Increasing tolerances of the body panel fit on a hybrid chassis

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Multiple chassis at the the Donkervoort assembly department [1].

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Preface

This report is a part of the master program of Mechanical engineering at the University of Twente. It is based on the internship followed at Donkervoort Automobielen. During this internship a production problem at their facility is to be solved.

A word of thanks will be given to both supervisors, Kees Venner and Roel Grooten, and the company Donkervoort Automobielen for making this internship possible. The internship has taken place in the month from January until May at the location of Donkervoort in Lelystad on the behalf of the Thermal and Fluid Engineering department of Mechanical Engineering.

Summary

During the assembly phase of the production at Donkervoort Automobielen, deviations are visible. These deviations mainly in the panel gaps, are also visible at the finalized cars. The fitting of the panels has a large influence on this problem. As after the panels have been joined, they cannot be repositioned. Therefore, possible faults made there are hard to fix from that moment on. The fact that the panels have deviations in their fit, can have two main causes. The chassis or the panel dimensions could be different after production, compared to the designed dimensions. Another cause could be the positioning of panel to chassis that could be out of the designed tolerances. Focus has been laid on the chassis deviations. Mainly this is done as most of the car is depended on the chassis. An optimization of the chassis would also increase positioning of more parts.

Out of a comparison with concurrents, a path has been chosen for designing a jig. The purpose of this jig is to detect where the chassis is out of its tolerance field. During the concept phase, the choice is made for a modular jig and focus was laid on measuring suspension, glue surfaces and some of the COP measurement points.

During the analyses phase of the jig, also test were done to improve the panel fit. Aluminum shims are used for positioning the panel to the chassis. Due to the limited varieties in thickness, improvement was searched for in a better positioning 'shim'. The solution was found in use of glue as a shim. The tests showed using epoxy glue with aluminum tape on the chassis side of the gap between panel and chassis, was successful in positioning usability.

In a simple calculation in the tolerances the importance of a precise fit of the panels became clear. Maximum tolerances were set on the chassis by the dimensions of the measuring jig. To reach the tolerances needed for measuring, a choice on material and production method was of importance to reach the high tolerances. After the design process a measuring jig CAD-model was made. Suspension, glue surfaces and COP points could be measured.

The multidisciplinary work of this internship is showed in the token side-track. Experiments were done to get a feel on their own developed EX-CORE. Not only by experimenting with EX-CORE itself but also by building a heated mold, for future production purposes.

Contents

1 Introduction

The assignment has been chosen out of a passion for the exclusive automotive industry. Donkervoort Automobielen is such a company. Donkervoort was founded 40 year ago by Joop Donkervoort, building cars out of inspiration given by the Lotus supers seven. A lot of steps and improvements have been made each day towards the present state. Their latest model, the Donkervoort d8 GTO and GTO RS are totally different from its starting point. Not only the looks and performance are changed, also innovative techniques are used during production. For example their hybrid chassis. Based on a chassis with steel and carbon fiber components combined to create a light and stiff chassis.

A start will be made with a description of the current state. Where the lay-out of the company becomes clear together with their work process. This will be combined to show their collaborations.

With use of the description of the current state, the problem can be addressed. The problem definition will be split into panels, chassis and jig. All will have their own problems, which will be combined and converted to the main goal. The main goal is to increase the precision of in the process of joining the panels to the chassis. To make this goal achievable, it is divided into smaller demands.

Next, the problem will be analyzed. Knowledge can be gained from their concurrents. This will be done by reviewing their process of joining panels to the chassis and the sort of jig they are using. The important details will also be addressed, as these are of importance for the measurements. During the generation of concepts, an extra method was thought off. The concept of a glue shim was analyzed here. Just after, the concepts in relation to the panels are explained and investigated.

After reviewing the problem in the analysis, the development process was started. In this process the construction of the jig is explained together with the assembly sequence.

At the end of the development process, a design was created. The in and outs of the result will be explained. Also the chosen tolerances are described. This section will be ended with a total picture of the end result will be drawn to get a better overview.

The earlier described goals will be checked here. With these checked goals, conclusions can be drawn in relation to the final product. After these conclusions, recommendations for future development will follow.

During the internship, also small assignments came up. These are explained in the section after the recommendations. First some samples and tests were done with EX-CORE to get familiarized with the product. A heated mold for an EX-CORE product was made next, so the total process has been experienced.

2 Current state

2.1 Departments

The production facility is split up in different departments at Donkervoort. A welding department, at which the chassis and multiple other parts are welded. A composite department, where they are creating lightweight composite panels and structural parts. Another department is the manufacturing department, where some metal folding, turning and cutting is done. The work of these three departments are joined at the assembly department, at this department they are assembling the car2.1. As not all parts or work can be made or done in house, external parties are fulfilling also some functions.

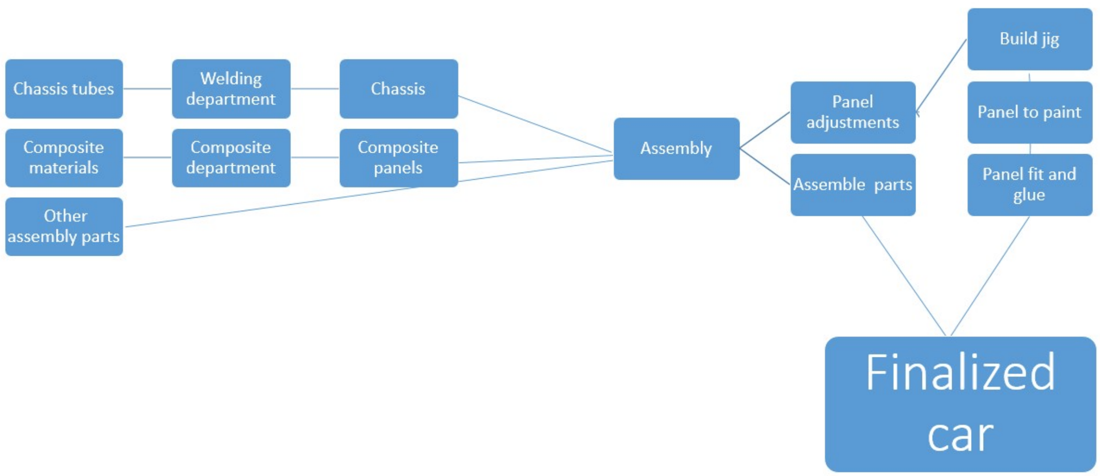


Figure 2.1: Process at Donkervoort starting with input materials and ending with a Finalized car.

2.2 Combined process

The production starts at the welding department, lasercutted tubes from an external party are located in a jig. Multiple jigs are used, to make sections of the chassis, see figure 2.2. These section are then joined in one large jig. This is done to reduce the warping after welding at the finalized chassis, as the section warping can be solved for in the large final jig. After welding a few measurements are done for Conformity of Production (COP), needed for type-approvals for their production cars.

Figure 2.2: Welding jig for a section of the Donkervoort chassis.

After these measurements the chassis will go to an external party for powder coating. After this coating, the frame will be brought to the assembly department. Started will be with assembling parts to the chassis. During this process also body panels will be test fitted and adjusted to make clearance with the chassis. This clearance should be more than 1.5mm, to have room for adjustments and an adhesive layer in between.

Next, a jig is used to determine the position of the body panels. Together with shimming plates the position of the panels can be found. The fit of the panels will be secured by making holes trough the panel and chassis, so a screw could be used to as a locating tool. Same location can be found after the panels are taken off, which is needed as panels need to come off for painting at an external party.

During the time having the panels at paint, the car gets assembled further. The freshly painted panels positions are then checked with positioning them with the screws, after which the panels will come off and putted back on with glue. After putting the panels back with glue, movement is hard due to the high viscosity of the glue. This makes it difficult to align the hole of the panel to the one in the chassis.

2.3 Equipment

During the above process a variety of equipment is used. Starting with the welding jigs, to create the chassis. As told above, first in sections, which are combined in a final jig.

During the panel fitting the following jig is used, as can be seen in figure 2.3. As this jig consist of large plates, stiffness is not high enough to keep tolerances low. This is because of movements that are possible in the range of a couple of millimeters. As the jig has to be build around the car, two people are needed for setting up this jig. Multiple plates have to be screwed together for positioning the panels to their position. This work cannot be done rushed, as scratched could be easily made.

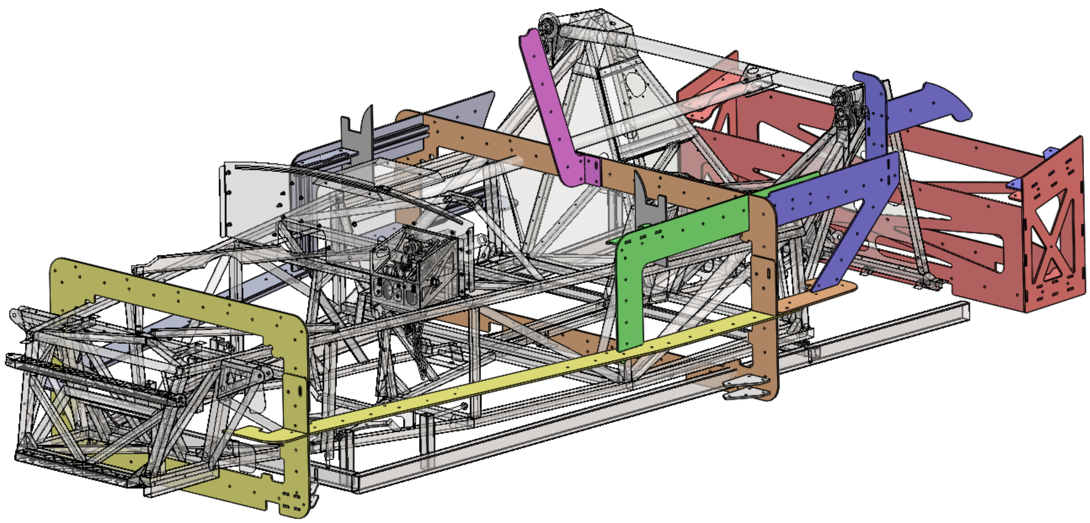


Figure 2.3: The current used jig, consisting of plates bolted togehter by extrusion profiles(not shown in figure).

2.4 Time distribution

During the production process, different factors determine the time distribution. For example the amount of people, tools, needed parts and materials. A simplified timeline can be seen in figure2.4. Under each step the time needed is placed. Token as a startpoint are the adjustments needed to fit the panel to the chassis. An average time of 90 min is spend on sanding the panels to fit the chassis. This fit is done in steps so no excessive material is removed. Next step is building the jig with two persons and adding shims between panel and chassis. As can been seen in the timeline, most of the time is spend here. Main problem is fitting the door. Lots of time is used for clamping it to the scuttle and checking the gap, with a closed door. The door has to be opened, the fixation has to be loosened after which the gap can be checked on a new fixed position. Also in these steps, the variety of people needed, is quite high. Most of the time the job can be done by one person, while help by an extra person is frequently needed for shorts amount of time. After panels have been taken off, refitting with glue is easy and can be done in an hour. Although precision can be improved, as will be explained in later on.

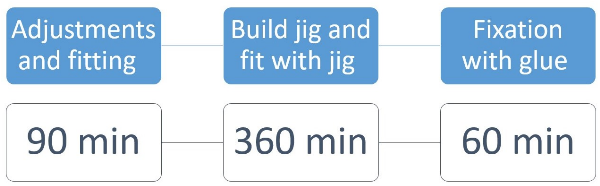


Figure 2.4: A timeline of fitting the panels to the chassis

2.5 Tolerances

As panels have to be aligned to each other to give a good looking end result with even gaps. A simple overview is created below in figure 2.5. This indicates the placement importance and also which tolerance will affect which panel. Therefore in the lower figure can be seen that it all starts from fitting the sidepanel to the chassis. The sidepanel and the chassis together will effect the placement of the door, scuttle and rear panel. Where those three will have a combined effect on the nose of the car.

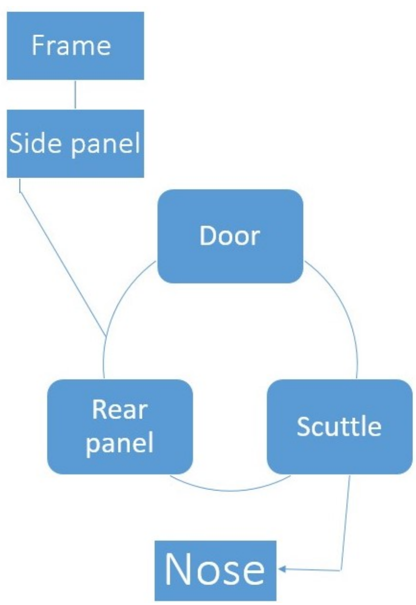


Figure 2.5: Tolerance dependency of the important panels.

3 Problem definition

During the production process as sketched in the current state. The process of panel fitting is very time consuming. During the adjustments on the panels for making the clearance fit, panels have to be taken on and off multiple times. Although this depends on personal skill and deviations of panel and chassis. These deviations are not measured at Donkervoort, at the moment. As the fit of the combination of panel and chassis is not equal to the designed fit, this is stated as the main problem of the assignment.

3.1 Panels

The dimension of the composite panels can be influenced. First factor can be the different options of paint that can be chosen by the customers, as paint thickness can fluctuate. For example panels can be ordered with a clear or color paint job. Where those in color mostly have a thicker layer on top of the panel. Making it harder to position as outer dimensions give the visual end result of the car. These fluctuations are solved for by using a jig that positions the outer surface of the panels. Second, aluminum shim plates are used to fill the space between panel and chassis. So the panel, before and after paint, will have the same position measured from the inside of the panel. A downside of this method is that for accurate shimming, lots of different shim plate thicknesses are needed, which currently aren't available at Donkervoort. Also only spots with flat surfaces can be shimmed. A full analysis on this problem should increase tolerances. Third, as panels are made as lightweight as possible, flexibility is unavoidable. Therefore the clamping force and amount of pressing points have influence on the dimension of the composite panels. As the panels become stiffer after being glued to the chassis.

3.2 Chassis

Explained in the current state is the production process of the chassis. As all components are combined to the chassis to create a finalized car, a chassis that is out of tolerance can be noticed at different stages at assembly: when fitting panels, suspension or in a later stage when mounting the the front nose for example. The impact can therefore differ on the moment of noticing.

3.3 Jig

The current jig consist of multiple lasercutted plates, bolted together. This jig is only mounted on the outside of the panels, this should ensure even gaps between panels. Although, there is some flexibility in the jig which could make it hard to ensure those even gaps. This flexibility mostly is on the spots were the plate are mounted together with bolts. No extrusion profile is added to stiffen that region. Also choosing the angle of the plate will bring more stiffness. Depending on the direction, choices for horizontal, vertical or combined plates and stiffeners should be considered.

3.4 Main Goal

The main goal is to increase the precision of in the process of joining the panels to the chassis. This should not only improve the speed of production but also the alignment of the panels. Which is a visible indication of the build quality of the vehicle. The main goal is divided into smaller demands, which could be checked one by one.

3.4.1 Demands

Ordered by importance, the following demands are set up. Starting with the jig design related demands are described, where the function of the jig is of greater importance then the possible damage it can make, as measurements are done in the earliest stage. Although off coarse, if this totally takes over the function of the jig, then this becomes of greater importance. After a chassis is fitted and tolerances are fine, then the visualization is of next importance, to have a better understanding of the warped sections and to localize the problem. At last the modularity should make the jig more future proof.

- Overall the jig should be an improvement to the production process.
- Check if chassis is within tolerances.
- The jig should have negligible tolerances in comparison with the tolerances on the chassis.
- The jig will not be able to damage the car while using.
- The jig should be modular. Changes could be made by engineers without changing the whole jig.

4 Analysis

4.1 Market Research

As the automotive industry is a large competitive one, not all manufactures show an inside in their production facilities. Only the information found applicable to the production at Donkervoort will be given in this section, while more information can be found in the appendix.

Interesting to see is the similarity of fixing some freedom of the chassis, and the use of movable arms. A difference is the moment of bonding the panels to the chassis. Most companies are bonding them before paint, so no additional thickness is present and some imperfections can be 'fixed' with the thickness of filler and paint. Methods which could be of interest are the one of Koenigsegg where they are fixing the frame together with the panels and Alfa romeo, who are using a dummy panel to guaranty a fit to that panel.

As can be seen in the Market Research, all jigs are extremely over dimensioned. Most of them are from steel with aluminium sub-pieces. Plastic and or rubber is used on the clamps, to prevent scratches. As the jig doesn't need to be lightweight, but needs to be stiff and cost effective, steel could be a good option.

4.2 Important sections of the chassis

The chassis can be divided into measurable sections. The suspension which consist of bolting points, and the chassis tubes, which consist of glue surfaces. Further the suspension will be divided into front and rear suspension. The chassis tubes can be divided into lower, upper and side tubes for the gluing surfaces. Also the steering tube and the seat bolting will be measured as a part of the COP measurements.

4.3 Type of jig

A chassis is build within certain tolerances, decisions have to be made how to handle them. Therefore two decisions are jet to make. One could create a jig where every chassis could be measured in, wherefore adjust ability is needed. This adjust ability will bring the chassis to a measurable position. Out of this position it will be shown if tolerances are met. Then the chassis should be within overall tolerances to have an approval.

In contradiction with an adjustable jig, a rigid jig is also possible. One could imagine a jig, with certain tolerances in which only a chassis within that range fits. Therefore this works as a first filter, so badly warped frames can go back to the welder instantly. If a chassis fits then base dimensions are within tolerances.

4.4 Moment of usage

The moment of usage of the jigs for measuring, fitting, and assembly can be thought out in different ways. This decision will affect not only the productions process of the cars, but also the design of the jig. The jig could be of added value, just after the chassis is welded, at the assembly, or during panel fitting. A first focus will be on the chassis tolerances, which can only be adjusted before painting the chassis.Therefore no further focus will be laid on using the jig during assembly, but only in an earlier phase.

4.5 Positioning mechanism for the sidepanel

One of the defects seen at finished cars is for example the differences in gaps in the right and left. This problem could be related to a difference in symmetry between the left and right side of the car. Symmetry should start at the sidepanels. As these will have a great influence factor on the other panels. A connections between left and right is needed to make these panels depend on each other. This could be done by just setting the adjusters left and right the same or by creating a rigid link between both.

4.6 Clamping of the panels

The outside of the panels, create the visual result of the cars. To make sure the outside of the panels are at their position, a position holder can be used. This holder can be designed in different ways.

The first concept is based on an easy method of picking up a panel. The corners of a panel are most of the times rigid, due to its shape. So picking it up will cause less deformation at that spot. For large panels, they can deform under their own weight or due to the force when putting pressure against the viscosity of the glue. When clamping the panel, only pressure will be set on the grabbing points, while the rest of the panel wont be pressed. This could cause waviness in the panel, which is also lightly visible on the cars currently made. Although this is unavoidable, it is improvable. Therefore on large panels the amount of pressing points is of importance.

Instead of clamping in the corners, also suction cups can be used. These cups can be used for both positioning and grabbing. But also for only grabbing, after which positioning points will bring the panel to position. This method will probably need more testing, due to relation between cup area and suction force.

Another thought on the Alfa Romeo concept created the concept of only adding guidance to the sides where other panels are fixed to. For example by using an old panel. To this panel the wanted gap can be added to that panel, or a gap measuring device can be added. This will make it possible to create an even gap between the fixing panel and dummy panel. This method ensures even gaps, but overall total position could be off from the designed position, while maintaining even gaps.

4.7 A simple calculation on tolerances

To get an idea of how the influences from above effect the placement tolerances, an example will be drawn here. Starting with a frame with tolerances of 1mm, Composite panels are added, assumed are tolerances of 0.5mm. So adding the sidepanel could bring the left panel to +1.5mm and the right to -1.5mm in worst case. Glue is needed for the bond between them, which also gives more space for movement. This space is dependent on the thickness of the panels. The sidepanel for example can, for example with the above used tolerances, move plus minus 4mm in its length dimension. It could be put 3mm inwards and in height direction also a 3mm movement is possible. These movements could put the most influencing panels, the sidepanels, to a position which creates a unsymmetrical looking car.

5 Adhesives at Donkervoort

As noted in the problem definition, during the assembly phase aluminum shims are used. These shims come in a variability of thicknesses. These should stay in position, starting when panels are fitted the first time until the panels have been glued on the chassis. Although this seems like an good option, better results could be achieved with a better shim. These shims can only be mounted on flat surfaces and are only applicable in a range of thicknesses. Therefore a better shim could help tolerances. An option for this could be using a glue between panel and chassis which only adheres to one of the two. This create a thickness equal to the gap between chassis and panel. So this tolerance is set to zero.

For the testing purposes two types of glue were tested to be used as a shim. The first glue was a fast curing epoxy glue, the Loctite EA9492. Second, Sikaflex 260-N, a polyurethane glue was used to compare the rigid epoxy glue to the elastic properties of a polyurethane glue.

Figure 5.1: A tube of Sikaflex2 260-N [13] and Loctite EA9492 [12].

Epoxy glue

A devision can be made between two groups of Epoxy adhesives [14] [17], 1-component and 2-component epoxy adhesives, respectively 1C and 2C epoxy. It it obvious that for 2C epoxy mixing is required. All 2C epoxies make use of the same basic principle of basic components, the resin and the hardener. The type of curing of the reaction between these two components is called curing or the polyreaction is polyaddition.

The amount of time needed to cure, can differ from less then a minute to days. Time of reaction is not only depended on the composition but can also be accelerated, for example with increasing temperature. Curing happens when crosslinking takes place. Acceleration of curing can have an effect on the degree of crosslinking, which means the epoxy becomes more stress resistant. The reaction inside an epoxy will generate heat itself. Therefore attention should be set on the volume of epoxy, where a too big volume with too less of cooling will let the ramp of temperature increase as a consequence of an exothermic reaction of the epoxy.

When using 2C epoxy adhesives therefore surrounding temperature is very important. As reaction time decreases, the handling time or also called the pot-life, decreases.

Properties of 2C epoxy adhesives

For 2C epoxies two often found mechanical properties are a high stress resistance, mostly over 30 Mpa, and low elongation to fracture. On the chemical side after curing, high resistance against temperature, chemical and physical agents will be present. Also it will have a tendency to absorb moisture an will have a good bond to aluminum, steel and lots of different plastics.

Properties of 1C epoxy adhesives

A 1C epoxy has the same basic ingredients but with a hardener which becomes active with heat input. Therefore no pot-life is present as it could be applied and only starts curing when enough heat is added. Difference with a 2C epoxy are for example an higher stress resistance for a 1C and oil will can be absorbed.

Polyurethane glue

Polyurethane adhesives [15] [17] are used in lots of different compositions, with their similarities in a range of chemical sharing. Reaction is caused by two components, which both often have two or more functional groups per molecule. Good adhesion can be accomplished with metals, cured epoxies, leather, rubbers, plastics and many others, although oily surfaces will not work.

In contradiction to epoxy adhesives, polyurethane adhesives can come in different degrees of flexibility, from rubbery and flexible to relatively inflexible and almost solid. For the polyurethane chosen, curing will occur due to humidity.

Testing glue for shimming

A first test has been done using a fast drying epoxy glue to test the principle of using glue as a shim. Therefore a piece of powder coated steel, same as the chassis, was glued to a piece of carbon fiber. This carbon fiber piece has been degreased and roughened with P80 sandpaper, to ensure good bonding. On the steel part different surface finishes were used. Difference was made with use of an aluminum tape spot, a release wax prepped spot and an unprepped spot. After the glue had dried the pieces where separated to look at the bonding quality. Bonding to the carbon fiber was good on every piece. On the other bonding side, at the steel part, only the unprepped spot gave a proper bonding. Where on both sides glue was still attached to the surfaces. At the prepped and tape spot, both didn't have good bonding. Resulting in a nice surface area. Which showed possibilities for testing on the gap between chassis and panels. The difference between the epoxy and polyurethane glue also became visible. The polyurethane glue was more flexible then the epoxy. This adds extra tolerances, while the epoxy surface would not add any. Another noticeable difference was the drying of the glues, as the polyurethane will only dry when the volume is within specified dimensions.

Testing the glue shim at assembly

To get a feeling of the difficulties at fitting the panels and testing the shim of glue. A view at the assembly department helped understanding the troubles they have to overcome during the fitting of panels. Also the difference in time consumption became clear. Where the rear panel and the door hinge took most of the time. As there was bad guidance from the jig, which made it hard to place it on position. For the rear panel, this was also due to a change of the design of this panel. This made is hard to secure the height. For the door hinge the main problem was securing the hinge at its position, after which it should stay in position while opening the door and drilling the holes.

After all panels had been secured and aluminum tape has been added to the chassis with a top layer of release wax, glue was added between the panel and chassis. This process was tried twice. After the first glue shims were made, the experiences were used for the next one. On the next one, less glue shims were used. After curing, panels were pulled of easily. Replacing them on the chassis brought back the same location as where it was taken off.

Figure 5.2: From left to right: Rear panel with glue attached to define the height and movement in horizontal plane. Second, an example of glue between the scuttle and aluminum tape on the chassis. This glue shim will define height. Last, out of experience from the assembly employees, an extra fixation in the form of an aluminum corner piece, was needed to withstand the panel from being mounted too far inwards. This was tried first with only glue, but this was too hard to reach with a glue gun. Therefore glue was added to the aluminium corner piece which could be mounted easily by hand at its position.

6 Process

6.1 Construction of the jig

Generating a final product in CAD had been divided in sub-stages. At first the modular concept was build with flat plates to see where difficulties came up, without taking the tolerances into account. Out of this concept discussions were conducted. These generated new ideas for a new assembly. Improvements were implemented and each plate became an independent part. Therefore changes could been made easier on individual parts. The plates were designed in such a way, that they could slide together to form a jig. Extrusion profiles could then be added to stiffen the jig. After completing this model, tolerances together with mounting holes and slots were added too. Below a division will be made between suspension and surface measurement points.

6.2 Material Choice

To reach the material choice, criteria are set: cost, weight, hardness, stiffness and environmental resistance (corrosion). To make a global decision a first choice will be made between steel, plastic, and aluminium, as these are the suitable materials mostly used at Donkervoort. From the market research also the use of steel was seen a lot. Together with the use of steel, small pressing elements out of a different material, like plastic, will be used too.

6.3 Production methods

The tolerances of the jig will depend mostly on the production method of the jig. Welding a jig, will bring same problems as with the chassis, warping. When wanting to bolt or slide the jig together laser cutting will be best option. Also high precision can be achieved [11]. The relatively low costs of this method is a plus too. The decision is made to use this technique on the parts where it is possible.

6.4 Suspension

The tolerances on the suspension are taken care of during the measurement of the chassis. This is done by adding a two plates near the hole. In those plates concentric holes are made in relation to the measurable suspension point. For the mounting holes a tolerance is set for 1mm on the radius of the hole. A pin will be used to check the diameters and painted slots in green and red will determine the axial position. Depending on whether the suspension A-arm is mounted with the chassis on the outside or inner side, tolerances will differ. For this width dimension of the suspension bushings, the width of the frame cannot be smaller as the bushing itself.

6.5 Surfaces

The surfaces for the body panels to be glued on to will also be measured. First method to measure these surfaces, is by the gap made between the plates perpendicular to the chassis and the chassis itself. A gap of 1 mm is taken as a tolerance. On the rear panel a plate is also set at 1mm distance. The second method is by using the lower chassis negative plate. This plate is set at a distance of the underside of the lower chassis tubes to help to see where problems start occurring in a warped chassis.

7 Results

7.1 Chassis jig

After a process of decision making, a jig design for measuring the chassis tolerances was created. Effort went to little changes on parts which created a snowball effect on other changes through multiple parts. The total picture of the jig can be shown in 7.1. An explanation and visualization of each measuring point of the jig will be shown in the figures below. The plates with the measuring holes in them will be colored yellow in the sections below.

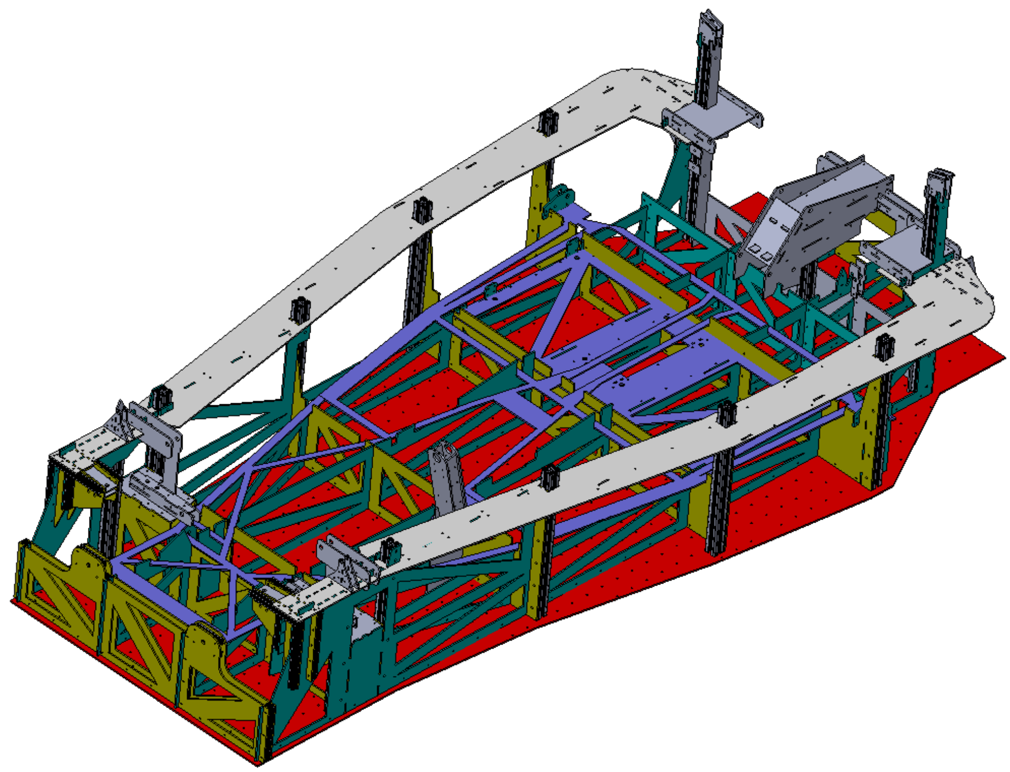


Figure 7.1: Total picture of measuring jig with the chassis mounted in.

7.2 Front suspension

As the front suspension consist of 2 A-arms with a shock tower. Only pins are needed for checking the dimensions. As can be seen in the figure below, some difficulties where found in the lower rear point of the front suspension (1). This is due to the lack of room to measure from below. Therefore a detachable measuring piece is needed, so the chassis is able to fit without interfering with the lower measuring pieces. On the lower measuring point in the front(2) this is overcome by creating some space between the chassis and the jig. The upper point in the front(3) is measured by a horizontal plate under an angle. The rear upper point(4) is measured with two plate, with one attached to the base plate. Just in front of these points are the shocktower measuring points(5), with also a measuring hole.

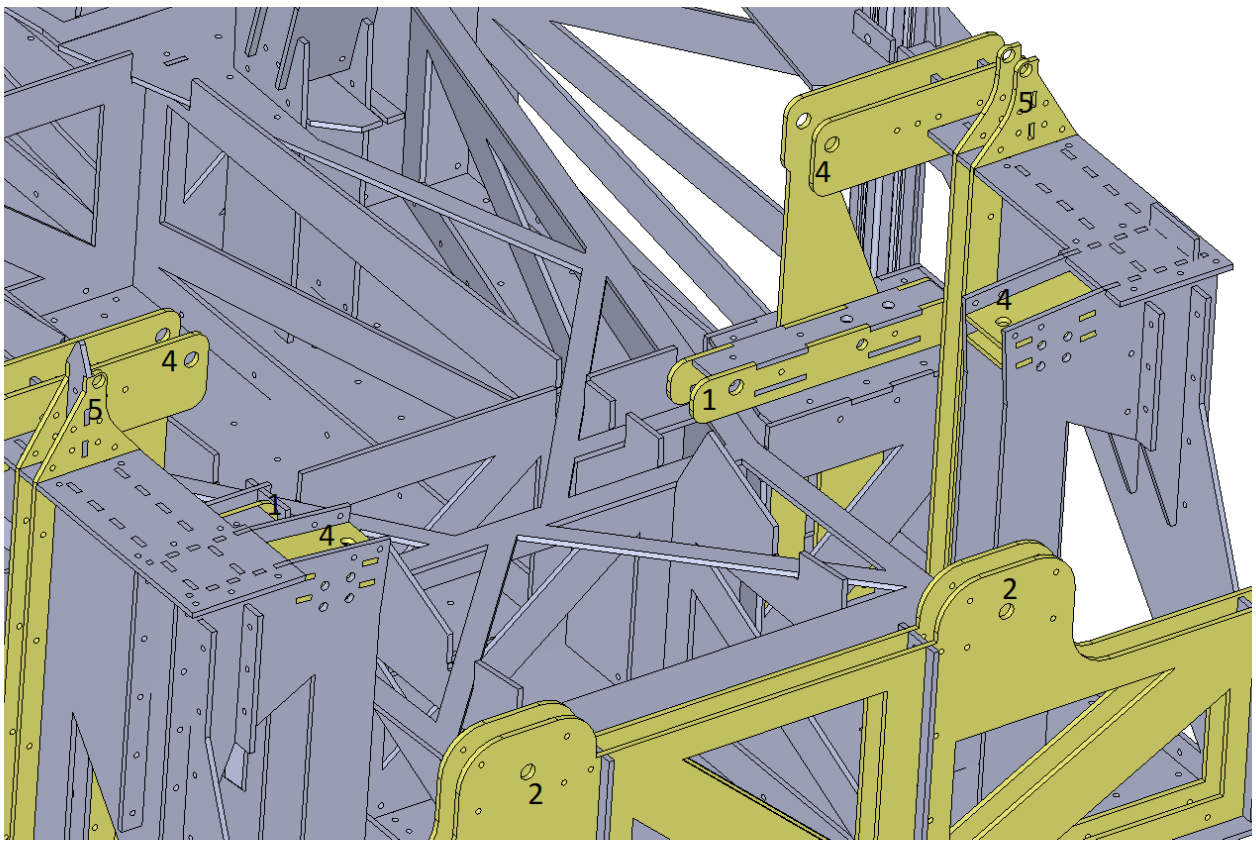


Figure 7.2: Front suspension measurements with a detachable part for the rear lower suspension point.

7.3 Rear suspension

The rear suspension can be split up into different sections. The middle piece, in which differential(6) and lower rear(7) of the rear suspension can be measured. This is a detachable piece. To measure these points, centering slots were made who can be fastened on with use of a bolt and a thread trough the center of this piece. Visible are also the plates, defining the rear panel tube(8) tolerance, shown as the most left and right rear vertical plates. The small plates on top of the extrusion profiles will function as points for measuring the rear shocktower points(9). The rest of the suspension points are rather straight forward. Holes are made in a plate near the measuring point of the upper points(10) and the lower front suspension points(11). A connection to the base plate is made where possible.

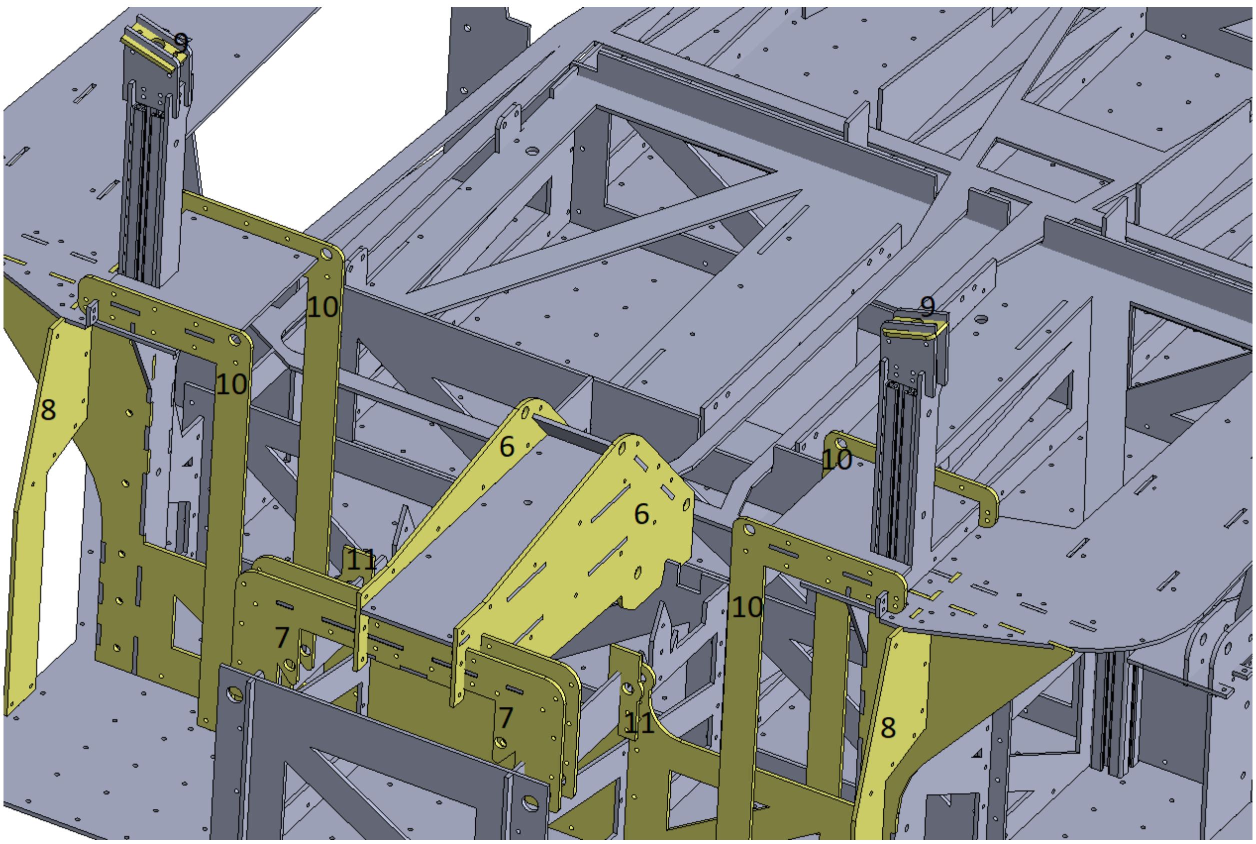


Figure 7.3: Rear suspension measurements with a detachable part for the differential and rear lower suspension point.

7.4 Seat bracket and hockenheim point

As the seat brackets are part of a standard measuring procedure, time could be saved when this could be measured too in this jig. Two ways of measuring are used on this jig, although for all holes are used for defining the position. As on the outer seat brackets, the brackets are welded to the chassis. Therefore the holes in the horizontal plate(12) are used for measuring. On the inner side, only holes are made in the chassis tubes. These could be measured with vertical plate holes(13). As actually being part of the rear suspension, the Hockenheim point(14), at the upper and lower left of the figure below, will be measured also. The method of using a pin will be used here, as with all measuring holes.

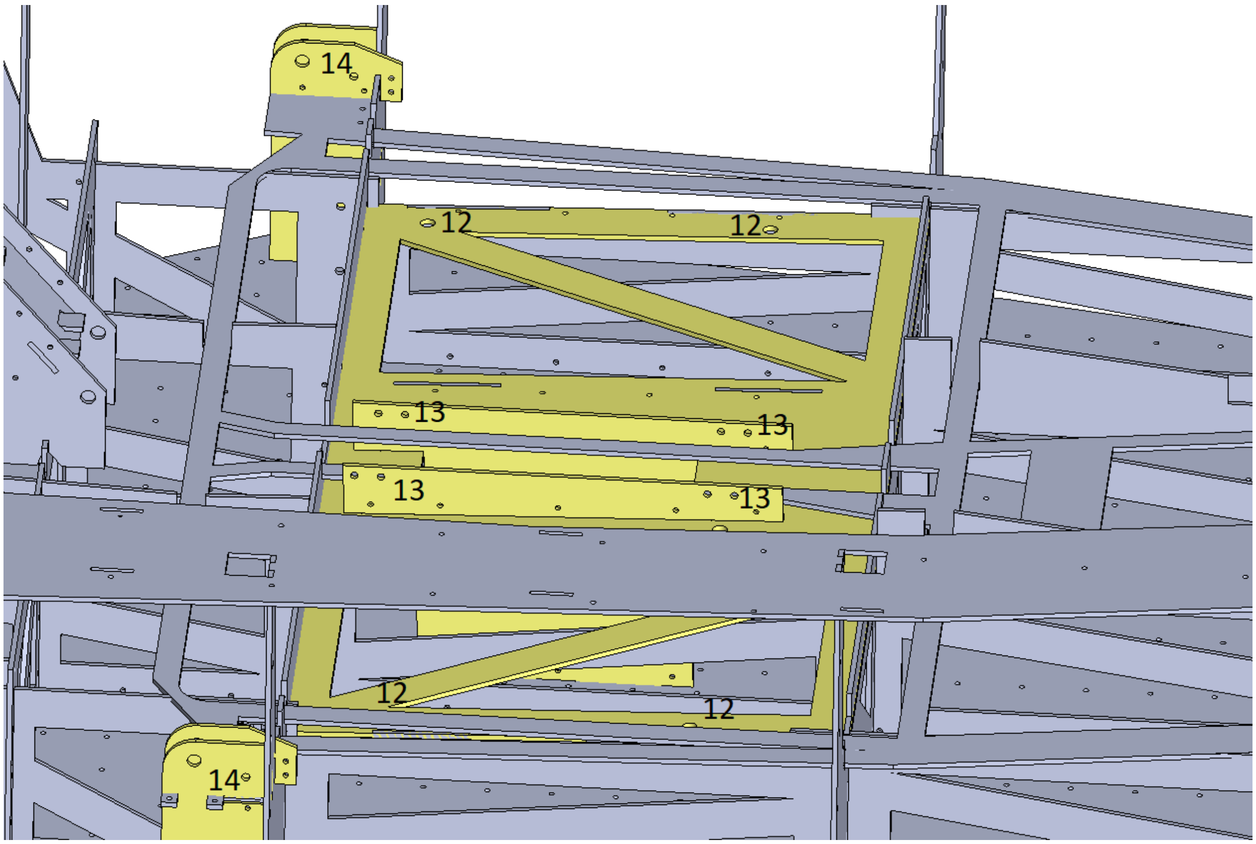


Figure 7.4: Combination of vertical and horizontal plates for measuring the position of the seat bracket holes, and the plates for measuring the hockenheim points.

7.5 Steering tube

As with some of the rear and front suspension measurement, also for measuring the steering tube, a detachable pieces is needed. Although only for the upper part of the tube, which is of later importance. The lower is easily measured by using a large pin to define if both are concentric, and if distance in between the tube and plate is within tolerance. This is shown in figure 7.5.

7.6 Lower chassis tubes

To get a total picture of how well the lower tubes are within tolerance, a negative of these tubes is placed under them at a distance of 1mm as could be seen in the figure below.

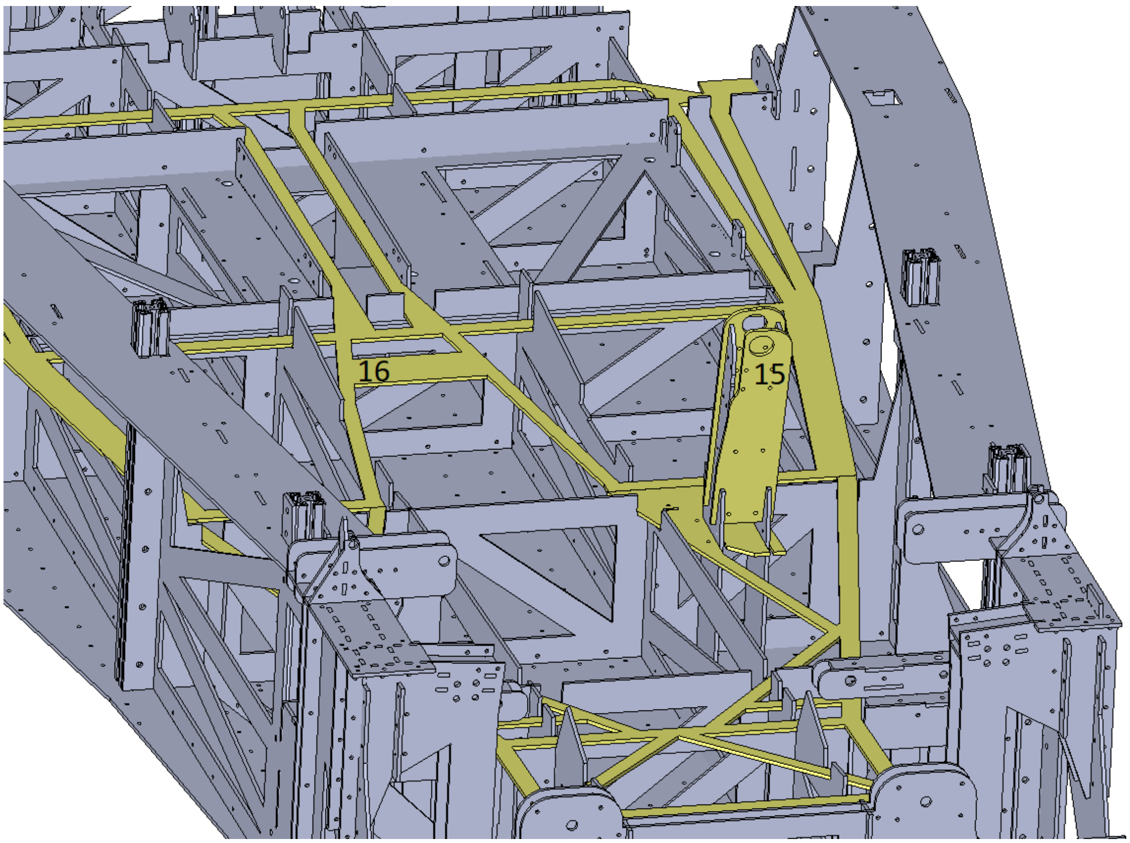


Figure 7.5: Measuring piece in front of the steering tube to measure if the tube is concentric and within distance. Also a visualization of the negatives of the lower chassis tubes can be seen.

7.7 Tolerances

As mentioned earlier tolerances are also present on the jig. But off course these are token much smaller than they are expected on the chassis. Too keep the tolerance field small, measuring points should be connected to the base plate. Then a tolerance off plus-minus 0.2mm will be present at those points when having two lasercutted surfaces mounted into each other. The only point at which this method failed, was the rear shock tower, the plane has been rotated in two ways, making it impossible to directly connect it to the base plate. Therefore the shock tower has a tolerance of plus-minus 0.4mm.

7.8 Suspension

For the suspension points on the chassis a minimum dimension is defined by the part that has to be mounted at that location, with rings needed for proper force transfer. This will ensure a fit will always be possible. If the tolerances are to large, an additional ring could be placed. The tolerances will therefore be set from the suspension part. For the diameter of the mounting holes the tolerances will be set to a minimum of the bolt diameter until an additional millimeter.

7.9 The total picture

As a lot of choices have been made until now, an overview will be given in this section. Beginning at the start of assembly. When the chassis gets out of the welder, it will be placed on a measuring frame. This frame will consist of a lasercutted plate as a base with enough slots and holes for future purposes. On this plate vertical plates, with negatives of the chassis taken out, are placed. Then only a frame within tolerances will fit. On this vertical plates also slots are made for additional plates for measuring the needed points. Plates will be connected with each other with extrusion profiles. To identify if a chassis is within tolerances, Pins will be used to measure the holes and distances are measurable with small measuring plates, or also called feeler gauges. After a check like can be seen in the checklist in appendix 10.2, the chassis can go on to paint and assembly. If measurements exceed tolerances, change to the chassis should be made, as otherwise the impact on assembly and probably the looks of the car will be to large.

7.10 Measuring manual

When using the jig, measuring pins and plates will be attached close to the measuring point with the same label to visualize if the chassis is within tolerance. For the pins this will be done by having a part green and a part red, where logically green is within tolerance in contrast to red. For the plates same will be done but difference is 2 plates are used, one green and one red.

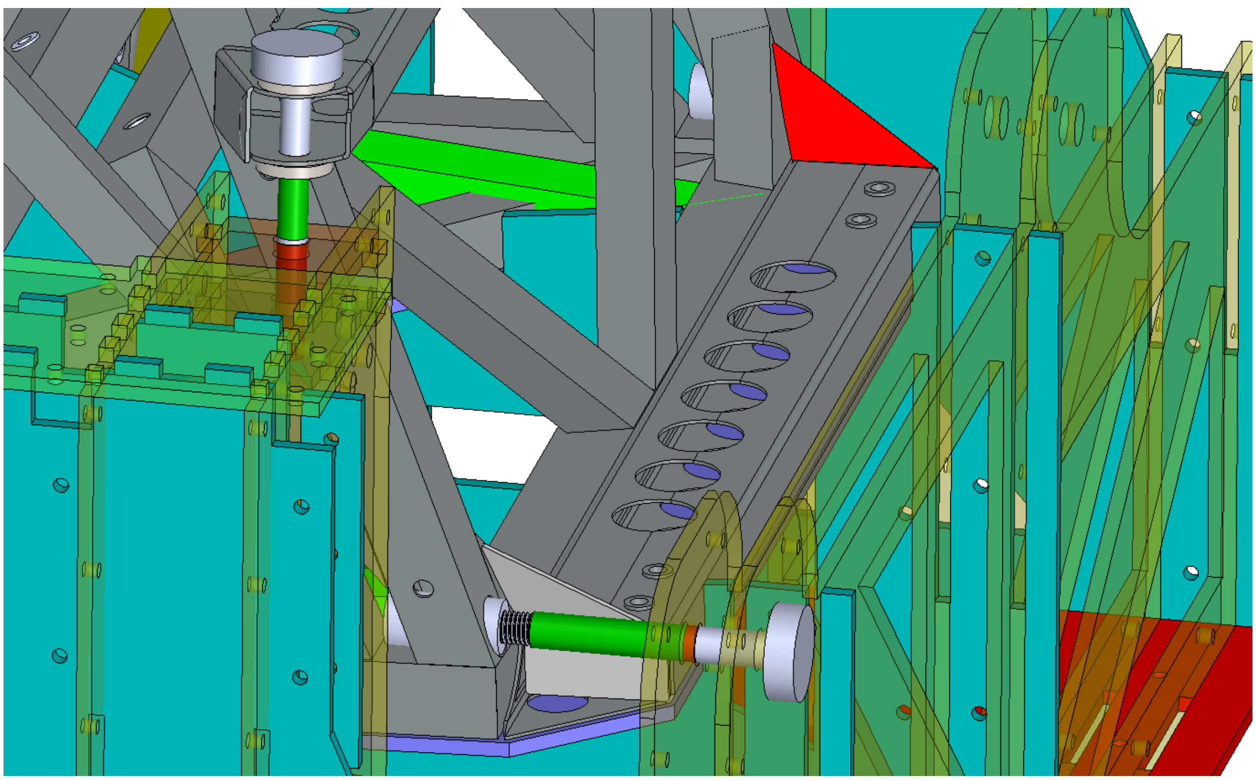


Figure 7.6: Pins used for measuring two points of the front suspension

8 Conclusions

During this assignment, knowledge is developed on a multidisciplinary scale. A jig was designed, improvements were done during the assembly of a car and experiments were done for future research. As an end result the jig could not measure all points as wished before, due to the time limit. At the current model the suspension, lower chassis tubes, seat brackets, rear panel tube and the steering tube can be measured.

The jig will add multiple improvements. During the assembly lots of uncertainties were noticed. When mounting a non-fitting part to the chassis, remeasuring is needed on chassis and part to find what causes the trouble of non-fitting. Same time could have been used at the beginning using the jig and solving for the possible later needed measurements, which will save time then. The time when discovering if a chassis is warped becomes optimal when using a jig. Re-welding can be done quick as no paint is attached at that stage. Therefore using the jig should give financial and time saving benefits.

After glue is added between panel and chassis, the high viscosity glue will make it hard to move the panel even without the glue having dried. Positioning with the screws will therefore not always work as well as expected before. Instead of this method, the method with glue shims will not have the same problem. As the test with the glue shims was successful, the option is open to use them in the assembly process.

Coming back at the main goal, it cannot be said if the precision is improved with the new jig, as the jig has not been build. As a definitive decision for building the jig has not been taken yet. Also the designed jig is only a starting point to make further improvements possible. As starting with a chassis without knowing its tolerances, makes it impossible to obtain a repeatable position related to chassis dimension. Also the demands out of the main goal can be related to the results.

First demand is the needed overall improvement to the old jig. This is hard to compare, as functions are not the same. But lessons learned from the old jig have been used to design the jig presented in this report. Further, tolerances of the jig are kept small by choosing the production method wisely and by making using of the base plate. Where this base plate is also base for later attachments. The possibility of damaging the car while using the jig during measurements could not be proved without the produced jig.

9 Recommendations

After the jig has been used quite a while and the usage has been proven to be successful. The pieces which were left, could be made to make the jig complete. Needed therefore is the movable upper piece. With this piece, one could additionally measure the upper tubes and the other side of the steering tube, for better measuring capabilities there. The steering tube could also be measured on another lower point, which will improve tolerances. Although an upper will be the best choice, as even higher tolerance values can be met.

When starting this assignment, focus was laid on fitting of the panels. It will be recommended to use the glue shims along with the wished panel fitting method. By using glue shims, no excessive amount of thickness varieties are needed of aluminum shims.

9.1 Consults between departments

From information of the employees at the assembly department, some improvement possibilities became visible. A lot off time was used in finding the right position of the panels, even with the current jig. This was not only due to jig design but also due to adjustments needed to the composite parts. At that moment it was uncertain if those were from the composite part or of the welded chassis. But if those adjustments are always needed, some debate between the composite and assembly department would make it possible to solve these bad tolerances. As changes in the mold should be done, when material is needed to be removed at the same spot for the same type of panel for every car.

9.2 Assembly sequence

The timing of painting the panels could totally chance the order of the assembly. Currently, panels are fitted twice. Once unpainted and once painted. The first time mounting unpainted panels is needed as adjustments have to be made to each panel to properly fit. Therefore two option are still open. First option is to take all panels off after fitting or they are kept on until the car is finished and paint will be added at the latest stadium. As the sidepanel has to be mounted after the exhaust is mounted, changes to the order of assembly can only be done when having changed the exhaust and panel sequence.

10 Side-track: building an internally heated mold and EX-CORE testing

10.1 EX-CORE

At Donkervoort, a good amount of research has been done about their own product, named EX-CORE. This is a thermo expandable foam, used for composite sandwich structures. Complex shapes become possible, even in as in one shot complex sandwich structures. Heated molds, as made above are used to add heat to the EX-CORE. The heat will not only cure the surrounding composite outer layers but also the EX-CORE itself, staying expanded after cooling down. Also during the addition of heat pressure is generated to push the composite layers to the wall to get a perfect finish of that surface.

Some samples were made and compression test were done to get a feeling about EX-CORE and how the process works. Difficulties during this process start with mixing of the epoxy with powders with some of very low density, which easily moves around to all spaces in the room. When mixed, the volume of the mold has to be exactly filled, so no air is present without compressing the foam. This can only be approached closely.

10.2 Mold

As part of the internship also some practical work has been done to gain knowledge about the techniques behind the build of a internally heated mold. The mold has been build out of fiberglass with a carbon tracing as an heat generator. Fiberglass was used as it has a low electrically conductivity and would not interfere with the tracing. Started was with some layers of release wax, needed to get the part out of the mold after curing. To get a smooth and hard top surface a layer of gel-coat was put on before the layer of fiberglass. Between the fiberglas layers the carbon tracing was placed. After a lot of work, the mold had been cured and then released from the plug it was based on. As a result a smooth mold had been made. For the upcoming molds to be build, it would be better to cut the fiberglass layers in larger patches. This would improve cutting time in total, and layers will move less when having a larger surface with high viscous epoxy between them. Also for the design of the mold, better releasing surfaces will save time. For one of the molds, there was almost no possibility to stick a wedge between the mold and the product to release those from each other.

References

[1] Donkervoort,*http://www.donkervoort.com/nl/*

[2] Koenigsegg, Build128 Agera rs station 1 – Chassis Bonding, *https://www.koenigsegg.com/build128-agera-rs-station-1-chassis-bonding/*

[3] Koenigsegg, Build128 Agera rs station 2 – Body alignment, *https://www.koenigsegg.com/build128-agera-rs-station-2-body-alignment/*

[4] Evo, alfa-romeo-4c-tech-rundown-and-video, *http://www.evo.co.uk/alfa-romeo/giulietta/13289/alfa-romeo-4c-tech-rundown-and-video*

[5] schloss-garage, Alfa Romeo, Abarth und Schloss-Garage Bildergalerie, *https://www.schloss-garage.com/?id=757 & album=77&paging=1*

[6] Speedhunters,Assembling Art: Touring Pagani's Production Line, *http://www.speedhunters.com/2016/08/assembling-art-pagani-production-line/*

[7] Speedhunters,The process building a mclaren mp4 12c, *http://www.speedhunters.com/2013/04/the-process-building-a-mclaren-mp4-12c/*

[8] Datona,Auto poetsbrug - 230V, *https://www.datona.nl/poetsbrug-auto.html*

[9] Charles Day,Laser Cutting Tolerances For Laser Cut Steel Parts, *http://www.daysteel.co.uk/laser-cutting/laser-tolerances/*

[10] Sika,Sikaflex-260-N, *Product informatieblad Sikaflex-260-N,18-4-17*

[11] Kuyer,Lasersnijden, *http://www.kuyer.nl/nl/wat-wij-doen/Lasersnijden*

[12] Amazon, Loctite 9492, *https://www.amazon.co.uk/Loctite-temperature-resistant-component-adhesive/dp/B00FGOB3BK*

[13] Nauticgear,sikaflex 260n krachtlijm, *https://www.nauticgear.nl/bootonderhoud/sikaflex/sikaflex-260n-krachtlijm.html?gclid=CjwKCAjwzoDXBRBbEiwAGZRIeE–4rsMiUclLc020va2nyFiFCCf9DsoPKRpzJLO7avEtPjHJnoRVhoCh8YQAvD_BwE*

[14] adhesiveandglue,epoxy adhesive, *http://www.adhesiveandglue.com/epoxy-adhesive.html*

[15] Christine DeMerchant,adhesive glue polyurethane, *https://www.christinedemerchant.com/adhesive-glue-polyurethane.html*

[16] Carblogger, Donkervoort D8 GTO: serieus snel, *https://www.carblogger.nl/de-donkervoort-d8-gto-hij-is-snel/*

[17] Edward M. Petrie, Handbook of Adhesives and Sealants, 2006

A Documents

Checklist chassis jig

Necessities:

What	Needed	Ok
Differential	Detachable differential part + 2x pin + nut	
Detachable front suspension	Clamp and detachable pieces 2x	

Checks:

Front suspension:

What	Needed	Left ok	Right ok
Lower a-arm front	Pin		
Lower a-arm rear	Pin + detachable front piece		
Upper a-arm front	Pin		
Upper a-arm rear	Pin		
Shocktower	Pin		

Rear suspension:

What	Needed	Left ok	Right ok
Lower a-arm front	Pin		
Lower a-arm rear	Pin + detachable differential piece		
Upper a-arm	Pin		
Schocktower	Pin		
Hockenheim	Pin		

Chassis tubes:

What	Needed	Left ok	Right ok
Outer tubes	Shimplate		
Inner tubes	Shimplate		
Rear triangle tube	Shimplate		

Others:

What	Needed	Ok
Seatbrackes	Stoel lip	
Steering tube	Pin	

B Market research

Koenigsegg

Koenigsegg is a well known supercar producer, with lots of own technology. For producing their composite chassis they use a jig to place and hold each panel during the gluing phase. As can be seen in the pictures below, the chassis placed on supports on the bottom. A plus of this option is that the frame only supports z-axis of chassis, the other axis are fixed by moving arms which also place the panels. But unfortunately the arms that fix the chassis will be less accurate as the chassis this is the part that will be painted on forehand with a variable thickness of filler and paint. Moreover, if the chassis is a little warped this method will also fail.

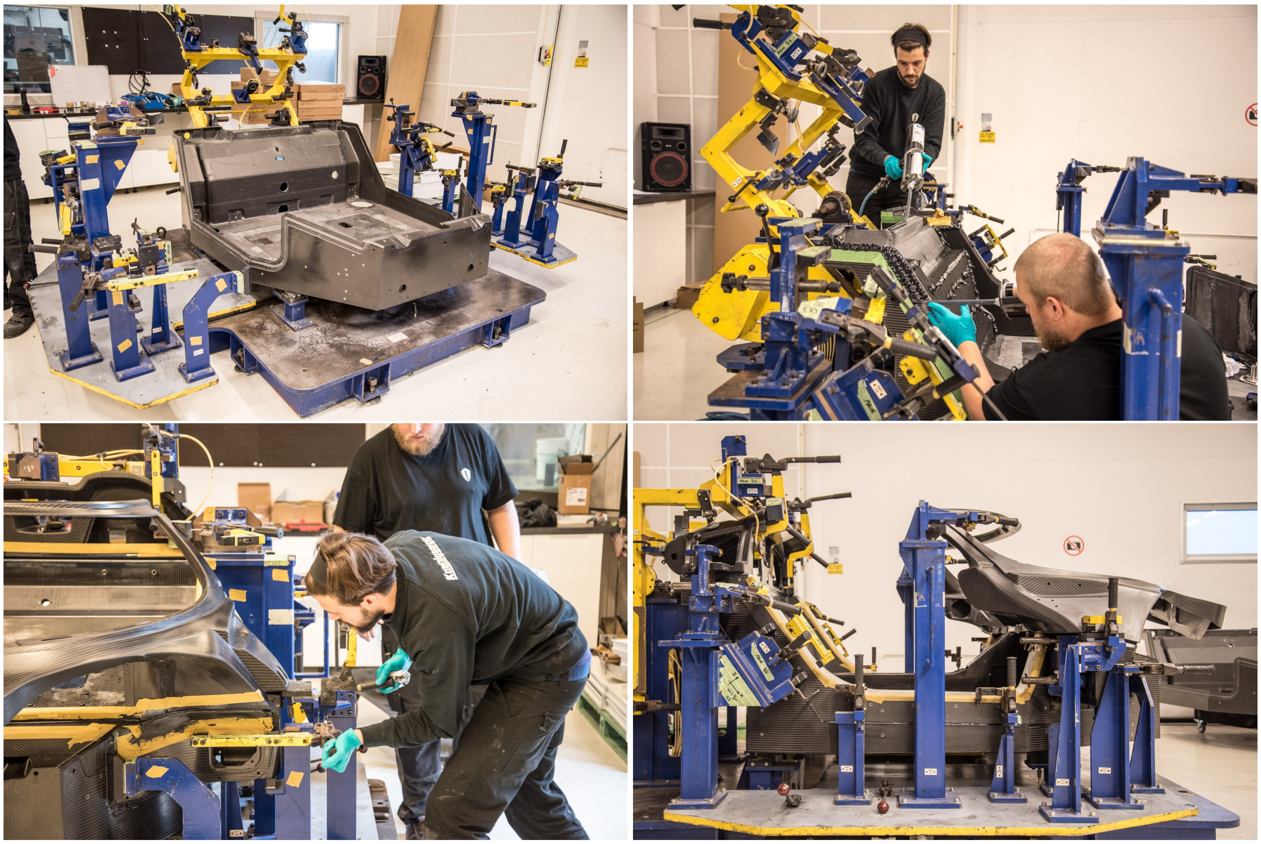


Figure B.1: Used jig during adhesion fase by Koenigsegg [2].

Figure B.2: Adhesion fase by Koenigsegg [2].

Pagani

A difference at the Pagani factory can be seen in the figures below. The panels are glued together before attaching them to the chassis. As this seems like a good option, it is not possible at Donkervoort. As parts that could have been joint together already are on forehand.

Figure B.3: Used jig during adhesion fase by Pagani [6].

Mclaren

At the Mclaren factory a real impressive jig is used to fit the panels. As this jig will be to expansive and not much new can be seen on it, this jig will not be discussed further.

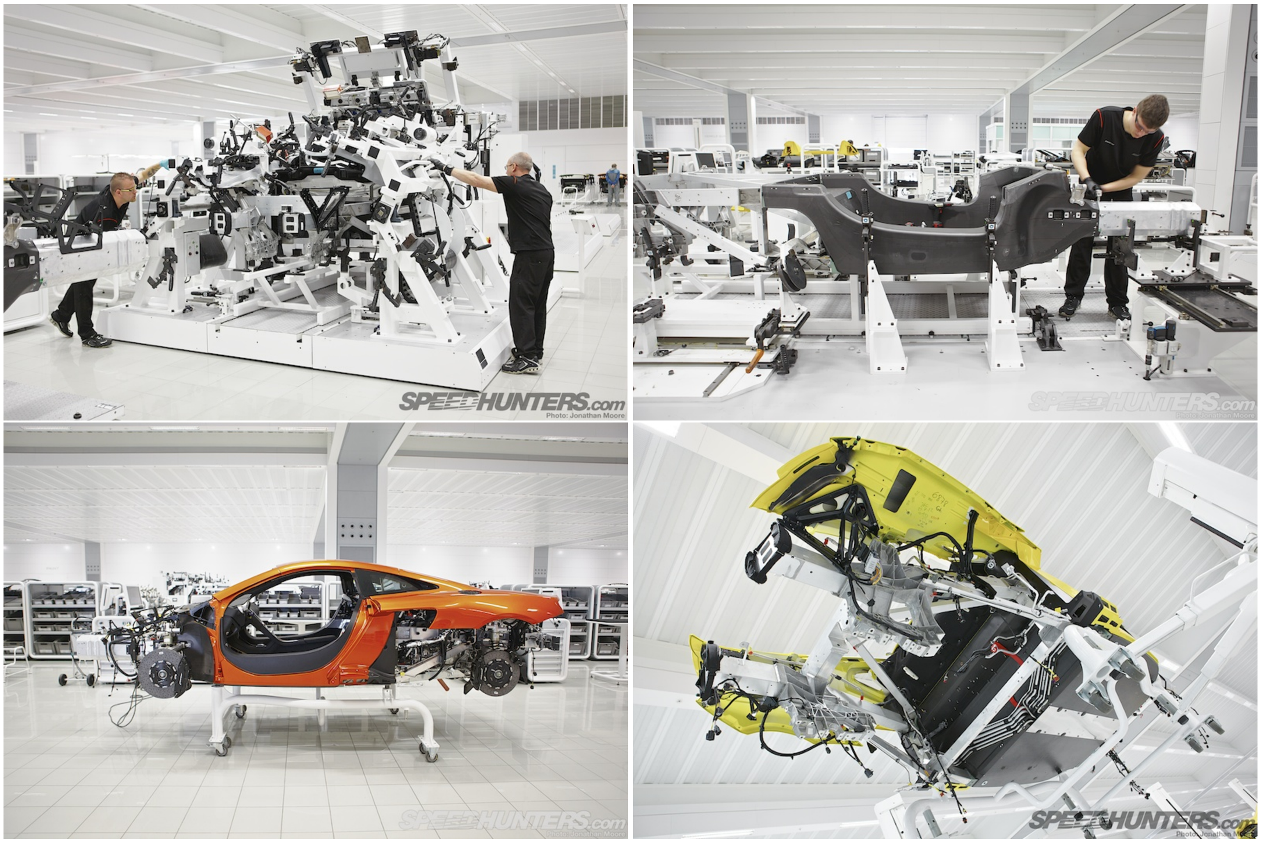


Figure B.4: Used jig during adhesion fase by Mclaren [7].

Alfa Romeo

A cool feature Alfa Romeo is using can be seen in figures below. They are using a dummy piece attached to an important part of the chassis. In the figures can be seen the door hinge is used

Figure B.5: Used jig during adhesion fase by Alfa Romeo [4] [5].

C Description of the employer

Donkervoort was founded 40 year ago by Joop Donkervoort building cars out of inspiration given by the Lotus supers seven. A lot of steps and improvements have been made each day towards the present. Their latest model, the Donkervoort d8 GTO and GTO RS are totally different from its starting point. With a weight of around 700kg mainly due to leightweight carbon fibre reinforced composite parts, and the power from an audi 2.5L turbo five-cylinder, acceleration from 0-100km/h can be achieved in 2.7s. Not only the looks and performance are changed, also innovative techniques are used during production, for example their one shot manufacturing of complex composite sandwich panels. Interns from different universities have been doing research to this technique in the past and current time. Around 30 to 40 people are working at the location in Lelystad C.1. This location is divided in sub-departments, a construction, composite, assembly, engineering,finance and event department. To bring the car to the people Donkervoort has it own dealers in Germany, Belgium and France.

Figure C.1: Location of Donkervoort Automobielen in Lelystad [1].

D Reflection

After working four months within the Donkervoort automobielen, I am feeling satisfied about the time working along with colleagues and finishing my own assignment. Working in such a small company with their own unique cars gave a good insight in the development of their cars. I enjoyed working along with the different departments, this gave a broad overview of the production, development and researches. Most surprisingly is the high standard of the finished product at the end. Their vehicles are internationally respected.

When started the assignment was solving the placement of the panels on the chassis. It was shown interest were laid by creating a solution that would help this problem, but mostly what could help the company the most. Therefore, some work done at the beginning could be 'thrown away', although lessons are learned off coarse. Better communication would make lower the change of repetition.

During the conceptual phase of this assignment, at a pre-stage already some CAD drawings were made to avoid drawing by hand. After going through the whole process, this time could have been used better. As CAD drawings were only usable for clarification and not as actual concept proposals.

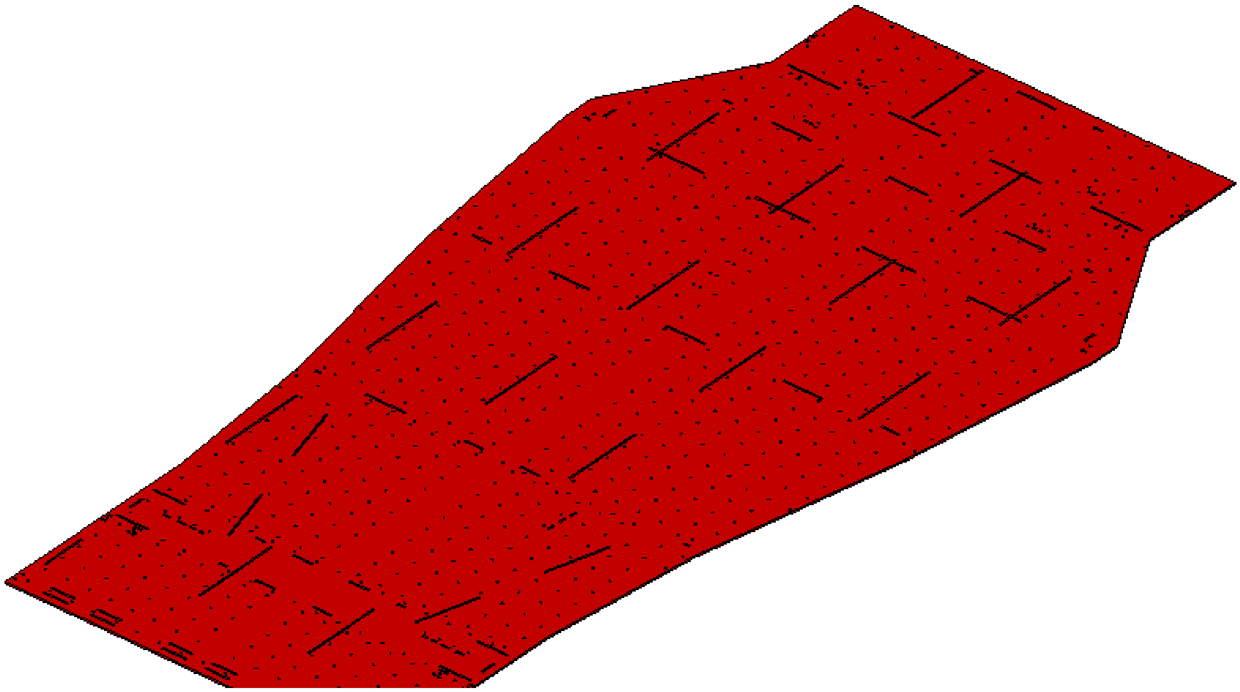
Also during working at Donkervoort, the differences with studying at the university were emerged. Differences in people with knowledge from study or those from experience, were working together. Showing that each has its profits. Although making it hard to explain something new they haven't been doing or seen.

After all, it was a pleasant experience. The company fitted well by my expectations. The assignment was more practical as expected this made me afraid I had not used enough knowledge from my study. But after all this internship was a success by letting me experience all differences in work and research.

E Figures of the Jig

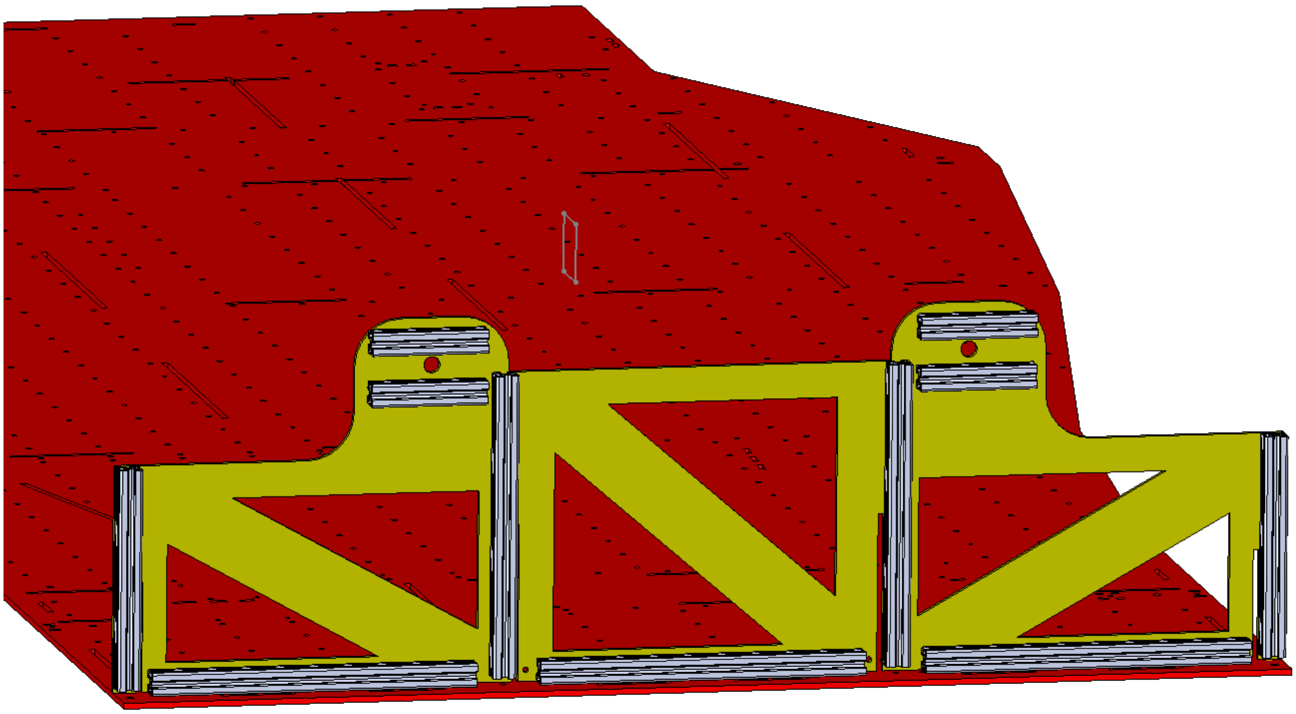
On the next pages, a collection of figures with explanation is organized to explain the final product. Figures are made out of the assembly made during this assignment. Colors are used for explanation purposes and to create a better distinguishable jig.

1 Baseplate



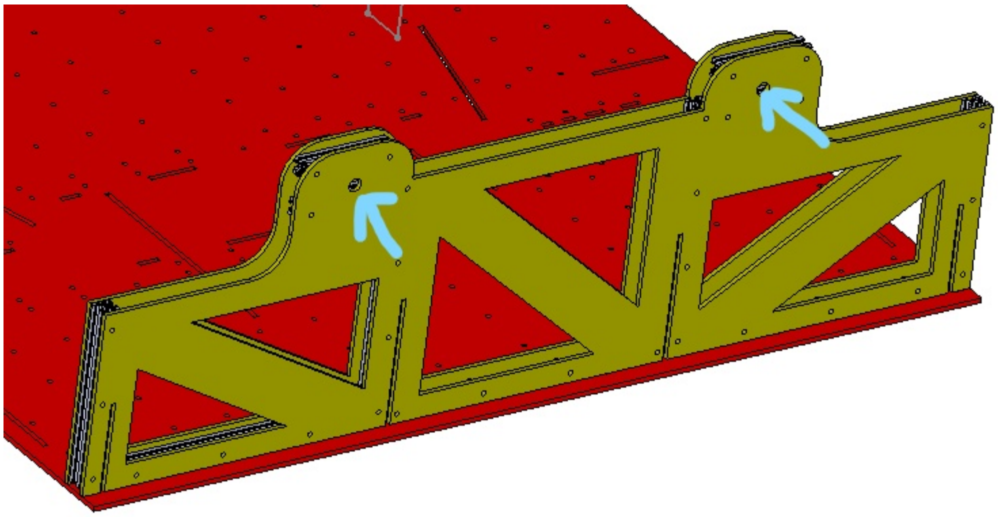
It all starts with the baseplate. This plate will be used to connect every part from front to end within the same tolerances. Slots are cut for plates to slip in and holes cut closely so the plates can be bolted to the baseplate. Also holes are made so extrusion profiles can be used as a flat bolting surface on the bottom, so a perfectly flat 'floor' is not needed.

2 Lateral plate and extrusion profiles as stiffeners



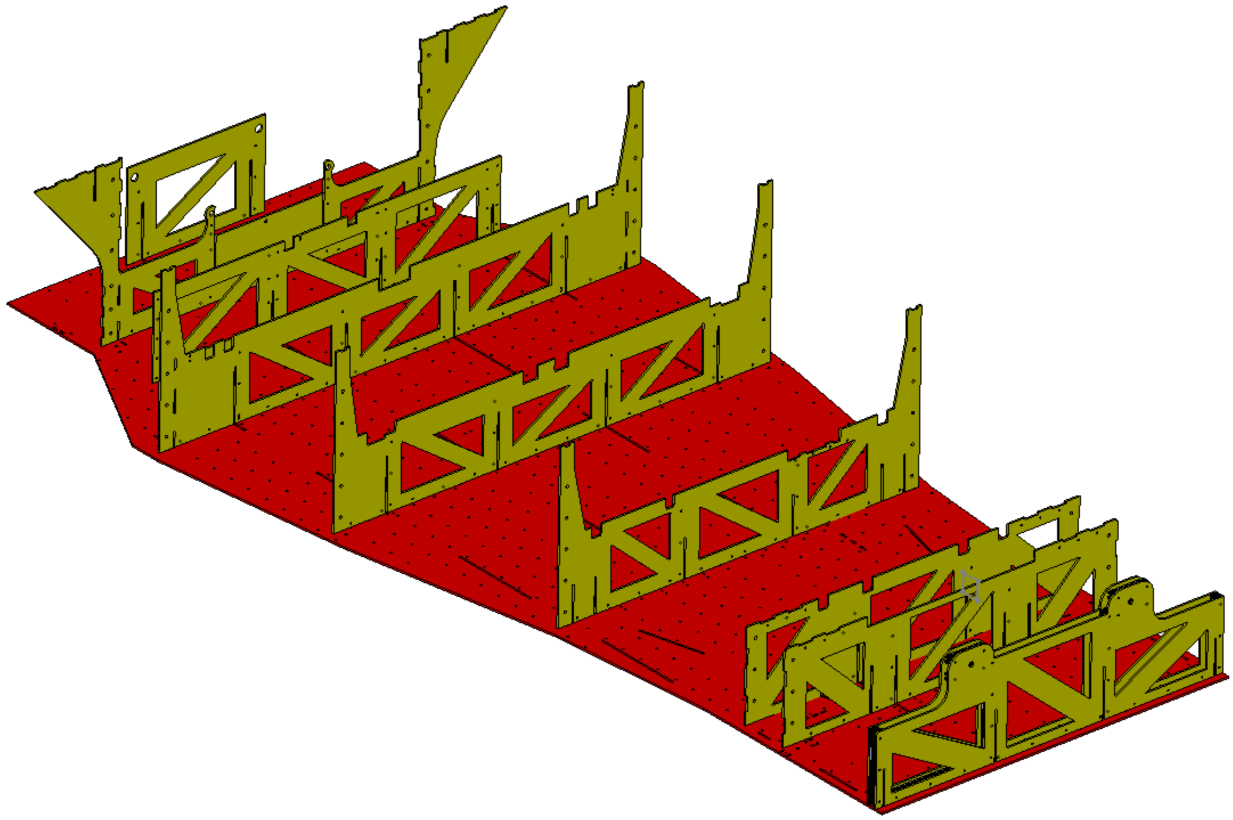
A lateral plate can be added, to stiffen the base plate and as can be seen later, to measure a point of the front suspension. Extrusion profiles are added to connect the plate to the bottom and later added plates.

3 Joining plates together



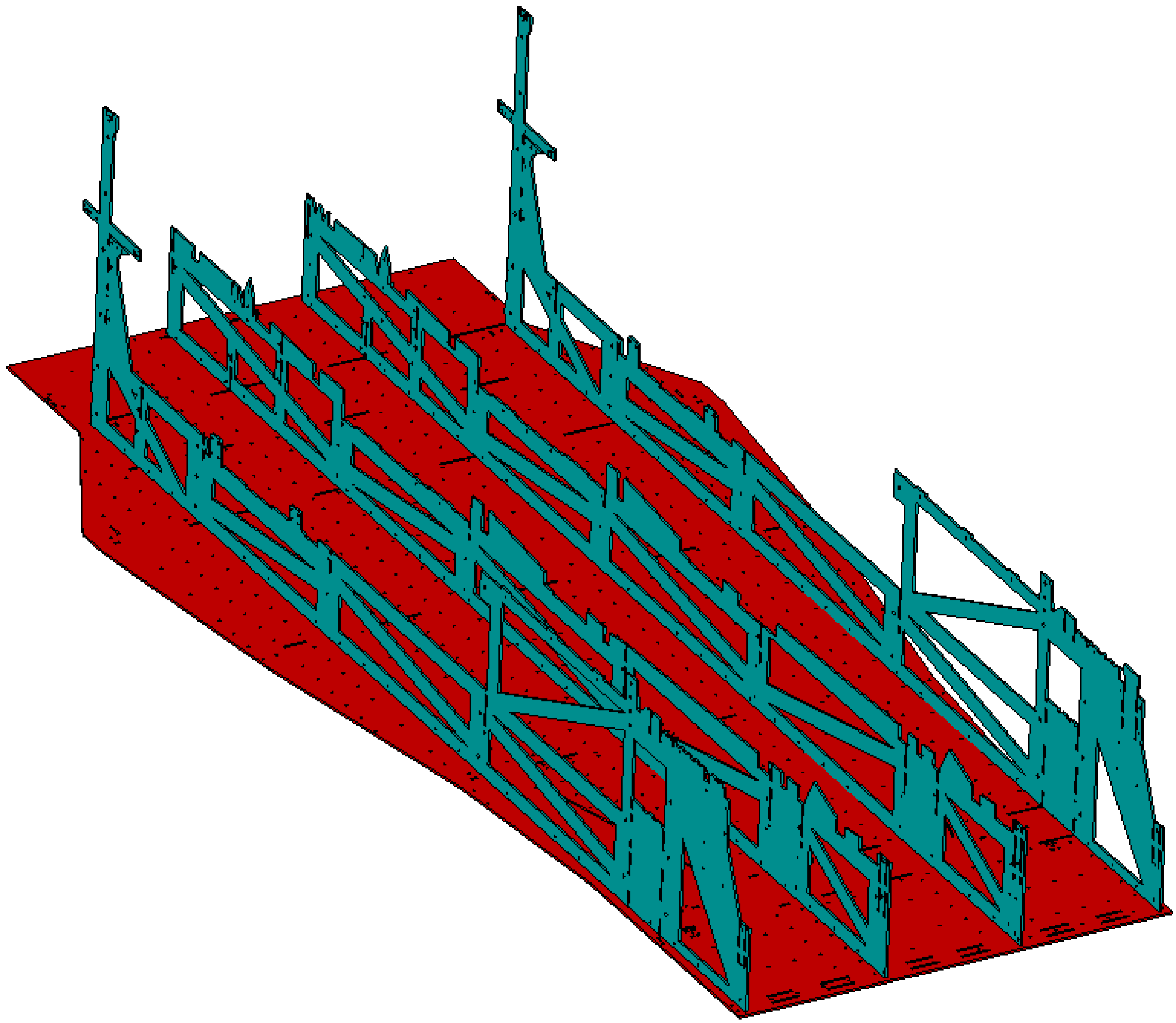
The extrusion profiles as seen in the last figure will be used to bolt the plates to the base and to each other. On the other plates extrusion profiles are left, because they don't add value to the 3D-CAD-model, except slowing the CAD-model down. The extrusion profiles needed can easily be cut by hand, as only the width's of the extrusion profiles are needed and not the length tolerance.

4 All lateral plates



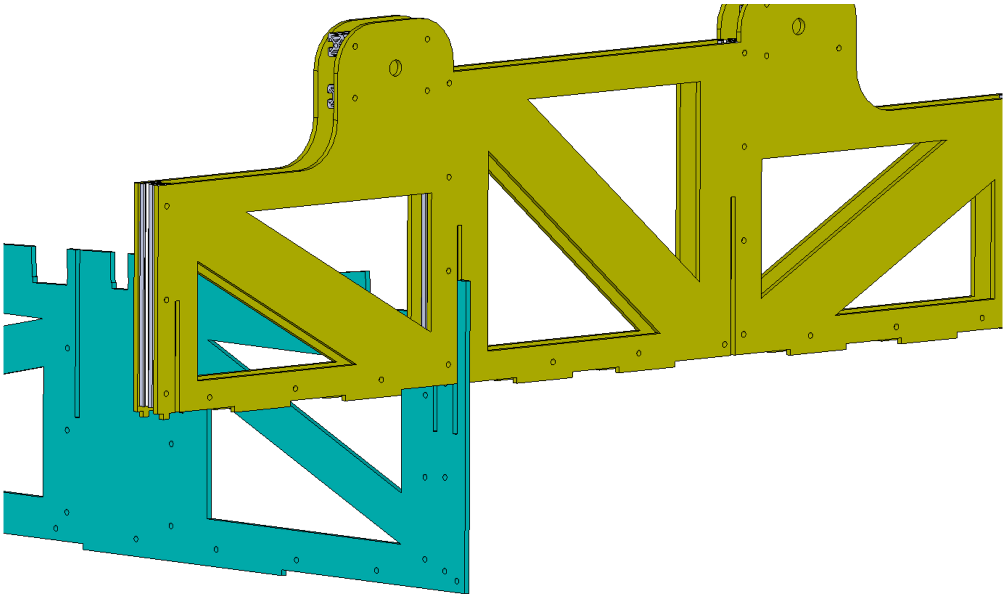
All lateral plates can be seen in this figure. A closer look will show that also the tolerances of the tubes can be measured in these plates.

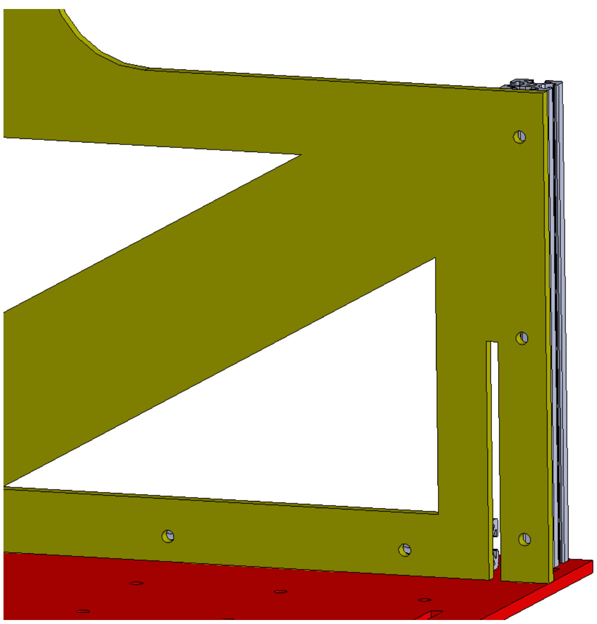
5 All longitudinal plates



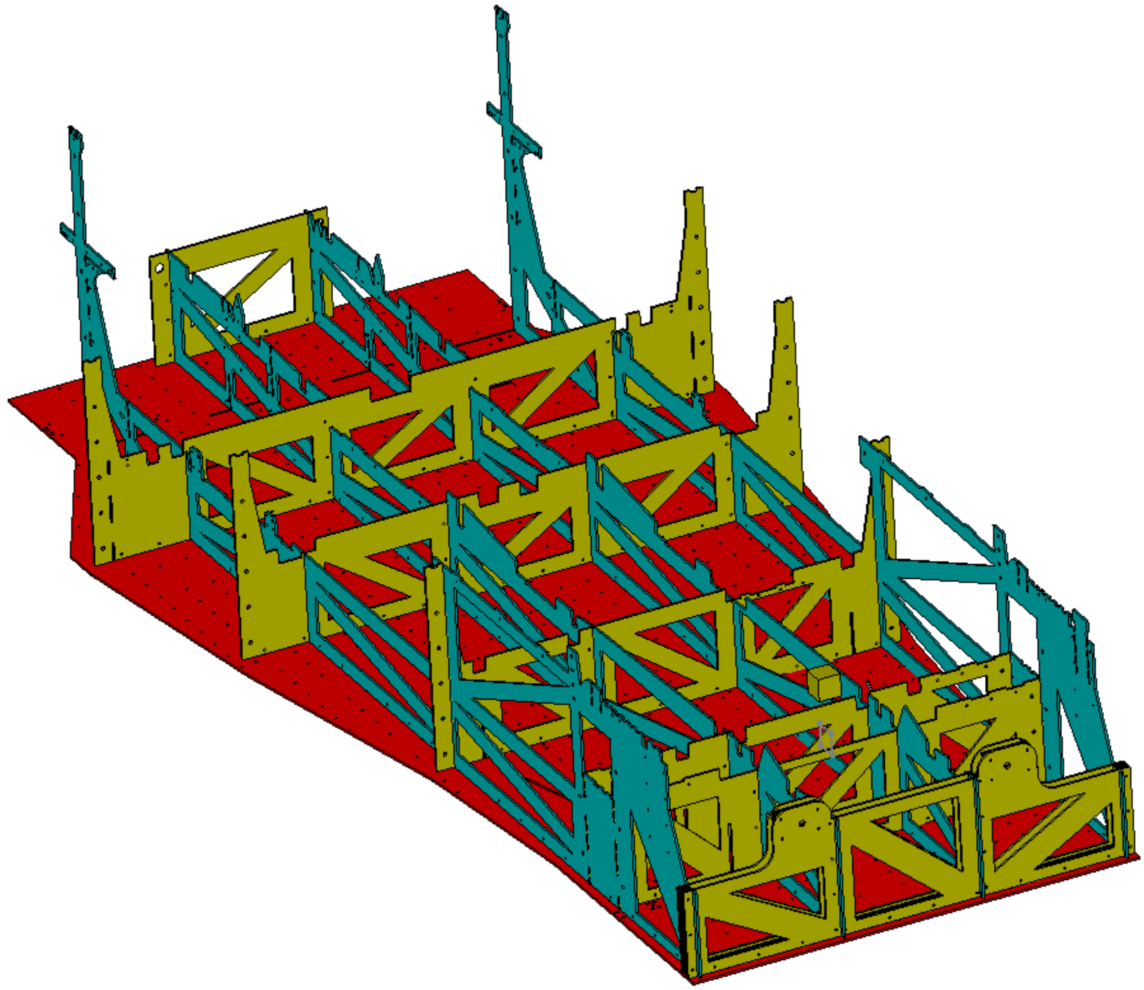
The longitudinal plates are also used as stiffeners and for the tolerances on the tubes.

6 Combining longitudinal and lateral to gain stiffness



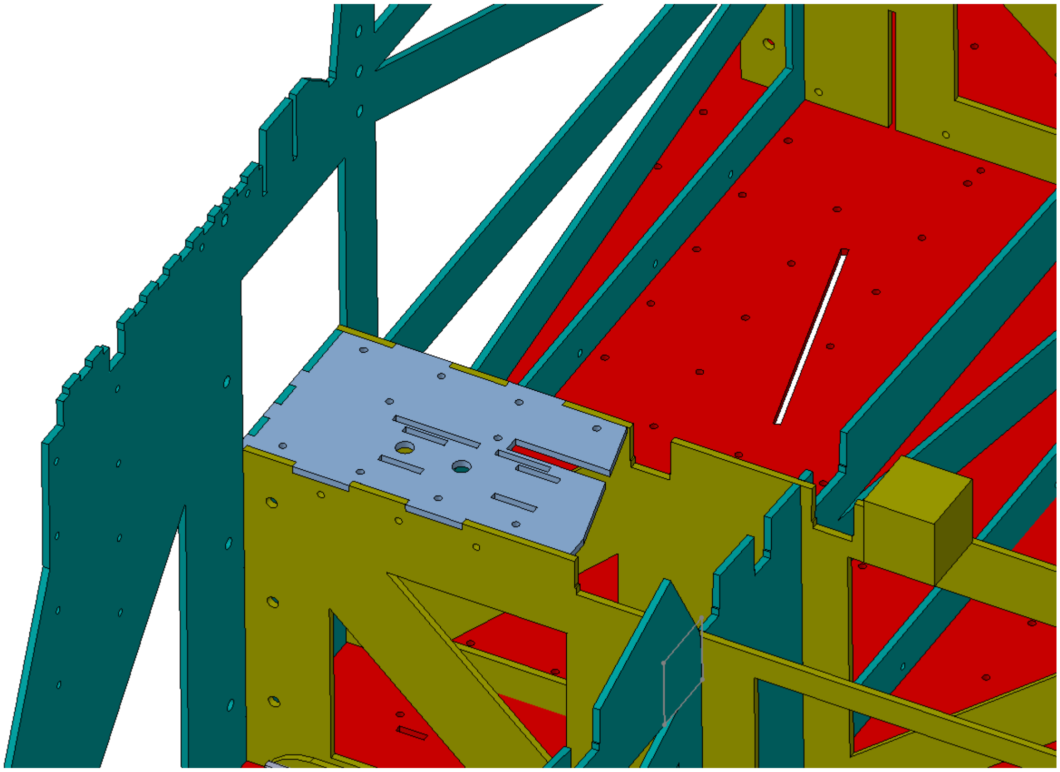


In the above figures the mechanism of attaching the longitudinal and lateral plates can be seen. First the two are slided into each other using the slots. When these are connected with each other and with the baseplate, an extrusion profile can be added to connect the plates together.



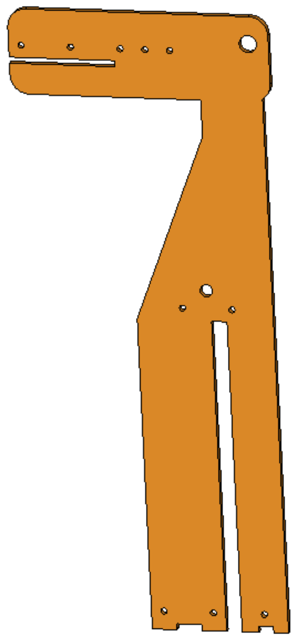
Combining both lateral and longitudinal will give a strengthened total. The holes in the front are used for the front suspension measuring.

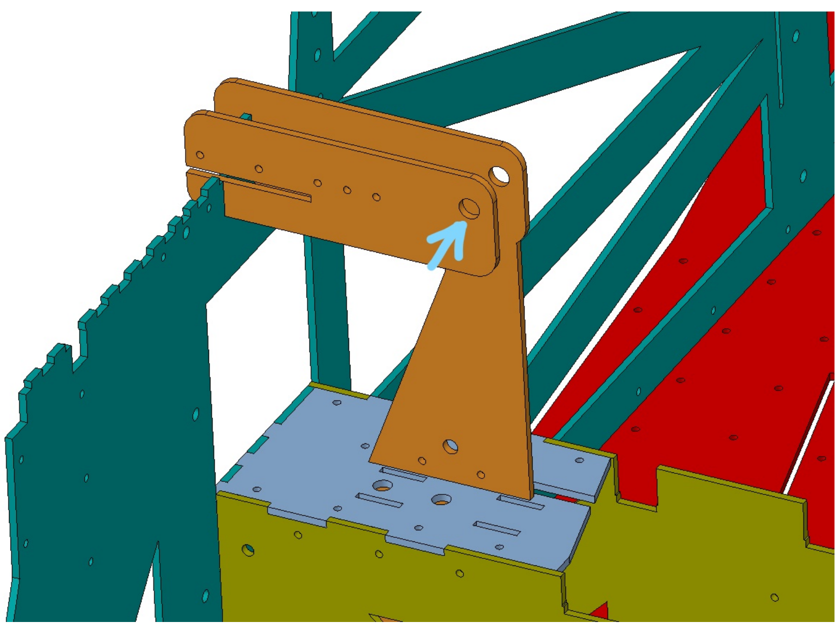
7 Front suspension



To measure the front suspension, multiple plates are used. The gray plate will be used as a base for a detachable part, placed later.

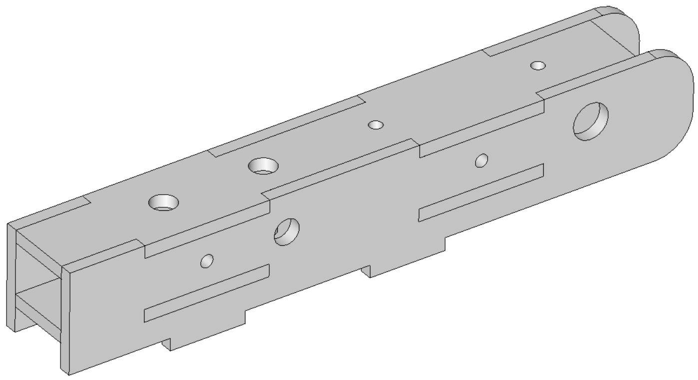
8 Front upper suspension

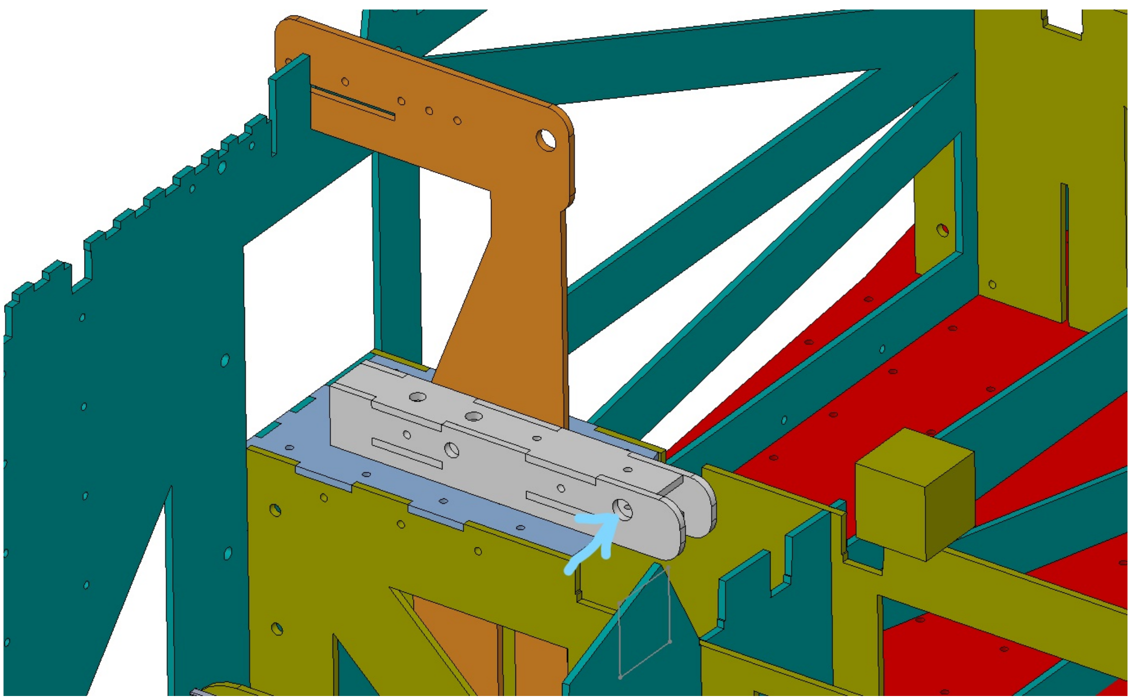




For the front upper suspension, two plates are used. The hole with the arrow will be used to check the tolerance of this suspension point. One of the two plates has a connection to both the baseplate of the suspension and the bottom red plate.

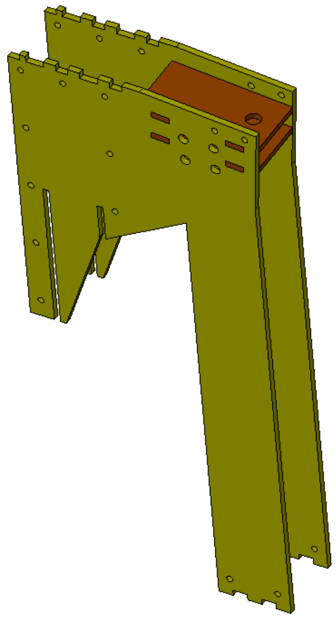
9 Front lower suspension

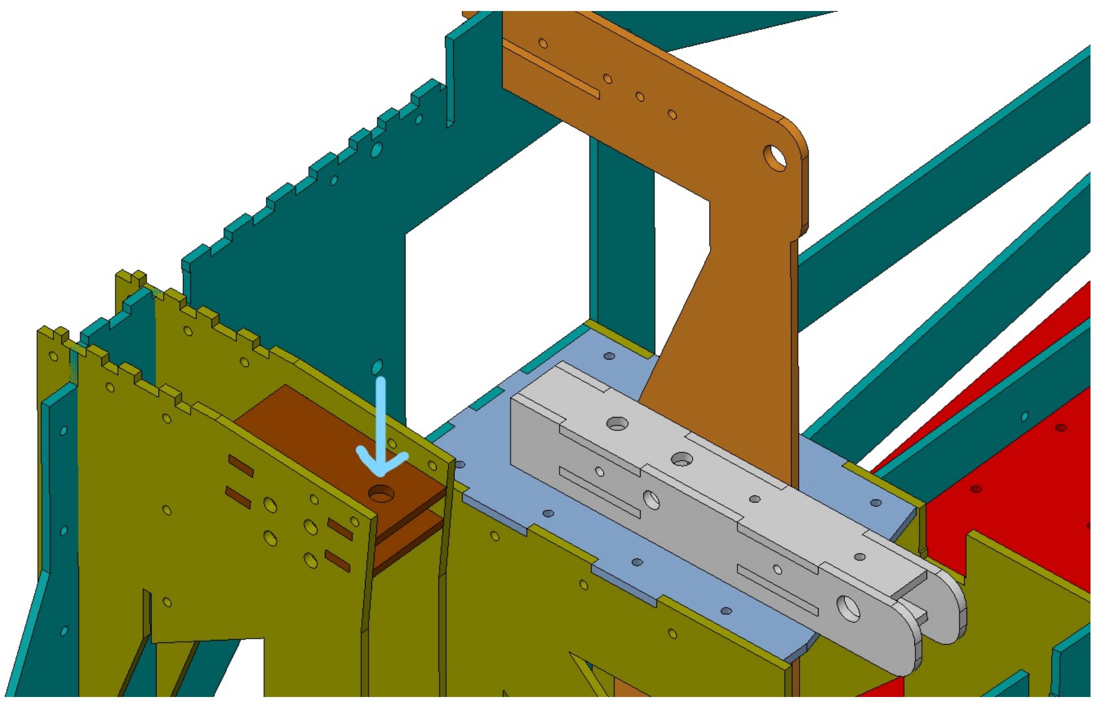




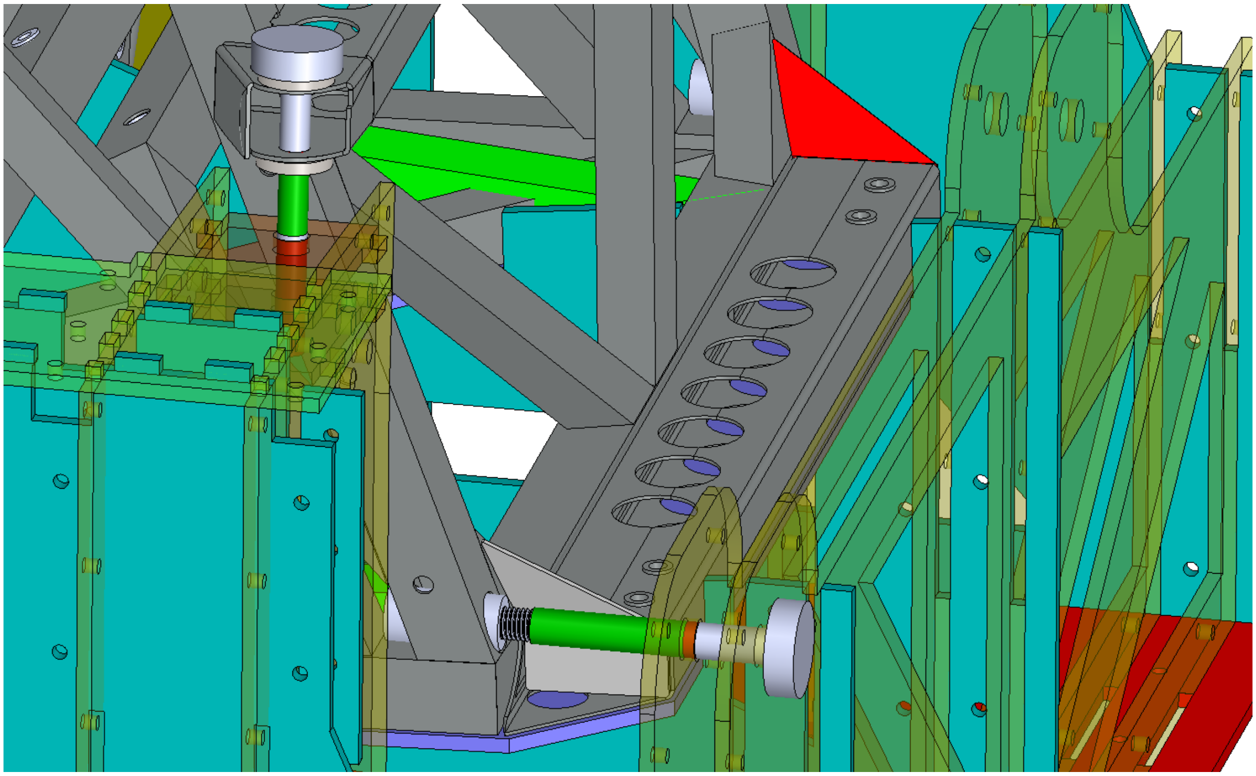
In upper figure, the detachable part for measuring on of the lower front suspension points is shown. This part consist of four plates to make it rigid even when detached. When mounted pins can be used to define its final position. In the future, when favorable, also a clamp can be used which could be attached to the orange vertical plate.

10 Front upper front suspension



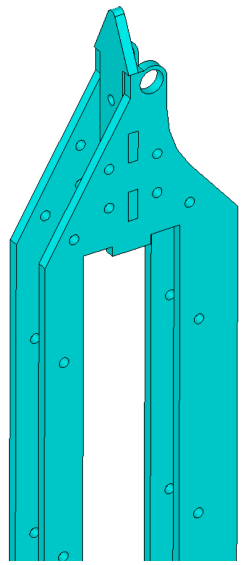


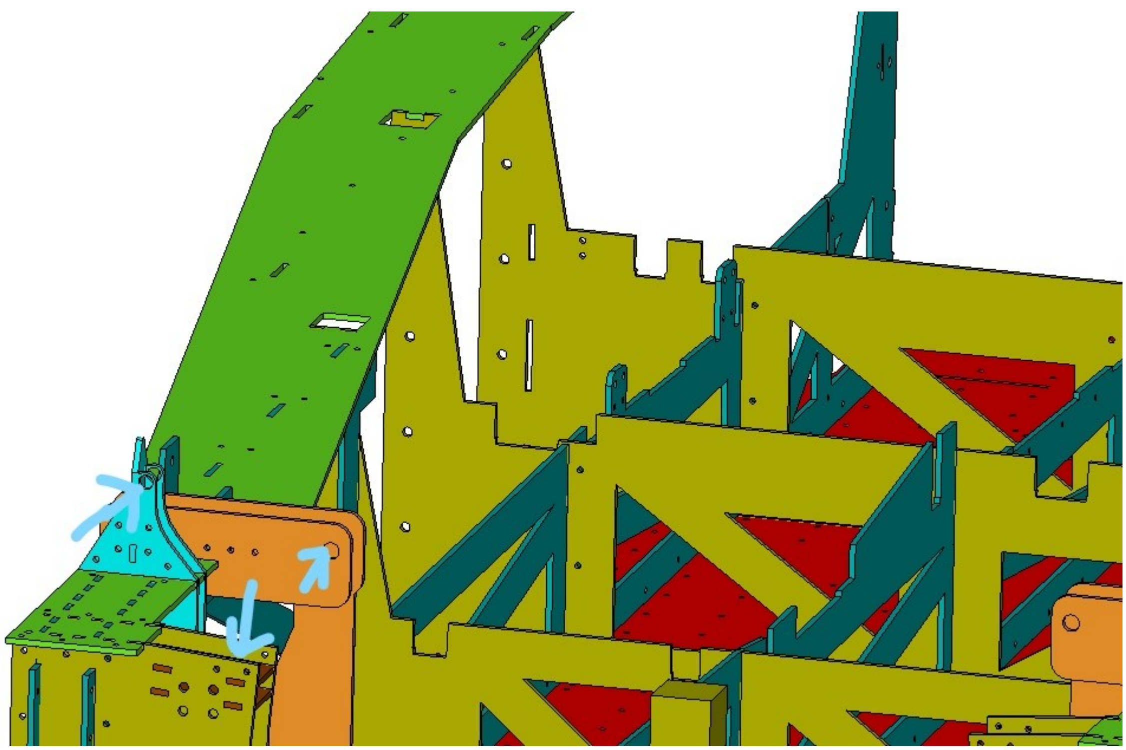
The upper front upper suspension point is measured with the two red plates underneath the suspension point. This is done, so no detachable part is needed here.



As can be seen in the figure above, pins are used to test the tolerances of the chassis. A fit from the measuring hole into the chassis point, proves the chassis is within tolerances of 1mm. For the axial position of the hole, the green faces should be visible, the red surfaces should remain invisible. This should show if tolerances are met.

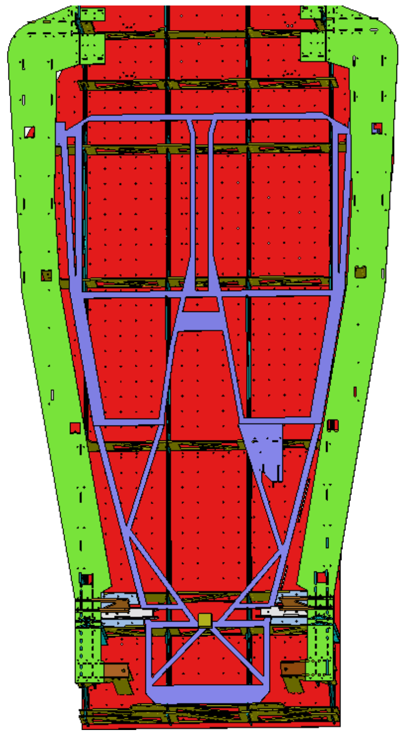
11 Front shocktower





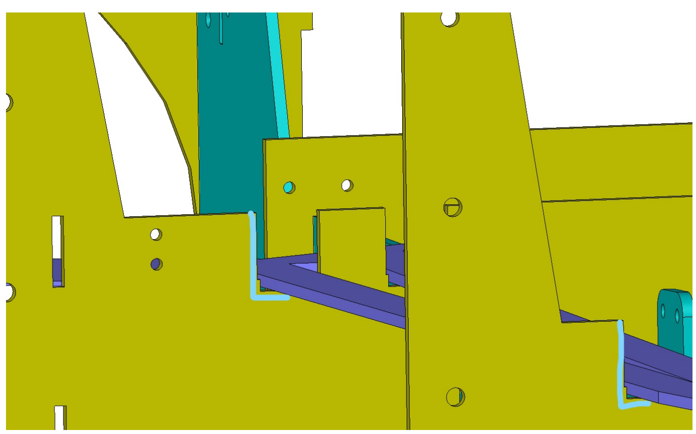
The shocktower along with some other front suspension points are shown. Pins will be used to both define the if they are concentric and if their location is within tolerance.

12 Measuring the tubes



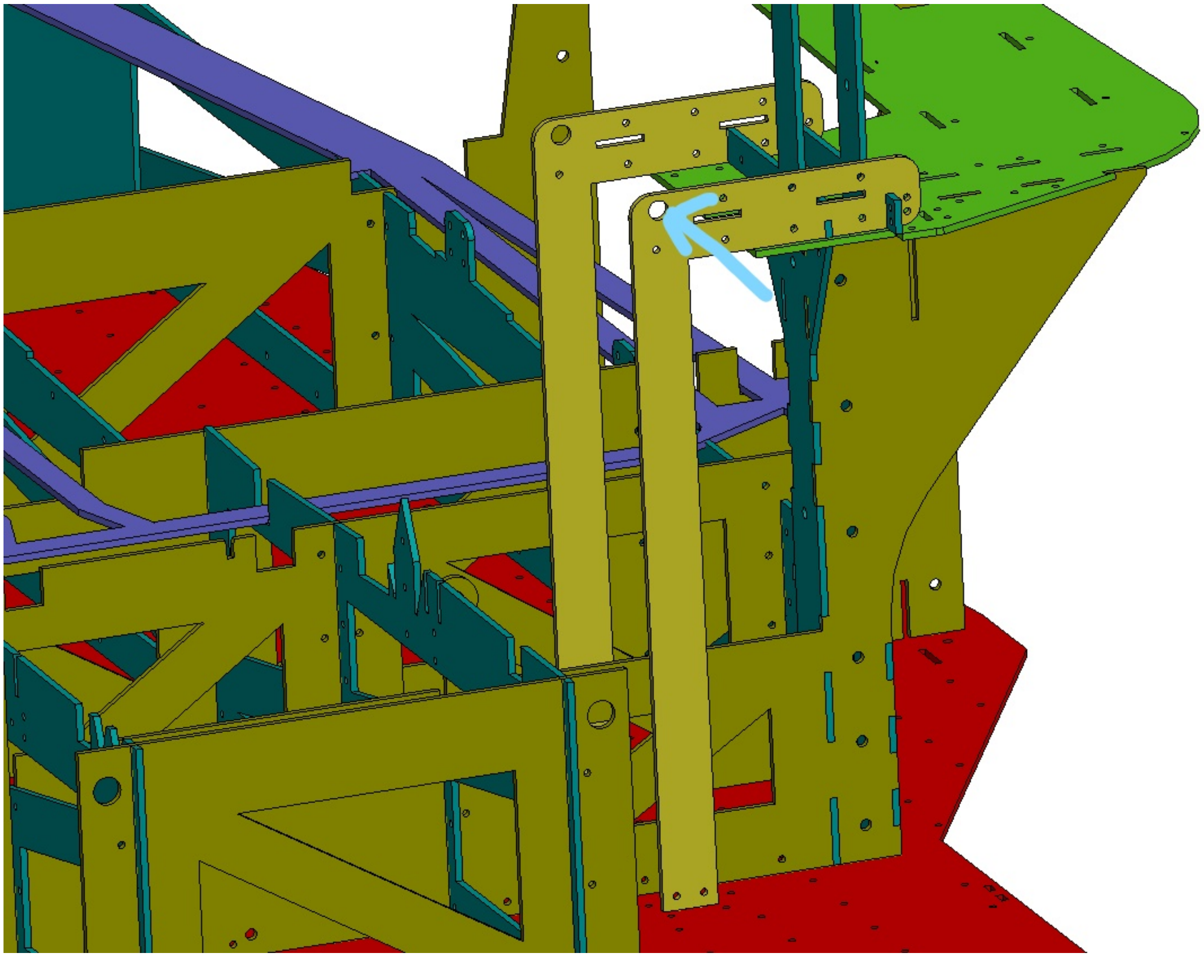
A visualization of all above can be seen in this figure. Also the horizontal upper plates are added fur the purpose of stiffening and as a base for the future addable piece to measure the upper surface of the upper chassis tubes.

The blue plate, a negative of the lower surface of the tubes, can be used as a guideline. This will ensure that between measuring points also no warping is present.

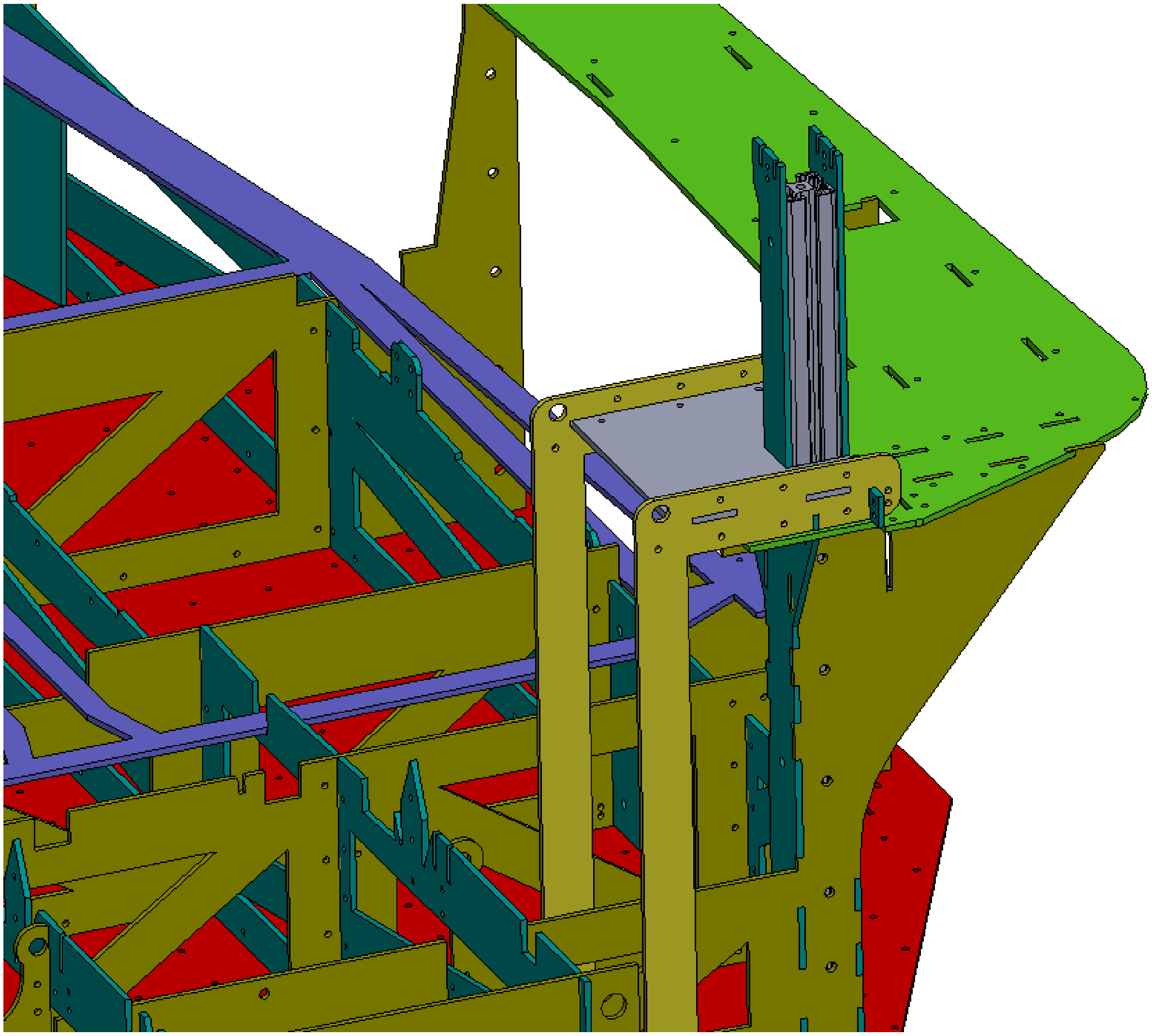


In this figure can be seen that U-shapes are taken out to make room for the tolerance of the chassis tubes. Of most importance are the outer surfaces of the tubes, as they are used as a glue surface for the body panels.

13 Upper rear suspension

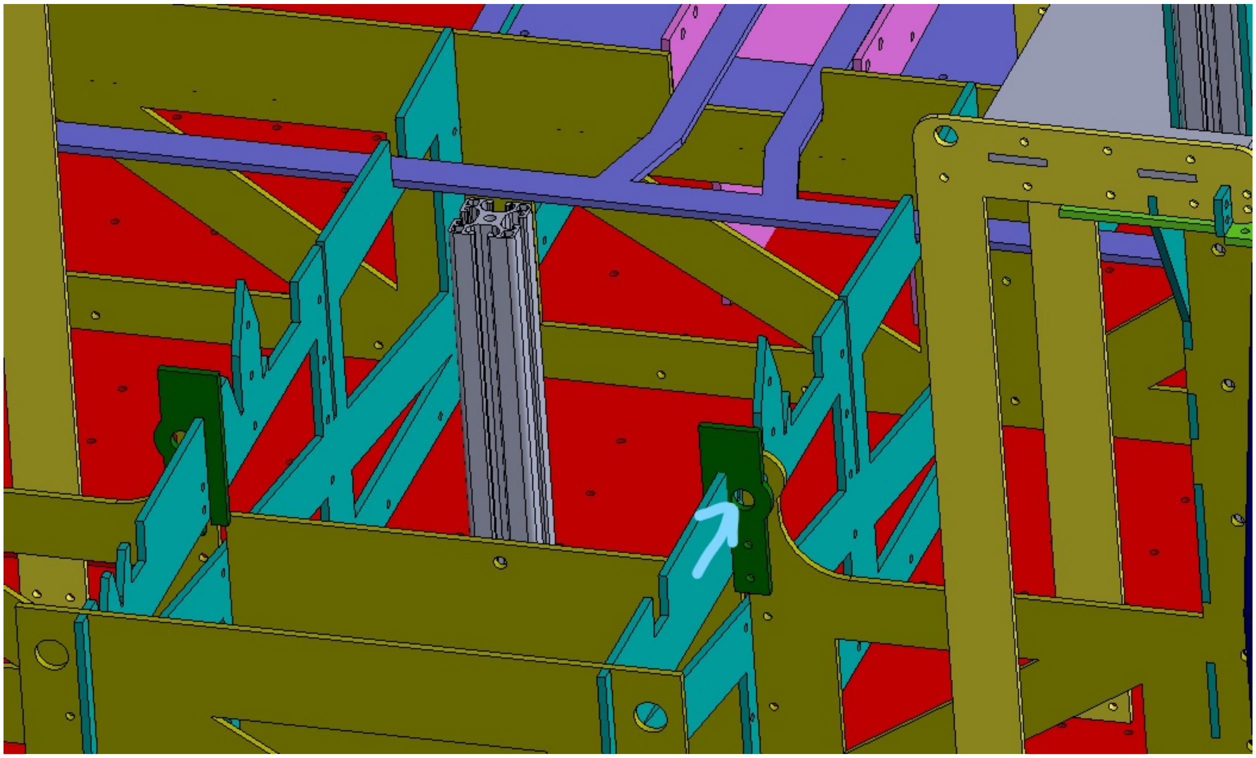


To measure the upper rear suspension, a plate connected to the base plate will be used. This connection is needed to keep tolerances low.



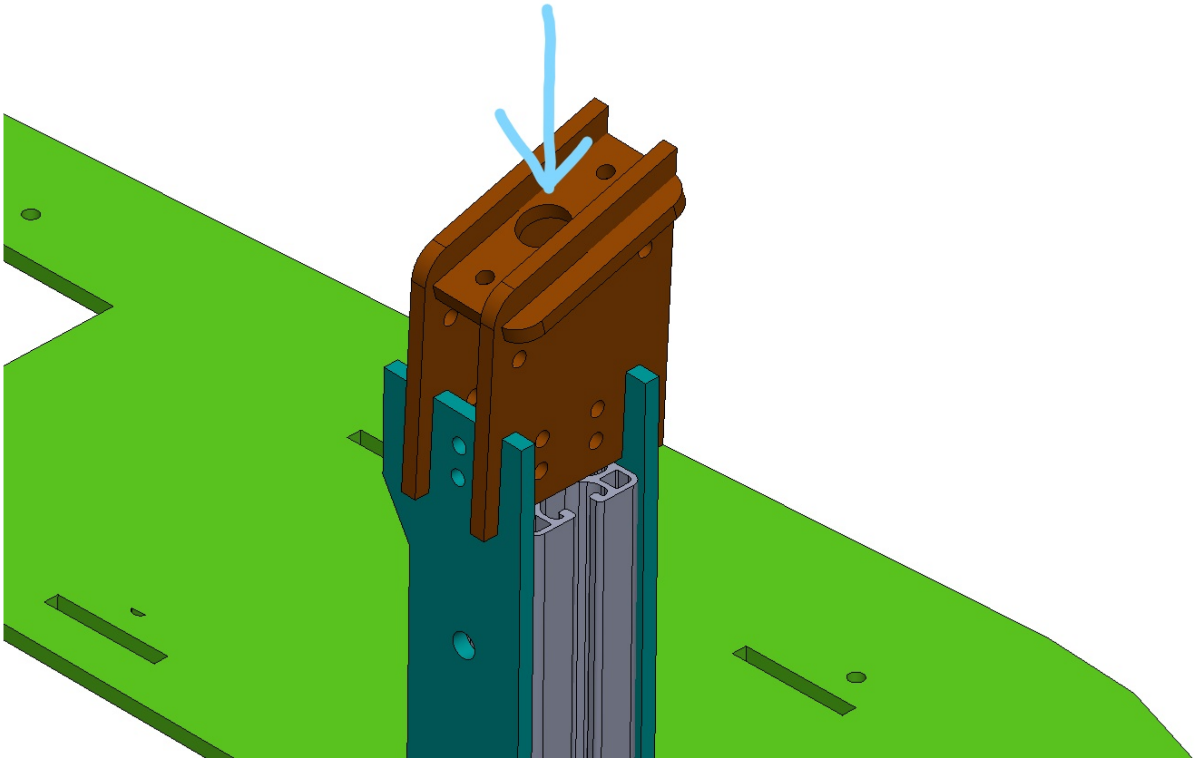
To make the this region stiffer, a horizontal plate is added in between and an extrusion profile is added, which will also be base for the rear shocktower.

14 Lower rear suspension



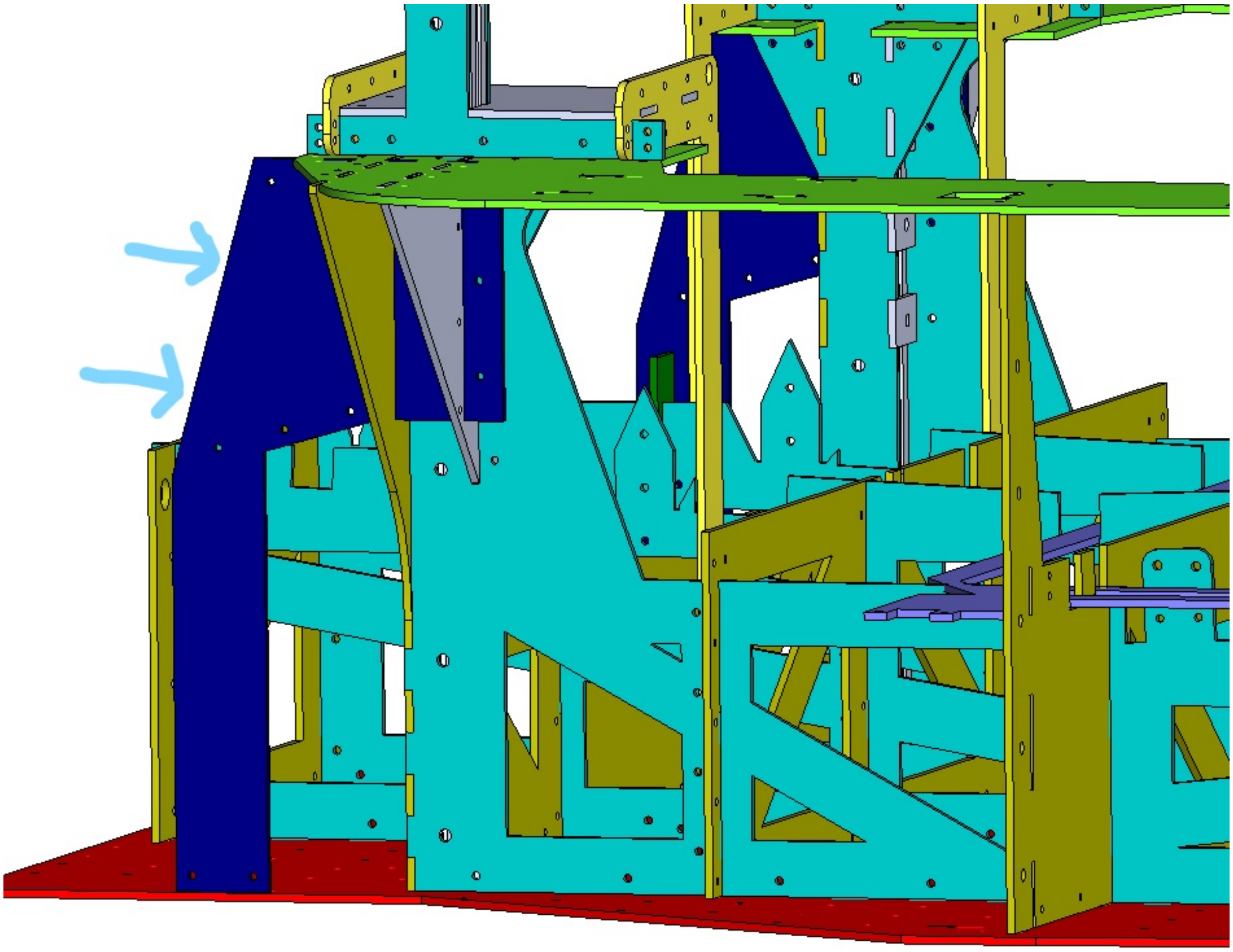
In this figure the lower front rear suspension will be measured. One measuring hole comes from on of the lateral plates in yellow and concentric to this is an extra measuring hole from the extra green plate.

15 Shock tower rear



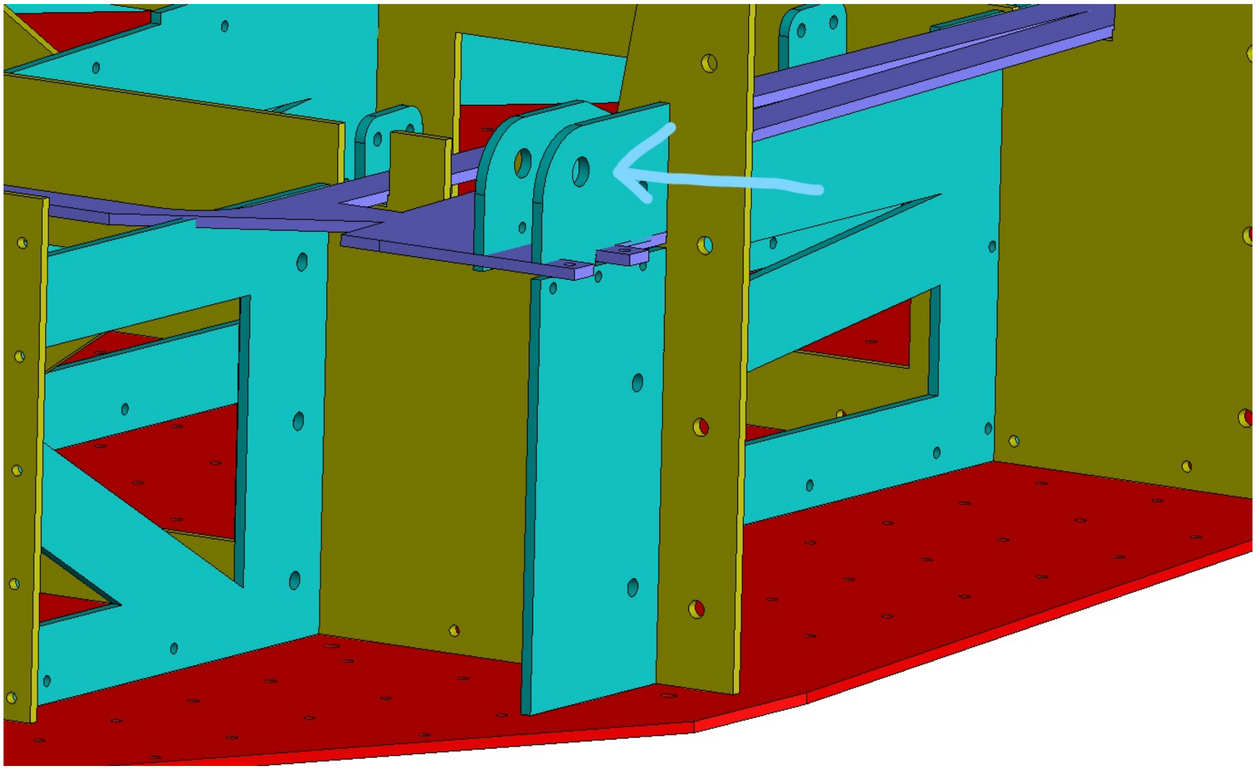
For measuring the shock tower point a piece is added to one of the longitudinal plates. As the shock tower is under two angles in relation to the longitudinal plate, two plates are needed.

16 Rear panel measuring



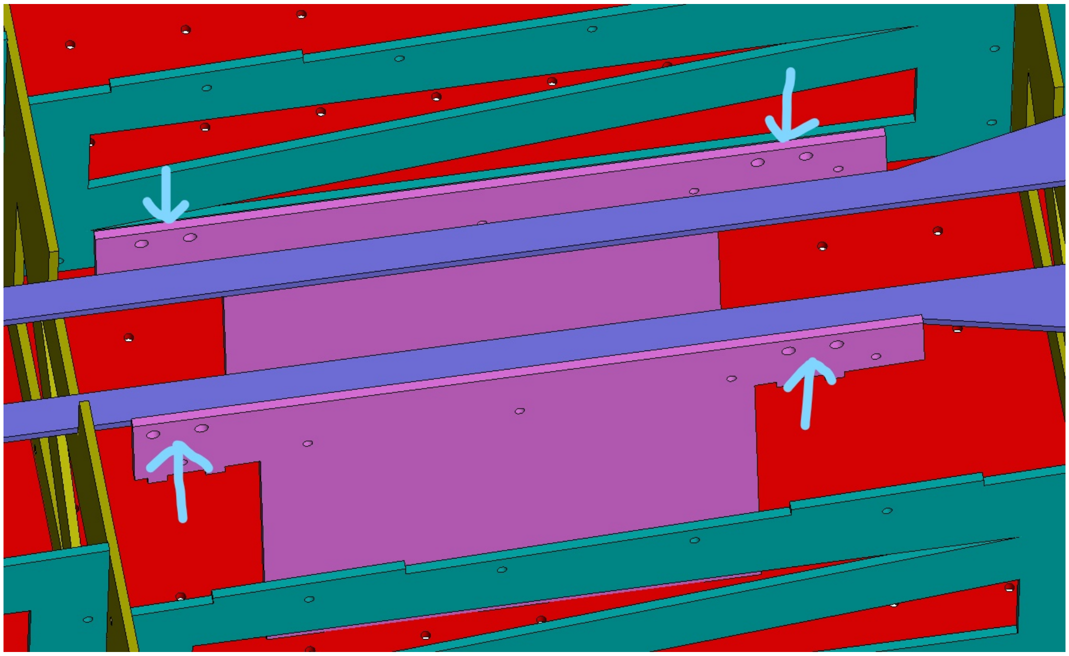
As the rear tube of the chassis is used as a surface for mounting the rear panel, this is measured too. For a stiffened total, this panel is mounted to the base and other near plates.

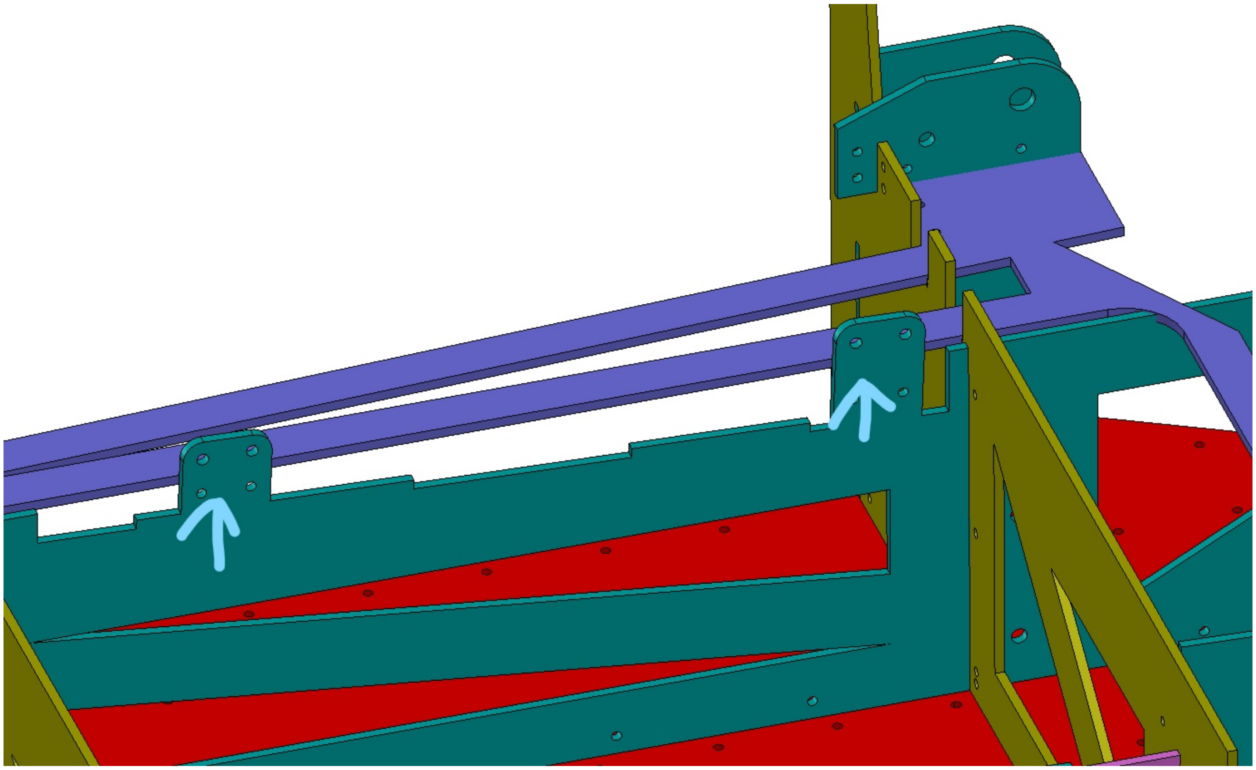
17 Hockenheim



The hockenheim bolting hole will measuring with two plates. One mounted to the base for tolerance purposes.

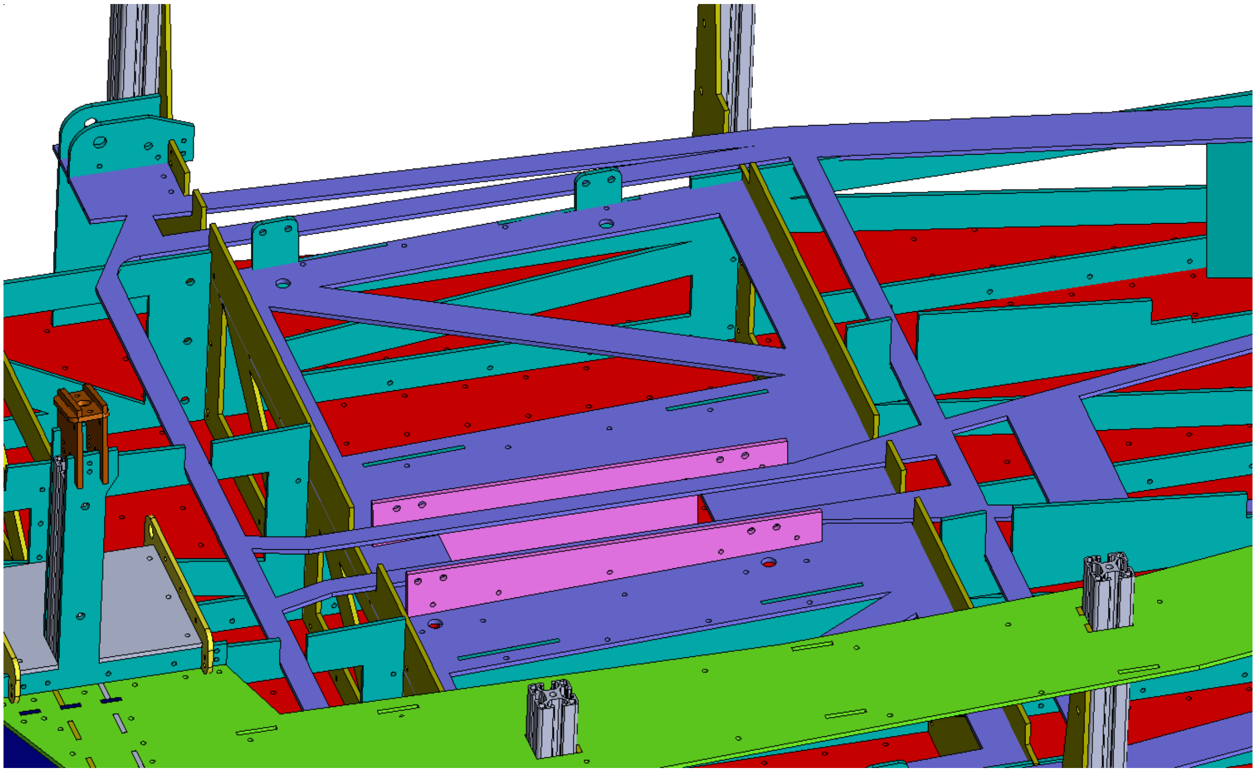
18 Seat brackets





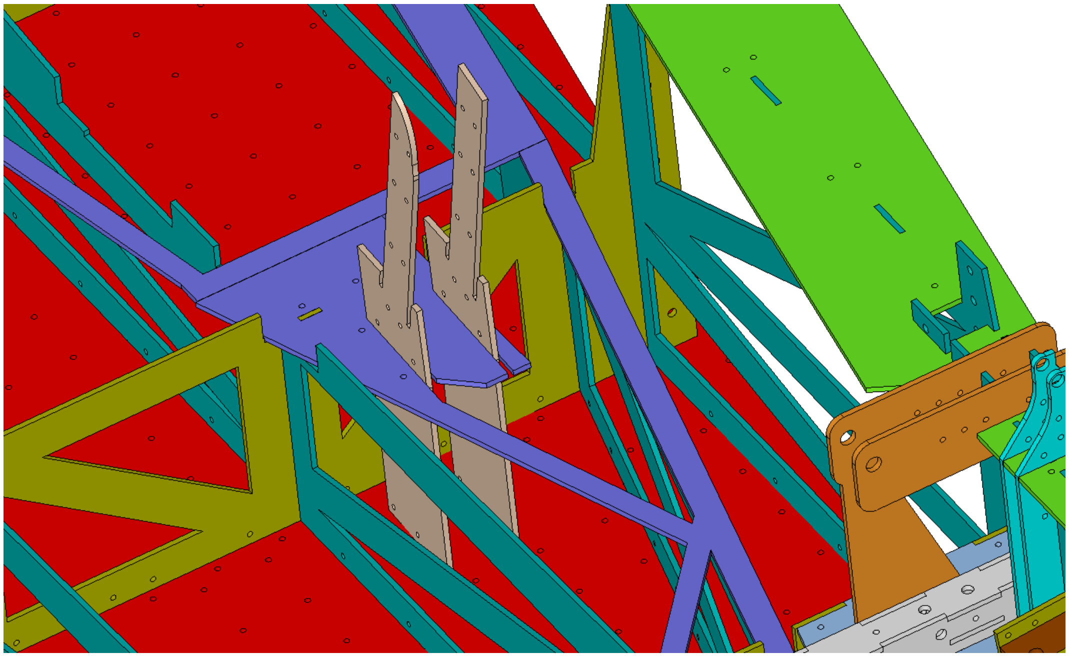
In the middle of the jig, two gray plates are added to measure the seat bracket holes. On the outside in the green longitudinal plates, these are added in their shape.

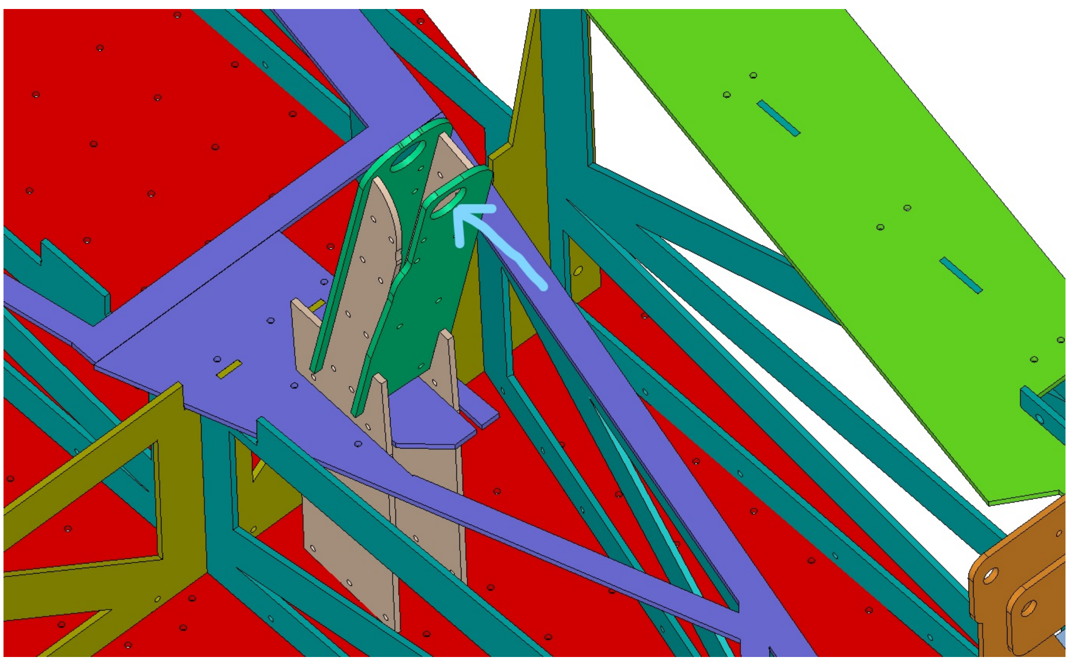
19 Seat bracket stiffening



To add some stiffness to the seat brackets the blue plate is added. also holes are added where seat bolts should come. This will be used as an extra check, or guideline.

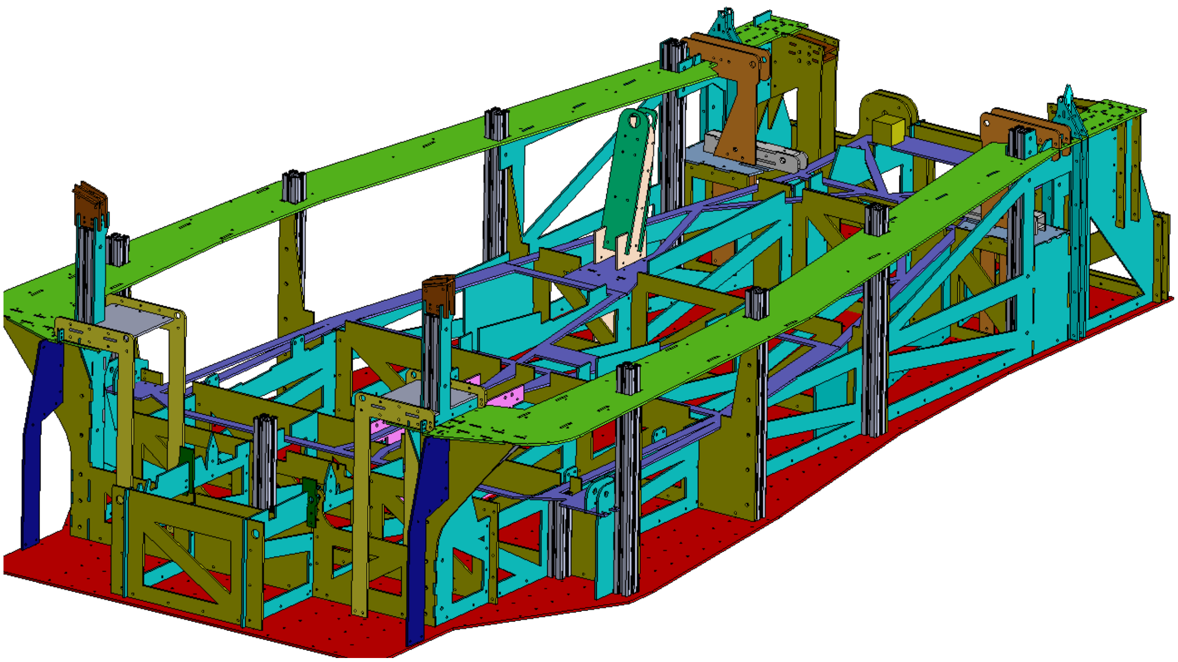
20 Steering tube





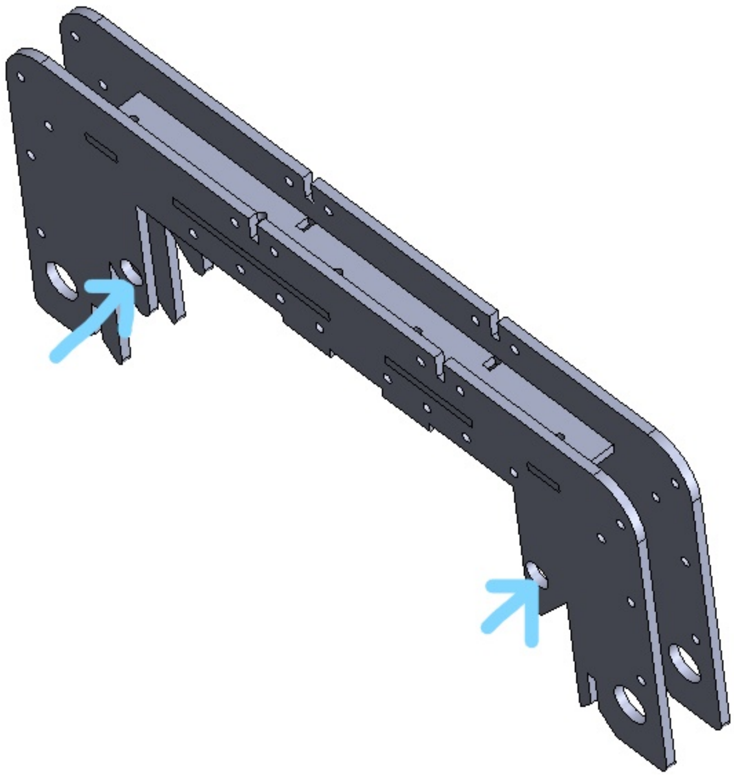
Mounted to the base are also the steering tube measuring plates. A small cut has been made to make room for taking the chassis in and out of the jig. The large holes in the top of the plates will be used for measuring.

21 Extrusion profiles added



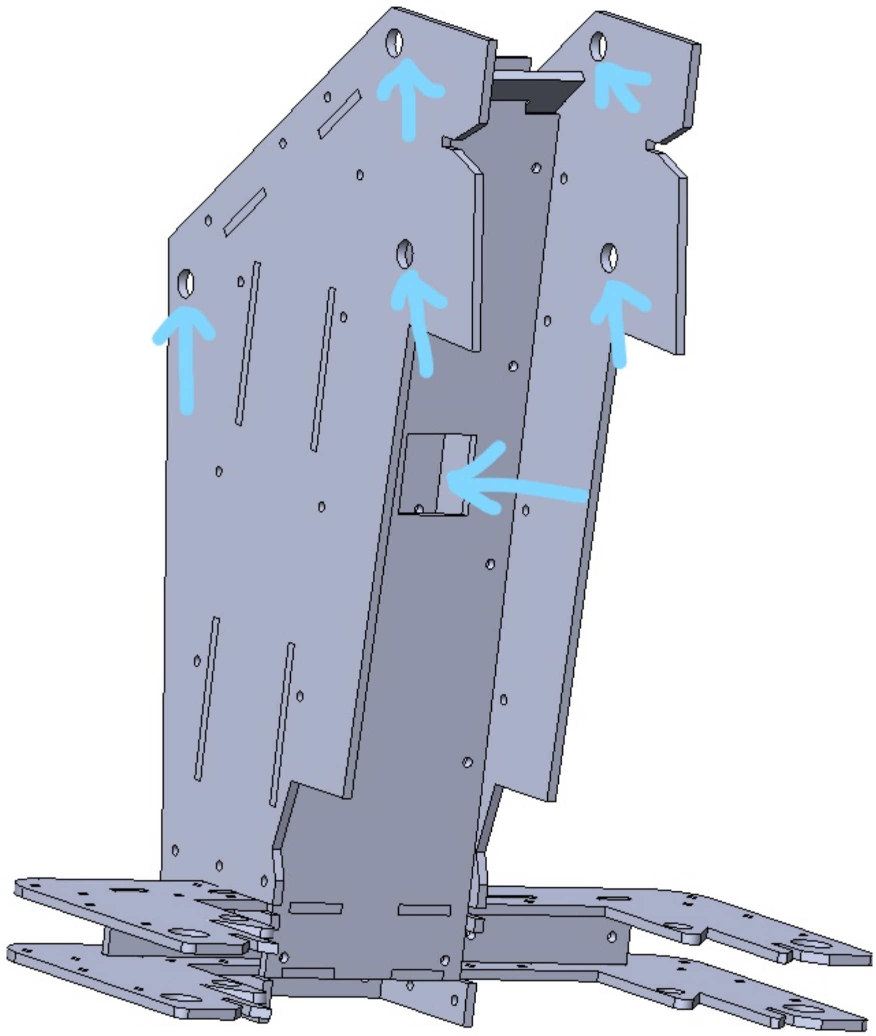
Extrusion profiles on the sides and in the center of the differential area are added in this figure. They will add extra stiffness to the total jig.

22 Rear differential part



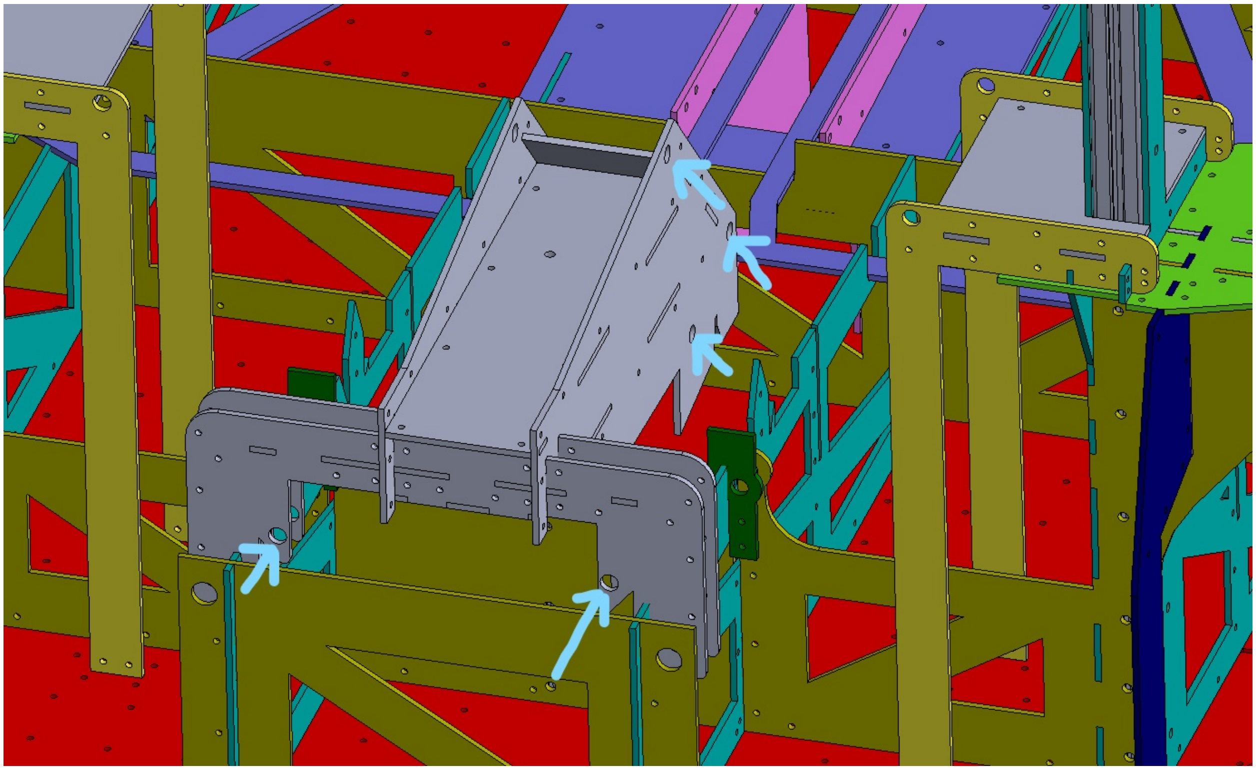
The differential measuring device will be made as a detachable piece. This piece will also be used to measure the lower rear rear suspension. This part will be connected to the differential part, to make one detachable part out of both detachable pieces.

23 Bottem vieuw of the differential part



To visualize the way of mounting the detachable differential part to the jig, a bottom view is made. In this view the square taken out for the extrusion profile in the middle of the differential area can be seen. This will be used as a guidance. Also the holes for measuring the mounting points for the differential are visible.

24 Mounted differential detachable piece



In this figure, the detachable part is mounted in its position. Rear lower holes can be used as centering holes to minimize tolerances. Another hole in the middle of the upper flat plate, will be used to tighten the part to the extrusion profile beneath, as shown above.

25 Closeups with chassis

This section is added to clarify the way the jig interacts with the chassis. Therefore close ups of all measuring points have been made.