Design & Development of Formula Student Chassis

Krunal Kania[1], Aditya Verma[2], Rushang Babariya[3], Jayendra Vasani[4]

[1,2,3] Student, Automobile Engineering, L.D. College of Engineering, Gujarat, India
[4]Assitant Professor, Automobile Engineering, L.D. College of Engineering, Gujarat, India

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Abstract - *This research primarily focuses on the design & development of the FSAE chassis frame. The chassis is basically a structural bracket to fit all vehicle subsystems like the powertrain, suspension, etc. It is a base with room for enhancement by reducing the weight & increasing the structural rigidity without hampering the performance of a high-speed vehicle.*

For a formula student team, either spaceframe or monocoque chassis can be developed while keeping in mind the FS events' guidelines. Besides achieving structural rigidity & torsional stiffness, an efficient design should also make an improvement in weight reduction & ease of manufacturing & manufacturability. A final spaceframe chassis completes all the checkboxes to make a vehicle with an important consideration of ergonomics (95th percentile) and driver inputs for the best drive positions. This research paper shows the criteria the team played with and the methods used to improve the final design.

***Key Words*: Chassis, Spaceframe, FSAE, Solidworks, Ergonomics, AISI 4130, Tube notching, Jigs & fixtures, Manufacturing.**

1.CHASSIS

The chassis is a base for the development of a formula-styled student vehicle. Designing an efficient chassis is a very important part of the vehicle's performance. It holds together all the subsystems like tractive systems, electric powertrain, suspension & wheels, driver & equipment, etc.

Mainly, the chassis is designed according to the rules & guidelines of Formula Student Events. Goals for the design team were the chassis weight ≤ 28 kgs, better flexural strength, torsional rigidity 2000 Nm with ease of manufacturing & fabrication, taking into account the driver's ergonomics & performance during dynamic events.

FSAE chassis are made of spaceframe or monocoque. Spaceframe chassis is a set of tubes welded together with triangulation for efficient load transfer across all tube members. Different sizes and dimensions are used in tubes according to the load acting on them. Materials like AISI 1080, AISI 4130, etc. can be used for the tubes.

On the other hand, monocoque chassis is a single material bracket made up of lightweight materials like carbon fibre or aluminium sheets. They can also be made as semi-monocoque where the rear structure is made up of tubes while the frontal part consists of carbon fibre layups as per the assembly requirements.

1.1 Design Methodology

For the season 2022-23, the spaceframe chassis was designed using Solidworks CAD modeling software. As the team had prior experience in spaceframe chassis design, there was enough room for optimization before jumping onto a monocoque frame design. The material selected was AISI 4130 after comparing various available criteria to match season goals which will be discussed in upcoming topics.

The table below shows the basic range of dimensions to choose for the tubes according to Formula Bharat 2022 rulebook.

Table -1: Chassis tube nomenclature & dimensions

Tubes	Nomenclature	Dimensions (mm)	MOI (mm^2)
Primary	Front Bulkhead	25.4 x 2.5	11320
	Front Hoop		
	Main Hoop		
Secondary	Front Hoop Bracing	25.4 x 1.65	8509
	Side Impact		
	Main Hoop Bracing		
Tertiary	Bracing Supports	18 x 1	6695
	Non-Structural Tubes		

Initially, an envelope was designed with the focus to understand positioning of subsystems with reference to the driver. This helped the team mark the basic sketch with all reference points. Then, driver inputs using Ergo Jig were taken to initially set the angles for the roll hoops, and the maximum horizontal cockpit space required was decided.

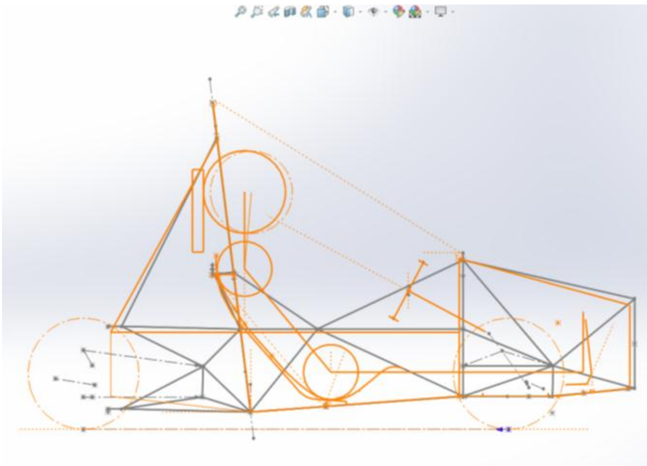

Fig -1: Driver Ergonomics & Vehicle Envelope

Then, secondary tubes are placed with reference to the suspension hard points & nodes. All the tubes sketched in software are made such that it satisfies triangulation condition at every node. The design of a vehicle chassis, for that matter, is going to be based on suspension points, powertrain layout, driver position controls, safety, etc.

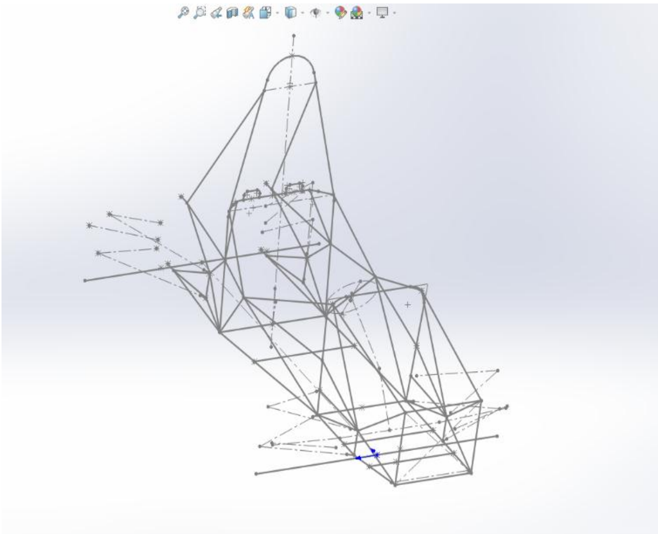

Fig -2: 3-D Sketch with Suspension nodes

At last, the tertiary structural tubes are attached to provide smooth load transfer through the frame and increase the structural stiffness of the chassis. This is done through repetitive analysis of the frame structure in ANSYS software.

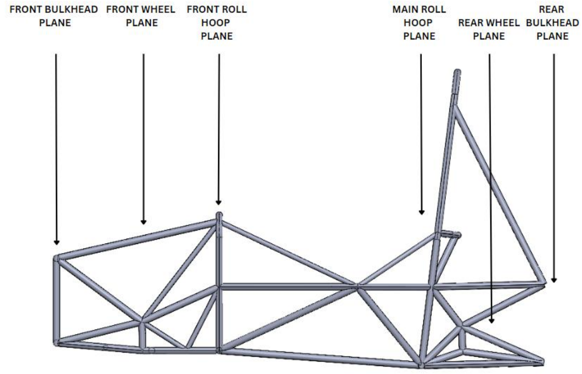

Fig -3: Planes & Tube nomenclature

1.2 Ergonomic Consideration

Ergonomics of driver plays a vital role in the performance of the vehicle due better driving feel, and controls over steering and braking system. Adding to this, ergonomics to an extent defines the weight distribution of the vehicle with regards to the driver's seating position.

The designed ergonomic jig featured a mock seat with the considerations of front and main roll hoops. A mock pedal box was added mark each driver, be it the tallest or the shortest, could easily have full pedal travel. The 95th percentile male percy (T 4.3.2) was used to design the reference seating position for the driver.

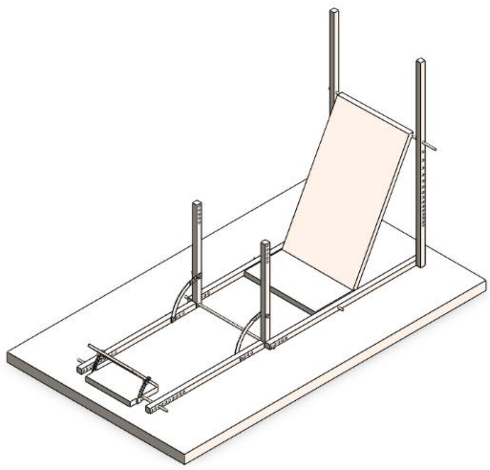

Fig -4: Ergonomic Rig

Once we had the jig manufactured, the real ergonomic test with the finalized drivers began. They were made to sit on the jig and their feedbacks about the positions of different subsystems were noted. The input points regarding the inclination angle of seat, the positioning of the steering, the pedal box etc. were interpolated and a final seating position was mocked with all the drivers. After the seating positions and inclination angle of the seat were finalized the design process for the seat began.

Fig -4: Real-time data on Ergo Rig

The inclination angle and seating position had large scale implications on the vehicle's defining parameters. Through the ergonomic test, we compared and deduced the optimum recline angle with respect to the driver visibility, moreover this also affected overall frame length influencing vehicle dynamic constraints. Table 2 shows the variations in Main Roll hoop height and total frame length according the different driver seating position.

Table -2: Driver Position Comparison

Driver Position (reclined)	Main Roll Hoop height (mm)	Total Frame length (mm)	Driver visibility	Driver Rating (out of 5)
35°	1187.9	2159.63	Better	4.5
40°	1149.56	2193.55	Good	4
50°	1062.74	2253.94	Moderate	3
60°	965.91	2302.93	Bad	2

1.3 Software Methodology

The software used during the designing process of the 2023 chassis were – SOLIDWORKS 2022. The process of designing the chassis was started by creating referencing the planes at the determined positions of the front bulkhead, the front roll hoop, the main roll hoop and the rear bulkhead as shown in fig. 3. A central plane is placed to divide the chassis into half in both Y and Z directions.

The suspension hard points were iterated with dynamics teams, then finalized and the triangulations for the same were sketched. The notching of the tubes was a tricky and lengthy part in the software as the notch have to be precise to minimize the manufacturing error. Every single tube is notched on both ends and the steps used are:

Step 1: Isolate & extend surface using Ruled/Extend tool

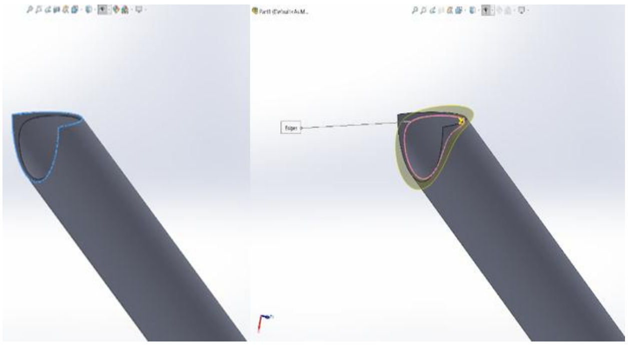

Fig -5: Isolated tube with extended surface

Step 2: Cut extended surface with respect to tube & delete surface extends.

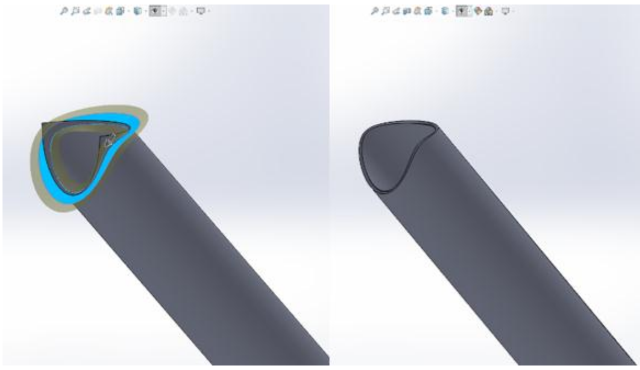

Fig -6: Notched Tube

1.4 Material Selection

The material selection for the chassis tubes impacts the vehicle's performance tremendously. The chassis structure must be stiff to an appropriate extent, torsional rigidity, adequately load bearing and providing optimum nodal load transfer. All these properties greatly impact on the material selected to make the roll cage.

The first things considered to select the material were their physical and mechanical properties like bulk modulus, flexural rigidity E.I., Poisson's ratio, density, yield strength and the ultimate tensile strength. Then after these properties, some auxiliary considerations like procurement period, cost and logistics etc.

The material that we finalized was AISI 4130 – (a high-grade chromium-molybdenum alloy) due its high structural properties and easy availability. The physical and mechanical property table for the 4130 is shown below:

Table -2: Material property comparison

Property	AISI 4130	AISI 1018	AISI 4140
Young Modulus	205	207	200
Density, (kg/m³)	7850	7700	8030
Poisson's Ratio	0.29	0.33	0.27
Yield Strength, (MPa)	435	276	417.1
UTS, (MPa)	670	350	655
Fail Strain	25.5%	17%	25.7%

2. MANUFACTURING PROCESS

While manufacturing a FSAE chassis precision & strength of weld are some of the main concerns. Strength can be controlled using the material of chassis, while precision is controlled using the aid of fixtures. TIG welding process can be opted due to the advantages like higher weld strength, no flux requirement, better weld finish & material adaptability.

2.1 Design method

The fixture structure is divided into three parts: - The weld table (base plate), fixtures & fixtures support. The base plate consists of slots whereas the fixtures and its supports consist of extended tabs which interlocks with each other. This assembly constrains the movement of the fixture on the base plate. The tube is placed on the fixture perpendicular to the axis of the tube.

2.2 Design considerations

The fixture components are made short vertically as it might lead to bending. The circular cut has slightly greater diameter than the tube diameter so as to avoid tube misalignment during heat treatment. The FOS provided is 25.4 ± 0.3 mm to reduce fixture errors.

According to the design, two materials were taken into consideration, MS (mild steel) and MDF (Medium density fiber). The tensile strength of metal plate is 380Mpa while that of MDF sheet of same dimension is 21MPa. Machining of MDF sheet is tedious & with moisture it gets swollen, also highly flammable. While the downside for MS sheet is issue of bending & deformation while spot welding .at their position. Taking into consideration, the issue of deformation, slightly thicker MS sheets were used & hence the team planned to go with fixtures made of Mild Steel sheets

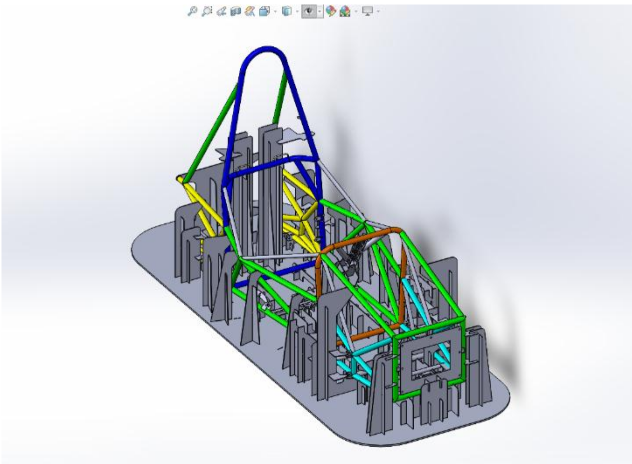

Fig -7: Jigs & fixtures

The fixture and its support plate thickness are important. We have selected 3mm MS sheet & base plate is 8mm thick MS sheet. Any slots laser cut is designed with FOS of ± 0.2 mm. The metal near laser cut expands & will not cool enough to maintain the previous dimensions. During design, we have avoided angular cuts as the precision reduces with increase in angle. In order to reduce the complexity faced during the removal of fixtures post welding, the large fixtures were designed such that the corresponding chassis members are not troubled. This was achieved by designing large fixtures in parts.

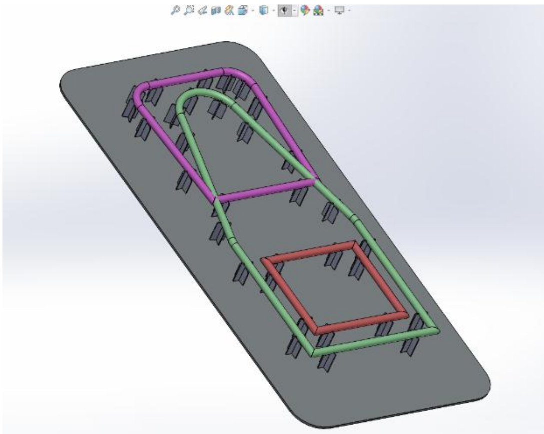

Fig -8: Separate jig for roll hoops

In order to keep the hard point of the tabs of A-arm in reference to each other a connecting fixture is added, similarly added for front-rear referencing. To prevent bending of vertically long fixture for the main roll hoop, we designed a pyramid structure that helped in giving adequate strength as well as support.

3. CONCLUSIONS

The objective of this paper was to define a systematic approach to the design process for an FSAE Chassis. To develop a competitive chassis, it is important to emphasize on a systematic and stage-based design process. The drafting process used, yielded in a design with notches much more precise at the triangulations than that observed in the previous versions.

Ergonomics had a huge impact in vehicle's performance due to much more centralized and lowered seating position affecting CG, Rolling Inertia and balancing polar moment of inertia. It was found that a 5° inclination change in the seating position resulted in increment of 40mm – 60mm frame length due to a more reclined Main roll hoop and a bigger driver's cockpit compartment.

Design Considerations made for fixtures affects the manufacturability of the Chassis. The design methodology used during tube notching and drafting fixtures resulted in a much more precise Chassis CAD draft. All these parameters had tremendous implications on the Chassis Design Process.

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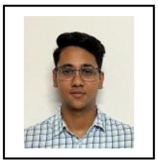
BIOGRAPHIES

Krunal Kania
krunalkania@gmail.com
Student, Dept. of Automobile Engg.
L.D. College of Engineering-380015



Aditya Verma
adityajverma29@gmail.com
Student, Dept. of Automobile Engg.
L.D. College of Engineering-380015

Rushang Babariya
rushang.babariya1111@gmail.com
Student, Dept. of Automobile Engg.
L.D. College of Engineering-380015