POLITECNICO DI TORINO

Master Degree in Automotive Engineering

Dashboard module innovation and weight reduction

Case studies on the application of innovative technologies, materials and concepts

Supervisor:

Dr. Massimiliana Carello

Candidate:

Luca Burani

Company Advisor:

Ing. Leonardo Tiberi

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Introduction

This thesis is the result of the activities carried out during the internship, lasted nine months, hold at the Research & Development department of the Automobili Lamborghini S.p.A. company, and more precisely in the Interiors team of the BIW/Trim unit.

The main topic of the internship was the innovation of the vehicle interiors, developed with numerous activities concerning the scouting of innovative cutting-edge technologies and materials, to be applied in different interior systems and components. Thus, most of the work I did has been finding new external companies and suppliers, managing contacts with them and setting up and carrying on some case studies in order to increase the company knowledge on these innovations, with the final aim of bringing them at a ready-to-use development state. These activities mainly focused on the research of innovative plastic materials and technologies, CFRP technologies, composite materials, acoustic insulation, interior lighting, metal 3D printing (ALM), considering as main objectives weight reduction, optimization of packaging, introduction of Design-Enabling-Technologies (DET), cost reduction and know-how increasing. Furthermore, I supported the other colleagues of the interior team in their developments activities making benchmarks and feasibility studies about different subsystems, thinking up and setting up tests on new components during the validation process for the production, building up FEM analysis to validate the geometry of some simple components and following some prototypes assembly tests.

Therefore, I have had the opportunity to interface with other R&D units (e.g. Aerodynamics, Passive safety, Centro Stile, Whole vehicle development) and other departments (e.g. Purchasing, Quality, Project management, Production). I had also the possibility to deal with many different components and subsystems, that allowed me to learn more about the different aspects that must be taken into account during the design and the development of a new vehicle and the managing of a big company as Automobili Lamborghini.

In particular this thesis will discuss the development of the two main studies I developed during the internship. The first one concerns the application of new lightweight technologies and materials to some existing brackets located in the dashboard module. More specifically, these components, that in the current production are in steel or aluminum, have been redesigned to be produced either in titanium, manufactured through 3D printing technology (ALM), or in CFRP with thermoplastic matrix, manufactured through a thermoforming process. The aim of this study was the weight reduction of the dashboard keeping unchanged the mechanical performances. This activity is structured in three sub parts, the first one concerns the redesign activity, the second the assembly on the vehicle of the components prototyped and the third the tests performed to assess the validity of the design decisions. The second case study deals with the introduction of innovative solutions and concepts on the Cross-Car-Beam (CCB), that is the structural crossbeam that is linked to the body frame and that sustains all the dashboard parts and subsystems. The aim of the activity was to develop a feasibility study modelling a new CCB geometry in order to integrate different functions on the same part (so as to reduce the number of parts and consequently also reducing weight and costs and optimizing the packaging), to bring visible some structural elements (so as to give them an aesthetic function) and to optimize the weight. The first part of the activity involves the building up of the CAD model (taking into account the constraints deriving from passive safety, packaging, assembling, comfort, visibility and ergonomics) and the second part the FEM analysis performed with the aim of structurally optimize the geometry and to estimate the weight.

Before the discussion of these two case studies I inserted a short chapter describing some notions about the components constituting the dashboard module and the Lamborghini interiors, in order to better understand the results of the analysis and the tests performed during the development process.

CHAPTER 1

1 Overview on dashboard module

During my internship activities I focused in particular on two case studies dealing with the innovation of the dashboard module. The first one was applied to the Aventador dashboard, concerning the redesign of some of already existing brackets, the second to the Huracán dashboard, regarding the introduction of some innovative concept. Since both case studies focuses on the dashboard module, I'm going to illustrate firstly its principal functions and components and secondly an overview on the Lamborghini dashboards.

1.1 Principal functions and components

The dashboard module is made up by many different components and subassemblies that are integrated in a single overall assembly in order to reduce costs, improve quality and reduce the space in the vehicle assembly line. In fact, the dashboard module is built up out of the vehicle in a station parallel to the main line, in which all the components are assembled on the Cross-Car-Beam (CCB), that has the function of a carrier. When the assembling is terminated all the dashboard module is brought into the passenger compartment and the CCB is screwed to the body frame. The main components that are part of the dashboard module are:

- Cross car beam
- Steering column
- Steering wheel + driver air-bag
- Instrument cluster
- Climate group/HVAC (Heating Ventilation Air Conditioning) + air ducts and air vents
- Pedal box (only in some cases)
- Firewall (only in some cases)
- Gearshift (only in some cases)
- Overall dashboard/ dashboard trims
- Body computer and electronic control units (ECUs)
- Passenger air-bag (PAB) and knee-airbags

- Wiring, electrical connections, swetches
- Car radio-set
- Glove box

Furthermore, the dashboard is a very important component of the car passenger compartment, contributing to some of the most important functions of the vehicle, such as:

- **Aesthetic function**: the dashboard is one of the key elements in the overall vehicle aesthetic judgement of customers, since it is the first and the most visible thing, after the exterior shape, and the primary interface between the driver and the vehicle.
- **Safety function**: It is important for the active safety to obtain a high level of visibility through the windshield and the front door glasses and it is fundamental to correctly distribute the air through the appropriate apertures (defroster/demister), present on the dashboard. Instead, for the passive safety, it is important to sustain the passenger air-bag and the knee-air-bags, because, in case of impact of the passenger head against the dashboard, the HIC (Head Injury Criteria) required must be respected and the absence of dashboard breaks, that could injure the occupants, must be ensured.
- **Ergonomic function**: it consists of an easy operation of the controls, located on the dashboard and a correct sight of the instrument cluster.
- **Comfort function**: a proper stiffness of the CCB controls the vibrations of the steering column, perceived by the driver through the steering wheel, contributing to a proper distribution of the air in the passenger compartment through air-vents located on the dashboard.
- **Objects containment function**: it is characterized by specific areas on the dashboard in which to place objects (e.g. glove box).

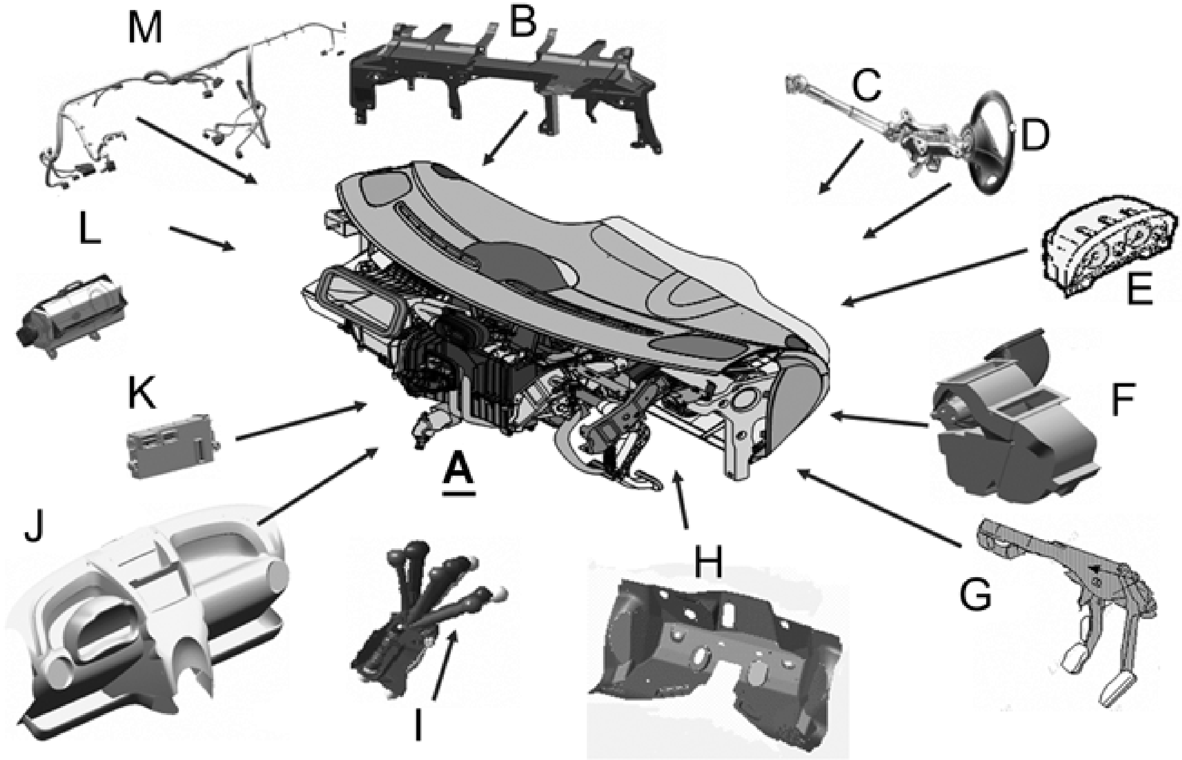


Figure 1.1: scheme of the components that are parts of a dashboard module. Dashboard module A, cross-car-beam B, steering column C, steering wheel D, instrument cluster E, climate group (HVAC) F, pedal box G, fire wall H, gearshift I, dashboard trims J, body computer K, passenger air-bag L, wiring and electrical connection M.

1.2 Description of Lamborghini Aventador and Huracán dashboard

The dashboard modules of the Lamborghini Aventador and the Huracán are visible in the Figure 1.2, respectively on the left and on the right. In this figure some of the components and sub-assemblies already described before, such as the Cross-Car-Beam, the HVAC module, the air ducts and the steering column can be seen. In the Figure 1.3, instead, all the different dashboard trims are represented. In particular, the two vehicles have a similar approach to different parts, constituting the trims of the dashboard. In fact, both have the following components:

- **Trim dashboard**: it is the front part near the windshield. This component incorporates also the defroster air vents and the airducts that exit from the HVAC and bring air to the defroster/demister.
- **Upper dashboard**: it is the upper part that incorporate also the PAB cover and some brackets of the PAB module.
- **Lower dashboard**: it is the lower part that incorporate also the glovebox cover and some of switches and controls.

- **Cluster trims**: they are the upper cover and the bezel of the cluster.
- **Lateral covers**: they are the two lateral covers that are not visible when the doors are closed.

Since the best performances in aesthetics and touch have to be reached, both vehicles have foamed dashboards, meaning that each trim is composed of three parts: the support, the foam and the covering. The supports are made of plastic with two different production technologies that depends on the number of vehicles produced: thermoplastic for the Huracán, of which are produced more cars, and thermosetting for the Aventador, that have almost half the production of the previous. Instead, for both vehicles the coverings are made of natural leather or Alcantara.

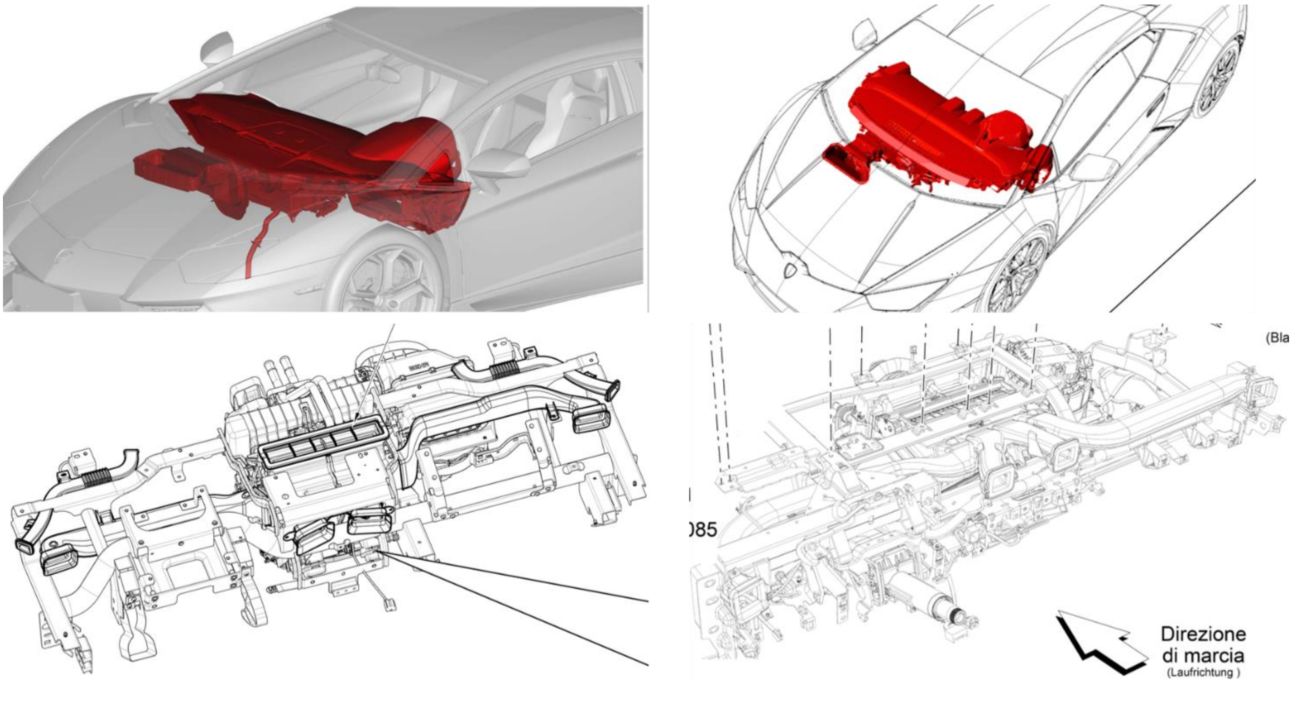


Figure 1.2: Dashboard modules of Lamborghini Aventador, on the left, and Huracán, on the right

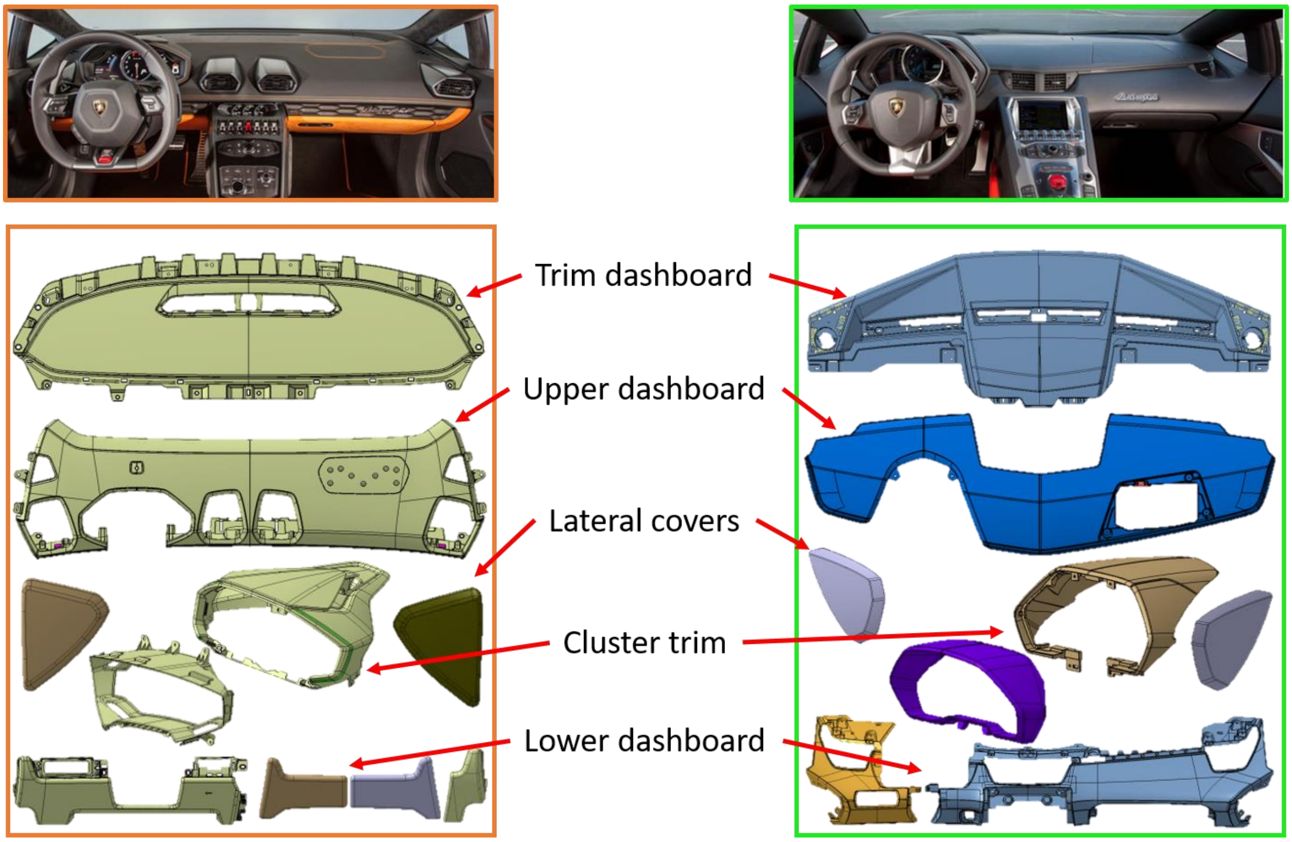


Figure 1.3: dashboard trims of the Lamborghini Huracán, on the left, and Aventador, on the right.

CHAPTER 2

2 Case study 1: Application of titanium ALM and thermoplastic CFRP technologies to the brackets of the Aventador dashboard

2.1 Activity and components description

This activity concerns the redesign of some brackets of the Aventador dashboard. It has been done with the purpose of reducing the weight and, at the same time, doing a technology scouting on the titanium ALM and the thermoplastic CFRP, with the aim of increasing the company know-how on these two innovative technologies. The first part of this work has been developed together with an external technical consulting company that did the manufacturing feasibility study, making 3D models, FEM simulations and the production of the new components prototypes. In this first phase my job was to follow the redesign activity, supporting the consulting company and making sure that the disposals and the mechanicals performance targets were respected, to check at DMU the eventual geometry interferences of the models proposed and find the eventual problems that the geometry changes could have brought. The second part instead concerned the mounting of the components on a prototype vehicle and the performing of the tests necessary to validate them and state if they are compliant with the technical targets.

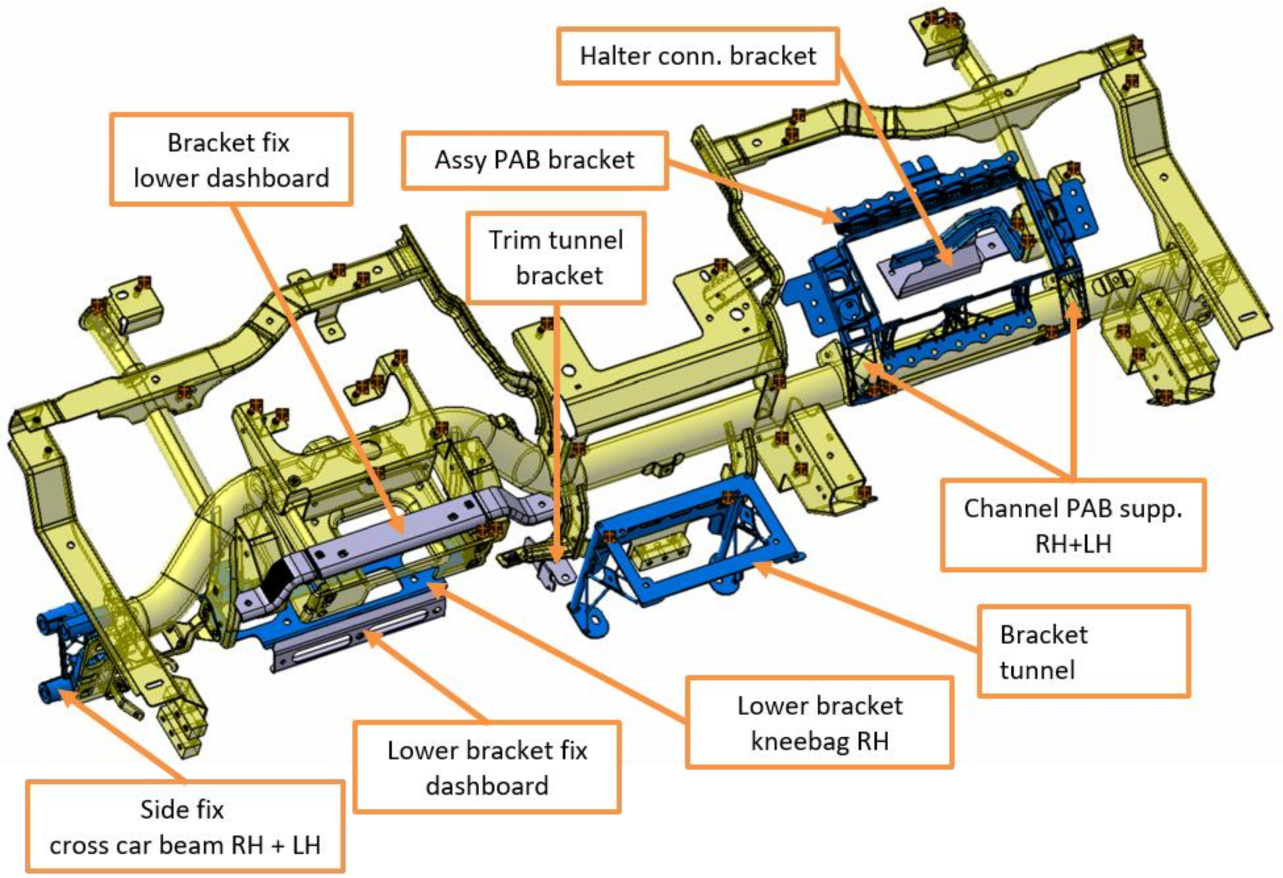


Figure 2.1: The 11 brackets objects of the study. In blue those redesigned to be produced through titanium ALM, in grey those redesigned to be produced through thermoplastic CFRP press-thermoforming.

The components selected for the study are eleven and they are visible in the Figure 2.1, where it can be seen the Cross-Car-Beam in *yellow*, the brackets redesigned to be produced through titanium ALM in *blue* and those redesigned to be produced through thermoplastic CFRP press-thermoforming in *grey*. They are all structural components with the function of interface between the CCB and other subsystems, such as the body frame or the upper and lower dashboard trims. These parts were chosen for their particular shapes, that could adapt better to the application of the two new technologies. Being the current brackets in steel or aluminium, the potential weight saving of the redesigned brackets derives mostly from the lower density of the CFRP and the higher maximum strength of the titanium, taking as reference the same mechanical performances.

In the next pages I'm going to describe, firstly the constraints and load cases utilized during the activity, secondly the application of the titanium ALM technology, thirdly the application of the thermoplastic CFRP press-thermoforming technology and finally the assembling and testing operations.

2.2 Constraints and load cases

This work is mainly focused on upgrading the design through weight savings of the selected components, keeping the mechanical performances unaltered or even improving them. In particular, the first target was to maintain the same stiffness, in order to keep unchanged:

- the deformations under normal loads (e.g. static loads due to weight of other component or dynamic loads due to accelerations, breakings etc.), in order to not generate creaks and noise due to parts in contact;
- the deformations under exceptional loads (e.g. during crash), to not have misuses of the parts with passive safety functions, e.g. a too high deformation of the brackets of the passenger-airbag and of the knee-bag could compromise the air-bags deployments;
- the natural frequency and the vibrations modes of the CCB and, in particular, of the steering column, to avoid too high vibrations on the steering wheel and on the dashboard trims, that could lead to the worsening of the comfort perception by the driver and the passengers.

Anyway, in order to better exploit the titanium and CFRP characteristic of having a very high yield strength, we have opted, in some cases, to not reach the stiffness target, but only verify that the stresses were below a certain threshold. The proposed geometries of the redesigned components have been validated by means of linear static FEM analysis, making stiffness and strength comparisons with the old pieces taken as reference.

Due to the complexity of the components and of the assemblies, in which they are placed, it was too difficult to estimate the real loads, that should be applied in the simulations, and the several tests, that would be necessary to evaluate them, were too much expensive in term of time and costing. Moreover, the reference components are currently in production, and, despite this, we don't have at disposal the loads used during their development at the beginning of the Aventador project (considering that it was presented in 2011 the development phase could have been about ten years ago). Nevertheless, being a relatively old project, we are sure that the current brackets have been tested finely and that their mechanical characteristics are good for the tasks they have to accomplish. As a consequence, the only method for the validation of the new proposed geometries has been act in a relative way, making detailed FEM models of both new and old geometries and comparing their results in terms of stiffness and strength. The load cases applied to these models are the inertial loads equal to ±10G in the main three directions X, Y, Z. To be sure that the mechanicals performance targets were respected, the deformations of the redesigned parts had to be smaller in all directions as well as the ratio between the stresses and the yield strength of the material concerned. For the sake of simplicity and brevity, in the following descriptions of the results of the FEM analysis of each component, only the most critical load cases are showed and described, even if, during the study, all of them have been taken into account and analysed.

Furthermore, a modal analysis has also been performed on the “Side fix cross car beam RH+LH” brackets, that have the critical task of linking the CCB to the CFRP monocoque, sustaining all the dashboard, and have, as a consequence, a primary role on the vibration modes of the steering column. This have been carried out utilizing a pre-existing FEM model of the Aventador CCB, to which the two brackets have been added. In this case the comparison was made analysing both the first natural frequencies concerning the steering column, that have to be equal or higher, and the deformed shapes of the first vibration modes.

Moreover, to not divulgate confidential information, the values of the FEM simulation results are not reported in this thesis and, as well, all the scales in the figures are cancelled. Only some percental values of comparison between the current and the new components mechanical performances are presented.

2.3 First technology: titanium Additive-Layer-Manufacturing (ALM)

The first technology I am going to describe is the titanium 3D printing, also called *“Additive Layer Manufacturing (ALM)”*. This technology has been chosen for its possibility to model very complex shapes, for its ability to put material only where it is necessary and for its capacity of leaving empty all the zones that are not stressed, saving weight. More precisely, the exact technology utilized for the titanium ALM is the *“Electron Beam Melting (EBM)”*, which I will talk about in the following.

The choice of the titanium, in particular the Ti6Al4V alloy, has been taken for the advantages given by the high yield strength (about 860 MPa) that is too much higher than the aluminium (about 150 MPa for AlSiMg alloy and 125 for the Peraluman) and than the steel (about 140 MPa for normal steel and 630 for INOX), materials currently used. The advantages from the stiffness point of view derive from the fact that the titanium has a Young’s modulus of 119 GPa, higher than aluminium (70

GPa) that, instead, has a lower density (4.42 kg/dm^3 vs. 2.7 kg/dm^3). The opposite is the comparison with the steel where the titanium has a lower Young's modulus (119 GPa vs. 200 GPa) but also a lower density (4.42 kg/dm^3 vs. 7.8 kg/dm^3). These characteristics can be reassumed by the ratio between the density and the Young's modulus and, as it can be seen form the Table 2.1, the titanium has the lower one, bringing a further potential weight saving.

Material	Yield Strength [MPa]	Young modulus [GPa]	Density [kg/dm^3]	Density/Young's modulus
Titanium (Ti6Al4V)	860	119	4.42	0.03714
Aluminium (Peraluman EN AW-5083)	125	71	2.66	0.03746
Aluminium (AlSiMg EN AW-6005)	150	69	2.7	0.03913
Steel (DIN EN 1.0130 DC 01)	140	200	7.83	0.03915
Steel (INOX, DIN EN 1.4301 X5CrNi 18-10)	630	180	7.92	0.044

Table 2.1: comparison between the mechanical characteristics of the titanium and of the materials utilized in the brackets of current production.

2.3.1 Description of the EBM (Electron Beam Melting) technology

The Electron Beam Melting (EBM) is a type of additive manufacturing, or 3D printing, technology used for metal parts. In this technique the raw material, i.e. metal powder, is placed under a high vacuum and it consists in built up metal components fusing together thin powder layers by means of a high-power electron beam. A schematic of the EBM operations is represented on the right of the Figure 2.2, where the fusing beam is concentrated, accelerated and directed towards the micro-powder particles, that have a granulometry of 45-80um. At the end the created parts have a density of almost 100%. The Electron Beam Melting process is a hot process, in which the powder is kept at high and constant temperatures throughout the whole melting procedure. The components produced have a low residual stress and they can immediately be used for mechanical processing or assembling. In fact, they are not subject to thermal stretching after melting, resulting in stress relieved components, and they have material properties better than cast and comparable to wrought material. The working process takes place in a vacuum chamber in which the vacuum is held by a system that provides a base pressure of 1×10-5 mbar throughout the entire build cycle. This clean and controlled environment is important to maintain the chemical specification of the built material during the melting process. In particular the machine used in this case is the 3D ARCAM Q20 Printer (on the left in the Figure 2.2), that is specifically designed for the production of aerospace components since it has a large envelope (Ø350×380 mm) that allows the building of large components and permits the optimal stacking of smaller ones.

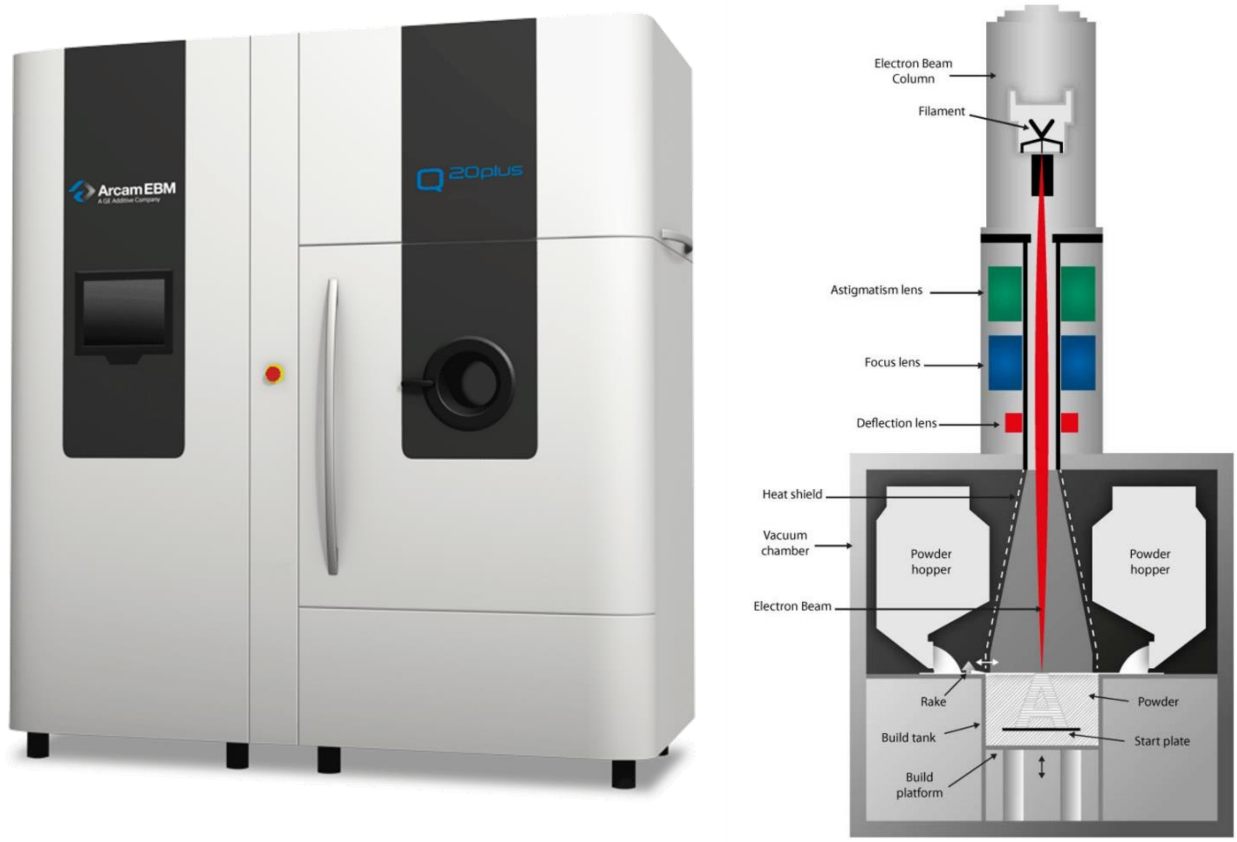


Figure 2.2: on the right a schematic of the EBM process, on the left the ARCAM Q20 plus machine

2.3.2 Components redesign

As stated before, the actual loads applied to the components were not known and this led to not fully exploit the potential of the ALM technology. In fact, knowing the exact loads could have brought to the possibility of carrying out also a topological optimization analysis, which could have helped to shape a more efficient geometry putting material only where was actually necessary with a potential additional weight saving. Since it has been impossible, the design of the geometry of the new components has been performed only by relying on the technical experience in this field of the external consulting company.

In the following, I'm going to describe in detail the manufacturing feasibility study that brought to the redesign of the brackets. For each one of them I will start describing the place in which it is positioned in the vehicle, highlighting the other parts with which it has to interface and the constraints deriving by the mounting operations in the vehicle. Then the final geometry will be showed compared with the current one and the results of the FEM analysis will be explained.

2.3.2.1 Bracket tunnel

The component *"Bracket tunnel"* is positioned at the centre of the dashboard behind the *center-consolle* and it has the primary function of linking the CCB with the CFRP monocoque central tunnel (Figure 2.3). This is one of the five points of junction with the structural body frame (Figure 2.4), so it is fundamental to sustain the dashboard module and to keep low values of the steering column vibrations. After all the adjustments the "Bracket tunnel" is the last dashboard component assembled on the vehicle. In the production line all the subassemblies (e.g. CCB, trims, HVAC, airbags, cables, control-units, etc.) of the dashboard module are assembled together on a special frame outside the vehicle and then brought inside the car. Here the two points in the front and the two laterals are fastened to the frame and adjustments are performed, in order to exactly align all the dashboard trims with the other interior trims. At the end of these operations the "Bracket tunnel" is positioned and it has the fundamental role of recovering the large tolerances due to the regulating operations, so this is why it has holes so large and elongated for the screw connecting the bracket to the CCB and to the central tunnel (Figure 2.6). The secondary functions it has to fulfil are to sustain a control-unit that is hang up to the upper part of the bracket, to have several points of connection for cable-guide grommets and to be an electrical ground connection point (Figure 2.5).

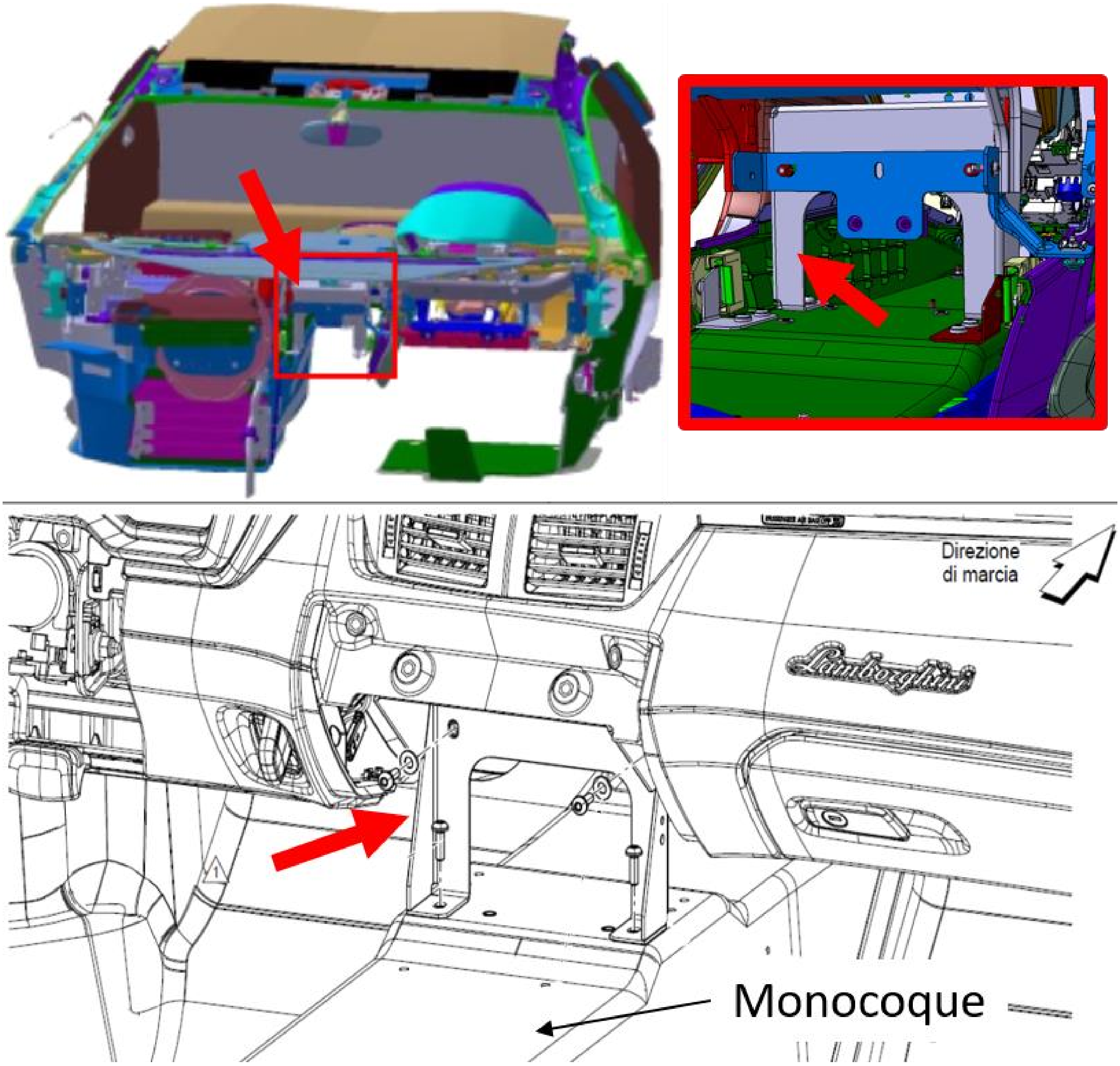


Figure 2.3: position of the "Bracket tunnel" (indicated by the red arrows) at the top and mounting operation in the vehicle at the bottom.

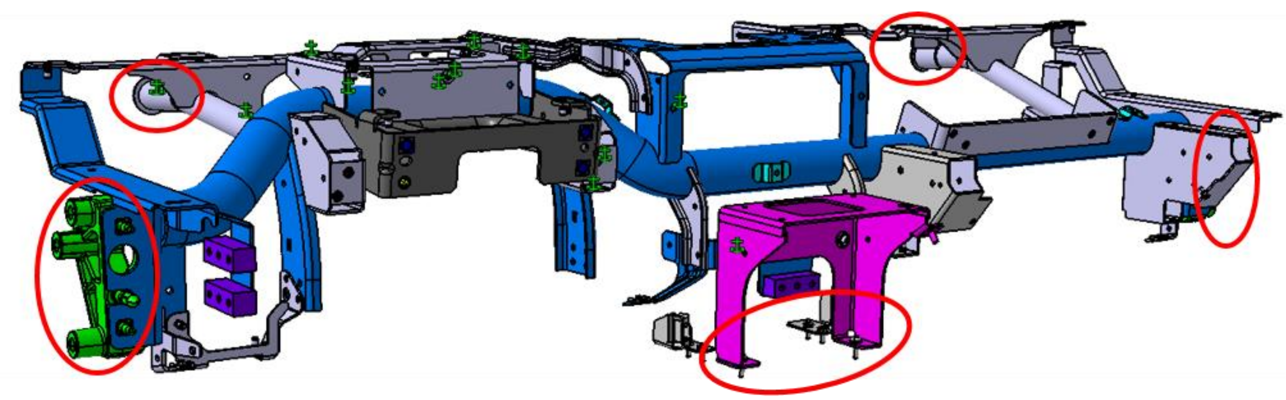


Figure 2.4: Cross-car-beam with highlighted (red circles) the five points of link to the body frame (two lateral, two in the front and one at the centre).

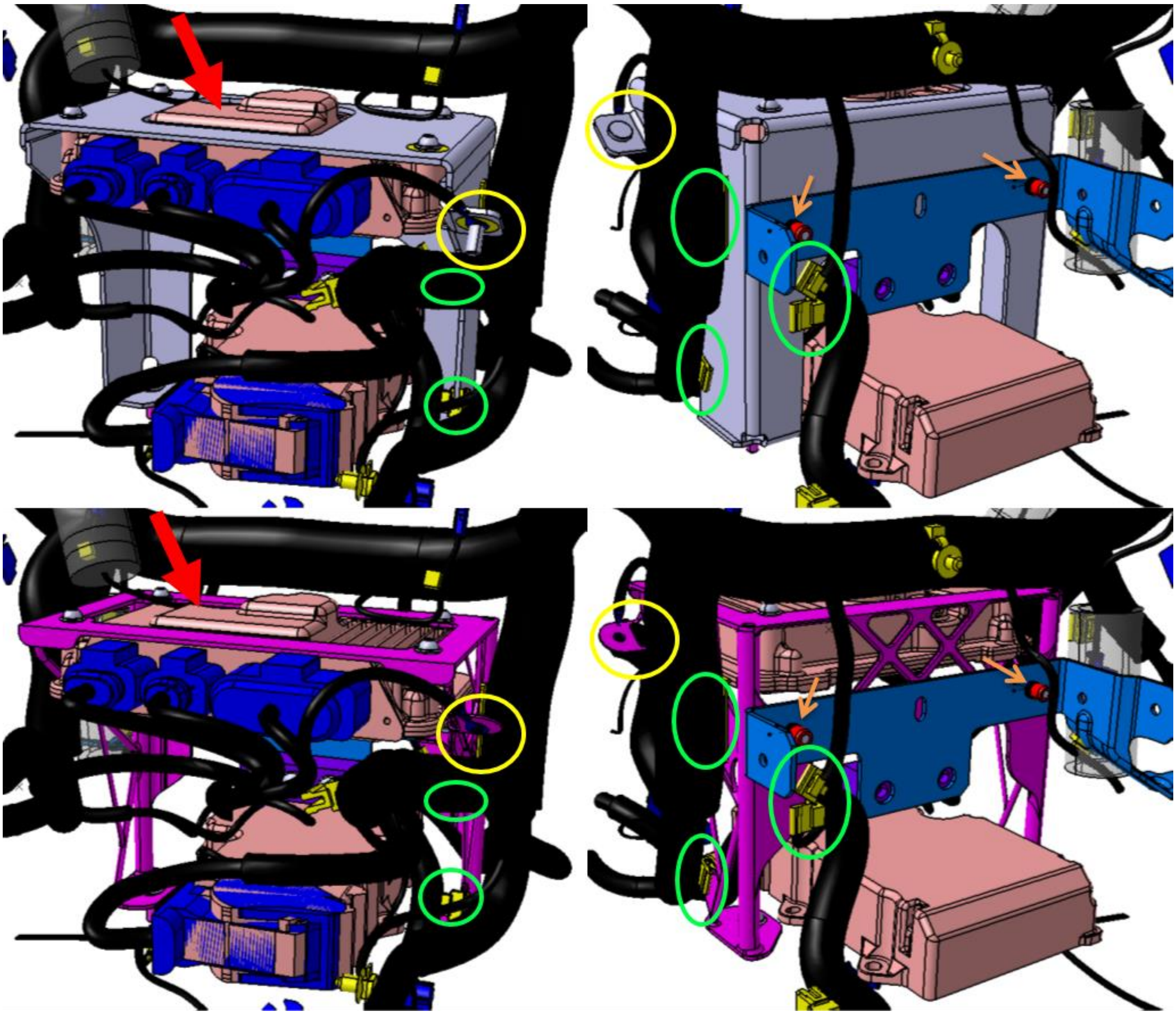


Figure 2.5: functions of the "Bracket tunnel": support a control-unit (red arrow), points of connection for the cable-guides grommets (green circles), electrical ground connection point (yellow circles). On the right the front view and on the left the rear view of the current production bracket(above) and the new one (below). The orange arrows indicate the points of fastening with the blue bracket that is part of the CCB.

The current production bracket**,** is made in a sheet metal of aluminium 5083 through a cut-&-bend manufacturing process. The new bracket (Figure 2.6) weights only the 16,4 % less, so the weight savings is not too high. This is due to the starting geometry that is not ideal for this application and, moreover, the place where it is mounted doesn't leave enough space to feel free to design an efficient shape from the structural point of view. Besides this, also the numerous functions and interfaces with other parts have a bad effect on the weight saving, in particular for the connection points of the grommets where we had to add more material that has not a structural function.

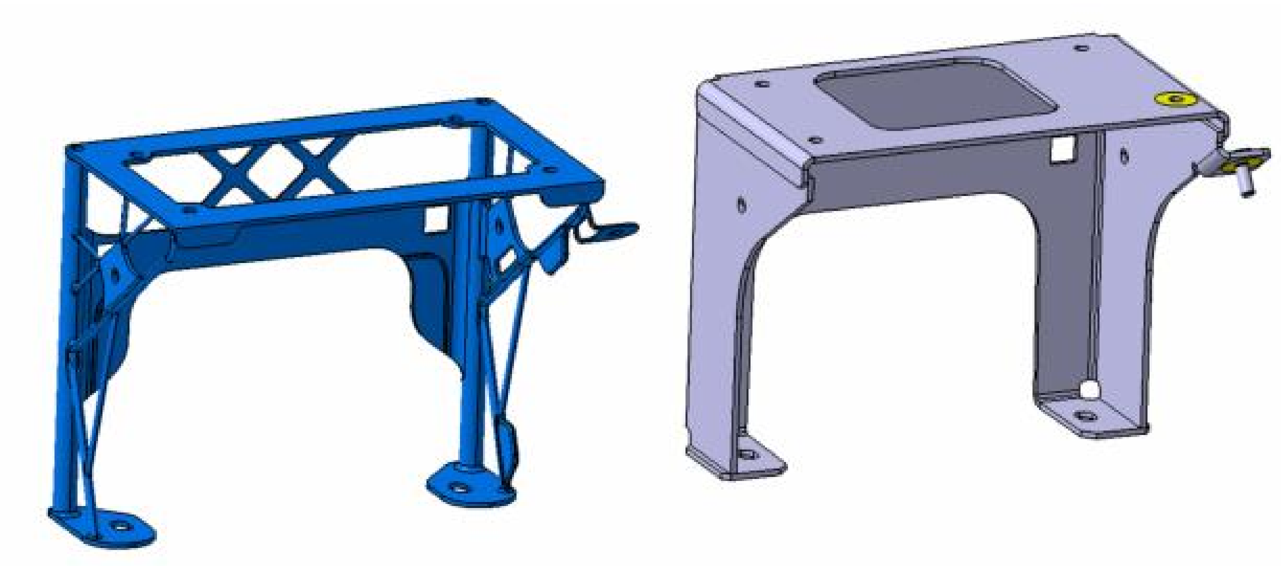


Figure 2.6: comparison between the geometry of the current production "Bracket tunnel" (on the right) and the new one (on the left).

In the Figure 2.7 a comparison of results of the FEM linear static analysis for the current (on the left) and the new component (on the right) are shown. In the upper part the displacements, that are mapped with the same scale, are visualized. In the lower part there are the stresses that, instead, are mapped with a different full scale that is set equal to the yield strength of the respective material. The displacements of the new geometry are higher, but they were, anyway, considered acceptable since they mainly concern the upper part of the bracket, that has only the function to sustain the control-unit, and because the stresses have very low values.

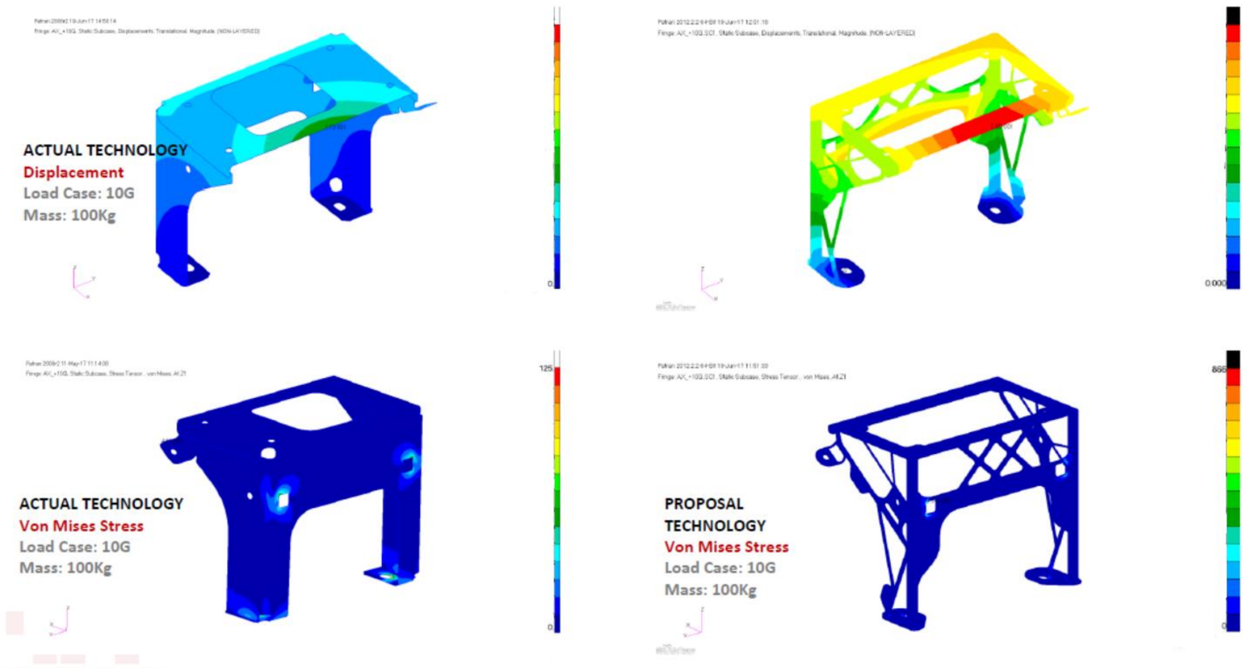


Figure 2.7: "Bracket tunnel" stiffness & strength linear static analysis. In the upper part the displacements of the current (left) and new (right) component are visualized, in the lower part the stresses. To make a better visual comparison the setting of the displacement scale is the same, instead for the stresses the full scale is set to be equal to the yield strength of the respective material.

2.3.2.2 Side fix cross car beam RH+LH

The components *"Side fix cross car beam"* are two, one symmetrical of the other, and are positioned at the sides of the dashboard, the "RH" at the passenger side and the "LH" at the driver side (Figure 2.10). These brackets are the two main points of junction to the structural body frame (Figure 2.9), and their main function is to sustain all the dashboard module, linking the CCB to the A-pillar of the CFRP monocoque. For this reason, having a structural role fundamental for the definition of the steering column natural frequency and vibration modes, in addition to linear static analysis also modal analysis were performed.

The brackets have a complex geometry characterized by three little cylinders with through-holes (Figure 2.9). The faces of these cylinders are in contact with the body-frame and the three bolts visible in figure (Figure 2.10) fasten the bracket to the A-pillar. Therefore, during the mounting process firstly this fastening operation is performed and only after the dashboard module is placed on the vehicle and assembled through the two nuts visible in figure (Figure 2.11) that fasten the CCB to the brackets. For this reason, in both the parts are present the three threaded pins visible in figure (Figure 2.9) that are screwed in three threaded holes present in the planar face of the "Side fix cross car beam". The pin at the top and the one at the bottom are a sort of stud-bolts threaded at both the ends to permit the tightening of the nuts, instead, the one in the middle is an eccentric-pin (visible at the bottom of the Figure 2.9) whose function is to permit the adjustments of the dashboard module position to precisely align its trims to the other interiors trims.

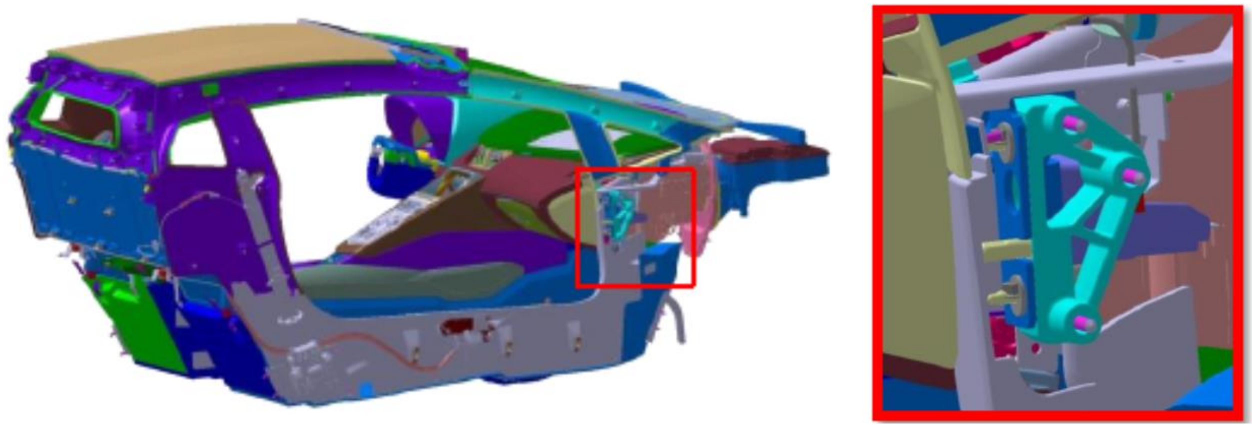


Figure 2.8 Position of the "Side fix cross car beam"

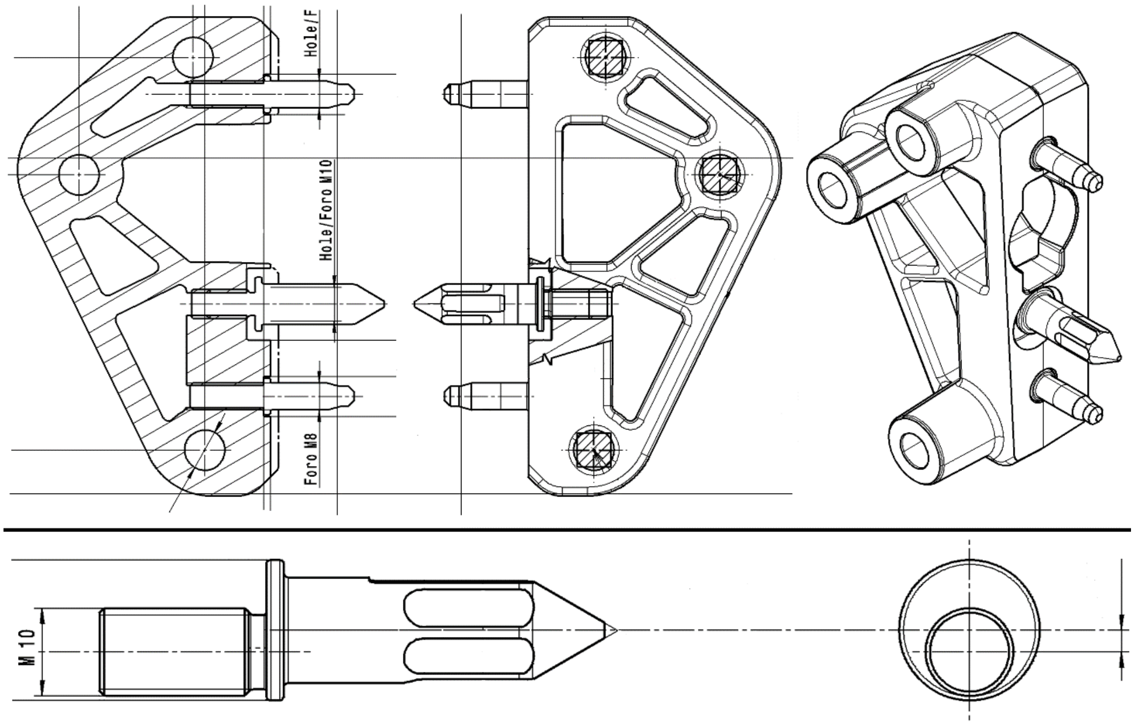


Figure 2.9: "Side fix cross car beam"

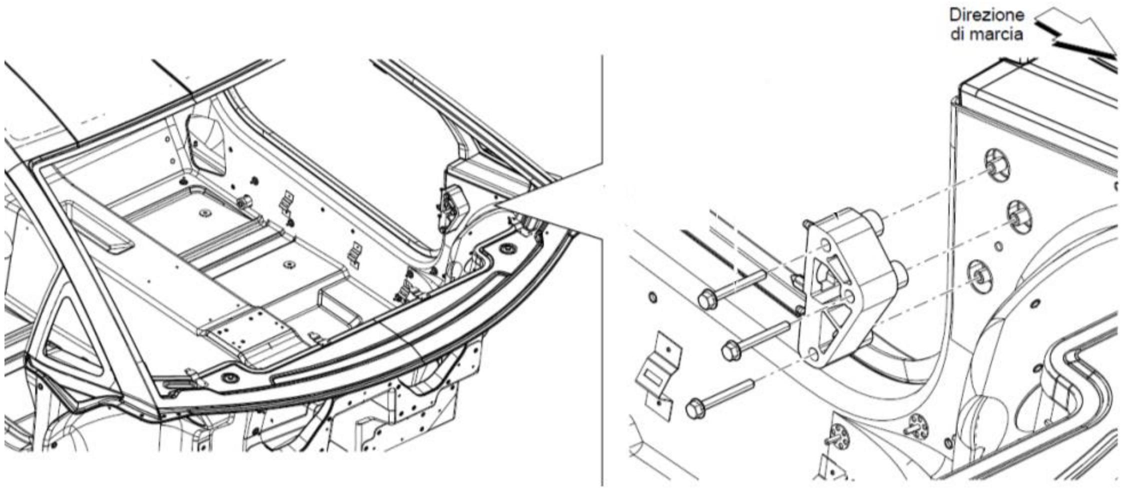


Figure 2.10: mounting operations of the "side fix cross car beam" bracket on the body frame A-pillar

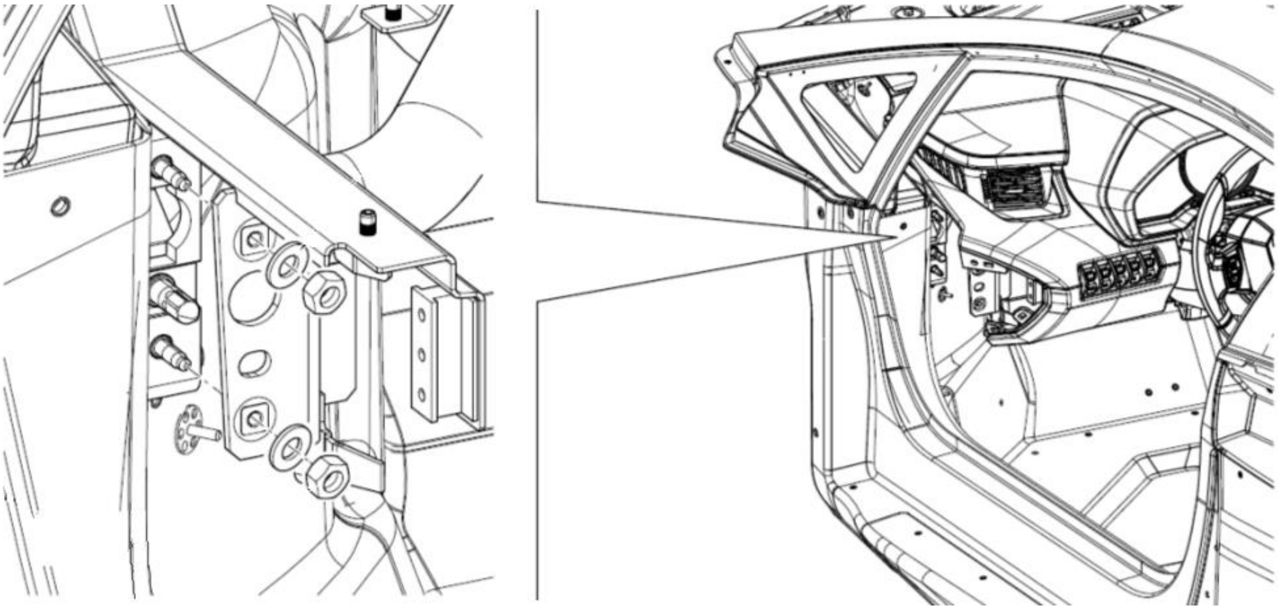


Figure 2.11: mounting operations of the CCB fastening it to the “Side fix cross car beam” bracket

To allow all the assembling operations described above and because there are fundamental parts both for comfort and passive safety of the occupants in case of crash (since they sustain all the dashboard and the loads deriving from the airbags deployments), these pieces have very tight tolerances that have to be respected also during the design of the geometries of the new components. They are currently made in aluminium AlSiMg EN AW-6005 with a casting manufacturing process. The new one in titanium weighs about 20% less. The figure (Figure 2.12) shows the new geometry compared with the previous one and, as it can be seen, it has a leaner shape with less material present.

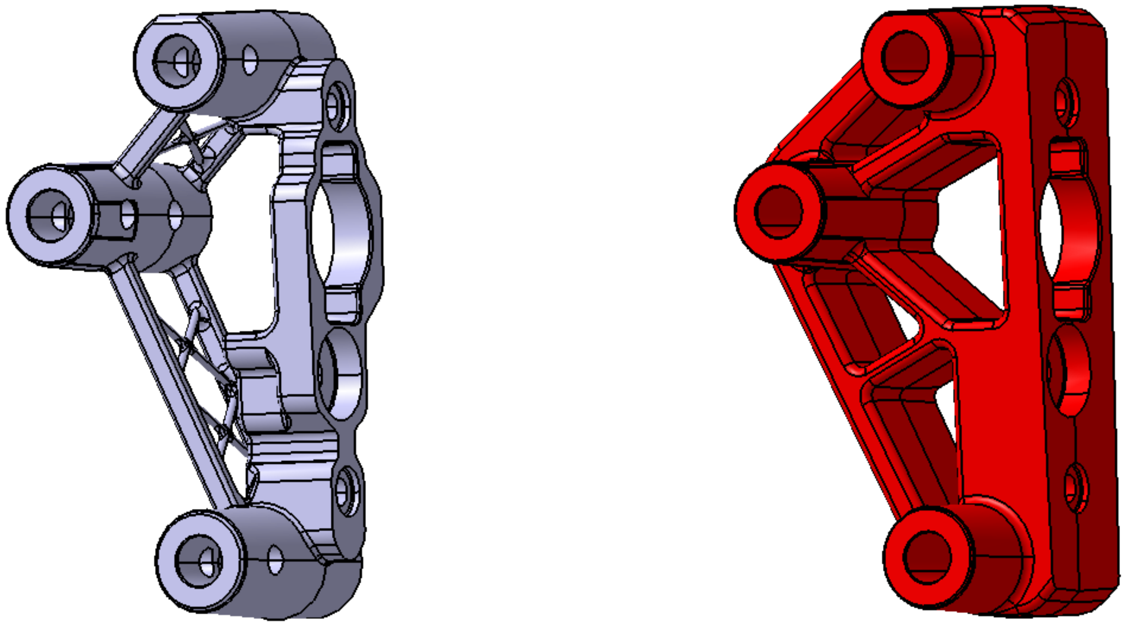


Figure 2.12: Geometry comparison

In the Figure 2.13 a comparison of the results of the FEM linear static analysis for the current (on the left) and the new component (on the right) are shown. In the upper part the displacements, that are mapped with the same scale, are visualized. In the lower part there are the stresses that instead are mapped with a different full scale that is set equal to the yield strength of the respective material. As it can be seen the displacements of the new geometry are higher (about two times), but, also in this case, they were considered acceptable, because of the lower values of the stresses (i.e. the structural integrity would not be affected) and because the lower stiffness of these parts didn't affect too much the values of the first natural frequencies of the steering column, that concern the comfort feeling of the driver. In fact, in order to validate the geometry of these brackets, a modal analysis concerning the cross-car-beam has been made. In particular a pre-existing FEM model of the CCB, that was created during the development of the Aventador project, had been used with the addition of the two "Side fix cross car beam" brackets. The results of the modal analysis can be seen in the Figure 2.14and in the Figure 2.15, that represent the deformed shape corresponding, respectively, to the first and second vibration mode of the steering column, more specifically the first is a displacement in the Z direction and the second in the Y direction. In particular the first **mode in Z** of the new component is at a frequency lower of **0.02 Hz**, that corresponds to a decrease of the **0.08%**, the second **mode in Y** is at a frequency lower of **0.03 Hz**, that corresponds to a decrease of the **0.09%**. Therefore, the decrease of the stiffness doesn't affect too much the natural frequency of the steering column, that was the principal target of these components.

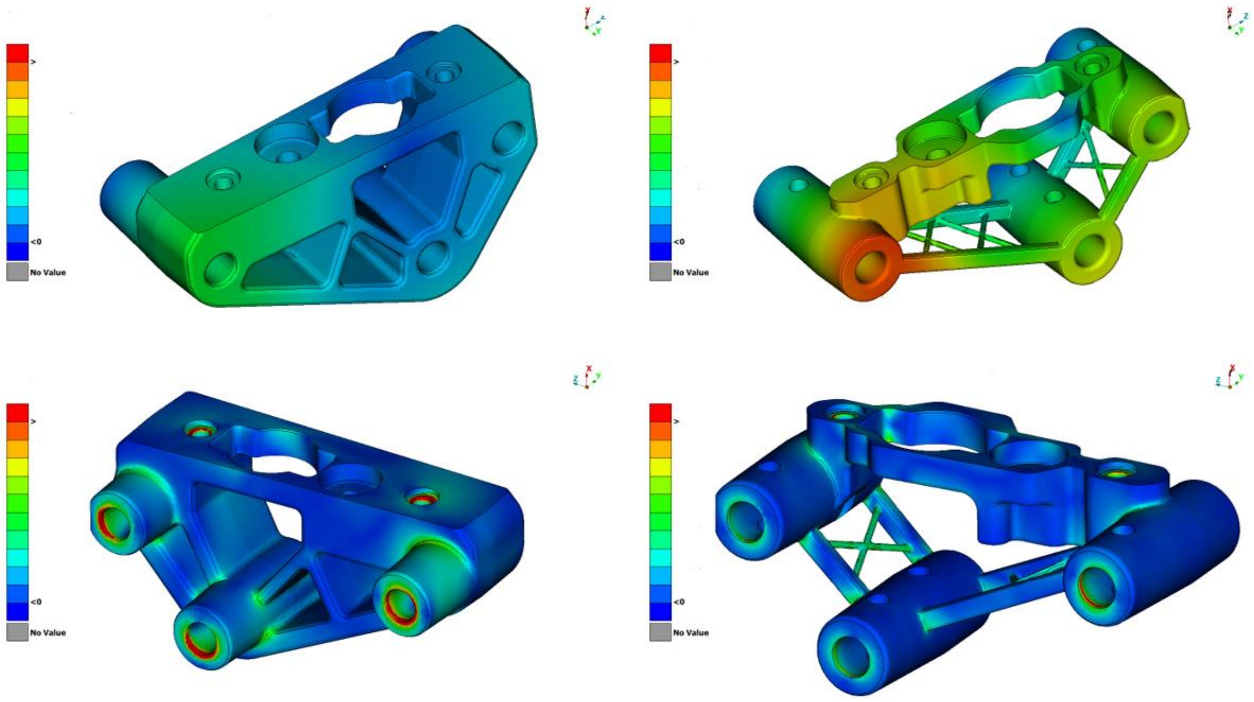


Figure 2.13: static linear analysis on the "Side fix cross car beam". The displacements are displayed on the top, and the stresses on the bottom

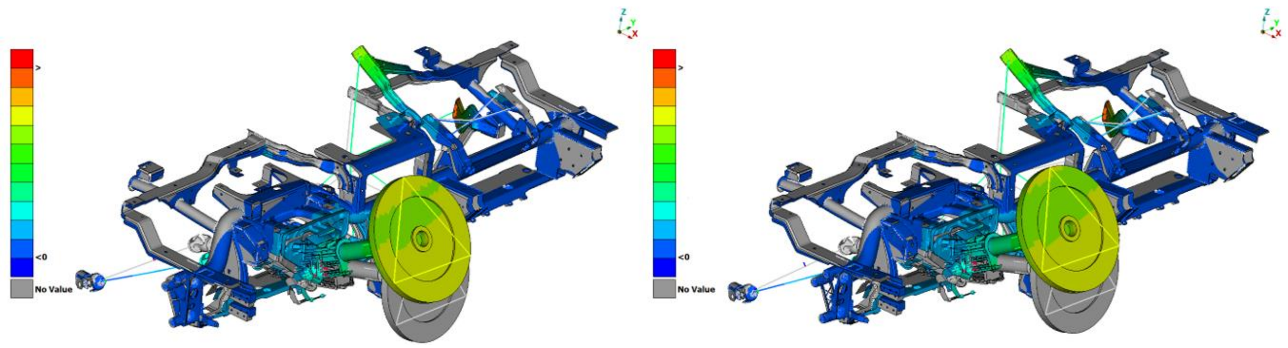


Figure 2.14: deformed shape of the first vibration mode concerning the steering column (displacement of the steering wheel in Z direction)

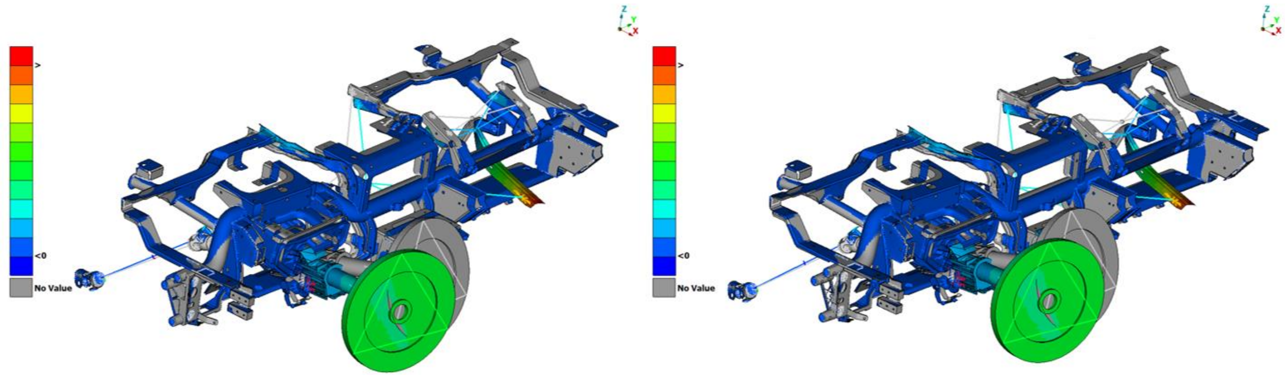


Figure 2.15: deformed shape of the second vibration mode concerning the steering column (displacement of the steering wheel in Y direction)

2.3.2.3 Assy PAB bracket + Channel PAB supp. RH + LH

The components I'm going to consider now are three: the "Assy PAB bracket" (the one coloured in green in the Figure 2.16) and the two "Channel PAB supp. RH + LH" (in pink in the Figure 2.16), that are symmetrical and positioned on the sides of the previous. These brackets are positioned at the passenger side, they are part of the PAB (passenger air bag) assembly and they have, as a consequence, a role in the passive safety of the passenger, sustaining the PAB module. In particular, the two "Channel PAB supp." have the function of counterbalance the recoil forces of the airbag deployment during a crash and the "Assy PAB backet" act as a slide for the bag and it restrains the upper-dashboard trims, allowing the correct detachment of the PAB-cover. Due to their occupants' safety function, the improvement of their mechanical performance has been particularly studied.

The "Assy PAB bracket" is composed by seven different parts (Figure 2.17) of INOX sheets-metal cut, bend and welded together. In the assembling operations of the dashboard module this component is firstly fastened to the upper-dashboard and lower-dashboard trims through many screws all along its perimeter (on the left of Figure 2.18), which permit the restrain of the trims during the deployment of the air bag, that causes the detachment of the cover. After that, the PAB-cover is positioned and fastened to the bracket by means of some rivets (on the right of Figure 2.18).

Both the two "Channel PAB supp." Are, instead, composed by only one part of steel sheet-metal cut, bend and welded to make the shape visible in the Figure 2.17. Moreover, as it can be seen in the Figure 2.21, two stud-screws and a pin are welded: the firsts have to sustain the PAB module and the second is necessary to avoid wrong mountings in the production line. These brackets are directly assembled on the CCB (Figure 2.19) by means of two screws each.

Subsequently, after some assembling operations, the dashboard trims are mounted on the CCB and the "Assy PAB bracket" is connected to the two "Channel PAB supp." by means of two screws (the two grey screws visible in the Figure 2.17) and at the end the PAB module is positioned from the bottom and it is constrained to the brackets (Figure 2.20).

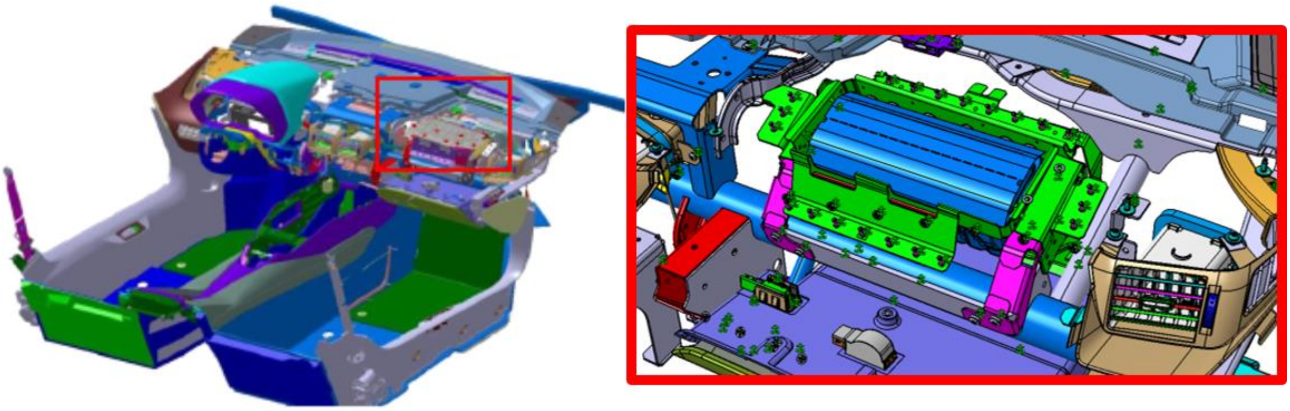


Figure 2.16: position of the "Assy PAB bracket" and "Channel PAB supp. RH + LH"

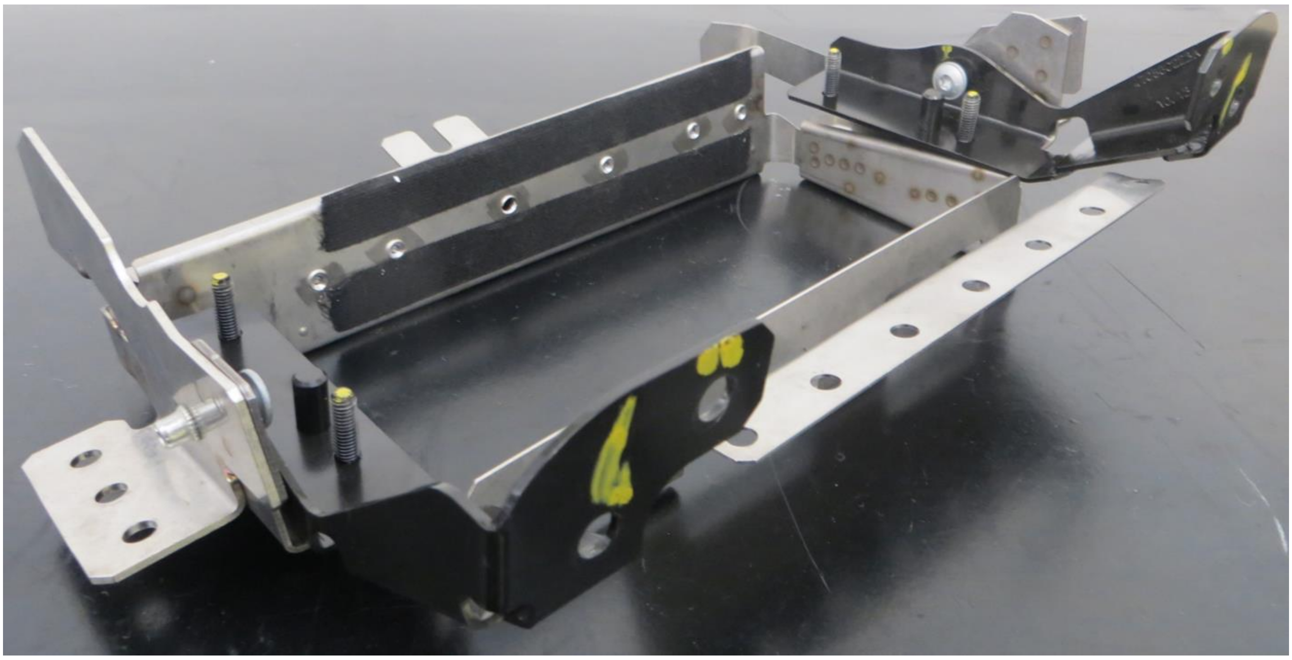


Figure 2.17 Assy PAB bracket + Channel PAB supp. RH + LH

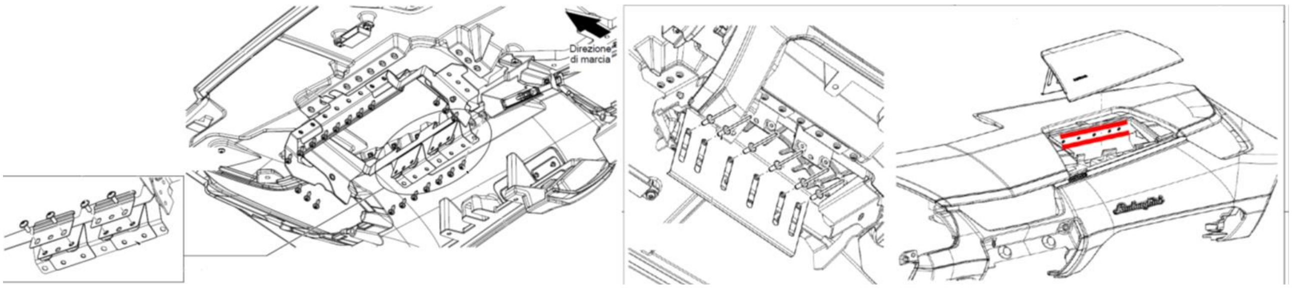


Figure 2.18: mounting operations of the Assy PAB bracket

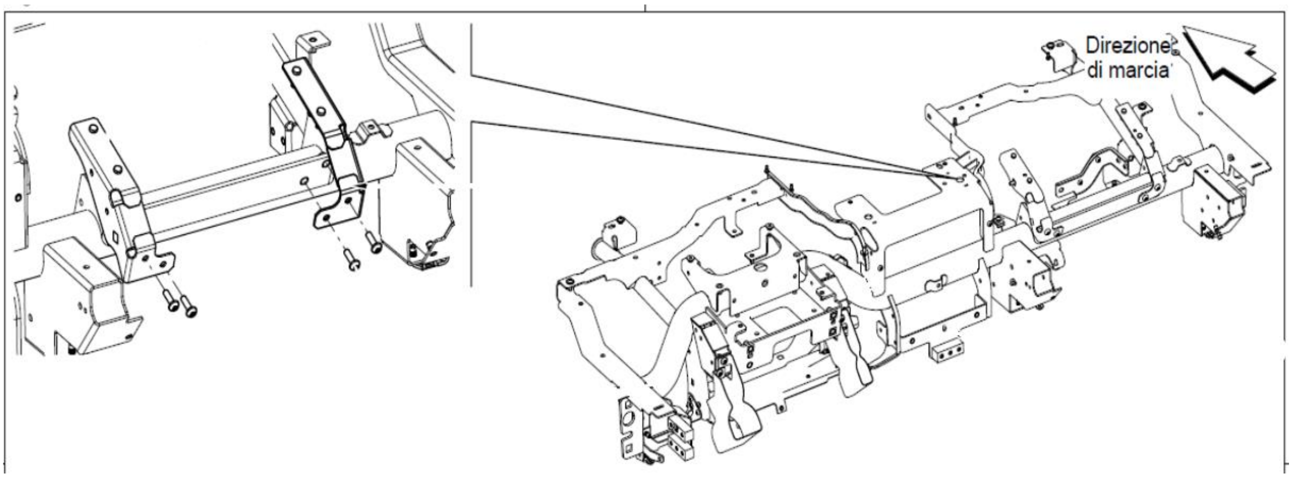


Figure 2.19: Mounting operations of the Channel PAB supp.

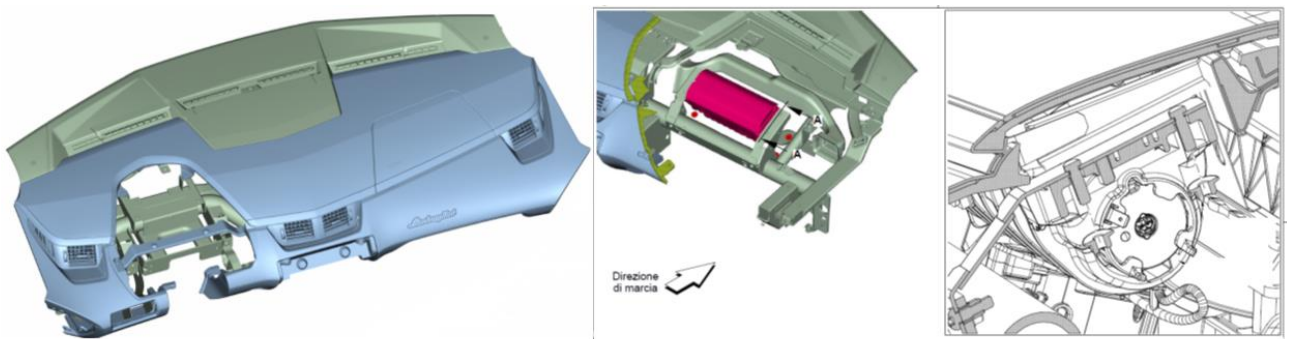


Figure 2.20: Mounting operations of the PAB module

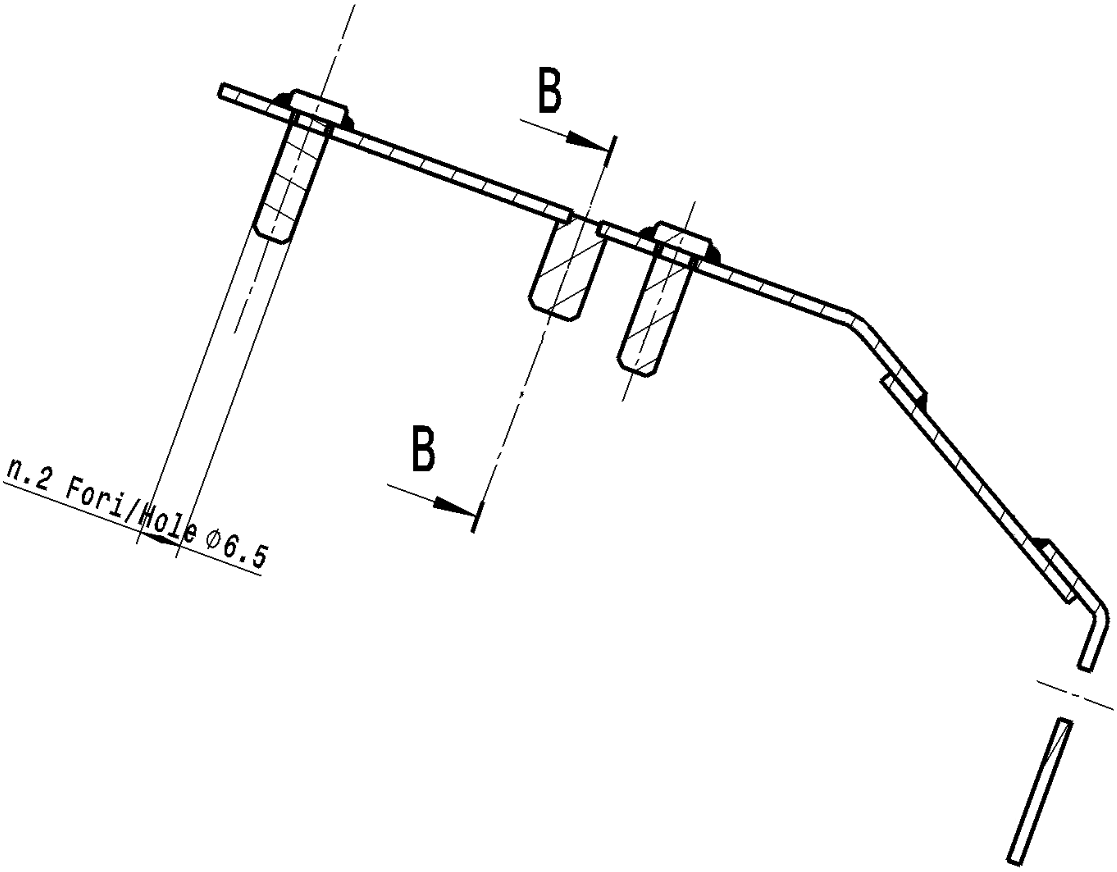


Figure 2.21: Drawing of the Channel PAB supp.

Due to these assembling operations explained before, it was impossible to merge the three brackets, integrating all the functions in only one, that would have been the best thing to exploit at maximum the ALM technology. Moreover, some constraints, derived from the surfaces of interface with other components (e.g. dashboard trims), didn't permit to be free in redesigning the geometries of the brackets. Anyway, thanks to the fact that they are currently made of steel (in INOX the "Assy PAB bracket" and in DIN EN 1.0130 DC 01 the "Channel PAB supp"), a very heavy material compared to the titanium, and that the starting seven welded parts were reduced to only one for the first bracket, it was possible to reduce the current overall weigh of the 57% for the new components. In the figure (Figure 2.22) it is possible to see the new lighted geometries compared with the previous. An important geometry modification, that has to be noted, regards the two "Channel PAB supp." in which the two welded screws have been substituted by two threaded holes in which are tightened two bolts creating two stud-screws. In fact, since the materials were changed to titanium, it would no longer be possible to weld the two steel screws and, therefore, this solution had to be adopted. For the welded pin, instead, this problem has been solved obtaining it directly from the geometry of the bracket modifying its shape.

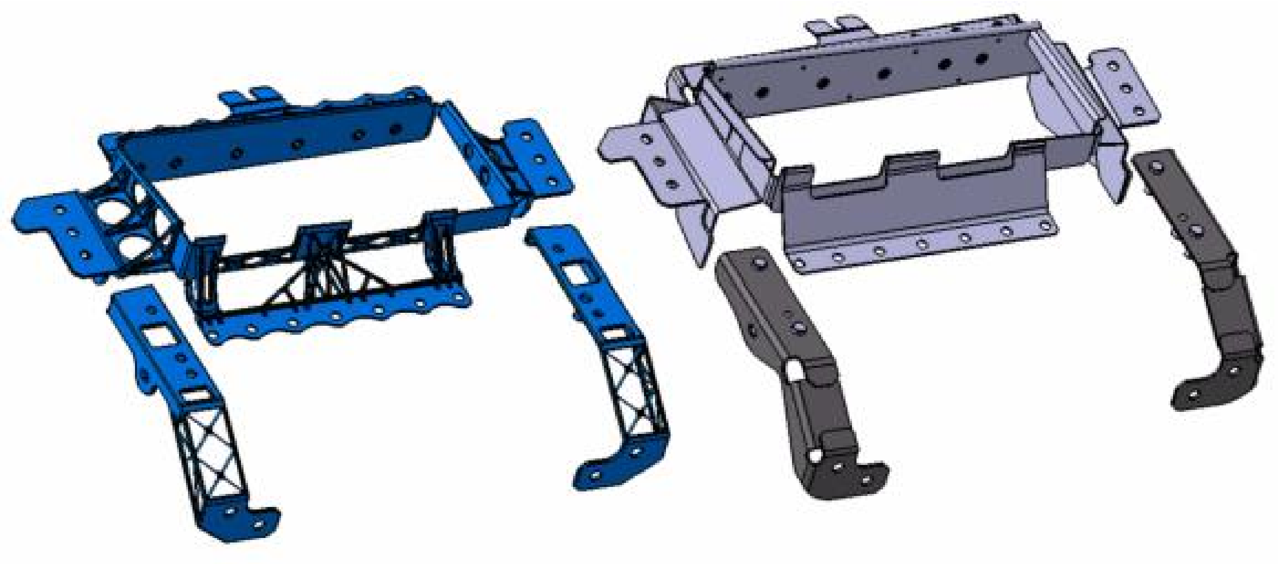


Figure 2.22: Geometry comparison

For these components the structural analysis had been performed putting them together in a single FEM model, because they are all part of a single assembly, leading to more accurate results. In the Figure 2.23 and Figure 2.24 a comparison of the results of the FEM linear static analysis for the current (on the left) and the new component (on the right) are shown. In the Figure 2.23 the displacements, that are mapped with the same scale, are visualized. Instead, in the Figure 2.24 the stresses are shown (with at the top the “Assy PAB bracket” and at the bottom the “Channel PAB supp.”) mapped with a different full scale, that is set equal to the yield strength of the respective material. As it can be seen both the maximum values of the displacements and the stress values of the new geometry are lower than the current geometry. In particular the stresses of the “channel PAB supp.” are very low despite the very thin shape of some of its details, that is fundamental to avoid eventual breakages of the pieces as a consequence of the heavy stresses to which they are subjected during the airbag deployment.

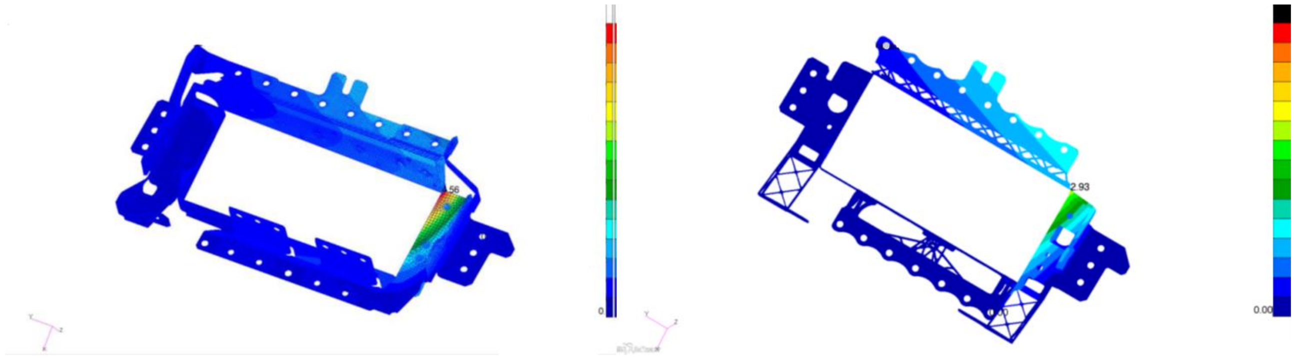


Figure 2.23: Displacements results from the linear static analysis

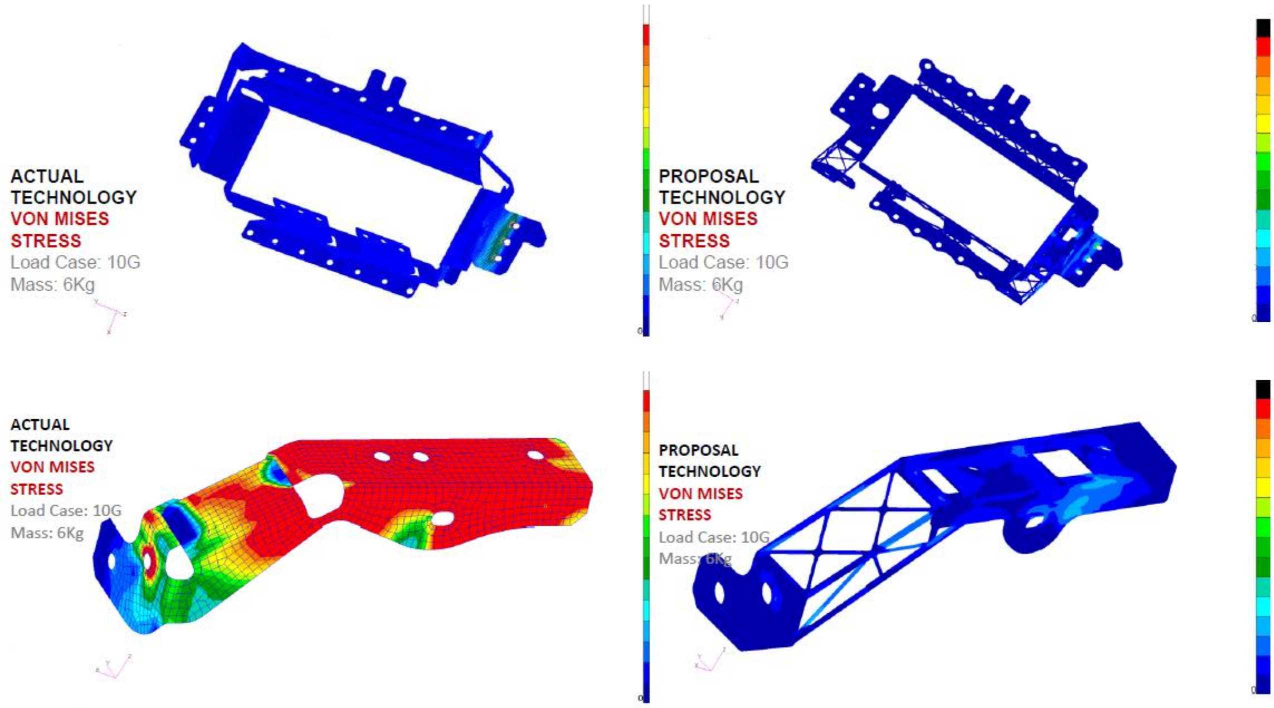


Figure 2.24: stresses results from the linear static analysis

2.3.2.4 Lower bracket kneebag LH

The component *"Lower bracket kneebag LH"* is positioned in the lower part of the dashboard, at the driver side (in green in the Figure 2.25). This bracket sustains the kneebag module linking it to the Cross-Car-Beam and it has to counterbalance the recoil forces of the airbag deployment during a crash. Due to its function for the driver's safety, particular attention has been given to the improvement of its mechanical performances.

The bracket is a simple sheet-metal of aluminium EN AW-5083 made through a stamping manufacturing process. It is joined to the CCB by fastening the two uprights with four screws, two per part, as showed in the Figure 2.26. The kneebag module is then assembled to the bracket though the four nuts. In the front part there is also a point of attachment, whose aim is to sustain an HVAC air-duct. In the rear there is another one used to sustain the “lower bracket fix dashboard”, that is the one of the bracket redesigned in thermoplastic CFRP that will be described in the following.

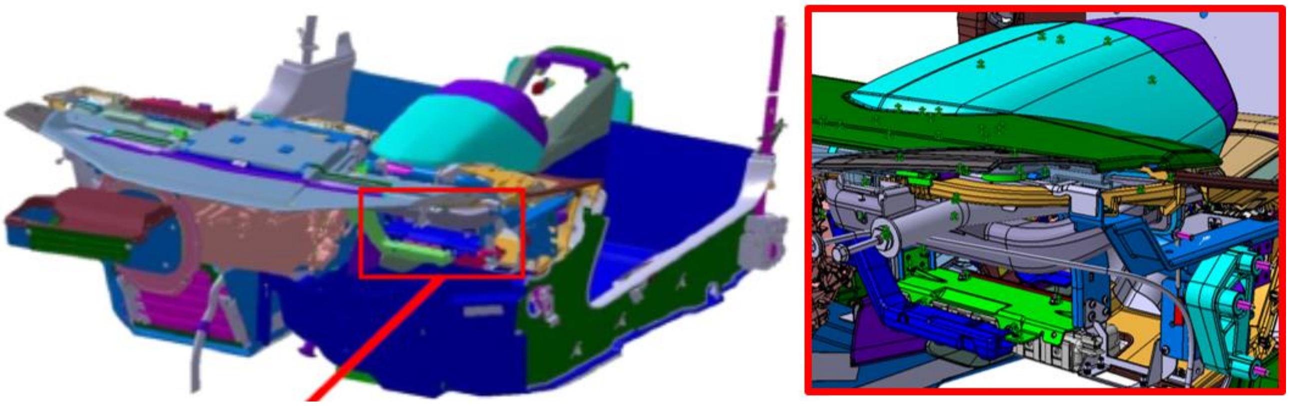


Figure 2.25: Position of the “lower bracket kneebag LH” in the vehicle

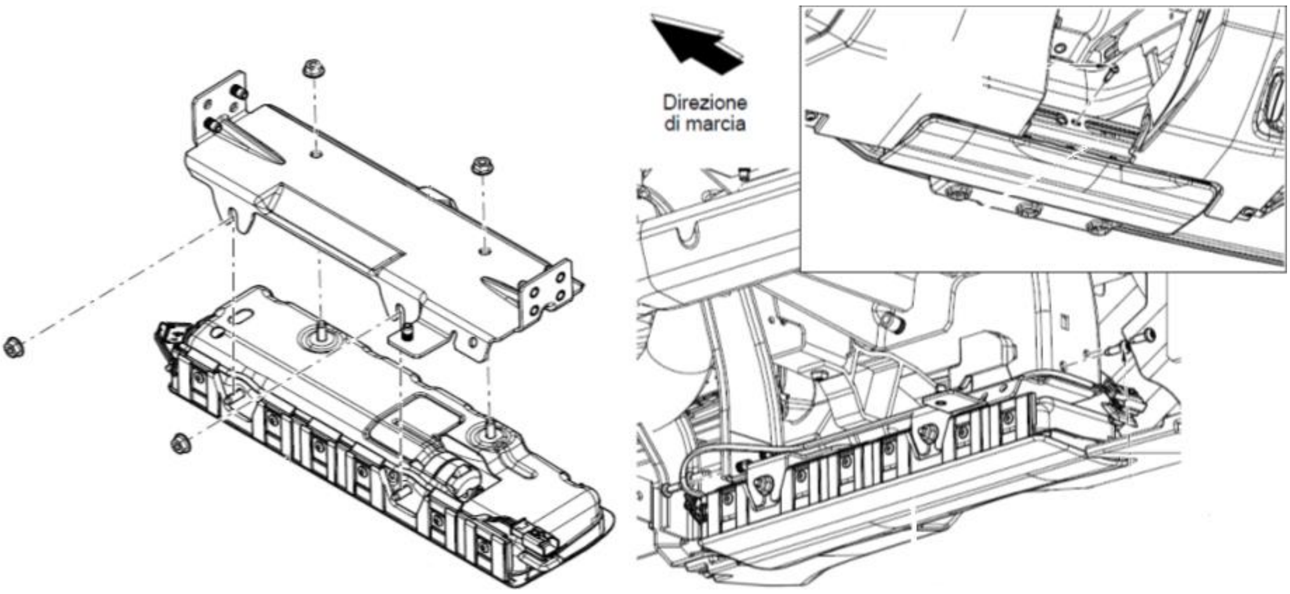


Figure 2.26: mounting operation of the “Lower bracket kneebag” and “Lower bracket fix dashboard”

The current production bracket is made in a sheet-metal of aluminium. The new bracket (Figure 2.27) weighs only 2.8 % less, so almost the same. This is due to the fact that this geometry is not appropriate for the application of this kind of technology. Moreover, the only modifications that were possible were the removal of the material from the zone less stressed, leaving the shape almost the same. Even if this part didn't help to reduce the overall weigh and it was a sort of failing, it was important to increase the know-how on this technology understanding which geometries are suitable for these kinds of applications and which are not.

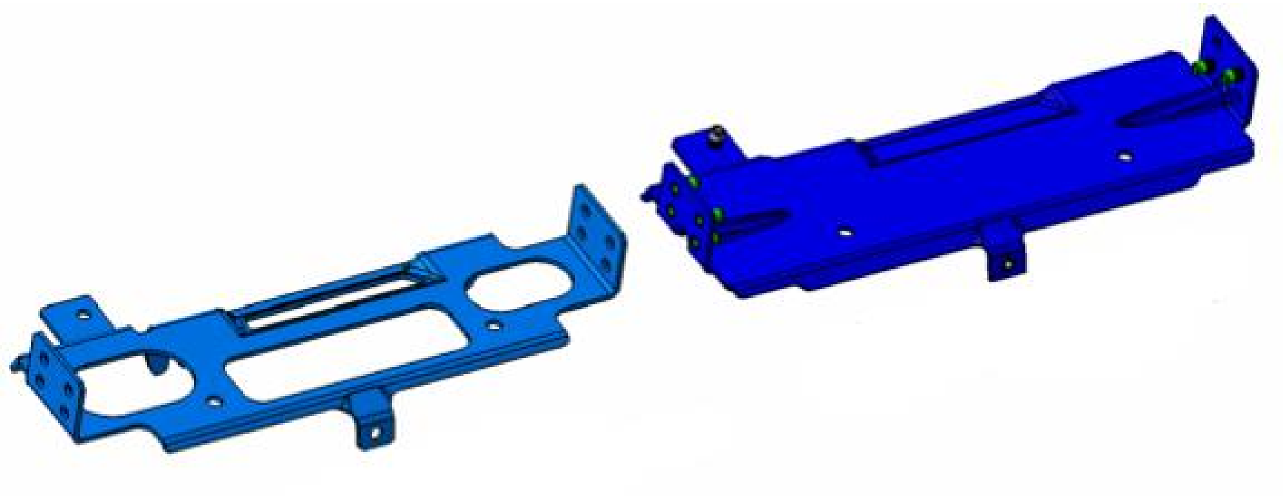


Figure 2.27: Geometry comparison

For this component the structural analysis has been performed putting it together with the "lower bracket fix dashboard" in a single FEM model. We took this decision, because they are part of a single assembly and this could led the results to be more accurate. In the Figure 2.28 a comparison of the results of the FEM linear static analysis for the current (on the left) and the new component (on the right) are shown. At the top the displacements, that are mapped with the same scale, are visualized. At the bottom the stresses are shown, mapped with a different full scale, that is set equal to the yield strength of the respective material. As it can be seen, the displacements of the new geometry are higher, but they were considered anyway acceptable since they were not considered a problem for its functioning and because the values of the stresses were very low. The values of the stresses are more important in order to avoid eventual breakages as a consequence of the heavy stresses to which they are subjected during the airbag deployment.

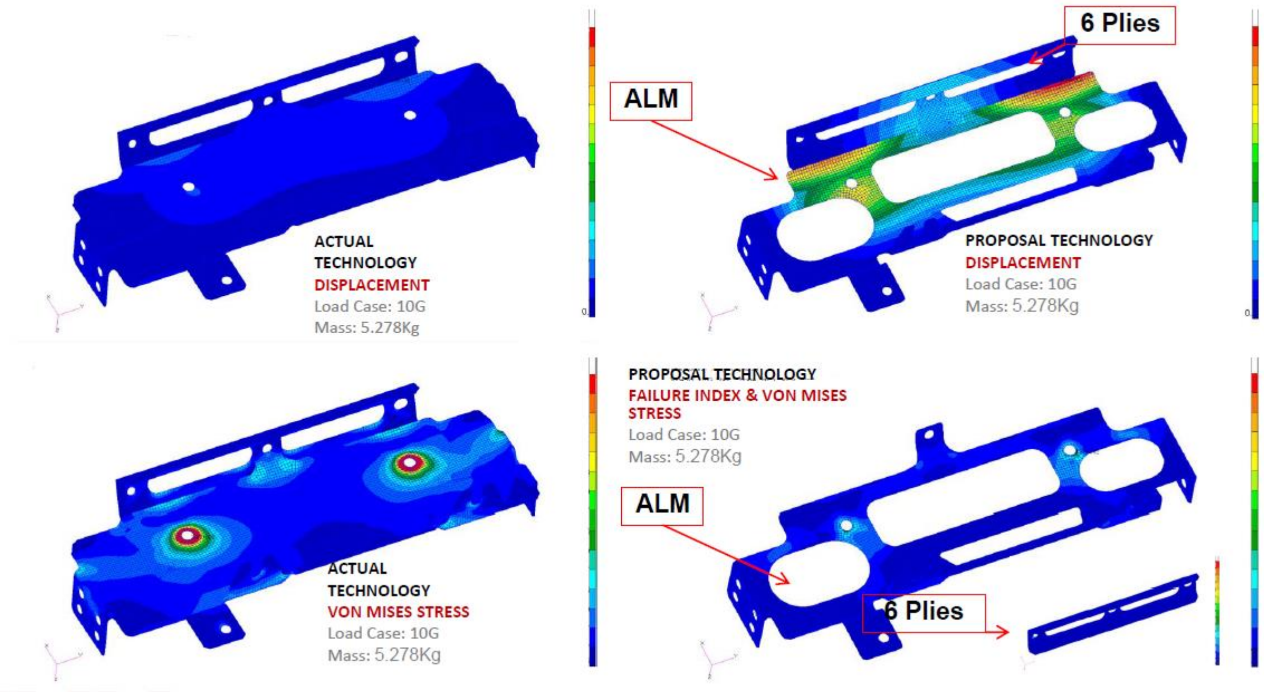


Figure 2.28:" Lower bracket kneebag" and "Lower bracket fix dashboard" stiffness & strength linear static analysis

2.4 Second technology: press-thermoforming thermoplastic CFRP

The second technology I will describe is the press-thermoforming thermoplastic CFRP. This technology has been chosen for the possibility to obtain components in carbon fiber at a lower production costs and at a reduced cycle time, since the manufacturing process could be almost totally automated avoiding hand lamination. In particular the material used is composed by a woven fabric with a 5 HS weave pattern of continuous high strength carbon fibres (T300 3k, 280 gsm) with a semicrystalline PPS (Polyphenylene Sulfide) resin as a binding polymer.

The decision of using the CFRP has been taken for its well-known characteristic of having a high stiffness and strength-to-weight ratio and a very low density (about 1.55 kg/dm^3). The consequent advantage is that it doesn't require a high modification of the current shape of the components to reach a high weight saving. Moreover, the thermoforming process, starting from a flat sheet, is similar to the stamping or cut-&-bend processes of the sheets-metal (i.e. the processes currently utilized for the brackets taken into consideration in the following). Therefore, from the manufacturing feasibility point of view, the geometry doesn't need to be changed too much, being perfect for a redesign activity of already existing components.

2.4.1 Description of the press-thermoforming production process for the thermoplastic CFRP

The great advantage of the CFRP, with the matrix made of thermoplastic resin, is the opportunity to manufacture finished parts by using a press-thermoforming process. The thermoplastic CFRP for the thermoforming process is typically supplied in pre-consolidated laminates in the form of flat multi-ply sheets. These plates are placed in a mould and then they undergo a thermoforming process to obtain the final shape. The pre-consolidated laminates have the dimensions of 3660 x 1220 mm and they are made using the customer's designated ply count and orientation. By using pre-consolidated sheets and avoiding hand lamination, the cycle time and the costs required to produce a finished part can be significantly reduced. Moreover, the thermoform line installed in the production plant of the partner company, that has done the reengineering activity and the production of the components, is fully automated using robots that can handle the sheets blanks, as can be seen in the Figure 2.29. Thermoforming is used to convert a flat consolidated laminate into one with a complex shape with no change in starting laminate thickness. The laminate should be heated to around 320°C in an infrared oven and then quickly transferred to a matched cavity mould where it can be formed at 10-40 bar. An example of the finished product can be seen in the Figure 2.30, that represent the "trim tunnel bracket" that is one of the redesigned components of this case study.

Figure 2.29: automated thermoform line used for the production of the components in thermoplastic CFRP laminates

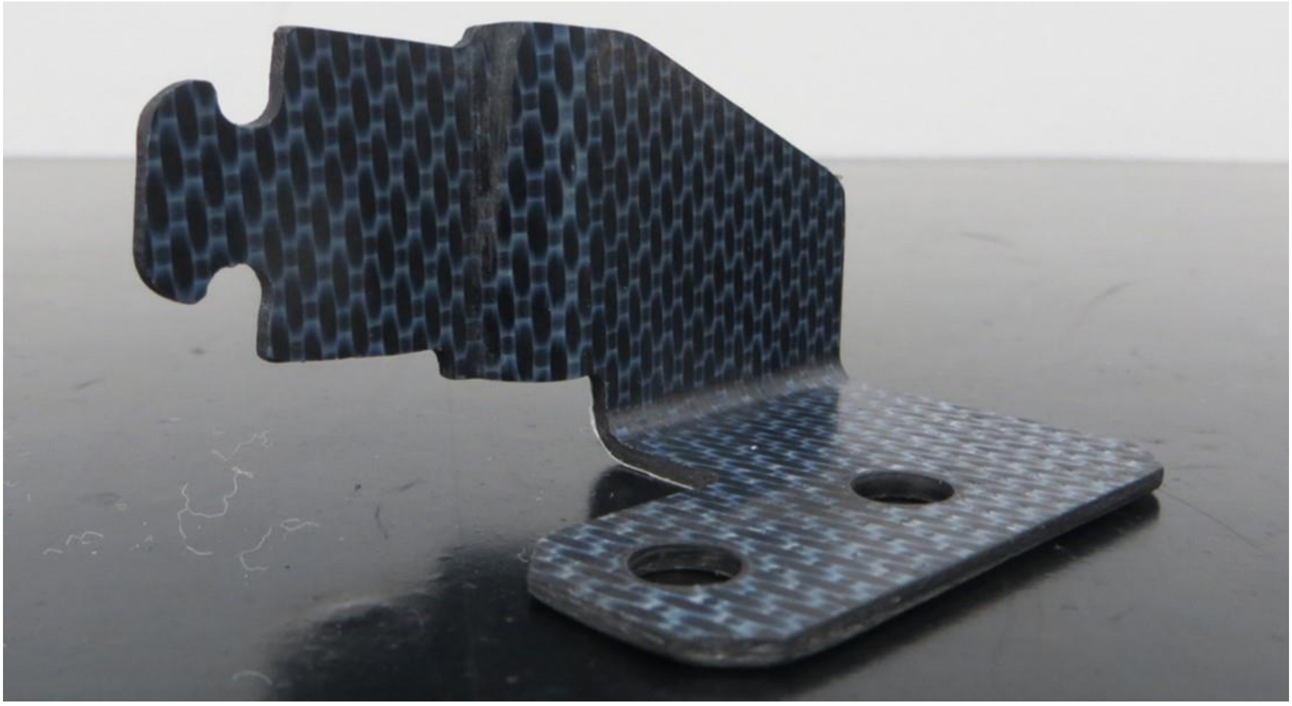


Figure 2.30: example of finished product made with thermoplastic CFRP ("Trim tunnel bracket").

2.4.2 Components redesign

As already said before, there wasn't the need of changing too much the shape of the brackets, that is remained substantially the same, thanks to the similarity of the thermoforming process, from the geometry constraints point of view, with the stamping process of the sheets-metal utilized for the current components. As a result, in this case most of the redesign work has been defining the orientation and the ply count of the fibres of the CFRP fabric and, as a consequence, the thickness of the parts, verifying that its change did not create problems or interferences with the other pieces in the assembly. Moreover, because the material used is a composite characterized by many plies, there was the necessity to build a FEM model with apposite techniques that would consider the fact that the materials is not isotropic. For this reason, in the post-process of the FEM analysis also the failure index was taken into account in addition to the stress values. In fact, in order to predict failure, that occurs when the failure index in a laminate reaches the value 1, in these cases the failure index is better than the stress value.

I'm going in the next pages to describe in detail the manufacturing feasibility study that brought to redesign of the brackets. For each one of them I will start describing the place in which it is positioned in the vehicle highlighting the other parts with which it has to interface and the constraints deriving by the mounting operations in the vehicle. Then the final geometry will be showed compared with the current one and the results of the FEM analysis will be explained.

2.4.2.1 Lower bracket fix dashboard

For what concern the redesign activity using the thermoplastic CFRP, the first component I'm going to describe is the "*Lower bracket fix dashboard*". It is positioned in the lower part of the dashboard (Figure 2.31), at the driver side (in red in the Figure 2.32). This bracket is linked to the previously described "*Lower bracket kneebag LH*" by means of a screw positioned at its centre (on the top right of Figure 2.26) that fastens it. It has only one function of sustaining the lower part of the lower-dashboard trims through the two screws at its sides. This component is fastened firstly to the lower-dashboard trims and, only after that, it is also fastened to the other bracket. This is the reason why it could not be integrated into the other bracket, creating an only one bracket.

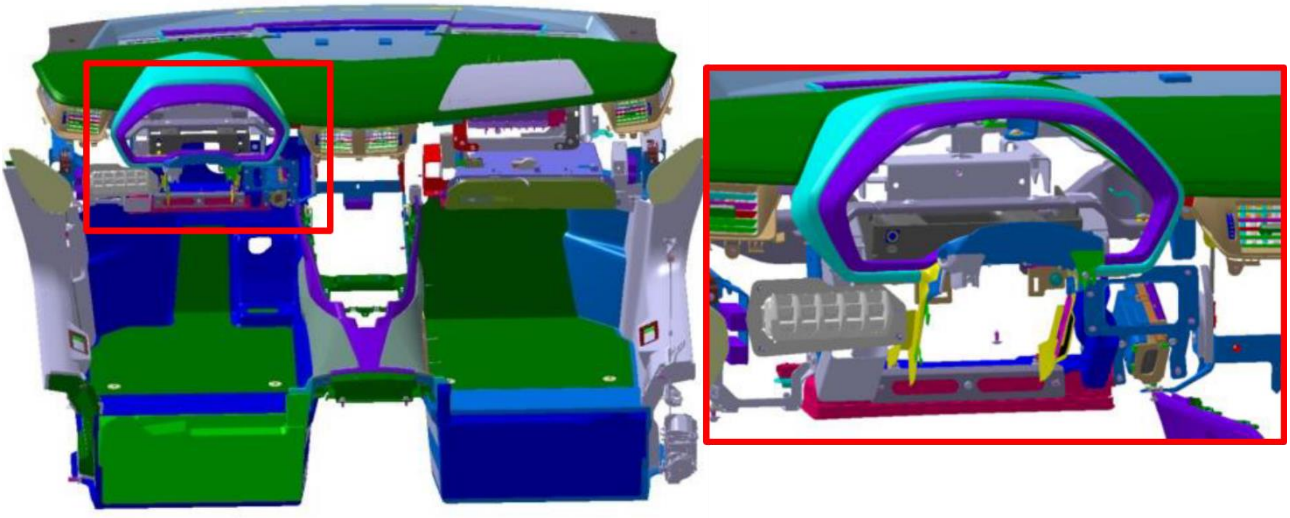


Figure 2.31: Position of the "Lower bracket fix dashboard" in the vehicle

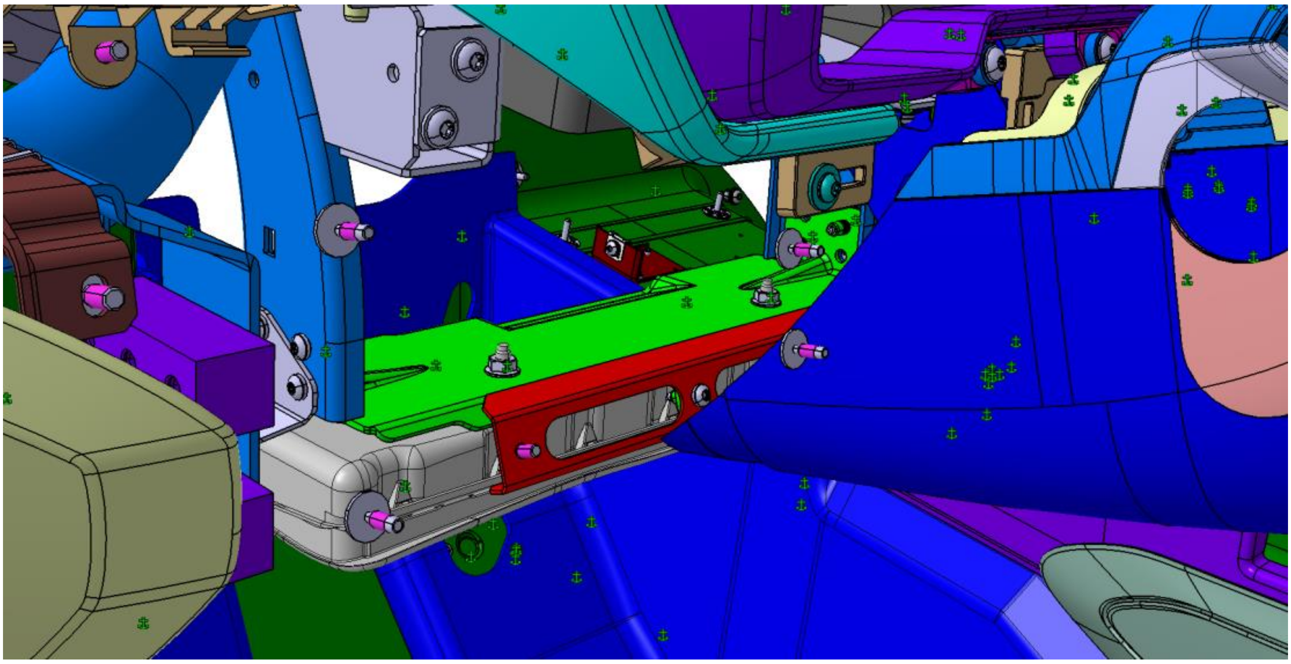


Figure 2.32: position of the "Lower bracket fix dashboard" in the vehicle

The bracket is currently produced with a simple sheet-metal of steel DIN EN 1.0130 DC 01, that is made through a stamping manufacturing process. The new bracket (Figure 2.33) instead weighs 75 % less, even if the thickness is increased of the 24%, since a composite consisting of 6 plies of carbon fiber has been used. The fact that the starting material was steel brought this great result. The steel has a density of 7.83 kg/dm3, a very high value compared to the 1.55 kg/dm^3 of the carbon fiber used to manufacture the redesigned component.

As explained before, this component has been simulated together with the "*Lower bracket fix dashboard"* in a single FEM model, because they were part of a single assembly and because the results could have been more accurate. The results of these FEM linear static analysis are visible in the Figure 2.28, where a comparison with the current (on the left) and the new component (on the right) is shown. At the top the displacements, that are mapped exactly with the same scale, are visualized. At the bottom the stresses are shown, instead, mapped with a different full scale, set equal to the yield strength of the respective material. The results indicate that the displacements of the new component are a little higher, but they were considered acceptable because it wasn't highly loaded during its operating life and because the values of the failure index and of the stresses obtained were very low.

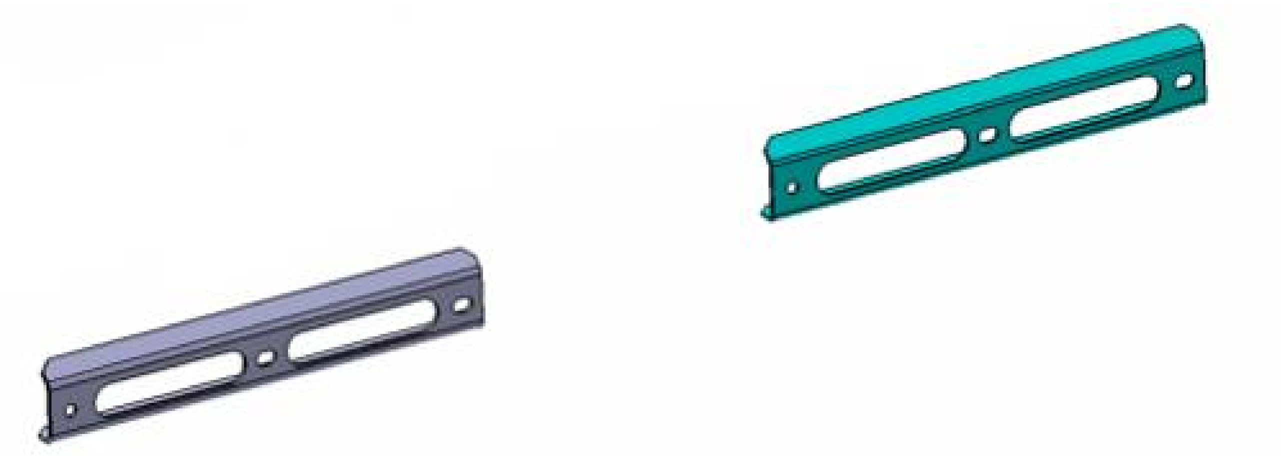


Figure 2.33: Geometry comparison

2.4.2.2 Bracket fix lower dashboard

The "*Lower bracket fix dashboard*" is positioned in the higher part of the dashboard, at the driver side (in pink in the Figure 2.34) just behind the instrument cluster. This bracket is composed of three different parts (Figure 2.35) and its function is to sustain the upper part of lower-dashboard trims through the two screws fastened in the holes at its sides. This component is fastened firstly to lower-dashboard trims and secondly to the CCB, as it can be seen in the Figure 2.36. The three different pieces are necessary to permit the assembly operations and to allow adjustments. They can't, therefore, be joined in only one.

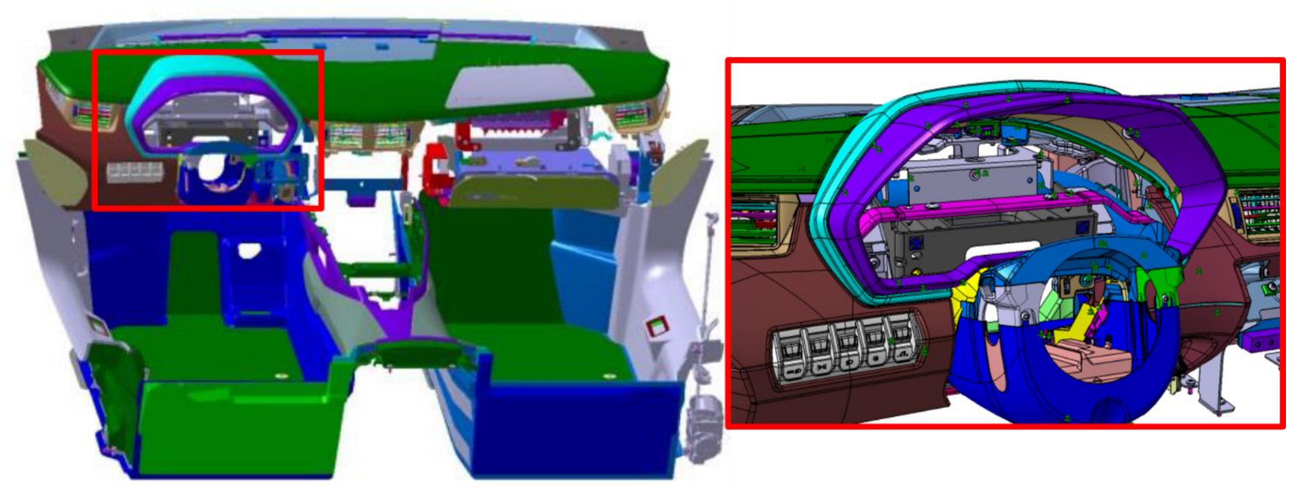
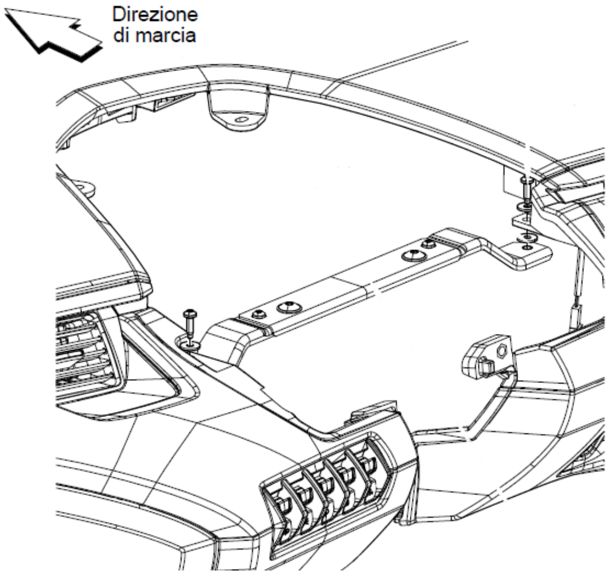


Figure 2.34: Position of the “Bracket fix lower dashboard”

Figure 2.35: the three part that made up the “Bracket fix lower dashboard”



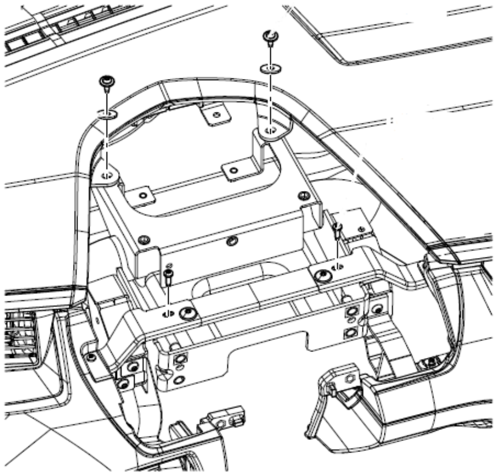


Figure 2.36: Mounting operation of the "Bracket fix lower dashboard"

The three parts of the current production component are made by sheet-metal of steel DIN EN 1.0130 DC 01 and they are obtained through a stamping manufacturing process. The new bracket, instead, weighs only the 45 % less with the thickness increased of the 86%, since a composite consisting of 9 plies of carbon fiber has been used. As already explained before for the previous component, also this high weight-reduction is due to the fact that the starting material was steel that is a much heavier material compared to the carbon fiber.

The three parts of the bracket, being effectively a single component, have been simulated together in a single FEM model. The results of these FEM linear static analysis are visible in the Figure 2.37, where a comparison with the current one (on the left) and the new component (on the right) are shown. At the top the displacements, that are mapped exactly with the same scale, are visualized. At the bottom left the stresses of the current component are shown, mapped, instead, with a full scale set equal to the yield strength of the steel. At the bottom right, the failure index of the redesigned component is shown. The results indicate that the displacements of the new component are equal to the current one and that we have obtained very low values of the failure index and of the stresses.

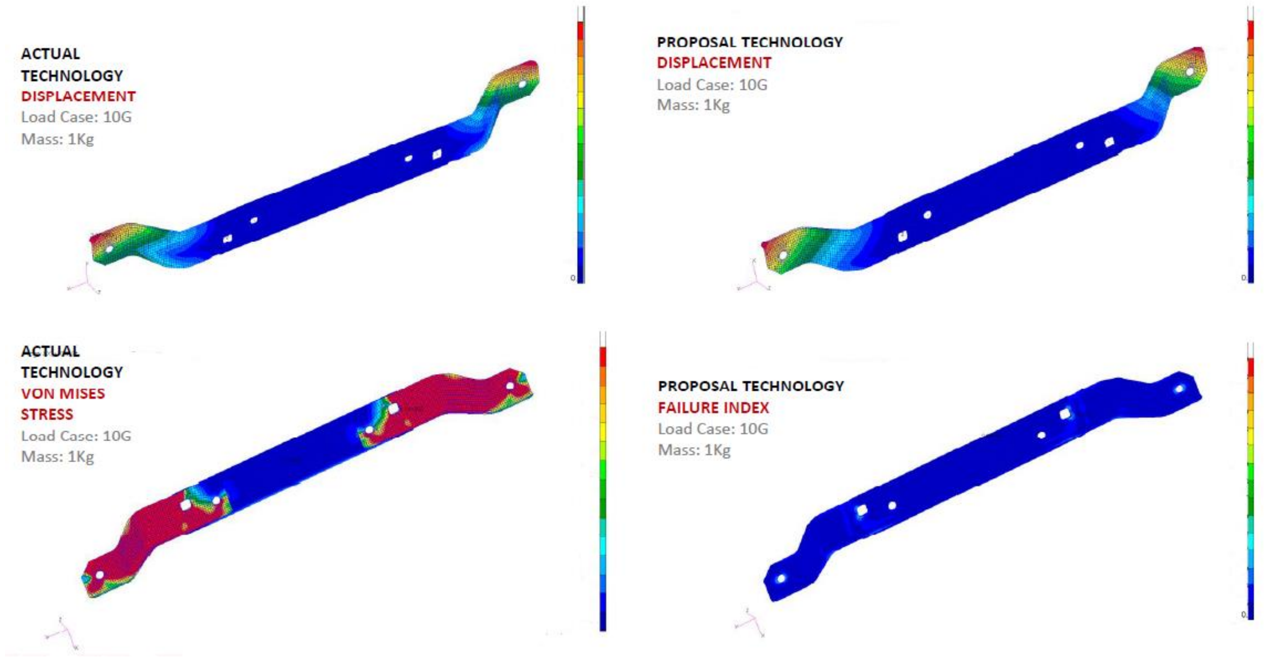


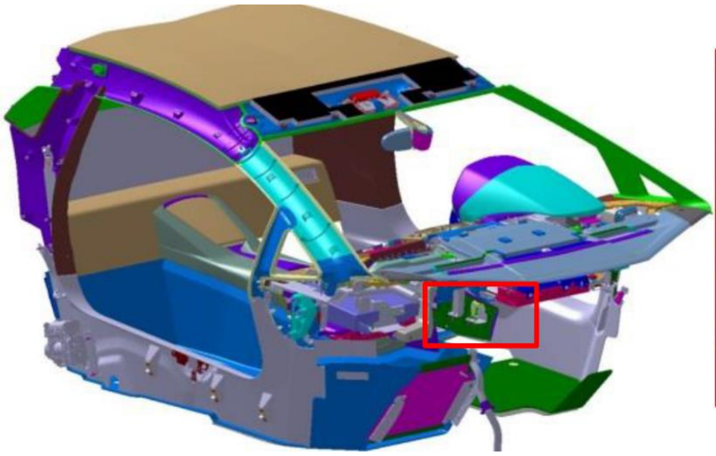
Figure 2.37: "Bracket fix lower dashboard" stiffness and strength linear static analysis

2.4.2.3 Trim tunnel bracket

The "*Trim tunnel bracket*" is positioned on the central tunnel at the driver side and it is indicated by the red arrow in the Figure 2.38. The function of this bracket is to sustain a trim of the central tunnel by means of the grommet (in light green in the Figure 2.38) in which it is fitted. This component is firstly assembled to the central tunnel body frame, fastened with two screws, and then the trim is fitted.

The current production component is made by sheet-metal of steel DIN EN 1.0130 DC 01 and obtained through a cut-&-bend manufacturing process. The new bracket (Figure 2.39), instead, weighs the 82 % less. As already explained, this high weight-reduction is due to the fact that the starting material was steel, a much heavier material compared to the carbon fiber, and to the fact that the thickness is increased of only the 8.5%, since a composite consisting of 7 plies of carbon fiber has been used.

The results of the FEM linear static analysis are visible in the Figure 2.40, where a comparison with the current (on the left) and the new component (on the right) are shown. At the top the displacements, that are mapped exactly with the same scale, are visualized. At the bottom left the stresses of the current component are shown, mapped, instead, with a full scale that is set equal to the yield strength of the steel. At the bottom right, the failure index of the redesigned component is shown. The results indicate that the displacements of the new component are much higher, but they were considered acceptable, because it wasn't highly loaded during its operating life and because the values obtained of the failure index and of the stresses were very low.



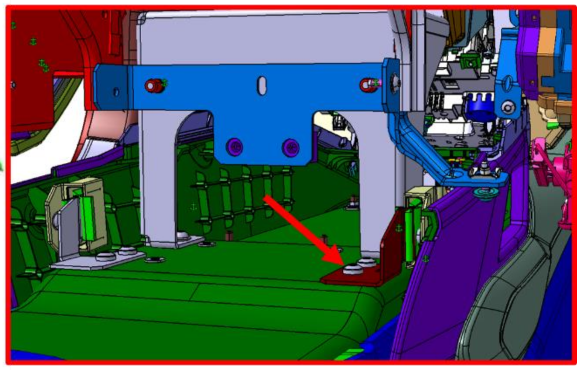


Figure 2.38: Position of the "trim tunnel bracket"

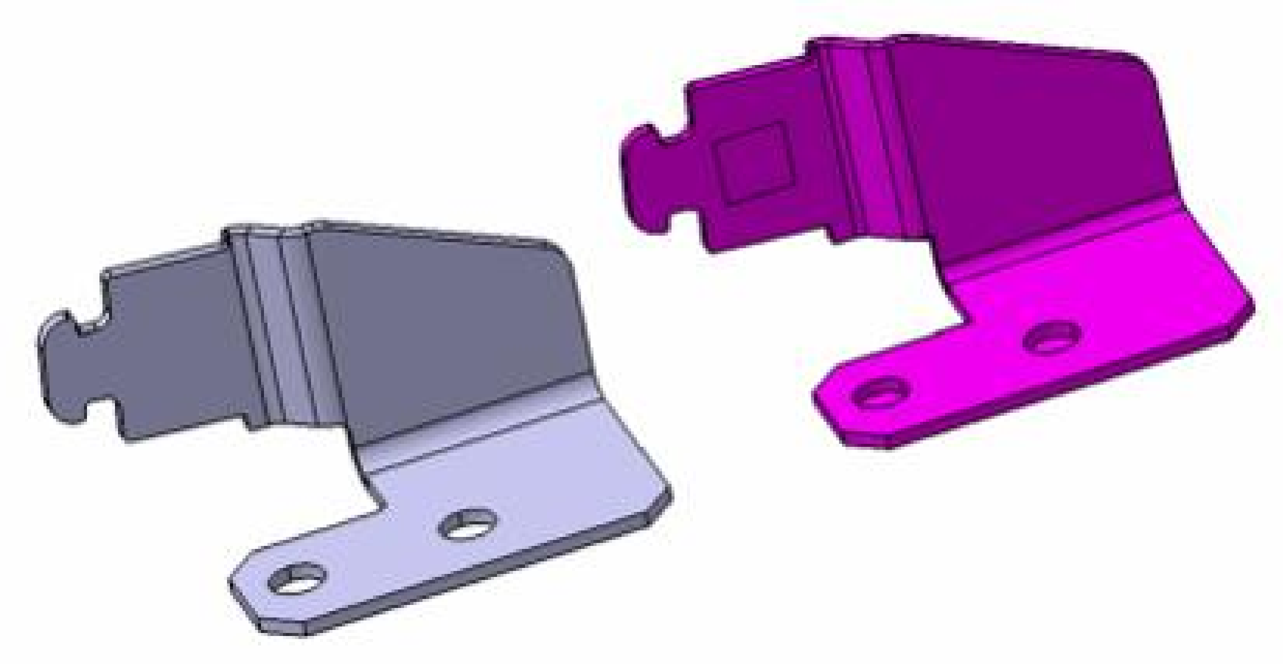


Figure 2.39: Geometry comparison

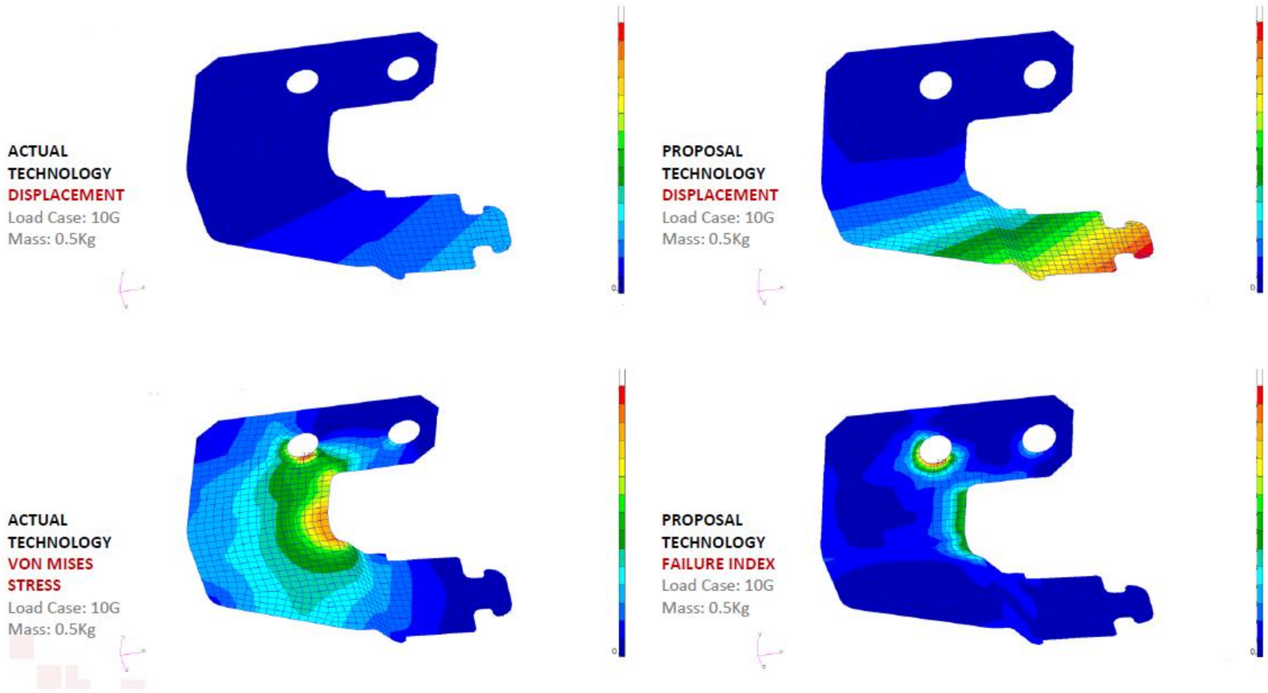


Figure 2.40: "Trim tunnel bracket" stiffness and strength linear static analysis

2.4.2.4 Halter connection bracket

The "*Halter connection bracket",* coloured in green in the Figure 2.41, is positioned in the front part of the dashboard at the passenger side between the glovebox and the HVAC module. The function of this bracket is to sustain the rear part of the glovebox by means of a screw. The other two holes visible in the figure are needed to fit the grommets of two cable-guides. This component is firstly connected to the pink bracket, that connects the HVAC to the CCB, visible in the figure fastened with two screws, and then assembled with the glove box.

The current production component, is made by sheet-metal of aluminium EN AW-5083 and obtained through a cut-&-bend manufacturing process. The new bracket (Figure 2.42), instead, weighs the 33 % less. In this case the weight-reduction is not as high as the other cases, because the starting material was aluminium, a much lighter material compared to the steel. In fact, the aluminium density is 2.66 kg/dm3, only 1.7 times the value of the CFRP (1.55 kg/dm^3). The thickness is increased of the 24%, since a composite consisting of 8 plies of carbon fiber has been used.

The results of the FEM linear static analysis are visible in the Figure 2.43, where a comparison with the current (on the left) and the new component (on the right) are shown. At the top the displacements, mapped exactly with the same scale, are visualized. At the bottom left the stresses of the current component are shown, mapped, instead, with a full scale settled equal to the yield strength of the steel. At the bottom right, the failure index of the redesigned component is shown. The results indicate that the displacements of the new component are equal to the current one and that we have obtained lower values of the failure index and of the stresses. Therefore, the overall mechanical performances have improved.

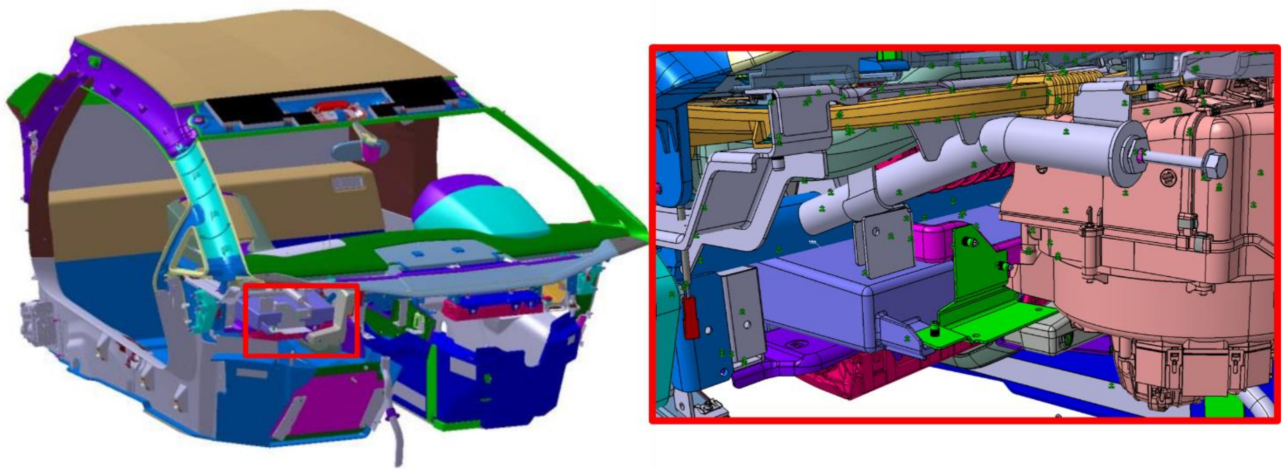


Figure 2.41 Position of the "Halter connection bracket"

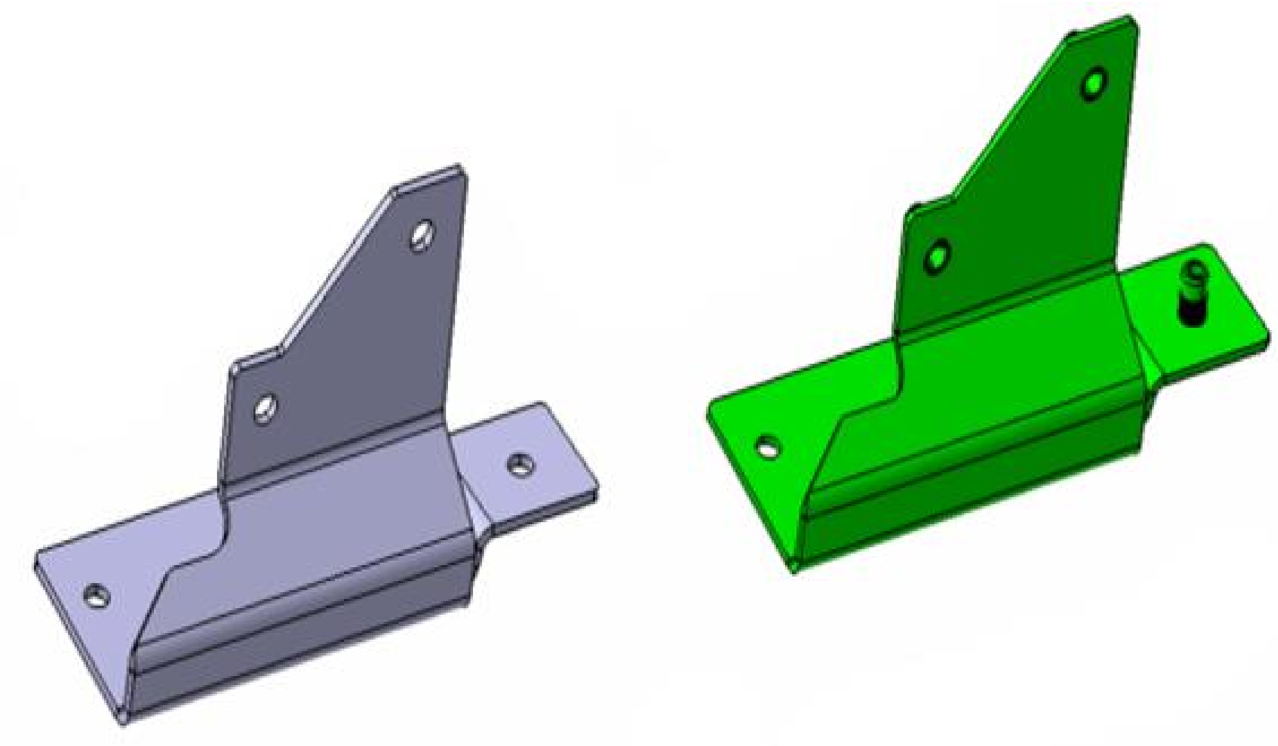


Figure 2.42: Geometry comparison

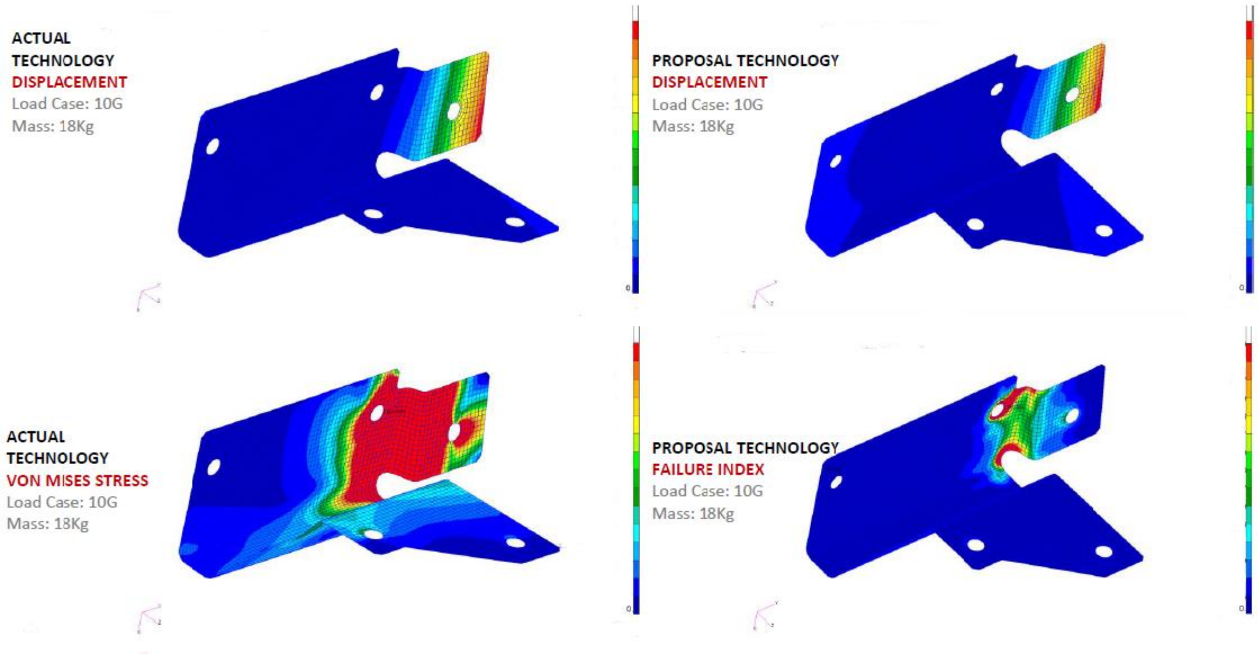


Figure 2.43"Halter connection bracket" stiffness and strength linear static analysis

2.5 Assembling and testing

2.5.1 Mounting operations in the vehicle and tests

When the redesign phase has been finished and the final geometries have been definitively released, the production of the prototype components has been finally performed. In this phase for the components "*Side fix cross car beam RH/LH*", "*Assy PAB bracket*" and "*Channel PAB supp. RH/LH*" a machining process in a CNC machine has been done, after the ALM manufacturing process, in order to guarantee the correct dimensional tolerances for the most critical couplings with other components and to realize the necessary threaded holes. For the "*lower bracket kneebag RH*" we noticed that its longer dimension was about 1 mm shorter than the CAD data. This was not a problem because this component didn't require tight tolerances for its functioning and the mounting operations have been performed using a washer with a thickness recovering the error. Anyway, this was an opportunity to better comprehend the problems related to the ALM process, since we have understood that pieces with too large dimensions were not ideal for this technology. In fact, large dimensions could have caused high temperature gradients into the piece, leading to a non-uniform material shrinkage with a consequents residual stress and/or, as in our case, not precise dimensions.

After the production phase the components have been assembled on a prototype vehicle. These operations have been complex because all the dashboard module had to be disassembled and placed outside the car, using a tool similar to the one visible in the Figure 2.44. Therefore, the total amounts of liquids relative to the HVAC module had to be removed. The dashboard was then positioned on an external frame on which all the disassembling and reassembling operations of dashboard trims and components have been performed. After checking that all the new components were compliant to the specifications of CAD data and drawings and that the mounting was correct, the dashboard module has been remounted on the vehicle.

Once finished the assembly the vehicle was ready for the tests. In particular, inertance tests, road tests and airbag deployment tests were planned in order to validate the redesigned components. The last two tests were needed, respectively, to check if were present some noises or vibrations and to verify that the structural performance of the brackets, sustaining the knee-bag and the passenger airbag, were adequate. However, they are not subjects of this thesis since they have not yet been carried out. The inertance test, that I'm going to describe next, instead was needed to check the natural frequency of the steering column and the steering wheel vibrations.

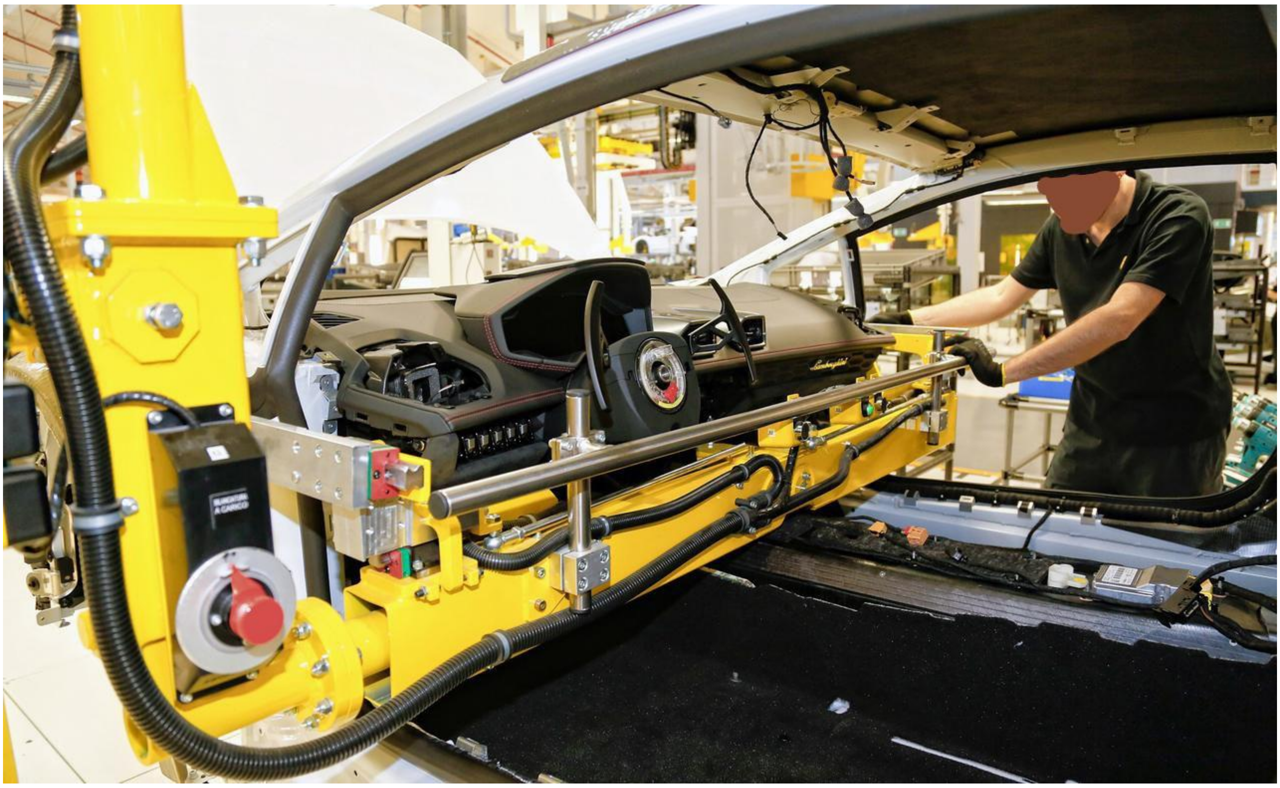


Figure 2.44: tool used in the vehicle assembling operations in order to place the dashboard module inside the car.

2.5.2 Steering wheel inertance test description

As already described before, one of the main targets of the redesign activity was to maintain the same firsts natural frequencies and vibration modes of the steering column, in order to avoid too high vibrations on the steering wheel and on the dashboard trims, that could lead to a worst comfort perception by the driver and the passenger. The natural frequencies of the steering column were designed to not resonate when it was excited by the vibrations introduced by the vehicle operations. For example, when driving over poor road or with the engine at idle speed there is a production of vibrations between 10 and 25 Hz, and, therefore, the steering column natural frequencies have to be higher than this range in order to not have undesirably high oscillation amplitudes. In order to state if this target has been reached an inertance test on the steering wheel was performed. This test concerns mainly the validation of the "*Side fix cross car beam RH+LH*" and the "*Bracket tunnel*", that are the three main structural brackets that links the CCB to the body frame. However, also other components, positioned in the area near the steering column (such as the "*Bracket fix lower dashboard*", the "*Lower bracket knee bag RH*" and the "*Lower bracket fix dashboard*"), could have a role in the definition of the vibrational characteristics of the steering wheel.

This inertance test is an experimental modal analysis that consists in making a modal impact test on the steering wheel, performed instrumenting the vehicle with an accelerometer and then using the hammer, visible in the

Figure 2.47, to impact the steering wheel. The position of the accelerometer is on the top of the steering wheel and is visible in the Figure 2.45 where there are also the three points of hammer impacts, necessary to analyse the dynamic characteristics of the steering column in the three main directions X, Y and Z. The hammer during the impact generates an input impulse force containing all the frequencies. The output acceleration is measured by the 3D accelerometer. The instrumentation for the data acquisition is composed by:

- Impact hammer
- 3D accelerometer
- Computer
- LMS SCADAS frontend: it is a recorder that connects the accelerometer to the computer for the data acquisition from vibration measurements.
- LMS Test Lab software: it is a modal testing and analysis software installed on the computer to process the data acquired in order to validate the test and elaborate the output diagrams

Since the steering column could be adjusted both longitudinally and vertically, the test was performed with the steering column in two different positions: firstly, a longitudinal adjustment fully extended and higher height position and, secondly, longitudinal adjustment fully contracted and lower height position. The output data acquired with the impact test were then elaborated to generate the diagrams of frequency response function (FRF) and the diagrams of the dynamic stiffness.

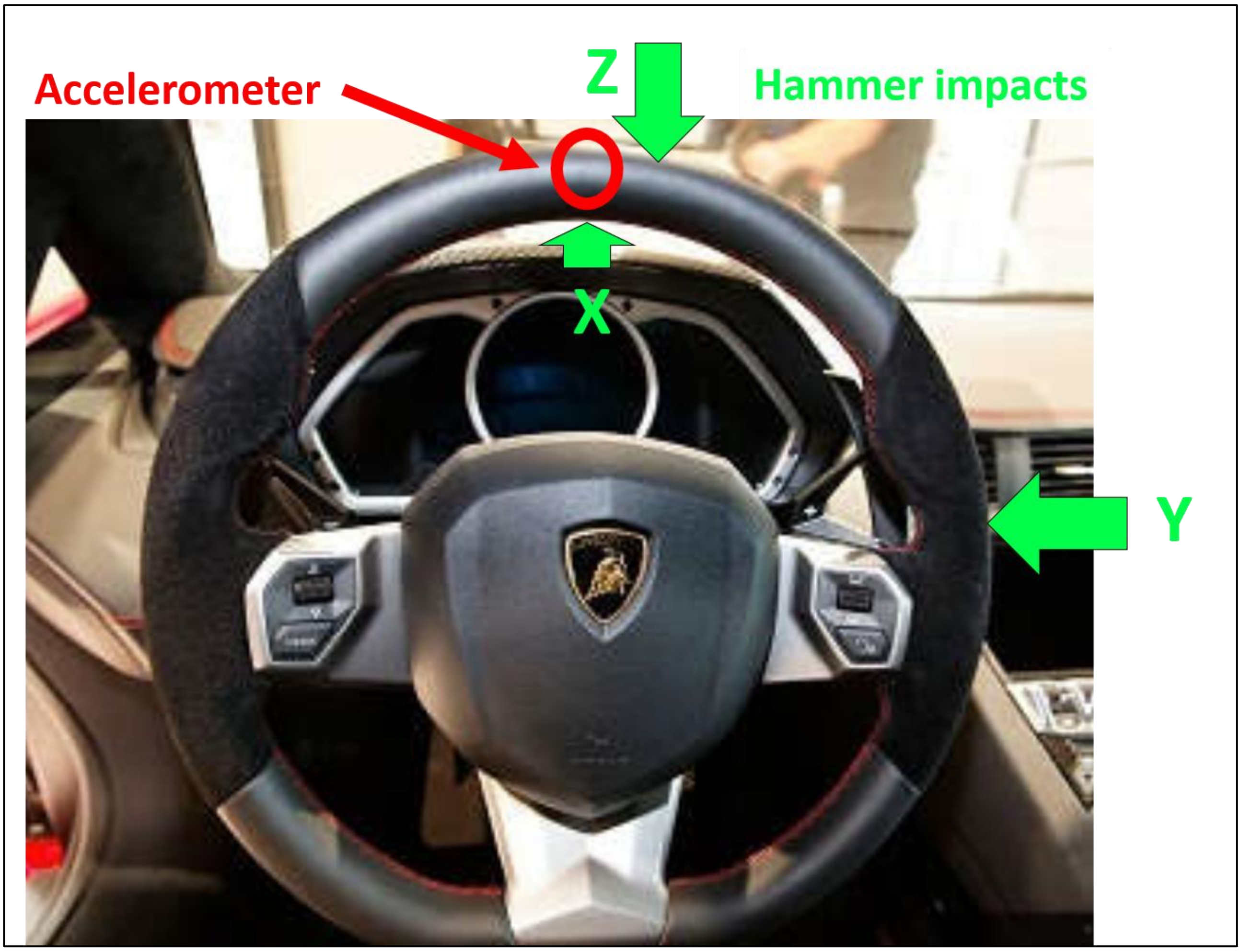


Figure 2.45: position of the accelerometer and of the points and directions of impact of the hammer.

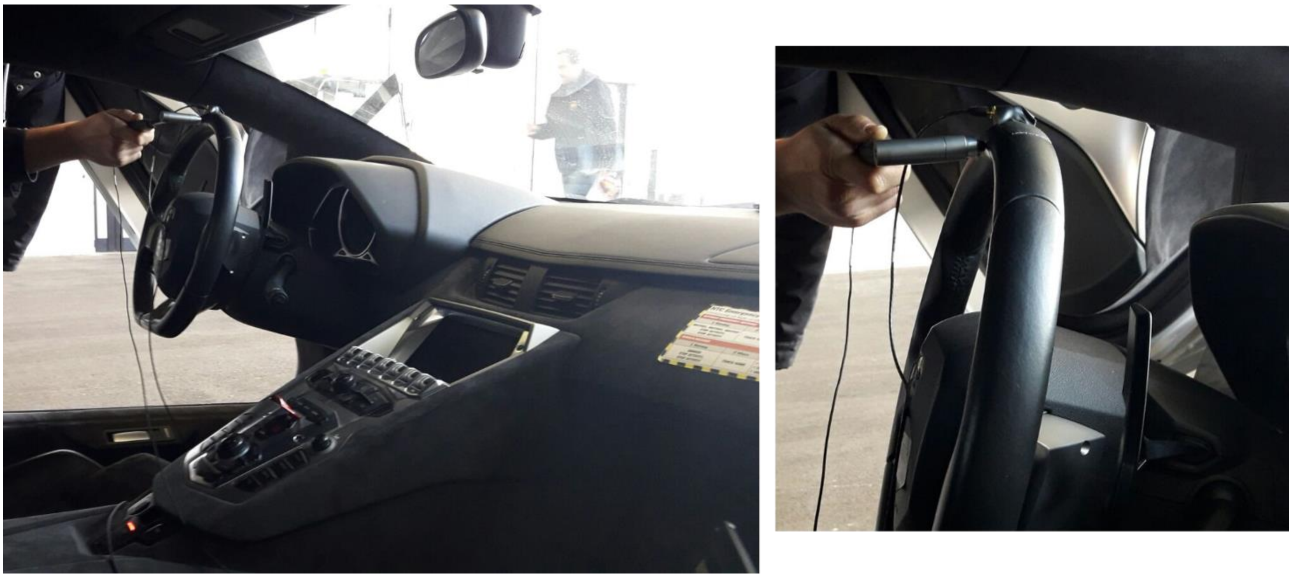


Figure 2.46: impact test performed on the vehicle

Figure 2.47: instrumentation for the data acquisition of the impact test

2.5.2.1 Frequency Response Function (FRF)

The Frequency Response Function (FRF) is used to characterize dynamically a system, identifying its resonance frequencies. It evaluates the response frequency and level as a consequence of an excitation of the system. It is measured quantitatively with the ratio between the magnitude of the output, in this case the accelerations measured by the accelerometer, and the magnitude of the input, in this case the impulsive force of the hammer impact. Since the impulsive force contains all the frequencies at the same level, from the analysis of the output magnitude it could be seen at which frequencies the accelerations were amplified due to resonance phenomena. In this way the natural frequencies of the system, that correspond to the peaks of the FRF curve, could be detected.

$$FRF = \frac{magnitude\ of\ the\ output}{magnitude\ of\ the\ imput} = \frac{Acceleration}{Force}$$

In the Figure 2.48 are displayed the FRF curves of the inertance test made on the vehicle in the standard version with all the components of the current standard production. This version is the reference for the comparison of the results of the version with the redesigned components. As described before the tests were performed with the steering wheel in two different position (the red and green curve in the Figure 2.48) and for three different directions (X, Y and Z) of the impact force excitation. In the figure the peaks corresponding to the resonance frequencies are highlighted with the orange circles.

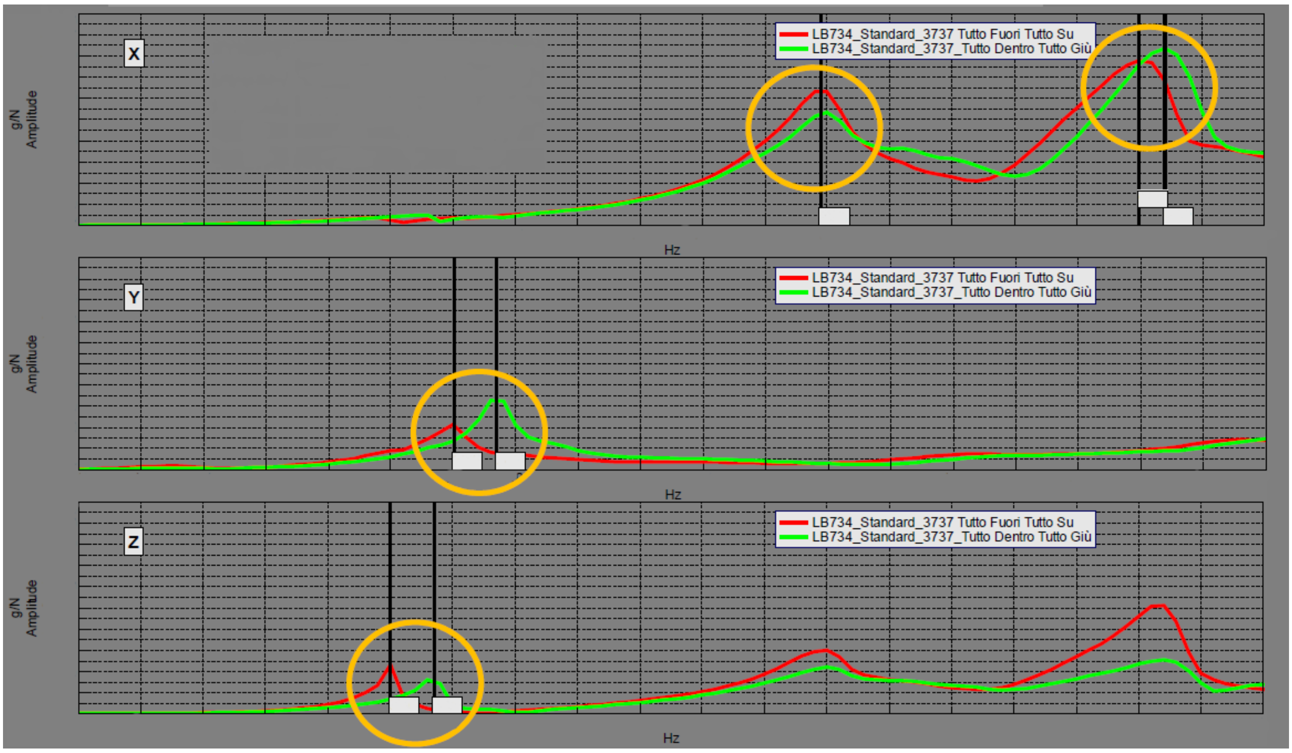


Figure 2.48: FRF curves for the vehicle standard version

2.5.2.2 Dynamic stiffness

The dynamic stiffness is the ratio between a dynamic force and the resulting dynamic displacement. The dynamic force is a force that changes in magnitude and direction with time, i.e. an excitation force frequency dependent. Instead, the dynamic displacement is the vibration response to that force. Thus, the increase of the dynamic stiffness at a determined frequency will reduce the vibration response of the system at that frequency.

The output of the inertance test is the dynamic stiffness curve that describe the variation of the stiffness of the system when it is varying the frequency of the force applied. In the Figure 2.49 are displayed the dynamic stiffness curves of the inertance test made on the vehicle in the standard version with all the components of the current standard production. This version is the reference for the comparison of the results of the version with the redesigned components. As described before, the tests were performed with the steering wheel in two different position (the red and green curve in the Figure 2.49) and for three different directions (X, Y and Z) of the impact force excitation. The negative peaks visible in the figure correspond to the frequencies in which we have resonance, the positive peaks, instead, correspond to the frequencies in which we have the maximum stiffness and so low vibration amplitudes.

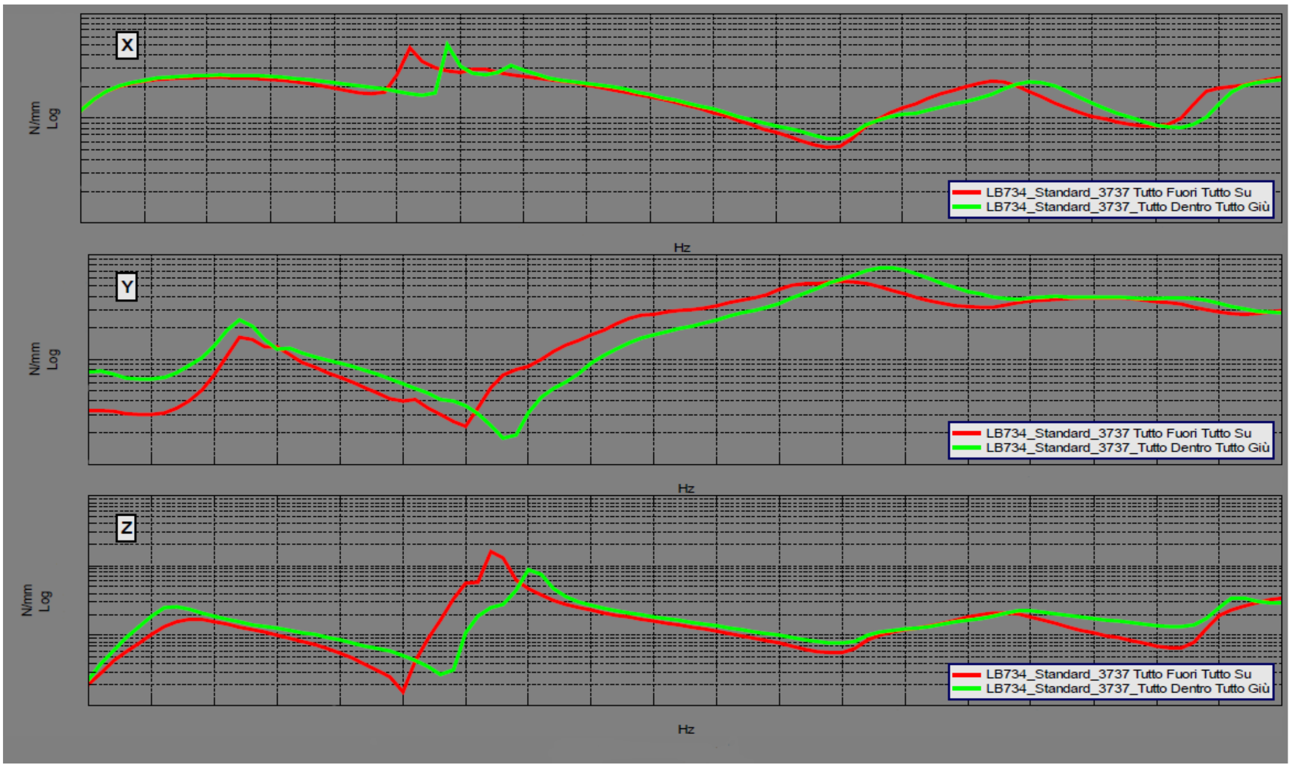


Figure 2.49: dynamic stiffness curves for the vehicle standard version

2.5.3 Test Results

The FRF, resulting from the steering wheel inertance test on the prototype vehicle with the redesigned brackets, can be seen in Figure 2.50, for the steering column configuration “longitudinal adjustment fully extended and higher height position”, and Figure 2.51, for the configuration “longitudinal adjustment fully contracted and lower height position”. In both the configurations the results are positive since the values of the peaks, that correspond to the natural frequencies of the system, are always higher than those of the standard version. This means that the system consisting of the new brackets is globally stiffer and they are suitable for substituting the standard ones.

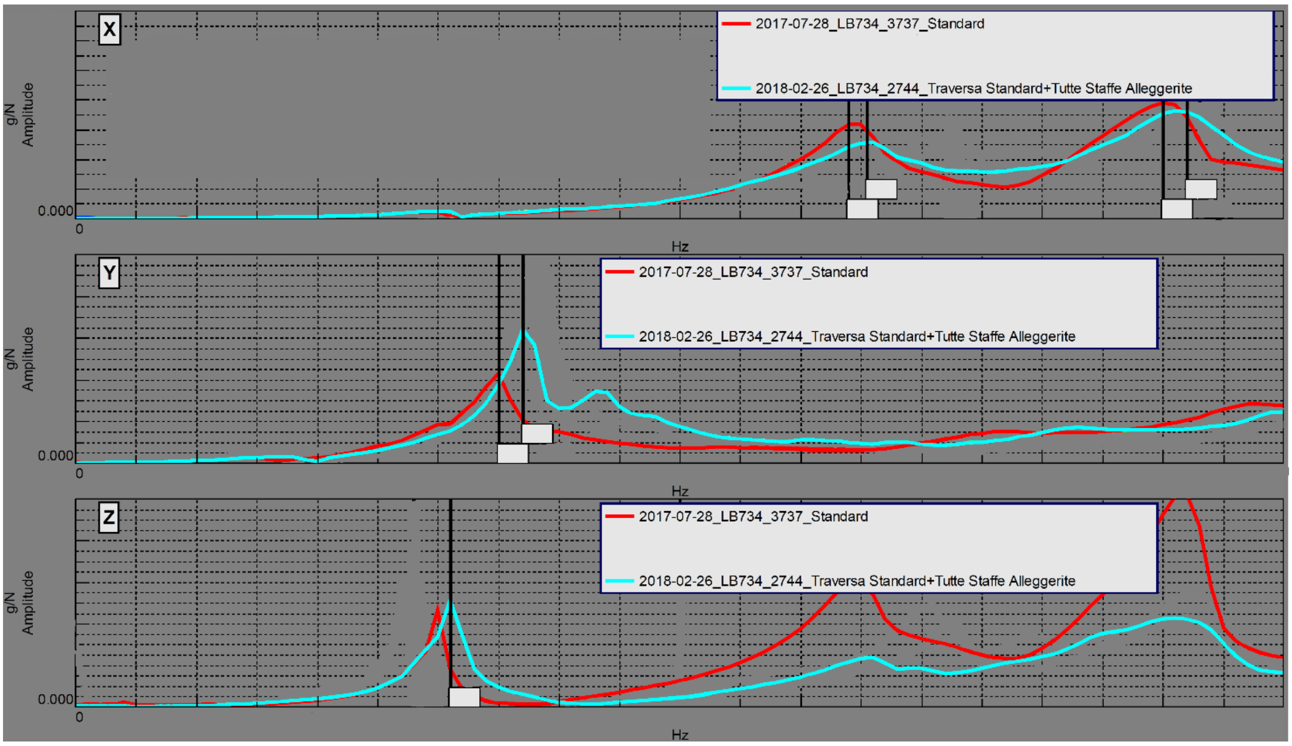


Figure 2.50: FRF for the vehicle with redesigned brackets with the steering column configuration “longitudinal adjustment fully extended and higher height position”.

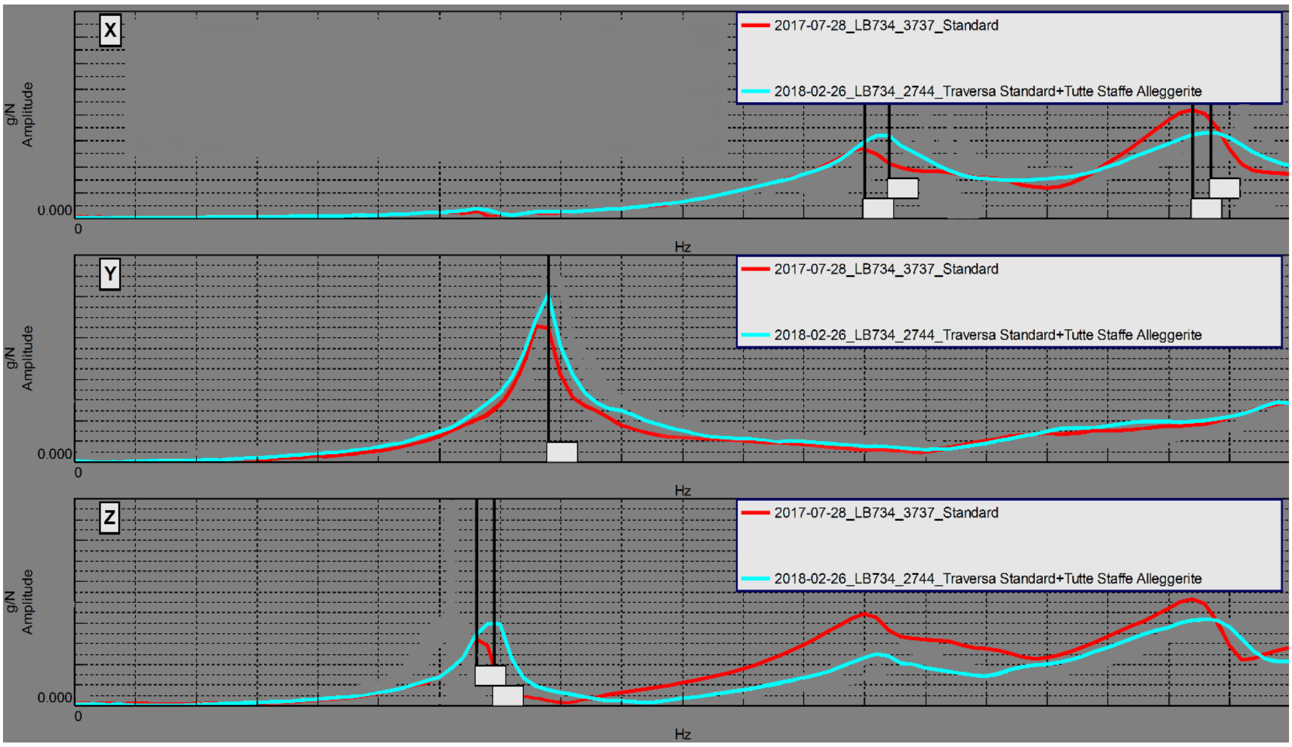


Figure 2.51: FRF for the vehicle with redesigned brackets with the steering column configuration "longitudinal adjustment fully contracted and lower height position".

2.6 Conclusions

The overall weight reduction, considering all the redesigned brackets, can be seen in the Table 2.2. The final total weight saving is of the 35.87 %, that is a significant result considering that some of the geometries could be still further optimized and that these brackets are only a part of the all brackets of the dashboard to which these technologies could be applied. The best weight saving performance are reached with the thermoplastic CFRP, but also the titanium ALM could be very good if applied in the proper way, for example for the "Assy PAB bracket" and the "Channel PAB supp" we reach respectively the -62% and -40%. In fact, as already stated before, the ALM technology could be better applied in cases where integrations between more components are possible and where a high level of freedom in the design of new geometries can be reached.

The press-thermoforming technology for thermoplastic CFRP probably is more suitable for a largescale production, because an almost fully automated process could be set and because of the need of some investments for the mould production. Instead, the titanium ALM is more suitable for the production of a lower number of pieces (e.g. for the production of low series vehicles or one-off vehicles) and for prototypes components, since there aren't necessary investments and since the changing of the pieces geometry can be performed without spending more money for the modifications of the production tools or for the building of new ones. Moreover, if compared with the technologies of the current production brackets (e.g. sheets-metal stamping or cut-&-bend) the costs of each part produced with titanium ALM are much higher. In order to reduce these costs the aluminium ALM technology could be eventually used since its per-part costs are half of the titanium.

The second main goal, that consisted in doing a technology scouting on these two innovative technologies, of this study is finally reached. We increased the company know-how that can be eventually applied on future cars and then the case study can be seen as a starting point for other future projects.

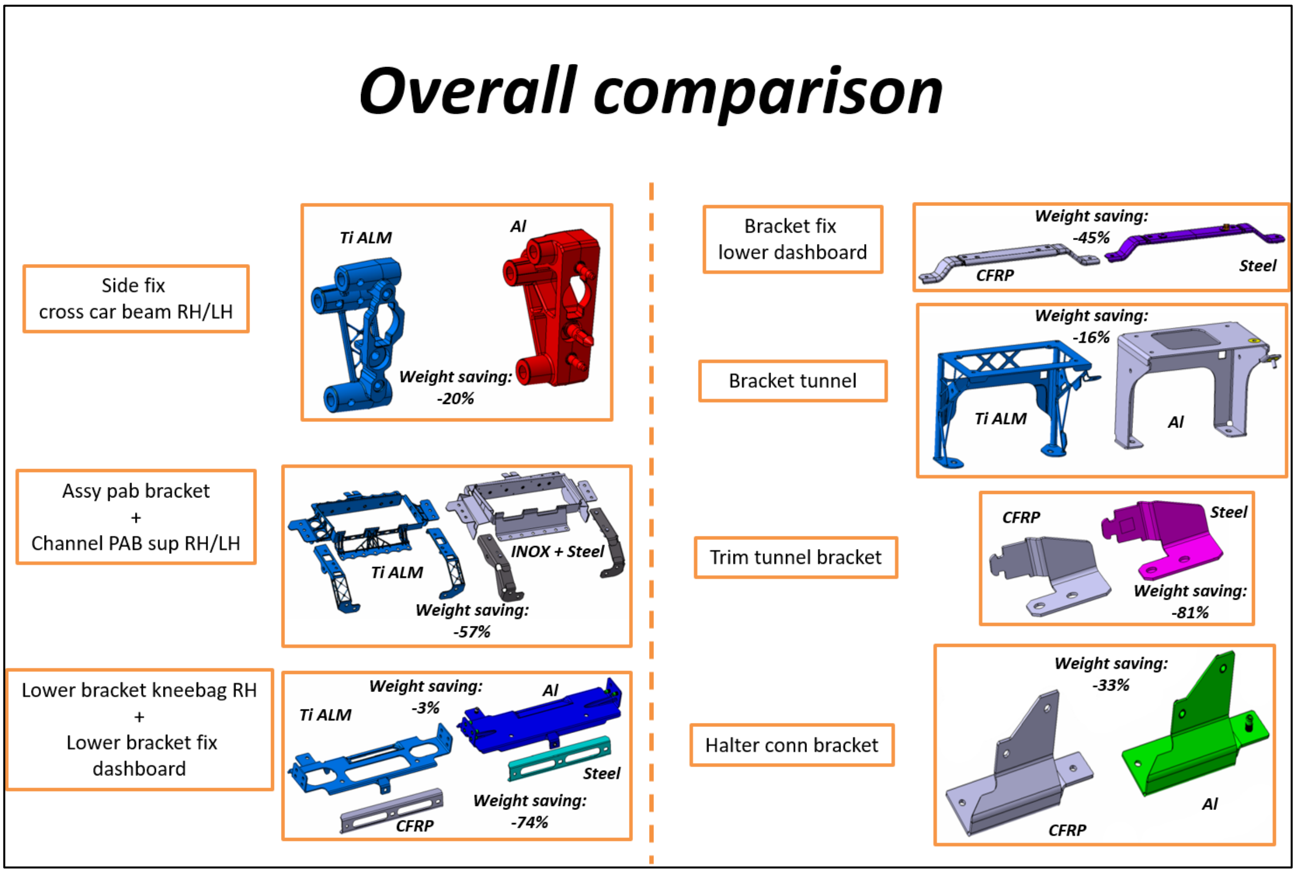


Figure 2.52: Overall comparison between the geometries of the different components

Part	Current material	New material	Weight saving %
Side fix cross car beam RH	Aluminium	Titanium ALM	-20,14 %
Side fix cross car beam LH	Aluminium	Titanium ALM	-17,58 %
Bracket tunnel	Aluminium	Titanium ALM	-16,41 %
Assy pab bracket	INOX	Titanium ALM	-62,32 %
Channel PAB supp RH	Steel	Titanium ALM	-40,24 %
Channel PAB supp LH	Steel	Titanium ALM	-40,49 %
Lower bracket kneebag RH	Aluminium	Titanium ALM	-2,79 %
Trim tunnel bracket	Steel	Thermoplastic CFRP	-81,67 %
Halter connection bracket	Aluminium	Thermoplastic CFRP	-33,33 %
Bracket fix lower dashboard	Steel	Thermoplastic CFRP	-44,59 %
Lower bracket fix dashboard	Steel	Thermoplastic CFRP	-74,26 %
TOTAL			**-35,87 %**

Table 2.2: overall comparison between the weight of the new brackets and the standard one.

CHAPTER 3

3 Case study 2: Introduction of innovative solutions on the Huracán Cross-Car-Beam (CCB).

3.1 Objectives of the study

This study has been performed to introduce new concepts on the dashboard module and to check their feasibility from the geometric point of view. The target was thinking out-of-the box trying to ideate innovative technical solutions that could be applied to the Cross-Car-Beam to overcome the concept of being only a structural part, evolving it to integrate also other functions. The purpose is to reduce the number of parts, through the integration of more functions in a single component, bringing three principal advantages:

- **Weight reduction**: because the number of components is lower also the weight could be lower
- **Costs reduction**: less components mean also less part-numbers (P/N) to manage for the logistic and production department. Moreover, there are less operations to do in the assembly line and less component to develop for the R&D department.
- **Packaging optimization**: less component in an assembly means the reduction of its overall dimensions, allowing more available space in the vehicle for the occupants.

The Cross-Car-Beam, being directly linked to the body frame, usually has only the structural function of carrying and sustaining all the other components of the dashboard module. In addition to the structural function we have thought to add also an aesthetic function and an air-duct function. The first has been performed making visible some of the CCB structural elements, that usually were hidden, modifying its geometry and raising up its beams in order to be at the height of the upper-dashboard trim. The second has been performed integrating in the horizontal transversal beam the air-ducts that bring air from the HVAC to the lateral air-vents. All the modifications have been done keeping in mind the optimization of the weight, thus trying to reduce the overall dashboard module weight.

The purpose of this work was performing a pre-feasibility study of the concepts listed above, i.e. verifying their geometric feasibility without taking into account particular technological constraints.

The activities concerning this case study can be divided in two different parts. The first involves the realization of the CAD model. In this phase the constraints deriving from passive safety, packaging, assembling, comfort, visibility and ergonomics have been taken into account. About the passive safety, particular attention has been given to the head impact of the passenger against the dashboard in case of crash. As a consequence, the impactable area has been identified in order to design the shapes of the CCB and of the trims, that could respect the required HIC (Head Injury Criteria). The second part involves the building up of a FEM model of the new CCB, in order to perform linear static and modal analysis, verifying that the same structural performances were maintained, structurally optimizing the geometry and estimating the weight.

Figure 3.1: DMU rendering of the dashboard with the remodelled CCB (on the left) compared with the current Huracán dashboard (on the right)

3.2 CAD model

The case study started with a deep analysis of the current dashboard of the Lamborghini Huracán through the DMU. This was the project taken as reference for the development of the work. In this first phase the constraints, that have to be taken into account during the development of the modelling of the geometries, have been decided. These geometrical constraints will be described more deeply in the following.

Afterwards, all the functions of the CCB and all the components that interface with it have been considered, in order to identify which opportunity of integrations should be exploited and to know how to use the available space to model the new geometry. After that, the development of the geometry has started. In this phase many issues had to be overcome and the principal critical points to which we had to pay attention will be displayed in the following. The final 3D model of the CCB will be then presented and how these issues have been overcome will be described in detail.

3.2.1 Geometrical constraints

The geometrical constraints decided at the beginning of this study were chosen to make the study suitable for the current production of the Huracán cars. The reason is that in the future hypothetic prototypes could be mounted on an existing vehicle. Furthermore, these constraints could be thought fairly the same also for the Huracán follower version. The components and subsystems taken as geometrical constraints for the development of the CAD model are the followings:

- Position and dimension of the steering wheel and the steering column
- Position and dimension of the PAB
- Position and dimensions of the HVAC
- Dimensions of the air-ducts exiting from the HVAC
- Dimension of the instrument cluster
- Position of the front and lateral fastening points of the CCB to the body frame (instead, the points on the central tunnel have been assumed free to move)

In the Figure 3.2 the DMU models of these components are showed.

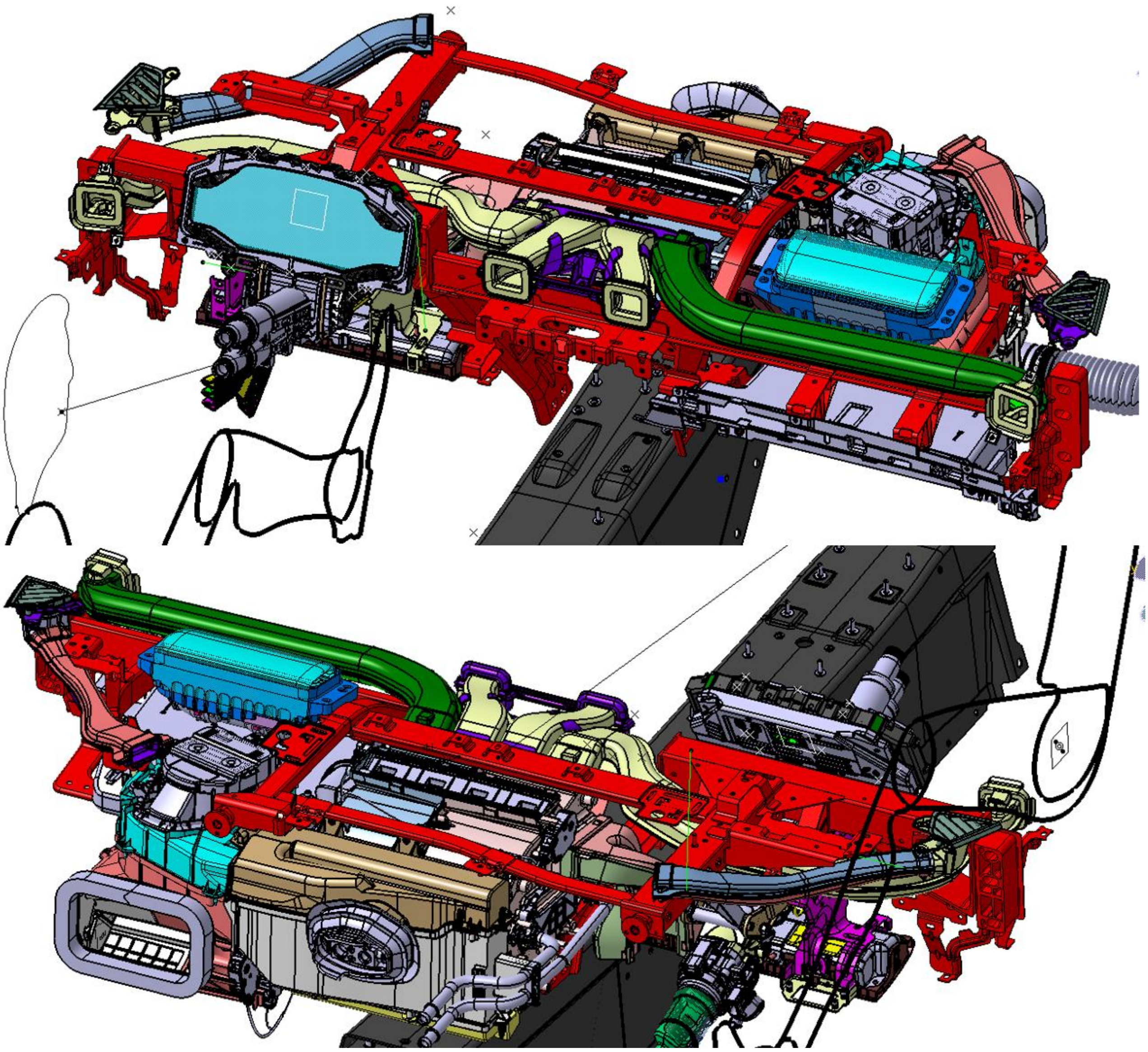


Figure 3.2: visualization of the principal components and subsystems taken as constrains and references for the development of the study.

3.2.2 Development of the 3D CAD model and principal critical points

The development of the CAD model took a considerable amount of time and numerous modifications have been made from the first model to the final one. All these variations and changes in the geometry have been made to face the problems encountered while the design required more and more details. The main critical points that we had to face during the development of the study have been:

- PAB dimensions
- Passenger head impact area on the dashboard
- Visibility and position of the instrument cluster
- Sustaining points of the HVAC module
- Pressure drop of air ducts and direction of the air exiting from the vents
- Vibration of the steering column

3.2.2.1 Passenger Air Bag (PAB) dimensions

The position of the PAB module couldn't be changed in any direction, since its passive safety performances highly depend on its location. The problem derives from its central position that leave a very low freedom to model the geometry of the beams in this area. Moreover, the upper dashboard in that area has to be maintained at the exactly same distance of the current one, because also the trim that covers it has a passive safety role during the deployment of the bag. The Figure 3.3 shows this distance between the PAB and the upper-dashboard trim, that has to be respected.

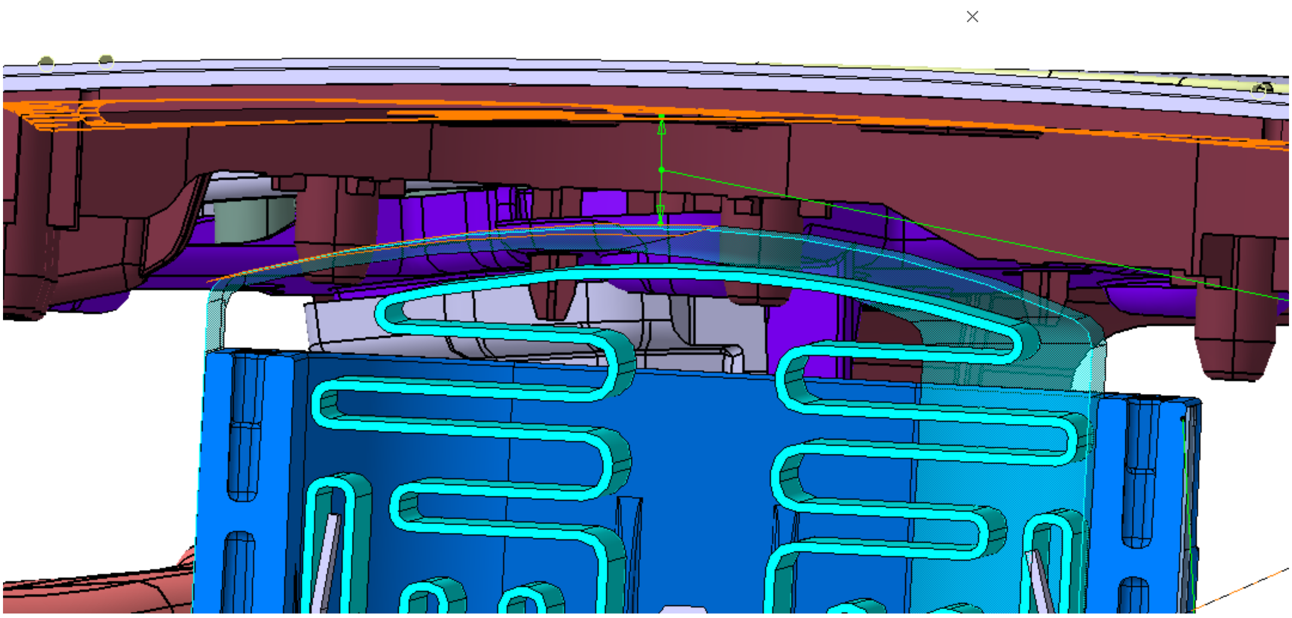


Figure 3.3: distance between the PAB and the upper-dashboard trim that has to be respected

3.2.2.2 Passenger Head Impact area on the dashboard

One of the regulations concerning the homologation of a vehicle regards the passenger head impact against the dashboard. In order to state if the desired HIC (Head Injury Criteria) value has been respected a special test was carried out. In this test was defined an impactable area, touchable by a sphere of 163 mm with the diameter connected to a pendulum of adjustable length of 29 to 33 inches. As an example, the head impact zone of the current Huracan dashboard is delimited by the green line in the Figure 3.4. In this zone there must be no objects potentially harmful or surfaces too hard, such as those of a structural component (e.g. the CCB). Therefore, only soft components should be placed in the impactable area and they have to be also at a certain distance from a hard surface positioned below. For this reason, we reproduced this test virtually at the DMU in order to check if the presence of the new CCB could make problems. In fact, the transversal beam of the CCB has been designed and located exactly in this area with the aim to be visible. It can be seen in the left of the Figure 3.5, where it is highlighted by the pink surface. To overcome this issue, the trims of the upper and lower dashboard in that area have been designed with a special shape, visible in the right of the Figure 3.5. This new design makes sure that the sphere doesn't impact the CCB even if it intrudes the trims up to a certain distance. In order to reach this goal a display for the passenger has been added, whose cover could help to protect the CCB from the sphere impact. The idea of introducing this passenger display has been inspired by its presence in other competitors' vehicles.

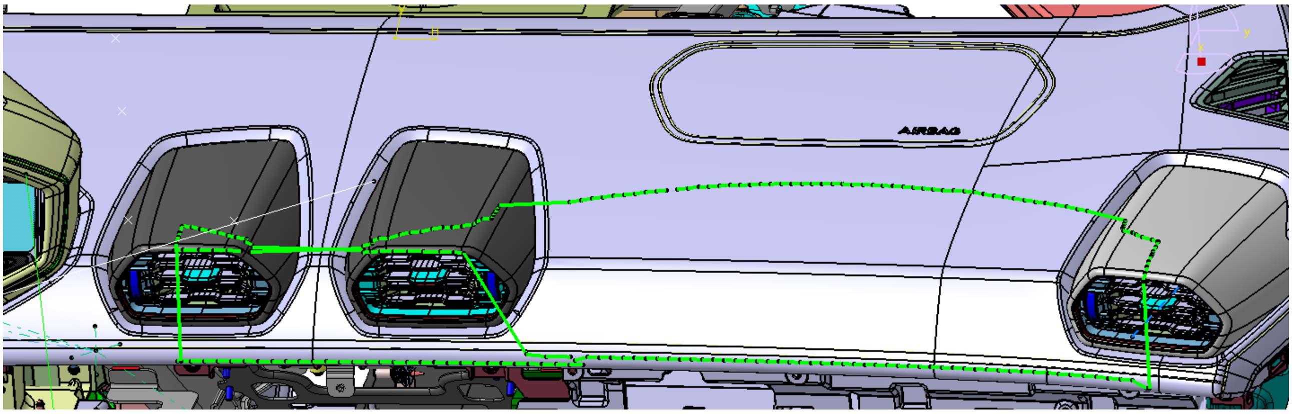


Figure 3.4: Head impact zone of the Huracan dashboard

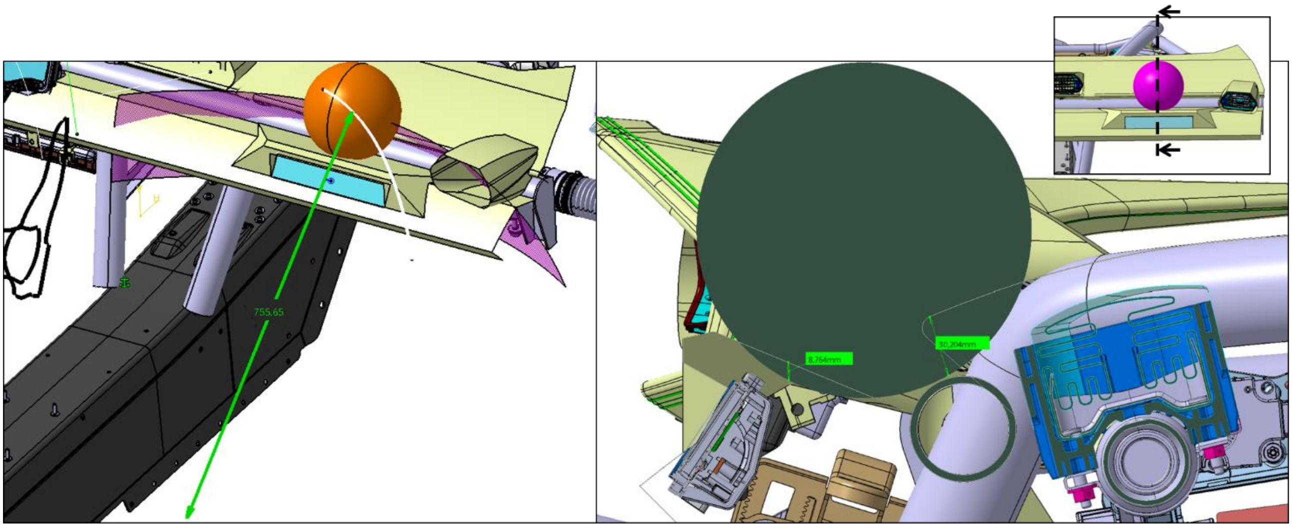


Figure 3.5: Passenger head impact test on the new dashboard trims, simulated at the DMU.

3.2.2.3 Visibility and position of the instrument cluster

With the aim to make visible the most CCB surface possible, we tried to change the position of the instrument cluster. However, the road visibility regulation had to be respected, leaving us a very small space to work, as it can be seen in the Figure 3.6 where the border of the visibility zone is showed. The alternative was to move the cluster in the X direction toward the front of the car. However, this solution could lead to a partial visibility of the cluster through the steering wheel, as it can be seen in the Figure 3.7. Thus, at the end, we decide to leave the cluster in the current position.

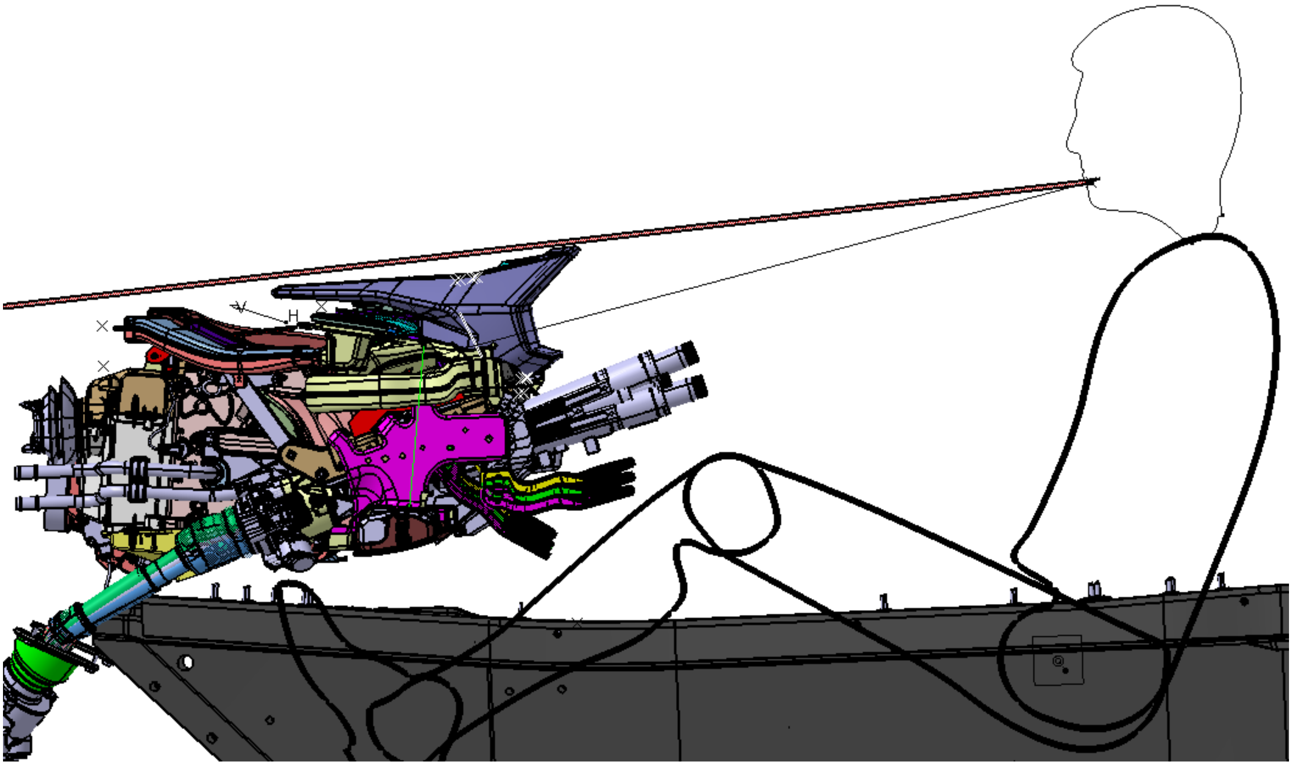


Figure 3.6: border of the road visibility zone

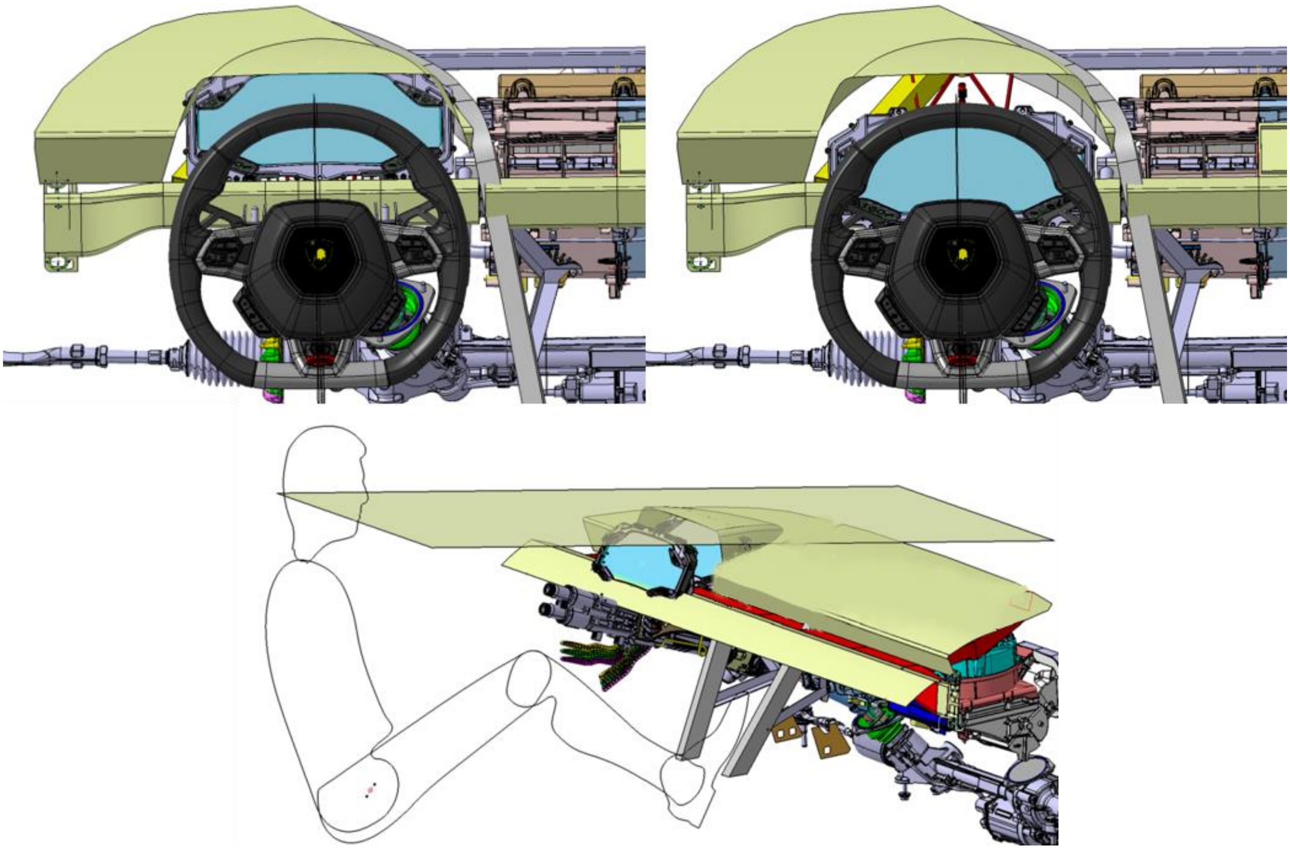


Figure 3.7: study for the change of position of the instrument cluster. At the top right there is the current position, at the top left the hypothetic new one.

3.2.2.4 Sustaining points of the HVAC module

One of the principal tasks of the CCB is to sustain the HVAC module. In particular there are four points in which the HVAC is fastened to the CCB: two are positioned at the top toward the front of the vehicle (on the top of the Figure 3.8) and two in the bottom near the central tunnel (on the bottom of the Figure 3.8). The design of the new beams took into account also these points in order to model a CCB that could be as stiff as possible.

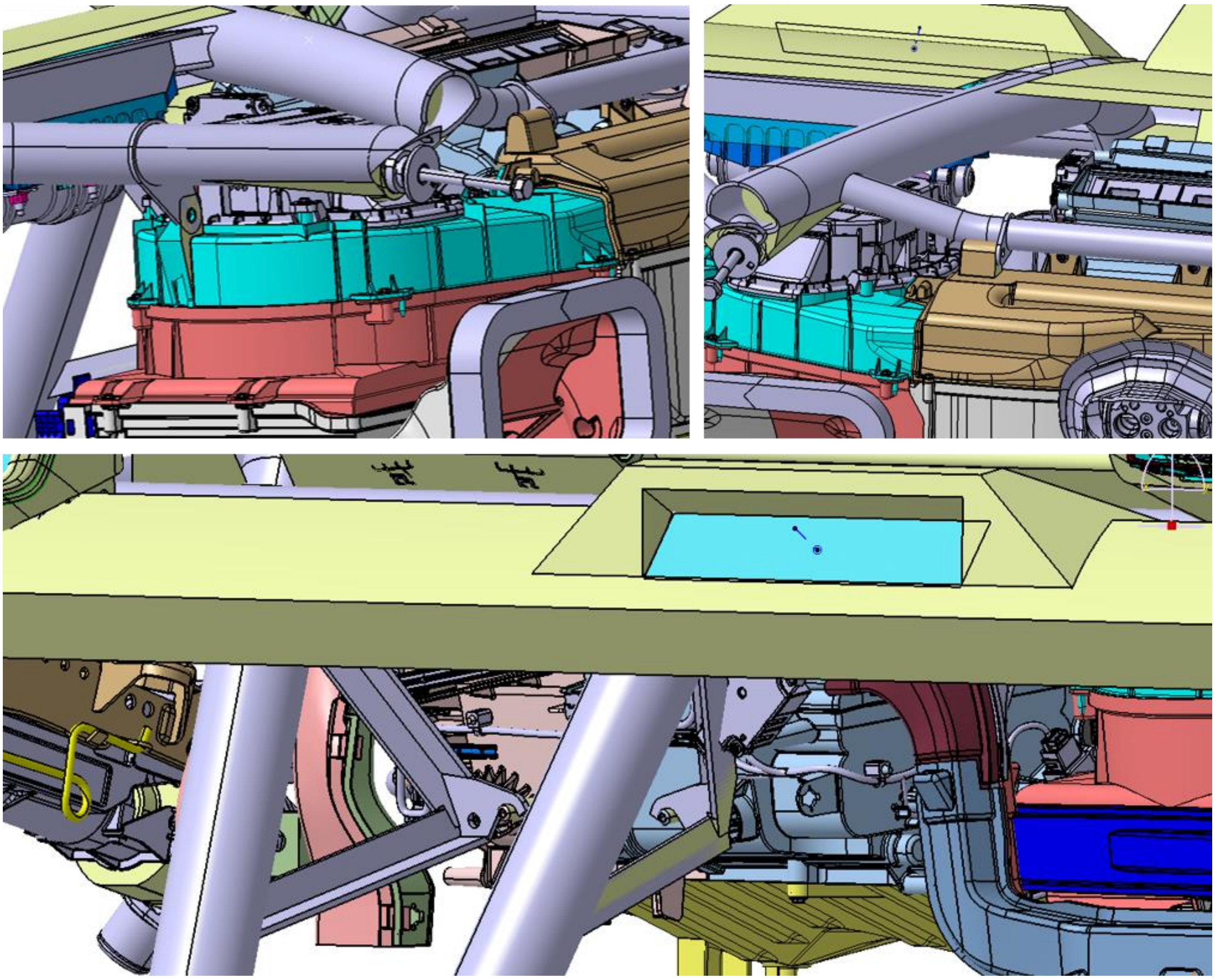


Figure 3.8: Fastening point of te HVAC to the CCB

3.2.2.5 Pressure drop of air ducts and direction of the air exiting the air- vents

As already stated before, one of the main targets of this study was to integrate into the CCB other functions. About this concept, an idea was born looking at the Figure 3.9, that shows the configuration of the current air-ducts. As it can be seen the main transversal beam of the CCB runs in the same zone and direction of the two air-ducts that bring air to the front lateral air-vents. As a consequence, we tried to integrate these air ducts into that transversal beam. In order to avoid a to high pressure drop of the air inside the ducts we had to respect three constraints:

- the transversal beam had to be designed with the same internal diameter of the current ducts;
- the interfaces between the HVAC and the beam and between the beam and the lateral air-vents had to be modelled making curves as large as possible;
- the direction of the air exiting the air-vents had to be maintained the same.

The Figure 3.10 shows how this integration has been developed highlighting the geometries of the interfaces of the HVAC and the air-vents with the transversal beam of the CCB.

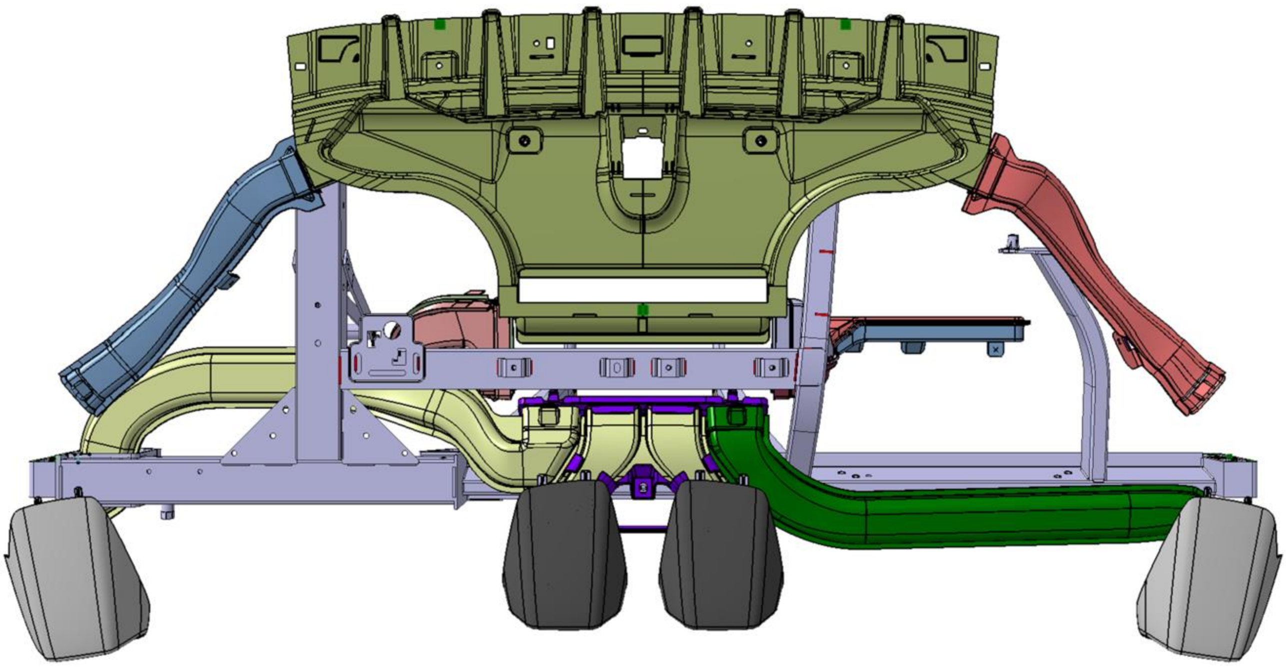


Figure 3.9: current configuration of the air-ducts that bring air from the HVAC to the air-vents

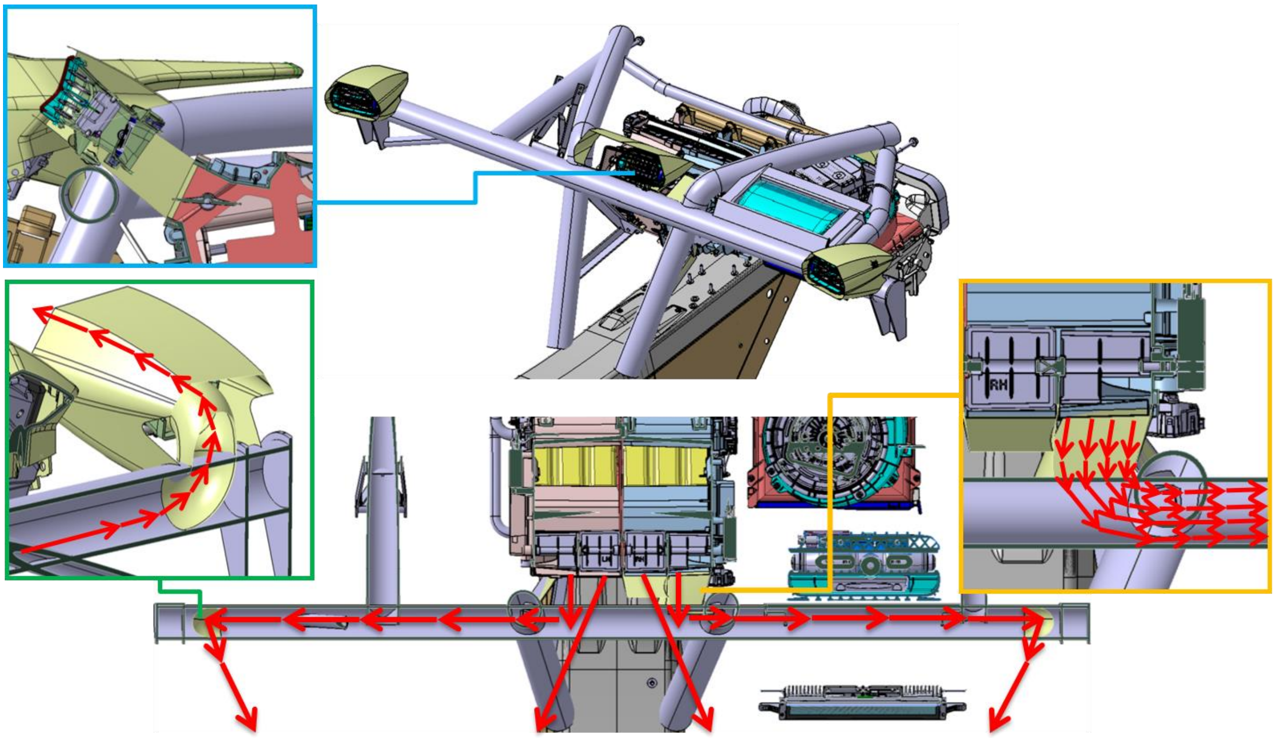


Figure 3.10: integration of the air ducts, that bring air to the lateral air-vents, into the transversal beam of the CCB

3.2.2.6 Vibrations of the steering column

The structure of the new CCB has been designed to maintain the same stiffness performances of the current one. The main target was to keep the natural frequencies of the first vibration modes of the steering column to limit the vibration of the steering wheel, that has a direct influence on the comfort perception by the driver. For this reason, a FEM model has been developed in order to validate the final geometry and to help the design of the cross-sections, of the positions and of the directions of the different beams that build up the CCB.

3.2.3 Final 3D model

The final 3D model of the new CCB can be seen in the Figure 3.11, where it is compared with the current one. The most important differences between the two are that in the new one the points of fastening of the CCB to the body frame on the central tunnel have been moved toward the rear of the vehicle. This has been made in order to make visible the two vertical beams from a lateral point of view and to place them just behind the central instrument board (Figure 3.13). Furthermore, the frontal point of fastening to the body frame on the passenger side has been moved laterally in order to make it symmetrical with the one on the driver side. The change has been possible since that point was already present on the body frame, that is the same for both left-hand drive and right-hand drive versions. Another important modification is about the rightmost beam that has the role to sustain the HVAC. In new model this beam has been extended and linked to the other diagonal beam, building in this way a more rigid geometry.

Additionally, as already described before, in order to show up in a better way the concept of aesthetic Cross-Car-Beam and to analyse the problem of the passenger head impact on the dashboard, also the shape of the upper-dashboard trim has been remodelled (see Figure 3.12). Furthermore, a display for the passenger has been added and the four frontal air-vents have been remodelled and repositioned. The final parts of the CCB that have an aesthetic function are the transversal beam and the two central vertical beams, as seen in the Figure 3.13

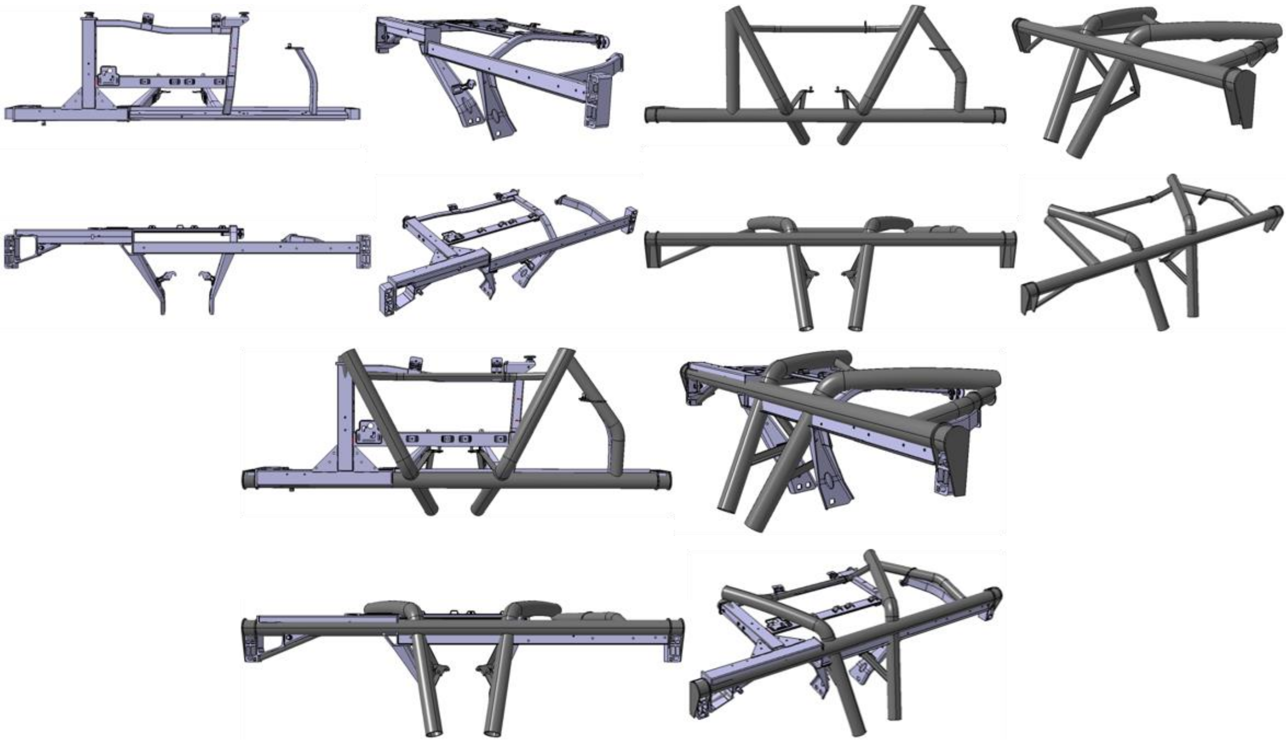


Figure 3.11: comparison between the current CCB and the final 3D model of the current one.

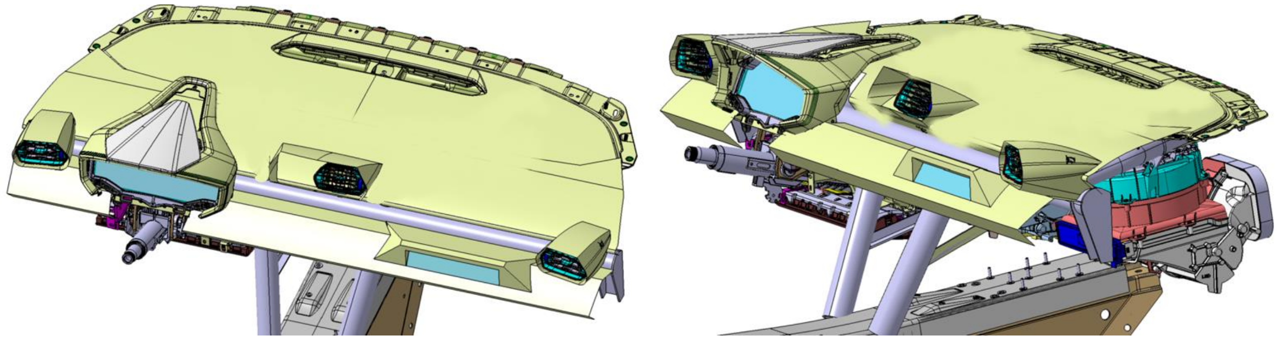


Figure 3.12: shapes of the trims of the upper-dashboard that have been remodelled

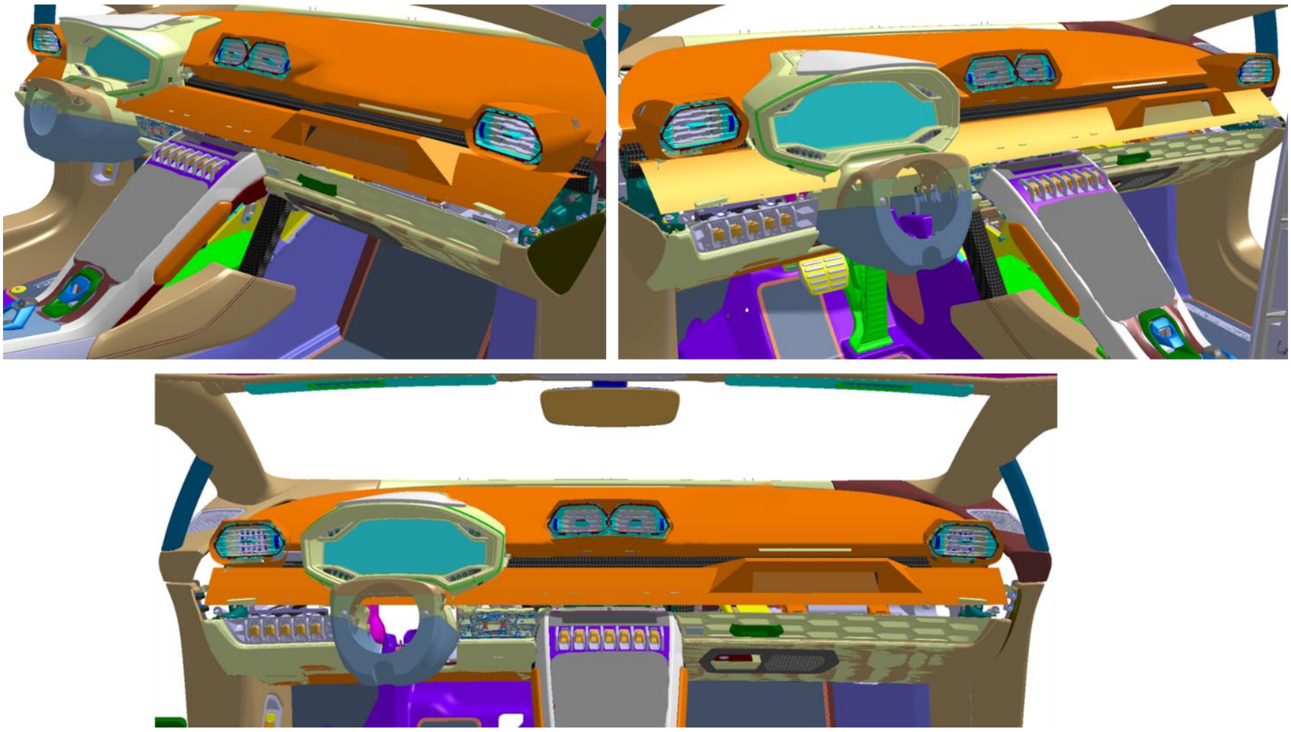


Figure 3.13: rendering of the final shapes of the remodelled CCB and upper-dashboard.

3.3 FEM model

During the development of the 3D CAD model, a FEM model has been built up in order to verify that the new geometry did not compromise the global stiffness performances of the Cross-Car-Beam. As already stated before one of the first goal of the CCB is to sustain and hold the steering column and so it is the most important component that influences the vibrational behaviour of the steering wheel. As a consequence, the first target from the structural point view was to maintain the same natural frequencies of the first vibration modes concerning the steering column. This was verified by making a modal analysis. Moreover, also a linear static analysis has been performed, applying a load on the centre of the steering wheel in the direction of the steering column axis to simulate the force due to the deployment of the air-bag and to the driver impact during a crash. All these analyses have been performed comparing the results with the current CCB that has been taken as reference. Guaranteeing the same mechanical performance was necessary also in order to estimate the thickness of the beams and, as a consequence, the overall weight.

The approach that has been used to build the FEM models is the use of 1D beam elements. This choice of using a simplified model was taken since it was the simplest way to easily change the shape of the beams, their disposition in the space and their cross-sections. In fact, there was the need of a model that could be changed fast and easily, in order to assist the design of the shapes and the decisions to be taken during the CAD modelling. Moreover, this approach has been possible due to the particular shape of the CCB, that, with its almost linear beams, adapted perfectly to the use of 1D elements.

As a starting point for the FEM models an already existing model of the current CCB, made with 2D shell elements, has been used. Since this model has been already tested and it has given accurate results, it was used as a reference for the validation of the current CCB 1D model. In this way the 1D model of the new CCB could be compared with a more accurate model.

3.3.1 Current CCB 1D-elements model creation and comparison with the 2D-elements one

The already existing 2D model of the current CCB, that has been taken as reference, can be seen in the Figure 3.14. In this model, beside the CCB, are present also the steering column and the HVAC. Starting from this, the 1D model has been built up (see Figure 3.15). On this 1D model, a work of continuous modifications and checks has been done, in order to make the results as near as possible to the 2D model. With this purpose different types of links between the different beams with elements RBE2 or RBE3 have been tried to reach the best results. The final results of modal and linear static analyses are showed in the Figure 3.16. The comparison between the two models states that there is a difference of the +0.78% between the natural frequencies of the first vibration mode, a difference of the +0.97% for the second vibration modes and a difference of the -1.78% for the linear static analysis. As expected the 1D model was stiffer than the 2D model and due to the very small differences, the 1D elements could be considered good for this type of application.

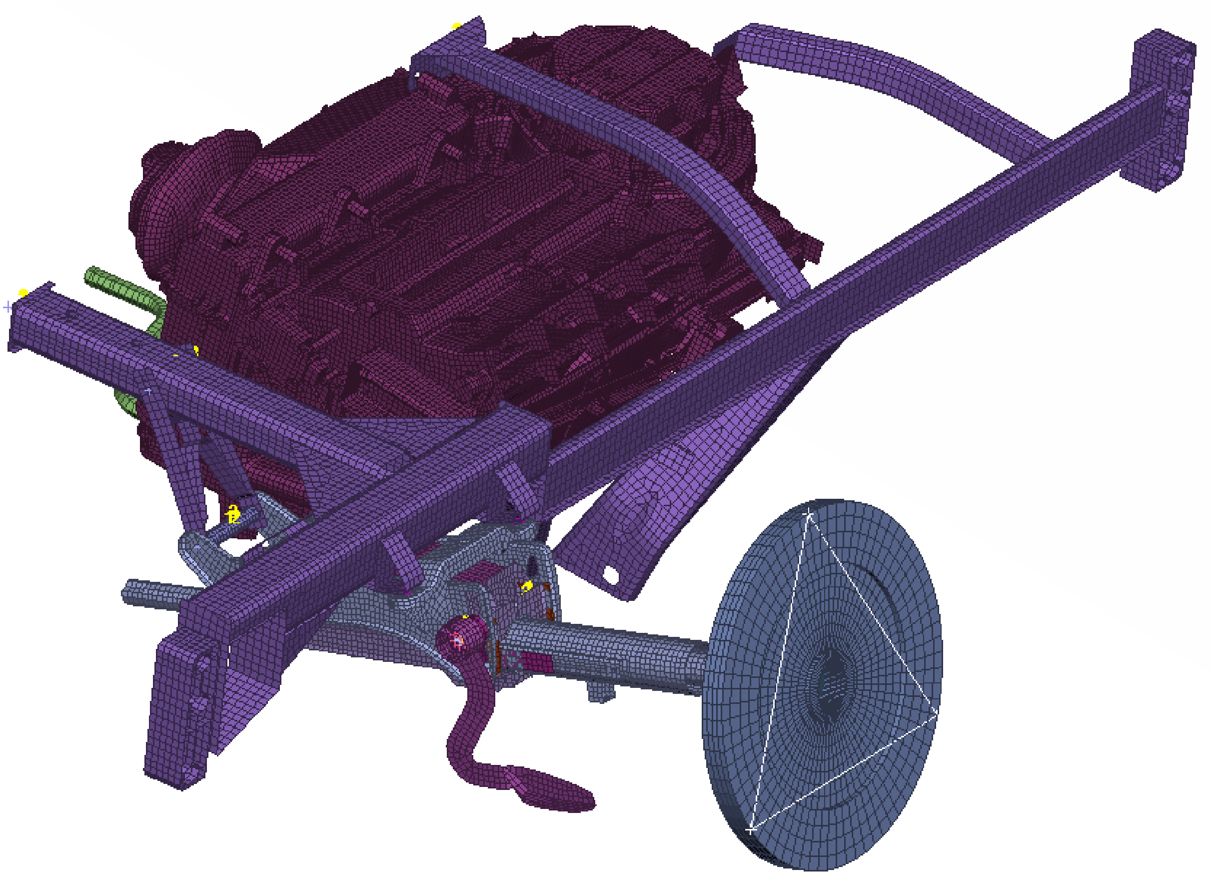


Figure 3.14: FEM model of the current CCB

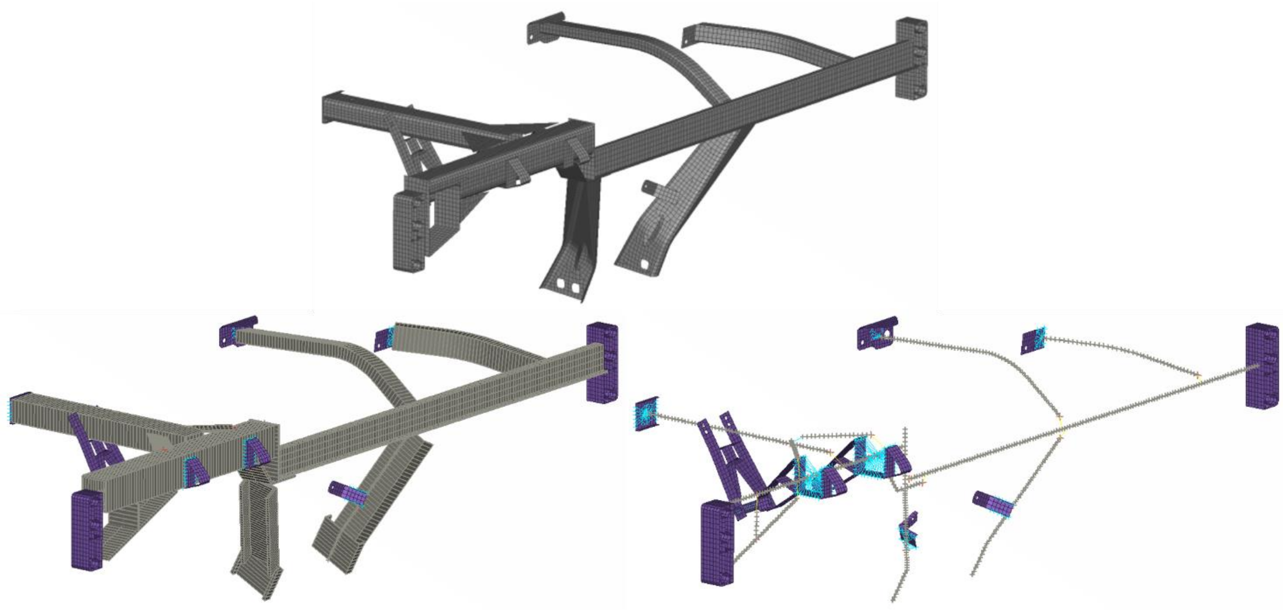


Figure 3.15: comparison between the models of the current CCB with 2D elements, on the top, and 1D elements, on the right bottom. On the left the 1D model is represented with the cross-sections of each beam displayed

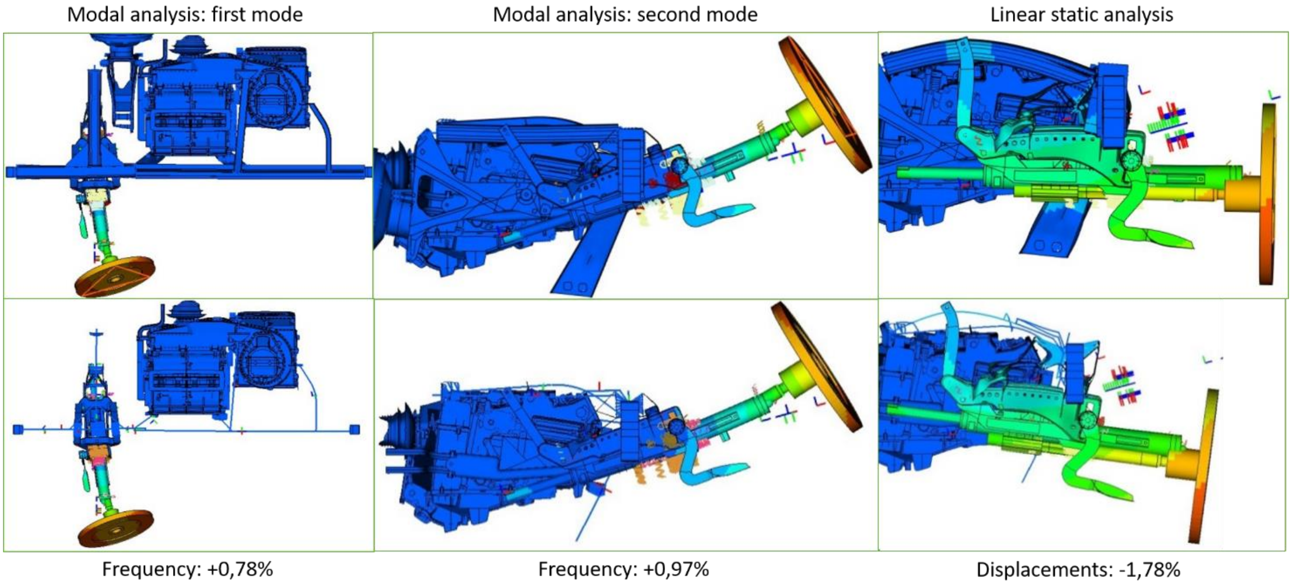


Figure 3.16: comparison between the results of the 2D model, on the top, and the 1D model, on the bottom, obtained from the modal and the linear static analyses

3.3.2 New CCB 1D-elements model and weight estimation.

The FEM model of the new CCB can be seen in the Figure 3.17, where it is also showed the representation of the model with the cross-sections of each beam displayed. This model has been built with the aim of verifying if the geometry of the new CCB would be suitable in terms of mechanical performances and of estimating consequently the weight. The cross-sections of the beams have been optimized to reach almost the same stiffness, verifying the results of the modal and linear static analyses with that of the current CCB 1D-elements model. The model of the current CCB that has been used as a reference was a modified version of that one previously described, since two cross-beams visible in Figure 3.18 have been added. Moreover, two different materials, aluminium and carbon fiber, have been simulated, with different cross-sections in order to optimize their characteristics. For the carbon fiber, since we were using a model with the elements 1D and because highly accurate results were not necessary, we made an approximation considering it isotropic even if actually it is not. The results of the modal analysis and the linear static analysis of both the aluminium and the carbon fiber versions are shown in the

Table 3.1 where they are presented in percental form with respect the results obtained from the simulations of the current CCB. The target consisting in obtaining at least the same stiffness has been reached, highlighted from the higher values of the natural frequencies of the first (displacement of the steering column in the Y direction) and second (displacement of the steering column in the Z direction) vibration modes of the steering column. Moreover, the displacements of the steering wheel that have been output from the linear static analysis are lower for both the versions. As already stated before the linear static analysis has been performed with a load applied at the centre of the steering wheel with the direction of the steering column axis.

Since the stiffness of the new CCB can be considered fairly the same to the current CCB, because of the small differences of the values of the analysed results, we can estimate the difference of weight that was the main purpose of the FEM structural verification. With the aluminium version we can save the 10% of the weight with respect to the current CCB. With the carbon fiber version, instead, the weight saving reach the 20%.

To complete the overall weight-saving analysis we have to add also the weight difference, deriving from the changed shape of the upper dashboard trim and from the two air-ducts that have been integrated into the CCB. The new upper dashboard trim brought an increase of the weight estimated in +12 % with respect the current one. However, we have to take into account that this value considers also the trim part covering the passenger display, that before there wasn’t. At the end, considering also this value and the weight saving brought by the integration of the two air-ducts, we reached an overall weight saving of -5% for the aluminium version and of -12% for the carbon fiber version.

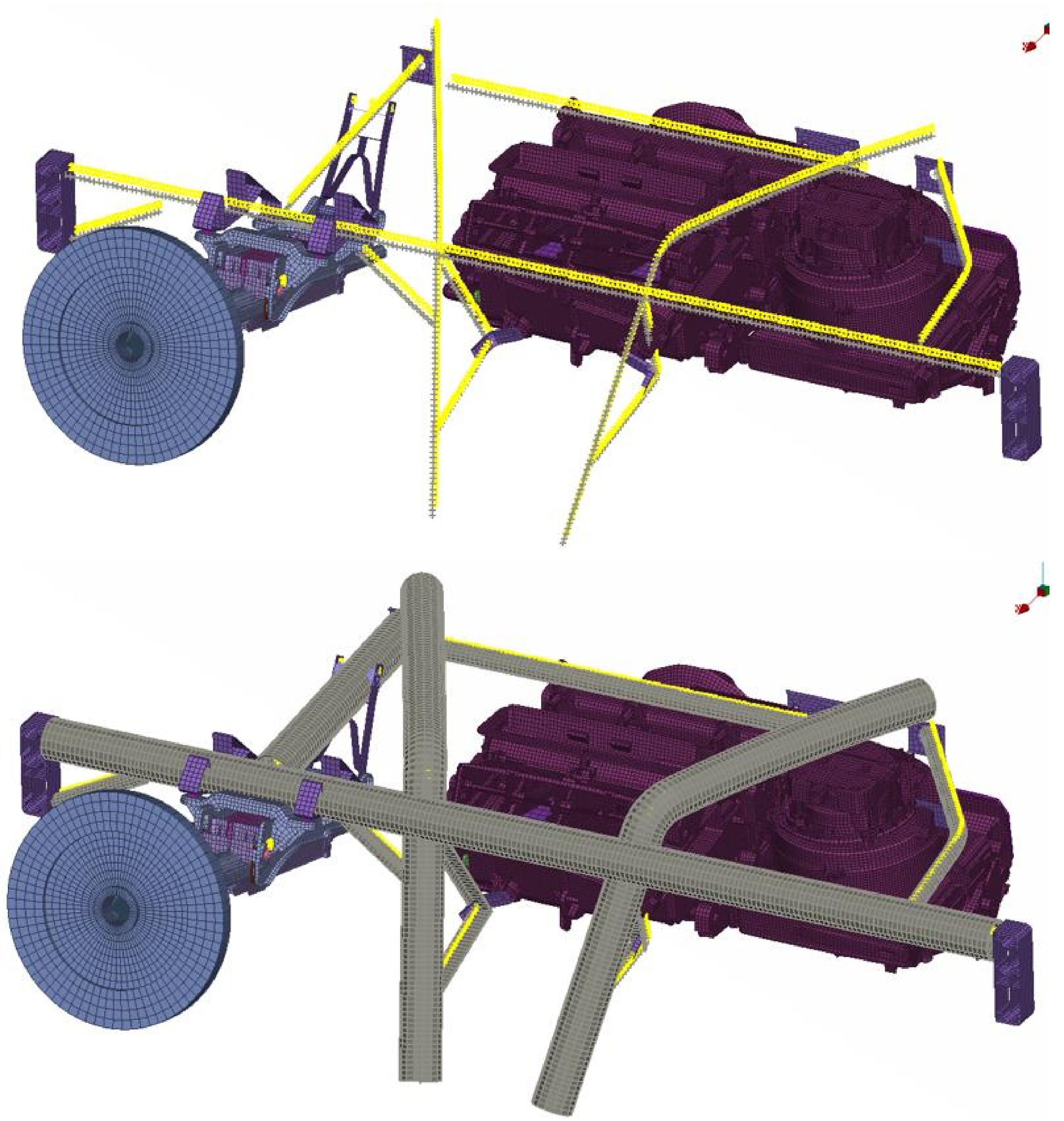


Figure 3.17: FEM model of the new CCB built up using 1D elements. On the bottom the model is represented with the cross-sections of each beam displayed.

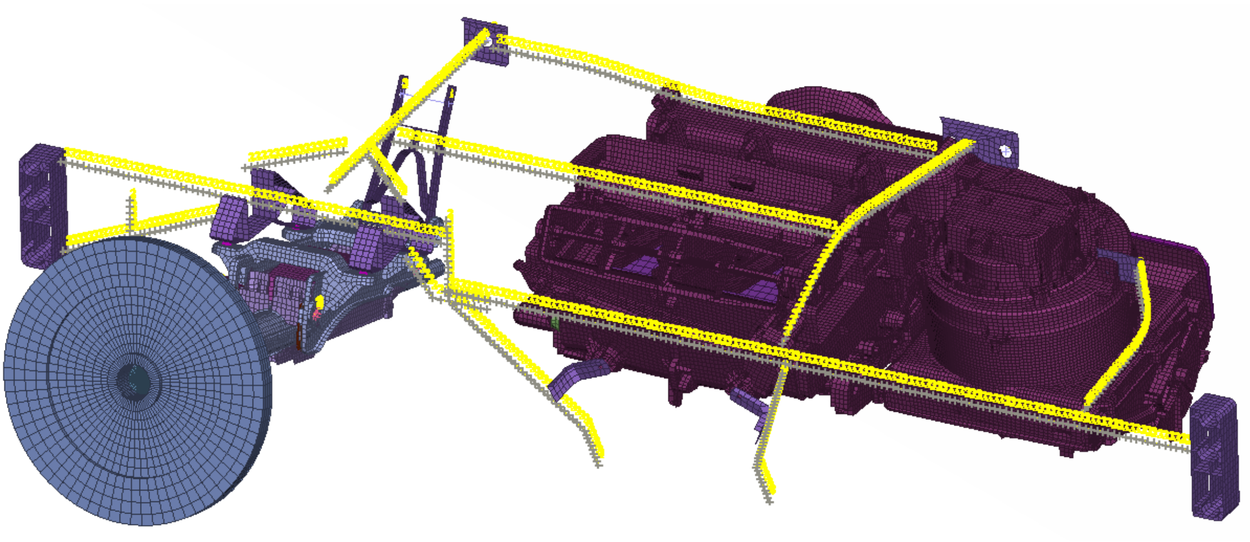


Figure 3.18: modified version of the current CCB taken as reference: two cross-beams added.

		Modal analysis		Linear static analysis
	Weight	1st vibration mode natural frequency	2nd vibration mode natural frequency	Displacements
Aluminium	**-10 %**	+0.60 %	+0.13 %	-1.45 %
Carbon fiber	**-20 %**	+0.50 %	+0.01 %	-0.36 %

Table 3.1: results of the FEM analyses. The values are given with respect to the result obtained in the simulations of the current CCB

3.4 Conclusions

The initial target of this study was to perform a geometrical feasibility check of the possibility to integrate new functions into the CCB, in order to introduce innovative concepts in the interiors. At the end, through the CAD and FEM models we have seen that both the two hypotheses, of integrating the air-ducts and of making some parts of the CCB visible, are feasible and brought also a potential weight saving. As already stated before this was a preliminary approximative study and it is only a potential starting point for deeper analysis and projects. Moreover, the geometry obtained could be further optimized in function of the material and technology that could be chosen. A technological study should be also done in order to state if effectively these concepts are feasible or not. These points depend also from the definition of the possible applications: for example to a one-off or to a low or high volume production cars.

Conclusions

The two case studies discussed in this thesis showed up different possibilities of innovation of the vehicle interiors, allowing to deepen the knowledge on different technologies, materials and concepts. Through these case studies it has been possible to demonstrate that the application of these innovative solutions could bring also a potential weight reduction on the dashboard module. The weight saving is a very important theme for the design of supercars as those produced by Automobili Lamborghini. As a consequence, it has been one of the central point during my internship in this company and clearly also the main subject of this thesis. Moreover, the work I have done during the internship and the development of this thesis allowed me to learn more about all the subsystems that are part of the dashboard and of the interiors, and to go deeply inside the different issues that should be faced during the development of components like these.

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