Ergonomics study for chassis construction of a SAE Formula Prototype

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ABSTRACT

This article has main goal of study the most ergonomic position for the pilot of a student team competing in the SAE formula (FSAE), to define all chassis cockpit angulations. Therefore, it was needed to build a cockpit mock-up, that simulated the situations in which a driver needs to undergo to perform well at the tests. To this elaboration, were used two members measures close to the percentiles described in the competition regulation. With the chosen position, a simplified spaceframe chassis was designed using the CATIA V5 R21 software and, posteriorly, the complete project was developed in the Autodesk Inventor 2020 program. Thus, the goal of ergonomics research was achieved, since performance and functionality requirements were attended in field tests and, as a result, the production of the cockpit mock-up enabled the development of a more comfortable and safe chassis for the pilot driving a prototype of FSAE.
Keywords: Chassis, Competition, Ergonomics.

INTRODUCTION

The Formula SAE (Society of Automotive Engineer) is an engineering education competition that challenges university teams to develop and manufacture a formula style vehicle, following some specific rules [1]. To design it, is necessary study the main vehicle components, such as suspension system, steering, aerodynamics, electronic and others, including the chassis system.

The automotive chassis is defined as a skeletal structure in which all mechanical parts of the car - engine, axle assembly, suspension etc. - are installed [2]. In the last fifty years, there have been only two main forms of chassis structure: spaceframe (or tubular) and monocoque. While the first is defined as a 3D structure formed from tubes, the second is a structure constructed from plates that form a closed box [3]. For this article, only the tubular type chassis will be considered.

The safety and comfort of the driver are some of the main points taken into account to start the chassis' design. Therefore, it is essential to choose the best position for driving before defining the prototype cockpit angulation parameters. Cockpit angles directly reflect on pilot safety, since its correct dimensioning may result in a better absorption of impacts and, consequently, in reducing the risk of injury to the pilot [4]. From this, an ergonomics study that aims to define this position can be performed before elaborating the chassis design.

The thought of wanting to improve the income of human labor, in order to mitigate the consequences on health, comes from the XVIII century; an example of this reality was when lead mine workers in Europe suffered from vertebral deformations as a result of their work and to alleviate this problem, the professionals analyzed ways to improve transportation and load elevation without interfering with the health of their employees. There is a growing concern about ergonomics; this term was first used in 1857 by the Polish scientist Wojciech Jastrzebowski, in a work based on the objective laws of science. In spite of this, ergonomics only it was formalized as a discipline in 1949, with the creation of the Ergonomics Research Society [5][6]. In these terms, it is defined as the study that aims to optimize the interaction between human beings and the system that surrounds them, in order to increase their comfort, safety and performance [7]. Wherefore, in the context of this article, the main result of investing on a study of this characteristic is to increase the performance of the prototype in competition tests; this increase performance is a consequence of the driver's better working conditions.

To understand the chassis most ergonomic position, it was necessary to make use of a wood and steel cockpit mock-up before starting the virtual design elaboration. This construction was necessary to represent any angulation that a cockpit chassis of this competition could be, and simulate the situations which the pilot needs to undergo - performing curves, pressing the pedals, viewing angles, etc. - in order to perform well in the tests.

In this way, the goal of this research was to perform theoretical-experimental tests to define the most ergonomic position for a Formula SAE driver and so determine the chassis cockpit angulations.

MODELING

COCKPIT MOCK-UP MANUFACTURE - The first step of this study was the mock-up construction, that supported the gathering of the most ergonomic position measurements. To begin the construction of it, was necessary to obtain the two team members measures, whose were approximated to the extreme percentiles of regulation. The 5th female and 95th male percentiles measurements are adopted by the regulation as minimum and maximum parameters, respectively; i.e., according to the rules, the car chassis of this competition must be able to accommodate any driver that has dimensions between these two limits.

Therefore, cockpit mock-up was constructed in such a way that there was possibility to regulate it for the desirable performance in position tests, so that all pilots with limited measures between the two extreme percentiles could drive the prototype whose chassis was based on this mock-up. Measurements of the two members, as well as those of the extreme percentiles can be found on table 1, and an image demonstrating the notation used to obtain the measurements can be found in figure 1.

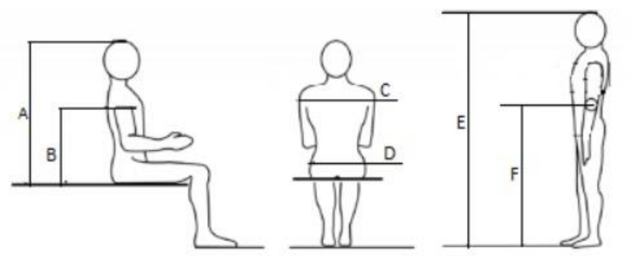

Figure 1. Notation used for measurements [4]

Table 1. Members and percentiles measurements [4]

Measures (mm)	Lower Member	Female 5th	Large Member	Male 95th
A	930	795	920	970
B	600	505	610	645
C	390	373	430	505
D	400	310	370	405
E	1600	1515	1840	1865
F	1030	740	1150	1000

From the table 1, it was possible to determine the maximum distances that the mock-up shall have to support the team's largest pilot, so that the smallest can perform the tests, it would be enough to adjust the apparat. Therefore, the distances used for the mock-up construction were: A=930mm, B=610mm, C=430mm, D=400mm, E=1840mm, F=1000mm. From these measurements obtained, it was possible to elaborate the virtual design of the ergonomic mock-up in CATIAV5 R21 software. An image representing this project can be found in figure 2.

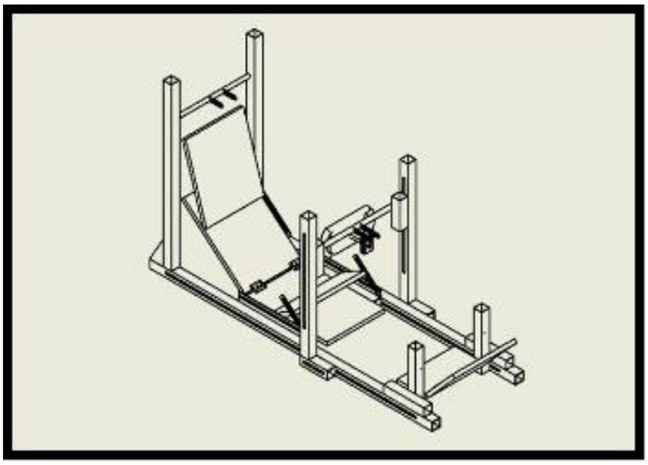

Figure 2. Perspective cockpit mock-up [8]

After preparing the cockpit mock-up virtual design, the materials for its manufacture were chosen: wooden sheets and carbon steel 1020. The wood was used to support the members' bodies in carrying out position tests; for the joining of the wooden boards, steel sheets were used and, for the support, square steel tubes. With the choice of materials, the team started manufacturing the mock-up which, when completed, it served to define the greatest chassis cockpit angulations and, from that, check the most ergonomic position for driving the car.

ACQUISITION ERGONOMIC POSITIONS - After the construction of the cockpit mock-up, position tests were performed with these two team members. To begin the tests, they were asked to sit on the mock-up in a position as if they were driving the car on the most comfortable way possible, respecting the following requirements: the knees should be flexed (for greater control of pedals), the angulation between arm and forearm would need to be as close to 90°, and the minimum distance between the hip and pedal should be 915mm. In addition, the members would need to be able to turn the steering wheel without touching their legs, and have a frontal view without interference. All these requirements have theoretical basis, which will be best presented on the Discussion Section. After the tests have been carried out, a cloud of points was obtained for each of the members to be analyzed by the CATIA V5 R21 software. With the result of the analysis, an average was performed to arrive at the measurements of an intermediate pilot, who was treated as ideal by representing the measurements of the actual pilots of the team; therefore, these intermediate measures were used as the basis for the chassis sketch elaboration. These measures were used because in addition to representing the members and being within the regulation, they have made sure that any driver with dimensions between the two extreme percentiles can drive the car. The essential angles for data analysis are defined as follow: alpha, which is the measure between the center of the head and the shoulders; beta as being the angle between the center of shoulders and hips; gamma indicating the measurement of the line that goes from the shoulders to the hip, and the point at which the steering wheel would be; and, finally, delta corresponding to the measure between the point at which the steering wheel (or the driver's hands) and the hip would be. All the angular results of the position tests will be described on the Results Section. An image representing these angles can be found in figure 3.

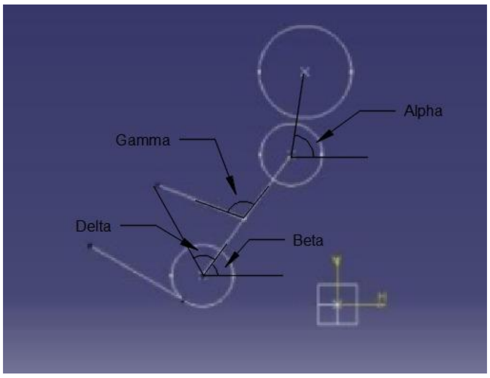

Figure 3. Notation used for pilot angles [8]

RESULTS

The angular measurements obtained for the members representing the extreme percentiles, as well as the resulting one for the ideal pilot can be shown in table 2.

Table 2. Angle measures for the two member and the ideal pilot [8]

	Lower Member	Large Member	Ideal Pilot
Alpha Angle	78,7°	90,0°	80,5°
Beta Angle	47,0°	32,1°	53,7°
Gamma Angle	47,0°	33,0°	53,7°
Delta Angle	92,0°	133,0°	105,0°

Performance of position tests with the lower member can be found in figure 4. Ergonomic points for that same member can be shown in figure 5.


Figure 4. Performance of position testes with the lower member [8]

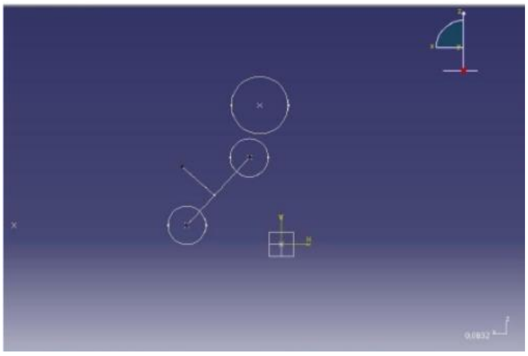
Figure 5. Ergonomic points of the lower member [8]

Performance of position tests with the large member can be found in figure 6. Ergonomic points for that same member can be seen in figure 7.

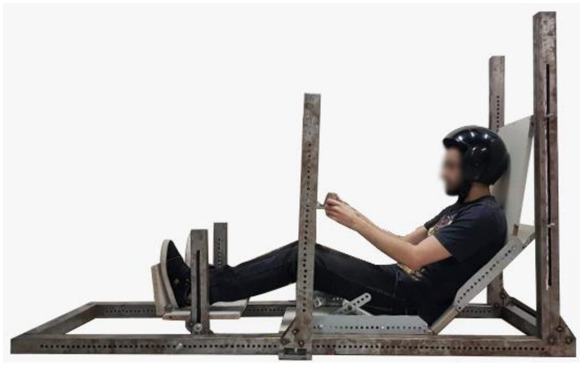
Figure 6. Performance of position testes with the large member [8]

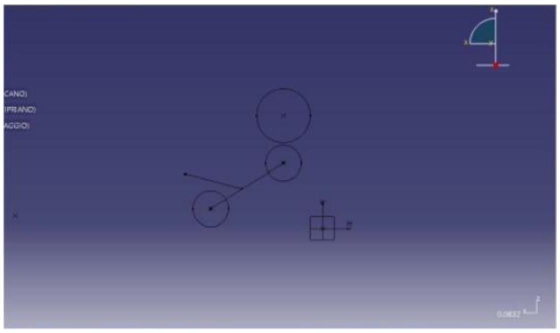
Figure 7. Ergonomic points of the large member [8]

Ergonomic points for the ideal pilot can be seen in figure 8.

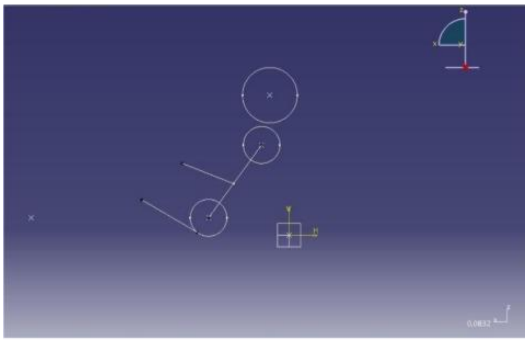
Figure 8. Ergonomic points of the ideal pilot [8]

A chassis sketch image with the measurements made in CATIA V5 R21 software, based on the dimensions of the ideal pilot, can be found in figures 9 and 10.

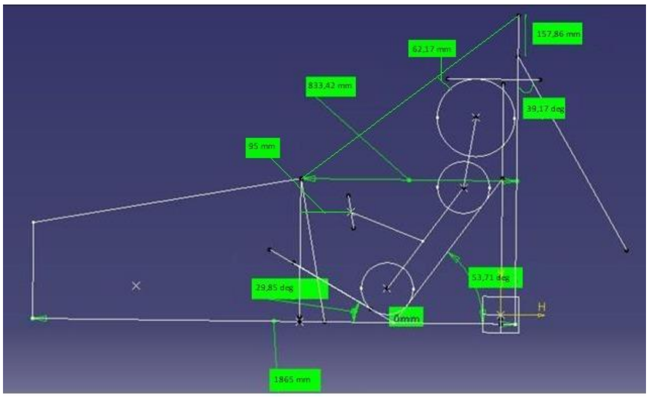

Figure 9. Chassis sketch from the side view [8]

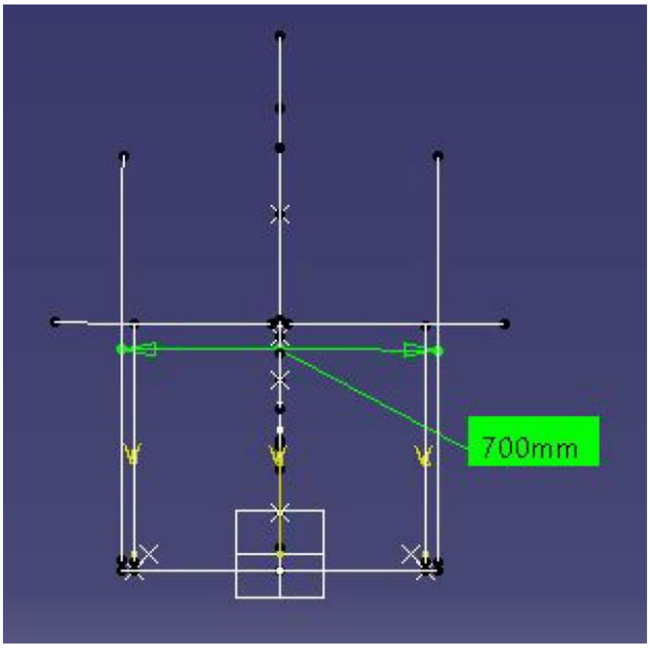

Figure 10. Chassis sketch from the front view [8]

DISCUSSION

All these results were obtained based on a study carried out in three stages: observation of the competition regulation that refer to the pilot's position, ergonomic analysis for a prototype of SAE formula based on the literature, and review of data from the research using Computer Aided Design (CAD).

The competition regulation that refer to the position of the driver have been carefully analyzed, and are divided into three topics: extreme measures (minimum and maximum) of driver, position that the largest pilot has to drive the car and distances of the chassis structural tubes [1]. Percentile is one of the types of separator measures, i.e., represents values that occupy positions in a data set, dividing it into equal parts - one hundred equal parts, at the percentiles case [9]. The 5th female and 95th male percentiles are used as minimum and maximum pilot dimension limits, respectively [1]; i.e., the chassis must be designed in such a way as to accommodate pilots who have dimensions in the range of these percentiles, whose measurements are found in table 1. For this purpose, it is necessary to analyze the positions of the largest pilot, which can be represented by a two-dimensional model, with measurements of a 300mm diameter circle representing the head with the helmet, and two others 200mm representing the shoulders and hips. This analysis should be done because according to the competition regulations, the car must have the ability to accommodate the largest driver according to specifications: the maximum distance between the circle center of the hips and the car pedals to be 915mm, and also that the maximum distance of the head circle and the head restraint to be 25,4mm [1]. An image representing these distances can be found in figure 8.

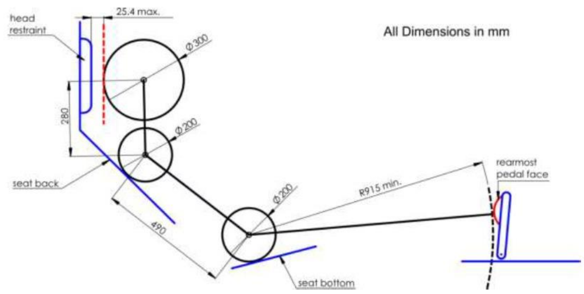

Figure 7. Extreme position of the two-dimensional model representing the 95th male percentile [1]

Before describing the rules referring to the chassis structural distances, some of the main tubes in this structure can be found in figure 9.

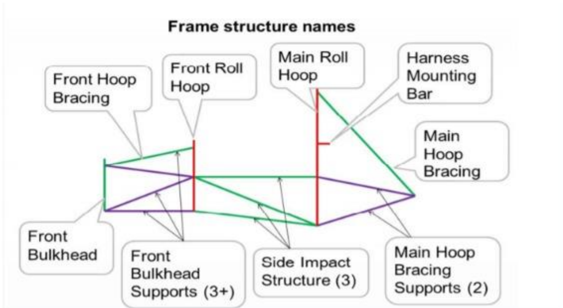

Figure 8. Chassis Structural Tubes of a SAE Formula Prototype [4]

The competition regulation described that when seated normally and restrained by the Driver Restraint System, there should be a minimum distance of 50mm between the male 95th percentile helmet (as well as that of all team pilots) and the line that connects the top of the Main Roll Hoop to the highest part of the Front Roll Hoop. In addition, the regulation specified rules for Roll Hoops: the Front Roll Hoop cannot have a distance bigger than 250mm to the front of the steering wheel. Besides that, when viewed laterally, the Front Roll Hoop cannot have an inclination bigger than 20° in relation to the vertical. About Main Roll Hoop, it is necessary that in front view, its vertical members have a horizontal distance of at least 380mm and that it does not have an inclination bigger than 10° in the parts that connect to Side Impact Structures.

Lastly, the Main Hoop Bracing must be attached at a distance of no more than 160mm from the Main Roll Hoop top, and that the fixing angle is at least 30° [1].

In addition to the regulation, data found in the literature were also taken into account in the ergonomic study of the pilot's position, and will be described below. A study conducted at Lawrence Technological University pointed out that for a SAE Formula driver to be ergonomically positioned inside the vehicle, it is necessary that the gravity general center of the car is as low as possible, and that the reclining seat back has such an angle that provide a comfortable position for driving the prototype. Besides that, the study pointed there must be an angle on the knees that assists the operation of the pedals, since pilots have greater control and leverage with their knees bent. There also needs to be a 95° to 105° angle between the seat bottom and the seat back for comfort and then, a better driver performance. As for the position of the steering wheel, it was observed that the driver must necessarily be able to rotate it freely, without collision between this object (or the pilot's hands and arms) and his legs; furthermore, the driver must be able to move his legs while operating the pedals, so that they do not touch the steering wheel. In particular, the steering panel must be constructed in such a way that the steering wheel is within the height limits approved by the competition regulations, and that the driver has his frontal vision free from any interference. Furthermore, it has been noted that there should be sufficient space on the chassis cockpit so that, if the driver has to leave in an unexpected manner, he doesn't have any kind of collision with the vehicle; there should also be enough space on the cockpit to accommodate the driver's legs, hip and shoulders in a comfortable manner. Finally, it was analyzed that the pedals should be mounted in a place that allows the pilot to reach them comfortably [10].

Based on these rules and on the ergonomics study described in this article, principal dimensions were defined for the car chassis: the distance between the helmet of the male 95^{th} percentile and the line connecting the top of the Main Roll Hoop to the Front Roll Hoop top was 62,17mm; the distance between the steering wheel and the Front Roll Hoop was 95mm; when viewed sideways, the Front Roll Hoop has a 0° angle in relation to the vertical; the horizontal distance between the vertical tubes of the Main Hoop was 700mm; the angulation of the Main Roll Hoop tubes that connect to the Side Impact Structure was 0°; the fixation distance of the Main Hoop Bracing was 157,86mm, and its attachment angle was 39,17°. In addition, the angulation between seat bottom and the seat back was 96,43°. In order to provide a better cockpit comfort, so that pilots could operate the steering wheel and pedals properly, 833,42mm horizontal distance was adopted between the Roll Hoops and 1865mm in length for the car chassis. The chassis sketch created in the CATIA V5 R21 software, resulted of all these conclusions can be found in figure 8, located in the Results Section.

Although it is only one of all parameters that must be considered to complete the development of a chassis more efficiently and safely, the study of ergonomics was essential for the beginning of its construction. Thus, the objective of the research was achieved, functionality and performance requirements have been met in field tests and, as a result, the manufacture of the cockpit mock-up enabled the development of a more comfortable and safe chassis for the pilot driving a prototype of SAE Formula.

CONCLUSION

After analyzing the results obtained with the cockpit mock-up test, it was possible to elaborate a study of the most ergonomic positions for an ideal driver, whose measurements approach the team members dimensions who will drive the car. It shall be noted that although the most ergonomic position has been based on the ideal pilot measures, the chassis construction was made in such a way that any driver with dimensions between the two extreme percentiles can drive the car. Thus, the goal of this research has been completed, as in addition to resulting in a chassis that does not violate the competition regulation, it determined the most ergonomic position possible a pilot who drives a SAE Formula prototype.

FUTURE WORKS

After the elaboration of this chassis sketch made in the CATIA V5 R21 software, and considering all the other aspects necessary for the development of a good project, the chassis based on this study, will be completely designed in the Autodesk Inventor 2020 program, tested for validation in the Ansys simulation software and, finally, manufactured following a chronology specified by the team that designed it.

ACKNOWLEDGMENTS

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