24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2472
EVOLUTION IN ANALYSIS OF A FORMULA SAE CHASSIS USING FINITE ELEMENT METHOD

Victor Quarésima Belote
Gustavo Chaves Storti
Carlos Alberto Alves Viana
Rafael Marques Oliveira
Miguel Ângelo Menezes
Amarildo Tabone Paschoalini
São Paulo State University (UNESP), School of Engineering, Ilha Solteira
e-mails: vbelote5@gmail.com, gucstorti@gmail.comviana4_gba@yahoo.com.br,, rafael.oliveira@caio.com.br, miguel@dem.feis.unesp.br, *tabone@dem.feis.unesp.br*.

Abstract. *The vehicle structure of a Formula SAE is a subsystem from the general design developed for the car, which involves other subsystems. Typically, teams use a tubular metal frame in the designs. This work aims to compare two structures developed over the years by Fênix Racing Formula SAE Team, focusing on the static simulations developed in the project, to ensure a reliable structure and to be able to withstand the loads coming from the driving conditions, as well by the car and pilot safety. Thus, the advances in the three years will be discussed, explaining the cause of the changes made, directly linked to the improvement of the structural performance of the prototype.*

Keywords: *Formula SAE, Chassis, Static Simulations, Finite Element Method.*

1. INTRODUCTION

The Formula SAE is a formula student competition category promoted by SAE (Society of Automotive Engineers); the engineering students are challenged to construct and design a high-performance vehicle of the "Formula SAE" type, single-seat and with an engine up to 700 cc following the rules for the design and constructing. The design involves a big challenge for the students, how design a safe car, reliable, stable and with dirigibility good, beyond low cost in manufacturing.

The structure from a Formula SAE is a subsystem developed especially for the car, being responsible for protecting all vehicle components. Teams use a steel tubular structure in most cases.

In the design development of chassis are analyzed various conditions for performance improvement, especially the torcional stiffness. The value of torsional stiffness is designed together with the suspension area to have a great job in the chassis-suspension set, particularly the performance in curves, improving the vehicle maneuverability or handling, the pilot comfort beyond contribute to the safety. (RILEY, W. B. and GEORGE, A. R. 2002).

Beyond the torsional stiffness, also are analyzed various track conditions aiming to improve the quality of chassis and the car safety. The analysis uses the Finite Element Method (FEM). The structure is submitted to effort conditions due to the vehicle suspension, being these forces transmitted from suspension to frame in the shock absorbers suspension points.

The forces and moments applied in these points are reactions of distributed forces in the suspension owing to track conditions that occur in the vehicle. The structure is developed using these analyses for withstanding these conditions imposed for asphalt paving variations, acceleration and decelerations, and the curve conditions. The analysis are made through numeric calculations using the *ANSY* software, where is possible to evaluating the chassis material properties, and carrying out the calculations according particular situation due forces transmitted through suspension.

Another aiming is to verifying the safety that structure offers for the vehicle conductor during piloting, being carrying out impact simulations for improving the analysis and chassis optimization, as is required by the Formula SAE competition; especially, for developing a competitive car that is reliable and extremely safe because is a student event. For that, the Fênix Racing Formula SAE Team has designed a side apparatus called side-pod that increases the car torsional stiffness, beyond of increasing the pilot safety for cases of longitudinal impacts. (OLIVEIRA, R. M., 2014).

2. COMPUTATIONAL PROCEDURE

The *ANSYS* 15 software was used to carry out computational simulations. Four different chassis were analyzed under the same loading conditions, with chassis 1, Fig. 1, the 2016 structure with side-pod and chassis 2, the same structure but without side-pod. The chassis 3, Fig. 2, corresponds to 2017 structure with the side-pod and chassis 4, the same structure, but without the side-pod.

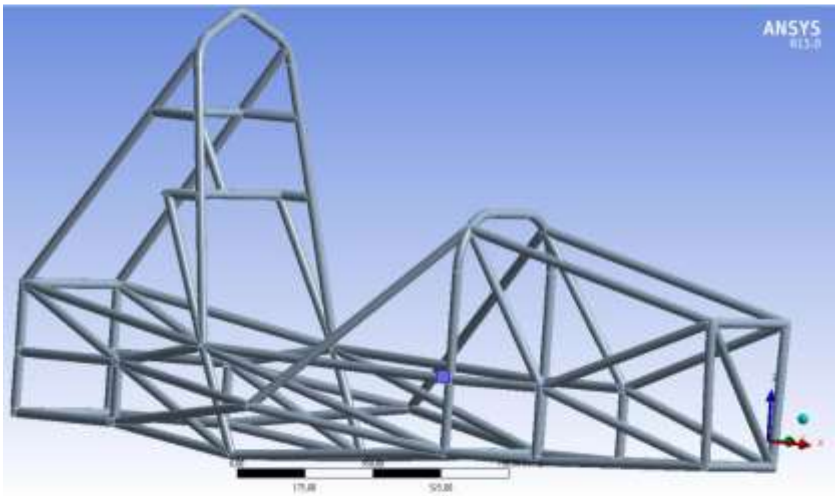

Figure 1. 2016 Chassis with side-pod (Chassis 1)

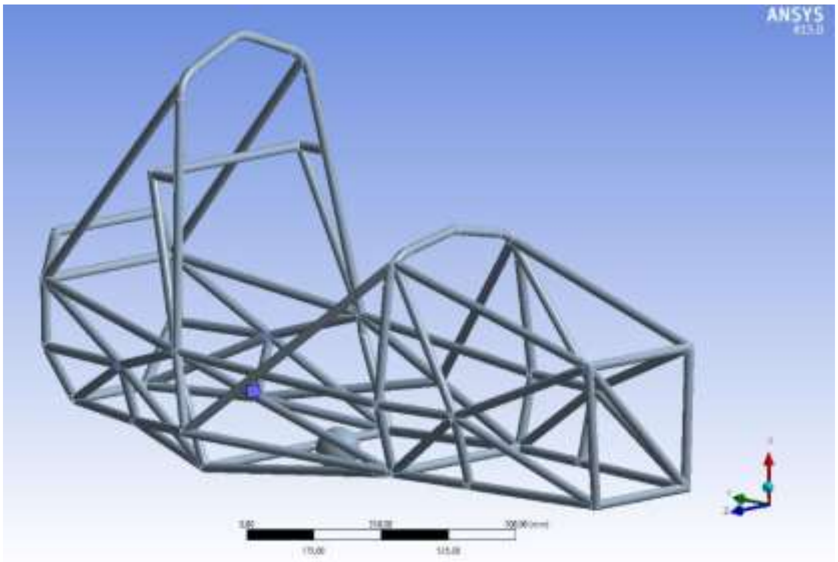

Figure 2. 2017 Chassis with side-pod (Chassis 3)

In 2016, steel tubes SAE 1020 were used for the development of the project, while in 2017 the project was based on use of steel tubes ST-52 with considerably higher mechanical properties than SAE 1020 steel (catalog Vallourec, 2017). The properties of each of these materials were duly entered into *ANSYS* 15 for a more realistic analysis.

In the four chassis analyzed, the same simulations were developed, under the same conditions placing them in equal conditions for evaluation of final results. The following analyzes were carried out: front and rear bump, front and rear conjugated, and simulation of front, rear and side impacts. The simulations were developed in the following way:

2.1 Front and rear bump

At first, in the bump analyzes, the applied loads and its points of application on chassis are defined. The application regions correspond to shock absorbers suspension points, once the load transfers between trays and chassis take place at these points. The forces used in simulations are taken from analyzes carried out through suspension area employing the Lotus Suspension software. The analyzes are carried out under maximum conditions of the suspension consisting of a mass application of 300 kg related to car with the pilot approximate mass for an acceleration of 3g in each of car wheels. For the chassis simulation, the values are withdrawn when the suspension is in its maximum travel, 60 mm, of vertical displacement, thus representing the worst conditions on the track.

In the front bump simulation, the chassis is fixed through shock absorbers rear suspension points, and the forces are applied on shock absorbers front suspension points, as in Fig. 3. In the rear bump case simulation, the front points are fixed and the rear ones undergo load actions.

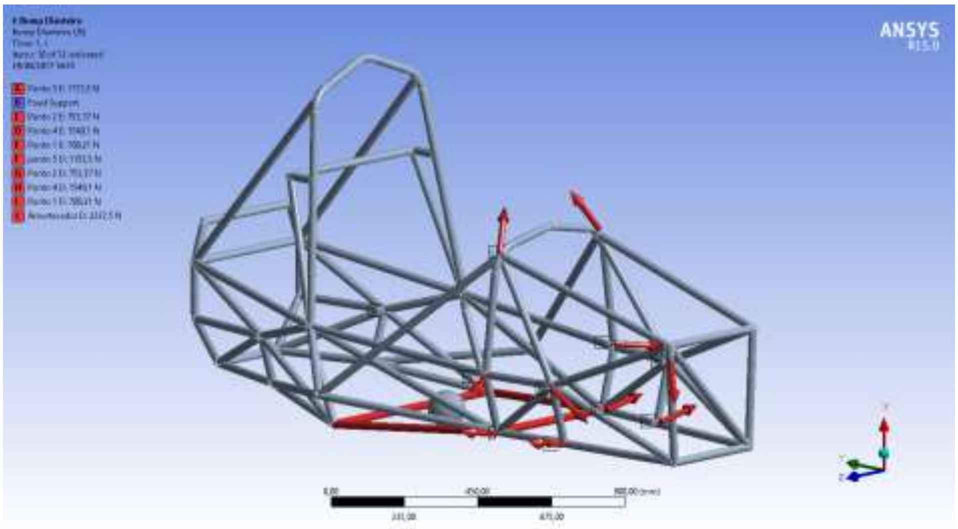

Figure 3. Front Bump in chassis 3

Through this analysis is possible preparing the chassis for the most adverse track conditions, where the asphalt paving can present several irregularities, such as small hole and waviness, which can raise the suspension to oscillating and consequently application of forces on the structure.

2.2 Front and rear conjugated

In the conjugate analysis as shown in Fig. 4 the loads are applied to the same bump analyze points; besides, the applied forces are the same used in the former analysis and they are obtained from the same way. However, in the conjugate simulations forces are applied only to the vertical direction with the purpose of generating torsional forces.

In the front conjugated simulation rear suspension points are fixed and conjugate forces are applied to the front. In the rear conjugated front suspension points are fixed and load is applied on rear points.

Through this analysis is possible to understanding better the chassis behavior in curves, when it is subject to torsions (twisting), particularly, when the vehicle passes on a speed breaker and generates conjugate loads on the structure and also during slalom (zigzag) movements, where the car changes suddenly the direction several times.

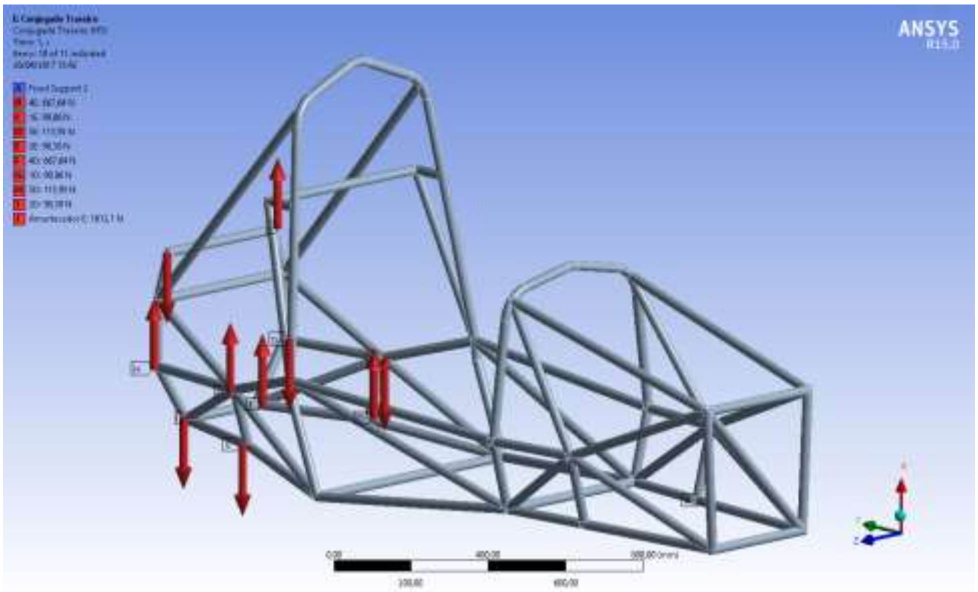

Figure 4. Rear conjugated in chassis 4

2.3 Front, rear and side impact

In the impact analyzes are evaluated the conditions to which chassis are submitted in the case of longitudinal and lateral bumps. For determination of the impact force, the Equation 1, is used;

$$F = \frac{mv_0}{\Delta t} \tag{1}$$

where F is the impact force, m is the mass of the car with the pilot, v_0 is the crash test impact velocity equal to 64 km/h and Δt is the impact time, being considered as one second in the cases under analysis.

In the front-rear impact simulations, the loading is applied to the chassis longitudinal direction, as shown in Fig. 5. Differently, for lateral impact simulation, Fig. 6, the force is applied to the side-pod and side impact tubes.

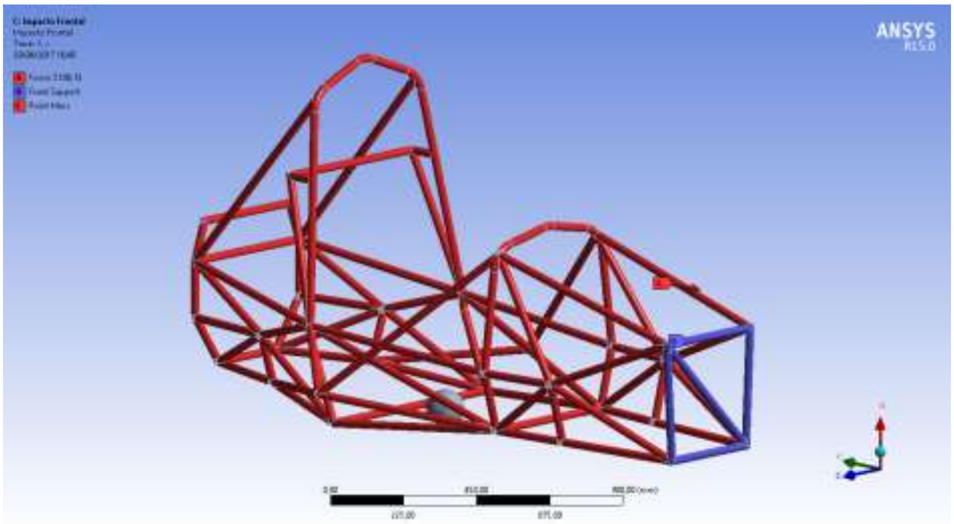

Figure 5. Front impact in chassis 3 (forces)

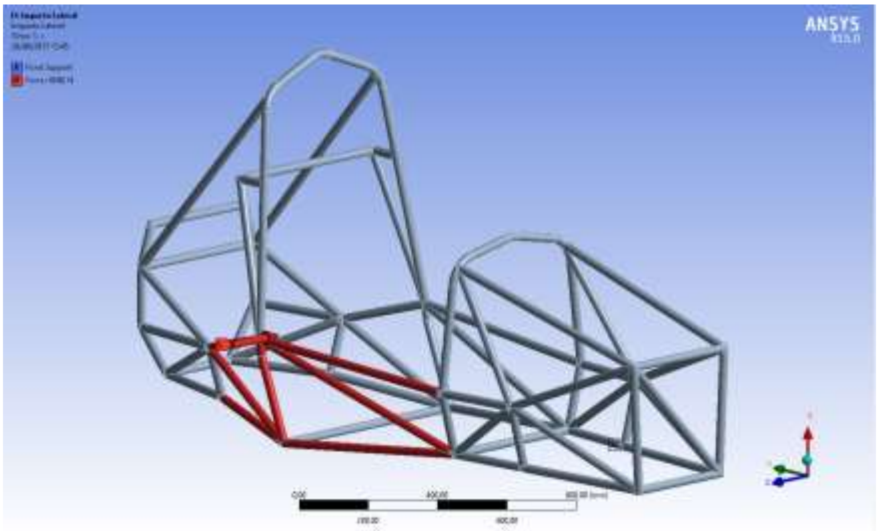

Figure 6. Side impact in chassis 4 (forces)

3. RESULTS AND DISCUSSION

From the proposed analyzes the information of maximum von Misses stress and maximum deformation in all the cases observed were extracted. The results are show in Tables 1 and 2.

Table 1. Max von Misses stress obtained for all analyzed cases (MPa)

Analysis	Chassis 1	Chassis 2	Chassis 3	Chassis 4
Front Bump	136,17	182,08	252,15	244,6
Rear Bump	147,67	194,77	244,91	246,45
Front Conjugated	168,05	143,26	248,41	178,26
Rear Conjugated	173,69	187,76	168,37	145,08
Front Impact	149,16	147,66	144,54	128,33
Rear Impact	107,11	115,92	85,71	75,26
Side Impact	213,62	337,01	311,46	283,44

Table 2. Max Deformations obtained for all analyzed cases (mm)

Analysis	Chassis 1	Chassis 2	Chassis 3	Chassis 4
Front Bump	2,8218	3,0026	2,9146	3,4764
Rear Bump	2,2436	2,6187	2,7347	3,0478
Front Conjugated	2,7445	3,3797	1,1729	3,3416
Rear Conjugated	2,7159	3,168	1,6511	4,1712
Front Impact	1,6777	1,9325	1,4451	2,0371
Rear Impact	1,0295	1,3532	0,8041	1,4177
Side Impact	2,099	2,6248	4,4718	4,4569

Thus, it can be observed from all analyzed cases, Table 1, that the chassis 1 and 3, which have the side-pod they present a considerably lower deformation in most cases, especially in cases of conjugated and twisting and longitudinal impacts.

In the case of longitudinal impacts, the reduction of the deformation of the structure reaches almost 50% in some cases, what is very effective for safety requirement, since the vehicle has a safety specific apparatus for impacts, the impact attenuator. Thus, reducing also chassis deformations, it is possible to avoiding yet more penetrations of structure parts into the cockpit that could hurt the pilot, and even penetrations in other car parts that would damage several important components.

In the context of the conjugate simulations, it is also notable how much more rigid the chassis has become with the use of the side-pod, what is quite good for the case, since this situation of twisting is very common on the track. So, a chassis that resists well to these efforts presents a better performance in the Formula SAE competition.

The single case that the side-pod does not work satisfactorily can be seen for side impacts, once this fact took place due to the chassis type employed, being a structure without stiffness for lateral normal loads that is a common problem for SAE Formulas. However, these cases do not present more concerning about, since is extremely low the chances of occurring a side (lateral) impact on the track conditions, particularly in competitions.

Furthermore, with simulations was possible getting weight reduction from the 2016 for the 2017 chassis, where the final project leads a 6 kg reducing to final weight of the 2017 structure.

Figures 7, 8, 9, 10 e 11 show some obtained results for all simulation of analyzed chassis types related to Von Mises maximum observed stresses (Maximum effective stresses), which are previously presented in Table 1. For all the cases, the stresses are below to 345MPa that is the yield limit value of the steel ST-52 used. (Catalog Vallourec, 2017).

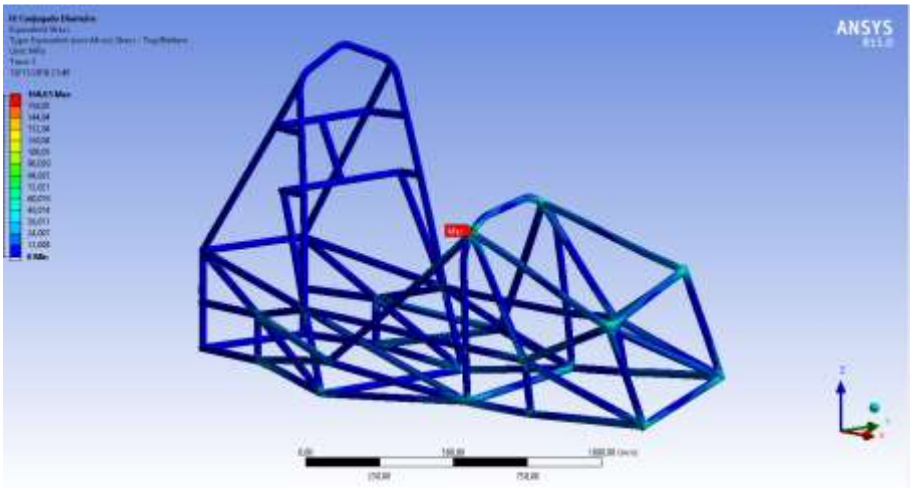

Figure 7. Front conjugated in chassis 1 (Max von Misses stress)

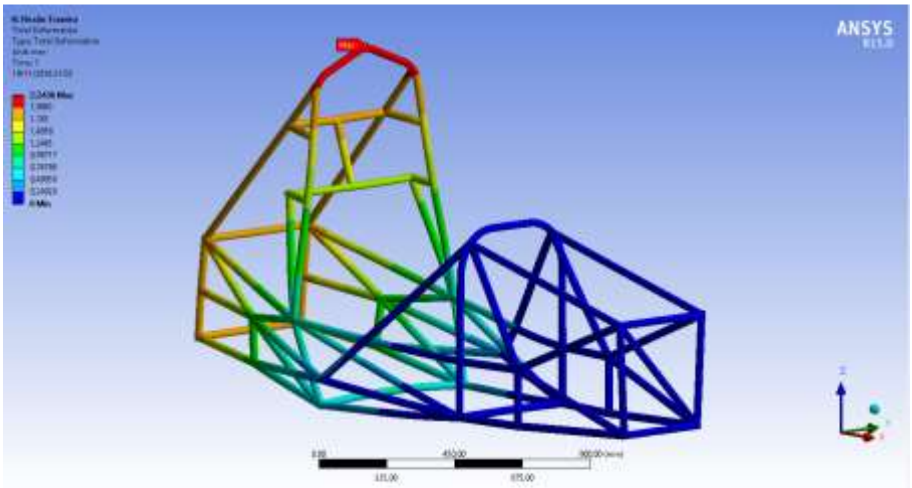

Figure 8. Rear bump in chassis 1 (Max deformation)

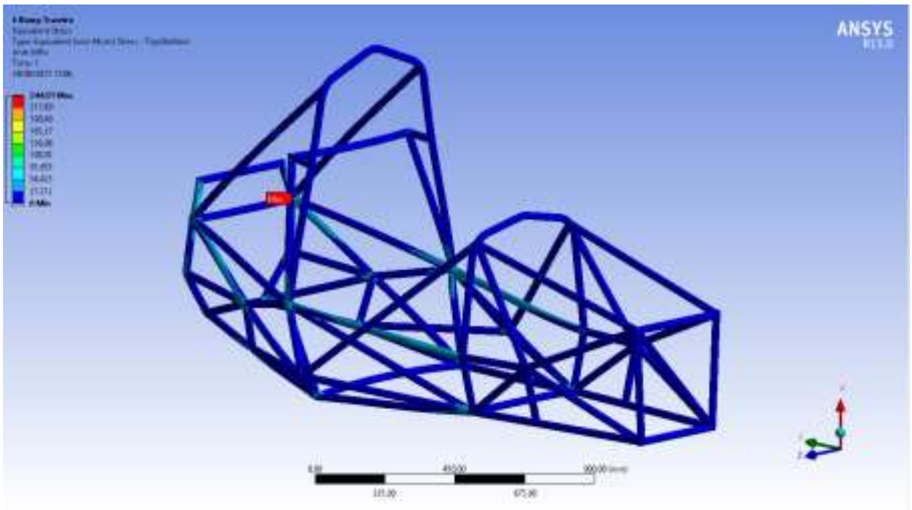

Figure 9. Front bump in chassis 3 (Max von Misses stress)

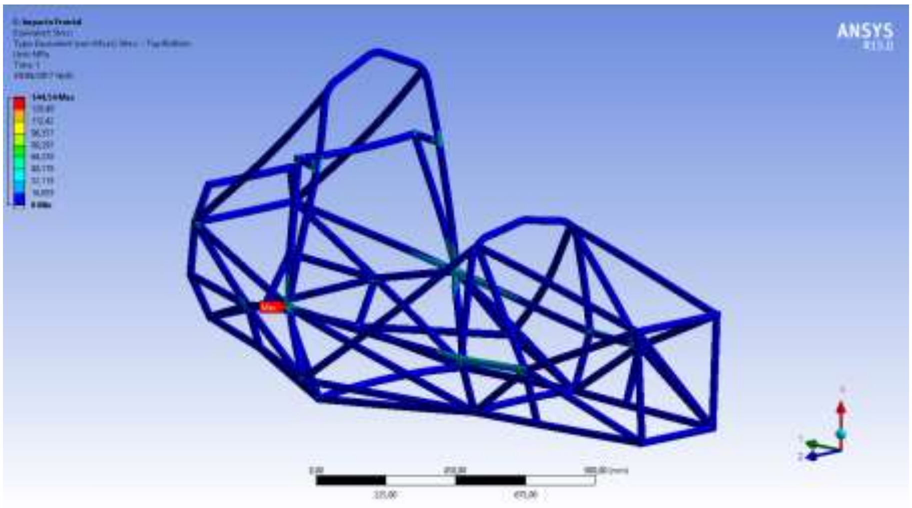

Figure 10. Front impact in chassis 3 (Max von Misses stress)

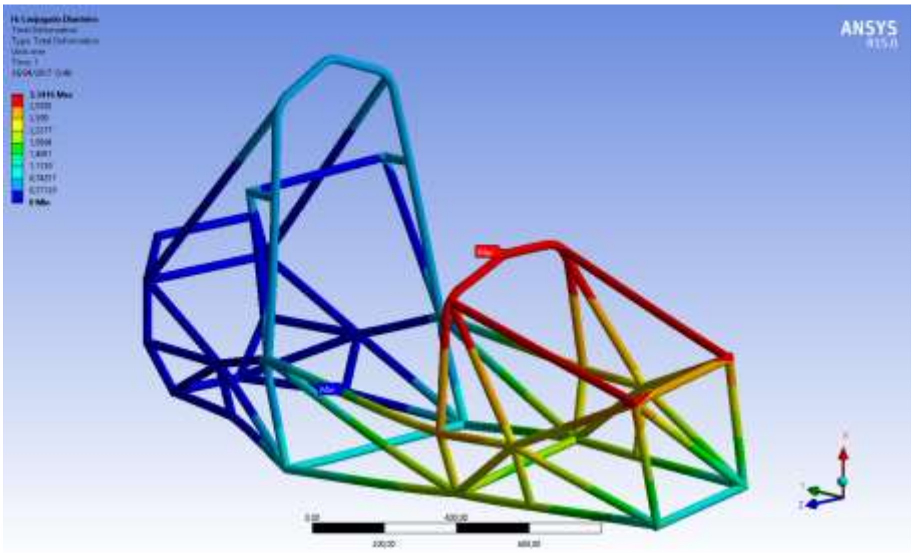

Figure 11. Front conjugated in chassis 4 (Max deformation)

4. CONCLUSIONS

From the obtained data for stress and deformations, for all simulation of analyzed chassis types, is possible to evaluate the importance and differences in the use or no of side pod. With the side-pod, even having some points with higher stresses, the chassis is more rigid, suffering minor displacements, what is slightly related to larger stresses, but, all the cases, the stress stays below the 345MPa that is the yield limit of the steel ST-52 used.

It can be also inferred that with the side-pod and therefore small deformations, particularly for cases of torsions and bump would be very important for the vehicle performance because with more rigid chassis, avoid situation of scrolling and skidding, improving the lap times and avoid more wear of car, beyond of improving the vehicle maneuverability or handling.

In the part of safety, as previously stated, the vehicle has an apparatus, the impact attenuator for the case of any accident. Thus, reducing also chassis deformations, it is possible to avoiding yet more penetrations of structure parts into the cockpit that could hurt the pilot, and even penetrations in other car parts that would damage several important components. Employing side-pod was reached the objective of reducing from 25 to 50% the maximum chassis deformation for situation of front and rear impacts.

Therefore, the present work shows the chassis evolution in years of 2016 and 2017, particularly in relation to weight reducing to increasing of safety of vehicle. The refinement and use of computer simulations has allowed a better analysis of track conditions, being possible search the maximum requirement of structure, reducing weight without harm the safety of conductor.

5. ACKNOWLEDGEMENTS

The authors would like to thank UNESP – Universidade Estadual Paulista “Júlio de Mesquita Filho”, Ilha Solteira Engineering Faculty, Mechanical Engineering Department and Graduation Course Council and also the Fênix Racing Formula SAE Team for material and financial support.

6. REFERENCES

OLIVEIRA, R. M., Projeto e estudo do Atenuador de Impacto adequado a um Veículo de Alta Performance Formula SAE. Relatório Final, Iniciação Científica, FEIS – UNESP. Ilha Solteira, 2014.

RILEY, W. B.; GEORGE, A. R.; Design, Analysis and Testing of a Formula SAE Car Chassis, Cornell University, SAE Technical Papers, 2002, 18 p., 2002-01-3300.

ABDULLAH M A., MANSOR M R., MOHD, T. M., ABDUL K. S. I., HASSAN, M. Z., NGADIMAN, M, N., Development of formula varsity race car chassis. 2nd International Conference on Mechanical Engineering Research (ICMER 2013). Kuala, Malaysia, 2013.

Catalog Vallourec. Accessed in 4 of May of 2017 in: www.vallourec.com/COUNTRIES/BRAZIL/EN/Media/Catalogues/Documents/Catalogo_Mec%C3%A2nico.pdf.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.