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Chassis design and development for a formula student car.

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1 Abstract

With this literature report, will be looking into chassis design for a formula student race car, with the view point of a new team entering the sport or an old team re-entering. Going through the regulations and show areas that will be studied and taken into consideration before looking at old designs, initial designs and developing them further and which materials are available and coincide with the rules and regulations.

2 Introduction

In this paper, it will be a review of the relevant literature, going through some of the regulations to draw an outline of the parameters for a new chassis design for formula student. Also reviewing information about different chassis types, including ladder, space frame and monocoque. Using this information to determine which chassis is best for a new team entry into formula student and the design of the chassis. Once an initial design has been completed, fea analysis will be conducted to see if the chassis has the required strength and rigidity. Then compared to the 2017 chassis file and the Uwtsd chassis file. Then working on developing the initial idea onto the ideal chassis for a new team or from a re-entering team, looking into which material will be optimal for the chassis and that also and is within the regulations.

3 Literature review

In this section of the paper you'll be able to see an insight of the regulations, the chassis types being considered as the initial ideas and development and also the materials that are of choice.

3.1 The formula student regulations

When it comes to starting the chassis design, first thing you'd need to do is look at the requirements and regulations for the race series that you'll be entering. *"Primary structure – The primary structure is comprised of the following components: Main hoop, Front hoop, roll hoop braces and supports, Side impact structure, Front bulkhead, Front bulkhead support system and all chassis members, guides and supports that transfer load from the driver's restraint system into the above-mentioned components of the primary structure"* (IMECHE, 2019) Using these components in your design as a base is a good place to start, then adding additional structural support where required, to keep the driver safe but not to over engineer the car and add too much weight because that's when you start to not be competitive at all. *"Among other requirements, the vehicle's structure must include: Two roll hoops that are braced, A front bulkhead with support system and IA and Side impact structures"* (IMECHE, 2019) the roll hoops are required in the unique circumstances of the car rolling and the roll hoops prevent the driver hitting the ground and protects the head and the front roll hoop protects the driver hands.

"The vehicle must have a wheelbase of at least 1525 mm." (IMECHE, 2019) With minimum requirements like this giving more detail to an initial baseline for a future that will be completed. *"The steering wheel must be no more than 250mm rearward of the front hoop. The steering rack must be mechanically attached to the chassis"* (IMECHE, 2019) skimming through the regulations and pulling

Figure 1-formula student regulations (IMECHE, 2019)

out anything that gives an idea to what will be needed to be implemented in the design of a first stage but competitive chassis for a new team to entre to competition.

Item or application	Minimum wall thickness	Minimum cross sectional area	Minimum area moment of inertia
Main and front hoops, shoulder harness mounting bar	2.0 mm	175 mm ²	11 320 mm ⁴
Side impact structure, front bulkhead, roll hoop bracing, driver's restraint harness attachment (except as noted above)	1.2 mm	119 mm ²	8509 mm ⁴
Front bulkhead support, main hoop bracing supports	1.2 mm	91 mm ²	6695 mm ⁴

The table above shows the minimum thickness, cross sectional area and minimum area moment of inertia. These are things to have in mind when making initial ideas and in the start of the cad work, can also use this in the comparison of the UwtSD formula chassis, as measured and design in solidworks by myself, this to be compared to a 2017 formula student chassis design by Stefan Badulescu. This task can be found in the fae chapter.

“Non-welded strength for continuous material calculations:

- *Young’s Modulus (E) = 200 GPa*
- *Yield Strength (Sy) = 305MPa*
- *Ultimate Strength (Su) = 365MPa*

Welded strength for discontinuous material such as joint calculations:

- *Yield Strength (Sy) = 180MPa*
- *Ultimate Strength (Su) = 300MPa”* (IMECHE, 2019)

Above are the strength specification, and limitation you must stick to when designing/ redesigning the chassis. Now onto the joints that can be used to mechanically brace spaceframe tubes together. Using nuts and bolts to attach them, FEA analysis will need to be done to see if this is a better alternative to welding it together.

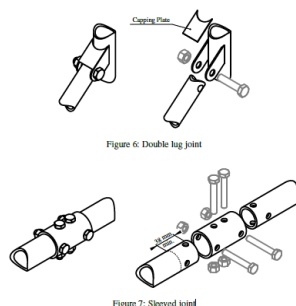


Figure 3 - 2019 regulations, mechanically joined bracing. (IMECHE, 2019)

In the 2019 regulations, it talks about spaceframe chassis need to be properly triangulated joined. And the 2020 draft of the regulations for formula student very recently got released. The diagram below shows a good representation of the tubing being properly triangulated and this would be the best way to design a chassis for space frame chassis.

3.2 Chassis types

There are multiple chassis types including ladder, monocoque and space frame. There is also combination and backbone, but these

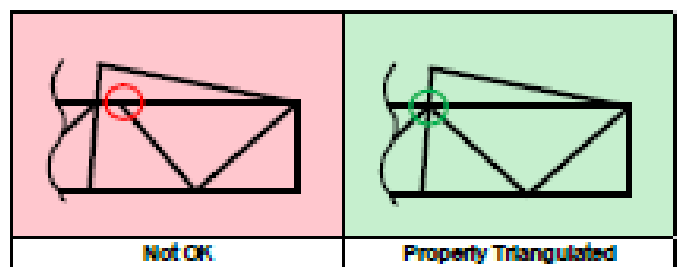


Figure 2 - 2020 draft regulations.

aren’t too common in the vehicle or motorsport industry. A brief insight into what these chassis are. “1. Ladder- A ladder frame car chassis is a common type of frame used as a base for vehicles, creating a solid base from the shape that the name suggests. 2. Monocoque- A monocoque car chassis is one that uses metal that is moulded from sheets of the material, which is the same method used to build other parts of the frame. This type of chassis is similar to a unibody type. 3. Space- A space chassis can also be known as tubular even though it is not tubular in the true sense. The components are welded together to create a strong frame that comprises some flexibility.” (Williams, n.d.) Going into more depth into each chassis is required to determine which is best for a design for formula student.

3.2.1 Ladder chassis

Ladder chassis is a good chassis design type and is predominately used for SUV's and was used a lot for older classic cars. *"For a dedicated off-roader like the Jimmy, the ladder frame offers the high ground clearance and extensive wheel articulation suited for rough terrain."* (Changaroath, 2019) It's a very strong chassis that gives the ability to elevate the body and driving position away from the ground and when it comes to cost, the ladder chassis is a somewhat cheaper alternative. *"Ladder chassis has the advantage of easy manufacturing and price. Their production and material costs are quite low."* (Kale, 2016) The ladder chassis is a very good and strong chassis for the likes of an off-road car but for motorsport it's far from ideal due to the ride height it allows far too much ground clearance, the opposite of what you'd want from your race car.



Figure 5- ladder chassis (Anon., 2019)

3.2.2 Space frame chassis

Space frame chassis are commonly used in motorsport, being a relatively cheap design but very strong and also being used as the go to chassis type for production vehicles too. *"The spaceframe chassis is about as old as the motorsport scene. Its construction consists of steel or aluminium tubes placed in a triangulated format, to support the loads from suspension, engine, driver and aerodynamics. Tubular space frame chassis employs dozens of circular-section tubes (some may use square-section tubes for easier connection to the body panels, though circular section provides the maximum strength)"* (Technical F1 Dictionary, 2019)



Figure 4- space frame chassis (Anon., 2019)

(Anon., 2019)

3.2.3 Monocoque chassis

"Monocoque design is when the frame is integrated into the body construction making it a single structure." (C, 2019) Monocoque chassis are used in high end motorsport chassis such as formula one, and used on sports cars, super cars and hyper cars. Being able to make an extremely strong base when designing and manufacturing a race car, whilst it being competitively light weight. *"The main advantage of the uni-body is its lightweight design since the metal framework extends to the furthest part of the vehicles body"*



Figure 6- Monocoque chassis (Anon., 2019)

structure. Monocoque handling will always trump a ladder frame derivative when compared on-road. Ladder frame vehicles are not known for their fantastic on-road manners. This is due to the fact that the monocoque centre of gravity is much lower which allows manufacturers to design more agile, aerodynamic vehicles resulting in superior performance on-road. Lower floor plan and ride height also mean easier exit and entry into the vehicle." (C, 2019)

3.2.4 Initial thoughts

As an initial thought at the start of this project, the idea was to produce a space frame chassis and monocoque chassis, but with the angle of the project going in a slightly different direction that has now somewhat changed the initial thought. To start with monocoque is arguably lighter, stronger and a more competitive of a design for a team's chassis but the space frame chassis offers a good starting point for a new team, with a good baseline to do a hybrid monocoque and space frame further down the line, maybe one or two years in the motorsport class of choice but certainly with formula student because of budget and time frame. *"Monocoque chassis have good rigidity and very light weight. But its complex structure and price are disadvantages. Space frame structures are slightly heavier than monocoque but they are still considered as light weight."* (Kale, 2016) With the UwtSD chassis made from steel, an idea that will be implemented is the use of both aluminium and steel, as steel is the stronger and more rigid material that can be used in key areas such as the roll bars and bracing, whereas the main space frame can consist of mainly aluminium.

3.3 Solidworks and FEA

Solidworks being the CAD software that the university uses, and is the programme that the chassis design will be designed and analysed on using to re-enact a crash/ impact from the front, front corner and side impact. This system is a student friendly programme, with a numerous amount of tutorials that are available. *"Coming up with engineering concepts and designs is one thing. Understanding how that design will perform in real-world conditions is another. Finite Element Analysis (FEA) tools help engineers find the answers sooner than later in the design cycle, which not only saves time and money but provides insights into how to improve quality before physical prototyping. In fact, the number of physical prototypes goes down significantly and can be eliminated altogether in some cases."* (Prokos, 2019)

3.4 Materials

With materials, the best idea was to do a steel and aluminium blend, with the roll bars being made of steel and also the bracing being steel, but then the rest of the spaceframe being aluminium, this will in theory provide enough strength and also a light weight baseline for a team to work from. In theory though, the keep aluminium up to strength thickness might have to be added but this potentially could still be lighter than steel parts. *"4130 is a chromium-molybdenum general purpose alloy steel tubing that is weldable and is capable of developing good strength. It has been for years the standard of the aircraft industry. Tensile Strength: 90,000 PSI."* (FSAEparts, 2019) *"This tensile strength difference means that aluminium parts need to increase thickness to meet safety standards, while advanced high-strength steel (AHSS) can be made thinner, thereby reducing weight. Granted, these thicker aluminium parts may still come out lighter than their steel counterparts."* (Maw, 2018)

4 Conclusion

To conclude this literature review, a concise understanding of the regulations of formula student has been shown and a look into the types of chassis that could have been considered as a competitive and reliable for a new team to enter formula student, with space frame the preferred choice. A look into materials has also been shown with a view to do a blend of aluminium and steel into space frame the end goal.

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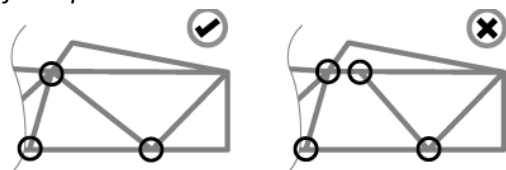
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6 Appendix

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“Chassis – The fabricated structural assembly that supports all functional vehicle systems. This assembly may be a single welded structure, multiple welded structures or a combination of composite and welded structures.



T1.1.2 Chassis member – A minimum representative single piece of uncut, continuous tubing or Equivalent structure.

T1.1.3 Front bulkhead – A planar structure that defines the forward plane of the chassis and provides

Protection for the driver’s feet.

T1.1.4 Front bulkhead support – A structure that defines the side of the chassis from front bulkhead

back to the top of the upper side impact structure and the front hoop.

T1.1.5 Front hoop – A roll bar located above the driver’s legs, in proximity to the steering wheel.

T1.1.6 Front hoop bracing – The structure from the front hoop forward to the front bulkhead.

T1.1.7 Impact Attenuator (IA) – A deformable, energy absorbing device located forward of the front bulkhead.

T1.1.8 Main hoop – A roll bar located alongside or just behind the driver’s torso.

T1.1.9 Monocoque – A chassis made of composite material.

T1.1.10 Node-to-node triangulation – An arrangement of chassis members projected onto a plane, where a co-planar load applied in any direction, at any node, results in only tensile or

Compressive forces in the chassis members as shown in figure 1.

T1.1.11 Primary structure – The primary structure is comprised of the following components:

- Main hoop
- Front hoop
- Roll hoop braces and supports
- Side impact structure
- Front bulkhead
- Front bulkhead support system
- All chassis members, guides and supports that transfer load from the driver’s restraint System into the above-mentioned components of the primary structure”

Figure 1: Node-to-node triangulation of chassis members (left correct and right incorrect).

“Material Definitions

T1.2.1 Fire Retardant – A material meeting one of the following standards:

- UL94V-0 for the minimum used material thickness
- FAR25.853(a)(1)(i)

Equivalent standards are only accepted, if the team shows equivalence and this is approved by the officials prior to the event.”

“Wheelbase

T2.7.1 The vehicle must have a wheelbase of at least 1525 mm.”

“Steering

T2.6.1 Steering systems using cables or belts for actuation are prohibited. (IMECHE, 2019)

[DV ONLY] This does not apply for autonomous steering actuators.

T2.6.2 The steering wheel must directly mechanically actuate the front wheels.

Allowable steering system free play is limited to a total of 7° measured at the steering wheel.

The steering wheel must be no more than 250mm rearward of the front hoop.

The steering rack must be mechanically attached to the chassis.

Rear wheel steering, which can be electrically actuated, is permitted if mechanical stops limit the range of angular movement of the rear wheels to a maximum of 6°. This must be demonstrated with a driver in the vehicle and the team must provide the equipment for the steering angle range to be verified at technical inspection.”

“GENERAL CHASSIS DESIGN

T3.1 General Requirements

T3.1.1 Among other requirements, the vehicle’s structure must include:

- *Two roll hoops that are braced*
- *A front bulkhead with support system and IA*
- *Side impact structures”*

“Minimum Material Requirements

T3.2.1 Table 4 shows the minimum requirements for the members of the primary structure if made from steel tubing.

Item or application	Minimum cross section	Minimum area
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wall thickness	sectional area	moment of inertia
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Main and front hoops,	2:0mm	175mm ²
		11320mm ⁴

shoulder harness mounting bar		
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Side impact structure,	1:2mm	119mm ²
		8509mm ⁴

front bulkhead,		
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roll hoop bracing,		
--------------------	--	--

driver’s restraint		
--------------------	--	--

harness attachment		
--------------------	--	--

(except as noted above)

Front bulkhead support,	1:2mm	91mm ²
		6695mm ⁴

main hoop bracing supports		
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Table 4: Minimum Material Requirements

T3.2.2 Steel tubing has to be made from unalloyed carbon steel with a maximum content of

0:3% carbon, 1:7% manganese and 0:6% of any other element. All other steel grades are considered alternative materials and require additional testing and documentation (see T3.3).”

“The steel properties used for the calculations in the SES must be:

Non-welded strength for continuous material calculations:

- *Young’s Modulus (E) = 200 GPa*
- *Yield Strength (Sy) = 305MPa*
- *Ultimate Strength (Su) = 365MPa*

Welded strength for discontinuous material such as joint calculations:

- *Yield Strength (Sy) = 180MPa*
- *Ultimate Strength (Su) = 300MPa*

T3.2.5 Any tubing with a wall thickness less than 1:2mm or a minimum area moment of inertia less

than 6695mm⁴ is considered non-structural and will be ignored when assessing compliance

to any rule regarding the vehicle structure.

T3.2.6 If a member of the primary structure (except for the roll hoops) is a bent tube or made from

multiple tubes an additional tube must support it. This support tube must: (IMECHE, 2019)

- *Have its attachment point at the position along the bend tube where it deviates farthest from a straight line connecting both ends.*
- *Be of the same dimension as the supported tube(s).*
- *Terminate at a node of the chassis.*
- *Be angled no more than 30° from the plane of the supported tube(s).”*

“Alternative Materials

T3.3.1 Alternative materials may be used for all parts of the primary structure and the tractive

system accumulator container with the following exceptions:

- *The main hoop and the main hoop bracing must be steel*
- *The front hoop must be metal*
- *Any welded structures of the primary structure must be steel*
- *However, the front hoop may be an aluminium welded structure*

T3.3.2 If any other materials than steel tubing are used in the primary structure or the tractive system

accumulator container, physical testing is required to show equivalency to the minimum material properties for steel in T3.2.

T3.3.3 If alloyed steel as defined by T3.2.2 is used, the team has to include tests and documentation in the SES to show structural equivalency. This may include, but is not limited to:

- Receipts and data sheets of the used tubing materials*
- Documentation about welding processes and filler materials*
- Documentation about heat treatments*
- Tests showing adequate strength and elongation at break in the welded condition”*

“Structural Documentation

T3.6.1 All teams must submit a Structural Equivalency Spreadsheet (SES) and Structural Equivalency 3D Model (SE3D).

T3.6.2 The SES spreadsheet form can be downloaded from the competition website.

T3.6.3 The SE3D must contain a three-dimensional CAD model of the chassis including all members

of the primary structure and all mechanical attachment details of the hoops and hoop braces

in “IGES” file format not larger than 40MB.

[EV ONLY] The accumulator container(s) and attachment must also be included.

T3.6.4 Vehicles must be fabricated in accordance with the materials and processes described in the SES.

T3.6.5 Teams must bring a copy of the approved SES to technical inspection.

T3.7 Roll Hoops

T3.7.1 Both roll hoops must be securely integrated to the primary structure using node-to-node triangulation or equivalent joining methods.

T3.7.2 The minimum radius of any bend, measured at the tube centreline, must be at least three

times the tube outside diameter. Bends must be smooth and continuous with no evidence of crimping or wall failure.

T3.7.3 The roll hoops must extend from the lowest chassis member on one side of the chassis, up, over and down to the lowest chassis member on the other side.

T3.7.4 Roll hoops attached to a composite primary structure must be mechanically attached at the top and bottom of both sides of the structure and at intermediate locations if needed to show equivalency.

T3.7.5 Mounting plates welded to the roll hoops must be at least 2mm thick steel or 3mm thick aluminium, dependent of the roll hoop material.

T3.7.6 Both roll hoops must have one 4:5mm hole in a non-critical straight location and its surface at this point must be unobstructed for at least 180°.” (IMECHE, 2019)

“Main Hoop

T3.8.1 The main hoop must be constructed of a single piece of uncut, continuous, closed section steel tubing.

T3 General Chassis Design

T3.8.2 In side view the portion of the main hoop which is above its upper attachment point to the side impact structure must be inclined less than 10° from vertical.

T3.8.3 In side view any bends in the main hoop above its upper attachment point to the primary structure must be braced to a node of the main hoop bracing support structure with tubing meeting the requirements of main hoop bracing.

T3.8.4 In side view any portion lower than the upper attachment point to the side impact structure must be inclined either forward or not more than 10° rearward.”

“T3.9 Front Hoop

T3.9.1 The front hoop must be constructed of a continuous and closed section.

T3.9.2 If the front hoop is made from more than one piece it must be supported by node-to-node triangulation or an equivalent construction.

T3.9.3 In side view, no part of the front hoop can be inclined more than 20° from vertical.

T3.9.4 If the front hoop is a welded construction made from multiple aluminium profiles, the equivalent yield strength must be considered in the as-welded condition unless the team demonstrates and shows proof that it has been properly solution heat treated and artificially aged. The team must supply sufficient documentation proving the appropriate heat treatment process was performed.

T3.9.5 Fully laminating the front hoop to the monocoque is acceptable. Fully laminating means that the hoop has to be encapsulated with laminate around its whole circumference, see figure 4. Equivalence to at least four mounts compliant with T3.16.1 must be shown in the SES.2"

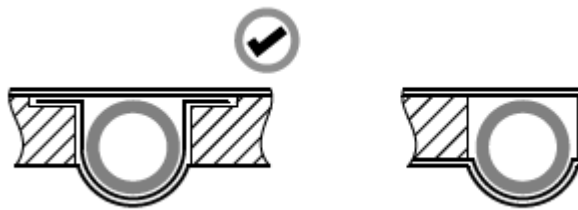


Figure 4: Front hoop laminating requirements

"Main Hoop Bracing

T3.10.1 The main hoop must be supported to the front or the rear by bracing tubes on each side of the main hoop.

T3.10.2 In side view the main hoop and the main hoop braces must not lie on the same side of a vertical line coincident with the top of the main hoop.

T3.10.3 The main hoop braces must be attached to the main hoop no lower than 160mm below the top-most surface of the main hoop. The included angle formed by the main hoop and the main hoop braces must be at least 30°.

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T3 General Chassis Design

T3.10.4 The main hoop braces must be straight.

T3.10.5 The lower ends of the main hoop braces must be supported back to the upper attachment point of the main hoop to the side impact structure and to the lower attachment point of the main hoop to the side impact structure by a node-to-node triangulated structure or equivalent composite structure.

T3.10.6 If any item which extends outside of the primary structure is attached to the main hoop

braces, additional bracing is required to prevent bending loads in a rollover situation.

T3.11 Front Hoop Bracing (IMECHE, 2019)

T3.11.1 The front hoop bracing consists of two single, straight tubes (one on each side of the front hoop) which connects to the front hoop and the structure forward of the driver's feet (e.g. front bulkhead).

T3.11.2 The front hoop bracing structure must be attached no lower than 50mm below the top-most

surface of the front hoop, see figure 5.

T3.11.3 If the front hoop is inclined more than 10° to the rear, additional braces extending rearwards are required."

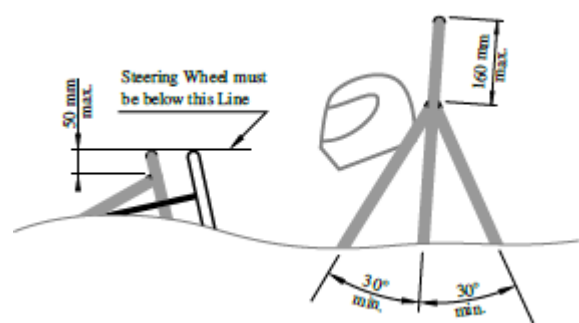


Figure 5: Front hoop bracing, main hoop bracing and steering wheel requirements

"Mechanically Attached Roll Hoop Bracing

T3.12.1 Any non-welded joint at either end of a bracing must be either a double-lug joint, see figure 6, or a sleeved joint, see figure 7.

T3.12.2 If threaded fasteners are used they are considered critical fasteners and must comply with

T10.1.

T3.12.3 Spherical rod ends are prohibited.

T3.12.4 Double lug-joints must include a capping arrangement, see figure 6.

T3.12.5 In a double-lug joint each lug must be at least 4:5mm thick and the pin or bolt must be

10mm metric grade 8:8 minimum. The attachment holes in the lugs and in the attached

bracing must be a close fit with the pin or bolt.

T3 General Chassis Design

T3.12.6 For sleeved joints the sleeve must have a minimum length of 38mm either side of the joint

and be a close-fit around the base tubes. The wall thickness of the sleeve must be at least that

of the bracing tubes. The bolts must be 6mm metric grade 8:8 minimum. The holes in the sleeves and tubes must be a close-fit with the bolts.” (IMECHE, 2019)

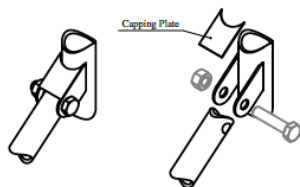


Figure 6: Double lug joint

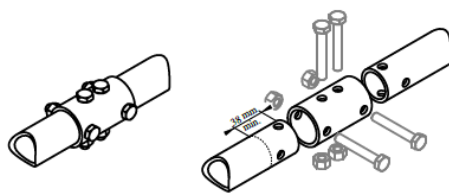


Figure 7: Sleeved joint

“Front Bulkhead

T3.13.1 Any alternative material used for the front bulkhead must have a perimeter shear strength

equivalent to a 1:5mm thick steel plate.

T3.13.2 If the front bulkhead is part of a composite structure and is modelled as an “L” shape, the EI

of the front bulkhead about the vertical and lateral axes must be equivalent to a steel tube

meeting the requirements for the front bulkhead. The length of the section perpendicular to the bulkhead may be a maximum of 25mm measured from the rearmost face of the bulkhead.

T3.14 Front Bulkhead Support

T3.14.1 The front bulkhead must be supported back to the front hoop by a minimum of three tubes on

each side; an upper member, a lower member and diagonal bracing to provide triangulation.

T3 General Chassis Design

- The upper support member must be attached to the front bulkhead a maximum of 50mm below the top-most surface of the front bulkhead, and attached to the front hoop a maximum of 50mm below the upper side impact member. If the attachment point of the upper member is greater than 100mm above the upper side impact member, node-to-node triangulated bracing is required to transfer load to the main hoop.

- The lower support member must be attached to the base of the front bulkhead and the base of the front hoop.

- The diagonal bracing must triangulate the upper and lower support members node-to-node.”# (IMECHE, 2019)

“Side Impact Structure

T3.15.1 The side impact structure must consist of at least three steel tubes, see T3.2, on each side of

the cockpit, see figure 8.

- The upper member must connect the main hoop and the front hoop. It must be at a height between 240mm and 320mm above the lowest inside chassis point between the front and main hoop.

- The lower member must connect the bottom of the main hoop and the bottom of the front hoop.

- The diagonal member must triangulate the upper and lower member between the roll hoops node-to-node.”

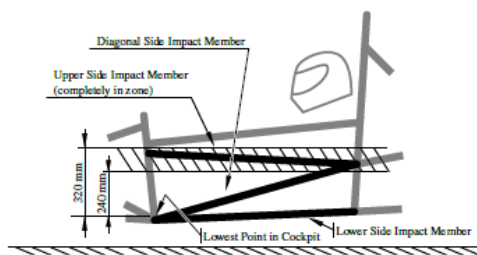


Figure 8: Side impact structure

"If the side impact structure is part of a composite structure, the following is required:

T3 General Chassis Design

- *The region that is longitudinally forward of the main hoop and aft of the front hoop and vertical from the bottom surface of the chassis to 320mm above the lowest inside chassis point between the front and main hoop must have an EI equal to the three baseline steel tubes that it replaces, see figure 9.*
- *The vertical side impact structure must have an EI equivalent to two baseline steel tubes and half the horizontal floor must have an EI equivalent to one baseline steel tube.*
- *The vertical side impact structure must have an absorbed energy equivalent to two baseline steel tubes.*
- *The perimeter shear strength must be at least 7:5 kN."*

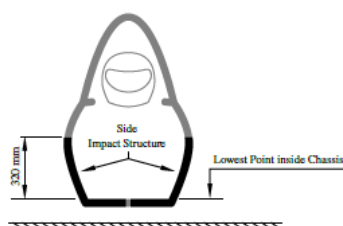


Figure 9: Side impact structure monocoque

(IMECHE, 2019)

"COCKPIT

T4.1 Cockpit Opening

T4.1.1 The size of the cockpit opening needs to be sufficient for the template shown on the left in figure 11 to pass vertically from the opening below the top of the side impact structure when held horizontally. The template may be moved fore and aft.

T4.1.2 If the side impact structure is not made of tubes, the template must pass until it is 320mm

above the lowest inside chassis point between the front and main hoop.

T4.1.3 The steering wheel, seat and all padding may be removed for the template to fit. Any other

parts may only be removed if they are integrated with the steering wheel.

T4.2 Cockpit Internal Cross Section

T4.2.1 The cockpit must provide a free internal cross section sufficient for the template shown on

the right in figure 11 to pass from the cockpit opening to a point 100mm rearwards of the face of the rearmost pedal in an inoperative position. The template may be moved up and down. Adjustable pedals must be in their most forward position.

T4.2.2 The steering wheel and any padding that can be removed without the use of tools while the driver is seated may be removed for the template to fit.

T4 Cockpit

T4.2.3 The driver's feet and legs must be completely contained within the primary structure when the driver is seated normally and the driver's feet are touching the pedals. In side and front views, any part of the driver's feet or legs must not extend above or outside of this structure.

T4.2.4 [DV ONLY] To allow for the steering actuator a reduced-height template (reduced by 50mm, shown in figure 11) may be used for a section measuring 200mm horizontally along the template's path (compare T4.2.1).

T4.2.5 [DV ONLY] The additional space allowed by T4.3.4 T4.3.4 and T4.2.4 may only be used

for steering, braking and clutch actuators. When the actuators are removed, the standard templates must fit into the cockpit."

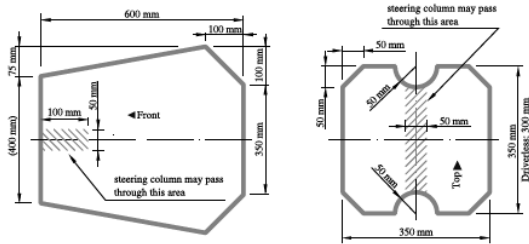


Figure 11: Cockpit opening template (left) and cockpit internal cross section template (right)

“The figure has to be positioned in the vehicle as follows, see figure 13:

- *The seat adjusted to the rearmost position”*

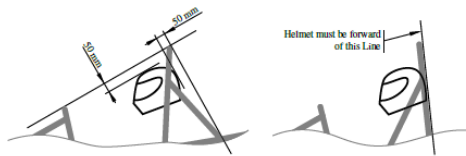


Figure 12: Minimum helmet clearance

(IMECHE, 2019)

“• The pedals adjusted to the frontmost position

- *The bottom 200mm circle placed on the seat bottom. The distance between the center of the circle and the rearmost actuation face of the pedals must be minimum 915mm.*
- *[DV ONLY] The distance from center of circle and pedals, as mentioned above, may be reduced to 865mm but only for placement of automated brake, steering or clutch actuators in front of the pedals.*
- *The middle circle positioned on the seat back*
- *The upper 300mm circle positioned 25mm away from the head restraint.”*

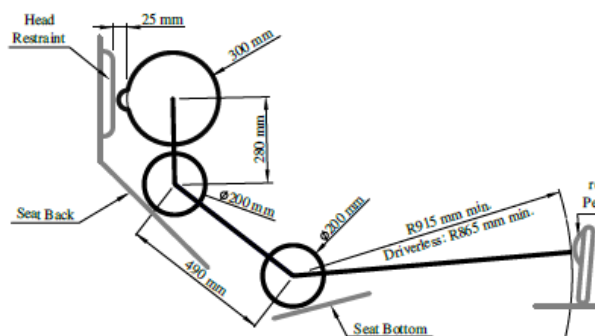


Figure 13: Percy placement

(IMECHE, 2019)