# NTNU

## Norwegian University of Science and Technology

TMR4500 MARINE STRUCTURES, SPECIALIZATION PROJECT
DRIVER INTEGRATION INTO A FORMULA STUDENT RACE-CAR

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# Project Description

## Description

Revolve NTNU is an independent student organization which develops and builds a high-tech Formula Student race car with which the Team competes in worlds largest competition for the student engineers - Formula Student. For pushing the boundaries in Formula Student, a high-tech solutions are as important as the drivers that controls the car. The car is only as good as the driver is. To complement the skill of the driver, the interaction between the race car and the driver is crucial for pushing the limits. That means that the drivers has to feel safe and comfortable in the race car.

Drivers Environment in Formula Student race car consists of Seat, Steering wheel, Pedal box - Acceleration and Brake pedal, Restraint Harness and dashboard layout. Regarding drivers safety there are strict guidelines that has to be followed so the systems are compatible with Formula Student regulations. Main goal of the Project is to design and build a Replica Construction for chassis that can be used to determine the positions for seat, steering wheel and pedals beforehand the production of the chassis it self begins, as well as drivers training for upcoming race season.

## Tasks

Throughout the course of this project the student will

1. Design and Build a replica Construction rig for real life system testing that includes seating position, steering wheel and pedal-box positioning

2. Construction analysis for the Construction rig to ensure it withstands the loads it gets exposed to from the drivers training

3. System design validation for the Drivers Environment training

# Abstract

Drivers Environment design for Revolve NTNU's race-cars haven't had significant changes since 2015, where a thorough work was done designing seat and steering wheel. Seat was molded from one of the drivers from 2015 season, 3D scanned and produced in carbon fiber, as well as steering wheel grips were molded, 3D scanned and 3D printed. But after changing the Monocoque design several times, seating position has also been changed, hence necessity for new seat design to fit the drivers better.

Focus in this report will be on developing a Drivers Rig where an optimal driving position will be determined with driver integration into the new race-car. Benefits of using drivers rig in an early stage of race-car development ensures that no compromises will be required to accommodate the driver when the car is built.

# Preface

With previous experience within motorsports already from young age as a driver as well as being part of the team from 2017 it was a reasonable choice to perform project thesis for Revolve NTNU. Experience gained from 2017 and 2018 seasons have given a valuable insight in what can be improved for Drivers Environment for 2019 season.

Having a privilege of being part of one of the worlds top Formula Student Teams, Revolve NTNU is an incredible experience with a really steep learning curve. Applying knowledge to design, produce and develop a race ready car in under 9 month is a quite unique challenge to tackle. Building a high performance race-car involves advanced problem solving, dedication and willingness to contribute to find creative solutions with good engineering practices as well as master cooperation skills with team members and sponsors.

# Acknowledgements

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# Abbreviations

| | | |
|---|---|---|
| DR | = | Drivers Rig |
| FS | = | Formula Student |
| FSG | = | Formula Student Germany |
| FSS | = | Formula Student Spain |
| FEA | = | Finite Element Analysis |
| BC | = | Boundary Conditions |
| SAE | = | Society of Automotive Engineering |
| CFRP | = | Carbon Fiber Reinforced Polymers |
| CoG | = | Center of Gravity |
| CAD | = | Computer Aided Design |
| HAZ | = | Heat Affected Zone |
| PWHT | = | Post Weld Heat Treatment |
| MIG | = | Metal Inert Gas |
| TIG | = | Tungsten Inert Gas |

# Symbols

| | | |
|---|---|---|
| t | = | Time [s] |
| F | = | Force [N] |
| m | = | Mass [kg] |
| g | = | Acceleration due to gravity at earth surface[$\frac{m}{s^2}$] |
| h | = | Jump height [m] |
| $h_{PO}$ | = | Push Off distance vertically [m] |

# Chapter 1

# Introduction

The main goal of this semester project is to design and build a construction that will help to design race-car around the driver. That will include accommodation of the driver in the given design space, developing new seat, firewall and steering wheel design as well as interfaces with other systems such as pedal-box and dashboard.

Previous years the focus area hasn't been targeted towards drivers environment since design from 2015 has served its purpose satisfactorily until 2018 when a redesigned monocoque was introduced. Monocoque is a structural system that uses external shell to support loads with using external surface for compression and tension distribution. To accommodate taller drivers into the race-car, drivers environment required some modifications to the firewall and adjustments to seat for it to fit drivers better. Later in the season it was also discovered that the steering wheel design could be improved to work better with limited space and for increased steering wheel control.

With experience from 2017 and 2018 seasons, a goal was set to improve Drivers Environment and overall ergonomics for all the drivers. To achieve this a replica construction of the Revolve NTNU's race-car monocoque is designed and produced. This construction will help to accommodate the drivers in the race-car according to given design space and best race-car ergonomic practices. The Construction hereafter will be referred to as DR.

## 1.1 Drivers Environment

Drivers Environment designates space and systems that interfere with the driver. For almost every high performance car, the limiting factor is the driver that operates the car. To ensure the driver operates at its best, the systems that interfere with drivers can not be the limiting factor.

Designing a drivers environment that ensures comfort and safety will help the drivers to perform at their best. Driver who feels confident in the race-car will be able to push its limits and that is the key to maximum performance. To achieve this all of the following

variables for drivers environment has to be evaluated. Overall seating position which includes reclining angle, seat height, arm and leg room for all drivers. Reclining angle and seat height depends on each other. More reclining angle will lower the seat height, which again will affect the field of view for the drivers. With more reclined seating position a lower center of gravity can be achieved, which plays a role for race-car load transfer. Reclining seat too much will limit the leg room for the taller drivers and field of view for shorter drivers. Firewall design will affect arm room for taller drivers and their ability to move freely in the race-car cockpit. Firewall is the only barrier between the driver and the Low Voltage, high Voltage component and any cooling system liquids. Firewall has to seal completely for any fluid passage, and in case of a fire protect the drivers so they can escape safely from the race-car. As shown in figure 1.1 angle $A$ should be as big as possible and angle $B$ after an experimental simulator training and reading research [2], is set close to $10°$ which gives possibility to have a fast glance at important information in dashboard without loosing eye contact with the track for too long. Car illustrated in Figure 1.1 and 1.2 is 2018 race-car ATMOS[1].



**Figure 1.1:** Side view of ATMOS from FSG demonstrating Vertical peripheral field of view

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[1]The name of 2018 Race-car.
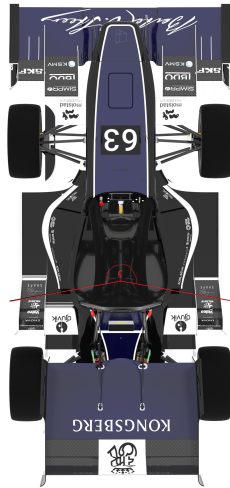
**Figure 1.2:** Field of View to the sides

Angle $C$ from figure 1.2 according to [1] has to be minimum $200°$, $100°$ to each side.

## 1.2    Formula Student

Formula SAE was first held in the United States of America in 1981 and made its first appearance in Europe, United Kingdom in 1998. What started as a small event has grown into Europe's most established engineering competitions for students. Formula student competitions has a close cooperation with one of the largest automotive brands in the industry as well as motor-sport society world wide. Students from all over the globe design and build single seater race-cars to compete in static and dynamic disciplines. Static disciplines include Business Plan Presentation, Cost and Manufacturing and Engineering Design events. Dynamic events include skid-pad where the cars steady state



**Figure 1.3:** Team Picture From FSG 2018

ability is tested, Acceleration on $75m$ long straight, Autocross and Endurance where overall speed, reliability and efficiency is tested. [1][3] [4]

## 1.3 Revolve NTNU

Revolve NTNU was establish in 2010 by four student with common interest in motorsports who sought after a new challenge besides theoretical engineering studies. After a little research, Formula Student seemed like the perfect opportunity to put their engineering knowledge to practice and build a race-car. In 2012 Revolve NTNU's first car $KA\ Borealis\ R$ was introduced and awarded $Best\ Newcomer\ Award$ at Formula Student UK. $KA\ Borealis\ R$ featured tubular space frame and Suzuki GSXR 600 engine.



**Figure 1.4:** 2012 Revovle NTNU race-car KA Borealis R

2014 was the year Norway's first electric race-car $KOG\ Arctos\ R$ made it's debut. CFRP Monocoque chassis with real wheel drive and impressive aerodynamic package which generated astonishing 1373 $Nm$ of downforce at 80 $km/h$.



**Figure 1.5:** 2014 Revovle NTNU race-car KOG Arctos R

Only two years later Scandinavia's first four-wheel drive electric race-car $Gnist$ was designed and manufactured, featuring electric motors in each wheel and Torque Vectoring system.
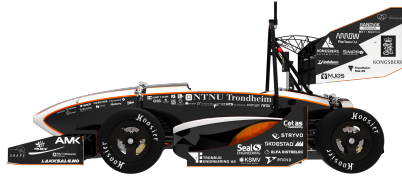
**Figure 1.6:** 2016 Revovle NTNU race-car Gnist

Most recent car $ATMOS$ which made its debut early 2018 is the third generation four-wheel drive electric race-car, and has been the most successful race-car yet Revolve NTNU has built. Featuring CFRP Monocoque, four-wheel drive with electric motors in each wheel, two piece CFRP and aluminum rims, advanced torque vectoring and extensive aerodynamic package producing 813 $Nm$ of downforce at $60km/h$. $ATMOS$ is multiple award winning race-car with Top 2 finish in FSG.[5]



**Figure 1.7:** 2018 Revovle NTNU race-car ATMOS

# Chapter 2

# Design Approach

## 2.1 Design Criteria

Main principles of DR has to include possibility of Driver Environment system testing and designing, validation and driver training. Very often the engineering decisions are made based on the simulated data from previous years along with newly developed designs. Being able to validate the decisions made will give a great advantage in an Engineering Design Event that counts 150 points from total of 1000 point. Engineering Design event evaluates the design decisions made, process and effort that went into the race-car production. Drivers Environment itself counts 15 points out of Total 150 points for Engineering Design. [1]

Another importance aspect of DR regarding system testing and designing is the ability of adjustment. DR has to be adjustable in such a way so different driving positions can be tested when seating position is changed, interference between driver and the rest of the systems such as pedal-box, steering wheel and dashboard, as well as available room for movement. Benefits of this is to detect eventual conflict between drivers environment and other systems on the car in early designing stage and address the problem.

One of the challenges for driver environment design, is to work around different drivers that are going to operate the vehicle. Short, tall, wider hips, longer arms and legs, all of this has to be taken into design consideration.

## 2.2 Rules and Limitations

### 2.2.1 Cockpit

Regulations set by FS has to be followed in order to have rules compliant race-car that will pass scrutineering. Designated templates as shown in 2.1 to check if cockpit opening is sufficient enough. Seat support for upper back and shoulders has to be designed in such way that the template can pass down to $320\ mm$ from the lowest point of the monocoque, in this case monocoque floor where the seat is placed. Complications regarding this was

experienced at one of the competitions in 2018 season and post modifications had to be done to the firewall in order to pass technical inspection, often referred to as scrutineering. The template illustrated in figure 2.1 on the right, ensures that the cockpit internal cross section opening is sufficient enough for drivers to escape the vehicle in under 5 seconds. 2.2.2
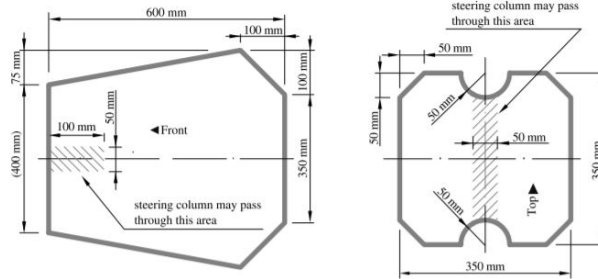


**Figure 2.1:** Left Figure demonstrates Cockpit opening template, figure to the right demonstrates cockpit internal cross-section template.(Figures taken from [1])

Seat design has to fit $95^{th}$ percentile male as illustrated in figure 2.2 [1]. The idea behind $95^{th}$ male and $5^{th}$ percentile female is to design and manufacture drivers environment as if the race-car will be sold to the market outside formula student. Designing drivers environment that would only fit the team drivers that will drive the car, therefore will not meet the Percy requirements.
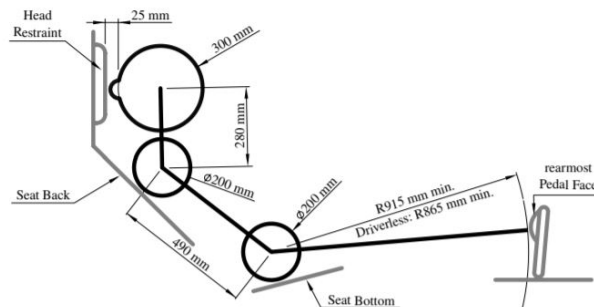


**Figure 2.2:** 2D figure representing $95^{th}$ percentile male.(Figure taken from [1])

Another important element for drivers environment to consider is harness and mounting point placement. New for 2019 race-car, lap-belt and anti-submarine belts will share

the same attachment point. Concerning the attachment of the drivers restraint system, following angles has to be achieved for restraint system to comply with the regulation as illustrated in figure 2.3.
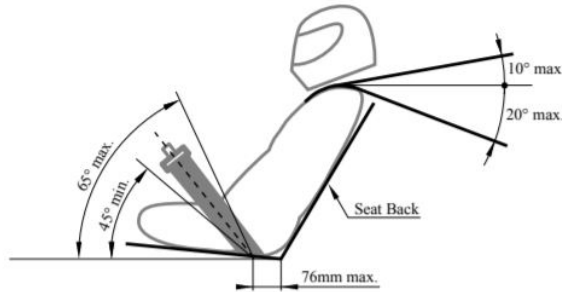


**Figure 2.3:** Figure represents Shoulder harness, lap and anti-submarine belt attachment angles for upwards sitting position.(Figure taken from [1])

Correcting the figure 2.3, 2019 race-car will feature reclined driving position, which means that maximum and minimum angles 65°- 45°will be 80°- 60°respectively.

### 2.2.2 Drivers Egress

A driver has to exit the vehicle in less than 5 seconds in case of an emergency. If the race-car is built without consideration of this, it may be really challenging to exit in time. Not only it would mean that the driver can not compete, but also it can be dangerous if a life threatening situation occurred.



**Figure 2.4:** Egress training from 2017 season with race-car **ELD**

## 2.3 Design Space

Very limited space is available for driver accommodation. Taller drivers have a limited arm space thus firewall has to be designed accordingly, as well as steering wheel position to fit shortest and the tallest driver.

Seat positioning has a big impact on CoG and weight distribution, so it has to be placed as low as possible without affecting field of view for the shortest driver, and as close to the car center as possible without compromising pedal-box position for the tallest drivers.

## 2.4 Production and Material choice

For DR production 3 different alternatives is considered. Thin walled steel tubing, aluminum tubing and profiles.

Aluminum profiles are easy to handle, assemble with endless adjustment possibilities, but are quite expensive. With little or no response from distributing companies regarding sponsorship for DR, this alternative was no longer looked into. But to mention, it could have been a very good alternative.

Aluminum tubing construction will give the same result as steel tubing and would be considerably lighter alternative, but that is not the main objective for DR.

Chosen material for DR is square steel tubing in dimensions $30 \times 30 \times 3mm$. Regarding the material dimensions for this construction, it was compromised due to the pricing and delivery time. Regarding construction strength, tubing dimensions could be reduced. Analysis with different tubing dimensions are presented in 3.3.2. Tubing is show in figure 2.5.
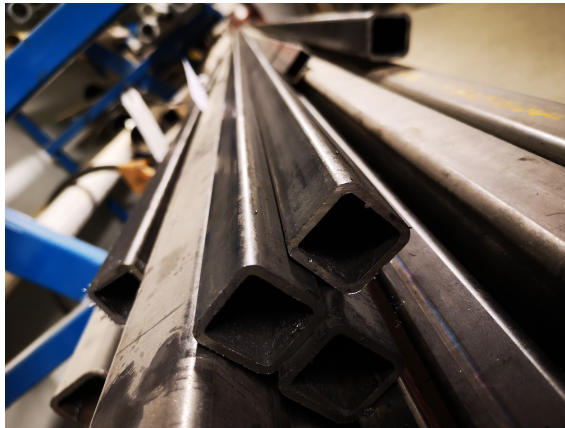


**Figure 2.5:** Steel tubing with $30 \times 30 \times 3mm$ and $40 \times 40 \times 3mm$ dimensions.

Main reasons for this decision, "Smith Stål" had short delivery time and nonetheless feasible price.

# Drivers Environment Rig

## 3.1 CAD Design

To replicate monocoque as accurately as possible, DR CAD model was modelled closely with the actual Monocoque CAD file. Internal sections of the DR construction are based on measurements from **ATMOS** and cockpit templates as presented in 2.2.1. Building an construction assembly in Solidworks, a wire frame constructions was modelled. Using in-built Solidworks feature called "Weldment". Using this feature it allows to assign standard construction profiles to sketches, and makes ready CAD model using profiles. Benefits of this feature is that it produces a ready cut-list which can be used for production, including necessary lengths and angles regarding the model. Figure 6.1 illustrates all profiles cut and made ready for welding. DR model with assigned steel profiles is illustrated in figure 3.1.



**Figure 3.1:** Bare DR construction without mounted Drivers Environment systems, seat & harness plates.

## 3.2   Load Case

Load case for drivers Environment arises from dynamic loading on the systems the Driver interact with. To determine the loads acting on these systems, information is found and studied using Revolve NTNU's own developed software "Revolve Ana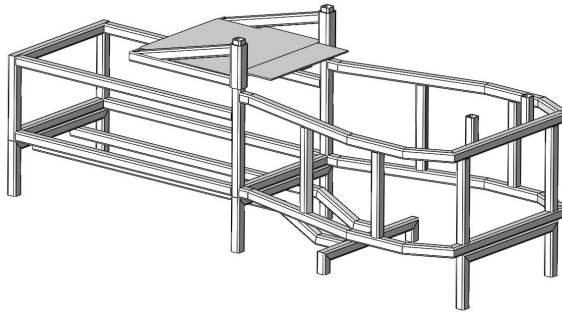lyze". As illustrated in Figures 3.2 and 3.3 Gravitational Force in Acceleration is determined from 2018 FSG competition. Weather conditions that day were optimal and total tire capacity was used, that way generating more G-Force in lateral direction. Ideally a gravitational force plot 3.2 should look similar to a circle. That would mean that a maximum tire capacity is utilized, therefore more gravitational force in acceleration is generated, and car is driven faster. From 3.2 is can be discovered that a lack of trail braking is present. Trail braking means a deceleration not only in straight line, but also into a corner. Lack of trail braking can be prone to the drivers insufficient confidence in the car under braking. To improve this, different solution for Regenerative braking implementation can be looked into. For Drivers Environment a gravitational force in acceleration plot 3.2 can be used to designate loads for seat dimensioning. A seat that is firm and supports the driver will give more confidence in vehicle control.

Concerning DR, static and cyclic loading is estimated to be relevant. Dynamic loading and impact loading can also be an interesting subject to look into, but will not be covered in this semester project report. Regarding cyclic loading, operating conditions and the fact that the current steel tubing 2.5 is used for production of DR, construction is over dimensioned. Loads that the DR will be exposed to under DR training will not exceed the any limits for the construction. Loads that the DR will be exposed to under DR training will not exceed any limits for the construction. Highest estimated load application will be under egress 2.4 training, with estimated person weighing 100 $kg$ with factor of safety 1,3.
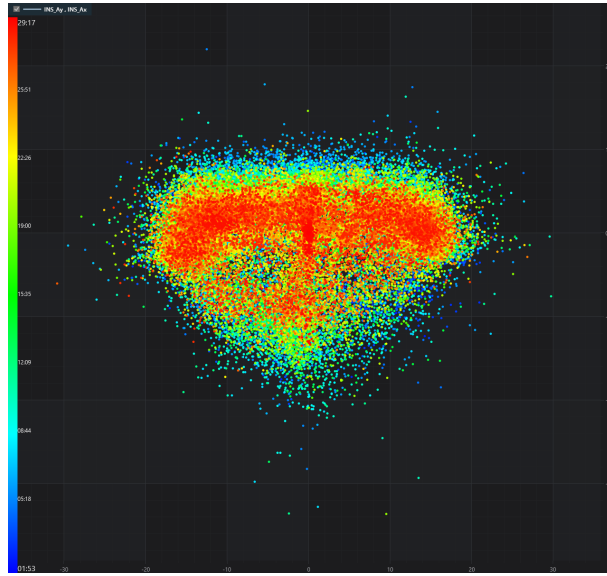
**Figure 3.2:** Graph of G-Forces generated with ATMOS from 2018 FSG Endurance. On X-axis & Y-axis units are $\left[\frac{m}{s^2}\right]$



**Figure 3.3:** Graph of acceleration of ATMOS from 2018 FSG Endurance. On X-axis unit is $\left[\frac{m}{s^2}\right]$ and Y-axis unit is [t]

## 3.3 Structural Analysis

### 3.3.1 Hand Calculations

Calculating force applied in area where the seat is placed, the force required to jump out of the race-car or DR in this case is calculated with equation 3.1. Tallest driver with full race gear is weighed to approximately 80kg. DR is design to be used as driving simulator as well, in that case a maximum persons weigh of 100kg with addition factor of safety as mentioned in 3.2 will be used. Mass for calculations is set to 130kg. Formula used in calculations are take from Journal of Biomechanics [6].

$$F = m \cdot g \cdot \left(1 + \frac{h}{h_{PO}}\right) = 130kg \cdot 9.81\frac{m}{s^2} \cdot \left(1 + \frac{0.65m}{0.45m}\right) = 3117.4N \quad (3.1)$$

$h$ is the height person has to jump to clear the side of the DR measured from top of the side to DR floor, $h_{PO}$ designated the distance person has to launch from the DR. This distance will vary from person to person and their ability to jump.

Deflections in DR is calculated with beam deflection formulas [7], and the largest deflection found is calculated in equation 3.3. Second moment of inertia for steel tubing is calculated in equation 3.2.

$$I = \frac{x^4}{12}_{Outer} - \frac{x^4}{12}_{Inner} = \frac{30mm^4}{12}_{Outer} - \frac{24mm^4}{12}_{Inner} = 39852mm^4 \quad (3.2)$$

Tubing has equal length sides and instead of $b \times h^3$ a variable $x^4$ is used to represent side length for the tubing.

$$
\begin{aligned}
\Delta_{Max} &= \frac{2 \cdot P \cdot a^3 \cdot b^2}{3 \cdot E \cdot I \cdot (3 \cdot a + b)^2} \\
&= \frac{2 \cdot 1275N \cdot (205.3mm^3 \cdot 98.7mm^2)}{3 \cdot 210GPa \cdot 39852mm^4 \cdot (3 \cdot 205.3mm + 98.7mm)^2} = 0.0167mm
\end{aligned}
\quad (3.3)
$$

Some simplifications were made for deflection calculation. Since the actual area where the load will be applied is welded and have a bend, it is more complicated problem than a simple cantilever beam problem. Drawing a straight line between fixation points for the structure calculated, $a$ and $b$ represent the distance from fixation points where the point load is applied. Possible Errors that will give deviation in hand calculations from simulated values is the assumed straight beam instead of including the bend. Another thing is the boundary conditions. Frame structure in simulation might flex and distribute with some bending moment, that way the deflection is found to be larger in simulation illustrated in figure 3.4 compared to calculated value in 3.3. Considering this another simulations was run with similar Boundary Conditions as assumed when conducting hand calculations, as shown in figure 3.6. Simulation Results shows closer value to the hand calculation and with that it can be assumed that simulated results are reasonable.

### 3.3.2 Solidworks FEA

Given that the construction is fairly simple, without complex geometries and expected loads that might lead to construction failure or deformation, a static analysis is conducted. Boundary conditions for the DR is fixed for the nodes that are placed on the floor, as well as the nodes where the construction is welded. Reason for that is the way how Solidworks treats the weldment model which is based on 3D sketches. Some of the sketches are not interfering, making the model as separate parts, when realistically the two parts will be welded together. Meshing the DR in SolidWorks are not as advanced as for other FEA Softwares. A specific element type can not be chosen. Beam Mesh type is selected for DR. Meshing for the part is based on either Number of elements or element size. For the following analyses meshing was done with element size rather than element number, and size for the element was set to $5mm$. That produced in total 2268 elements for the DR. Simulation results are illustrated in figures 3.4, 3.5 and 3.6.
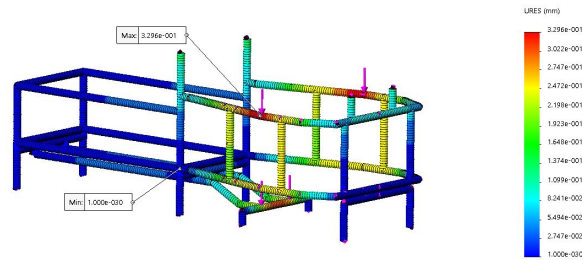


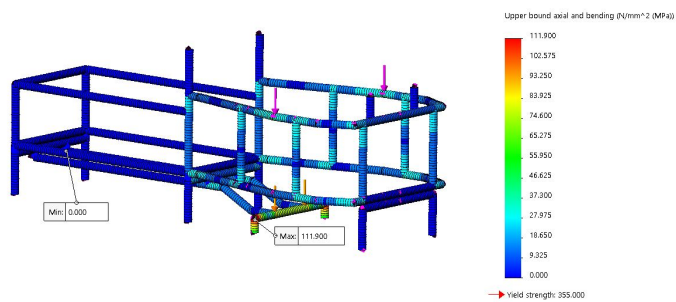**Figure 3.4:** Resultant Deflection [mm]
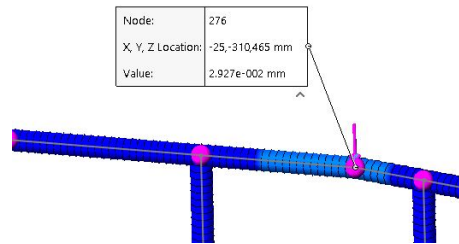


**Figure 3.5:** Stress [MPa]

**Figure 3.6:** Resultant Deflection with custom BC for hand calculation comparison [mm]

One of the possible errors that might give deviation in simulated values could be located close to the welded area. Area will classify as HAZ, and with that the strength might be weakened giving different response for deformation and stresses compared to the simulated values.

## 3.4 Production

Steel tubing was picked up from "Smith Stål" October 19, and production planning is started. Due to limited access to the workshop, the only work with DR could be performed during workdays between 07:30 to 15:30.

Production started with cutting the steel tubing in required dimensions, sorting and labeling for easier recognition. That made fabrication process faster and ensured that correct parts was used for each sub-assembly. All parts made ready for production and layout out for DR are illustrated in figure 6.1.

Another important aspect when building DR, is to maintain accuracy throughout the welding process. In this case warping can become an issue. To reduce the chance of warping several precautions can be made. When assembling the whole DR, only point-welds are used instead of over-welding. Over-welding most likely will result in warping due to residual stresses. One of the alternatives is to mount the DR to the welding table, weld all joints and then perform Post Weld Heat Treatment. Benefits of performing PWHT is the reduction of residual stresses, possibility of enhanced material strength and sort of hardness control for DR. [8] Due to the limited time frame to complete this project and do all necessary measurement for the Drivers environment, spot-welding was used to assemble the DR and then gradually welding all of the joints. Welding process took considerably longer due to considerations of warping, instead of welding everything at once and then performing PWHT.

For welding it was possible to choose between MIG and TIG welding machines. For faster production and lower tolerances require for welds, MIG welding machine was the best solution in this case. But to mention, as shown in figure 6.2, some of the parts were welded with TIG welding machine for the DR.

With DR welded, pedal-box, steering wheel assemblies can now be mounted onto the DR

as well as drivers harness. Seat is going to be molded in the drivers rig.
Finished DR with attached drivers environment system from 2018 race-car **ATMOS** for measurement purposes, is illustrated in figure 3.7.
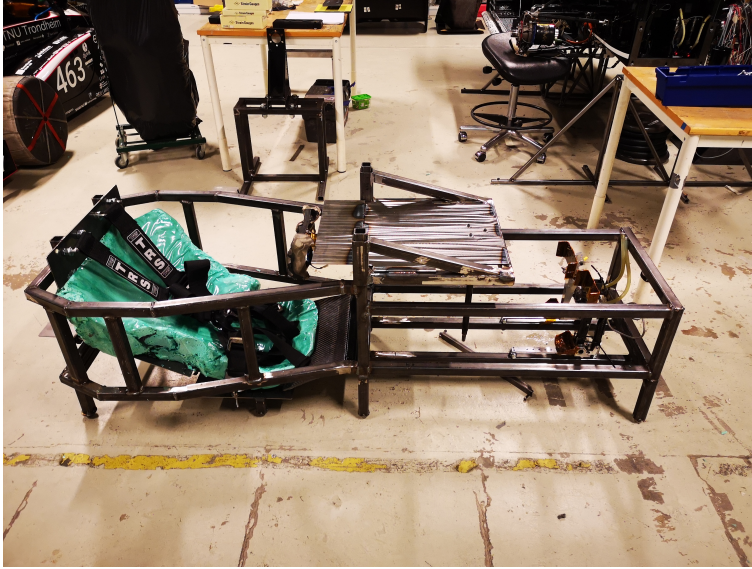


**Figure 3.7:** DR with attached Drivers Environment systems from 2018 race-car **ATMOS**.

### 3.4.1   Adjustability

An important aspect of the DR as already mentioned, is the possibility of adjustments in the future. Pedal-box should have possibility of adjustment in X and Z direction as illustrated in figure 3.8.
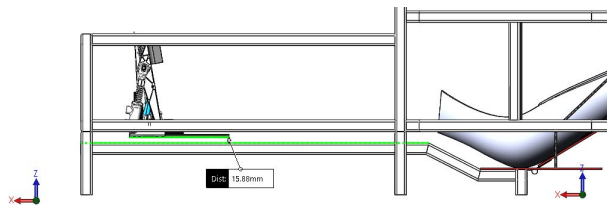


**Figure 3.8:** Illustrates the height of the pedal box in the DR.

Pedal box is attached to the monocoque, 80 $mm$ higher i Z-axis direction from the lowest point of the chassis floor. Empty space between pedal-box assembly and the DR represents the adjustability area. For future changes in monocoque pedal-box assembly can be lowered almost 16 $mm$ or raised.

Steering Wheel will be mounted in the same place as before with no possible adjustments for the steering wheel column, but minor design changes will be made for steering wheel itself to increase the comfort, resting arm angle and grip for improved full-lock control.

For seat molding, a two component foam was used. Data sheet in Norwegian is shown in Appendix, figure 6.3. Foam was sprayed in the plastic bag, placed in the DR, position to cover all parts of the body for maximum support with the driver in the DR and cured. As shown in the data sheet, curing took approximately 30 $min$. This process was repeated 3 times to achieve solid, good fitting seat form that fits all drivers and are rules compliant regarding the Percy 2.2.

Additional fabrication is done to manufacture extra supports for simulator wheel and pedals for drivers simulator training.

## 3.5 Testing

### 3.5.1 Drivers Feedback

Test plan and overall drivers environment system improvements are based from the previous drivers feedback and experiences during 2018 season. Main feedback received was regarding seat and the firewall. Seat was too narrow near the waist and was quite uncomfortable for taller drivers and during extensive testing even painful. Problematic area are illustrated in figure 3.9 and marked with pink sketches.
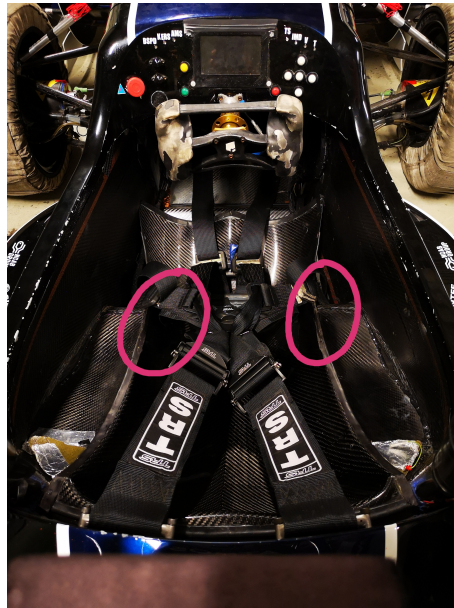
**Figure 3.9:** Cockpit from 2018 race-car **ATMOS** illustrating seat and the part that extensively presses on hips.

Another important thing that has to be improved is the steering wheel grips. During full lock turns, thumb has to be released in order to turn it to full angle. As shown in figure 3.10, this is a situation with full lock turn during endurance in Spain.



**Figure 3.10:** Full Lock Turn from FSS demonstrating steering wheel grip.

As shown in figure above, right hand is gripping steering wheel fully, while left hand has to let go of the steering wheel in order to achieve full lock. That is not ideal in racing situation. Loosing contact with steering wheel results in loss of feedback from the front wheels the driver receives.

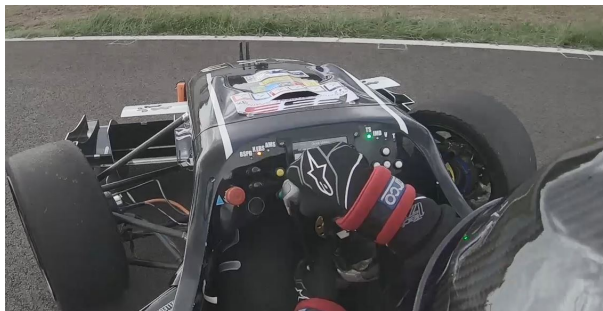Last two things to address from drivers feedback is regarding elbow room and pedal-box placement. Firewall should be measured and design to give enough space for taller drivers as well as further pedal-box placement for more leg room.

### 3.5.2   Test plan

With all systems attached to the DR and seat molded, testing can begin. Test plan is as described in table 3.1. Tolerances for DR is within $1mm$ or less after the production is finished, and with that accurate measurements for the drivers environment systems can be done.

**Table 3.1:** Test Plan for DR

| Test Name | How to Do it? | Persons Involved | Which Measurements are needed? | Priority |
|---|---|---|---|---|
| Seat position & Angle | Adjust reclining angle | All Drivers | Seat angle and knee placement for Drivers | 1 & 2 |
| Elbow room & Firewall | Measure Elbow placement, X & Z axis. | Tallest Driver | Lowest point of elbow + movement | 1& 2 |
| Harness attachment points | Angle between horizontal plane and Harness. | All Drivers | Side view angle 2.3 | 3 |
| Pedal Position | X-axis distance | All Drivers | X, Y and Z- axis measurements and pedal angle from Z-axis | 4 |
| Knuckle & Arm space | Measure knuckle distance from dashboard | All drivers | X-axis distance from dashboard | 5 |
| Steering Torque | Attach weight | All drivers | Max steering Torque acceptable | 6 |
| Dashboard layout | Mock-up of dashboard design, Shutdown placement | All Drivers | | 7 |
| Egress 2.2.2 | Full race-gear, Jump out of the car | All Drivers | Time has to be under 5 $s$ | 8 |

### 3.5.3 Post Season Testing

Regarding steering wheel testing, a different style steering wheel was tested during post season testing. Steering wheel which was tested is illustrated in figure 3.11. This steering wheel had better thumb grip during full-lock corners, but due to its heavy weight a custom steering wheel will be designed.



**Figure 3.11:** Post season testing with OMP racing wheel.

In addition a further pedal position was also tested, which with current setup was not rules compliant. After several test days, the overall comfort was increased for tallest driver, and pedal-box assembly will be slightly redesigned to achieve desired pedal-box position.

# Chapter 4

# Results

## 4.1 Seat and firewall

With seat molding and elbow measurements done as shown in Appendix 6, firewall CAD model is made. Seat mold is modified for harness placement and will be 3D-scanned to built CAD model of the seat as well. Figure 4.1 illustrates potential seat design for 2018 race-car. Main visual changes to the seat are the holes for harness. Instead of having anti-submarine belts between legs, they are now attached to the same mounting point as lap-belts which are behind the seat i X-axis direction. That means that drivers are now going to sit onto anti-submarine belts, which will give comfortable and more secure fit.

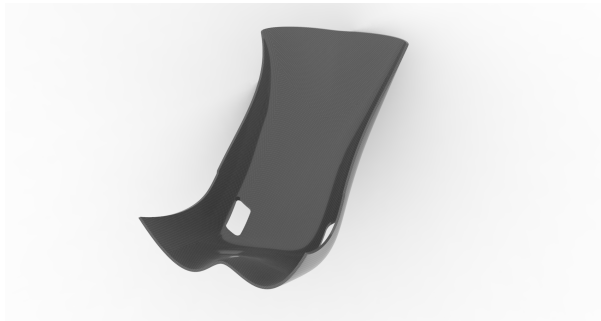

**Figure 4.1:** Possible design of the 2019 race-car seat.

The rendered picture of seat in figure 4.1, is the first draft of the seat. A new and final seat design will be made after 3D-Scanning of the molded seat form illustrated in figure 4.2.

**Figure 4.2:** Molded seat form for 2019 race-car

On Friday 7. December 2018. with help from Christian Frugone, a 3D-Scanning of the seat mold was performed. Scanned seat mold file is illustrated in figure 4.3 when opened in SolidWorks.
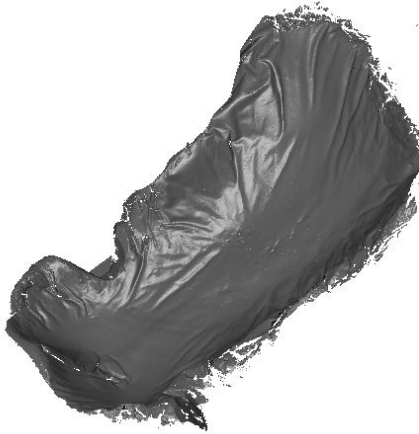


**Figure 4.3:** 3D-scan file of the Seat Mold.

Firewall CAD model is illustrated in figure 4.4 placed in DR. Cutout for the seat in the Firewall will be made when the final seat CAD model is finished. Measurements made for Firewall design are also illustrated in appendix 6.
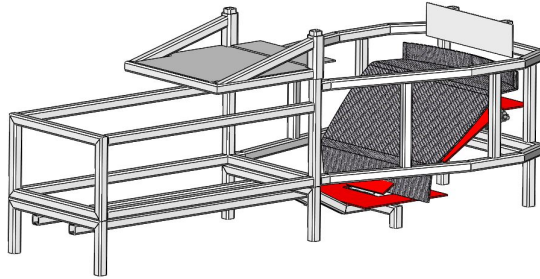


**Figure 4.4:** Carbon Fiber CAD model of Fire Wall design

## 4.2   Steering Wheel

After completed testing in search of steering wheel design that works well in all driving situations, a design concept shown in figure 4.5 is one of the possible designs for 2019 race-car.



**Figure 4.5:** Rendering for one of the Steering wheel concepts.

With this concept a light weight construction is maintained with increased thumb grip for full-lock turns as well as aesthetic look. Production vise this design is also more favorable

compared to the design used in 2015-2018 race-cars.

In order to achieve desired thumb grip for the steering wheel, custom steering wheel grips are made. With satisfying design and feel of the grips, they were also 3D-Scanned. Since the form is quite small, it was challenging to make a good 3D-scan of the handles, with some parts of the handle surface missing. A new CAD model will be based on the 3D-scanned part. 3D-Scanned handle part in SolidWorks is illustrated in figure 4.6.



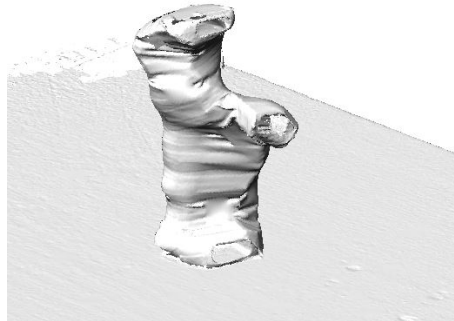**Figure 4.6:** 3D-scan file of the steering wheel handle design concept

## 4.3   Other Systems that interfere with Driver

Just to mention, rest of the systems are still fully in development. Pedal-box placement is set, but pedal design still are not finished. Heel Caps will be raised to secure both feet from lateral movement when driving, and Toe Caps will be removed to save weight. Pedal- Box illustrated in figure 4.7.
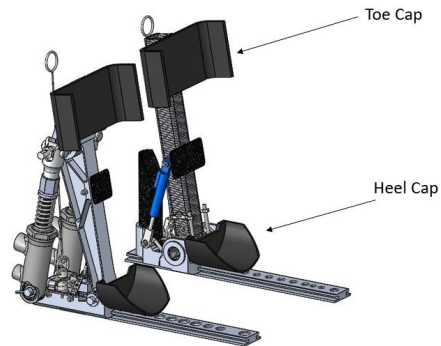
Toe Cap

Heel Cap

**Figure 4.7:** Pedal-Box from 2018 race-car **ATMOS**

Dashboard layout also will be tweaked, but more or less will have similar layout as illustrated in figure 3.10 & 3.11.

Drivers restraint harness is ordered after all required measurements was done. Harness measurement sheet illustrated in Appendix, figure 6.4.

Chapter 5

# Discussion

## 5.1 Production

### 5.1.1 Alternative Materials for Drivers Rig

As mentioned in section 2.4, a several production material options was considered for DR. First alternative which would have been a really good choice, as shown in figure 5.1, a steel tubing with dimension $20 \times 20 \times 2mm$ could have been used for DR production. It would withstand loads with a good margin to yielding, as well as construction would have been lighter, but since the delivery time was longer than for $30 \times 30 \times 3mm$ tubing, it was an easy decision.
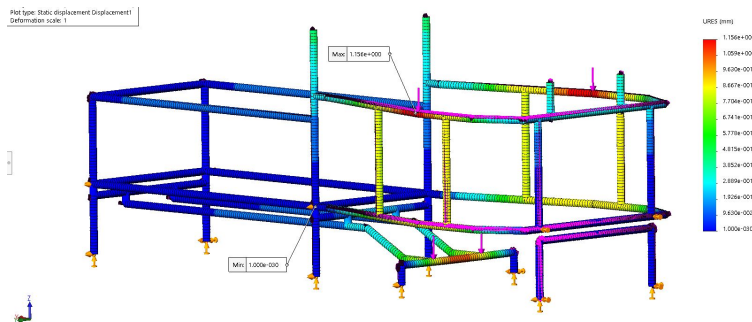


**Figure 5.1:** Displacement of $1.15mm$ for an Steel tubing with $20 \times 20 \times 2mm$ dimensions.

Experimental analysis including aluminum tubing was also conducted. As shown in Figures 5.2, Tubing with $20 \times 20 \times 2mm$ dimensions did exceed Yield value in the bottom tubing on the corners, due to the force generated from jumping out of the DR.

Analysis for the $30 \times 30 \times 3mm$ Aluminum tubing is shown in figures 5.2c and 5.2d. This could have been a potential substitution for the chosen steel tubing, but again due to the pricing and delivery time, it was looked away from this material choice.
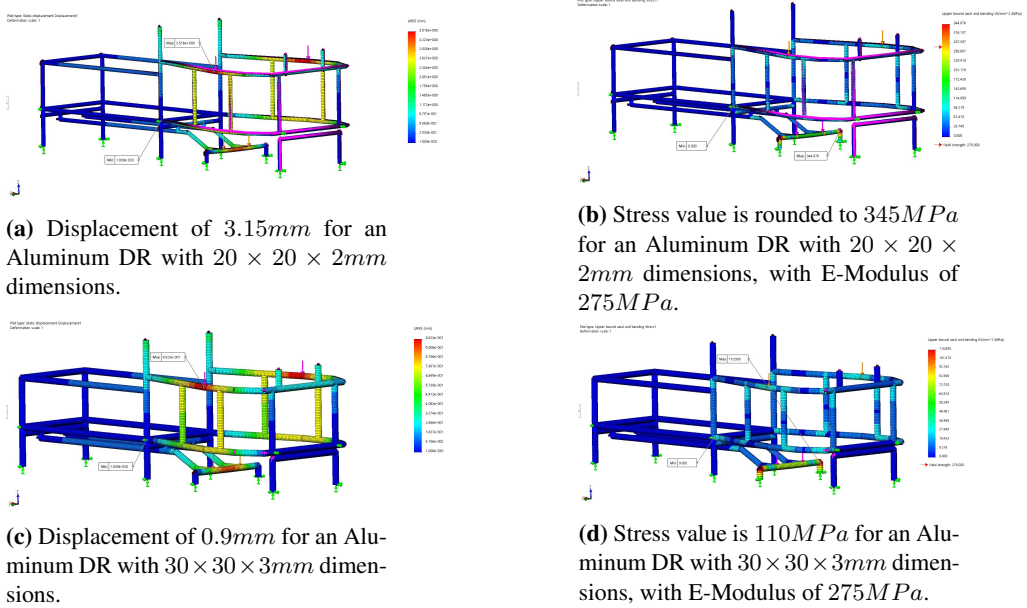


**(a)** Displacement of $3.15mm$ for an Aluminum DR with $20 \times 20 \times 2mm$ dimensions.



**(b)** Stress value is rounded to $345MPa$ for an Aluminum DR with $20 \times 20 \times 2mm$ dimensions, with E-Modulus of $275MPa$.



**(c)** Displacement of $0.9mm$ for an Aluminum DR with $30 \times 30 \times 3mm$ dimensions.



**(d)** Stress value is $110MPa$ for an Aluminum DR with $30 \times 30 \times 3mm$ dimensions, with E-Modulus of $275MPa$.

**Figure 5.2:** Aluminum DR analysis with different tubing dimensions

Another alternative for building the DR could have been to go with Aluminum Profiles which can be ordered in desired length and with different connections possibilities. Drawback with this solutions was the price, as they are quite expensive. Without any success for sponsorship from any of the contacted distributors, it was too expensive to use for DR. Other than that, it would have taken less time to assemble and have more adjustment possibilities, since it would not be welded together.

### 5.1.2 Drivers Environment

Production of the Drivers Environment systems will start in the middle of January. First the Seat form will be sent for milling to one of our Sponsors **Molstad modell & form**. The Carbon fiber for seat is not chosen yet, but the decision will be made latest in January. The same applies for the steering wheel production. Changing the design of the steering wheel, will make production easier and less time consuming. To set production time for previous steering wheel design in perspective, it took 3 days to produce.

## 5.2   Further Work

Rest of the December and early January will be spent for the Seat and Steering Wheel CAD modelling and FEA running. In February most of the Carbon Fiber part production will take place, which includes Monocoque, Rims, Seat, Firewall and Steering wheel.

Desired experiment for future seat designing, is to conduct testing with pressure mats in seat for load measurement in racing situation and compare those to assumed loads used in FEA models. Such experiment would help to improve FEA models used in early design stage. Another thing to look into is the rigidity of the seat, and how it affects the feedback received from the car and find the stiffness to weight ratio to what will be acceptable from the drivers perspective as well as weight saving perspective.

# Chapter 6

# Conclusion

The main goal for this project was to design and build a construction, that could be used for driver integration into a formula student race-car in an early design stage. Building an replica DR from formula student race-car chassis will help to determine actual space required for each driver. After DR completion a seat mold was made to fit all drivers and 3D-scanned for further design development. A first draft of a steering wheel is made that will fit taller drivers better, have increased ergonomic feel and will help to perform in all racing situations as well as easier to manufacture. Mounting points for the drivers harness is also made possible to place with extensive testing and measuring for each driver to cut unnecessary harness length meant for adjustment that previously has not been used for maximize weight saving. With all systems tested and now finalized before the production start, DR can now be used as a drivers training platform with the actual seat mold for the 2019 race-car, pedal position as well as steering wheel position. This will help the drivers to get familiar with 2019 race-car ergonomics and hopefully reveal any design flaws before the production starts. DR is an unique tool that can be used in designing period, trying out different position while getting feedback from the drivers and used all year around for drivers training.

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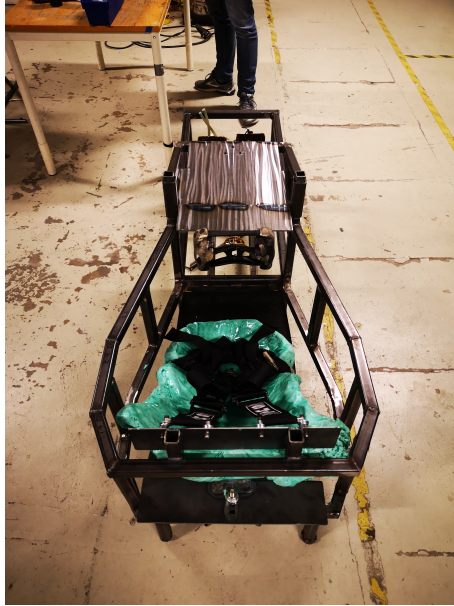
# Appendix

# Production



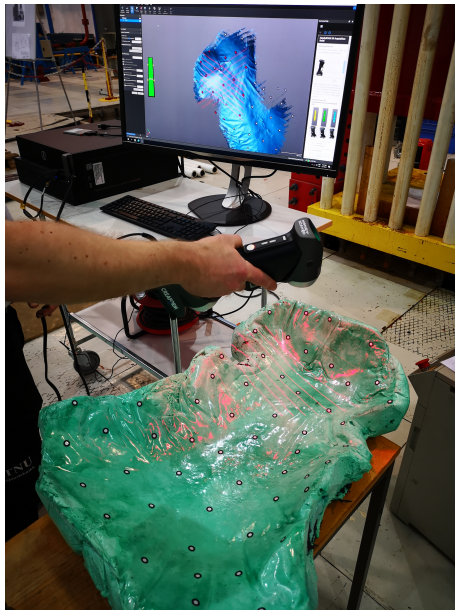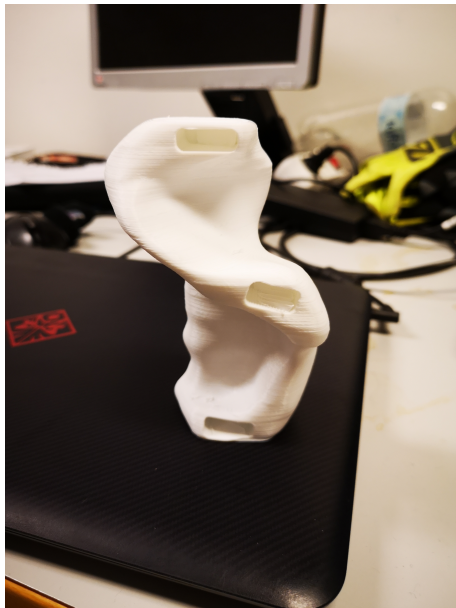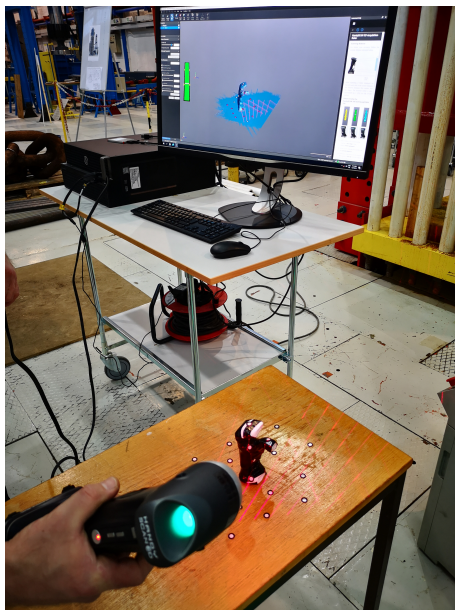**Figure 6.1:** All parts cut, sorted and made ready for production.
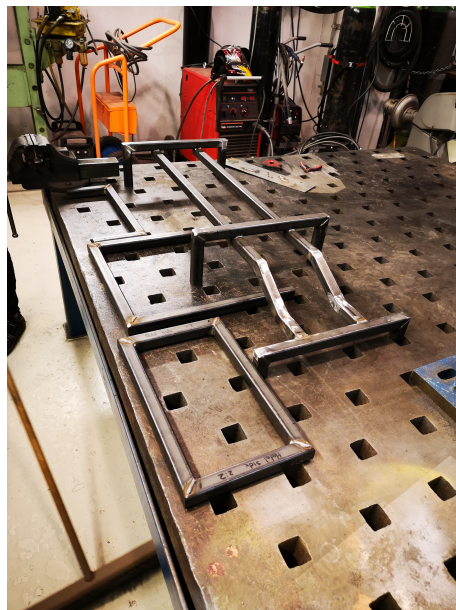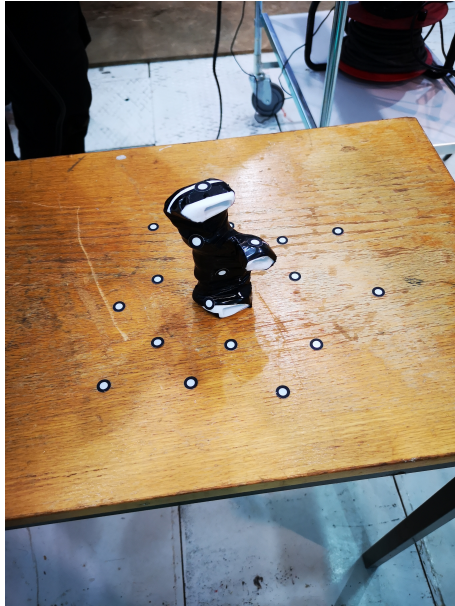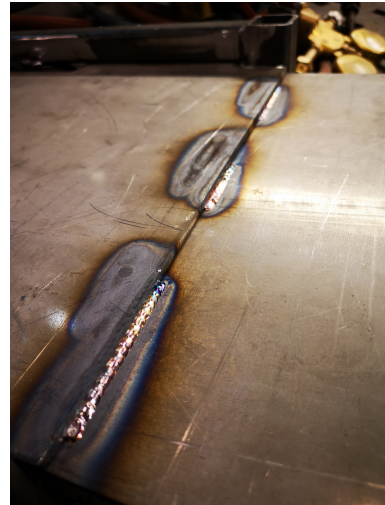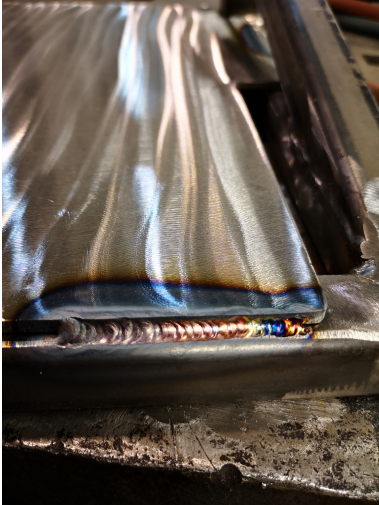
**Figure 6.2:** TIG Welds for DR steering support.

**WÜRTH**

## BYGGSKUM PURLOGIC FAST

### 2 komponent hurtigherdende monteringsskum

- Til tetting og liming av vinduer, dører og mindre hullrom
- 2 komponent, alt i en boks, trenger ikke å tilføres fukt
- Tidsbesparende - skjærbar etter 15 min, belastbar etter 1 time
- Lyddemping 61db DIN 52210
- Inneholder ikke stoffer som skal unngås i henhold til sjekkliste A20
- Obs! Inneholder Isocyanater

### Teknisk info

- Manuell montasje og fyllskum
- Brukes med medbrakt dyse
- Silikon- og løsmiddelfri
- Lyddemping 61db DIN 52210
- Energibesparende 9% DIN 18055/EN 42
- Varemreduserende 0,0035W/mK DIN 52612
- Hefter ikke på PE, PP, silikon, olje og fett
- Inneholder ikke stoffer som skal unngås i henhold til sjekkliste A20
- Inneholder ikke ammoniakk
- Lagring: +10°C til +20°C
- Lagring ved høyere temperaturer forkorter lagringstiden

| Varetekst | Art. nr. | Pk/stk | Pall/stk |
|---|---|---|---|
| Purlogic Fast 400 ml | **0892 144** | 12/1 | 825 |

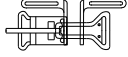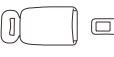| | |
|---|---|
| Lagringstid | 12 mnd. mellom 10 °C og 20 °C |
| Innhold | 400 ml |
| Pistol/manuell | Manuell |
| Bearbeiding temp. | +10 til +25 °C |
| Temp e. utherding | -40 til +80°C |
| Farge | Lindgrønn |
| Skumutbytte ca. | 10 L |
| Miljøgodkjenning | EC1+ |
| Klebefri | 4-6 min. |
| Skjærfast | 15 min. |
| Belastbar (Ø 20 mm) | 1 timer |
| Komponenter | 2 |
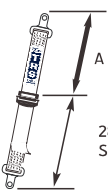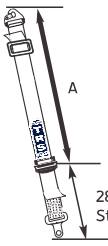
**Figure 6.3:** Datasheet of Würth 2K Purelogic Fast foam

# TRS Harness Specification Sheet

**£20** charge applies for all bespoke harnesses

| Date: 30.11.2018 | | **Internal use** | |
|---|---|---|---|
| Dealer Name: **Kollevold** | | Code: | |
| Customer Name: **Roberts Racko** | | Description: | |
| Contact No. in case of query (Daytime): **+4797185887** | | | |
| Email address: **Roberts.Racko@revolve.no** | | | |

F.I.A Approved ☑    SFI Approved ☑    E Approved ☐

Number of Harnesses Required: | Measurements in: ☑ mm

Colour: ☐ Red ☐ Blue ☑ Black ☐ Yellow ☐ Green ☐ Orange ☐ Silver

Make of Vehicle: | Type: | Year:



A
28cm Standard
Single Seater Type ☑
Two Seat kit Car ☐

A
28cm Standard
Saloon Type ☐

HANS Specific **50mm Shoulder** ☐

Rotary (Aircraft) Buckle ☑
Lever Latch & Link ☐
Push Button ☐

## Shoulder Straps - measurements should be taken with driver seated in vehicle **with harness fastened tight**

Webbing Width: 75mm ☑  50mm ☐

Length: **280mm**  (Measure distance "A" from centre of anchor mounting **point** to centre of adjuster)

## Lap Straps - measurements should be taken **with harness fastened tight and adjustment in midway position**
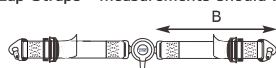
B
Webbing Width: 75mm ☐  50mm ☑

**"B"** is 55cm as standard

Length: **350mm**  (Measure distance "B" from centre of anchor mounting to centre of release buckle)

## Direction of Lap Strap Adjustment

Pull Up ☑

B    C

**"B"** is 55cm as standard

Pull Down ☐

B

**"C"** is 12cm as standard

Single Seater Pinch Plates ☐

C
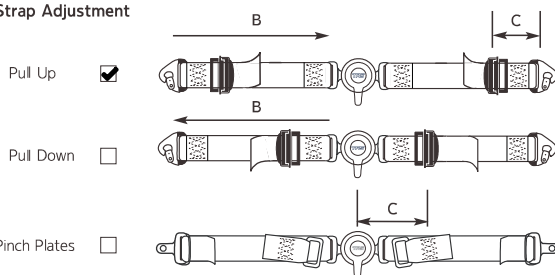
Length C: **120mm**  Standard length of 'C' Pull Up or Pull Down is **12cm from centre of mounting point to centre of adjuster**

**Crotch Strap - Measurements should be taken with driver seated in vehicle**

"D" is 65cm as standard

Single point crutch

2 point crutch moustache

Single seater crutch

D

D

D ✔

Length D: **600mm**    (Measure Distance "D")

**Rotary Buckle Permanently Fixed To:**

Right Hand Lap Strap ✔
(Std for single seater or 4pt saloon)
M10-0001

Left Hand Lap Strap ☐
M10-0002

Crotch Strap M10-0003 ☐
(Std for 5pt/6pt saloon)

**Anchorage** (Mark appropriate box to identify requirement)

| Snap Hook | Bolt Fixing Type A | Wrap Around | **Flat sewn loop** | Pinched Becket | Bolt Fixing Type B | Pinch Plates | Open End | Carabina | |
|---|---|---|---|---|---|---|---|---|---|
| M30-0002B | Please state hole diameter: 8 mm M20-0004 or 9.5 mm M20-0003 | If using this type of mounting provision must be made to prevent lateral movement | Please state loop diameter in CM **4cm standard** | Please state loop diameter in CM **4cm standard** | Please state hole diameter: 11 mm (7/16 inch) M30-0011B 13 mm (1/2 inch) M30-0010 | Please state hole diameter: 8 mm M20-0004 or 9.5 mm M20-0080 | | M30-0020 | |
| | | | 2cm ✔ | | | | | | Shoulder Straps |
| | | | | | | | | ✔ | Lap Straps |
| | | | | | | | | ✔ | Crotch Straps |

**Adjuster Types & Extras** (Mark appropriate box)

| 3 Bar Locker | Standard 50mm Adjuster | 75mm Steel Adjuster | 75mm Aluminium Alloy Adjuster | 50mm Aluminium Alloy Adjuster | Velcro Shoulder Straps | HANS Specific **50mm Shoulder** | |
|---|---|---|---|---|---|---|---|
| 75mm M20-0060B 50mm M20-0065B | M20-0050B | M20-0037B | M20-0040 | M20-0049 | | M30-0108 | |
| | | | ✔ | | | | Shoulder Straps |
| | ✔ | | | | | | Lap Straps |
| | ✔ | | | | | | Crotch Straps |

*TRS Technical Tip*
Use Alloy Adjusters for fast and easy adjustment

*TRS Technical Tip*
Will a "STANDARD" harness fit. Check the size chart to avoid the extra charge

**Notes:**

**Figure 6.4:** Spec Sheet for TRS Drivers restraint Harness order.