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DESIGN OF THE STRENGTHENED FRAMEWORK FOR A DESIGNED CONCEPT OF THE SPORT CAR BODY

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Abstract: This paper presents design process and checking of the static stiffness of a sport car chassis at the conceptual design stage. Based on the requirement list, the concept of car body is designed, which is then analyzed from the point of aerodynamics, i.e. CFD analysis. With the analysis is determined that the car body is exposed to predominantly laminar flow of fluid with the presence of turbulent flow in the rear part of the car body. According to the data obtained from the aerodynamic analysis, the construction of the chassis is started. The chassis is the central supporting part of the overall car construction, which by its shape needs to follow outer contours of the car body. The chassis is reinforced with front and lateral attenuators. Attenuators are absorbing the energy that is releasing from strike.
Keywords: Car chassis, Computational Fluid Dynamics (CFD), Design process, Function, Requirement list

1. INTRODUCTION

The car body is using for accommodation and protection of driver, passengers and luggage from outside influences. Depending on the design, certain assemblies such as aggregates, tanks, electrical appliances, etc. also can be placed to the car body.

In addition to the general requirements (minimal weight, sufficient lifecycle, simple design), car body needs to satisfied the following specific requirements: space for vehicle assembly accommodation, passive safety of driver and passengers, a suitable aerodynamic profile, good visibility, sound isolation, dust isolation, isolation from the cold, heat and moisture.

Self-supporting car bodies ensure higher stiffness and have lower mass. Such a car body is often calling a chassis. Chassis therefore has the following functions: ensures the safety of passengers, serves as a foundation for attaching other parts of the car and gives the exterior form of the car.

Below the work are presented the chassis design forms used in the auto industry for the production of racing cars. Ladder chassis (Fig. 1a) consists of two longitudinal rails that are assembled with multiple transverse rails [1]. Longitudinal rails take over stress, lateral rails provide resistance to lateral forces and increase chassis torsional stiffness. Because it is a two - dimensional structure, it has small torsional stiffness.

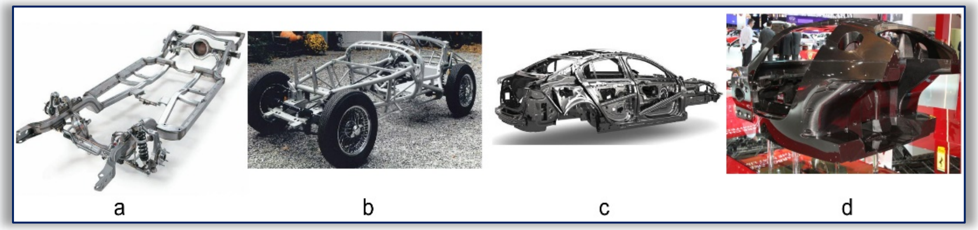

Figure 1. Car chassis design forms

Tubular chassis (Fig. 1b) represents a three - dimensional structure with greater torsional stiffness compared to the ladder chassis [2]. Tubes are positioned in different directions to take over stresses from different directions. Tubes are mutually welded. Chassis is expensive for production, takes a lot of space and car access is inaccessible.

One part chassis (Monocoque) consists of one part that defines the entire car form (Fig. 1c). It occurs by welding individual parts into a unified whole. The entire structure makes an exterior shell that is designed to provide greater space for passengers. Therefore, it has reduced stiffness. It is suitable for mass production and robotization, but it has a large mass [3].
Carbon fiber chassis (Fig. 1d) usually uses kevlar as the kind of carbon fiber for its making [4]. Carbonic components are made of layers of carbon fibers, which are wrapped in aluminum foil after stacking. The foil takes the form of the panel from which the air is extracted. Then, it boils for about 3 hours at 120 ° C under a pressure of 0,6 MPa. After that, the carbon fiber panels are assembled in solid form. This chassis, compared to other chassis, has the smallest weight and the greatest stiffness, but is also the most expensive to make.
In this paper was analyzed the problem of creating a downforce. This force presses the car on the ground and allows better tire adhesion to the ground. The problem was analyzed by installing the rear diffuser in car body. Such a construction solution reduces the area of accumulated turbulent air behind the car. In the rear part of the car body has implemented a spoiler, which in this embodiment does not constitute a separate element. The car body is shaped in such a way that its form is aerodynamic. It looks like a drop of water. This form in the nature is the most aerodynamic body. According to the form of the car body whom we designed, the design of the chassis was started. The chassis form needs to be implemented in a form of a car body. It should be designed as a three - dimensional supporting element. It also should be resistant to torsional stresses, dynamic strikes and made of materials that reduce total chassis mass.

2. REQUIREMENT LIST OF THE CAR BODY AND CAR CHASSIS

By the requirement list [5] are involved requirements for the design of the car body and chassis. A detailed description of the all requests is presented in [6]. In Table 1 are listed the most important requirements, according to which the forming and design of the car body and car chassis is made.

Table 1. Requirement list of the car body and car chassis

No.	Requirement	No.	Requirement
1.	Car body dimensions: L_{max}=4850 mm, W_{max}=2100 mm, H_{max}=1200 mm	12.	The maximum weight of the vehicle with thrusters is 1550 kg
2.	Wheelbase 2600 mm	13.	The chassis must submit a static load up to 3g
3.	Place two people in the chassis	14.	To form the front part of the chassis to absorb the front dynamic strikes
4.	Most of the car mass place between the axles	15.	To form the side piers of the chassis to absorb side dynamic strikes
5.	To enable the force of aerodynamic thrust by car body geometry	16.	To achieve the force of aerodynamic thrust through an car body to ensure better wheel adhesion on the ground
6.	To enable laminar air flow by car body geometry	17.	To form the rear part of the car body to reduce the impact of the traction force on the car
7.	To reduce turbulence of the wind by car body geometry	18.	To form the roof of the chassis so that it does not bend during uncontrolled rotation of the vehicle
8.	To enable engine cooling by car body geometry	19.	Make chassis from noncorrosive materials
9.	To enable braking system cooling by car body geometry	20.	Make chassis from lightweight materials
10.	Maximum vehicle speed up to 350 km/h	21.	The chassis material should submit dynamic loads
11.	The chassis must wear the car's components	22.	The driver's seat space should not be damaged when the frontal impact of the car is 56 km/h

3. MODELING A COMPUTER 3D MODEL OF CAR BODY

Because of the complex geometry, modeling of the car body has done in the Autodesk May [7] software package, not in any of the commercial CAD systems. The car body is made of polygons freely deformed in space and there are no necessarily dimensional constraints, as is the case with commercial CAD systems. This approach allows free form design, which in a much faster way leads to the desired form of car body. A primitive *plane* was used for modeling, which was upgraded with several polygons and then with the free form design techniques formed into a surface model of the car body (Fig. 2a). The final surface model of the car body is shown in figure 2b.

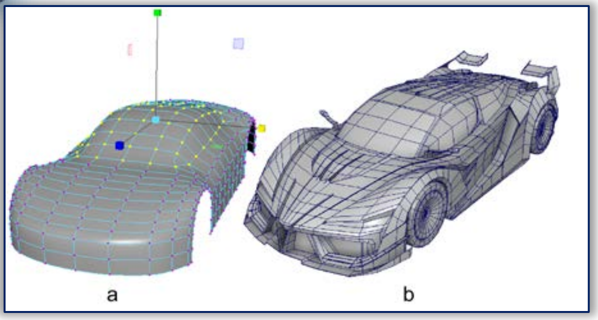

Figure 2. Car body form in Autodesk Maya

In order to calculate the car body aerodynamics, the model was imported from Autodesk May into one of the commercial CAD systems and a solid model of a car body was made from the surface model of a car body. Generation of solid model was performed in SolidWorks [8].

Orthogonal projections of the surface model of the car body from Autodesk May were imported into the sketching planes in SolidWorks (Fig. 3a). From orthogonal projections, curves were generated in the sketching planes (Fig. 3b). The curves are interconnected using surface segments and form a closed surface model (Fig. 3c). Procedure is very long and requires great precision in the modeling process. From surface model, by filling the volume, a solid model of car body was generated. The surface model that was generated in the solid model consists of 700 2D sketches, 200 3D sketches and 300 space curves.

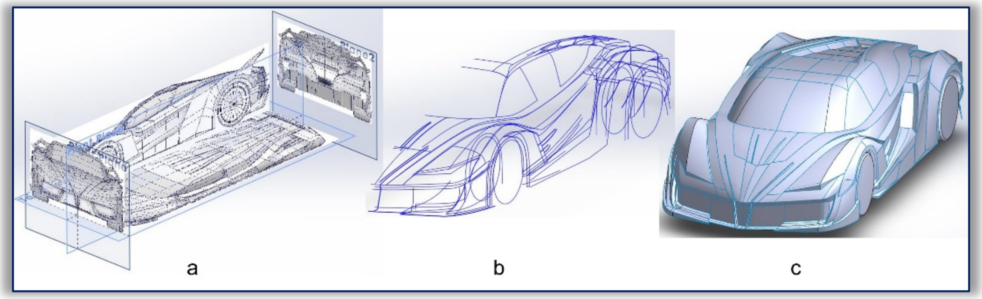

Figure 3. A car body space model in SolidWorks

4. AERODYNAMIC CALCULATION OF THE CAR BODY

An analysis of the airflow around the car body was made in the ANSYS Fluent [9] software package. Due to the complexity of the geometry and the limited resources of the computer on which the calculation was performed, there was a need to simplify the CAD model. Therefore, the numerical calculation results obtained by CDF analysis are not within the values that would be expected if the above condition was met. Since this is a conceptual solution, these results are satisfactory and acceptable from the point of view of the conceptual design phase. The simplified model contains the basic contours of the car body and presented is in figure 4.

Domain discretization was performed. The goal of the discretization is to divide the physical space in which fluid flow is calculated into a large number of elements called the mesh [10]. The entire car body model was taken into account due to the airflow through the symmetry plane from left side to right side of the car body and inversely. Also, turbulent and laminar flow will not be equal on both sides of the car body. On the car body was added closed space. This space represents air. The Boulean operator took away the car body from the air body. The final domain is shown in figure 5a. The domain length consists of three car body lengths; two lengths behind the car and one length in front the car. The domain height contains two car body heights. The domain width consists of three car body widths. Tetrahedral finite elements were selected and a structured and unstructured grid was laid (Fig. 5b). The structured mesh is set up in five layers around the car body. The minimum size of the first layer is 5 millimeters and increases by 20% up to the fifth layer. This layer is called the inflationary layer of the mesh (Fig. 5c).

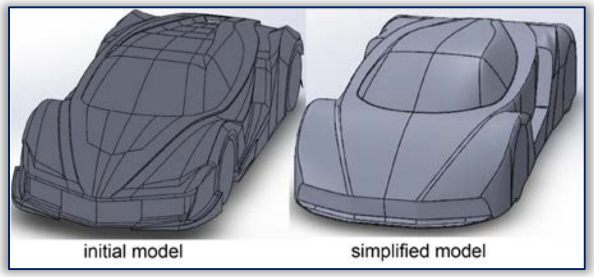

Figure 4. CAD model of car body prepared for aerodynamic analysis

An unstructured network of tetrahedral elements makes the rest of the discretized domain with an initial element size of 5 mm. Towards the edge of the domain the element size is 100 mm. A k - epsilon fluid flow model is placed. Domain`s working media is air with temperature of 25°C. The following boundary conditions are set: the velocity of airflow at the front surface of the domain is 50 m/s, the pressure at the back surface of the domain is equal to atmospheric pressure and is defined as 0 MPa, the surfaces through which air cannot pass and turns down with the path change (lower surface, which is the ground on which the car moves and surfaces that represent the contour of a car within a domain) and definition of the space within which the air motion is analyzed (left / right side surfaces and the top surface of the domain).

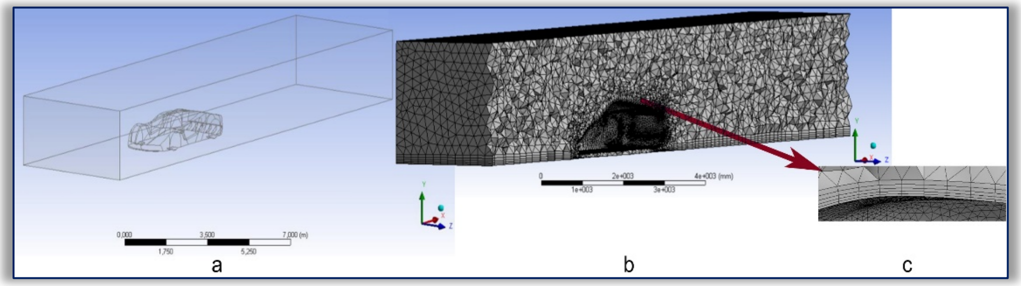

Figure 5. Discretized domain and finite element mesh

With the results of CFD analysis are covered: wind flow velocity in the domain`s area around the car body model (Fig. 6) and pressure distribution on the car body (Fig. 7).

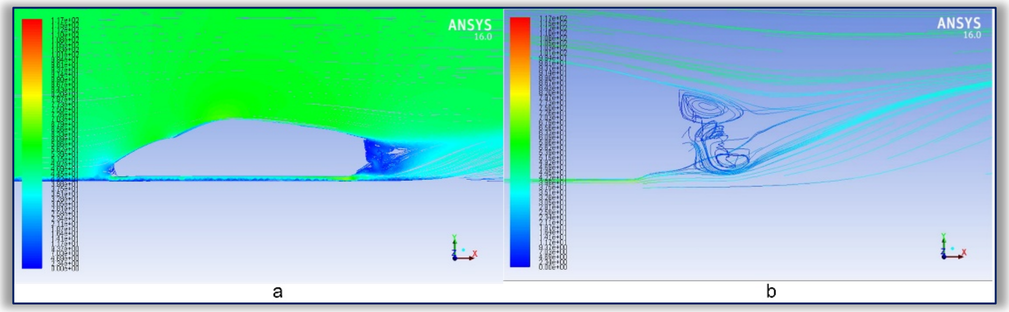

Figure 6. Wind velocity in the area of the discretized domain

The lowest wind velocity is present in front of the car body, because the wind hits the front nose (Fig. 6a). Also, the lowest wind velocity is at the rear car part where the air is spinning (Fig. 6b). Air velocities are higher at places where geometry changes. At the rear diffuser part, the air velocities below the car are increased, where a low-pressure area is created. Therefore, at the exit of the diffuser, the air slows down and pressure increases.

The air velocity before exiting from the diffuser is about 90 m/s (Fig. 6b). This velocity is higher than the air velocity above the car, creates an under pressure area under the car, and draws it to the ground. In the rear part, a region of turbulence is visible, which appears due to the large diffuser angle. Wind flow cannot follow this angle well enough when exiting under the car. The wind separates from the diffuser and creates a larger area of turbulence. It would be desirable to decrease the diffuser angle due to the reduction of the turbulent area behind the car.

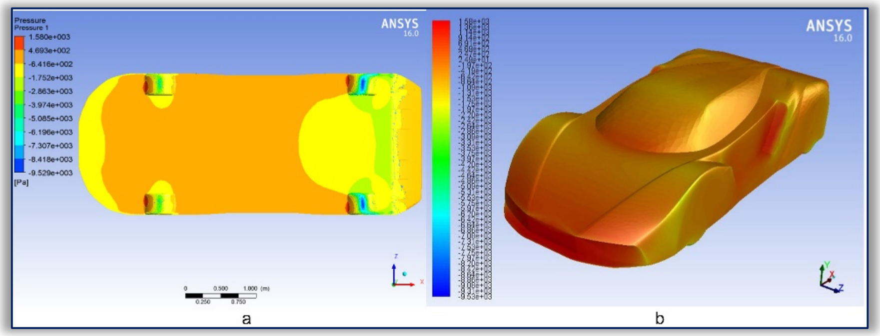

Figure 7. Pressure distribution on the car body

Figure 7a shows the pressure distribution below the car. The under pressure area prevails under the car and creates a vacuum that makes the car better fit to the ground with its wheels. This creates a downforce that pushes the car to the ground. Figure 7b shows the pressure distribution over the entire car body. The highest pressures occur at the front of the car body. This is because the body of the car directly encounters air resistance. The same phenomenon occurs in areas where air is sucking into the engine.

5. DESIGN AND CALCULATION OF CAR CHASSIS STATIC STIFFNESS

The chassis needs to be designed and shaped to follow the outer contours of the car body. It needs to be implemented within the car body. The chassis should absorb as much energy as possible from the impact. This must be achieved by decreasing the material resistance of the front part of the car body to the resistance of the material that forms the structure that protects the driver in the car.

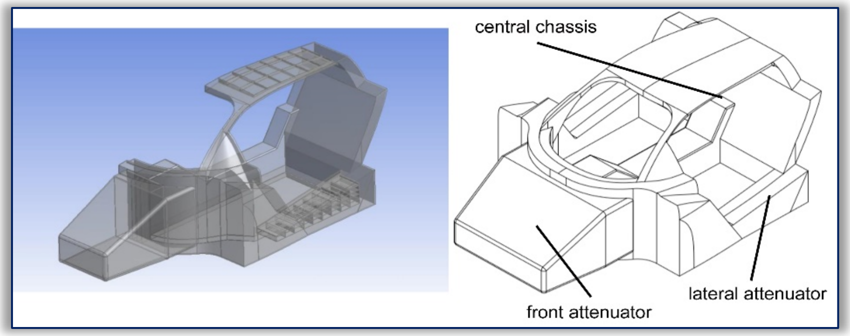

Figure 8. Design solution of car chassis

Therefore, it is necessary to design attenuators. An attenuator is a safety barrier between the driver and the surface exposed to impact. It needs to be deformable and needs to absorb as much as possible of the energy released as a result of the impact. Accordingly, a chassis was designed consisting of a front attenuator, two lateral attenuators and a central chassis (Fig. 8). The chassis is designed as a single body. This kind of chassis has higher torsional stiffness than multi-body chassis. For the chassis material, a composite material from the Ansys Workbench material library is selected. The material properties are presented in Figure 9.

Properties of Outline Row 5: Epoxy_Carbon_UD_395GPa_Prepreg

	A	B	C
1	Property	Value	Unit
2	Density	1,54E-09	mm^-3 t
3	Orthotropic Secant Coefficient of Thermal Expansion		
9	Orthotropic Elasticity		
10	Young's Modulus X direction	2,09E+05	MPa
11	Young's Modulus Y direction	9450	MPa
12	Young's Modulus Z direction	9450	MPa
13	Poisson's Ratio XY	0,27	
14	Poisson's Ratio YZ	0,4	
15	Poisson's Ratio XZ	0,27	
16	Shear Modulus XY	5500	MPa
17	Shear Modulus YZ	3900	MPa
18	Shear Modulus XZ	5500	MPa
19	Field Variables		
23	Orthotropic Stress Limits		
24	Tensile X direction	1979	MPa
25	Tensile Y direction	26	MPa
26	Tensile Z direction	26	MPa
27	Compressive X direction	-893	MPa
28	Compressive Y direction	-139	MPa
29	Compressive Z direction	-139	MPa
30	Shear XY	100	MPa
31	Shear YZ	50	MPa
32	Shear XZ	100	MPa

Figure 9. Chassis material properties

The following stresses are applied to the chassis: diagonal accumulation stresses, lateral flexion, vertical flexion at rapid acceleration, torsional stiffness and static stiffness. In this paper, testing was only performed on static stiffness. It is therefore necessary to determine the condition of static stiffness. The chassis must persist 2,5 to 3,5 car weights [11]. The weight of the car also includes the weight of the person. For the average mass of one person, we took the mass of 75 kg. The mass of the vehicle is m_v = 1402,83 kg. Static force by which we load the chasses, according to [11] is:

$$F_z = 3 \cdot g \cdot (m_v + 150) = 3 \cdot 9,81 \cdot (1402,83 + 150) = 45699,78\,\text{N} \approx 45700\,\text{N} \qquad (1)$$

Because the chassis model is symmetrical, we only analyzed half of the model. The amount of static force is F_z = 22850 N. The chassis is on the compressive stress on the roof (Fig. 10a), front attenuator (Fig. 10b) and lateral attenuator (Fig. 10c). The temperature of the composite material is 22°C. The chassis model is cross-linked using 5 mm tetrahedral elements.

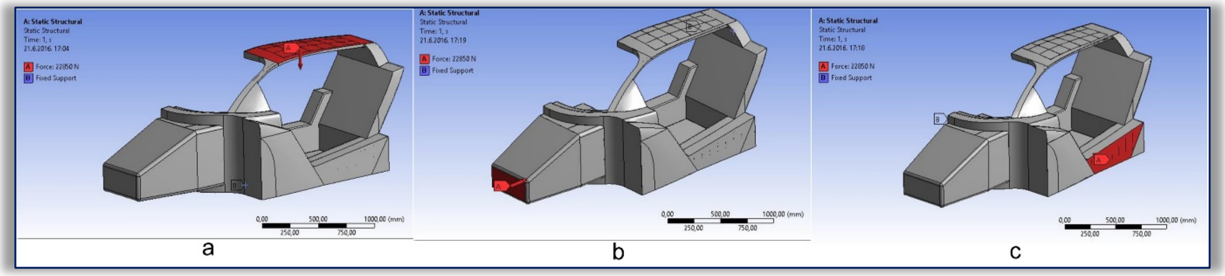

Figure 10. The activity of static force on the chassis

When loading the chassis by force F_z from the top side, a maximum displacement of 10,272 mm was obtained (Fig. 11a). Depending on the type of material, the amount of displacement is acceptable. The amount of maximum stress is 212,18 MPa (Fig. 11b). Such stress appears at sharp edges because the material is on that place thin. Because the amount of stress is less than the allowed material stress, no plastic deformation of the material has occurred. Therefore, it is possible to conclude that the construction satisfies.

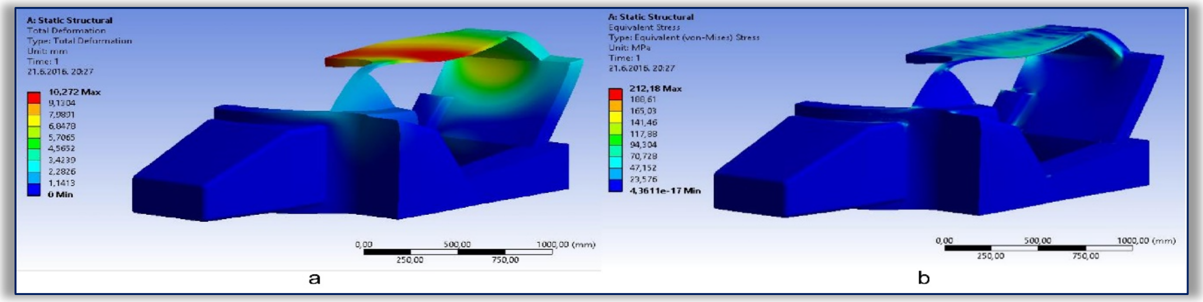

Figure 11. Overall displacement and stress of the upper chassis part

When loading the chassis by force F_z from the front part, a maximum displacement of 4,9915 mm was obtained (Fig. 12a). The amount of displacement is acceptable. The amount of maximum stress is 101,04 MPa (Fig. 12b). Because the amount of stress is less than the allowed material stress, no plastic deformation of the material has occurred. It is possible to conclude that the construction satisfies.

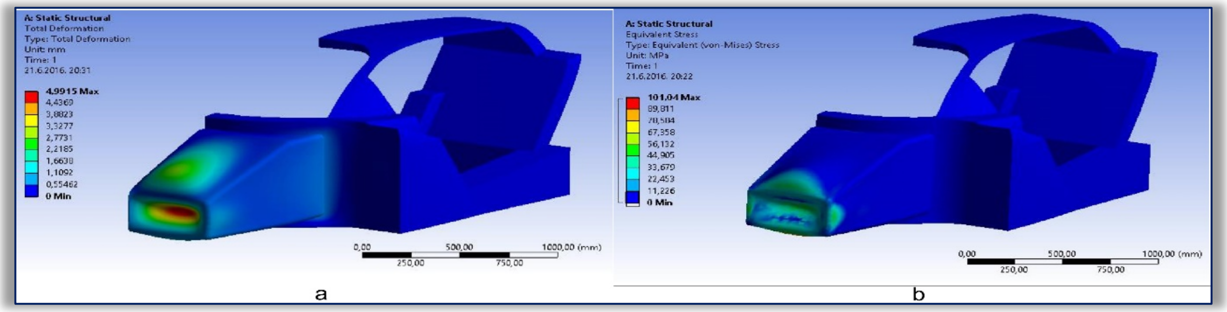

Figure 12. Overall displacement and stress of the front attenuator

When loading the chassis by force F_z from the lateral side, a maximum displacement of 0,68812 mm was obtained (Fig. 13a). The amount of displacement is negligible, and the chassis has a very high static stiffness on the lateral side. The amount of maximum stress is 79,156 MPa (Fig. 13b). Because the amount of stress is less than the allowed material stress, no plastic deformation of the material has occurred. It is possible to conclude that the construction satisfies.

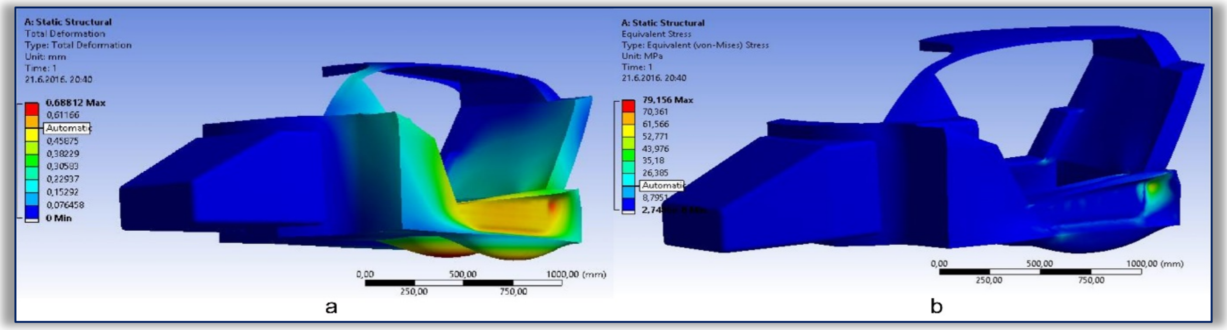

Figure 13. Overall displacement and stress of the lateral attenuator

6. CONCLUSION

The aim of this paper is to present the design procedure and calculation of the static stiffness of a sports car chassis in the conceptual design phase. After the car body was designed according to the requirements in the requirement list, the aerodynamic calculation of the car body was performed. Analysis of the airflow around the car body, using CFD analysis, was performed in the ANSYS Fluent software package. The analysis shows that the airflows is laminar along the above contour of the car body. Below the car body, the air is accelerated relative to the air velocity above the car body. This is why a vacuum is created under the car body. This creates a downforce that pushes the car to the ground and allows better tires grip.

Turbulence occurs at the rear part of the car body, due to the large diffuser angle. Wind flow cannot follow this angle well enough when exiting under the car, therefore the wind separates from the diffuser. The problem should be solved by optimizing the angle of the diffuser.

The calculation of the static stiffness of the chassis with respect to the static force has performed. The calculation results are satisfactory with regard to the choice of composite material. From the results obtained from the calculation of static stiffness, it can be concluded that the chassis can be further optimized in order to reduce its mass. This is also desirable in order to reduce the overall mass of the sports car and in such a way improve driving performance.

The paper proposes some guidelines that could produce better results, but for such approaches, it is necessary to have more powerful computers and knowledge that sports car manufacturers are not yet ready to cede outside their research institutes. The reasons are more than clear, as they greatly affect to their competitiveness.

Note:
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References

[1] HotRod Magazine, PalmCoast, FL, Christopher Campbell: 64-81 Muscle Car Chasis Guide-Getting Framed: http://www.hotrod.com/howto/chassis-suspension/1208phr-64-81-muscle-car-chassis-guide/
[2] British RaceCar, Connecticut, Bob Millstein: Walt Hansgen Jaguar XK120 Special: http://www.britishracecar.com/BobMillstein-Jaguar-HansgenSpecial.htm
[3] CarThrottle, Matt Robinson: Watch Your Back: https://www.carthrottle.com/post/watch-your-back-bmw-3-series-the-new-jag-we-is-gunning for-you/
[4] Motortrend, ElSegundo, CA, Eric Ayapana: 2012 Paris: Ferrari shows off carbon fiber chassis of enzo sucessor: http://www.motortrend.com/news/2012-paris-ferrari-shows-off-carbon-fiber-chassis-of-enzo-successor-268659/
[5] Eder, V. E., Theory of Technical Systems-Educational Tool for Engineering, Universal Journal of Educational Research, Vol. 4, No. 6, pp. 1395-1405
[6] Salamunović, D., Konstruiranje ojačanog okvira I platforme za dizajniranu oplatu sportskog automobile, Strojarski fakultet u Slavonskom Brodu, 2016.
[7] Autodesk Maya, Release 2012, Autodesk Inc., 2012.
[8] SolidWorks 2018, Release 2018, DassaultSystem SE, 2018.
[9] Ansys CFX, Release 16.0, ANSYS Inc., 2016.
[10] Wallin, S., Applied Computational Fluid Dynamics, 2nd Edition, Stockholm Dept. of Mechanics and Systems Dept., FOI, 2009.
[11] Trzesniowski, M., Rennwagentechnik, Grundlagen, Konstruktion, Komponenten, Systeme, Auflage 2, Wiesbaden, Springer, 2008.

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