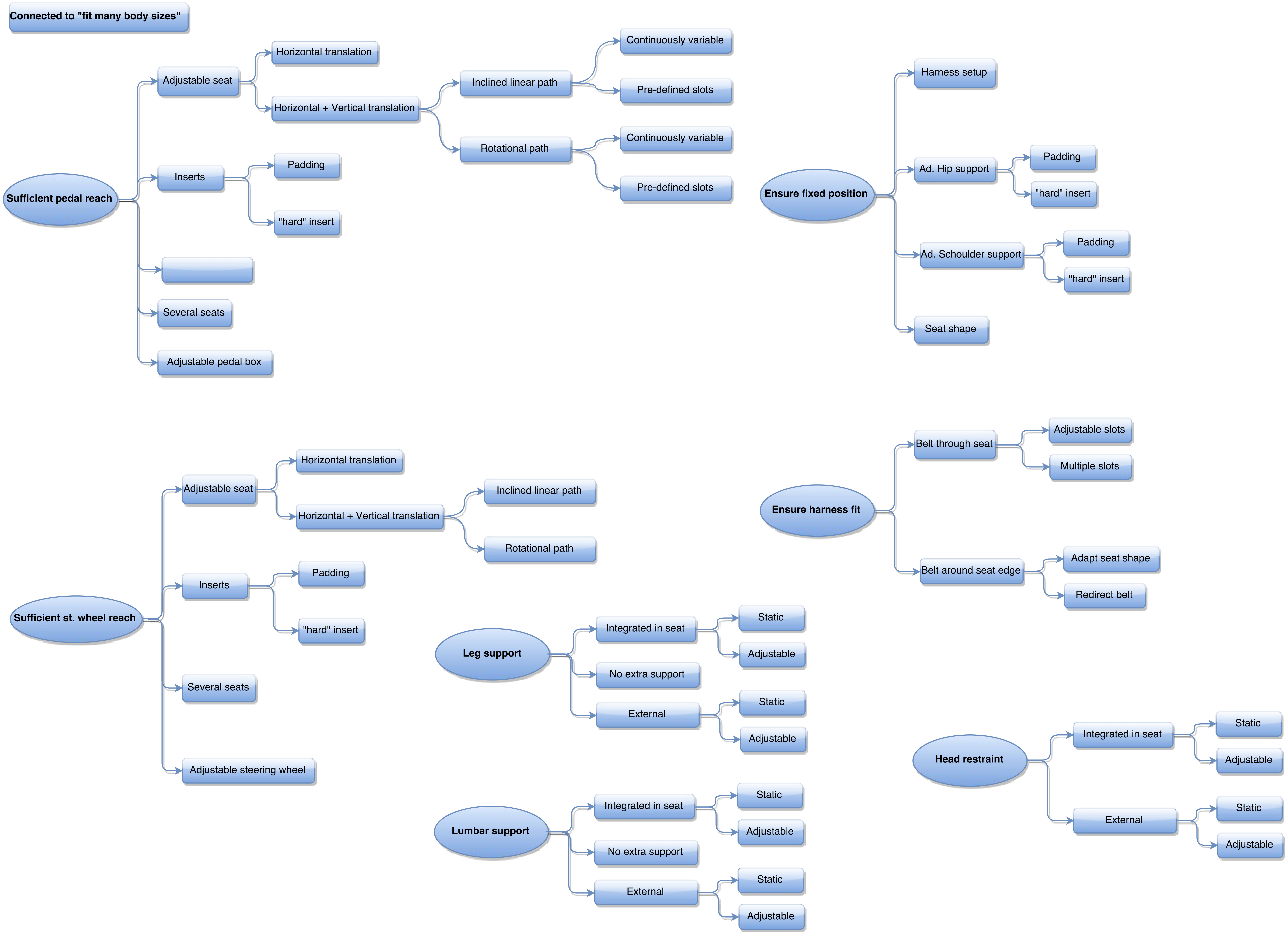
T5.5 Anti-Submarine Belt Mounting

T5.5.1 The anti-submarine belt of a 5 point harness should be mounted in line with, or angled slightly forward (up to twenty degrees (20°)) of, the driver's chest-groin line.

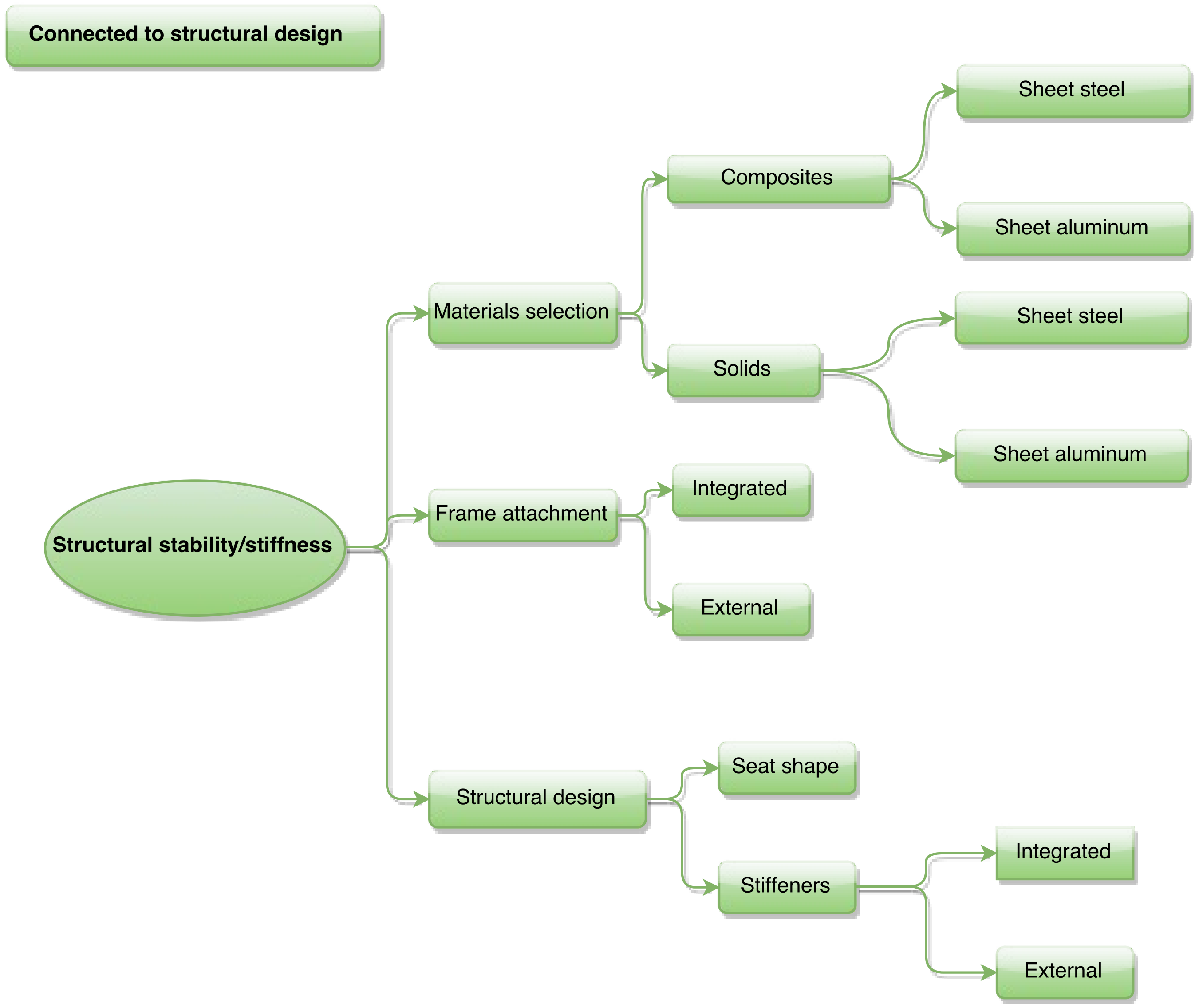
T5.5.2 The anti-submarine belts of a 6 point harness should be mounted either:

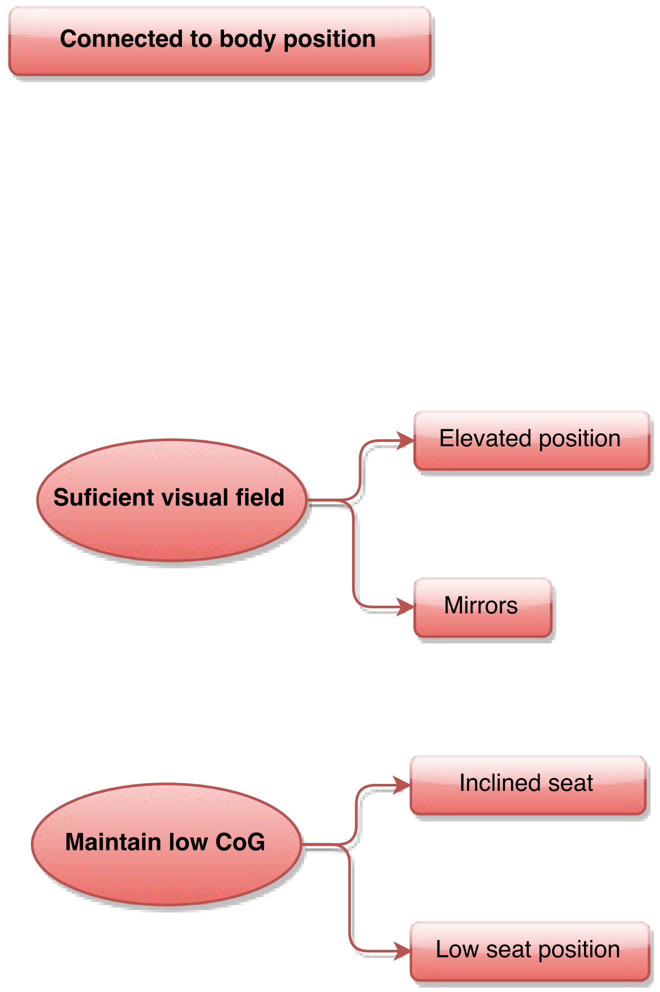
a. With the belts going vertically down from the groin, or angled up to twenty degrees (20°) rearwards. The anchorage points should be approximately 100 mm (4 inches) apart. Or

b. With the anchorage points on the Primary Structure at or near the lap belt anchorages, the driver sitting on the anti-submarine belts, and the belts coming up around the groin to the release buckle.



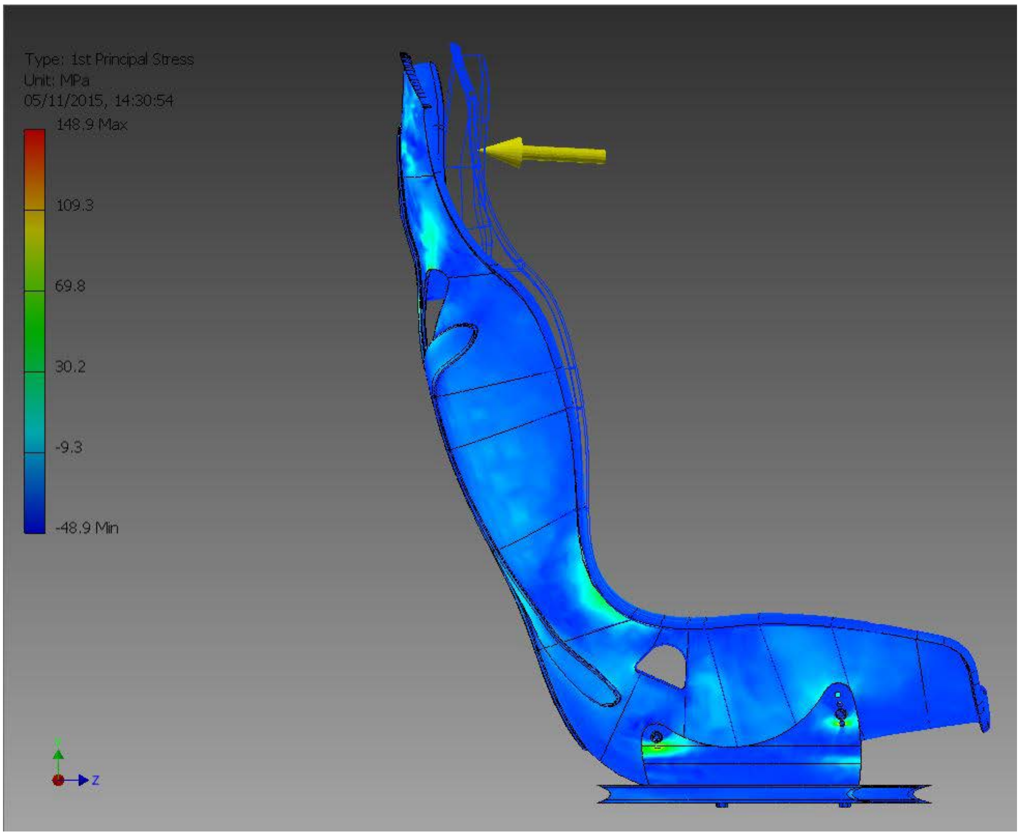
Connected to "fit many body sizes"
Sufficient pedal reach
Adjustable seat
Horizontal translation
Horizontal + Vertical translation
Inclined linear path
Continuously variable
Pre-defined slots
Rotational path
Continuously variable
Pre-defined slots
Inserts
Padding
"hard" insert
Several seats
Adjustable pedal box
Ensure fixed position
Harness setup
Ad. Hip support
Padding
"hard" insert
Ad. Schoulder support
Padding
"hard" insert
Seat shape
Sufficient st. wheel reach
Adjustable seat
Horizontal translation
Horizontal + Vertical translation
Inclined linear path
Rotational path
Inserts
Padding
"hard" insert
Several seats
Adjustable steering wheel
Ensure harness fit
Belt through seat
Adjustable slots
Multiple slots
Belt around seat edge
Adapt seat shape
Redirect belt
Leg support
Integrated in seat
Static
Adjustable
No extra support
External
Static
Adjustable
Lumbar support
Integrated in seat
Static
Adjustable
No extra support
External
Static
Adjustable
Head restraint
Integrated in seat
Static
Adjustable
External
Static
Adjustable

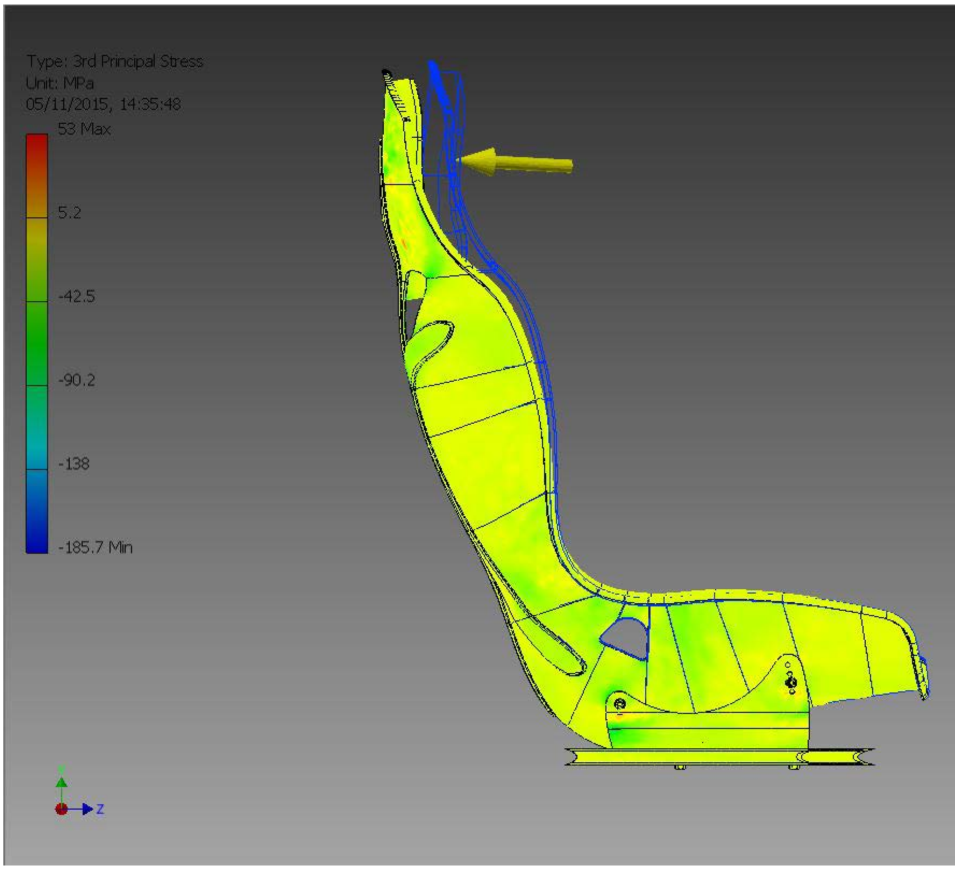

Connected to structural design
Structural stability/stiffness
Materials selection
Composites
Sheet steel
Sheet aluminum
Solids
Sheet steel
Sheet aluminum
Frame attachment
Integrated
External
Structural design
Seat shape
Stiffeners
Integrated
External

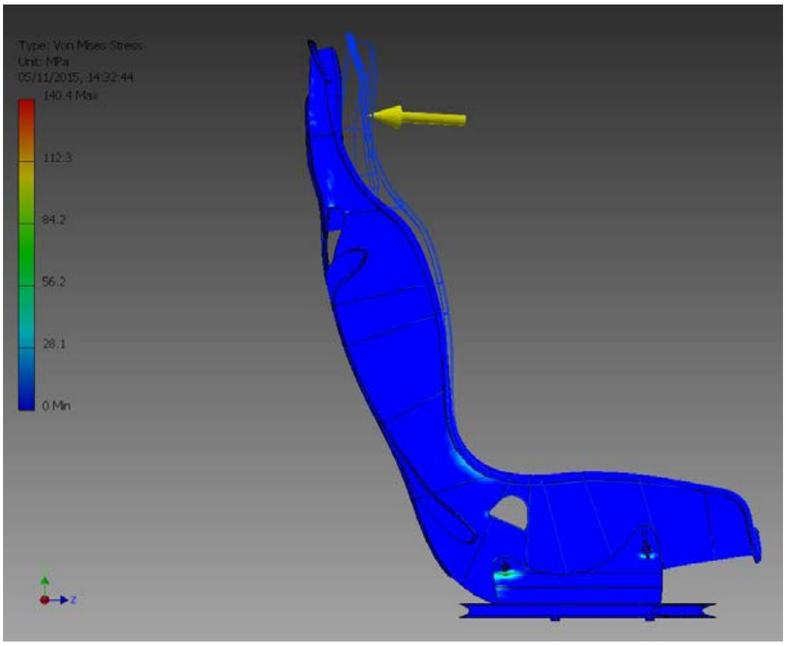

Connected to body position
Suficient visual field
Elevated position
Mirrors
Maintain low CoG
Inclined seat
Low seat position

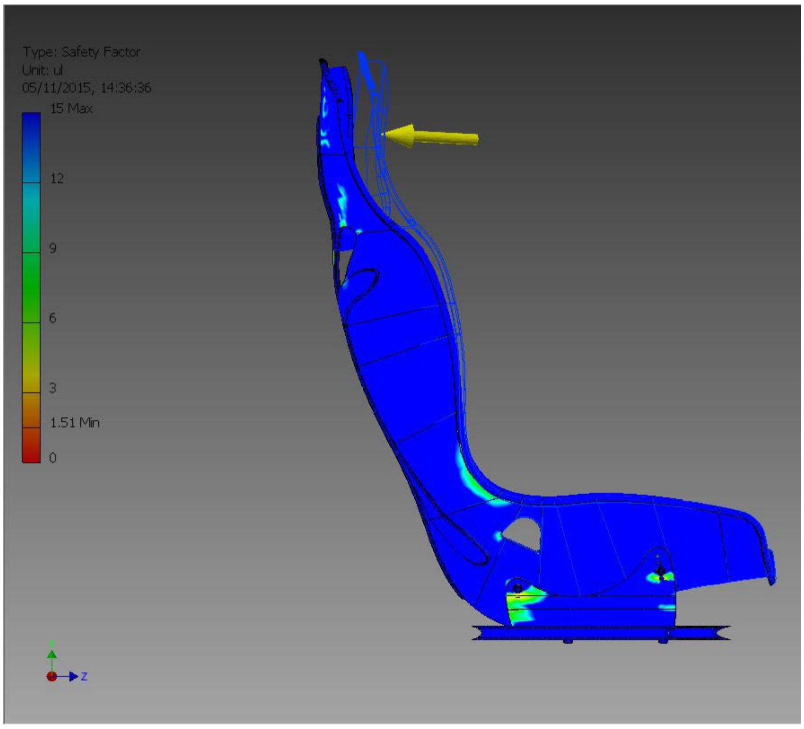
Appendix 6 - Stress Analysis images

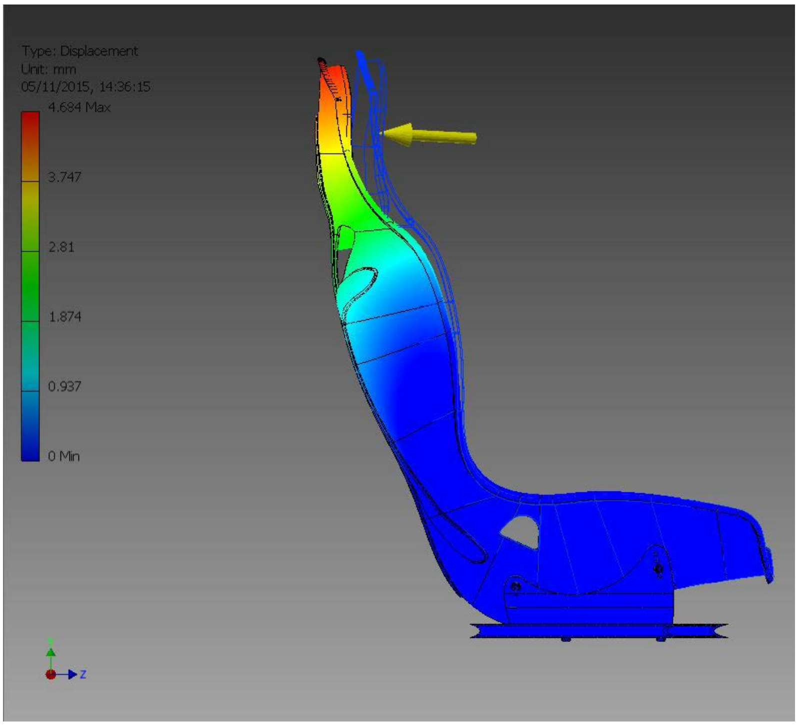
Test type and result is shown in image






Type: Von Mises Stress
Unit: MPa
05/11/2015, 14:32:44
140.4 Max
112.3
84.2
56.2
28.1
0 Min


Type: Safety Factor
Unit: ul
05/11/2015, 14:36:36
15 Max
12
9
6
3
1.51 Min
0


Type: Displacement
Unit: mm
05/11/2015, 14:36:15
4.684 Max
3.747
2.81
1.874
0.937
0 Min