Department of Mechanical and Mechatronics Engineering

Design of an FSAE Firewall

A Report Prepared For:

The University of Waterloo

Prepared By:

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[redacted]

September 19th, 2022

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Dear Bill Owen,

This report, entitled Design of an FSAE Firewall, was written to fulfill my 2B work term report requirements. This is my second work report submission.

Over the Spring 2022 term, I worked on several projects for the University of Waterloo Formula Motorsports student design team. The team is currently designing the 2023 vehicle, and one of the projects I took on was to design the firewall for the 2023 car. There were some issues with the 2022 firewall discovered during competition, so I focused on implementing solutions to those problems, as well as worked on making the manufacturing process easier. This report will analyse the problems of last year's firewall, investigate different design solutions to those problems, and discuss the manufacturing processes that will be used this year.

This report was written entirely by me and has not received any previous academic credit at this or any other institution. I would like to acknowledge the contributions of [redacted], and [redacted] as they helped to identify the shortcomings of the 2022 firewall, as well as gave me valuable manufacturing feedback as I worked on the design. My role in the project was to design solutions to last year's issues while incorporating their feedback, and write this report.

Regards,

Remy Lambert
20898945
2B Mechanical Engineering

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Summary

The firewall in the 2022 University of Waterloo Formula Motorsports vehicle had some issues that were corrected later in the season with subpar solutions. The objective of this report is to investigate solutions to the problems of the 2022 design, and implement those solutions in the design of the 2023 firewall.

The first issue with the 2022 design is that the firewall had openings on either side of the cockpit, which meant that it failed to seal against the passage of fluids. To allow the vehicle to enter the competition, foam mats were cut to shape, wrapped in tape, and inserted into the openings to create the required seal at the last minute. Manufacturing was also difficult because the mold had some issues which caused the carbon fibre to not sit flat. The firewall also has aluminum inserts embedded into the carbon fibre to support the fasteners when mounting, however, due to the manufacturing difficulties these plates were misaligned with the hole locations once installed.

To fix the sealing issues, the firewall can not simply be extended to the edges of the cockpit, because the frame geometry will make it impossible to insert or remove. So instead, the side flanges were made larger to allow for a greater sealing surface, and expanding foam will be used to create form-fitting inserts for each side of the firewall. Using expanding foam will create a perfect seal, regardless of manufacturing errors, as well as allow the firewall to have simpler geometry. To improve manufacturing, the firewall mold was designed to have flanges that are 45 mm larger than the actual firewall – this is so that any carbon fibre irregularities created by the edge of the mold will be outside of the actual firewall. The excess material will be cut off with a Dremel afterwards. The mold also does not have any gaps that the carbon fibre will have to bridge, which will help with the reliability of the mold. Finally, the aluminum inserts are 60% larger to allow for more error when drilling the holes for the firewall fastener.

On the 2022 car, an additional piece of carbon fibre panel was zip-tied above the engine to protect the driver's neck in the event of a fire. This was called the upper firewall, and there were no significant issues with this design. However, in the 2023 vehicle the intake is in the way of any flat panel, so the solution is to have a cut-out in the carbon fibre to allow the intake to pass through. The intake is aluminum, so aluminum tape can be used to seal the upper firewall to the intake, and protect the neck and head of the driver.

This new design will be manufactured in October 2022, and will be implemented into the vehicle in the first few months of 2023. From there, the firewall will run the test of the season, and the increased experience of the team will likely lead to more improvements for the 2024 design.

1.0 Introduction

1.1 UWFM Team

The University of Waterloo Formula Motorsports (UWFM) team is a student design team that builds a formula-style vehicle (Figure 1) to compete in the Formula Society of Automotive Engineers (FSAE) student design competition [1]. These vehicles must adhere to a strict set of rules, and in order to participate, vehicles must pass a technical inspection before each competition to verify rule compliance. Lighter vehicles are typically favoured due to power restrictions and tight courses.

Figure 1: 2022 UWFM vehicle [2]

1.2 Objective

One of the major focuses of the competition is student safety – there are several requirements for safety features that must be included in the design, including a firewall that separates the driver of the vehicle from certain engine components and seals against the passage of fluids. For the 2022 car, a carbon fibre panel was used for this, but there were several issues with sealing, manufacturing, and ergonomics that will be discussed in Section 2.0. The objective of this report is to investigate solutions to the problems of the 2022 design, and implement those solutions in the design of the 2023 firewall.

2.0 Problem Definition

2.1 2022 Firewall Design

The 2022 firewall (Figures 2 and 3) is a composite material. The base material is 3 mm ROHACELL foam core [3], and this is covered in four layers of 3K twill carbon fibre [4]. 3K refers to the size of the carbon fibre bundles, and twill refers to the pattern in which it is weaved. The carbon fibre is covered with a clear, heat resistant resin [5] which will protect the driver in the event of a fire. There are also cut-outs in the foam core for 1/8" aluminum plates to be inserted so that the holes drilled into the firewall for mounting will have adequate support. The carbon fibre and foam are laid up on a sheet metal mold which is made by laser-cutting a 0.065" sheet of aluminum into the flat pattern, then using a sheet metal brake to bend it into the 3D shape. Once the carbon fibre and foam are in position on the mold, resin is poured onto the carbon fibre, and the whole assembly is placed inside a vacuum bag to cure. The firewall sits behind the driver because the engine is in the rear of the vehicle, behind the driver. Everything that the firewall must protect against is situated around the engine (Section 2.2).

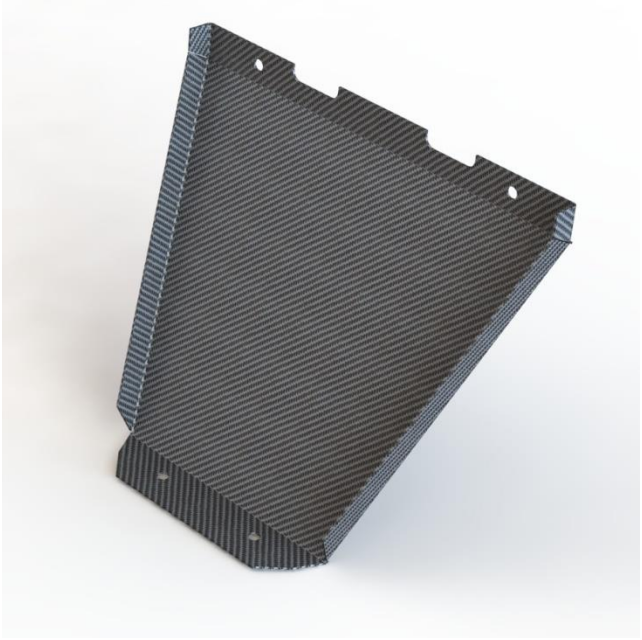

Figure 2: 2022 Firewall [6]

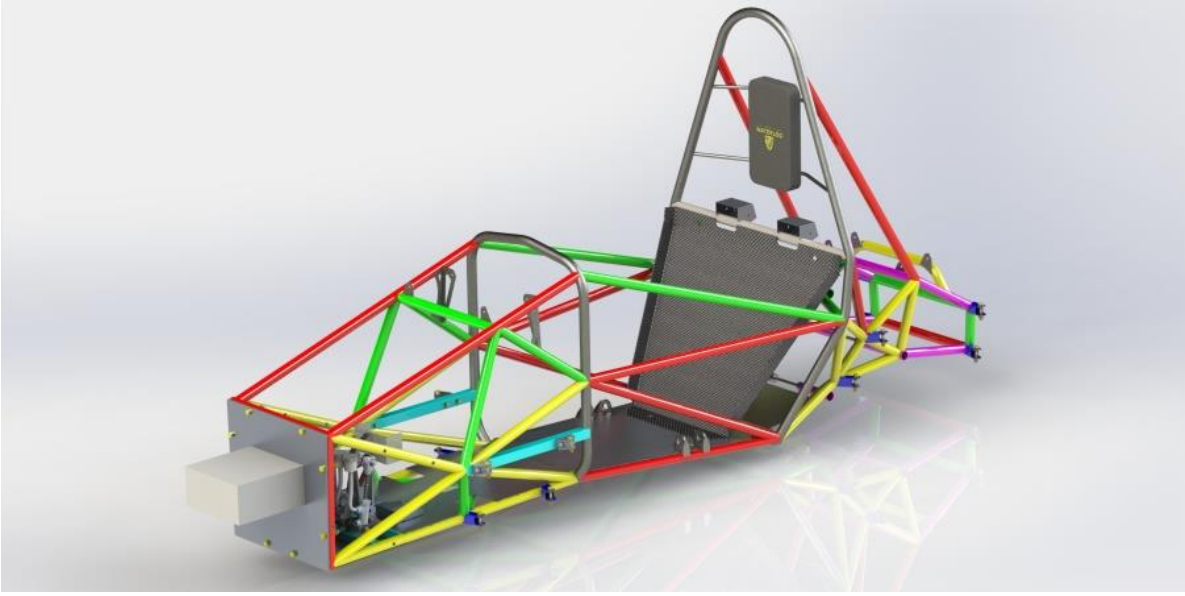

Figure 3: 2022 Firewall in Chassis CAD [6]

The 2022 firewall has several design features that serve specific functions. Firstly, it has two main flanges that sit flush against the floor at the bottom, and flush against the shoulder harness bar at the top (Figure 3). These flanges must be flush because the firewall is fastened at these points. The four holes distributed across the top and bottom flanges are there for the Dzus, or quarter-turn fasteners (Figure 4). This is a fastener which only requires a quarter turn to hook onto a mounted wire, and it remains attached to the mount when disconnected. It has two pieces: the wire, which is riveted onto the chassis, and the fastener, which is attached to a small plate that is riveted to the aluminum inserts. These fasteners make mounting and dismounting fast and easy, which is necessary since the firewall must be removed to access the battery. The side flanges are designed to help protect the driver from the engine components and seal against the cockpit, but as discussed in the next few sections, there are several reasons why it did not meet those requirements. Finally, the slots at the top of the firewall are meant for the shoulder harnesses to come through, as they attach to the car by wrapping around the shoulder harness bar (hence the name).

Figure 4: Dzus Fastener (left) and Wire (right) [7]

2.2 Relevant Rules

Given that this vehicle is designed to participate in the Formula SAE competition, there is a specific ruleset that the vehicle's design must follow in order to be eligible to compete. This ruleset is updated yearly, but typically the ruleset for a given year is released after the manufacturing for that year has already begun. Because of this, the previous year's ruleset (2022) [8] is used for design, and this is reasonable given that the rules usually do not change significantly.

The firewall is referenced in many sections throughout the ruleset document, but the major design considerations are introduced in T.1.8 Firewall(s). The entire section can be found in Appendix A – FSAE Firewall Ruleset, but the major considerations are listed here:

T.1.8.1.a: A Firewall(s) must separate the driver compartment and any portion of the Driver Harness from all components of the fuel supply, the engine oil, the liquid cooling systems, any lithium batteries

T.1.8.2.b: Any Firewall must seal completely against the passage of fluids (the Firewall itself, edges, and Floor Closeout)

T.1.8.3: The Firewall must extend sufficiently far upwards and/or rearwards and/or sideways where any point on the driver's body less than 100 mm above the bottom of the helmet of the tallest driver must not be in direct line of sight with any part mentioned in T.1.8.1 above

The 2022 firewall design was not compliant with Rule T.1.8.2.b because there was open space between the edge of the firewall side flanges and the side walls of the cockpit (Figure 5). In order to enter the competition, this space was filled with foam mats which were cut to shape and wrapped in electrical tape.

Foam mats were used because this solution was created while away for the first competition, so resources and time were limited. The firewall was then sealed to this foam with aluminum tape, which made removal of the firewall difficult. This was not ideal, as the foam mats were not fire rated, so the 2023 firewall design will aim to avoid these issues. This rule was also breached by the shoulder harness cut-outs, as they were about 10 mm too deep, resulting in bypass area that had to be covered with more tape. For brevity and simplicity's sake, the components that the firewall must seal against, mentioned in T.1.8.1.a, will be referred to as "the engine components", since all those components are in and around the engine location.

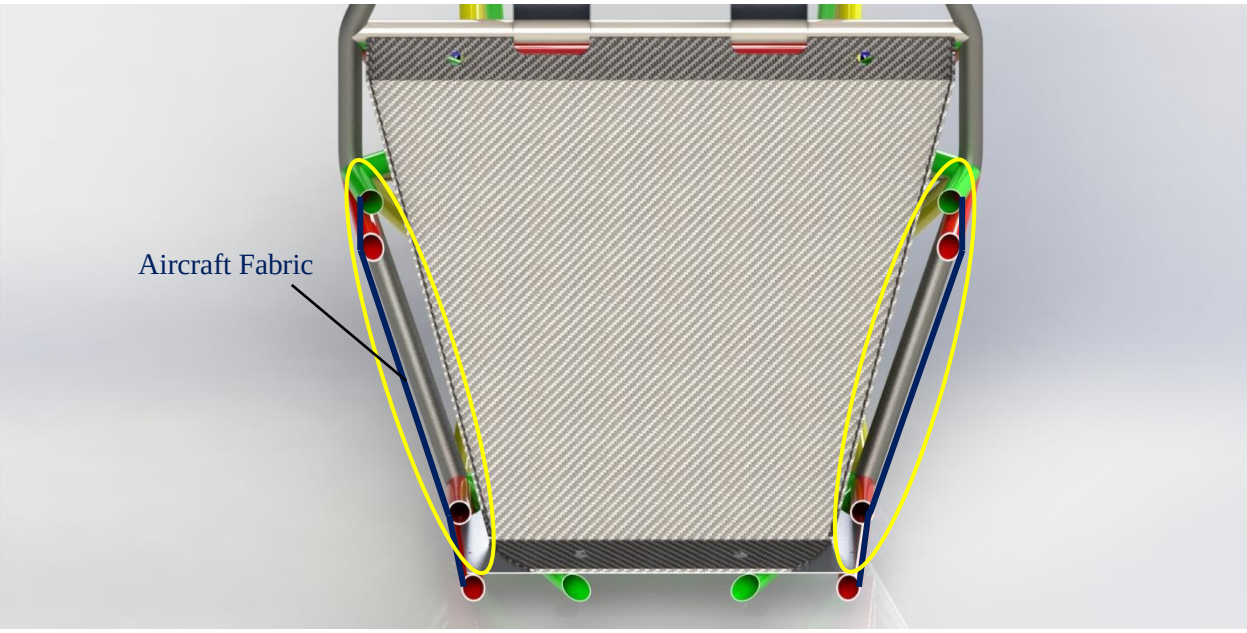

Figure 5: Cross-section of 2022 vehicle, circled sections were filled with foam. [6]

Rule T.1.8.3 was met in 2022 by having an additional piece of carbon fibre mounted above the engine protecting the driver's neck, and sealing against the same shoulder harness bar. This panel, called the "upper firewall", was not put into the 2022 CAD because the design was straightforward, and the team was pressed for time. This year, the intake is in the way of any flat panel, so the design will have to be modified slightly. Similarly, the 2022 car employed an aluminum shield which protects the rear of the shoulder harness when wrapped around the tube. As can be seen in Figure 3, the shield only covers the top half of the harness, so the lower half was exposed to the engine components. This sheet metal shield will be extended for the 2023 design.

2.3 Ergonomics

Each driver has their own seat, which is a piece of form-fitted foam that rests on the firewall. This means that the firewall is the basis for the driver seat as it defines the back angle. The largest driver of the vehicle (99^{th} percentile male) does not have a foam seat and simply rests their back directly on the firewall to allow

room for their legs to fit in the car while resting their feet comfortably on the pedals. For the 2022 car, an ergonomics study was performed that determined the best back angle to be 55 degrees from the horizontal plane, as this allows a broad range of drivers an adequate sight line while also keeping a low centre of mass and keeping the driver comfortable. A similar ergonomics study was performed for the 2023 car, and the back angle chosen was the same – that study is out of the scope of this report, but the basic methodologies and results can be found in Appendix B – 2023 Ergonomics Study.

Another ergonomics consideration was the shoulder harness bar. This is the bar to which the shoulder harness mounts, and the largest driver had trouble complying with the shoulder harness rules in the 2022 vehicle due to their height (see Appendix C – FSAE Shoulder Harness Bar Rule). For the 2023 vehicle, the ergonomics study determined that the bar height should be raised by 22 mm, so the firewall design also must elongate to accommodate this change.

2.4 Manufacturing

According to the students who manufactured the 2022 firewall, there were several problems that could have been avoided with better design. The first error with last year's design is that it did not account for the thickness of the foam when modelling the firewall to fit the frame in CAD. This caused an issue where the firewall had to be elastically deformed into position during mounting, which was difficult and put unnecessary stress on the material. This problem, combined with other manufacturing tolerances and difficulties, meant that the original position for the bottom holes on the firewall did not align with the holes drilled into the floor (Figure 6). The holes were able to be moved slightly to fix the issue, but the aluminum inserts were no longer in the correct position, resulting in poorly supported holes.

Figure 6: Skewed location of the aluminum insert

The mold itself had several flaws as well. Firstly, the mold flanges were the same size as the firewall flanges (Figure 7), which meant that extra material had to fold underneath, resulting in pleating at the corners and several failed manufacturing attempts. Secondly, there were gaps between the side and bottom flanges, which meant that unsupported material could cause similar issues as the first problem. Finally, the edges of the foam inserts were stiff enough that they were able to create a sharp bend in the carbon fibre at transitional locations, creating stress concentrations within the carbon fibre (Figure 8). This effect was accentuated at the corners of the foam, where it was possible for the fibres to catch and stretch out.

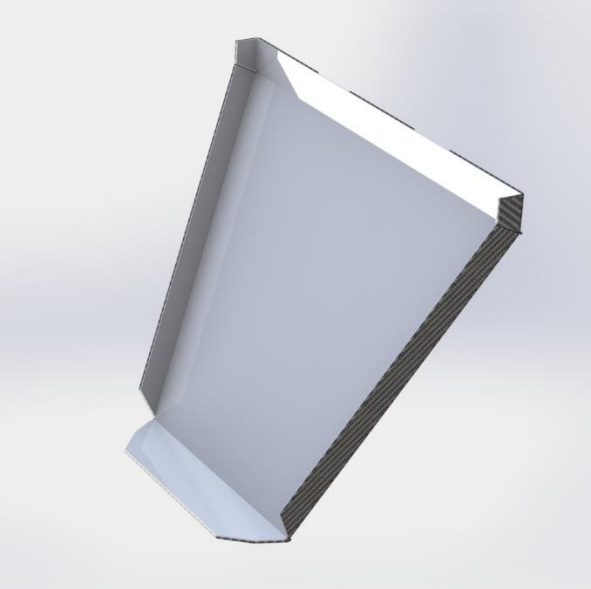

Figure 7: 2022 Firewall Mold Assembly [6]

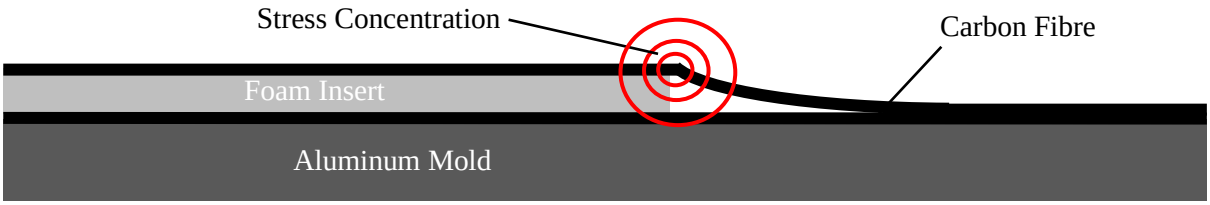

Figure 8: Stress concentrations in the carbon fibre

2.5 Older Firewall Designs

Interestingly, the 2021 firewall design is quite similar to the 2022 firewall design (Figure 9). There are two main differences however: the first is that the back angle of the 2021 design is 45 degrees because it was following an older ergonomics study, and the second is that the 2021 firewall has a side flange length of 60 mm, where the 2022 firewall has a side flange length of only 38 mm.

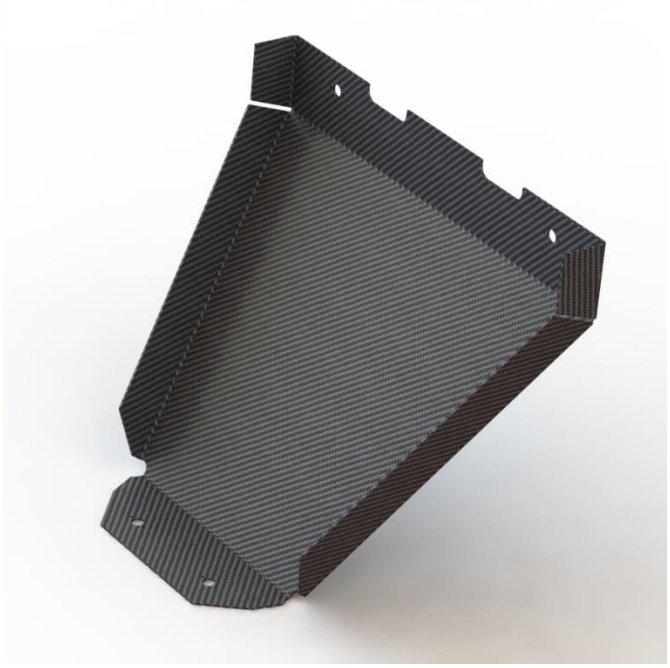

Figure 9: 2021 Firewall Design [9]

Examining older firewall designs, there seems to be a trend starting from 2015 (when the firewall was still being made from aluminum) where the side flanges have become progressively smaller with each year's new design, likely in pursuit of weight savings. Interviewing older team members, these older firewalls never had issues passing technical inspection, even though they had the same bypass flaws as the 2022 design. This means that the 2023 design would likely pass technical inspection just by increasing the flange size from last year. However, the bypass area is a potential safety hazard which should be corrected for future vehicles.

3.0 Design and Analysis

3.1 Design A – Contact Sealing

The first design that was created focused on sealing by having the firewall side flanges meet the edges of the cockpit (Figure 10). This would mimic the seal created by the top and bottom flanges against the shoulder harness bar and floor, respectively. The edge of the cockpit, however, is aircraft fabric which is wrapped around the outside of the frame tubes – this means that these tubes are in the way when attempting to seal against the fabric (Figure 11). One solution to this is to design the firewall with cut-outs for the frame tubes.

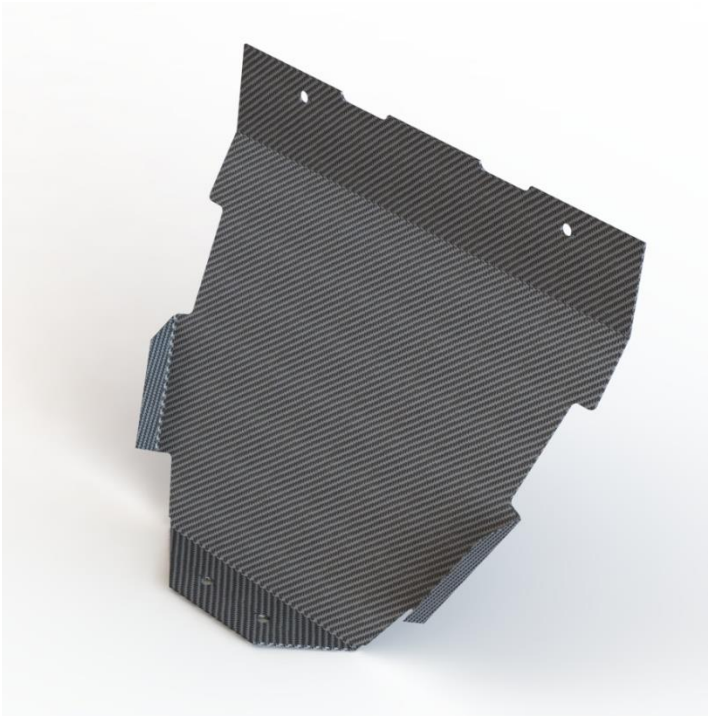

Figure 10: 2023 Firewall Design A – Contact Sealing

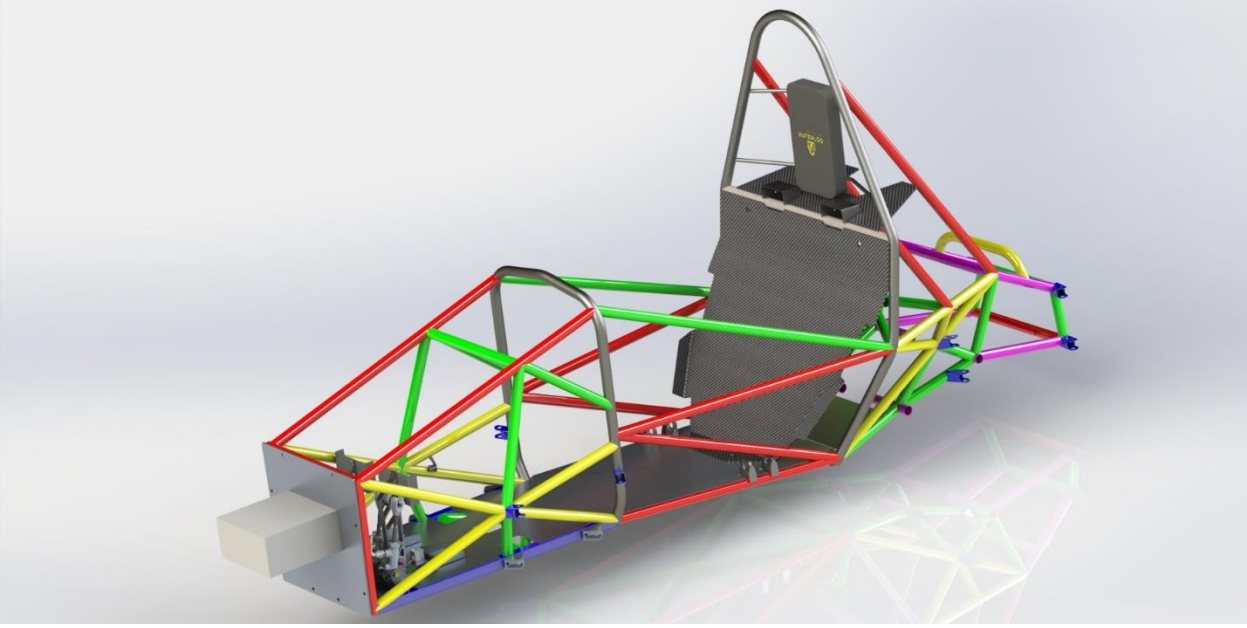

Figure 11: 2023 Firewall Design A in Chassis CAD

Design A shares most features with the 2022 design, but with a few key changes. Firstly, the cut-outs for the shoulder harnesses have been reduced from a depth of 20 mm to 10 mm to avoid having excess room around the harness. Secondly, the top flange is slightly larger to accommodate the higher shoulder harness bar, while keeping the space behind the firewall constant. The main change however, is the cut-outs for the frame tubes at both edges, and the wider firewall to allow the side flanges to extend to the aircraft fabric. As well, the side flanges do not extend all the way to the top of the firewall – they only exist in between the chassis tubes because there is nothing to seal against above the cockpit. However, because the flange is in between the tubes, this design would be difficult if not impossible to insert and remove. Even widening the cut-outs and reducing the flange size to just 40 mm (slightly larger than 2022) only helps this issue slightly, while significantly worsening sealing ability.

3.2 Design B – Foam Sealing

Design B is also similar to the 2022 firewall design, but still has several changes that will improve functionality. The first two changes, regarding the top flange and harness cut-outs, are identical to Design A. The main change is the side flanges: these now extend fully from top to bottom and are double the size (75 mm) (Figure 12). This is because expanding foam would be used to fill the gap between the aircraft fabric, tubes, and side flanges with this design (Figure 13). Using expanding foam would also allow for more manufacturing error while keeping a perfect seal, and the firewall would be easy to insert and remove without catching on any frame tubes.

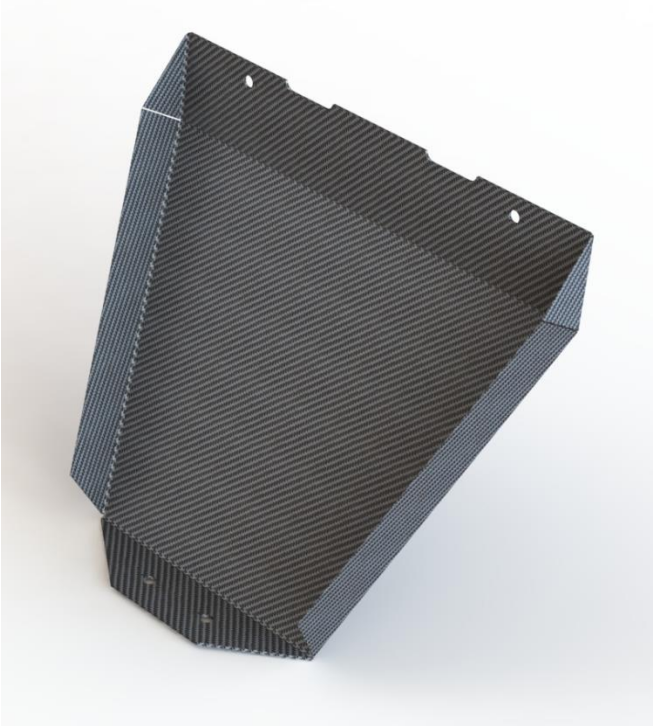

Figure 12: 2023 Design B - Foam Sealing

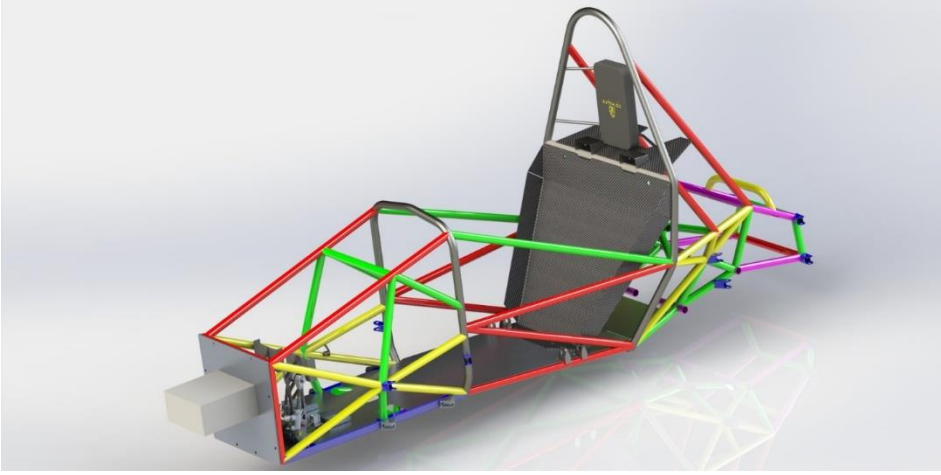

Figure 13: 2023 Firewall Design B in Chassis CAD

3.3 Upper Firewall

The upper firewall, as discussed in Section 2.2, needs to change because of the intake which is in the way of any flat panel (Figure 14). However, bending it upwards out of the way would result in poor vehicle aerodynamics, especially since this panel is directly in front of the rear wing. Alternatively, the panel can have a cut-out for the intake and remain mostly horizontal. This is the method chosen, because it will not have any negative effects on aerodynamics, and it can meet rules by using aluminum tape to seal against

the aluminum intake. The upper firewall does not need to be removed during normal use once installed, so permanent fixtures are not an issue – this means that zip ties can be used to fasten it onto the shoulder harness bar and roll hoop braces, as in the 2022 design.

Figure 14: Upper Firewall in Vehicle CAD

3.4 Design Analysis

Analyzing the benefits and disadvantages of each design, Design B will be more practical since it is easier to remove, easier to manufacture because it does not have complicated cut-outs, and will likely have the better seal thanks to the expanding foam. For these reasons Design A was rejected and Design B was chosen for the 2023 vehicle. The upper firewall design will be used in conjunction with Design A as discussed in Section 3.3, and the shoulder harness shields will be extended to cover the lower half of the harnesses, as discussed in Section 2.2.

3.5 Manufacturing

As discussed in Section 2.4, there were several manufacturing problems caused by the 2022 mold design. As a result, the 2023 mold has been improved in several ways. Firstly, the mold flanges (120 mm) are much larger than the firewall's flanges (75 mm). This allows excess material to drape flat past where required, causing any creasing or pleating due to wrapping to be outside of the actual firewall area. Once the firewall has set on the mold, a Dremel will be used to cut off the excess material. Similarly, the harness cut-outs will be Dremelled out afterwards to allow for the carbon fibre to sit flat around that area during the molding

process. Also, there are no gaps between the flanges, eliminating another potential source of creasing in the carbon fibre. The mold material is 0.065” aluminum 5052 H15 sheet metal, which is the same as last year since there were no issues with the material itself. This sheet will be laser-cut and then bent into shape using a sheet metal brake (Figures 15 and 16).

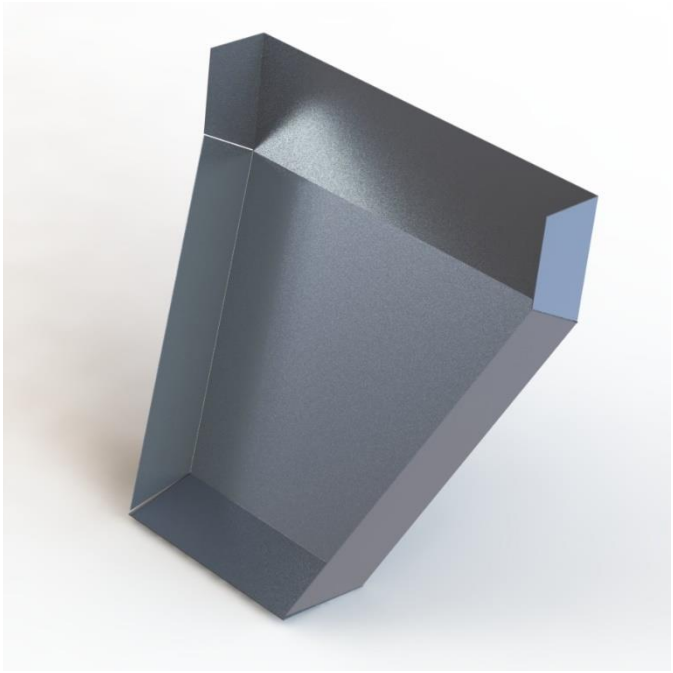

Figure 15: 2023 Aluminum Firewall Mold

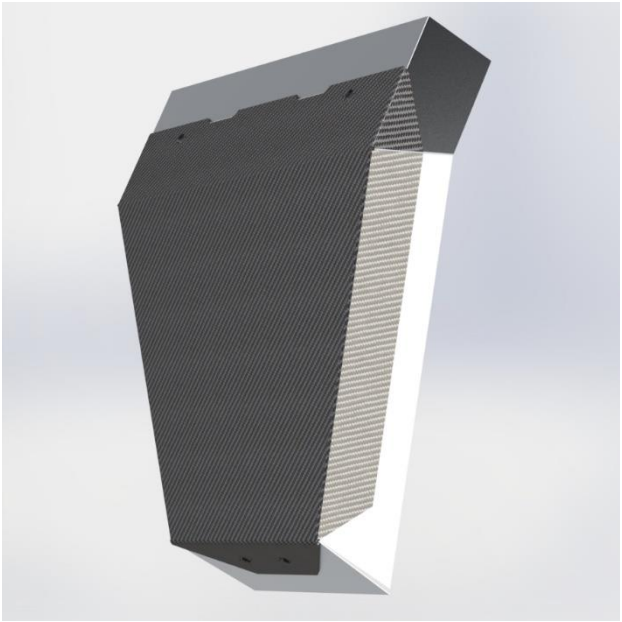

Figure 16: 2023 Mold Assembly

One downside with this design compared to last year is the difficult bending pattern. As can be seen in Figure 17, there are several bend locations where making a bend straight across the entire part would cause bending in unwanted locations. The sheet metal brake that this will be bent on has adjustable clamps on the top clamping surface, but the bottom clamping surface is fixed (Figure 18). This means that the top clamp can be adjusted to avoid collisions with other small bends, but any larger bends elsewhere in the part or overhanging edges will still collide when trying to bend. However, this part is still possible if certain bends are started on the machine, and finished by hand in a vice. Because the side flanges are 90° bends and will be sealing against the expanding foam, tolerances can be looser and so they will be finished in the vice. Here is how the bending will be done:

1. Line 1 will be bent 35° in the brake.
2. Lines 2 and 3 will be bent 10-15° in the brake.
3. The mold will be taken to the vice and Lines 2 and 3 will be fully bent to 90°.
4. Line 6 can then be bent 55° in the brake. The large side flanges will be bent along with the bottom flange, but they can then be flattened in the vice afterwards. This will leave the surface slightly uneven in that area, but that area is only there to support the excess carbon fibre during the molding process, and will not affect the actual firewall (Figure 16).
5. Lines 4 and 5 can then be bent 90° in the brake.

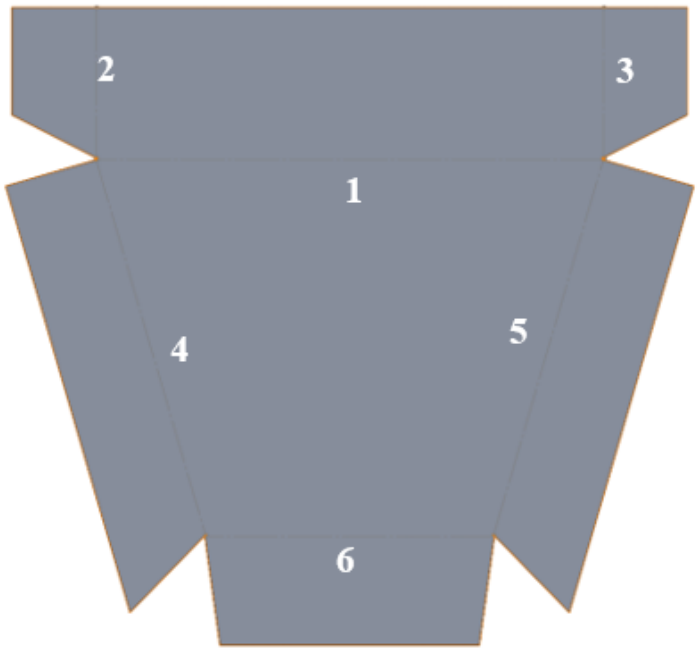

Figure 17: Flat Mold Pattern

Figure 18: The sheet metal brake to be used - note the sliding "fingers" on the top clamping surface

There are also several changes to the foam and aluminum inserts. The aluminum inserts are 60% larger in the 2023 design to allow for more tolerance when drilling the holes for the Dzus fasteners. This way, if the manufacturing does not exactly match the CAD model, then the hole placement has some room for adjustment to allow the firewall to fit without forcing. The top flange foam insert also does not have harness cut-outs anymore, as these were difficult to cut, and it will be easier just to Dremel through the foam along with the carbon fibre. Finally, the foam inserts will be chamfered at the edges to allow for the carbon fibre to transition better. By sanding the edges to a point, there will be less of a stress concentration at each edge of the foam, making a significant difference at the corners where it was possible for fibres to catch (Figure 19).

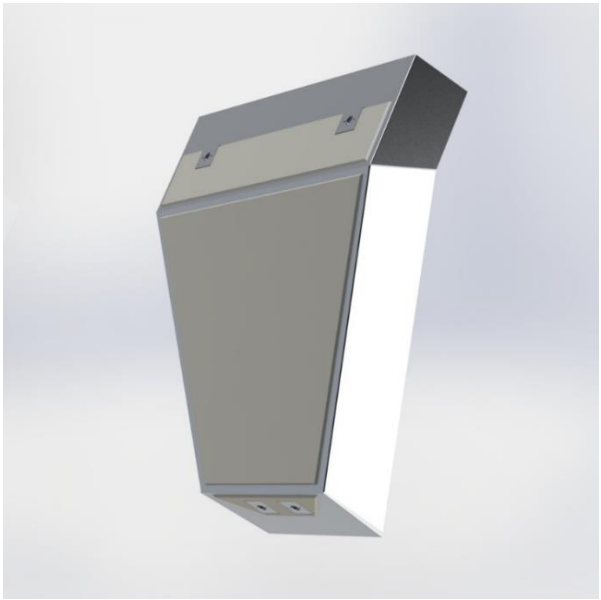

Figure 19: 2023 Foam and Aluminum Inserts on Firewall Mold

The expanding foam pieces will be made once the firewall is manufactured and installed in the car. The same foam of which the seats are made will be used to create the foam side pieces. The product is called FOAM-iT!™ [10], and it is a two-component mixture which expands into a rigid polyurethane foam. To start, a thick garbage bag will be placed in between the firewall side flanges and the aircraft fabric. The liquid components will be mixed, then poured into the bag to expand. Supporting material, such as wooden boards will be placed behind, and potentially in front of the firewall so that the foam expands upwards rather than outwards. The foam generates heat when curing, so this step may need to be done in multiple pours to avoid elevated temperatures. Once the foam has set, the firewall and garbage bag can be removed from the vehicle, and the garbage bag can be cut off of the foam. Any excess foam that extends beyond the front or rear of the firewall side flanges can be cut away. Thanks to the garbage bag, the foam will be removeable, which will be good for maintenance if the brake lines and electronics cables that typically pass beside the firewall need to be moved, inspected, and/or replaced. Because the foam is not rated for fire resistance on its own, it will need to be covered in the same carbon fibre and resin as the firewall. This will allow it to safely seal in the event of a fire, and the carbon fibre will also improve the aesthetic of the inserts, avoiding showing the pale yellow colour of the foam.

4.0 Conclusion

Several solutions were found to the problems encountered in 2022, and they have been implemented into the 2023 firewall design, while also taking into consideration other key factors (such as rule compliance). The main difference in firewall design between 2022 and 2023 is the larger side flanges which will help with sealing. These side flanges will seal against the expanding foam which will fill the space between the sides of the cockpit and the firewall flanges, to improve safety from last year while remaining easy to insert and remove. The upper firewall positioning and fastening will not change, but this year it will have a cut-out for the intake, and will be sealed to the intake with aluminum tape. Manufacturing will also be easier thanks to an improved mold that offers additional support for the carbon fibre, as well as larger aluminum inserts to allow for more error in the hole positions. Design B will be manufactured in October 2022, to be ready for testing and competition in 2023. After competition, the design will be evaluated once more, to determine further improvements for 2024.

References

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Appendix

Appendix A – FSAE Firewall Ruleset

T.1.8 Firewall(s)

T.1.8.1 Requirement

A Firewall(s) must separate the driver compartment and any portion of the Driver Harness from:

a. All components of the fuel supply, the engine oil, the liquid cooling systems, any lithium batteries

b. (EV only) All Tractive System components that are not subject to T.1.9.4

T.1.8.2 Construction

Any Firewall must:

a. Be a non-permeable surface made from a rigid, Nonflammable Material

b. Seal completely against the passage of fluids (the Firewall itself, edges, and Floor Closeout)

c. Be rigidly mounted

T.1.8.3 Positioning

The Firewall must extend sufficiently far upwards and/or rearwards and/or sideways where any point on the driver's body less than 100 mm above the bottom of the helmet of the tallest driver must not be in direct line of sight with any part mentioned in T.1.8.1 above

T.1.8.4 Details

a. Firewalls composed of multiple panels must overlap and be sealed at the joints. Sealing between firewalls must not be a stressed part of the Firewall

b. Grommets must be used to seal any pass through for wiring, cables, etc

c. Any seals or adhesives used with the Firewall must be rated for the application environment

T.1.8.5 (EV only) The Accumulator Container may be used as part of the Firewall if it meets these requirements.

The Firewall should be separate from the Accumulator Container. Rule T.1.8.5 may be removed at the next major revision to the Formula SAE Rules. [8]

Appendix B – 2023 Ergonomics Study

The 2023 ergonomics study used almost identical methodology to the 2022 ergonomics study. Six participants, ranging from a 6th percentile female to a 99th percentile male, were sat in a jig which allowed the back angle, steering position, steering angle, pedal position, and pedal angle to be adjusted. For a range of back angles, the ideal steering and pedal positions were determined, as well as the extreme viable

positions for the steering wheel (closest lowest, closest highest, furthest lowest, furthest highest). The final positions and angles of the mentioned components for the 2023 car were set by analyzing the collected data and determining the position closest to each participant's ideal location, while also being within each participant's viable position range. However, the final positions were slightly biased towards the ideal positions of larger participants because all the current drivers on the UWFM team are larger than a 50th percentile male. The results are summarized in Table 1:

Table 1: 2023 Ergonomics Study Results

Component	**Reference**	**Value**
Back Angle	Horizonal plane	55 degrees
Steering Wheel Angle	Horizonal plane	15 degrees
Steering Wheel Distance	Tailbone (bottom firewall bend)	308 mm
Steering Wheel Height	Tailbone (bottom firewall bend)	469 mm
Shoulder Harness Bar Height	Tailbone (bottom firewall bend)	441 mm
Pedal Face Plane Distance	Tailbone (bottom firewall bend)	1028 mm
Heel Cup Distance	Pedal Face Plane	65 mm

Note that although these were the ideal values, there were a few compromises that had to be made while integrating them into the vehicle, resulting in slightly different positions for some parts.

Appendix C – FSAE Shoulder Harness Rule

T.2.6 **Shoulder Harness**

T.2.6.1 From the driver's shoulders rearwards to the mounting point or structural guide, the Shoulder Belt Side View Angle must be between 10° above the horizontal and 20° below the horizontal. [8]

The 99th percentile male driver's shoulders were above the shoulder harness bar, which caused the shoulder harness angle to be more than 10° above the horizontal. To become rules-compliant, they had to slouch to lower their shoulders to an acceptable height. By raising the bar 22 mm, they will be able to sit straight, while the other drivers will still meet this rule. Shorter drivers would require a booster seat to meet this rule, and also to be able to see over the wheel when the wheel is turned 90°.