SAE23 Fibersim & Composites Manufacturing Report

Chassis/Fibersim

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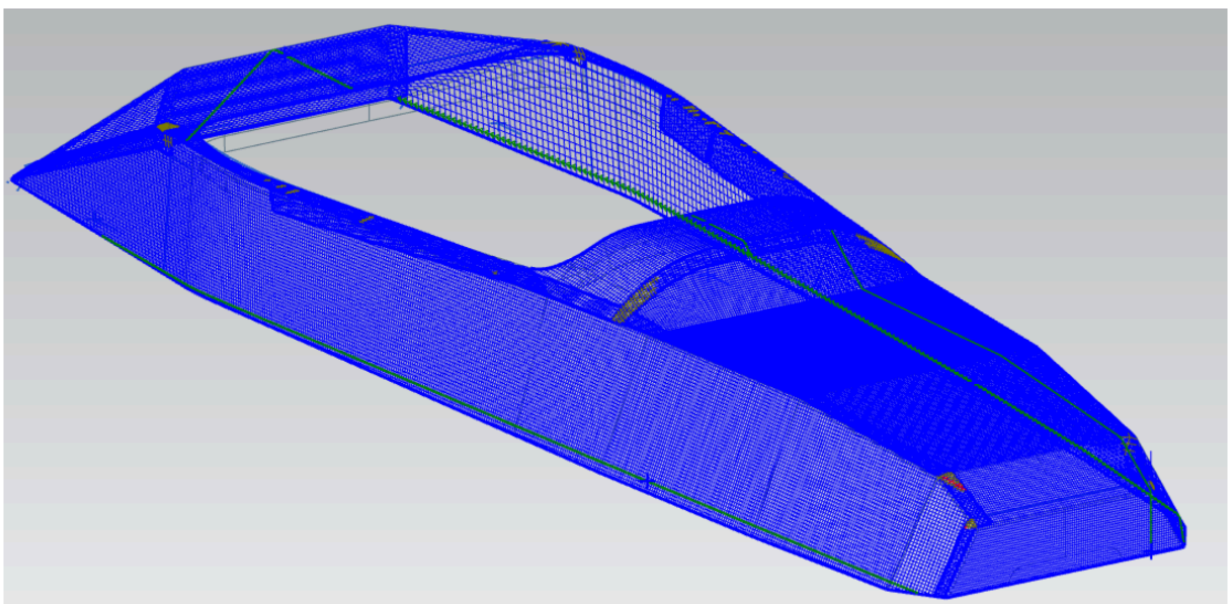
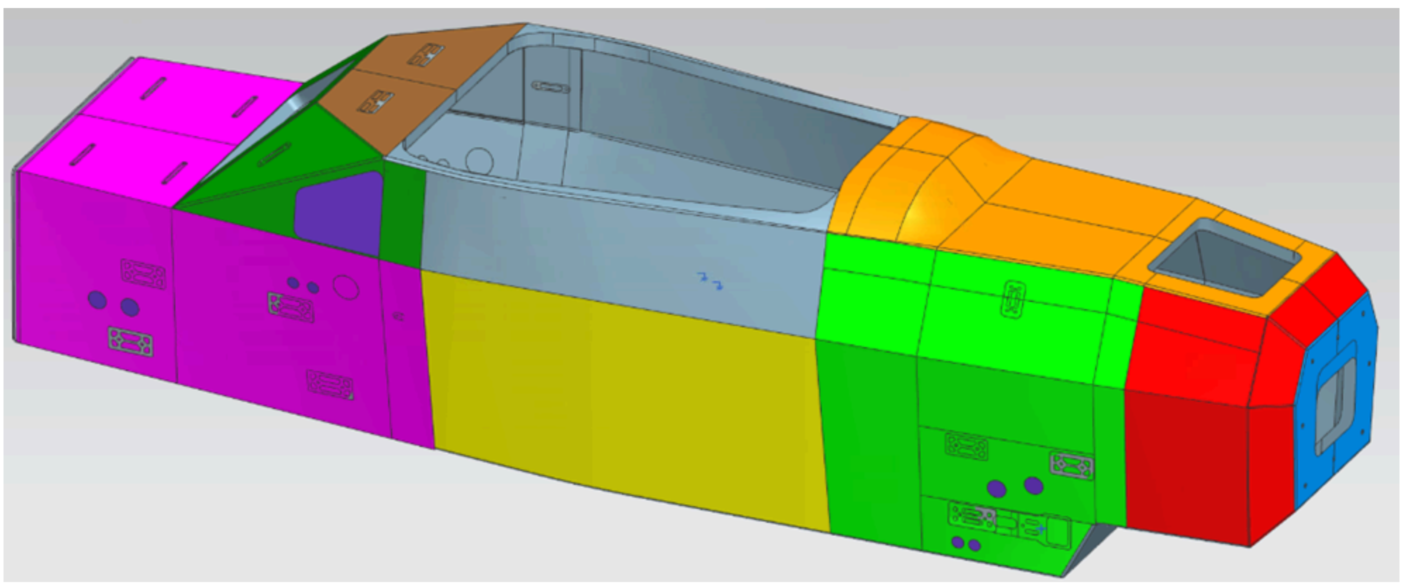


0. Abstract/Design Specification

The goal of this document is to provide a process description of how the carbon fiber monocoque is tested, designed and implemented. It will make comparisons from previous years and outline changes to the 2024 vehicle. It is highly recommended to follow the steps outlined in this report to ensure that proper operating procedures are being followed. This capstone project is not much of a design project- the SES team builds the layup schedule and the FiberSIM senior must execute as accurately as possible. On top of creating plies based on the Detailed Layup Schedule 2024, the primary deliverable for this project is: 1) finding methods to reduce the weight of the chassis, 2) creating reinforcement in component mounting locations, and 3) ensuring an easy lay-up process. This can be accomplished by reducing excessive ply overlaps, designing patches, and adding darting to avoid bridging/tearing. It is highly recommended that the 2025 senior use the 2024 FiberSIM model for their project, if possible. The model is well labeled and well-documented to ensure that the next capstone student can follow it. *Finally, the senior must ensure that during the Winter term, they have a light class load. The Manufacturing season can be very intense and it requires several long hours. The FiberSIM senior should be mentally prepared to handle the load of creating plies, exporting them, and then cutting them on the ply cutter- it is an intense process but the learning & satisfaction makes it all worth it!*



1. Project Description

1.1 Introduction

The Global Formula Race Team (GFR) creates two carbon fiber monocoque chassis per season. A Monocoque is a structural module where the outer and inner shell is fully load bearing. An effective shell for motorsport and Formula usually balances lightness, stiffness, and strength. The composite shell is made by cutting the material plies and laying them up; a ply represents a single piece of fabric in a laminate.

This procedure ensures a solid body without localized stress concentrations such as wrinkles, cracks, or holes. For this reason, the Fibersim software is used to find optimal ply patterns and simulate them in a ply lay-up. This software holds information detailing various types of plies, its material type, stackup order, and flat pattern. Using a 3D skeleton of the mold, the size and shape of each ply can be determined to align with the geometry of the chassis. The Structural Equivalency Spreadsheet (SES) uses the FSAE and FSG Rules to output design requirements needed to create the composite laminate of the carbon monocoque. The layup that is selected by the SES seniors will be simulated on Fibersim. A DXF File is then exported to PatternSmith to be cut using the Ply Cutter Machine [4] .

The primary deliverables for this project are to redesign necessary ply shapes, create the ply books, and to cut the upper and lower half plies for both chassis.

1.2 Requirements

1.2.2 Team & Subteam Requirements

The objective of this project is to create a Chassis for the GFR24 car that can win in competition. The Design Goals were outlined by the executive team and the 2024 team will be working to achieve these parameters. Firstly, the Chassis must meet all the stiffness and strength specifications while executing an efficient manufacturing process. Secondly, all critical components must perform at their designed function and there should be maximum access for maintenance and servicing. The team motto is to “validate simplicity, reliability, and simulation using Physical Testing”

The requirements of the subteam were outlined in the Group Charter. Each individual must keep an up-to-date calendar and use Google Chat for team communication. Additionally, to create a culture of teamwork and partnership, the group will use the class time to touch base and attend the weekend workshops together. Any issues or concerns will be openly discussed without delay. The team should understand that consistent dialogue is critical for the operation. By “expecting the unexpected” and “planning ahead”, the group can ensure a streamlined and cross-functional effort to build the Chassis. Finally, all members should complete their required training and maintain responsibility for their deliverables. The executive team and the GFR alumni are great resources that should be used to ensure improvement of the car from year-to-year.

1.2.3 Component Requirements

The Chassis is the skeleton of the car and must undergo design, simulation, testing, validation and manufacturing to prepare for the competition. The first action item is to create a plybook; this is a “lego-guide” to tell the manufacturers where the plies must go. The Fibersim software will create a composite layout and simulate how the plies should be shaped and laid up. The second action item is to create a layup schedule; this will allow the team to produce many global plies; the larger plies provide structural integrity so zonal plies can be added and ensure a more optimal composite structure. This will allow for quicker manufacturing time and less material usage. Additionally, less plies ensures a lighter vehicle which will help in the dynamic scoring events. The results from the Structural Equivalency Spreadsheet (SES) will tell how many plies are required in each zone to meet strength specifications. The PatternSmith 10.2 Forge Command can be used to check how the piles will nest into the carbon sheets. If the Chassis is completed early, more testing and validation can be executed to ensure a winning vehicle.

1.2.4 Customer and Rule Requirements

The customers are the judges in the competition, the other subteams, and the driver of the vehicle. The FSG and FSAE Rules are the proper guidelines that must be followed to gain points in the static and dynamic events. The other subteams rely on the effectiveness of Chassis manufacturing. The suspension group will not be able to move forward with their project until the chassis is complete. From here, the aero team will not be able to mount the rear and front wing until the suspension mechanism is complete. It is important to keep communication with other teams because it will affect how attachments are designed and the weak points on the vehicle. Finally, the driver relies on the Chassis to remain safe while driving the car. The vehicle must be able to make tight turns, brake effectively, and accelerate harder during the competition.

1.3 FSG & FSAE Relevant Rules

FSAE Rules (F - CHASSIS AND STRUCTURAL)

Section	Rule Set
F.1.1 Definition	The fabricated structural assembly that supports all functional vehicle systems. This assembly may be a single fabricated structure, multiple fabricated structures or a combination of composite and welded structures.
F.1.3 Definition	A type of Chassis where loads are supported by the external panels
F.2.1.2 SES	The SES provides the means to: a. Document the Primary Structure and show compliance with the Formula SAE Rules b. Determine Equivalence to Formula SAE Rules using an accepted basis
F.2.5 Fabrication	Vehicles must be fabricated in accordance with the design, materials, and processes described in the SES.
F.4.1.1 Composite	The SES must contain: Documentation of material type, (purchase receipt, shipping document or letter of donation) and the material properties.
F.4.1.2 Composite	The SES must contain: Details of the manufacturing technique and/or composite layup technique as well as the structural material used (examples - cloth type, weight, and resin type, number of layers, core material, and skin material if metal).
F.7.1.1 Monocoque	The Structural Equivalency Spreadsheet must show that the design is Equivalent to a welded frame in terms of energy dissipation, yield and ultimate strengths in bending, buckling and tension
F.7.1.3 Monocoque	Corners between panels used for structural equivalence must contain core
F.7.8.1 Attachments	Each attachment point between the monocoque or composite panels and the other Primary Structure must be able to carry a minimum load of 30 kN in any direction.

FSG Rules

Section	Rule Set
T2.1.1 General	The vehicle must be designed and fabricated in accordance with good engineering practices
T3.2.5 Materials Requirement	Any tubing with a wall thickness less than 1.2 mm or a minimum area moment of inertia less than 6695 mm4 is considered non-structural and will be ignored when assessing compliance to any rule regarding the vehicle structure.

T3.4.3 Composite Structures	For any laminate in the primary structure or the TSAC, the maximum weight content of parallel fibers, relative to the weight of all fibers in the laminate, is 50 %. All fibers laid within any orientation +/-10◦ count as parallel in this case.
T3.4.4 Composite Structures	If an asymmetrical lay-up is used in the primary structure, the thinner skin must have a thickness of at least 40 % of the thicker skin.

2. Current State Analysis and Benchmarking

2.1 Current State Analysis

The current state analysis will walk through each step of the Fibersim project. It will overview previous designs from other seniors and issues that were encountered during that stage. There have been several iterations of ply design and Chassis manufacturing, and this section will highlight these changes.

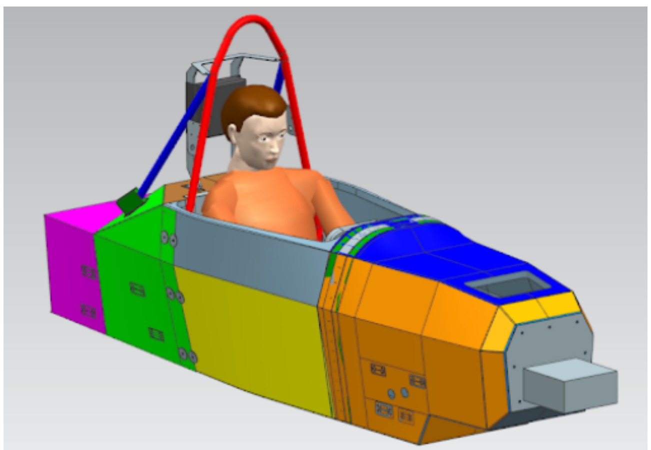


Fig. 1: Outer skin Chassis 2023

Fig. 2: Manufactured Chassis 2023

The FiberSIM tutorials are a great starting point for getting up to speed with the project. Once the Chassis skeleton is received, the user must first extract the layup faces and create a net boundary (using NX). The Chassis zones and overlaps can then be defined and from there a layup scheme can be created. Every zone should have a rosette defined for it; FiberSIM can then simulate the layup of the plies. There will be producibility issues during this stage, therefore the senior must then troubleshoot these problems. Finally, the plies can be exported to Patternsmith as DXF files to be cut on the plycutter.

In 2017, the introduction of the ply cutting machine was important because it automated the ply-cutting process, which was a significant time saver. Prior to this, the team would have to manually measure out and cut the plies from the composite rolls. The Forge function on PatternSmith was also a critical upgrade to the manufacturing process; this software simulates the ideal distribution of the cutting patterns to reduce material consumption. Prior to this function, the team would have to manually nest each ply. This would take hours of tinkering and modifications to ensure that each ply was fitted properly in the nesting window. When using the ply cutter, the team must ensure accountability for how it is being used. The Chassis plies take ~6 hours to cut therefore the machine must be turned off properly and re-homed each time it is used.

In 2018, the GFR team transitioned to the Zonal method for Fibersim simulation. Each zone of the car has different strength requirements, therefore the zonal method allows the team to create unique layups for each region; the strength requirements are determined using the Structural Equivalency Spreadsheet (SES). The SES document and the various testing give insight on the optimal layup design. The primary reason for using this method is because it provides design flexibility to make changes on certain plies or multiple plies. The 2023 vehicle will also utilize this method to create the ply design. Before Zonal is applied, the user must first create continuous faces and ensure unbroken boundary lines. For Fibersim to work, it is critical that there are continuous lines and surfaces. If this is not done properly, there will be gaps between individual plies (surface continuity issues), rather than ply overlaps. Garth Westcott suggested that the best way to ensure this is to iterate over several boundary types (until one works) and then extract them to create composite curves. After this step is done, the SES-defined zones can be inputted into FiberSIM and it will automatically create layers based on those zones.

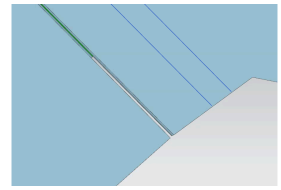


Fig. 3: Surface continuity issue

During composite manufacturing, the team utilizes global plies and smaller zonal plies. The globals provide foundational strength to the Chassis, and the zonal plies are meant to add strength to desired regions. The patches from the 2021 season were oversized to fit the overbuilt internal hardpoints; therefore, the patch overlaps used to protect the hardpoint zones will require more attention this season. The team will aim to create single overlaps for these zones. In general, patch overlaps help transfer loads between plies. If an overlap is too small the composite structure will break due to added stress concentrations, and if it is too large it will cause an increase in vehicle weight. This season, for patch simulation, the team will use the Manual Method; the zone is defined (by FiberSIM) for each patch and the user manually defines the orientation to establish where the ply boundaries are. Although this takes more time, it will ensure consistent patch sizes.

Once the ply modeling on FiberSIM is complete, the ply-book and layup schedule is created. The patch and ply layup schedules must be accurately tracked to ensure that a mistake is not made during the material layup stage. This is a primary goal for the FiberSIM senior and it should be completed by the fall term.

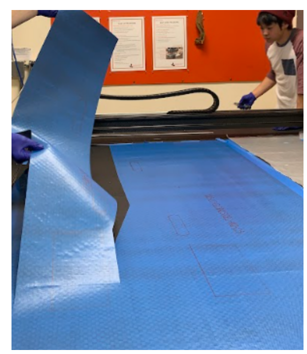


Fig. 4: Cutting plies

In winter term, the team will move towards Chassis manufacturing. In 2022, Joshua Ring selected the Teflon Wrapping Chassis (TWC) concept in Manufacturing. The main strength of this concept was that it eliminates the need for post-processing the Medium Density Fiberboard (MDF). Grace Anders pioneered this TWC concept which involves removing the film adhesive around insert areas and wrapping the insert in teflon tape. Wrapping the insert in teflon tape allows for the natural lubrication of the teflon to minimize the bonding to the carbon skin. This allows the MDF to be removed in a single piece after curing. Overall, this will eliminate the need for routing the MDF which will save time and tooling. The team will explore utilizing this concept for this season.

This TWC design was implemented on the Generation 2 chassis; the generation was first introduced in 2015 which utilizes flat panels on the chassis. This year, 2024, the team is using a Generation 3 chassis; this involves continuously twisting and curving panels on the body. Additionally, the Front roll hoop will be laminated directly into the inner skin of the chassis; this is better for aerodynamics and provides more space inside the body. If this is not done, the team would have to bolt the front roll hoop to the vehicle, which would require a full “single” ply across the entire laminate.

Fig. 5: Zonal Terms

Color	Zone
Orange	Front Bulkhead
Green	Main Hoop Brace
Pink	Tractice Rear
Blue	Global Front
Yellow	Side Impact side
Brown	Shoulder Harness (heaviest zone for FSAE rules)

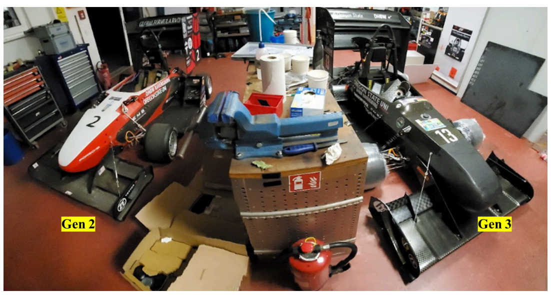


Fig. 6: Generation comparisons

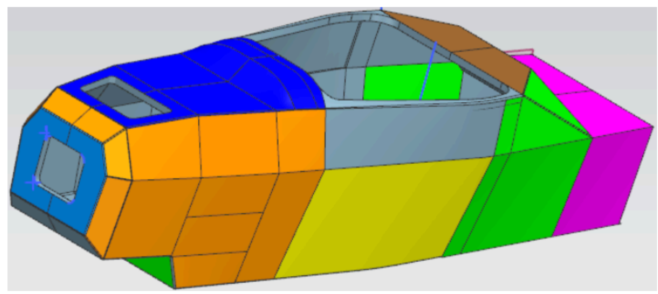


Fig. 7: Chassis Zones

SWOT Analysis

INDIVIDUAL	HELPFUL	HARMFUL
INTERNAL	→ There are several Fibersim tutorials posted that assist in getting up to speed. → The Composite Workshop is a useful activity to understand the project	→ The initial onboarding and the NX Tutorial took a bit longer therefore I was not able to start the Fibersim tutorial immediately. → GFR uses NX 12 which does not align with the University
EXTERNAL	→ Once I have gained comfort with Fibersim, I would lead workshops for underclassmen → Edit/Improve current tutorials → Amy Nigh is hosting a Fibersim workshop	→ Fibersim is a new software for me, therefore there will be a learning curve → The software compatibility issue (NX 12 vs. 1980) may pose as an issue for learning

SUBTEAM	HELPFUL	HARMFUL
INTERNAL	→ The GFR Alumni are still very active and could be a great resource → The previous Fibersim student is still on the team and can provide support → There are several internal tutorials to get started	→ Each member of the subteam relies on each other, therefore a bottleneck may occur → Software compatibility issue may affect what is possible on Fibersim
EXTERNAL	→ The Siemens Fibersim tutorial is a resource for fundamental concepts → Train other Chassis Team Members in the basics of Fibersim	→ The tutorials may not be enough for me to fully grasp the Fibersim software → The scope of the project will be changing so I must remain flexible

TEAM (GFR)	HELPFUL	HARMFUL
INTERNAL	→ The GFR Alumni are still very active and could be a great resource → There are several returning seniors that can share their experience with the project	The tutorials may not be enough for me to fully grasp the Fibersim software → The scope of the project will be changing so I must remain flexible
EXTERNAL	→ Train other GFR students in the basics of Fibersim → There are industry professionals who provide valuable insight on Composite Manufacturing	→ The competition rules are strict and the Fibersim model will affect the performance of the overall vehicle on race day → Competing universities may have more experienced Fibersim students

2.2 Benchmarking

The goal of this section is to provide a quantitative analysis of the steps required to design, simulate, and manufacture the Chassis. This is the largest component on the Formula vehicle and all other sub-teams will rely on it. For this reason, the manufacturing will require a hands-on effort from the Chassis seniors as well as support from undergraduate members. The primary modes of benchmarking are FiberSIM simulation time, manufacturing time, and material usage.

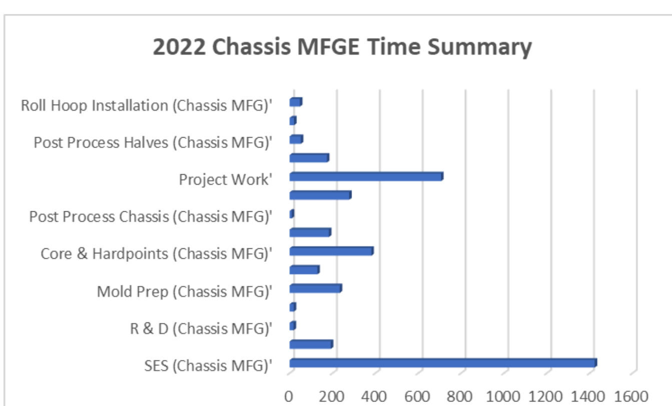
2.2.1 FiberSIM simulation time

The GFR team has done a great job creating extensive FiberSIM training tutorials. The successful completion of these tutorials will greatly impact how fast the simulation will take on the actual Chassis model. The FiberSIM Basics Tutorial is a great starting point and it can be completed in one sitting. From there, the Fibersim Intake Plenum & Steering Wheel Tutorials should be straightforward. After these 3 training sessions are concluded, it is recommended that the student explore the Full Chassis Tutorial, as well as other training stored on the drive. Week 1 and Week 2 of Fall Term should be used for project selection and background research. In Week 3, it is critical that a few FiberSIM tutorials are done each day; this will allow the student to be fully prepared.

2.2.2 Manufacturing time

With the use of the Plycutter, it takes approximately 300-400 hours to complete the manufacturing of the Chassis. By leading Composite Bootcamps and gathering the support of underclassmen, the team can ensure effective knowledge transfer which will allow for a smooth manufacturing process. The 2023 team did not do a great job tracking hours during manufacturing therefore there is no exact reference. However, in 2022, the team tracked hours ranging from the SES phase to Mold Preparation to Ply cutting to Post Processing. The detailed list can be seen below. The full list can be found here: [GFR 2022 MFGE Hours Total]

Fig. 8: MFGE Time



Simplicity and reliability through simulation validated by physical testing.

2.2.3 Material Usage & Vehicle Weight

The Material usage tracker is one of the most critical benchmarks for the Chassis. The Composite materials are extremely expensive and one Chassis is worth close to $10,000 of raw material. For this reason, it is important to create a materials tracker so the team has a strong understanding of how the resources are being used. The material usage also affects the weight of the vehicle. The weight of the car will affect speed, acceleration, aerodynamics, and competition points. The materials used from the 2023 season can be seen here: [Material Consumption 2023]

MATERIAL	ROLL ID (Labeled on bag)	DATE (cntrl+;)	LINEAR LENGTH USED (m)	DESCRIPTION	MATERIAL OUT-TIME (Hours)	METHOD
T700PW	GFR2022.A3	8/1/2022	5	Red car repair	3	Hand-cut
9696-030		8/2/2022	2.5	Red car repair	3	Hand-cut
9845		10/11/2022	0.5	SES		Hand-cut
HM63_PW/TC275	HM63PW-23-1	10/11/2022	2.4	SES	4	Hand-cut
HM63_UD/TC275	HM63UD-23-1	10/11/2022	0.5	SES	4	Hand-cut
HM63_PW/TC275		10/14/2022'	8	Transfer roll	6	Hand-cut
HM63_UD/TC275	HM63UD-23-1	10/14/2022'	10	Transfer roll	4	Hand-cut
HM63_PW/TC275	HM63PW Transfer 1	10/15/2022	1.2	SES	6	Hand-cut
HM63_UD/TC275	HM63UD Transfer 1	10/15/2022	adjacent length	SES	6	Hand-cut
9845	n/a	10/15/2022		SES	6	Hand-cut
9845	n/a	10/20/2022	0.5	SES	3	Hand-cut

Fig. 9: Materials Tracker

Weight of Chassis

Chassis	Weight [kg]
2023	~23
2022	23
2021	21
2020	21
2019	16
2018	16
2017	18.6
2016	19.3
2015	20

3. Design Analysis

The primary goal of this section is to discuss the Fibersim process for 2024 and zonal changes from 2023. Fibersim will be used to simulate the composite layup of the car by redesigning patches and plies; this will allow the team to effectively manufacture the Chassis.

3.1 Fibersim Order of Operations

1. Review the CAD model of the Chassis
   a. Amy Nye stated very clearly that a fully-defined CAD model of the Chassis will make using Fibersim much easier.
   b. When creating a ply shape for a specific zone of the car, 3 parameters must be specified: Laminate of entire body, Net Boundary of specific zone, Rosette of specific zone
2. Review the layup schedule
   a. The SES team creates the layup schedule and it is important to have a strong understanding of the optimal order of ply creation. The schedule will have separate tabs for lower outer/inner & upper outer/inner. Additionally, identify zones and overlap parameters between zones.
3. Specify the laminate for the entire body
   a. This is done by defining the layup surface and the overall net boundary [5] (Figure 10).
   b. Figure 11 below shows the defined laminate for the lower half of the vehicle. The layup surface is the entire body of the mold, and the net boundary is highlighted in green.

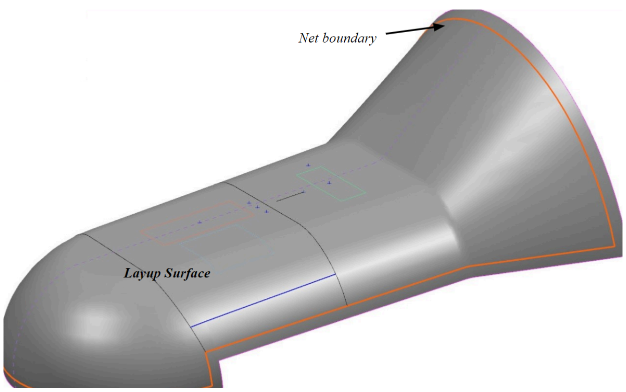


Fig. 10: Example of defining laminate

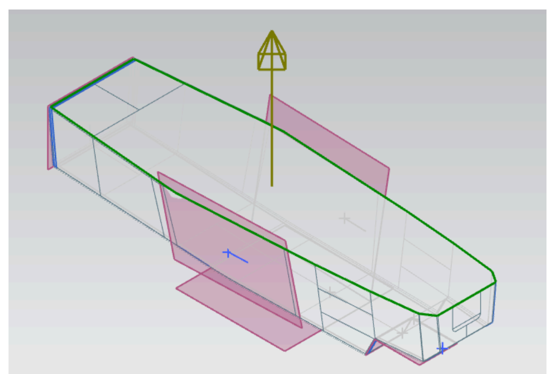
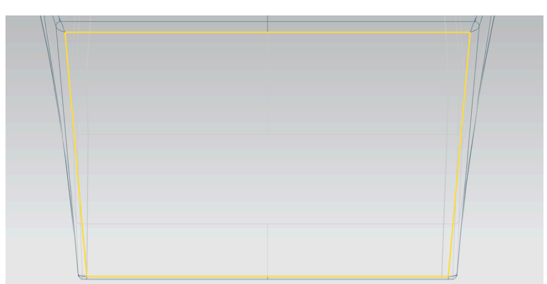


Fig. 11: Laminate defined for lower half

4. Create a net boundary for a specific zone
   a. The laminate for the entire car has now been created. Now, the Net Boundary of the specific zone must be created. Select a zone that you would like to make a ply shape for and create composite curves around its boundary.
   b. The CAD model provided has existing curves that outline each zone. By creating a composite curve, you are specifying the net boundary. The ply will be created within this region.
   c. The image below shows a composite curve created around the tractive rear zone of the car



5. Create overlap region
    a. Each zone of the car should have plies overlapping. In order to do this, use the Offset in Face function to specify an offset from the composite curve.

    b. The image below shows a curve that is set 0.5 inches offset from the Composite Curve.

Fig. 13: Offset curve around Tractive Rear Zone

6. Create Rosette
    a. The rosette is a measuring tool to define fiber orientations on the composite part; it acts as a datum for the ply.
    b. The rosette is defined using a point and a line. It should be created on the face of the zone. During chassis manufacturing, the first ply is laid up based on the location of the rosette that was defined. For this reason, it should be placed in a convenient location.

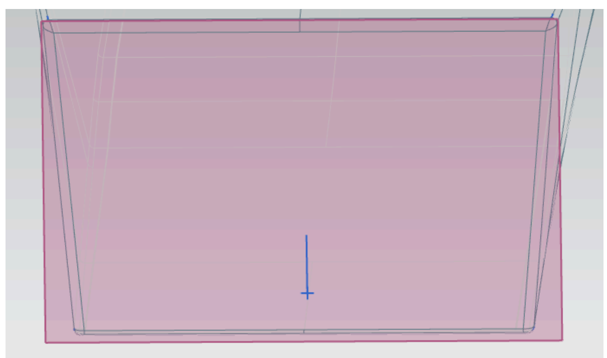


Fig. 14: Rosette defined on Tractive Rear

7. Create ply simulation
    a. Open fibersim and specify the laminate, the rosette, and the ply

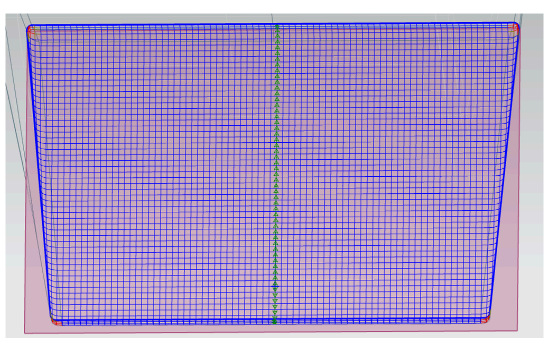
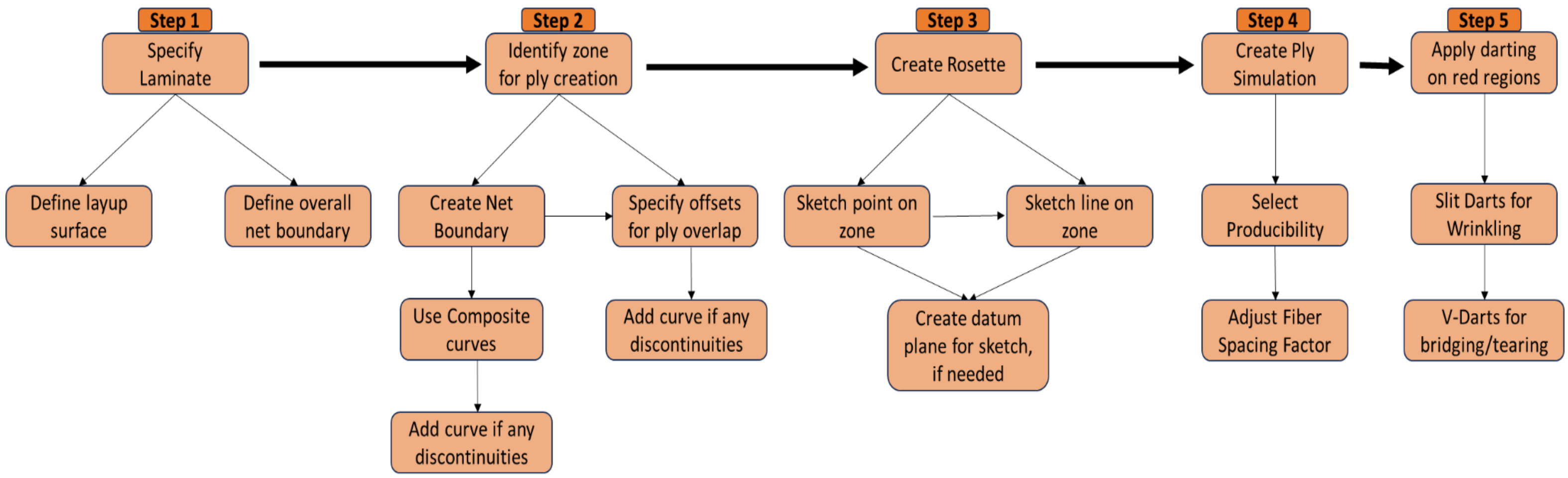


Fig. 15: Producibility for Tractive Rear

8. Apply darting
    a. The red regions (in the corners) indicate producibility issues. Darting can be used to resolve this
9. Create the ply book for use during layup and competition
10. Export flat-patterns as DXF files and import them into patternsmith
11. In patternsmith (and using NestFab), nest the plies and save the tables for future use
12. Use the ply cutter to cut out the plies
    a. [5]



3.2 Discontinuities and Overlaps

The CAD model will influence the effectiveness of Fibersim. When defining a net boundary around a zone, it is common to have disconnected lines. For this reason, it is important to review each line around the zone and ensure that they are all connecting. If they are not connecting (discontinuous), then the Curve on Surface tool can be used to add a line. The image below (circled in red) shows a gap between two lines in the tractive rear zone. When selecting your composite curves, the yellow arrow indicates that there is a gap between lines.

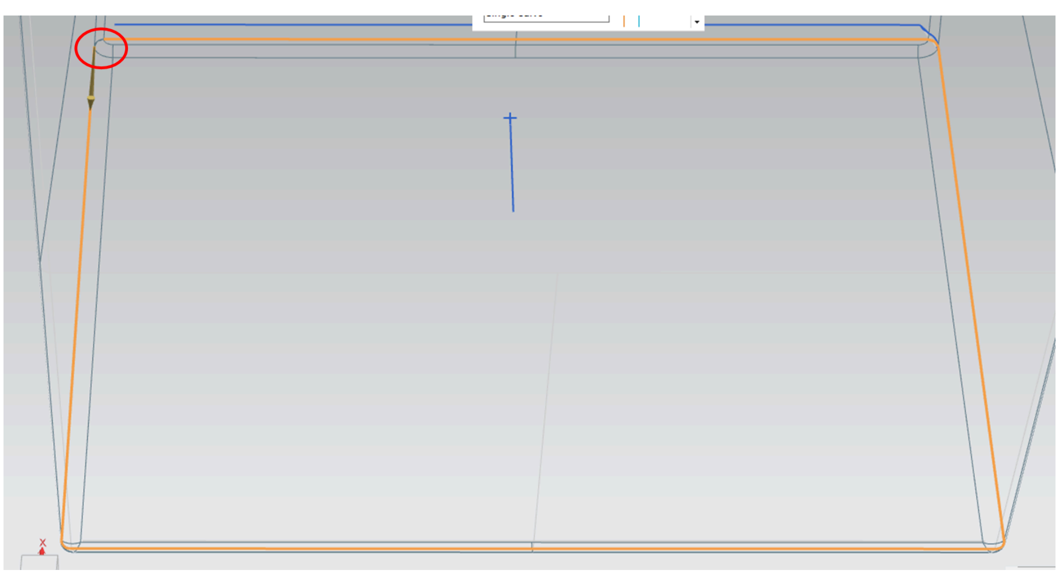


Fig. 17: Discontinuity in Net Boundary

The net boundary should be fully continuous. If it is not, Fibersim will not recognize the region and it will not be able to create the ply simulation. In order to correct the discontinuity, insert a Curve on Surface to fill in the disconnecting lines. It is common for there to be multiple occurrences of discontinuity in each zone therefore you may have to repeat this process multiple times.

In previous years, excessive overlaps between zones have been an issue. It is important to specify the correct ply overlaps to ensure excess material is not being used.

Material	Offset Amount
Sigmatex	½ inch (O2)
T700 PW & Kevlar	¾ inch (O3)
Unidirectional Materials	½ inch (when possible)

b. [3] *Fig. 17: Overlap spec from* Garth Westcott Report

Figure 18 below shows the overlap region for Tractive Rear and Non-Regulated Front. Now that the overlap has been specified, all other ply layers in this region should remain consistent. The goal for this year is to avoid double overlaps between regions. During Chassis manufacturing, the NR-Front ply will be laid up first and then the Tractive Rear will be laid up with the overlap. The Fibersim senior can decide which plies are overlapping in each zone; however, this should be discussed closely with the Manufacturing team to ensure the overlap selected is most convenient.

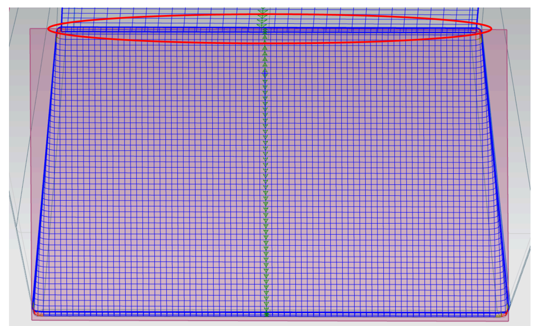


Fig. 18: Example of O2 ply Overlap

3.3 Darting Techniques

3.3.1 Fibersim deformation Warnings

After the producibility simulation is executed, darting techniques must be used to eliminate wrinkling or bridging/tearing conditions in the ply. These defects occur because the composite fabric materials will deform to maintain contact with the surface. Fibersim Material warnings are parameters to define how drapable a material is. The Angle Warning determines where the simulated fibers transition from blue (low deformation) to yellow (higher, but acceptable, deformation).The Limit Angle Warning defines where the fibers turn red (out-of-tolerance fiber deformation). If deformation exceeds the user-specified Limit Angle of the material, then deformation will occur. This is considered to be due to either wrinkling or bridging out of the materials tolerance. The Material width is Exceeded error indicates that the roll width of the actual material used in the ply is not enough to cover the entire ply area; the ply will therefore need to be spliced into two or more separate plies.The *Splice Function* splits a ply into A and B plies that can then be separated for nesting and cutting then joined back together during layup [5].

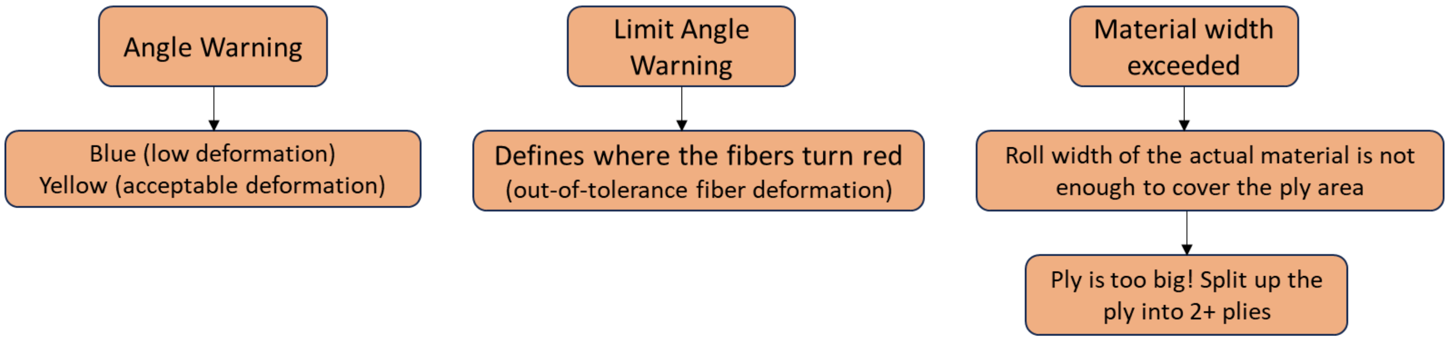


Fig. 18: Common Fibersim warnings

3.3.2 V-Darts & Slit Darts

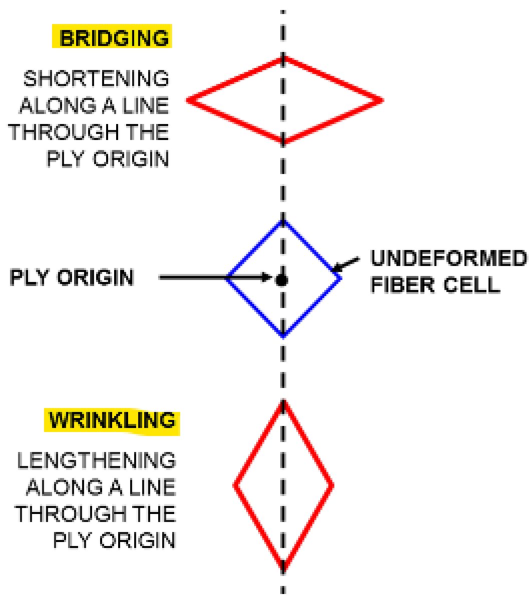


Fig. 18: Determining Deformation Type (Wrinkling vs. Bridge/Tear)

Wrinkling is defined as excess material in a given region of the surface ("out-of-plane" deformation). This can be identified if red fiber cells are elongating along a line drawn through the ply origin. Bridging or tearing is defined as a lack of material in a given region of the surface ("in-plane" deformation). This can be identified if red fiber cells are contracting along a line drawn through the ply origin. The fundamental cause of bridging is due to material being stretched to the point where the angles between the fibers lock; as a result, the material is no longer physically able to drape over the surface. [6]

<u>Instructions for creating Slit Dart (Wrinkling):</u> [5]

1. Area of red or wrinkled fibers is identified
2. The two fibers that border the red fiber region must be located
3. These are the fibers that point back toward the Ply origin
4. The location where these two curves intersect indicates the location of the fibers that must be cut
    a. Often, these fibers are not red fibers, and can be some distance from the area of red or wrinkled fibers
5. Determine the path of the dart over the layup surface
    a. Optimal path starts at the initial fibers that must be cut, and passes through the center of the red wrinkled region, to the edge of the Ply boundary

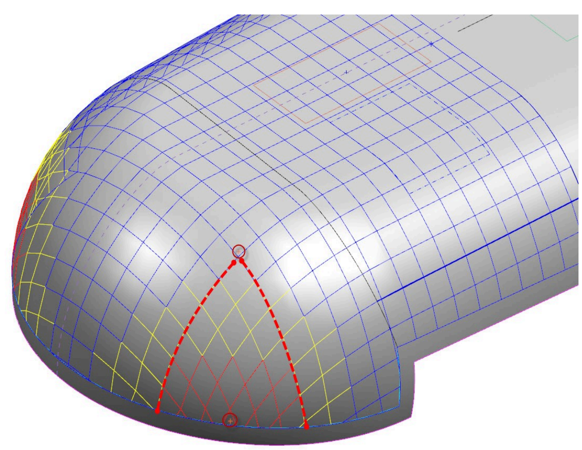


Fig. 19: Example of Wrinkling

Instructions for creating V-Dart (bridge/tear): [5]

1. Define two curves that start at a single point ("top" of the dart)
2. Spread out and stop at different locations along the boundary.
3. The region of the ply that is deforming out-of-tolerance for that material (the red fiber cells) is bounded by these two v-dart curves
4. **After V-dart is inputted → Two plies must be created**
    a. Original ply with V-shaped dart
    b. Patch ply to fill in the V-shaped gap on the tool

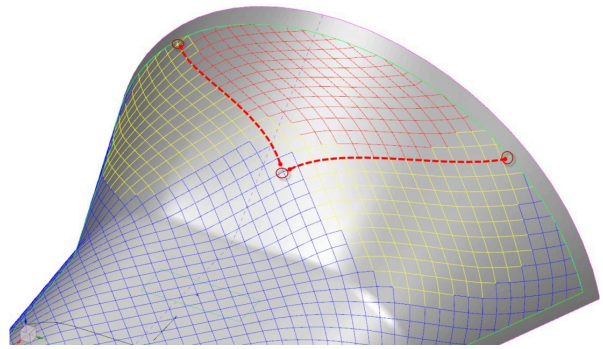


Fig. 20: Example of Bridge/Tear

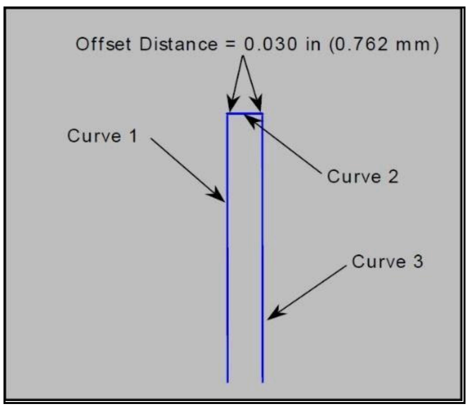


Fig. 20: Slit-Dart (Bridge/Tear)

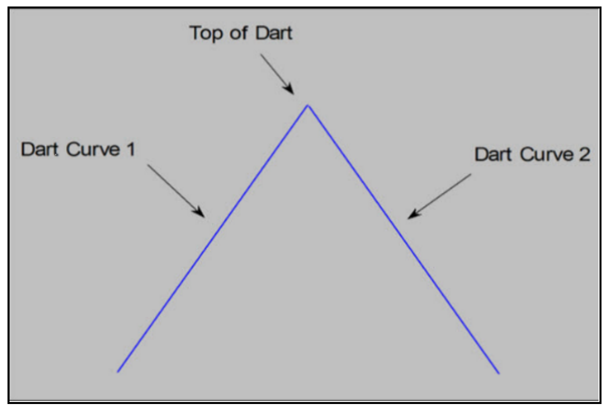


Fig. 21: V-Dart Creation(Wrinkle)

NOTE [5]

Placing a slit dart in a region of bridge/tear allows more material to enter the region

□ this extra material forms an overlap that would be impossible to cut

□ **slit-darting will not work in regions of bridging or tearing**

3.4 Overview of Patches

As stated earlier, an effective shell balances lightness, stiffness, and strength. Every sub-team relies on the Chassis for component mounting. However, in these regions of mounting, there will be localized stress concentrations. When external forces are applied to the chassis walls, these stresses can lead to damage to the structure. For this reason, hardpoints and patches are utilized to provide extra reinforcement. A hardpoint is an object that is installed during Chassis manufacturing; it is a solid material within the panel to absorb higher loadings that the panel itself cannot handle.

rough simulation validated

Fig. 21: Example of Hardpoint

Fig. 21: Example of Hardpoints during manufacturing

When a hardpoint is added to the structure, the stress can be distributed and carried throughout the hardpoint. This allows the chassis walls to carry even higher loads than before (without worry of the structure being damaged) [7]. Patches are small sized plies (simulated on Fibersim) that encompass the specific hardpoint. For example, this year, the team will need to change the Front Suspension (lower half) patch. In 2023, the team created 3 small patches for each of the 4 hardpoints and then one large patch on top of them. The GFR 2024 vehicle will just have one large patch that encompasses the entire zone (in purple).

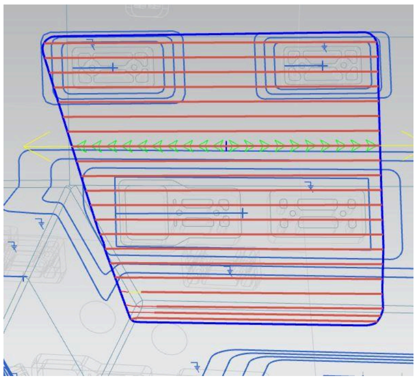


Fig. 22: GFR 23 Patch

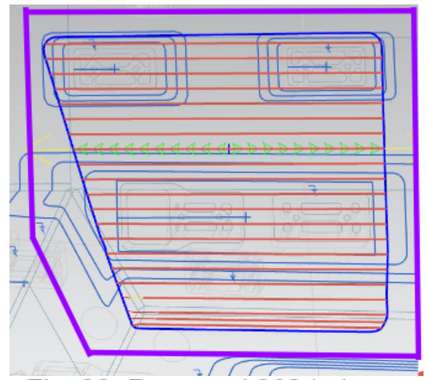
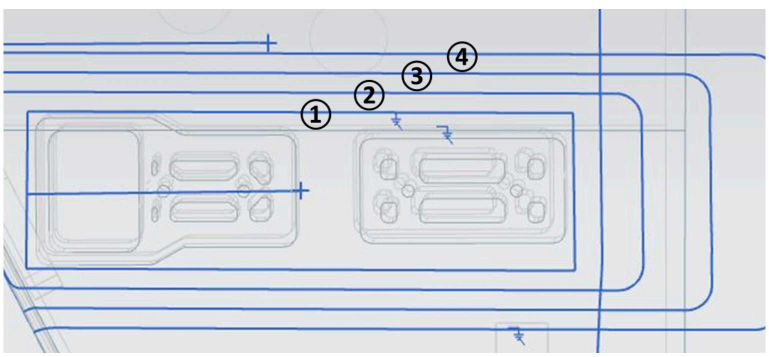


Fig. 23: Proposed 2024 change

Patches are created using the *Offset Curve in Face* function.



①: Composite Curve created around hardpoint

②: Offset Curve from Composite Curve

③: Offset Curve

④: Offset Curve

Fig. 23: Example of patch around hardpoint

3.5 Plybook Creation

The SES team creates a layup schedule to specify the types of plies and patches needed for each zone of the car. Once this is created, the Fibersim senior uses it as instructions to simulate the plies on the Chassis CAD model. While doing the Fibersim, a plybook is created for the lower half and upper half of the car. The goal of the plybook is to provide a visual guide to display the correct position and orientation of each ply that goes onto the chassis [4] . It will display how each zone of the car will have its respective patches, plies, and darting.

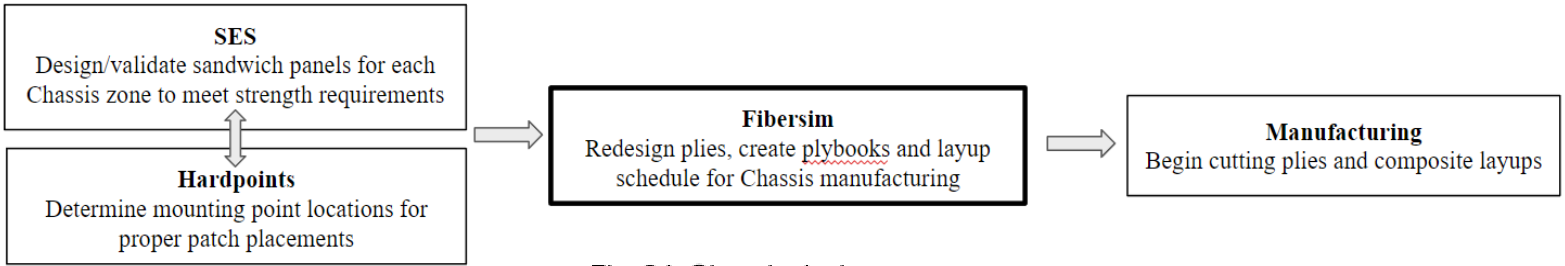


Fig. 24: Chassis design process

Fibersim provides a ply book generation feature. However, GFR has not used it because it does not provide information that is important during Chassis layup. For this reason,the team will continue to make the plybooks on powerpoints. Each ply or patch will have a single slide that shows a name, a layer, an orientation, a location, a quantity, and a picture.

Ply	202-SIS_L-Y0-O2
Layer	2
Material	Y
Orientation	0°

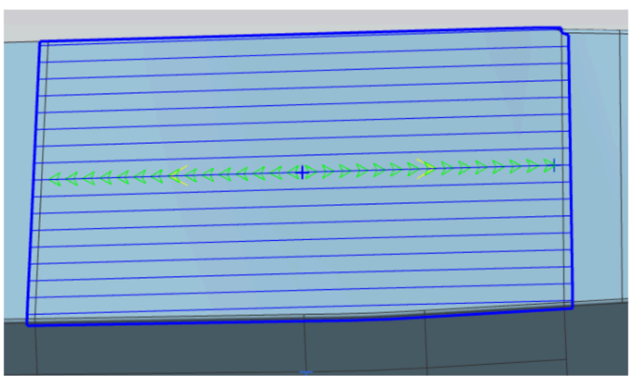


Fig. 25: Example of Front suspension Ply on Lower Half 2023

Patch	FUF_A45p3
Location	Front suspension
Quantity	2

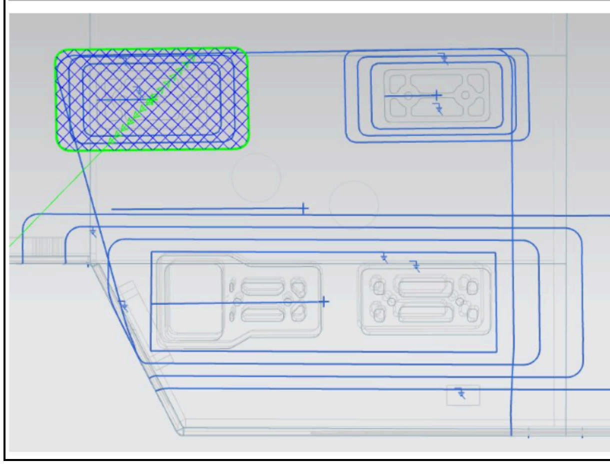
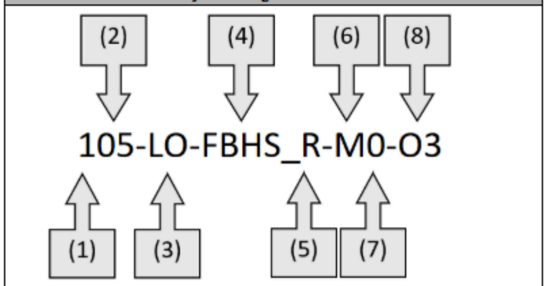


Fig. 26: Example of Front suspension patch on Lower Half 2023

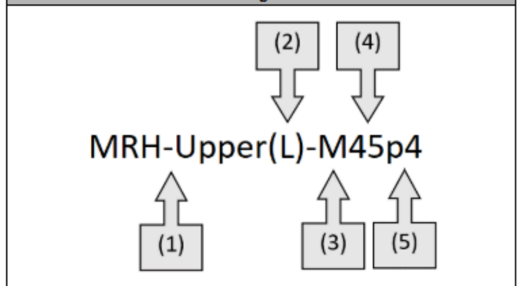
The naming convention is critical because it helps the team keep track of the various patches and plies. During Chassis manufacturing, there are several people referring to the layup schedule and the plybook to correctly layup the car. For this reason, a standard naming convention is utilized. The template is provided below, from [4].

Ply Naming Convention



(1)	**Layer number**
(2)	**Step number**
(3)	**Mold half and skin designation**
	UO = Upper Half, Outer Skin
	UI = Upper Half, Inner Skin
	LO = Lower Half, Outer Skin
	LI = Lower Half, Inner Skin
(4)	**Chassis zone(s) covered by ply**
(5)	**Ply location**
	(L) = Driver's left
	(R) = Driver's right
	(T) = Top (Upper half only)
	(B) = Bot (Lower half only)
(6)	**Ply material**
	M = T700/2511 PW
	Z = T700/Dry ST
	C = T700/2510 UD
	G = T800/2511 UD
	I = Kevlar/TC275-1 4H
(7)	**Ply fiber orientation angle**
(8)	**Offset type**

Patch Naming Convention



(1)	**Hardpoint/location name**
(2)	**Patch location**
	(L) = Driver's left
	(R) = Driver's right
	(T) = Top (Upper half only)
	(B) = Bot (Lower half only)
(3)	**Patch material**
(4)	**Patch fiber orientation angle**
(5)	**Patch size**
	p1 = 1.25x of hardpoint length and width dimensions
	p2 = 1.50x
	p3 = 1.75x
	p4 = 2.00x
	p5 = 2.25x

Fig. 27: Ply Identification Template

3.6 Exporting to Patternsmith

After plies are created on Fibersim, they are exported (on NX) to a 2D Flat pattern layout. This flat pattern layout is what the ply cutter uses to cut plies. The Flat Pattern layout on NX is a .DXF file. The ply cutter (located in Graf Hall) is controlled by a single computer inside Graf.This computer is not connected to the internet. For this reason, the .DXF files must be saved on your computer (using naming convention), and then exported using a USB. The USB should then be plugged into the Graf Computer to be loaded into the ply cutting software.

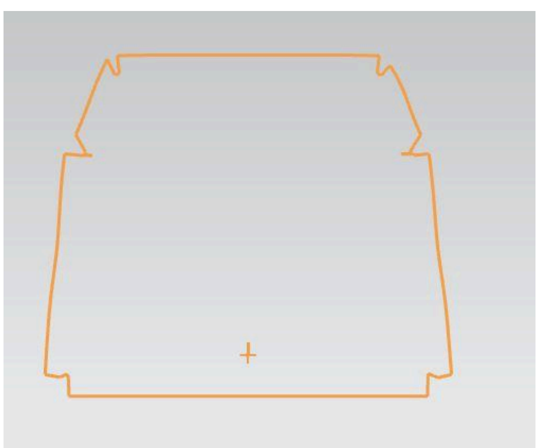


Fig. 28: Example of Flat Pattern (NR-Front)

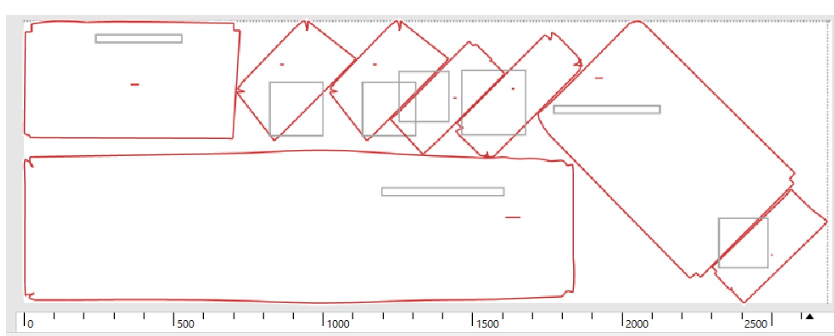


Fig. 28: Example of PatternSmith nesting

Simplicity and reliability through simulation validated by physical testing.

The ply cutting software is known as Patternsmith; it is a nesting software that is used to communicate with the ply cutter. The ply cutter table has dimensions of 1.2 x 3 meters. The Patternsmith software allows the user to manually shift around the location of the flat patterns to allow for efficient ply cutting. Nestfab is an add-on to Patternsmith that automatically nests flat patterns without any user intervention. Without this, the user has to manually move around flat patterns on Patternsmith to create optimal orientations- this is very time consuming. A detailed ply cutter data management system is shown below [4].

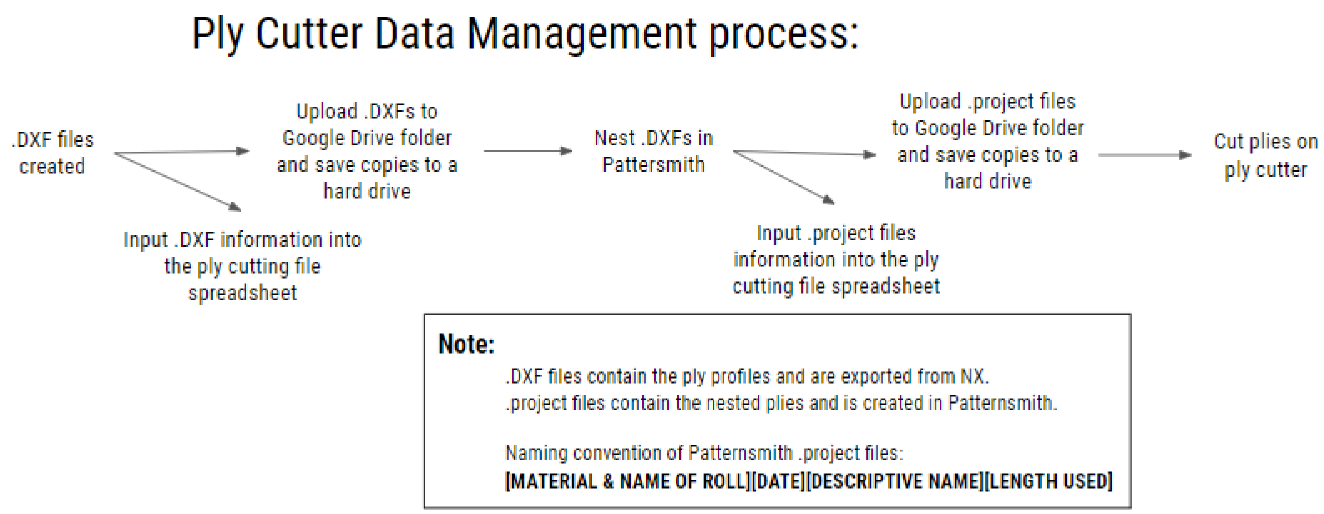
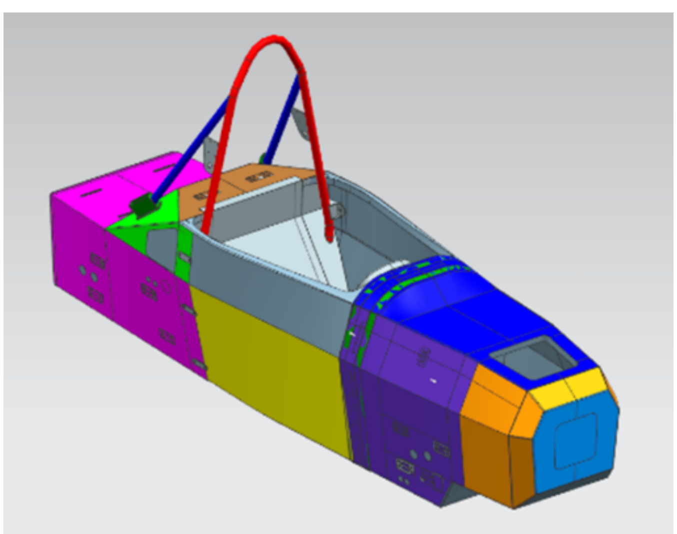


Fig. 28: Process flow for ply cutter

4. Design Selected

The GFR24 vehicle uses the same geometry as GFR23. For this reason, the same mold can be used during chassis layup. However, the SES team did make zonal and structural changes to the design of the car. This caused slight changes in the ply and patch analysis on Fibersim. The upper portion of the vehicle will have minimal modifications in Fibersim, however it is expected that the lower half will take much longer because of new patches and excessive overlapping from the 2023 design.



Zone Color	Acronym
Front Bulkhead	FBH
Front Bulkhead Support	FBHS
Front Suspension Inserts	FBHS Rear
Front Hoop Bracing	FHB
Side Impact Side	SIS
Side Impact Floor	SIF
Main Hoop Brace Support	MHBS
ACC/Tractive Side	ACC/TS
Rear Impact Protection	
Shoulder Harness	SH
Non-Regulated-Floor and NR MHBS	NR
Non-Regulated SIS	NR
Lap Belt Attachment	

Fig. 30: GFR24 Zonal Breakdown

The primary change is the insertion of a new zone for the Front suspension inserts. In the previous year, this purple zone was entirely part of Front Bulkhead Support (FBHS). However the team chose to make this region two plies thicker to add strength for the suspension attachments.

Zone Color	Acronym	Outer Skin Layup	Inner Skin Layup
Front Bulkhead	FBH	[A0/A45/C0/A45/A0/A45/C0/A45/A0]	[A0/C0/A45/A45/C0/A0]
Front Bulkhead Support	FBHS	A0/C0/A45/A0	A0/A45/C0/A0
Front Suspension Inserts	FBHS Rear	A0/C0/A45/A45/C0/A0	A0/A45/C0/A0
Front Hoop Bracing	FHB	A0/C0/A45/A45/C0/A0	A0/A45/C0/A0
Side Impact Side	SIS	[A0/A45/C0/A45/A0/A45/C0/A45/A0]	[A0/C0/A45/A45/C0/A0]
Side Impact Floor	SIF	A0/A45/A0	A0/A45/A0
Main Hoop Brace Support	MHBS	A0/C0/A45/A0	A0/A45/C0/A0
ACC/Tractive Side	ACC/TS	A0/C0/A45/A45/C0/A0	A0/A45/C0/A0
Tractive Rear	TR	A0/C0/A45/A45/C0/A0	A0/A45/C0/A0
Rear Impact Protection		A0/C0/A45/A45/C0/A0	A0/A45/C0/A0
Shoulder Harness	SH	[A0/A45/C0/A45/A0/A45/C0/A45/A0]	[A0/C0/A45/A45/C0/A0]
Non-Regulated-Floor and NR MHBS	NR	A0/A45/A0	A0/A45/A0
Non-Regulated SIS	NR	A0/A45/A0	A0/A45/A0
Lap Belt Attachment		[A0/C0/A45/A45/C0/A0]	[A0/A45/C0/A45/A0/A45/C0/A45/A0]

Fig. 31: GFR24 Detailed Layup

4.1 Ply changes

Zone	Impact
Front Bulkhead (FBH)	• No front opening (better for SES - increased panel height → laminate could get thinner)
Main Hoop Brace Support (MHBS)	• Side wing mounting will change based on loading requirements
Tractive Rear (TR)	• Plate mounting is changing → Patch locations will change at Carbon plate (rear impact)
Shoulder Harness (SH)	• Two points (shoulder harness) mounting is changing → New patches/plies
Regulated Floor & Non-Regulated (NR) Non-Regulated SIS (NR)	• SIS-NR will change → Adding plies for torsional reinforcement and aero mounting
Front Bulkhead Support (FBHS)	• Front wing patches have hardpoints • Improved patches in suspension zones → create one larger patch for improved load transfer
Front Suspension Inserts	• Hardpoint changes due to (potential) movement of damper • Lower A-arm hardpoint change in shape

Side Impact Floor (SIF) (*zone change*) MRH to FRH	● Sectioning up SIF zone, adding reinforcement at harness attachment points (decrease laminate thickness) ○ Maintain support around lap belt connections ● Adding patches to 4 points shoulder harness (lap belt, lap anti-sub)

The table above details the key changes to each zone of the GFR24 vehicle. In 2023, a hole was inserted into the Front Bulkhead zone during post-processing. The reason for this is because the hole provided better accessibility to the pedal box area (it is very difficult to access that zone through the top opening). However this year the team found it effective to remove this front opening because it would improve Structural Equivalency values.

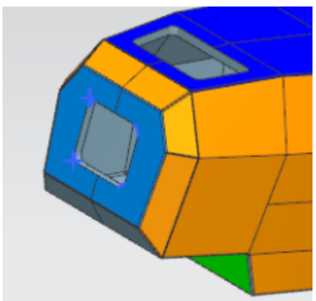


Fig. 32: GFR23 FBH

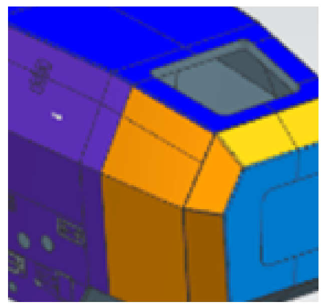


Fig. 33: GFR24 FBH

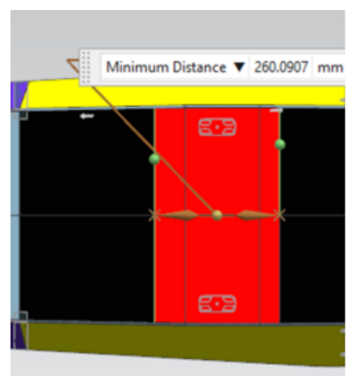
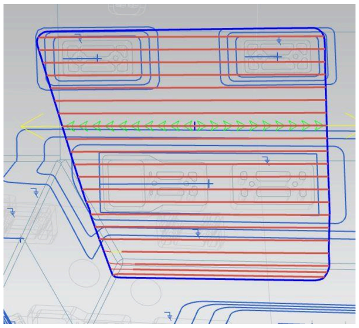
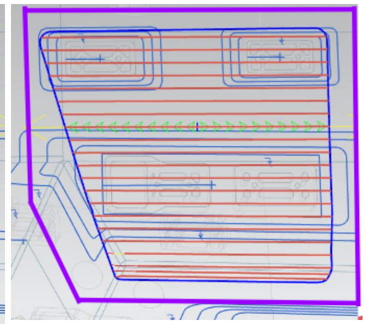
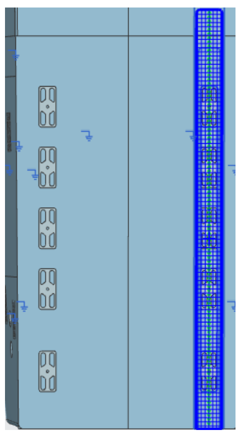
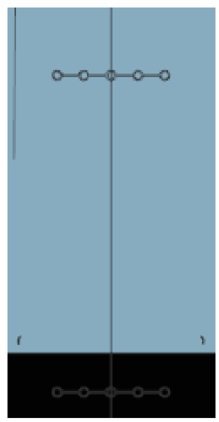
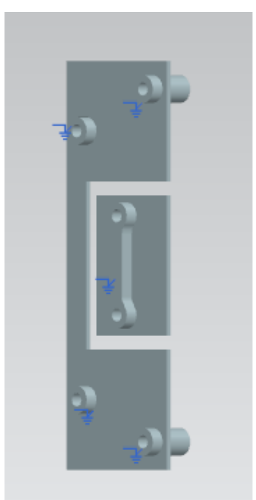


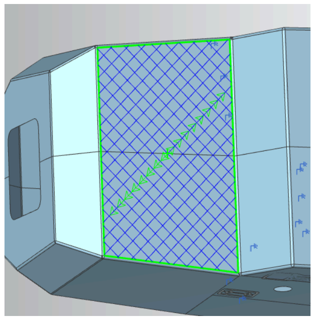
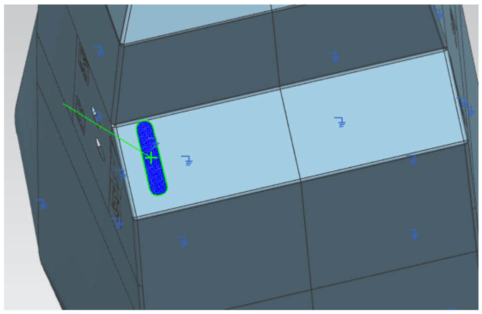
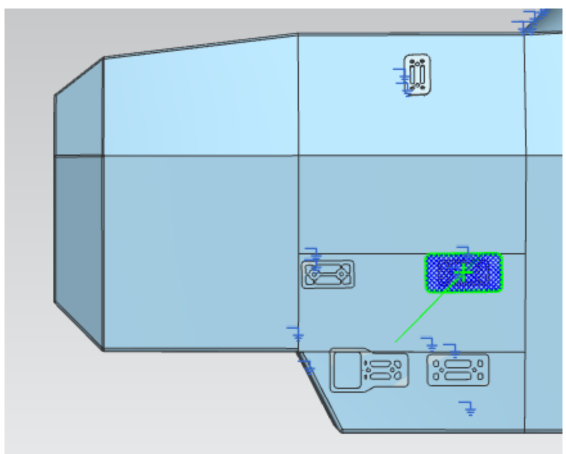
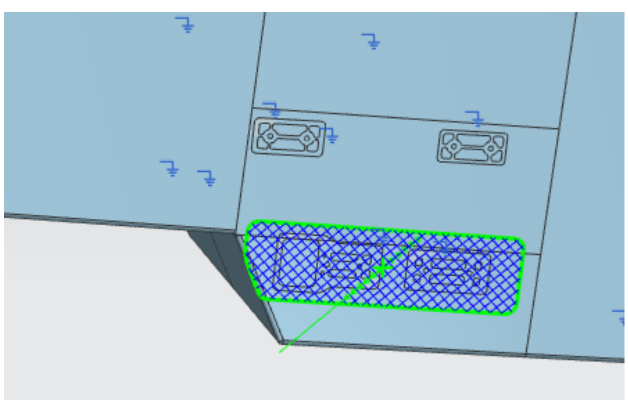
Fig. 34: SIF Zonal change

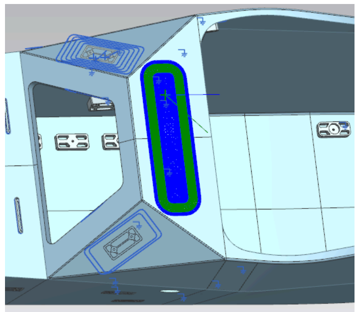
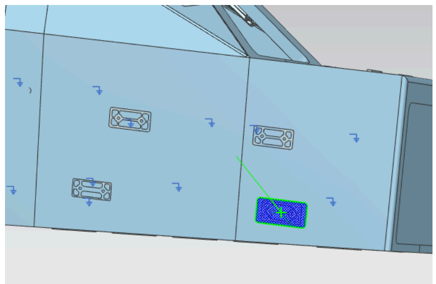
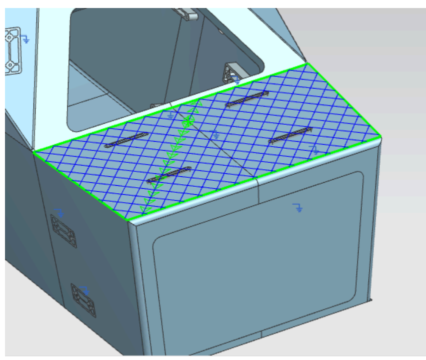
In the Tractive Rear zone, the team will be removing the brackets that were mounted there last year. There were many brackets which were unnecessary and heavy. As a result, the rear plate will be bolted flush to the rear face of the Chassis (no brackets necessary). Another significant change is in the Side Impact Floor (SIF) zone. The team has chosen to make the laminate thicker for improved loading. According to the rules, the SIF must be between the roll hoops; the team found that they could reduce the material in this region, pass SES, and reduce overall Chassis weight. The geometry of this zone can be seen in the image on the left. The Side Impact Side-NR Zone will also have some modifications. The team will be adding plies to provide torsional reinforcement and strength for aero mounting. Figure 31 provides a detailed explanation of all zonal changes. It is recommended that a similar table is made for the GFR25 vehicle. This allows for improved tracking from year to year.

Fig. 31: Ply Modifications on GFR24

4.2 Patch changes

Critical Patch change	Diagram	Notes
Front Suspension (lower half)	  **GFR 23** **Proposed Change**	- GFR23 had smaller patches around each region - GFR24 will have one large "zonal patch" - More Unimaterial for some patches ⟶ Fibersim challenge
Battery Container	  **GFR 23** **Proposed Change**	- Mounting of battery container is changing - Patches will just be strips - Team was considering using corner or circular patches
Steering patch	 **GFR23**	- Steering mounting is changing ⟶ Will need to change the patch - Last year the patch was only around the steering mount - This year we will do it around entire collection) – GFR24 (proposed change) image is pending

Pedal patch		- Does not change - It is going to remain as a zonal patch
Steering Rack Pillow patch		- This might slightly move in location - The Fibersim senior should be prepared to change just in case
Steering column support patch		- Changing because hardpoint is changing - Not a highly loaded region (keep standard offsets)
Lap Belt (Anti-sub)		- Patch is moving because lap belts are moving - Shifting lap belt back a little because we need to change the belt angle (to fit rules) - Angle should be in 60-80 degree range → in general, same shape - Wraps slightly onto Chassis wall

Shoulder patch		- Shoulder harness patch will stay the same
Rear Suspension (Rear Front, Rear Rear)		- There will be a single patch that goes over the two hardpoints - Crucial patches because provides load distribution between upper and lower
Upper roll heave		- Possible change in mounting positions - Patches and shapes should remain the same - Full zonal patch
Rear Impact	- Adding ¾ in plate that we will bolt in - May have to add patch - Do not need to worry about Anti-Intrusion Plate anymore	
Cockpit reinforcement	- Patch sits on top of NR-SIS ply - Provides torsional stiffness at cockpit	

In general, the 2024 vehicle will not have many changes in upper half, besides laminate modifications
As a result, the upper half patches were very efficient and were completed quickly. The lower half patches are still pending. Below is a table showing the status of the Fibersim senior at the end of Fall term 2023.

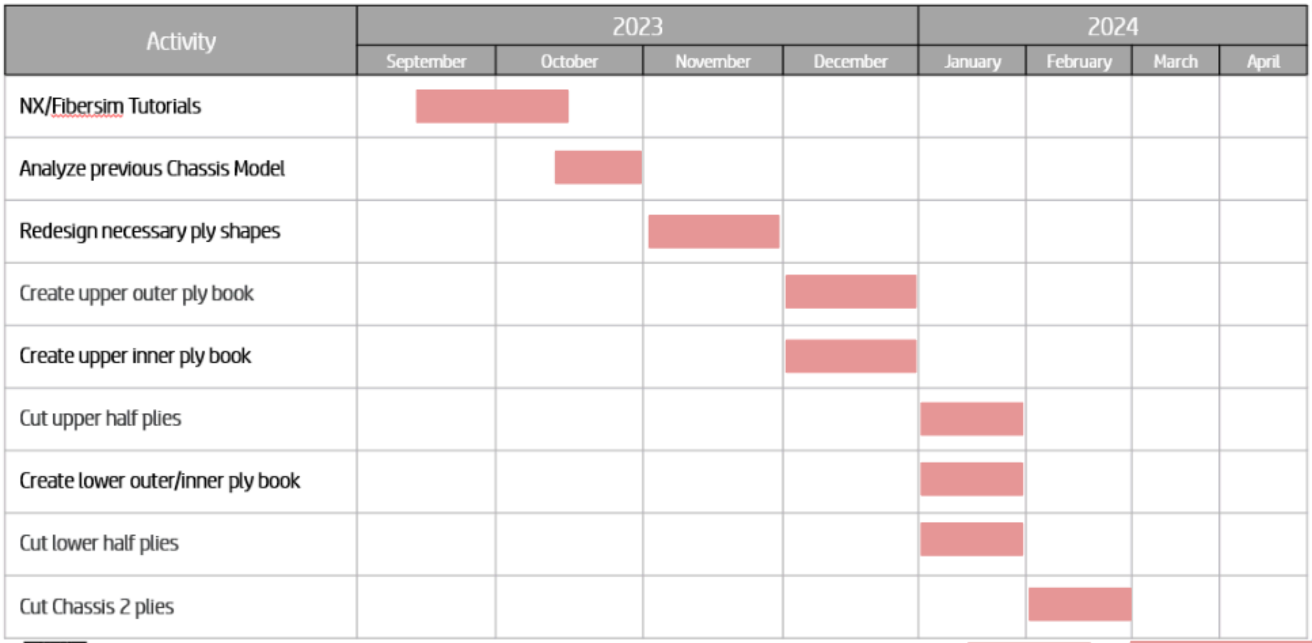


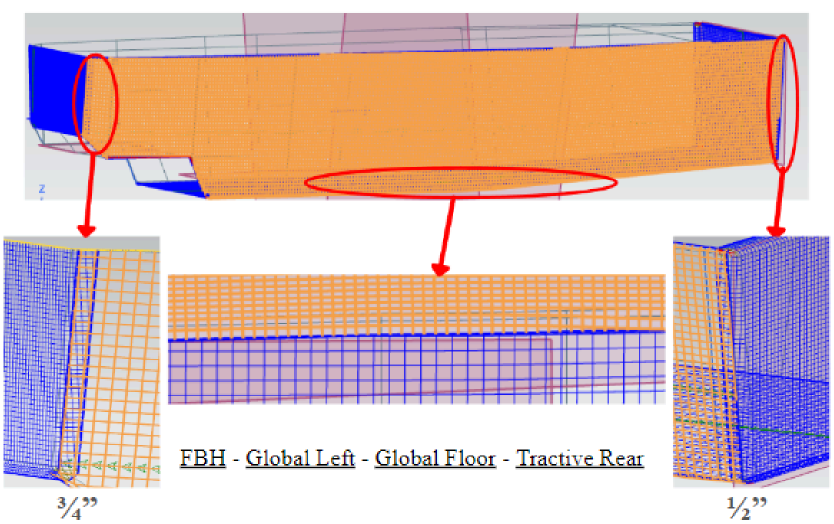
Fig. 35: Fall 2023 Status

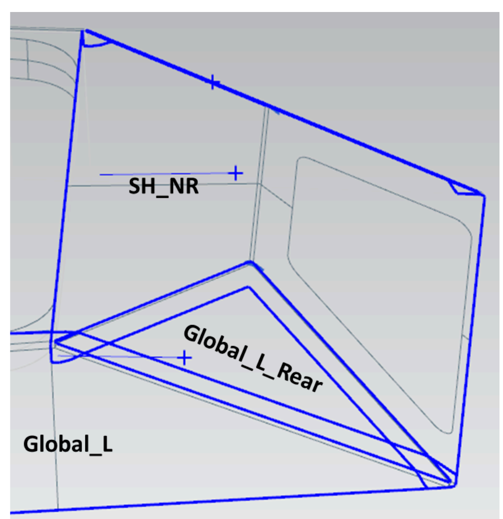
In 2022, the team had to design a brand new plug and mold for the new Chassis. The team will be using the same plug, mold, and mold inserts for the 2024 GFR carbon fiber monocoque.

4.3 Ply Validation

4.3.1 Specifying offset

As discussed in previous sections, utilizing correct offsets is a primary goal this year. It is up to the Fibersim senior to decide how the overlap is specified. Despite this there is still certainly inaccurate overlaps during the layup caused by human error. Figure 36 below displays the difference between a 0.75” offset and 0.5” offset.



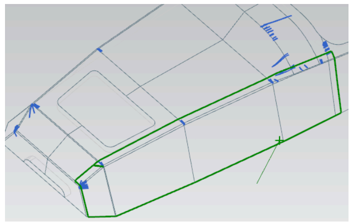
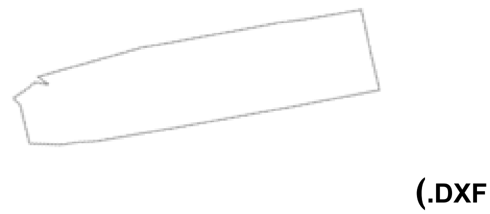
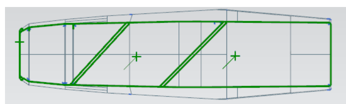
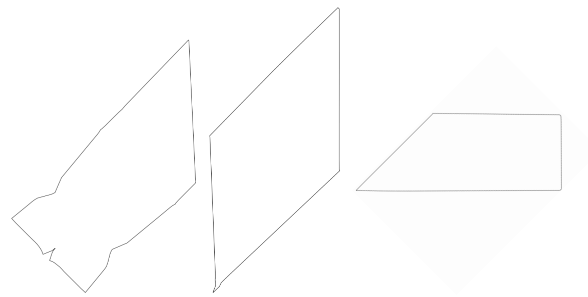
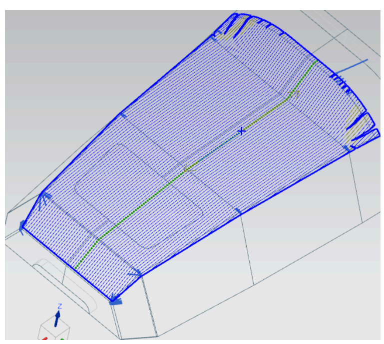
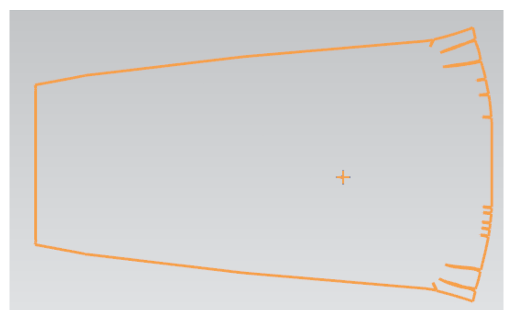


4.3.2 Fibersim considerations

Prior to Chassis manufacturing, it is critical that the Fibersim senior understands the shift from simulation to ply cutting. The carbon material, donated from SpaceX, should only be cut after full validation. The primary concerns when using the software are:

1. 45 degree plies are restricted by the width of the carbon roll
    a. The material roll width is 940 mm, which restricts the size of certain zones.

2. Darting for unidirectional plies became challenging at times
    a. High darting on the UO-FHB_Front-C0 plies
    b. Material has limited flexibility, which would cause serious deformation.

Zone	**Concern**	**Simulation**	**Flat Pattern**
403-UO-FBHS_L-A45-O3-C	1		
401-LO-Global_Floor_A-A45-O3	1		
502-UO-FBH_Front-C0-O2	2		

As seen in the table above, the UO-FBHS_L-A45 is approximately 600 mm long, which is well within the limit. Next, the 401-LO-Global-Floor-A45 ply had to split into 3 zones. Its zonal width was approximately 2353 mm long. Although creating a single large ply on Fibersim is acceptable, actually cutting the material on the ply cutter is not possible Finally, the deformation on most unidirectional plies are severe causing heavy time consumption on v-darting and slit darting. The 502-UO-FBH_Front-C0 required several v-darts near the curved edges of the Front Hoop Bracing; slit darting was found to be less effective. During manufacturing, large v-darts can cause noticeable gaps in the ply layup. As a result, the team will sometimes have to add scrap

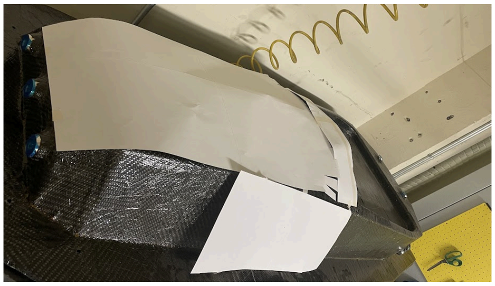


Fig. 36: Mock layup

patches over the gap created by the v-dart- this is not ideal and should be avoided. Figure 36 shows a mock layup of:

- 502-UO-FBH_Front-C0-O2
- 401-UO-Global_Front-A45-O3_B
- 302-UO-FBHS_Rear_L-A45-O3

4.4 Steps after Fibersim

The team is on pace to begin Chassis 1 manufacturing on January 1st. After the upper outer/inner plies and patches were modeled, they were pasted into the plybook. The goal of the plybook is to provide a guide to the team so they can get a visual understanding of location, orientation, and size. Fibersim does offer an auto generated plybook, however the format and visuals are not suitable for the team. The material will be stored in the Graff Hall freezer for 2 weeks prior to ply cutting. The goal will be to cut the plies during winter work week, and the outer skin will be laid up during the start of winter term. After this is complete, core fitting and hardpoint bonding process will commence, followed by inner skin. Once this stage has been finalized, the two halves will be bonded together.

The Fibersim senior can also assist the aerodynamic subteam in cutting, and laying-up their components.

	2024 Plies	2024 Patches	2023 Plies	2023 Patches
Lower Half Outer Skin	52	75	70	97
Lower Half Inner Skin	-	-	60	90
Upper Half Outer Skin	51	41	47	51
Upper Half Inner Skin	35	27	45	51
Total	138	143	222	289

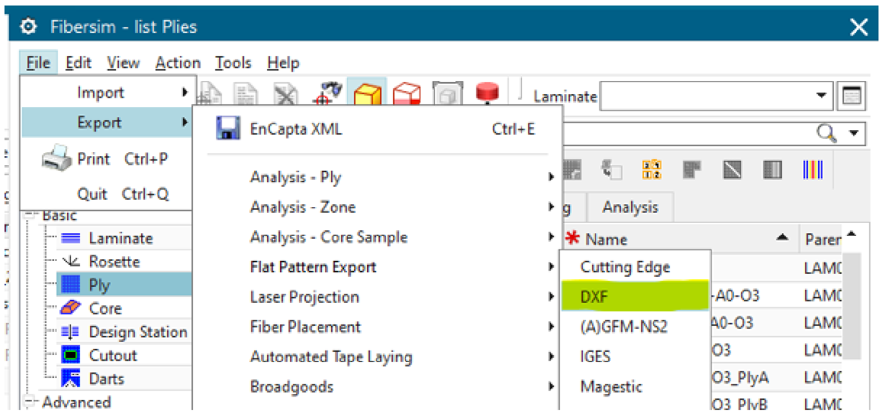
Fig. 39: CHASSIS 1 Ply & Patch Count

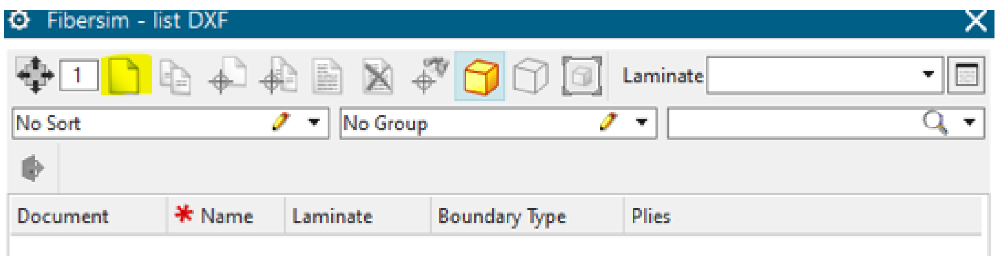
[2024 Upper Outer Plybook]

Selection and justification, using technical analysis, of a design option from those presented in Section 3. Explanation given of how this design best meets all requirements.

5. Implementation

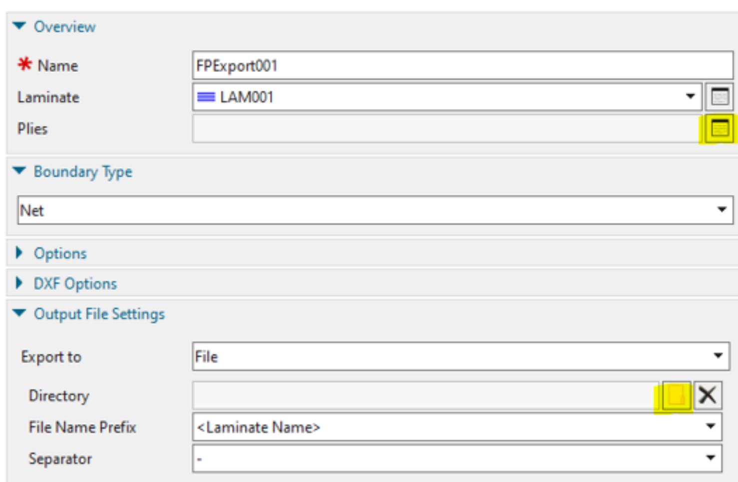
5.1 Auto-nesting on PatternSmith 10.2 (new feature in 2024)

<table>
<tr>
<td>1.
Export Plies as .dxf files from FiberSIM</td>
<td>


</td>
</tr>
<tr>
<td>2.
Select ‘Create New’</td>
<td>


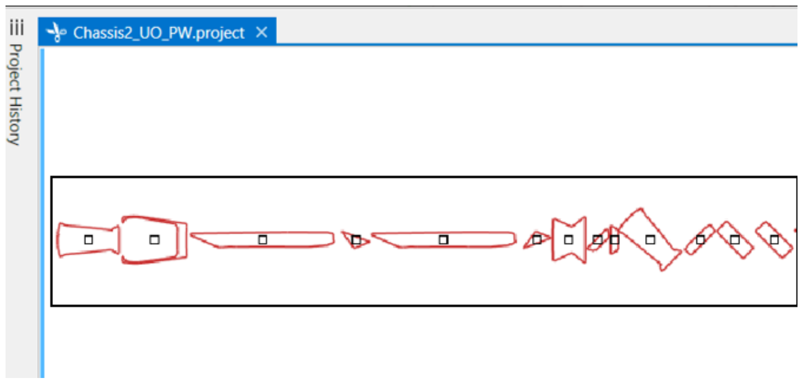
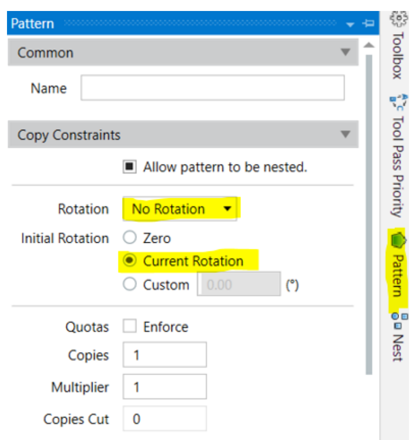
</td>
</tr>
<tr>
<td>3.
Select ‘Plies’ then select ‘Directory’

In File Explorer, navigate to ‘This PC’ and select your ONID directory. The file export must go in the Documents Folder.

Select ‘EXPORT’</td>
<td>


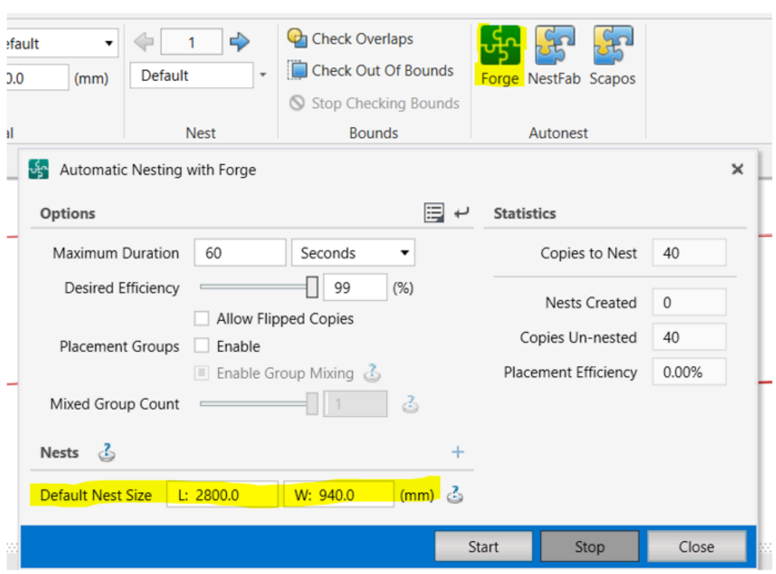
The file directory must be >>PC/ONID/Documents. Example: PC/bhattr/Documents
</td>
</tr>
</table>

4. Create separate folders for Uni and PW Plies
5. Transfer all .DXFs to USB Flash Drive
6. Open ‘New’ Sheet on PatternSmith 10.2
6. **Import** .DXFs on PatternSmith 10.2

<table>
<tr><td>7. ‘Select’ all plies on PatternSmith 10.2</td><td></td></tr>
<tr><td>8. Ensure the following conditions on the ‘Pattern’ tab [Left side toolbar]</td><td></td></tr>
<tr><td>9. Select ‘Forge’ and ensure dimensions

Plycutter Max length: 2800 [mm]

Roll Width: 940 [mm]

All plies are nested → SAVE PatternSmith file and open file on Graff Ply Cutter Computer</td><td></td></tr>
</table>

5.2 Ply Cutting & Ply-Prep

The Detailed Layup Schedule 2024 is meant to assist the FiberSIM senior to create the proper plies and patches. It is also meant to be a checklist of components that have been Nested, Cut, and Laid-Up. The command [CTRL ;] enters the day.

Nested?	Cut?	Laid up?

Nested?	Cut?	Laid up?
3/18/24	3/18/24	3/18/24

Fig. 40: Patch/Ply Checklist

After patternsmith nesting, the FiberSIM senior should check every ply and patch to ensure that it was nested properly. It is very common for the flat pattern export to be incorrect. This could be caused due to insufficient darting, improper net boundary, or a flawed rosette.
Once the plies have been cut, they should be placed into a large bag. The patches can be grouped into small ziploc bags and placed into the large ply bag.The Material Consumption Tracker must be filled out after ply cutting.

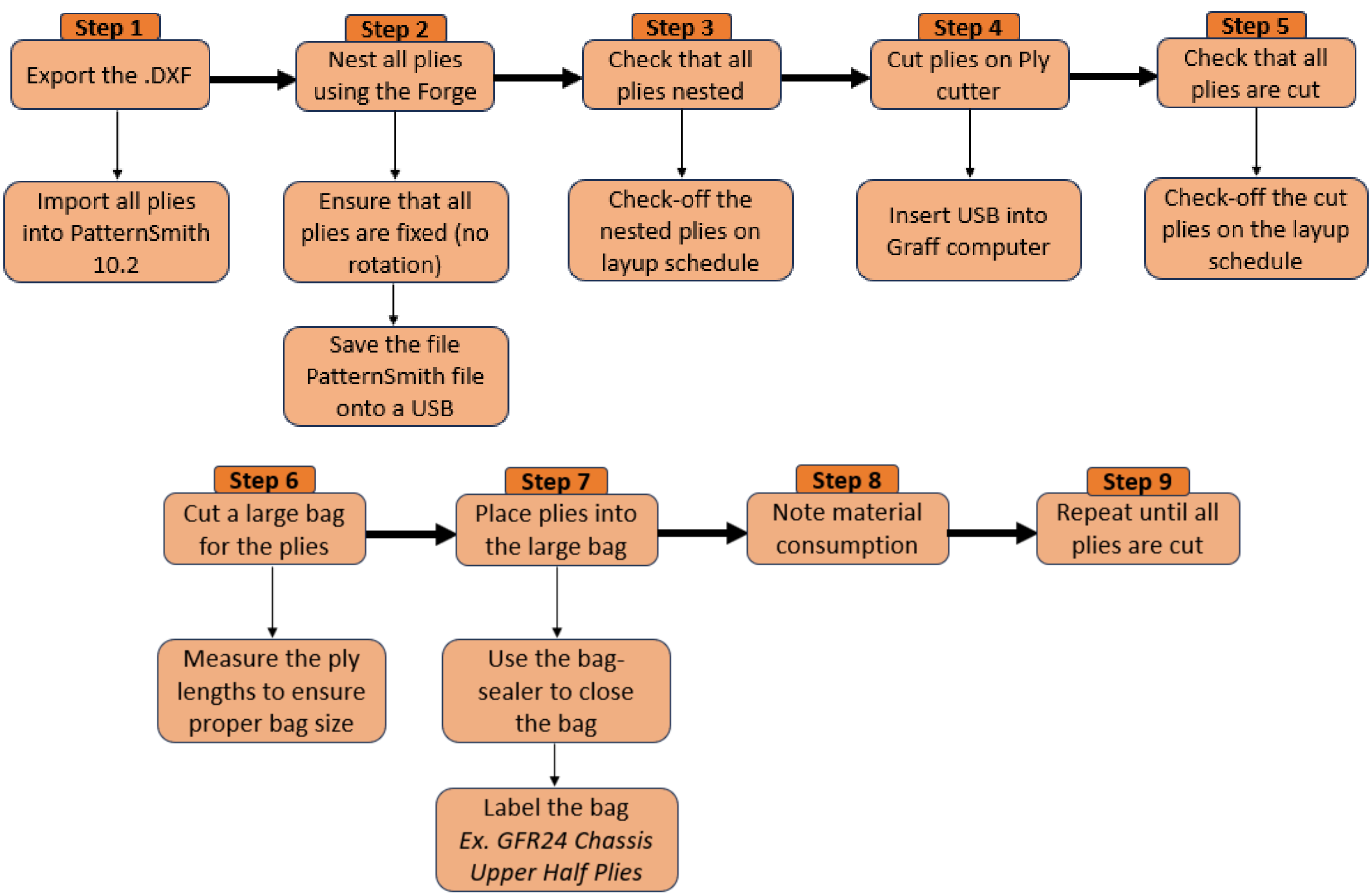


Fig. 41: FiberSIM to Manufacturing Steps

5.4 Quality Control

The Chassis ply cutting process requires attention to detail and a careful approach. Firstly, the ply cutter should be wiped down with Isopropyl alcohol prior to any cutting. There is heavy dust collection in Graff Hall, and not wiping the table can cause contamination of the carbon roll. Secondly, the composite roll must be removed from the freezer several hours before cutting to allow for proper thawing. A large diameter roll can take 10-12 hours to thaw and a medium diameter roll takes about 6-8 hours. If the bag is opened prematurely (before thawing is complete), then water damage will occur; this damage will only become noticeable after the car is laid up and removed from curing. Thirdly, during the cutting process, it is important that the ply cutter blade is being checked and cleaned regularly. It is very common for resin to build up on the blade which causes blade jams, poor edge trims, and damaged fibers. Fourthly, during the bagging process, the sealing should be air tight and no holes should be present. This is particularly challenging because the Chassis plies are so large; therefore, it is easy to mishandle the bag and unknowingly cause a tear. For this reason, it is recommended that two people assist in ply bagging and placing it into the freezer. Once the ply layup commences, it is important to be present during the layup. The plybook is meant to be a guide however the Fibersim senior is responsible for clearing up any confusion.

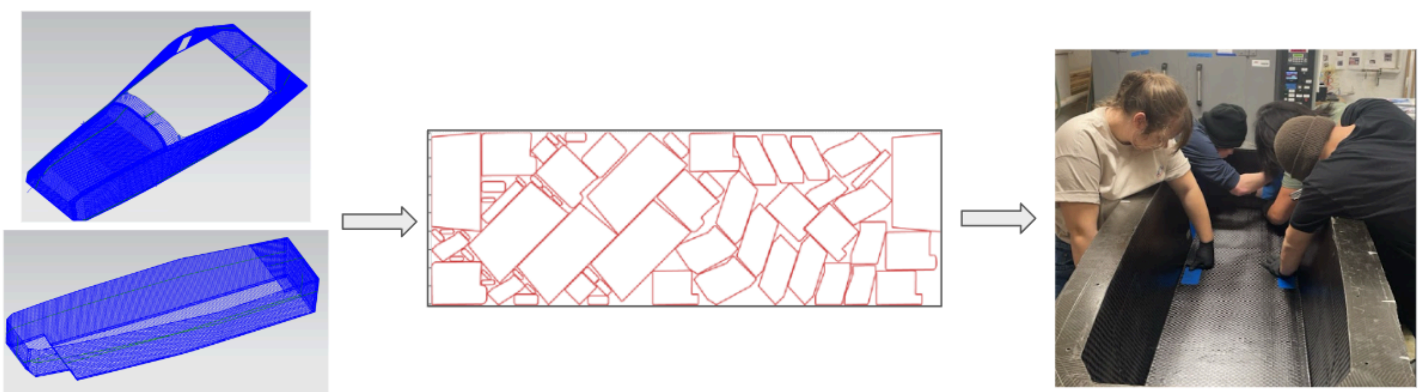


Fig. 42: Manufacturing Process

The figure above displays the steps after fibersim which involves nesting, cutting, bagging, and overseeing the ply layup. Throughout the process, there are several areas where errors or mistakes can occur. By maintaining communication with sub-team leads, and following the Composite Lab Standard Operating Procedures, the team can ensure a properly designed chassis.

5.5 Laminated Roll Hoop

The roll hoop is laminated directly into the car to allow for a slimmer & more aerodynamic chassis. Additionally, it is also meant to increase the volume of the cockpit; the large space allows for the inclusion of a newer steering rack design, an inverter at the front of the car (improved weight distribution), and increased space for driverless systems [1]. The GFR24 design for the roll hoop is the same as the GFR23 design. The general order of operations of roll hoop installation is to first conduct inner skin layup and core fitting; the FRH inserts can be installed during this. After this, post-processing must take place such as removing FRH inserts, post-processing excess flanges, and surface prepping for the film adhesive. Finally, the FRH can be installed by situating the roll hoop in place using epoxy (while inserting supporting foam core), laying up the roll hoop laminate, inserting the laminate core, laying up the roll hoop inner skin, and then bagging and curing [1].

During the first stage where the plies are being laid up and the MDF Block must be inserted, the inner skin global plies need to be slightly modified. The inner skin global plies should be split into two sections to account for the gap.

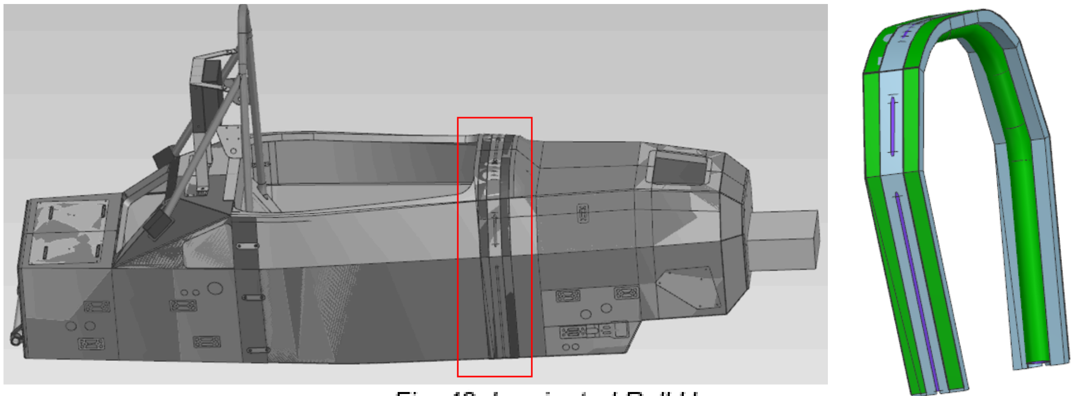


Fig. 42: Laminated Roll Hoop

By splitting up the global plies into two sections, the ply layup will be much smoother and will reduce ply deformation. If the global plies are not split, the manufacturing seniors would have to splice the plies manually, to account for the laminated roll hoop.The image below shows the proper sectioning of the lower half inner skin global. The same process should be applied to upper half inner skin.

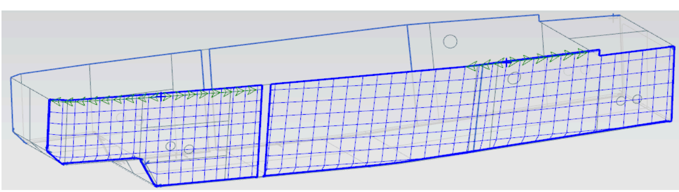


Fig. 43: Splicing of Inner Skin Globals

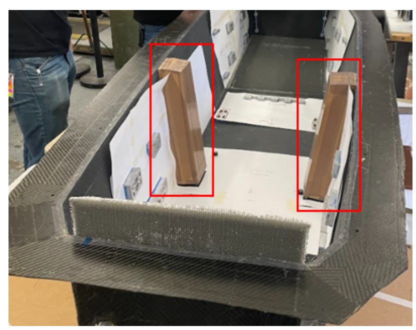
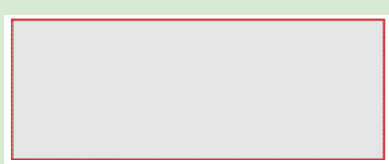
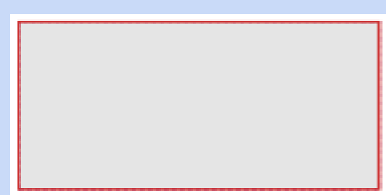
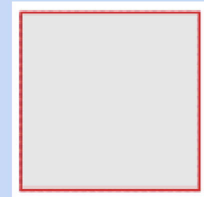
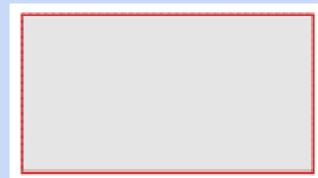


Fig. 44: Roll Hoop MDF Blocks

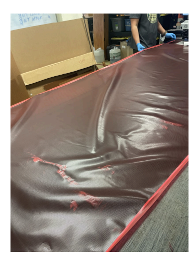
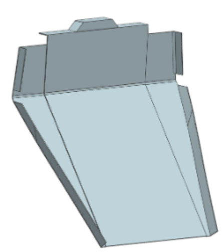
In 2023, a formal layup schedule did not exist for the laminated roll hoop. However, this year it was implemented to allow for better tracking of required plies (Detailed Layup Schedule 2024). The plies are named based on the approximate region it should be placed on the Chassis:

Outer Skin (A0/C0/A45/A45/C0/A0)		**Inner Skin (A0/A45/C0/A0)**	
UO-FHB *165 x 435 [mm]*		UI-FHB *200 x 435 [mm]*	

UO-FHBS-L & UO-FHBS-R *200 x 165 [mm]*		UI-FHBS-L & UI_FHBS-R *200 x 200 [mm]*	
LO-FHBS-L & LO-FHBS-R *368 x 165 [mm]*		LI-FBHS-L & LI-FBHS-R *368 x 200 [mm]*	

5.5 Firewall Ply Cutting

The team chose to use prepreg fiberglass for the 2024 firewall. In 2022, the car only needed one firewall because all of the tractive system components were located in the chassis rear. However, in 2023, an additional firewall was added because the inverter was relocated to the cockpit underneath the drivers legs. The use of prepreg fiberglass is an upgrade from 2022, which used a wet layup. The high strength-to-weight ratio of prepreg fiberglass is a strong step to ensure high strength while reducing weight in the chassis. Additionally, the high durability and low thermal expansion coefficient ensures reduced deformation during layup and stable dimensions while curing[1].
The layup of the Firewall was also a challenge because a mold must be inserted inside the chassis to layup the flanges. The downside of laying up inside the chassis is that it can be difficult to pull a strong vacuum when curing the flanges. As a result, there is a considerable decrease in strength. The upside of using the Chassis as a mold is that the flange geometry is nearly perfect inside the vehicle. A possible solution would be to create a seperate mold to allow for layup outside the chassis and thus ensuring proper vacuum[1]. However, this is a challenge because of geometric variances between each chassis that is built. For this reason, a standalone mold may cause poor dimensional accuracy.

Prepreg Fire Retardant Fiberglass	
Main Firewall[1] This component is located behind the driver, separating the cockpit from the tractive system components such as the accumulator and the rear inverter. It is meant to protect the driver from the high voltage components in the vehicle.	

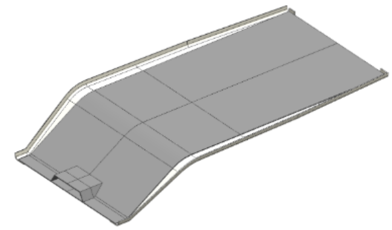
Front Firewall This component is located below the drivers legs, separating the cockpit from the front inverter. It is meant to protect the driver from the inverter.	

Fig. 45: Table of Firewall Design by Josh Hancock

Main Firewall Flange [L,R]	
Front Firewall Flange [L,R]	
Main Firewall Body *375 x 644 [mm]*	
Front Firewall Box *370 x 534 [mm]*	
Steering *179 x 348 [mm]*	
Driver *75 x 348 [mm]*	

Fig. 46: Table of Firewall Plies

The primary considerations when cutting the Firewall plies are the high resin content of the prepreg fiberglass roll. As a result, there is significant damage to the ply cutter blade if proper care is not taken. The plies will begin sticking to the blade, causing them to be dragged across the table. For this reason, the blade must be cleaned intermittently while cutting- especially for the flange plies which require heavy darting and high angles of blade rotation. It is recommended to cut the same table twice with the Blade Pressure set at 35 PSI on both passes. This ensures reduced blade damage and sharp ply edges.

5.5 Battery Container FiberSIM

The battery container layup is handled abroad at DHBW. Since they do not have a ply cutter, Tom Russ led the effort to manually cut plies based on the dimensions of the container. Without using Fibersim, it can be difficult to predict where structural deformities may occur. For this reason, a Fibersim model was created to assist in the manual ply cutting process.The battery container is made up of an outer skin (floor & walls), and the inner skin (inner walls). It was decided that FiberSIM will not be done for the inner skin because of its relatively small, and simple geometry. However, the layup for the outer skin is shown below.

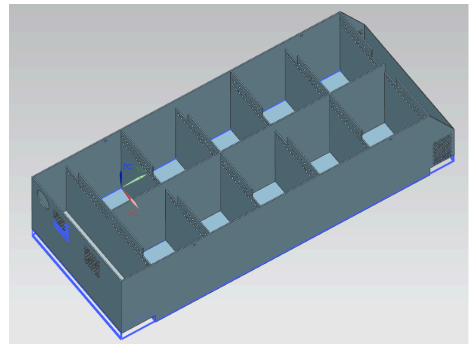
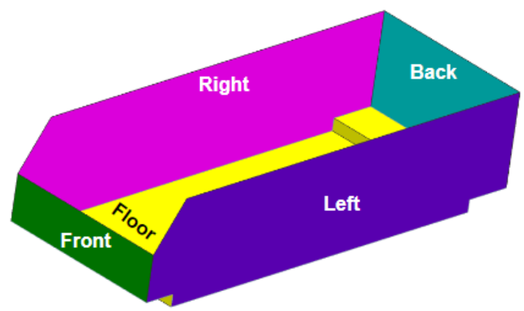


Fig. 47: 2024 Battery Container

Location *(OS: Outer Skin)*	**Layup** *(Floor: 13 layers, Walls: 7 Layers)*
OS_Global_Wall_Left	0/45/0/45/0/45/0
OS_Global_Wall_Right	0/45/0/45/0/45/0
OS_Front	0/45/0/45/0/45/0
OS_Back	0/45/0/45/0/45/0
OS_Global_Floor	0/45/0/45/0/45/0/45/0/45/0/45/45



The 2024 Battery Container Plybook displays instructions and visuals on how to layup the component. The team chose to maintain ¾" offsets on the simulation. After the full CAD model was provided by the Powertrain Team, I created a new file and used 'Assembly Load Options' to load in the part. I did this to create a distinct copy of the CAD model so it can be modified without interfering with the original model. I utilized the wave geometry linking feature to create a face chain by only selecting outer skin faces (Front, Back, Left, Right, Floor). I then used the sew tool to sew each sheet together and create a single body. This allows Fibersim to recognize a single layup surface; if these steps were not taken, FiberSIM would create disjointed net boundaries.

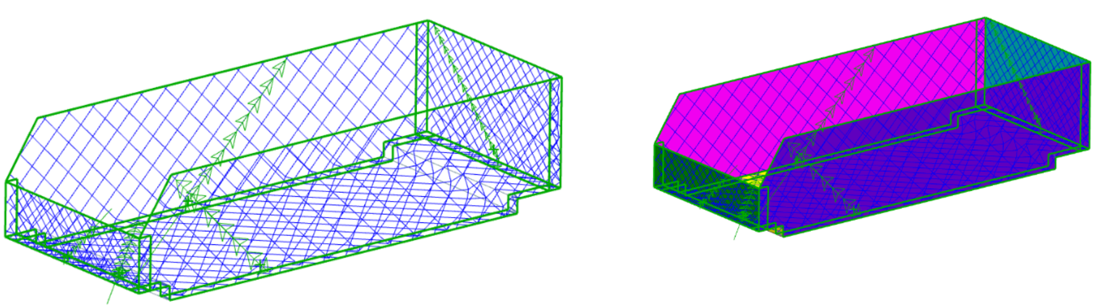


Fig. 48: FiberSIM Model

Simplicity and reliability through simulation validated by physical testing.

5.6 Carbon Rims FiberSIM

Frederick Boulton is the senior responsible for designing the Carbon Rims. The goal of this project is to cover all aspects of development required to implement carbon fiber race wheels. The 2024 car will use aluminum wheels however the aim of this project is to implement the upgrade in the 2025 vehicle. The lightweight carbon rims would reduce the unsprung mass of the car (total weight of every component that is not supported by the vehicle's suspension system, including wheels, tires, springs, shocks, linkages, brakes) [8]. The proper implementation of this would improve the vehicle's handling, acceleration, and overall weight [9]. Throughout the 2024 season, Frederick has allocated stock materials to implement the master mold of the rims. The molds were then manufactured, and the CAD model was provided in order to complete the Fibersim. After this is done, the team can commence with the mold layup process.

Fig. 49: Carbon Wheel halves from 2017

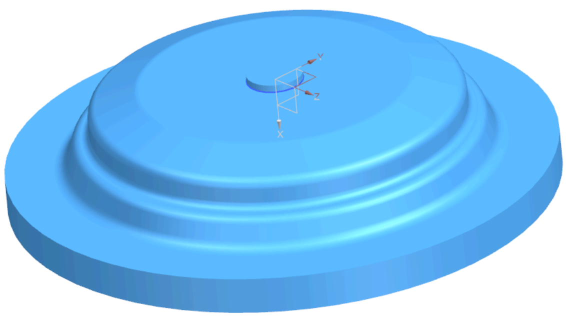


Fig. 50: 2024 outer wheel master plug

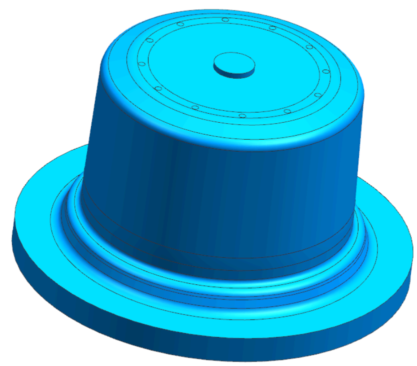


Fig. 51: 2024 inner wheel master plug

6. Testing

6.1 Offset & Paper validation

As stated previously, the primary goal of the FiberSIM senior this year was to maintain proper ½” and ¾” offsets. This was tested by cutting a variety of plies on printer paper. The team could then inspect that the overlaps were optimal and that the ply geometries were proper. During actual ply layup, there will be bridging, tearing, and other deformations of the composite plies. The printer paper is challenging to drape over the chassis mold, however it can provide indications of regions that require darting.

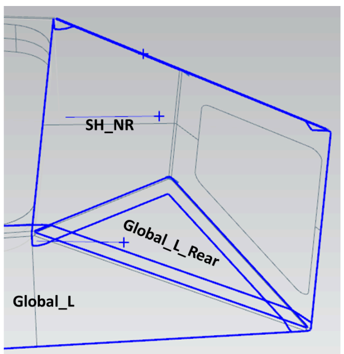


Fig. 52: Example of Ply Offsets

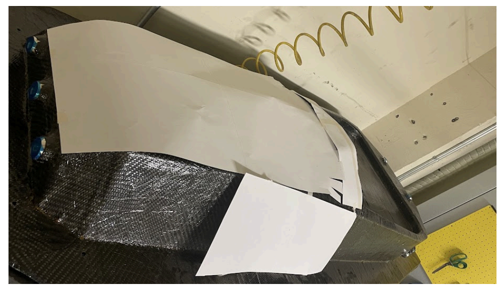


Fig. 53: 2024 Paper Validation

The paper validation testing was particularly helpful for the patches. The Front and Rear Suspension patches encompassed several hardpoints this year. For this reason, there were non-symmetrical patch offsets that had to be created. The paper testing allowed the team to check that the patches were overlapping properly.

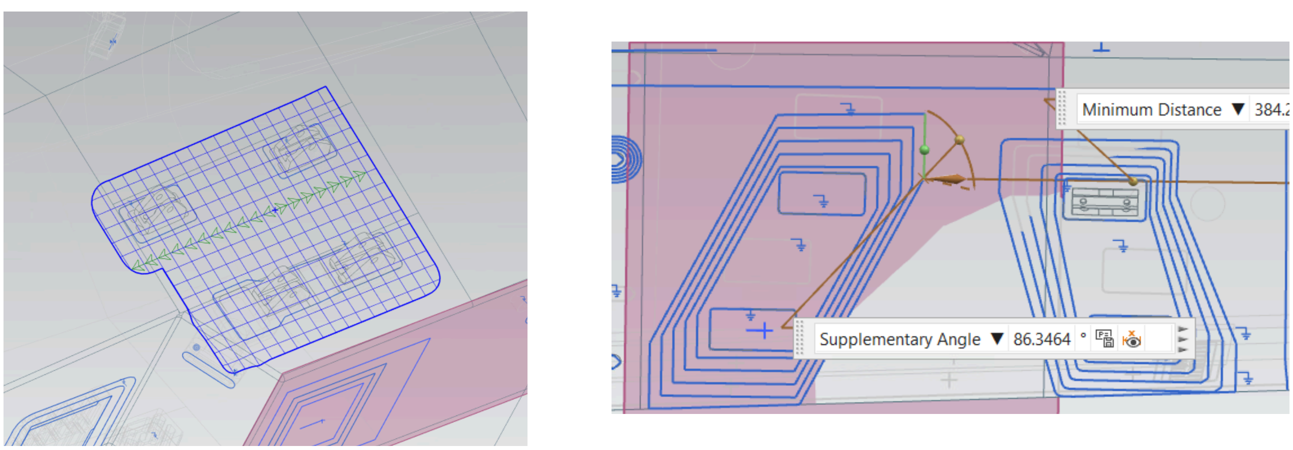


Fig. 54: Front Suspension & Rear Suspension will have larger patch offset

6.2 PatternSmith Nesting Validation

During the Fibersim process, it is common to have producibility issues due to excessive deformation, a poor rosette, an improper net boundary, or even a flawed CAD model. As a result, it is common to get incorrect flat pattern (dxf) files. Additionally, it is common for some plies to be too large for nesting within the constraint of material width. For example, the 301-302-303-LI-Global_Floor-ABC-A45-O3 plies were to be cut on PW material which has a roll width of 940 mm. The image below shows the screenshot of PatternSmith where the plies are nesting off the page. For this reason, the Global Floor region was split into 4 plies. This allowed all plies to properly fit into the PatternSmith bounding box.

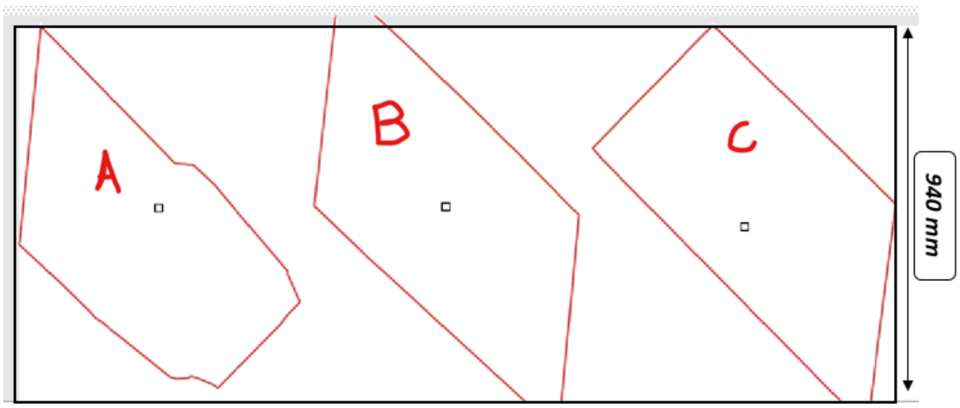


Fig. 55: The plies each exceed the material width of 940mm when nesting

PatternSmith Nesting	
Max nesting length	**Max nesting width**
2800 mm (Ply Table Length)	Roll Width *PW: 940 mm* *UD: 980 mm*

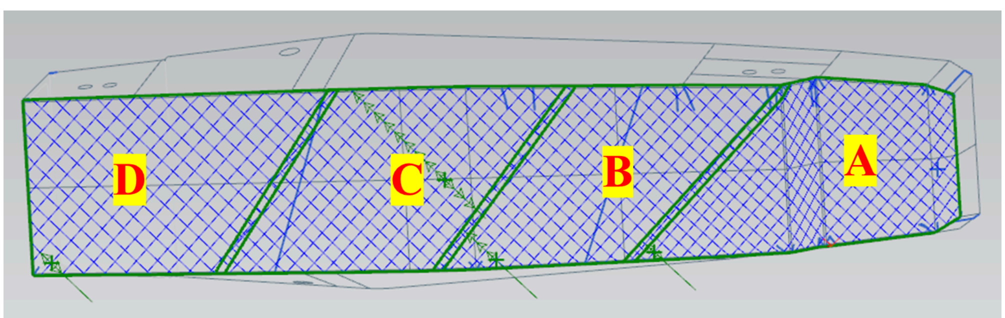


Fig. 56: The Global Floor was split into 4 plies so it could fit into the PatternSmith nesting

6.3 Additional Analysis

The following subsections provide an overview of testing to ensure strength, reliability, structural integrity, and lifetime of the chassis plies.

6.3.1 Materials Testing

Prior to Winter term Manufacturing, the SES team conducts material testing to determine tensile, compressive, and flexural strength. This style of testing is meant to ensure that the mechanical properties of the sandwich panel is understood and that it meets Formula specifications.

6.3.2 Prepreg Material

The team has been conducting a dry layup for several years because Oregon State receives composite rolls that are pre-impregnated with resin. It is important to check the spec sheet for the material that will be used. For this season, the specifications for T700 PW and T700 UD can be found here: T700 Material Spec Sheet

When conducting FiberSIM, it is important to ensure proper orientation (0°, 45°, 90°) of the plies. This is done by specifying the proper rosette direction. For the GFR Chassis, the rosette should be pointing in the forward direction of the vehicle. As a result, all ply orientations are designed with respect to the direction of the rosette.

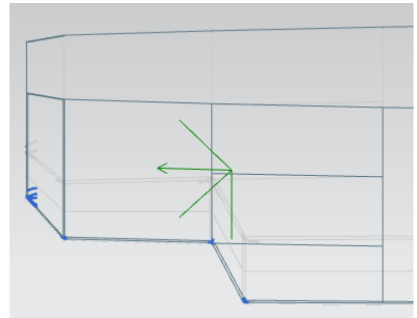


Fig. 57: Ply Direction

6.3.3 Layup Process Monitoring

During the layup process, it is important to monitor the layup of each ply. This could involve visual inspections to ensure proper alignment, orientation, and absence of defects such as wrinkles, voids, or resin-rich areas. In industry, it is common to use laser projection systems & templates to assist in precise ply placement. Ultrasonic gauges or calipers can also be used to check thickness of composite stacks. Additionally, thermal imaging can be used to look for internal defects or inconsistencies in the layup.

7. Conclusion

7.1 Reflection

The 2024 season was a success because the team remained very organized and most tasks were completed on time. There was strong continuity from the 2023 season which allowed for great mentorship from the sub-team leads. The GFR24 FSG & FSAE Chassis has a much smaller ply and patch counts compared to the previous year. The FiberSIM for the Red Car was a much smoother process because the layup was similar to the Orange Car. The primary goal of this year was to reduce chassis weight and ensure proper overlaps between chassis zones. In 2023, the team had very heavy corners and excess material in many areas. This year that issue was nearly eliminated; all offsets were placed properly and that can be seen in the table below. I worked closely with Chris Pearson and Bryce Atha, the Chassis leads, to ensure that plies were designed properly. As the manufacturing season winds down, I will begin uploading my work to Google Drive. This work includes the FiberSIM files, the DXF files, the PatternSmith nesting, and all additional material used throughout the year.

ORANGE CAR	2024 Plies	2024 Patches	2023 Plies	2023 Patches
Lower Half Outer Skin	52	75	70	97
Lower Half Inner Skin	42	61	60	90
Upper Half Outer Skin	51	41	47	51
Upper Half Inner Skin	35	27	45	51

Total	180	204	222	289
Total Patch/Ply Weight	**8.041 kg**		**15.151 kg**	

RED CAR	2024 Plies	2024 Patches
Lower Half Outer Skin	54	76
Lower Half Inner Skin	47	62
Upper Half Outer Skin	53	39
Upper Half Inner Skin	34	26
Total	188	203
*Time spent ply cutting	~37 hours	

*The time spent ply cutting includes the cutting of FRH plies, Firewall plies, and Film Adhesive Globals.

Red Car Manufacturing Process

Day	Task
Sunday (2/18) to Tuesday (2/20)	Entire fiberSIM of Red Car
Wednesday (2/21)	Export DXFs & use Forge to auto-nest
Thursday (2/22) from 8AM to 4AM	Cut UO, UI, LO, LI Plies & Patches
Saturday (2/24) from 8AM to 8PM	Cut Laminated Roll Hoop & Film Adhesive Globals
Sunday (2/25) from 8AM to 1PM	Cut Firewall Plies

7.2 2025 Recommendations

In the 2025 year, it is recommended that the FiberSIM seniors utilize the same FiberSIM model from 2024. The CAD model I created has very detailed labeling and each ply has been placed into its own Feature Group. The net boundaries, rosettes, and darts are all labeled clearly. It is recommended to take advantage of this in order to speed up the design process. The 2025 senior should spend more time on patches next year. It can be time-consuming to create the patches and the organization from 2024 could have been a little better. The senior should work very closely with the SES lead to ensure that they understand the Chassis zones. Finally, it is critical to get started on manufacturing as soon as possible. The process of exporting flat patterns, nesting, cutting, bagging, and cleaning up is very intense. Throughout the manufacturing season, it is important to follow the Composites Lab Standard Operating Procedures. This means unbagging and bagging properly, ensuring proper dimensions, sealing the bags, and carefully placing them into the freezer.

8. Works Cited

Use the Chicago Manual Style to create a full Works Cited page, per SAE International recommendation. For OSU SAE documents that were linked within the body, simply write the title & author(s) ("2011 Chassis Manufacturing Team") is acceptable for author) and create another hyperlink. For external documents, write a proper citation.

[1] Hancock, Josh. “GFR23 Driver/Cockpit Safety” GFR23 Driver/Cockpit Safety by Josh Hancock

[2] Salisbury, Michael. “GFR23 Fibersim & Composites Manufacturing” GFR23 Fibersim & Composites Manufacturing by Michael Salisbury

[3] Westcott, Garth. “GFR21 FiberSIM & Chassis Manufacturing” GFR21 FiberSIM & Chassis Manufacturing by Garth Westcott

[4] Lam, Richmond. “GFR22 Fibersim/Composite Manufacturing” GFR22 Fibersim/Composite Manufacturing by Richmond Lam

[5] Siemens DISW.” n.d. Community.sw.siemens.com. Accessed November 15, 2023. https://community.sw.siemens.com/s/article/fibersim-101-1-of-14-model-setup

[6] Siemens DISW.” n.d. Community.sw.siemens.com. Accessed November 15, 2023. https://community.sw.siemens.com/s/article/how-to-resolve-ply-producibility-problems-in-fibersim

[7] Neel, Richard. “GFR19 Chassis Hardpoint Design” GFR19 Chassis Hardpoint Design by Richard Neel

[8] Autoshop, Developer. “Unsprung Mass – What’s This Mean to You?” Drive Auto Sports, 4 Mar. 2024, driveautosports.com/unsprung-mass-whats-this-mean-to-you/#:~:text=It%20refers%20to%20the%20total,%2C%20handling%2C%20and%20overall%20performance.

[9] Boulton, Frederick. “GFR24 Carbon Rims Mechanical Design” GFR24 Carbon Rims-Mechanical Design

5. Implementation

A detailed manufacturing/implementation record. Description of construction issues encountered and design changes made. Includes pictures and engineering analysis to support and describe all design changes made during the testing process. Engineering methodology justifies selection and sizing of tools used to manufacture or implement the process. Equations and sample calculations used included and explained. Assembly and process tutorials included in appendices when appropriate.An example of a good visual process flow chart for the manufacturing of the Formula chassis can be found HERE. (From Formula Chassis 2012 Report)

This section is intended to be an actual record of the manufacturing processes to match the outline above plans.

5.1 Sub Section 1

5.1.1 Sub Sub Section 1

5.2 Sub Section 2

5.2.1 Sub Sub Section 2

6. Testing

6.1 Sub-System Validation Design of Experiment

Specific requirements for this subsection:

- ❏ **Detailed list of tests required to validate calculations and simulations**
- ❏ **Detailed plan on how to measure subsystem performance**

6.2 Tests Complete to Date

A detailed explanation of the tests performed & analysis of test results. Testing process tutorials included.

6.3 Tests to Complete

A detailed testing plan for the tests that to be performed on your system to validate functionality & design calculations. Detailed designs for needed testing apparatus or fixture included. Testing process tutorials included when appropriate. Sample calculations of the end analysis & expected values given.

7. Conclusion

Reflection on the entire project and your individual contribution. Suggestions/advice for future team members and management on design, manufacturing, and team aspects.Graded by quality of content; positive & negative critiques are encouraged.

7.1 Sub Section 1

7.2 Sub Section 2