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NU Racing Formula SAE - Chief Engineer and Body Kit Lead

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FYP REPORT

NU24-NU25

Joshua Wenham

2024

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Acknowledgements

I would like to thank Dr. Alexander Gregg for welcoming me into the NU Racing team in the middle of 2023 as an ENGG2200 student. The work Dr. Gregg put into making NU Racing and NU Teams an excellent learning experience is truly amazing, and I will never forget the vast number of lessons and skills I have learned in the TA building.

A massive thanks is owed to Dr. Dylan Cuskelly as well as Malcolm Sidney for their continued support throughout 2024. Nothing in NU Teams is possible without them and their hard work that goes into making NU Teams a happening thing. Their willingness to help with leadership issues and technical issues is truly a blessing to anyone fortunate enough to ask for their help.

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Thank you to everyone in the 2024 team who spent the time to make NU24 what it is now. The friendships and laughs shared with everyone will be a memory to be cherished. A particular thanks to Tim Kerr, Lachlan Fisher, Alec Chapman and John Jones are owed for putting in insane effort on the body kit project. Your assistance in that terrible project to help make it end, as well as the laughs had with you all are what got me through 2024. Thankyou deeply.

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1. Introduction

This report is intended to detail the work contributed by the author to the NU Racing Formula SAE (FSAE) team for the duration of December 2023 through to January 2025. Contributions from the author vary from overall team/competition platform work through to individual component design and manufacture, as well as scoping of developments for the 2025 car. The first section of the report is dedicated to the readers understanding of the established function of the chief engineer role, as well as recommendations for the scope of work for future years' chief engineers.

NU Racing is a student led engineering team that competes in the yearly Formula SAE competition against other university teams who all engage in the process of building an open-wheeled formula style racing car from the ground up. The typical final year project (FYP) role in NU Racing will see students take technical lead of a system(s) on that year's competition platform/car where they go through the complete engineering design-build-test-validate cycle for their focus system(s). The exception to this is the leadership roles of which chief engineer is included amongst team leader, chief mechatronic engineer, and chief mechanical engineer. The students in these roles will commonly engage in the management of people within the team, scoping of work, setting goals and deadlines, doing design reviews and approvals, leading manufacturing, and with a priority above all ensuring the team's personal attendance and completion of all events at the FSAE Australasia competition in December.

The NU Racing team of 2023 put considerable work into setting NU Racing on a path of sustainable development for the competition cars and to adjust the timeline of the phases of designing, building, and testing. As such, 2024 was used by the team to perform iterative development on the subsystems of the car across the board, aiming for reliability above all. An indirect goal of losing weight from NU23 to NU24 was set at 25 kg. Many smaller goals are kept in mind by the leadership team each year including meeting the many target dates of rolling chassis, first spin test, first drive, to name a few. Another key metric tracked is kilometres of testing of the competition car, to indicate time spent driver training, of which over 350 km of testing was completed with NU24.

The team mostly achieved the primary goal it had of completing all the dynamic events at competition, with a time put on the board for all events and only having issues occur in the second half of the autocross event. At the weigh-in at competition, NU23 had a curb mass of 265 kg, dropping by 22.5 kg down to NU24's 242.5 kg.

The 2024 NU Racing team managed to successfully attain the team's personal best score at FSAE Australasia placing in 4th place overall out of the electric vehicle class. Although no podium places were had in 2024, compared to the event specific podiums achieved in 2023, the team achieved a pride worthy result in all dynamic events bar autocross due to a technical fault within the battery management system of NU24. The successful completion of the endurance event alongside good scores by the team across the board resulted in NU Racing placing 4th for the electric vehicle class. This was all despite considerable financial strain within the team's budget due to multiple off-the-shelf component failures including a DC-to-DC voltage converter breaking weeks from leaving for competition, and an expensive near-brand-new motor controller failing.

2. The Role of Chief Engineer

The purpose of this section is to convey to the reader the responsibilities of the chief engineer of NU Racing for the past two years and to provide recommendations as to the future responsibilities and scope of work to be undertaken by future chief engineers.

2.1. NU Racing Operational Structure

Important to the operation of the team is the consistent attendance of students to the Tunra Annex (TA) building, as it allows for direct and quick communication between the faculty leaders and the technical members of those faculties. It is already difficult for people to allocate the amount of time required to do a final year project on the critical path of NU Racing, and getting people in TA at the same time can pose challenges to effective communication across the entire team. It is important to stress early on the importance of students attending the team meetings for their own sake of keeping up to date with the progress of the team. This is not to say that people working from home are left unsupported but messaging between people doesn't support communication of engineering concepts as well as an in-person discussion.

NU Racing is a student led engineering team that has been operating since 2003 (Hollier, 2023), and as such it has settled into an established team structure. The structure of NU Racing is essentially divided into 3 levels of hierarchy. Team leader is a student role, above all roles in terms of importance. They are responsible for ensuring that key documents are submitted to FSAE on time (or else risk team disqualification), maintaining stakeholder (sponsor and industry partner) relationships, booking track days, and ensuring fairness throughout the team. Budgeting and resource management is closely linked to the work of a team leader.

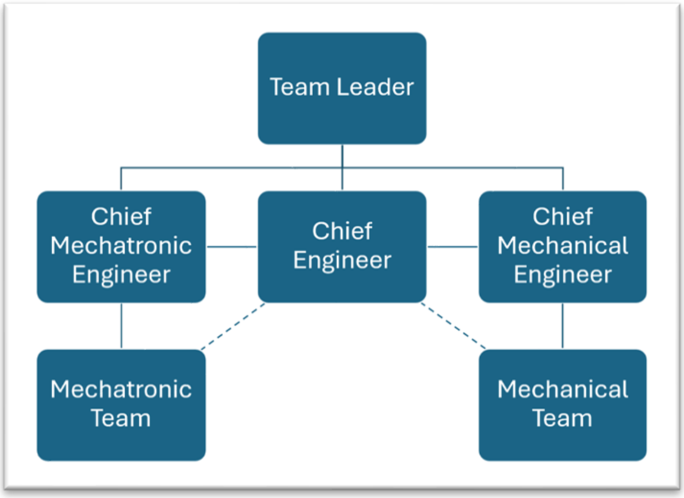


Figure 1 - Team structure of NU Racing

The chief mechatronics engineer and chief mechanical engineers are the leaders of their faculties and do work such as outlining design requirements, design approvals, managing manufacturing, assisting with testing, and in 2024 they also lead the cost report event for their respective faculties.

The chief engineer role entails identifying aspects of the car and of the team that need working upon and coming up with solutions or improvements to these issues. Some things requiring improvement are directly told to the team in the form of feedback from competition however the chief engineer should also be seeking to identify and remedy issues in aspects not covered by the competition feedback.

The role of chief engineer ought to be taken on by someone who has been with the team for at least the testing period of the prior year, but a chief engineer with more team experience than that would be more desirable. The witnessing of the test phase from the previous year is important for being aware of the issues present in the current platform of car for the sake of planning ahead of time what changes are to be made. Changes for the current year are typically suggested by the previous year's chief engineer however a context for the current chief engineer allows them to better act upon and execute the changes.

Typically, all the "chief" roles will end up doing some capacity of technical work on aspects of the car due to limitations of team size. This scope of extra work was large for all chief roles in 2024 but especially for the faculty leaders. The large extent of technical work done by Alec Chapman and Lachlan Fisher will be detailed in their reports for 2024, and it is not sustainable for any leadership team going forward to do this amount of technical work on top of their leadership scope.

Students in the technical engineering roles apart of the mechatronics or the mechanical team will take on a scope of work pertaining to a subsystem(s) on the car, or on research for the team. They communicate frequently with the faculty leaders to ensure they are up to date with what is required of them, and to ensure they are meeting goals and deadlines set by the leadership team.

2.2. Recommendations to Future Chief Engineers

Table 1 below contains tasks with a description and potential solutions to implement that would be suitable work for future chief engineers to do. The tasks are generally linked to planning workloads and scopes, and to ensure technical engineers are prepared for competition through earlier thorough implementation of compliance requirements.

A particular focus that needs to be improved upon going forward is the methods used to validate the changes made to the cars taken to competition. For 2023 and 2024 both years had feedback that validation of subsystem performance was a shortcoming for the team. Validating subsystems is as simple as defining key metrics of which to measure 'performance' by and to design and implement the testing measures needed to test and demonstrate the clear progression of the team's designs and car overall. Validation can also be not just for performance metrics but to validate things such as FEA work or validation of mathematical models such as radiator heat rejection.

The design ethos of reducing part count and reducing weight plays into the validation aspect of the team's workload as these are two of the easiest performance metrics to validate and present to judges at competition. They require little to no resources to test and can easily demonstrate at least some aspects of progression. For NU Racing however, these two metrics alone are no longer enough to impress judges and score well in the design event. To push the professional engineering aspect of the team further significant investment in either purchased or student designed testing equipment will need to be made. This is an investment, and the reward of well executed testing is not just for competition points but for being able to improve NU Racing's designs further.

The author recommends people in future leadership roles as the scope of their final year project do not undertake any directed reading courses within NU Teams at the same time as their final year project unless the scope of the proposed directed reading is very precise in the deliverables and the handover of any unfinished work to do with the project. This is to avoid similar situations occurring as the author's own investment in the body kit as a directed reading course placing him in a position requiring addition of body kit manufacturing scope to his final year project. The author was often in a position where urgency of body kit work conflicted with urgency of chief engineer work, reducing the efficiency of work done.

Table 1 - Recommendations of work for future chief engineers

Task / Problem	Description	Potential Solution(s)	Note
People Management and Timeline Planning	The task of managing timelines is incredibly important for all in the leadership team to ensure they meet goals and deadlines, and to stay on top of what scopes of work are still remaining.	Leadership meetings should be done with frequent revisions to the planned timeline. Communicating timelines to technical roles may be better done by making it a greater focus during the whole team meeting. Instead of asking people what they have done in a casual way, present the timeline for everyones scope for the next few weeks and ask them critical questions about where help is necessary or if they are ready to move on. Communicating everyones progress to each other is a way to get individual team members to feel the progress being made by the whole team and can be a motivator for some.	Writing up timelines on a whiteboard can be done in detail for up to a few months and it is a good idea to have at least the next 4 weeks of work planned in detail to ensure smooth progress. Colour coding work done by a student vs workshop is helpful, as is setting a time goal and working backwards. Deadlines should be set where drastic measures may have to be made if they are exceeded. If a student seems like they will miss a timeline goal, or they have missed one, have a plan to divide up the work if possible.
Car Compliance	Compliance of the FSAE rules amongst all systems on the car. Commonly a big 'push' for compliance at the end of the year is required to meet all the FSAE rules, requiring large amounts of time.	Compile all of the relevant rules and inspections and divide them up by subsystem. Produce a table for technical engineers to fill out that details their intended method to ensure compliance rule-by-rule. Assist the technical engineers with finding solutions to compliance if it is not immediately apparent to them. Be more involved with the design approval process prior to manufacture and try to think about how our designs can enable easier ways to implement compliant solutions (such as embossed or recessed faces for areas requiring colour markings, access to measure critical components in tech inspection).	In technical inspections at competition, samples may be used for demonstrating compliance of systems on the car, however in 2024 most judges in mechanical tech inspect would always prefer to just check the compliance of the car itself, so enabling easy access to these components allows for a smoother technical inspection. Being confident in presentation and smooth in delivery will assist in a technical inspector believing that you have 'thought of everything' and are compliant across the board.
Competition Feedback - General	Each year FSAE releases feedback for teams based on their performance. They provide direct feedback for the design event. A chief engineer should plan to address this feedback.	The chief engineer should dedicate time to planning out methods to use to improve on the performance and to directly address any areas of recommendation made by the judges. A table can be used to sort out feedback and planned responses in a formal way.	Critical things such as team budget and team size should be accounted for in the planned responses to the feedback, and the chief engineer should try to ensure the solution is realistically achievable by the members of the team without pushing scopes too far.
Competition Feedback - Validation	Feedback from both 2023 and 2024 competitions is that NU Racing must work on the validation of both the changes that are planned to be made each year, and to validate the end result of the changes, isolated to each subsystem. This is to help identify in what way individual subsystems are actually improving, and how they contribute to the car as a whole.	A chief engineer could directly ask the technical team members to design tests or test equipment for validating parts of their design. Engineering is about coming up with solutions to problems, and the tests people design should validate that their solution meets the requirements, and is better in key areas compared to previous designs. There are many things that can be tested to derive metrics demonstrating an increase in performance. Things such as efficiency, thermal factors, deflection and stiffness of components, response behaviour to name a few.	An expensive but very informative way to do mechanical validation is destructive testing. Engineers should think carefully about allocating resources to do this kind of testing. Chassis stiffness testing should get a new method, as the currently used one from 2023-2024 only explores a tiny band of 'torque' amounts applied to the chassis. Many examples of chassis testing are available online. Electrical equipment should not be exempt from demonstrating subsystem level improvements. Bench testing should be done in more depth to include thermal testing and not just functionality testing. Weight of a node is not generally important but is an easy metric to document.
Team Performance Evaluation	Feedback and scores from competition does not directly reflect the efficiency or quality of work done by the team, the quality of communication within the team, team pride, or professional development of the team.	A form that is to be filled out by members of NU Racing at the start and end of each year, can demonstrate clear forwards or backwards progress in the areas mentioned by getting the team members to record their thoughts with simple 1-10 scales and notes.	Distinctions should be made for critical path students, but it is also important to consider the feedback that juniors or people new to the team may have, as this is important for team growth and the sustainable development of the team.

3. NU23 Summary

This section exists to convey to the reader the context behind the performance of NU23, and the intentions behind the developments that went into NU23 to better frame the understanding of developments made to NU24, and planned changes for NU25.

3.1. NU23 Goals

In 2023, the team performed preliminary testing of systems of EV.Three to evaluate and validate their planned changes to be made for NU23. Testing the effectiveness of EV.Three's aerodynamics package was done with back to back comparisons with and without the aerodynamics package, using ballast to account for missing mass. Improvements in driver feedback drove the decision to remove wings from NU23's design.

Asides from the preliminary testing, some necessary changes were self-evident from the performance of EV.Three. Major issues were present with the accumulator as dynamic performance was highly limited by temperatures inside of the accumulator, which must remain under 60 degrees Celsius for competition compliance. The powertrain of EV.Three featured two EMRAX 188 motors, driving independent rear driveshafts. Without implementation of torque vectoring, these motors only served to lower the power-to-weight ratio of EV.Three, without the usual benefits of a dual motor setup. A single EMRAX 188 motor would have been capable of outputting the power output that the EV.Three accumulator was capable of. The steering system from EV.Three was designed with unintended degrees of freedom and had side effects of binding, and was due to be updated for a properly constrained solution with a 90-degree bevel gearbox to replace a multi-link system of universal-joints (Hollier, 2023).

Informed by the goals of improving upon all of these designs, and in particular aligning all of the bottlenecks of EV.Three's performance, the team put together plans for potential fixes and the methods for integrating them into NU23. A breakdown of subsystem issues, fixes, and implementation methods is provided in Table 2. This tabulated breakdown was taken directly from Jye Hollier's final year project report and is <u>not</u> the original work of this report's author (Hollier, 2023). It is provided for context to the reader.

Table 2 - Summary of developments for NU23

Subsystem	Issues	Priority	Potential Fixes	Plan to Implement
Chassis	Non-compliant, new chassis not designed.	High	Chassis modified, or new chassis. Conservative changes to minimise change.	Required members modelled and ordered from VR3.
Accumulator	Temperatures	High	Improved air cooling, increase number of cells.	Consider chassis changes to increase space for improved packaging.
Powertrain	Excessive weight and complexity, traction issue, torque output, changes required to suit compliant chassis	High	Single motor/controller, spool final drive.	Design NU23 powertrain with changes in mind.
Steering	Not correctly restrained, no guarding for compliance.	High	New design, implementation of gearbox.	Incorporate mounting requirements into NU23 chassis.
Aerodynamics	Wing performance did not justify weight, difficult to install/remove.	High	Remove wings from NU23 design, develop body kit to provide sponsorship area.	Design a new single-piece body kit to suit NU23 chassis with extended coverage.
Cooling	Excessive cooling capacity and weight.	Medium	Implement rear mount for single radiator.	Incorporate new mounting into NU23 chassis.
Suspension	High ride height, must suit new chassis.	Low	Adjusted coil-over lengths to lower vehicle as no front wing requiring clearance.	Adjust later in year, minimising changes by maintaining geometry where possible.
Pedal-box / Braking	Pedal feel, not suitable for spool.	Low	Revised pedal-box design, revisions to plumbing to suit single rear caliper.	NU23 chassis to suit EV.Three pedal-box with potential replacement completed later in year. Plumbing changes as required for single caliper.

3.2. NU23 Competition Dynamic Performance

Across the board, NU23 managed to improve scoring in all dynamic events except for endurance and efficiency. This was due to an unfortunate BMS fault that occurred during the endurance run of the second endurance driver. Details on the BMS fault that occurred in 2023 are available in Jye Hollier's final year project report.

Acceleration performance for NU23 increased from EV.Three with a result of 4.45 seconds as opposed to 5.2 seconds, or 50 points compared to 15 points, in NU23's favour. NU23 was a car that was unfortunately not traction limited, meaning the full power and torque output of the single EMRAX 188 motor was not enough to break traction with the ground, and therefore did not perform to the maximum capabilities of the tyre compound.

Skid-pad times were improved from EV.Three's 5.44 seconds down to 5.29 seconds, resulting in a 2nd place for NU23 in the EV class for skid-pad. Jye Hollier mentions in his chief engineer report that a tyre compound change was made between 2022 and 2023, changing from Hoosier R25B to Hoosier LC0. There is potential that more efficient tyre loading contributed to the better skid-pad times of NU23 compared to EV.Three, as an approximate 50 kg of weight was removed in the development of NU23. Skid-pad, however, is very sensitive to unknowable factors such as ambient temperature, driver inputs, track conditions, and it is difficult to demonstrate for certain that an improvement in steady-state cornering performance was made, in a meaningful and consistent manner.

NU23 placed 2nd place in auto-cross for the EV class with 120 points, up from 93 points by EV.Three. Like skid-pad, times in this event have many external factors influencing them, including the change of track and location from 2022 to 2023.

The endurance event was left uncompleted due to a BMS fault, scoring only 9 points, 1 point for each completed lap, out of the available 275 points. Efficiency scores also decreased as in 2022, EV.Three was driven at a much more conservative pace to regulate the thermal issues of the accumulator (battery pack).

Asides from endurance, 2023 was a very successful year for NU Racing and NU23 as a platform, that proved the notion of aligning bottlenecks and aiming for as simple a car as possible could still provide incredibly competitive dynamic results within the Australasian FSAE competition. For this reason, and for sustainability of NU Racing, the author recommends that NU Racing sticks to the continued incremental improvement of it's already competitive NU23 and NU24 platforms.

Figure 2 - NU23 amongst other FSAE cars at 2023 competition

4. NU24 Summary

4.1. 2023’s Design Goals for 2024

From September 2023 to January of 2024, members of the 2023 team who were finishing up their FYP’s within the team were tasked with the design of NU24 to have a smooth handover with designs ready for order and manufacture by the 2024 team.

Upon the success of NU23 and the significant weight reduction from ~300 kg down to ~250 kg (~16.6% reduction in weight) the goals for the 2023 team in the design of NU24 were not explicitly stated, and instead the mentality from the design period of NU23 was carried across to the NU24 design period executed by the 2023 team.

This meant that designs made for NU24 initially were focused on iterating on existing systems, with weight being the primary design factor that was to be optimised for. Unfortunately, a focus on weight reduction without clear design direction from the 2023 leadership lead to many issues in the designs, flawed in ways such as increased part count, increased deflection, or issues in the manufacturability.

This is not the fault of the leadership of 2023, as the original chief engineer had left early in the year due to an incredible job opportunity, meaning the lead mechanical engineer Jye Hollier would have to step up into the chief engineer role. This left the lead mechanical engineer role vacant, and with the reduced capacity leadership operating at full speed in the lead-up to competition due to technical issues involving motor controllers, focusing on repairing and testing NU23 took justified priority over designing NU24. Without guidance from the leadership team, many technical engineers were left designing a car with no clear vision, through no fault of their own.

4.2. 2024’s Team and Design Goals

Expectations for the 2024 team included increased driving time compared to 2023, to spend more time driver training. Driver training is arguably one of the best time investments an FSAE team can make when it comes to extracting performance from their competition platform. Dynamic event points make up 67.5% of all available points at competition, so having well trained drivers who can extract the most pace from a team's car is critical. Driver training also familiarises drivers with any potential issues with the car, such as thermal regulation of batteries through throttle control. Spending time with NU24 driving was a high priority for the 2024 team, as it was evident throughout 2023 that driving NU23 was the best way of identifying technical issues with the car, which can then be fixed. A slow functional car that is well tested and completes every event with mechanically sympathetic drivers will score points. Fast cars that don't finish events don't score points.

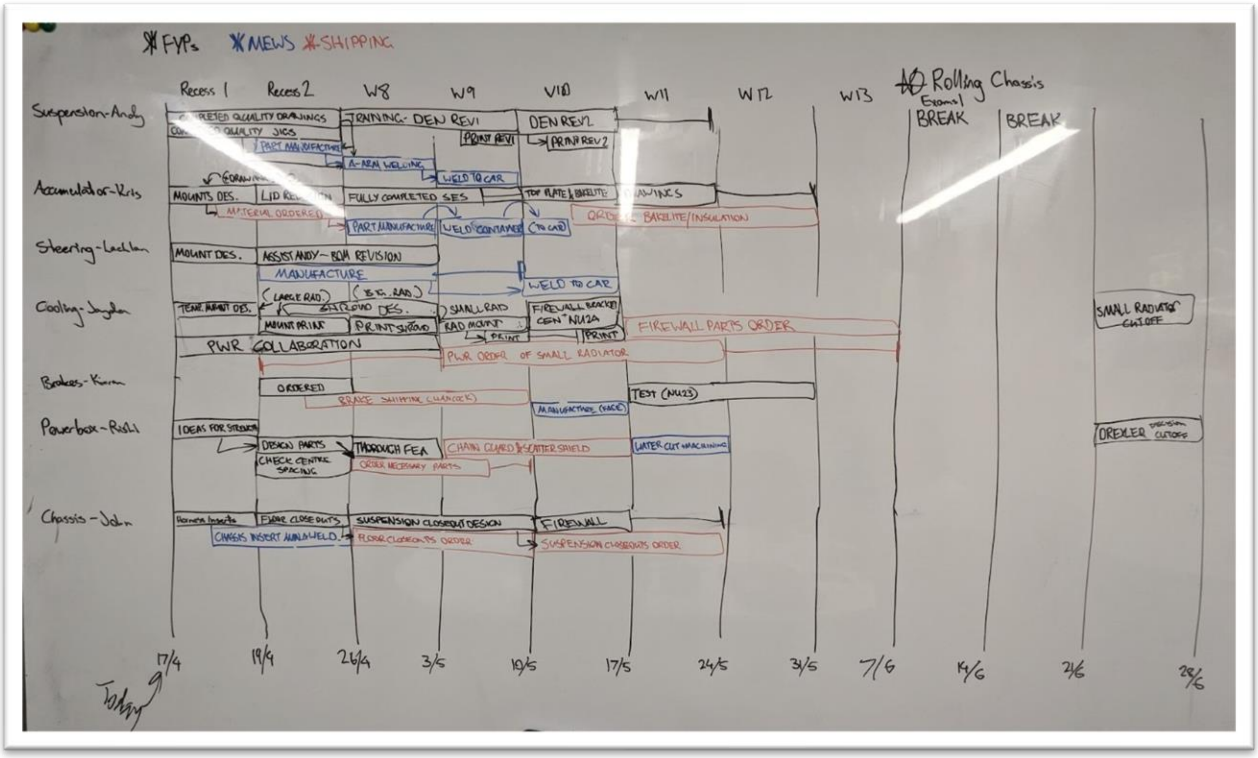


Figure 3 - Whiteboard Gantt chart for planning several weeks of work

Driven by the team goals of having a rolling chassis by the 31st of May, and a driveable car by the 30th of June, the author along with the leadership team created timelines from handwritten Gantt charts on whiteboards, with an example seen in Figure 3. Handwritten timelines are one of the most useful techniques for identifying the flow of work on the critical path, and for deploying resources appropriately. Working in a leadership meeting to write out these timelines starts with placing goal dates for deliverables, followed by working backwards to work out the time allocated to various stages of technical projects. After this, it is critical to place deadlines at some time after the goal delivery date. A plan should be put in place for if a project misses its goal delivery date, and it is recommended to involve final year project supervisors – to at least make them aware of the problem, and to work towards a solution suitable for all students involved. If deliverables are not submitted by the deadline, drastic measures may need to be made.

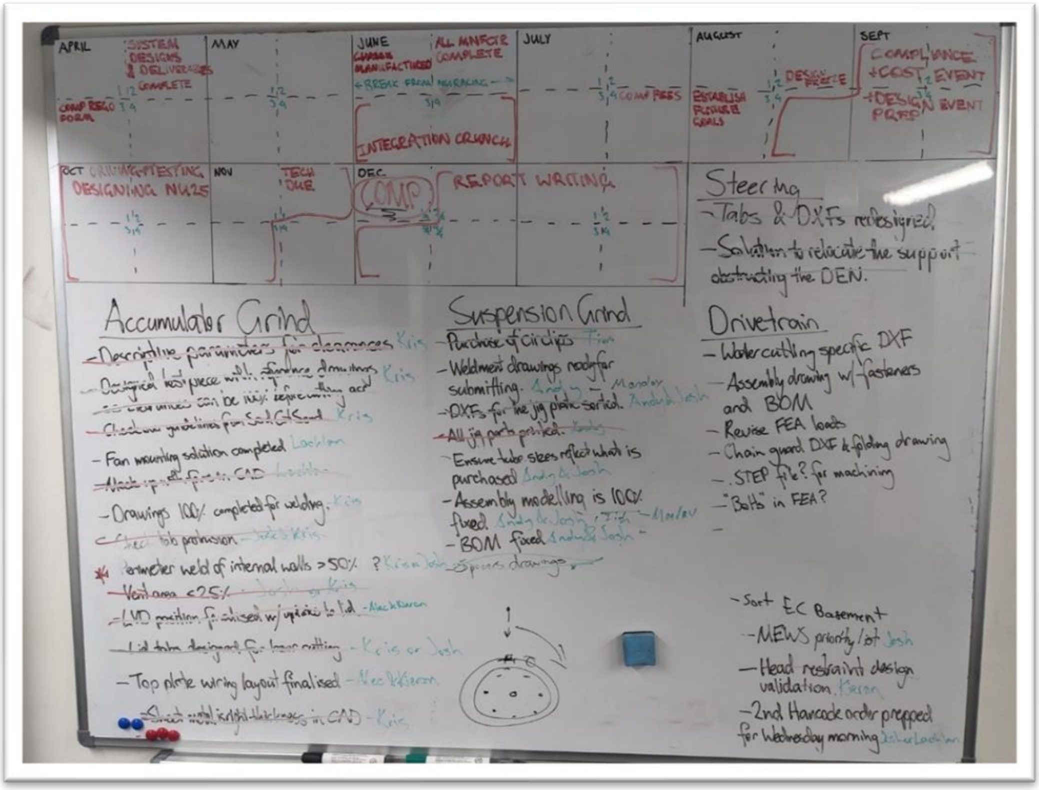


Figure 4 - Whiteboard year planner, including checklists for work due in a "crunch period"

Depending on the priorities of a deliverable, goal dates for deliverables may be pushed back, or the scope of deliverables may be cut down to meet the goal date. Priorities for deliverables are uniquely individual to each technical project in NU Racing, and the chief engineer must come to understand the scope of each project, and the significance of the goal and deadline dates to be able to balance them with the abilities of the students applied to the scope.

Communication of student scopes was done through chief mechanical engineer and chief mechatronic engineer roles in 2024. For further information of effective communication of workloads and scopes to technical students, refer to the reports of Lachlan Fisher and Alec Chapman for 2024.

Sacrifices to the intended development of some systems was made in favour of driving NU24 sooner. The steering system of NU24 as designed by Drew Bender included aluminium link bars to make the steering gearbox supports entirely removal from the chassis, a development intended for future use with a monocoque chassis. An issue with this design included the addition of an aluminium link bar directly in the way of the MoTeC dash system that is necessary to provide key information to the drivers of NU Racing’s FSAE cars. Without the central upper link bar, the decision was made by the author to have the steering supports redesigned by Lachlan Fisher to resemble a similar welded steel tube and mount plate design to that of NU23, due to concerns over the stiffness of the remaining aluminium steering supports. A reduction in material used was still possible due to the neatened packaging provided by Drew Bender’s design of the steering input shaft and bearing block. The steering system was still able to reduce part count and weight, while maintaining function by cutting scope from the project.

Throughout early 2024 it was intended for a newer smaller radiator to be purchased and tested on NU24 to examine the possibility of running NU24 with a smaller, lighter, potentially more efficient cooling system. Due to prolonged wait times in the selection and ordering process, testing and implementation of the smaller radiator was scrapped. To make this decision, a hard deadline was put into place by the leadership team, after which – if a new radiator had not arrived – the testing of the new radiator would be scrapped. Original intentions were to purchase 2 of these smaller radiators, but financial concerns resulted in only purchasing 1 new radiator. Intentions to test the radiator on NU25 are detailed in section 8.7.

Table 3 - Summary of changes for NU24

Subsystem	Issues	Priority	Fixes / Improvements	Plan for Implementing
Chassis	Excess member count and therefore weight. New chassis required each year to avoid loss of points.	High	Design by Joseph Barker. Reduced member count and mass, shortened wheelbase and track to move towards a tighter handling car.	Check over of critical dimensions, notching, and order process all done by the author.
Suspension	Direction of car was to move towards a smaller and nimbler car in general. Wanted to test potential improvements to manufacture method.	High	Reduction in wheelbase and track width. Change to design to have notched tubes and turned bearing pockets.	Finalising design, engineering drawings, manufacture jigs.
Accumulator	Still temperature limited. Excess weight from steel container.	Medium	Design of an aluminium container initially made by Jacob Searle. Retain the increase from 8 to 9 segments from 2023 as this significantly dropped temperatures to a level allowing competitive performance.	Check over of design. Required changes to sealing electrical connections, mounting, manufacture method, material profiles before it could be made.
Powertrain	To extract the full potential of the drive tyres, drivetrain must become traction limited.	High	Change to EMRAX 228 motor and select gearing to achieve wheelspin at the rear.	Design and manufacture of powerbox taking into account changes to chassis space.
Steering	Increase of part count in handed over design. Aluminium supports presented concerns with stability of components.	High	Change back to the style of mounting of NU23 but with changes to the mounting plates afforded by the improvements made by Drew Bender's design for retaining the steering wheel input shaft.	Redesign mounting to be welded and more suited for the space frame by foregoing the high part count modular monocoque compatible design.
Aerodynamics	Low influence on vehicle design and packaging due to findings of 2023 team's aero testing. Design must be made to accommodate the rest of the car.	Medium	Must provide clearance for the changes to coil-over positioning and the general chassis shape overall. Improved stiffness through returns on edges and added geometry around front coil-overs.	Design by the author as an ENGG3200. Manufacture was not a scope allocated to anyone at the time of the designing.
Cooling	Rushed design due to 2023's motor controller incident requiring higher flow rates for a new controller type.	Low	Requires further validation of flow rates through motor controller.	Testing via flowrate meters. Purchasing of the pumps recommended by Cascadia if needed to obtain higher flowrates.
Pedalbox	Needs to fit new chassis. Old pedalbox could not be used due to a much smaller front bulkhead changing lower front bulkhead support tubes.	High	Smaller pedal box to suit chassis, reduced weight.	Follow typical design, review, manufacture process.
Brake Package	The brakes theoretically could have lighter rotors without reducing brake performance	Low	Lightened brake rotor design with 'drilled' rotors supposedly seeing benefits in dust buildup and cooling rates.	Manufacture of an already complete design

Even with the reductions in scope for some projects, it is important to note that the amount of manufacturing done in 2024 is not likely to be a sustainable practice for NU Racing in future years, as the size of the team of students working on the critical path to competition is varied year-to-year, as well as the abilities of the students onboarded to critical path scopes. The manufacture workload of 2024 was partially determined prior to the onboarding of 2024's final year project students. This resulted in ambitious changes across the entirety of NU24 and necessitated the scope reduction of certain projects post-haste. Moving forward, the author highly recommends future chief engineer's scope out the bare minimum changes before considering other optional upgrades for when it comes to planning the developments of the next year's team, alongside providing a clear vision of the planned integration of the systems, keeping driver time and minimum-viable-product in mind.

4.3. NU24 Competition Dynamic Performance

Scores for NU24 and the 2024 team in both static and dynamic events are displayed in Figure 5, however this section only covers discussion on the dynamic performance of NU24.

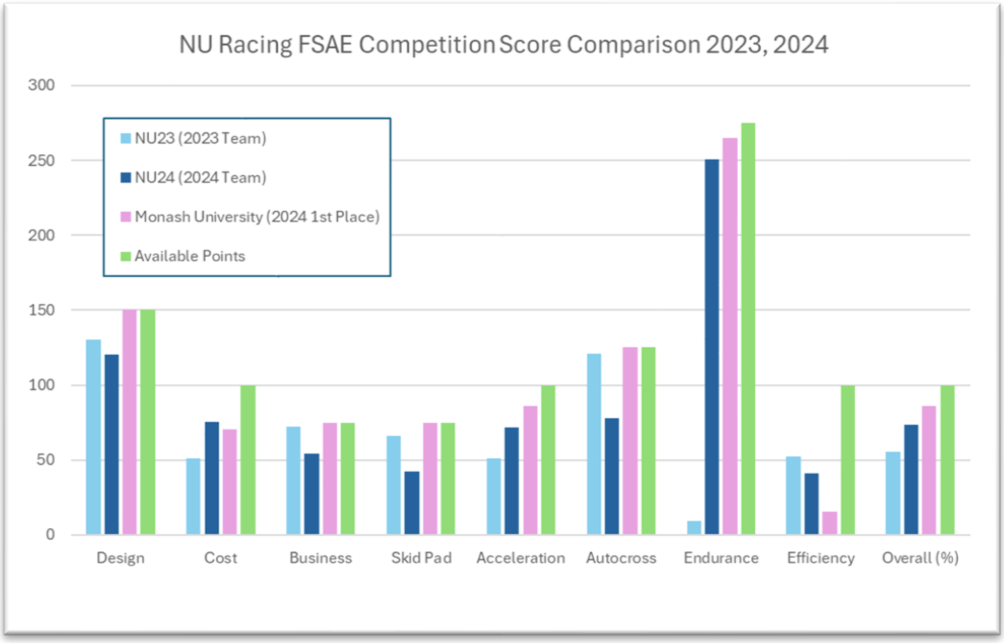


Figure 5 - NU Racing competition scores for 2023, 2024

In the acceleration event, NU24 ran a 3.939 second time. This is much faster in comparison to NU23's 4.45 seconds acceleration run. As a result, NU Racing achieved 4th place in the 2024 acceleration event. The primary change that would have contributed to achieving this result is the implementation of the EMRAX 228 motor, which delivered more torque to the ground than NU23 was capable of. It is worth noting that the acceleration of NU24 was not traction limited by the tyres to the asphalt, like NU23. In fact, observations after the acceleration runs saw that the stickers on the wheels – used to mark tyre and wheel combinations as having passed technical inspection – had sheared as the tyres had spun on the wheels before traction with the ground could be broken. To achieve faster acceleration times, either NU25 and future cars must lose mass, or a method to affix the tyres to rims that prevents them from rotating relative to each other must be used to transfer more force into the ground.

Skid pad saw poor results for NU24, as overcast weather meant puddles were present on the course. With both driver's completing their runs before the sun had come out, the track dried up allowing for other teams to set much better times on dryer warmer asphalt.

Auto-cross for NU24 saw the first driver completing a "banker" lap. This is a safe lap for the sake of putting a time down to ensure some points are scored at a minimum. On the second lap of the first driver, NU24 experienced a battery management system fault. Recommendations for remedying this fault are contained in section 7.1 and reports by Joshua Hayward and Alec Chapman. The resulting score for auto-cross in NU24 was low in comparison to the fantastic laps done by Zak Lobko in NU23, which were enough for 2nd place in EV class auto-cross in 2023.

Endurance for NU24 went smoothly with updates to the firmware settings in the battery management system in the accumulator, as a temporary fix to the issue that occurred in auto-cross. Consistently competitive lap times were set resulting in a very competitive score. Compared to the performance of NU23 in endurance which did not finish, this marked a great accomplishment for the 2024 team, securing their place as the highest scoring year of team in NU Racing's history.

The overall performance of NU24 at competition was fantastic and scored the team 4th place overall for the EV class. NU24 is a competitively viable car for the dynamic events of FSAE Australasia, and future teams should seek to make wise decisions regarding the sustainable incrementation and development of systems of the car.

5. NU24 Subsystem Work

This chapter covers the most important bodies of work done by the author on the NU24 project at a technical level.

5.1. Chassis

The design for NU24's chassis was created by Joseph Barker from the 2023 NU Racing team, and further details on the design process are available in his FYP report.

In February of 2024 the author of this report completed a check-over of Joseph Barker's work to ensure the chassis was suitable for manufacture, suitable for NU24's subsystems, competition compliant, and ready for order. Afterwards the author did the correspondence with the Canadian company "VR3 Engineering" for ordering the individually bent and notched chassis tubes. Upon the commencement of the first round of welding at the Mechanical Engineering Workshop (MEWS) in EC Building, the author did the simple design work required for the anti-intrusion plate and later the attachment of the FSAE standard honeycomb impact attenuator.

The ordering process included making a design with re-notched tubes for a standalone rear half of the chassis to be used as a part of the half-monocoque-half-space-frame design for Josh Bywater's final year project.

The chassis for NU24 is a space frame style welded tubular steel chassis like those seen elsewhere in motorsport. A steel space frame is suitable for NU Racing at the present as NU Racing's cars tend to be designed (at least in part) in the year that they are entered for competition. This is beneficial to the team due to the ease of adding additional brackets and tabs to the chassis via welding, compared to a composite monocoque style design, which must have inserts added to the chassis during layup for attachment of critical components. Other advantages of space frames are that they allow for easier access to components across the entire car and manufacture can generally be outsourced to workshops (preferably the Mechanical Engineering Workshop – MEWS) for welding, ensuring quality and better accuracy of manufacture compared to a student welded chassis.

Primary benefits of a monocoque design include increased stiffness to weight ratio (which is difficult to truly analyse the benefits of without a complicated lap time sim, modelling four corner suspension with chassis stiffness included), potentially much lower weight, and the experience students gain from working hands on during the manufacturing process. Developing a monocoque chassis that outperforms a steel space frame typically requires years of experience accrued through multiple people working as a part of a dedicated team completing considerable amounts of engineering work to test and document layup structural equivalencies, methods for manufacture, repairs and other such work.

A steel space frame can realistically be designed by a single engineering student with under a year of FSAE experience by reading reports from previous chassis engineers, and with a decent understanding of CAD best practices and intuition regarding manufacture. This is due to the structural equivalency spreadsheet requirements dictated by FSAE being based on meeting equivalency for a steel tube chassis, where all requirements of a steel tube chassis are documented in a manner that a chassis can be designed to be rules compliant. For example, all key dimensions and thickness of tubes, as well as nominal potential layouts of named tubes are documents in the structural equivalency spreadsheet.

A well-executed and well-built monocoque chassis, paired with suitable accompanying sub-systems could greatly outperform a steel space frame in terms of total mass, and potential suspension performance due to a stiffer chassis increasing the ‘effectiveness’ of tweaking suspension characteristics. However, as previously stated, proving definitively the magnitude of benefit gained by a monocoque chassis is a difficult task.

5.1.1. Structural Equivalency Spreadsheet

The structural equivalency spreadsheet (SES) is a spreadsheet provided by FSAE that documents the design of a few critical components of an FSAE team’s car. It uses formulas to demonstrate compliance with the relevant structural rules. The spreadsheet records the use of tube thicknesses in certain parts of the car, the selection of different layouts of tubes, distances between key points, welded inserts into tubes, accumulator design, and front-on collision protection amongst other key details. When filling out cells in the SES it will automatically evaluate if a rule is satisfied using the calculations within the SES spreadsheet, and will label cells as EQ (equivalent), CHECK (must be inspected in further detail by FSAE upon submission), or REJECT (grounds for rejection/non-compliance).

When filling out the SES it will list the rules pertaining to the section being filled out alongside a brief description, however it is always best practice to fill out the SES with a copy of the rules open to be able to reference the wording within the actual rules document, as well as the Australian local rules addendum. This is due to some inconsistencies in how rules are worded between the SES and the rules documents which may cause confusion. If in doubt, it is recommended to make a rules inquiry.

The SES is a submittable document to FSAE Australasia and must be filled out in completion prior to its due date, and submitted on time or teams may risk non-compliance or disqualification.

A preliminary SES was filled out by Joseph Barker in the process of designing NU24's chassis. The author filled out a separate SES document from scratch to double check the work of Joseph Barker, including the tube chassis section and additional work completing the designs for the welded inserts and front impact protection sections.

5.1.2. CAD Preparation

The CAD program used by the NU Racing team is currently Onshape, a browser based parametric modelling software with a set of modelling tools specifically intended to be used for frame based designs. The typical modelling process uses sketch features to define points and curves from which the frame tool is used to generate the tubes.

The chassis tubes for both NU23 and NU24 were ordered through VR3 Engineering in Canada. On their website is a range of available documents describing the requirements for producing suitable CAD files (VR3 Engineering, 2023).

The '3D Modelling and Document Guidelines' document from VR3 Engineering covers guidelines for correct modelling procedures. The most important things to pay attention to prior to reaching out for quotes are as follows:

- Be aware of how the tubes are notched. The cut path follows the loop at the edge of the tube that has the complete thickness of the tube, effectively removing feathered edges from the tubes as seen in Figure 6.

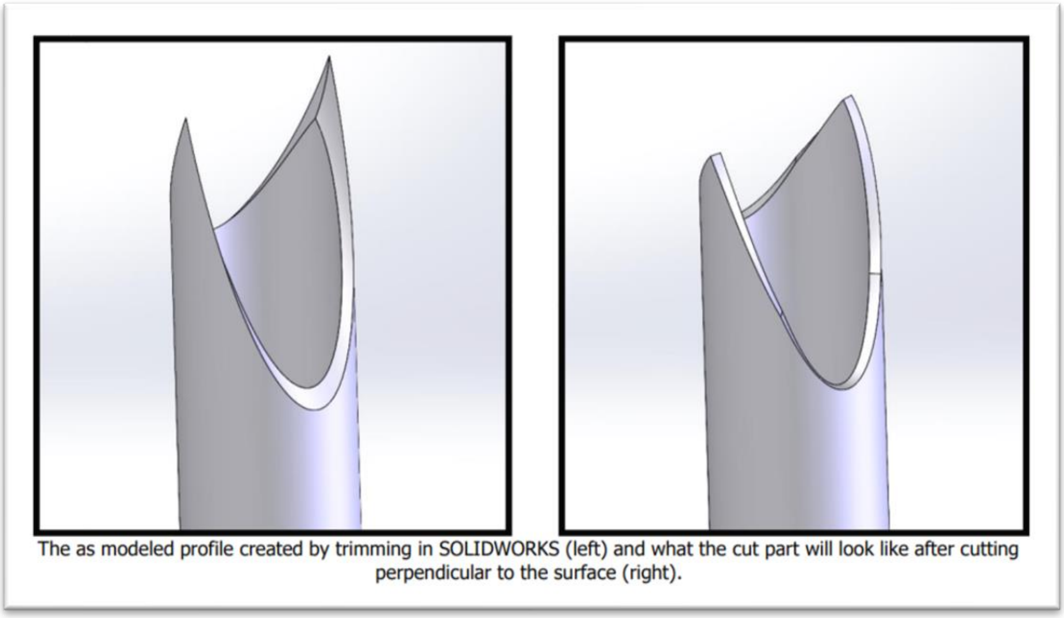


Figure 6 - Demonstration of tube notching path (VR3 Engineering, 2023)

- Ensure that the bend radii used by the CAD match that of the CNC mandrel bend tooling list provided by VR3 on their Technical Documents page.
- Ensure the profiles used, particularly for square and rectangular profiles match the profiles stocked by VR3. A document is provided by VR3 Engineering on their website with sketches of each of their commonly stocked profiles. Sketches can be made in standalone part studios and used as inputs to Onshape's frame tools.

- Avoid "hollow nodes" as this can add difficulty to the assembly process and especially during welding, and results in a marginally weaker joint. Issues during welding arise from the cut path followed during the notching resulting in gaps that must be filled.

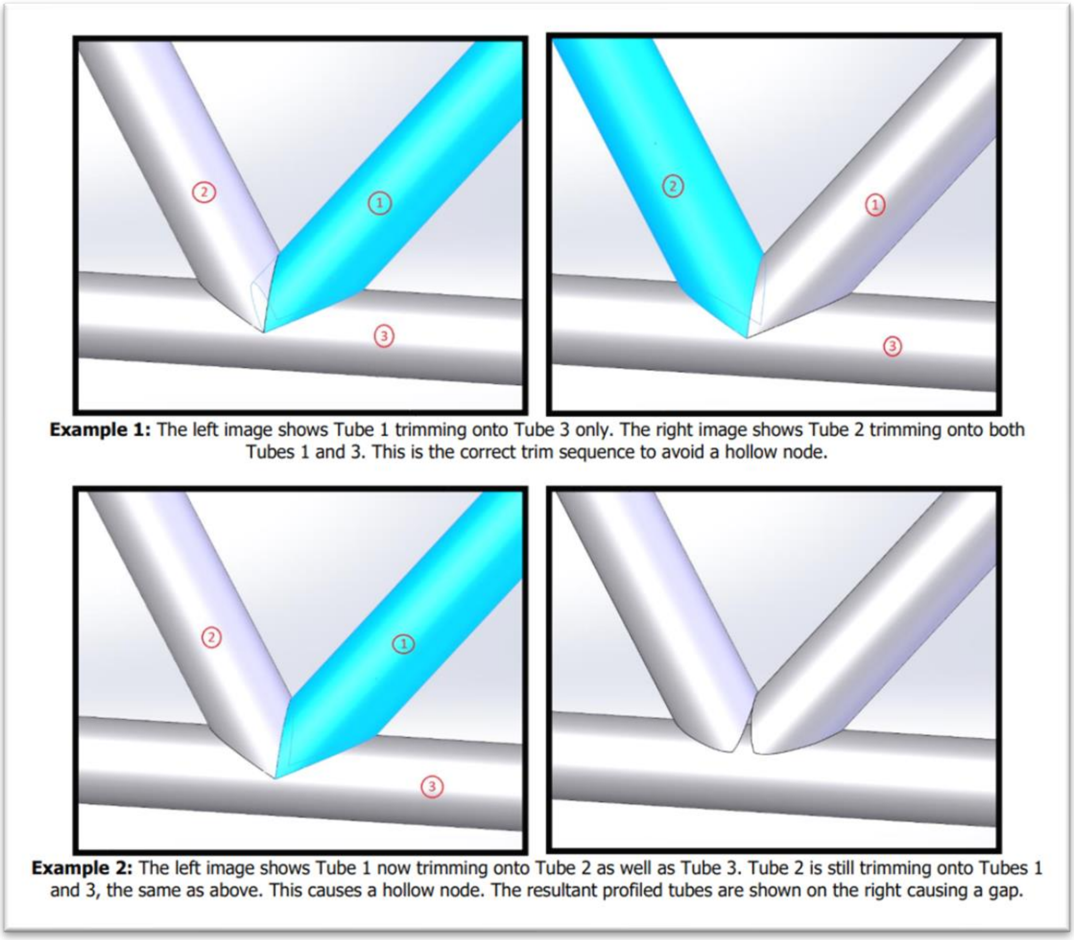
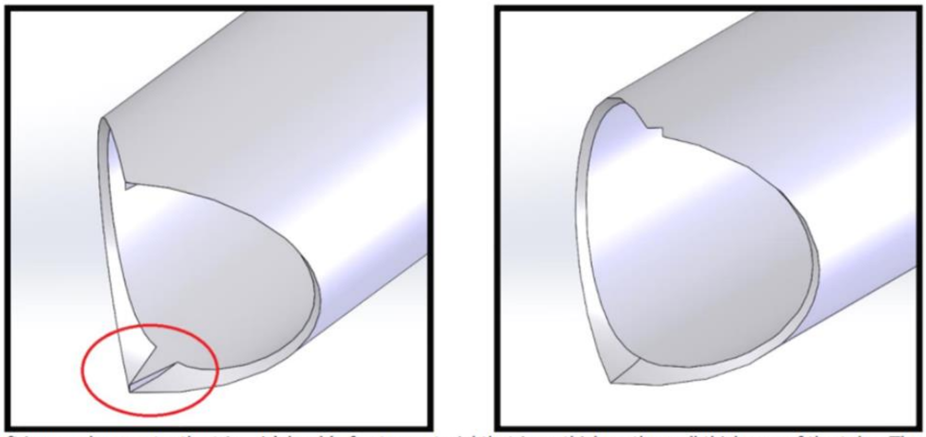


Figure 7 - Demonstration of hollow nodes (VR3 Engineering, 2023)

- Avoid 'toothy' trims with sections of full thickness tube jutting out along the notched edge, as this can interfere with the intended fitment of the tubes.



The left image shows a toothy trim. A 'chunk' of extra material that is as thick as the wall thickness of the tube. The right image shows a properly trim to a mitre. Notice the top 'V' cut out. This generally means the trim to the mitre is good.

Figure 8 - Demonstration of toothy notching (VR3 Engineering, 2023)

- If you are unsure about notching order, a conversation with staff at MEWS can prove incredibly beneficial.
- Further instructions regarding notching can be found in Jye Holliers FYP report of 2023.

5.1.3. Half Monocoque

In February of 2024 when the chassis ordering process was underway, the author did work to model the half chassis intended to be used by Joshua Bywater's FYP project of the aluminium monocoque.

This half-tube-half-monocoque design would require tubes notched in a different style compared to the regular NU24 chassis. The purpose of the different notching is to enclose the ends of all tubes as per the FSAE rules to prevent any open-ended tubing being present.

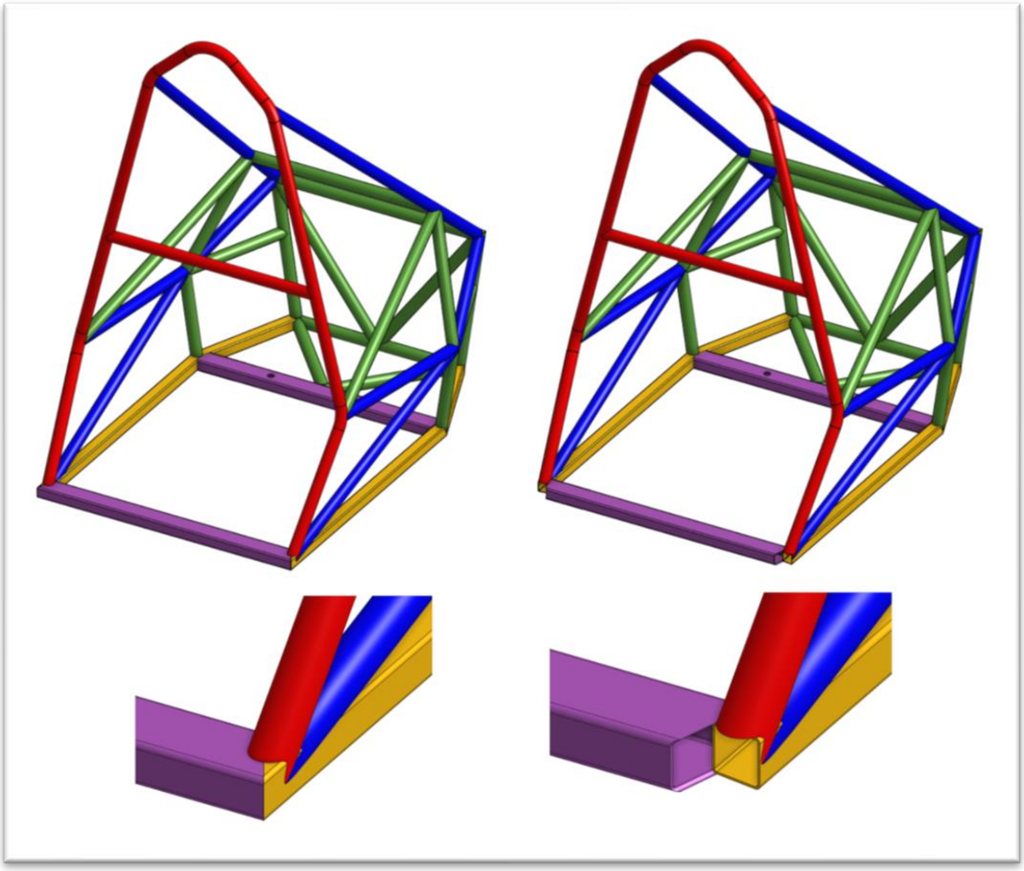


Figure 9 - Differences in notching between half-chassis for monocoque (left) and regular NU24 chassis (right)

This resulted in 5 uniquely notched tubes for the monocoque. Duplicates of the remaining tubes for the half-monocoque would be added to the order in the BOM as well as the uniquely notched tubes.

5.1.4. Document Preparation and Ordering Process

For the purposes of ordering a tube chassis through VR3 Engineering after completing check over of all items mentioned previously in section 5.1.2, an engineering drawing clearly labelling every tube in the chassis alongside an exported .STEP file from the chassis assembly can be used for an initial reach-out to VR3. The engineering drawing submitted to VR3 engineering by the author is available in Appendix B – NU24 Chassis Drawing.

Table 4 - Preparation checklist for reaching out to VR3 Engineering

Purpose of Inquiry	Items Required	Description	Checklist	Note
To inintally reach out to the VR3 engineers to check your CAD work is suitable for manufacture. The drawing must be clearly labelled to engage in a proper conversation by referencing tubes by number. If done to a proper standard this can be enough to provide a quote.	Engineering drawing of entire assembly	An isometric view engineering drawing with every tube clearly labelled. This drawing is important as it will be need to be referenced by the engineers at VR3 when trying to describe any tubes or joints that have flaws.	Clearly labelled BOM with: Tube number, tube name, profile, estimated length of raw section required	Onshape does not allow renaming BOM columns. Someone with admin privileges is able to temporarily rename 'Title 1' and 'Title 2' custom sections in the organisation settings to allow for an export of the drawing with correctly named 'Profile' and 'Length' columns.
	.STEP file of entire assembly	.STEP files are a universal CAD format that can be opened in nearly all parametric CAD packages. The entire assembly is used for the initial reachout as it contains every tube that can be inspected individually and also allows the VR3 engineers to inspect correct notching between multiple tubes in the context of each other.	Correctly notched tubes. All tubes thicknesses checked against minimum requirement by SES.	Inspect the .STEP file by opening it to make sure it was exported as intended. Orientation does not matter. Make a version in Onshape prior to exporting.
To provide all files needed to VR3 for them to update the quote if necessary. After these files are sent you have done all final checks you may be ready to approve the manufacture of the order. VR3 typically aims to manufacture tubes within 2 weeks from approval and will send for shipping once the shipping information is complete alongside NU Racing's ABN number in place of the EIN number.	Engineering drawing of entire assembly	The same drawing as before, updated if necessary. Include revisions in title block with an apt description.	Clearly labelled revision in title block and file name.	-
	.STEP file of entire assembly	The same .STEP file as before but with revisions made to the CAD as per recommendations by the engineers at VR3.	Clearly labelled revision in the file name.	Make sure to action all feedback by the VR3 engineers. Make a version in Onshape prior to exporting.
	BOM	The BOM template provided by VR3 filled out to completion. Additional columns for area, estimate length, volume and therefore mass can be used to add additional required information. Make sure to describe which tubes are bent with what number of bends, and which tubes have holes / notching at places other than just the end.	For each tube, BOM contains: Customer part number Item number matching drawing Quantity Outside dimensions Profile type (round, square, rectangular) Wall thickness Approximate length Estimated weight Bend features (number of bends) Holes or cutouts (Y/N)	Example email chain from 2024 including attachments emailed to hello@nuracing.org
	.STEP files of each individual tube	The individual files for every tube used by VR3 to generate their tooling code.	Name every step file with just the number corresponding to that tube.	These can be attached as a compressed .ZIP file of a folder containing all the tubes. It is recommended to make a version in the Onshape at the point in which you export these.
	Shipping Information	Shipping information form to be filled out and sent back to VR3.	All entries filled correctly.	May be sent by VR3 when they are ready to provide a quote. Consider asking if you cannot locate a copy of one and are ready to fill one out.

After completing the initial reach-out an engineer from VR3 will contact the student in correspondence with any necessary changes needed to be made to the CAD. If the CAD and drawing are to a suitable standard a quote may also be put forward at this point.

When ready to move forward a follow up email can be sent with the attachments listed in the blue section of Table 4.

Shipping information will need to be filled out and provided prior to shipping, however an approval to manufacture can be sent before this. Approval to manufacture should only be given once all files have had a final check-over and finances within NU Racing are appropriate, and a purchase order has been initiated within NU Racings current purchase order system.

When corresponding with the team at VR3, it can be helpful to call in the early hours of AEST (2 AM to 5 AM) to inform VR3 you have responded. Often being on the phone with any business is useful when trying to speed up the process of responses.

Manufacturing at VR3 is aimed to be completed within 2 weeks of approval to manufacture, and shipping via DHL air express was approximately 1 week in 2024. Timelines are subject to change and should have an appropriate buffer when setting timeline goals.

Shipping was supposedly going to have an increased cost due a “bent out of plane” front hoop and main hoop in 2024 but should not generally be considered a financial factor as shipping is small compared to the total cost of the chassis.

5.1.5. Chassis Upon Arrival

Regarding compliance with FSAE, when the chassis tubes arrive on campus, it is important to take stock of all the ordered chassis tubes including the thickness of the material. To do this the author moved tubes from one pile to another measuring the thickness of each tube with vernier calipers and marking off the corresponding tube from the previously created engineering drawing(s) as seen in Figure 10.

Figure 10 - Marked off order received from VR3 Engineering

Included with an order from VR3 will be a document containing certification of the origins for all the materials used for the order, and this must be scanned as a digital copy and kept for record keeping. This is important as at competition, it may be required for proving the suitability of the material for the chassis. A hard copy should be present for tech inspection if required.

5.1.6. Anti Intrusion Plate

The anti-intrusion plate is a plate located on the frontmost face of the front bulkhead intended to prevent intrusions of foreign objects into the cockpit of the car from a front-on direction. As per FSAE rules it must be made from either 1.5 mm thick steel, 4 mm thick aluminium or a composite material demonstrating structural/energy absorption equivalency.

Given that the chassis was already ordered from 4130N steel and was to be welded, this meant potential options for bonding was welding for steel, bolted joints for all material options, or bonding for all material options. Benefits for NU Racing using a detachable (bolted) impact attenuator (IA) with a steel spaceframe chassis are limited as the access to all components on NU24 after removal of the body-kit already greatly exceeds the access available to components on a monocoque style chassis. This means that for a steel space frame the deciding factor for attachment came down to weight, as ease of attachment for welding and bonding is very similar.

For the sake of completeness, simple calculations for the minimum weight of a welded steel design compared to a bolted aluminium design were compared.

FSAE rules state the minimum area covered by a welded steel AI plate must cover up to and including the centreline of the chassis tubes viewed from the front, whereas a bolted or bonded joints must have an AI plate extending up to or beyond the entire front-on perimeter of the front bulkhead. For NU24's square bulkhead of 275 mm tube centres with 25.4 mm diameters, the following AI plate masses can be derived.

Table 5 - Anti intrusion plate basic mass calculations

Material	Area Covered (cm^2)	Minimum Thickness (mm)	Density (g/cm^3)	Estimated Mass - excluding welds, fasteners (g)
Steel - Welded	756.3	1.5	7.9	890.5
Aluminium - Bolted/Bonded	902.4	4.0	2.7	974.6

From Table 5 above for the welded steel AI plate the estimated minimum mass is less than that for the aluminium plate whether the aluminium is bolted or bonded. To bond the aluminium plate either rolled edges matching the front bulkhead, or plates welded to the front bulkhead to provide a flat adherable area must be added, increasing mass beyond the basic estimate. For the bolted aluminium plate, bolts must be added including either chassis tube inserts or welded tabs, increasing mass. The welded steel plate only requires that it be welded (like most other designs requiring at least some welding) and reduces part count and mass compared to all other designs.

For these reasons, the welded steel AI plate was the chosen design for the steel chassis. Even without an analysis of the weight this should be an obvious choice for a steel chassis designer, but the full thought process is documented here for clarity.

In the future if the team moves to a monocoque chassis, a bolted aluminium or bolted composite AI plate would be preferable as they regain some amount of access to the leg area of the chassis when working on the car, while being lighter than a bolted steel option (as bolted steel must cover the same area as bolted aluminium/composite).

Engineering drawings for the AI plate made by the author can be found in Appendix C – Anti Intrusion Plate Drawings.

5.1.7. Impact Attenuator Attachment

For 2024 NU Racing changed to using the FSAE standard aluminium honeycomb impact attenuator to meet FSAE compliance requirements, as opposed to previous years of using the FSAE standard foam impact attenuator. The primary advantages of the aluminium honeycomb impact attenuator (IA) are that it is significantly lighter while also being smaller in all dimensions compared to the foam IA, allowing for a smaller front bulkhead of the chassis, smaller nosecone, and overall shrinking of the front of the car.

The aluminium honeycomb IAs purchased by the 2024 team were ordered from “Plascore” in Michigan of the USA and were $70 USD each plus $470 USD shipping at the time of purchase.

There is the option of designing a custom IA in the future however due to factors including the compliance requirements dictated by FSAE, it is not a good option for the team to do:

- In 2024 the NU Racing team purchased 6 honeycomb IA’s, with 5 being spares. Which assuming no front-end collisions will last 5 more years.

- The aluminium honeycomb IA is already at the smallest possible dimensions allowed by FSAE (200 mm long, 200 mm wide, 100 mm tall), therefore packaging of the front of the car will not improve by making a custom IA.
- The aluminium honeycomb IA is less than 680 g. Trying to lose weight from the IA is not to be considered a low-hanging fruit.

F.8.5 Impact Attenuator Attachment

F.8.5.1 The attachment of the Impact Attenuator to the Anti Intrusion Plate or Front Bulkhead must be documented in the SES submission

F.8.5.2 The Impact Attenuator must attach with an approved method:

	Impact Attenuator Type	Construction	Attachment Method(s):
a.	Standard or Custom	Foam, Honeycomb	Bonding
b.	Custom	other	Bonding, Welding, Bolting

F.8.5.3 If the Impact Attenuator is attached by bonding:

a. Bonding must meet **F.5.5**

b. The shear strength of the bond must be higher than:

- 95 kN for foam Impact Attenuators
- 38.5 kN for honeycomb Impact Attenuators
- The maximum compressive force for custom Impact Attenuators

c. The entire surface of a foam Impact Attenuator must be bonded

d. Only the pre-crushed area of a honeycomb Impact Attenuator may be used for bond equivalence

Figure 11 - FSAE rules for attachment of the impact attenuator

The primary challenge of attaching the aluminium honeycomb IA is that due to its smaller size, the requirements of the adhesive suitable for its attachment are increased compared to the foam IA. Specifically, the shear strength of the bond between the aluminium IA and the AI plate must be at least 38.5 kN for honeycomb IAs. For attaching the foam IAs in the past, NU Racing was able to use Sikaflex 552 as the adhesive, but for NU24 the author found that using Loctite Epoxy Marine was suitable for attaching the IA.

The 2024 SES and previous SES documents do provide a list of recommended adhesives for IA attachment however these are all adhesives that are available in the USA and not Australia. To meet the requirements for adhesives dictated by the 2024 rules, “referenced bonding strength must be appropriate for both substrate types” (SAE International, 2023) and therefore any referenced datasheet must reference the shear strength on both an aluminium bond surface and a steel bond surface. For this reason, it is difficult to find technical datasheets for adhesives available within Australia that provide at least this much detail.

If for some reason a usable adhesive with a sufficient technical datasheet cannot be found in the future, the author recommends doing testing for equivalency using the tensile testing machine available in EC. This will likely require clarification and a rules enquiry however, as the test procedure for adhesives used in FSAE is only described for bonding of laminates (such as lap joints in a monocoque chassis), and it should be investigated as to if this is also the intended method for testing equivalency for IA attachment, or if other similar test procedures must be used.

A method for calculating the area of the pre-crushed surface of the IAs that is used for the bond strength calculations was made by the author and it operates as follows:

- Take a photocopy of the pre-crushed face of the IA at the highest dots-per-inch (DPI) available on the photocopier.
- You must crop the image to the profile of the IA’s pre-crushed face as closely as possible.
- Write a script in python or Matlab (the author used python but now recommends using Matlab for the easier sharing of scripts without having to build project environments around them).
- The script shall do the following:
    - Import the image of the IA face.
    - Convert the image from colour to greyscale.
    - Set a threshold brightness value from 0%-100%. Around 35% to 45% is suitable for this method.
    - Convert the image to strictly black (brightness 0%) or white (brightness 100%) on a pixel-by-pixel basis based on whether the existing brightness value of a pixel falls above or below the threshold value.

- Take the average brightness value for the entire image. This brightness value will be from 0% to 100% and will represent the percentage of area of the image that is occupied by the white pixels. Therefore, this represents the percentage of adherable area there is on the pre-crushed face of the IA.
- Multiply the percentage of adherable by total area to calculate the adherable area.

- Complete a sensitivity analysis on the IA adherable area by varying the threshold value. The trend will be that lowering the threshold value will increase the calculated adherable area due to the increased presence of decidedly white pixels around the aliased edges of the aluminium of the IA.

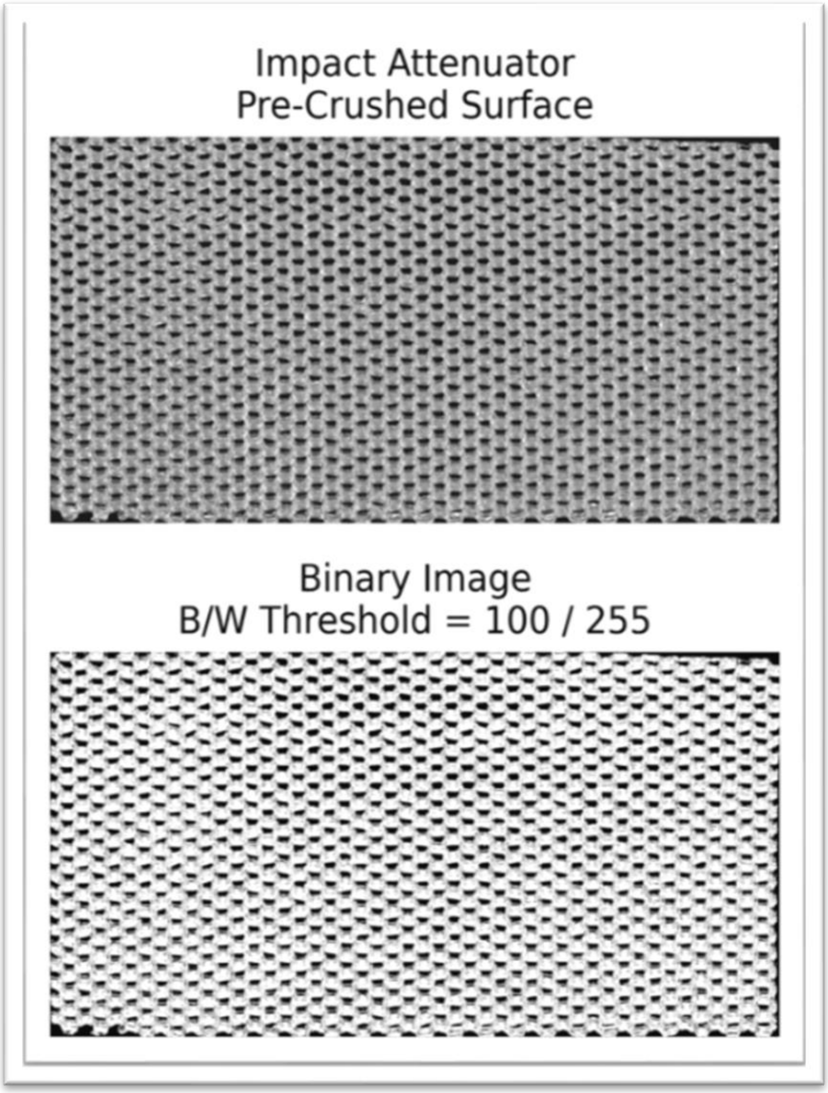


Figure 12 - Impact attenuator adherable area visual representation

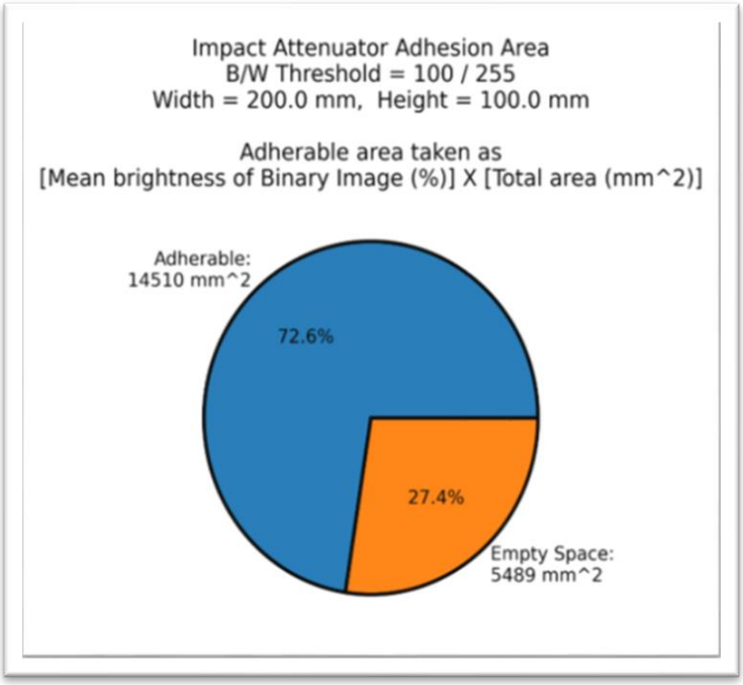


Figure 13 - Impact attenuator adherable area results

The calculations done on the IA used for NU24 found an adherable area of 14 510 mm^2, which is highly likely to be indicative of the adherable area on the remaining 5 IAs. In the SES document for 2024 the maximum possible area to be entered into the cell for adherable area was 9 999 mm^2. For this reason, the author was required to enter 9 999 mm^2 into the cell and find an adhesive that was technically rated for a higher strength necessary than for what the competition rules state.

The author originally purchased the Loctite Epoxy Marine from Bunnings in Wallsend, however upon writing this report Bunnings no longer stocks this epoxy. The author recommends using the same epoxy in the future but purchased from a different retailer such as Glues Australia.

The code used for calculating the adherable area of the IA is available in

Appendices

Appendix A – Impact Attenuator Adherable Area Code.

5.1.8. Chassis Compliance Issue

On the 14th of November, feedback from FSAE on the SES document submitted by NU Racing was received that informed the team that the chassis design was deemed non-compliant due to a lack of complete triangulation between the rear impact structure and the main hoop of the car. The specific area that was not triangulated was the opening for the driveshafts, which had been a square opening since at least 2022's EV.Three car. Partly due to the past two years of this going unnoticed by judges it was not picked up during any SES check-overs done by the team before submission.

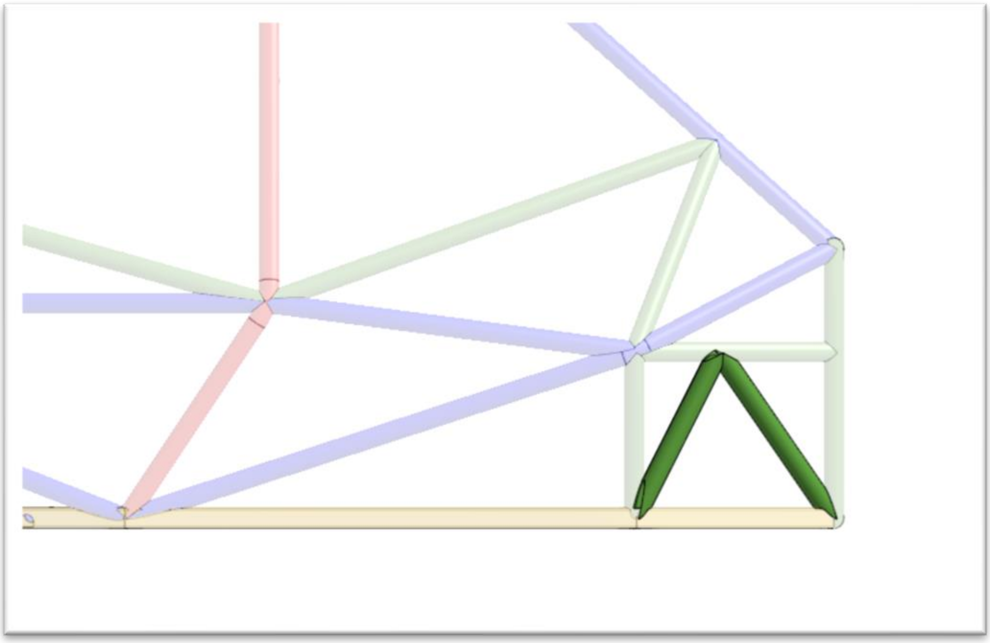


Figure 14 - Additional members to NU24's chassis added for compliance

At Sydney Motorsport Park (SMSP) on that day, the author in conjunction with the chief mechanical engineer Lachlan Fisher designed two additional tubes for either side of the car that would completely triangulate the rear end of the chassis. As it was feasible to have EC hand notch and weld these tubes into the car it was decided to do this to avoid complications with requesting exemption by FSAE to let the team run with a non-compliant chassis.

Checks for driveshaft clearance were done by Lachlan Fisher and the modelling was done by the author. 3D printing was used by Lachlan Fisher to test tube designs in the intended location and a couple revisions were made to the positioning of the tubes to ensure proper driveshaft clearance.

The evening of that SMSP track day saw the team disassembling the car to a bare chassis ready to go to EC building's MEWS workshop for the additional members. The new triangulation around the driveshafts was compliant and no further issues regarding the chassis were identified at mechanical technical inspection at competition.

5.2. Accumulator Container

The accumulator container is a team-made custom energy storage device that functions as the electrical battery pack for the teams competing in FSAE. The current general configuration of the accumulator since 2022 to 2024 is of a design with 'segments' of cells separated by internal walls welded at the exterior and using a large slab of insulating and fire retardant material on top of the segments to both retain the segments and separate the control electronics such as the battery management system (BMS), precharge board, and insulation monitoring device (IMD). A lid lays across the top and bolts down to retain all the components, and to hold down the 'service handle' that uses bus bars to connect/disconnect the individual 60 V segments together to achieve a nominal pack voltage of 400 V in 2022 to mid-2023, or of 450 V from mid-2023 to end of 2024.

Historically a major performance limiting aspect of NU Racing's accumulator electrical design has been the thermal limitations imposed by the heat generated within the accumulator's cells as power is discharged during driving due to the internal resistance of the cells. In 2023 the NU Racing team elected to increase the total energy capacity and voltage of the accumulator container by going from 8 x 60 V segments to 9 x 60 V segments, upping the nominal voltage from 400 V to 450 V. This assisted with reducing the voltage sag under high power outputs, which helps maintains lower amperage and therefore heat generation. The added segment also distributed that lower heat generation across an increased thermal mass. The 2023 team greatly benefited in the reduction of accumulator temperatures, allowing them to operate NU23 at a consistently higher average power output than with the previous 8 segment design. More details on this change are detailed in the FYP reports of Jye Hollier and Jacob Bush (Hollier, 2023) (Bush, 2023).

Two potential designs were put forward by Jacob Searle of the 2023 team for the accumulator container design of NU24. Both designs featured an aluminium accumulator container.

One design was for a “weight optimised” container that omitted several of the existing segments and cells for the sake of reducing the weight of the entire accumulator. This reduced electrical capacity design was created without proper analysis of the impacts on cooling and heat generation within the accumulator which as previously stated had been a major issue with EV.Three.

The other design was for an accumulator container that retained the same number of segments and total energy stored, while converting the container material to aluminium, the insulation lining material from FR4 to Bakelite, and with changes to fan-to-container mounting and container-to-chassis mounting.

For the reason of wanting to avoid an overheating battery pack the decision was made to go with the second option, as it would still provide benefits of reduced weight due to the aluminium container.

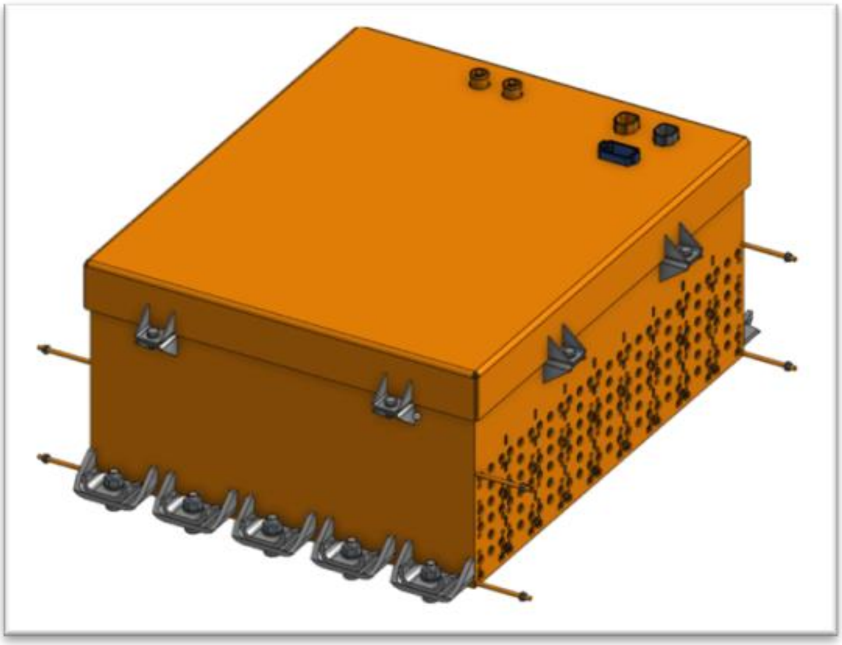


Figure 15 - Initial design of accumulator upon handover

Changes had to be made for the accumulator design from the original designs that were handed over. The changes made are documented in the following sections.

5.2.1. Fan Manifold Mounting

In 2023 issues arose in the compliance of the accumulator container design due to the presence of 'non-crushable' items within 1 inch of the surround chassis tubes (excluding where the mounts are present). A rules inquiry was made by Michael Dalton; however, the responses were not exactly conclusive in terms of their wording. Summarised, the response says:

- Plastic fan manifolds are considered crushable. It is not clear if this includes the plastic of the fan blades itself, or the plastic used for integrated fan housings.
- Metallic fan blades are non-crushable.
- The metal of the accumulator container is non-crushable.

Further information on the rule inquiry is available in the FYP report of Michael Dalton (Dalton, 2023). The information taken from the response is that the plastic fans used by the 2023 and 2024 team are considered crushable however the metal of the container was not. As such the action taken by the 2023 team to remedy the issue before competition was to notch away the ends of the fan manifold mounting of the accumulator container that were within a 1-inch distance of the chassis, with some extra clearance added to ensure clearance was not questionable.

The original purpose of the supporting lip that held the fan manifolds was to take the weight of the fan manifolds and to also shield them from the presence of rocks and debris that may be kicked up from the driving surface.

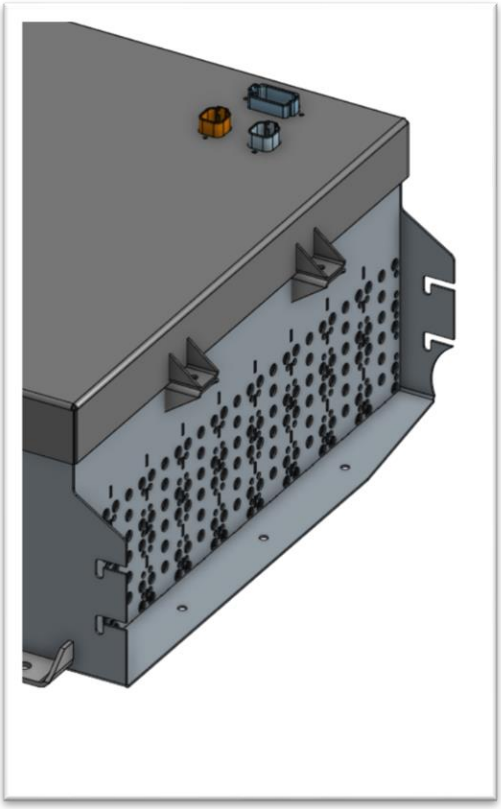


Figure 16 - Accumulator fan mounting lip for NU23

The designs for the accumulator container presented by the 2023 team changes from a supporting lip around the fan manifold to aluminium M4 threaded rods that would be welded to the container from which the fan manifold would slide onto and be fastened down with nuts. This design did not remedy the issue of non-crushable items in the 1-inch area around chassis members as the threaded rods were long enough to reach that zone. It also posed issues with how frequently the fan manifolds are installed and removed when working on the accumulator, as aluminium threads are more prone to cross-threading, and it was likely they would be knocked and bent over the course of the year. Also, it did nothing to address the claimed feature of debris protection that the 2023 accumulator had.

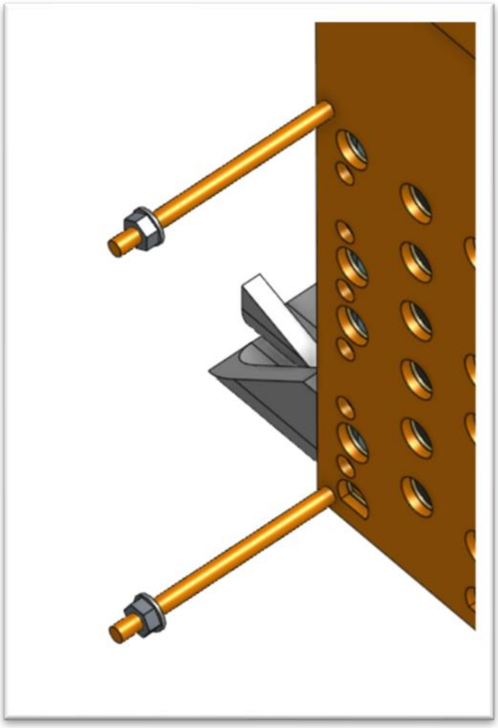


Figure 17 - Accumulator fan mounting design using welded threaded aluminium rods

To fasten the fan manifolds to the accumulator container the author changed the design to use an extended lip of the accumulator walls like 2023, without extending it all the way to the edge of the fan manifold. This would take all the weight of the fan manifold and provide the same notched places for the manifold to slide back into and drop down, locking it in place in the same quick and serviceable manner as the 2023 accumulator. In addition to the side notches, locating cutouts were present in the bottom lip that could interface with the fan manifold to retain it at the bottom without the use of fasteners.

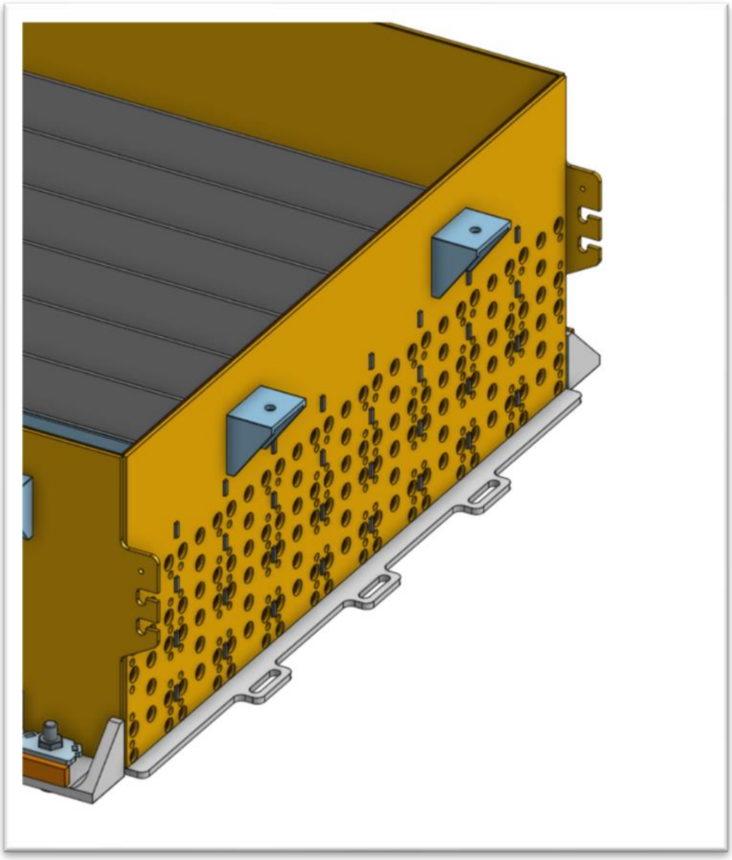


Figure 18 - Accumulator fan manifold mounting solution by the author

The feature of protection from debris was shown unnecessary as no damage to fan manifolds was sustained with this mounting design over the duration of 2024.

5.2.2. Accumulator Mounting

Mechanical installation of the accumulator to NU Racings cars currently goes as follows:

1. Place the accumulator on the accumulator trolley for transport.
2. Have the car on top of sawhorses to elevate it above the accumulator.
3. Jack up the accumulator trolley through the space between the chassis mounts until it reaches the intended height.
4. Line up the accumulator mounts with the chassis mounts.
5. Bolt through the accumulator mounts and fasten by hand.
6. Remove the accumulator cart once the accumulator is secure to the chassis.

Important to the installation process is that the accumulator can fit through the gap in the chassis mounts. The design for the aluminium container handed over by the 2023 team did not include enough space between the chassis mounts to fit the full size of the accumulator lid through and up into place. Interference by approximately 3 mm total was present that would prevent installation of the accumulator. It is also worth noting that the proposed material sections in the original mount design were not obtainable or commonly manufactured in Australia.

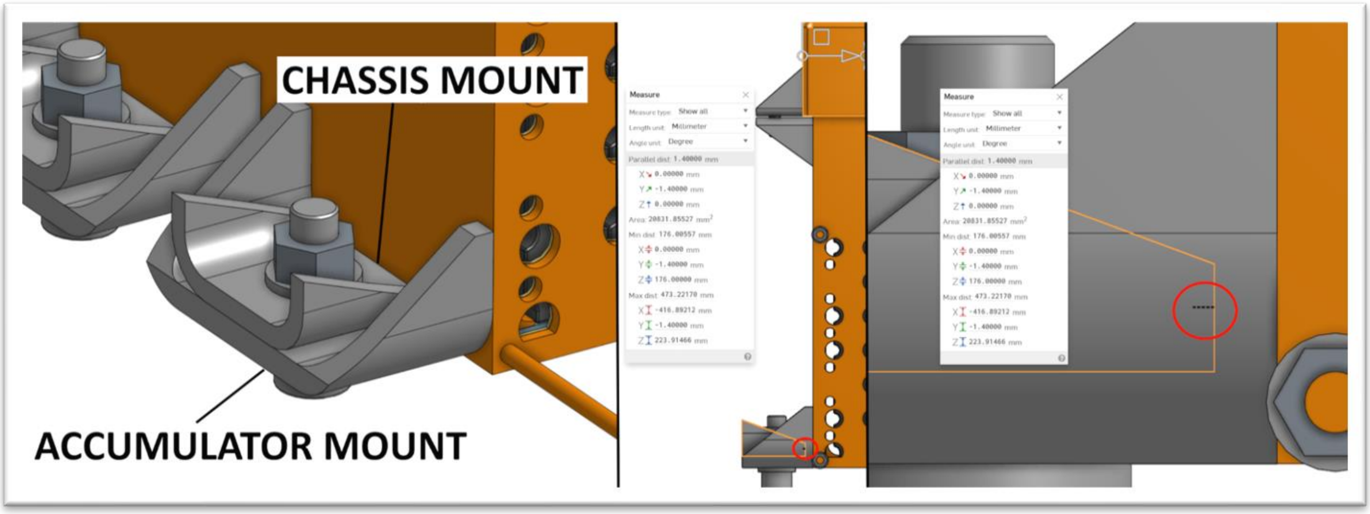


Figure 19 - Handed over design for accumulator mounts, demonstrating interference between lid and mounts

At the point in time this was discovered, the chassis had already been ordered and as such it was only feasible to make changes to the yet manufactured accumulator container.

The size of the lid is determined by the size of the accumulator container base itself, which was already at the minimum size based on the dimensions of the cells packaged within, and the thickness of the aluminium to be used. This meant the lid could not be shrunk to fit within the gap between the chassis mounts.

The author elected to modify the design of the accumulator mounts to achieve an SES compliant design.

When designing accumulator mounting for SES compliance, the design must account for adequate safety factors regarding:

- Accumulator Mounts

  - Pullout of mount from parent material
  - Tearout of fastener from mount material longitudinally
  - Pullout of bolt through mount material vertically
- Chassis Mounts
  - Pullout of mount from parent material
  - Tearout of fastener from mount material longitudinally
  - Pullout of fastener from mount material vertically
- Fastener
  - Fastener shear from longitudinal load

Upholding these safety factors creates a fight with mount dimensions to maintain minimum shear areas and material thicknesses as well as weld perimeters when designing a mounting solution.

The author found that it was possible to decrease the fastener size from M10 to M8, with the entry for fastener diameter needing to be the minimum shear diameter due to how the threads of the bolts are loaded in shear. This allowed an increase in the shear tearout area which was needed to gain SES approval. This was due to the limited distance between the accumulator lid width and the chassis member width meaning that getting acceptable shear areas on the accumulator mount and chassis mount at the same time directly contradicted each other.

A design that used folded 6.35 mm thick 6061 T6 aluminium for the accumulator mounts was created. These mounts were initially water-cut as a part of the accumulator container water-cutting and were folded by the author at his place of work. Further detail on these folded samples and why this design was not used is in the following section 5.2.3.

After the failure of the folded design, a new design was created that met SES design requirements using newly found commonly stocked materials. 12 mm thick mild steel plate was used by the accumulator mount, while an accumulator mount design was made from C76387.9MI5.5NL aluminium 6061 T6 extrusion from Ullrich

Aluminium (Vulcan, 2020). A full section was purchased for $168. This is much cheaper than the length price on the initial quote from Ullrich of $305. The author recalls the price difference as being due to paying upfront. Much of this aluminium length is left over in EC building as of writing.

The final mounting design used is not an ideal design and is technically an inefficient use of material however it achieved competition compliance and successfully works to retain the accumulator in the car. Future designs for accumulator mounting should investigate the usage of U-shaped chassis mounts and T-shaped or L-shaped accumulator mounts or vice-versa. This will enable the usage of smaller fasteners due to the fastener being loaded in double shear. Also, future designs should investigate using corner attachment as the proposed equivalency test, due to a rectangular prism shaped box of cells only requiring 8 mounting points in comparison to the weight-based design, which NU24's accumulator is in the heaviest weight bracket requiring 10 mounting points minimum. Corner attachment should be done to nodes on the chassis, if possible, instead of the span of a chassis tube, to avoid putting the chassis tubes in bending.

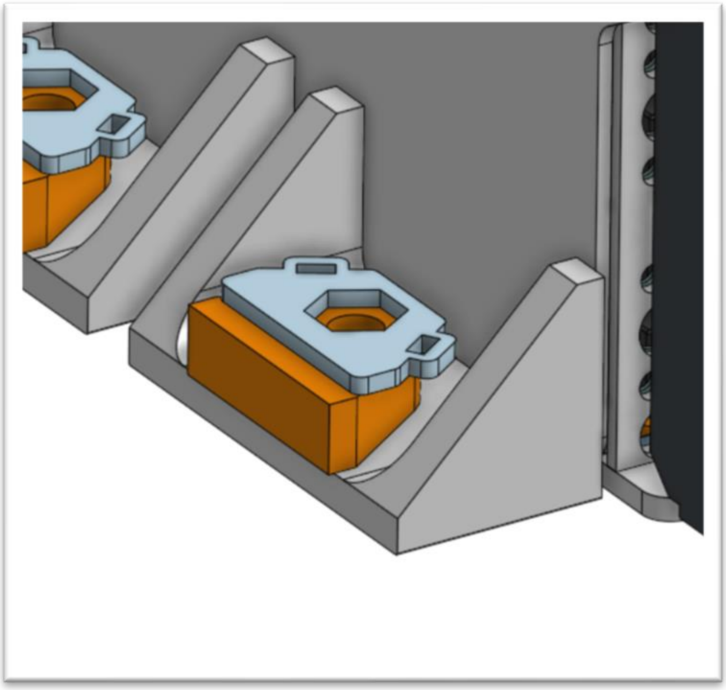


Figure 20 - Modifications to accumulator mount design made by the author

The final design also features a 3 mm thick mild steel tab welded on top, to restraint axial rotation of the nuts placed on top of the chassis mount and provides zip tie points for a 3D print that restraints axial translation of the nuts too. This method of retaining the nuts for the bolts works but is only necessary due to the lack of access by hand to the central 3 mounts of each row of mounts.

5.2.3. Accumulator Manufacture

The accumulator container is designed to be manufactured from sheets of 6061 T6 aluminium welded together externally. The sheets of aluminium have tabs and notches to enable the dry assembly of the container by hand prior to welding, where the tabs and notches are filled with weld and ground back to a smooth surface. The interface of these tabs and notches requires a reasonably accurate fit and as such the author directed the appointed accumulator structural engineer Kristopher Kerr to design test samples that would be water-cut the same way that the rest of the container would be. These test samples contained tabs and slots of varying lengths and thicknesses to find the most suitable tolerances for the rest of the container to use.

Parts designed by the author were water-cut alongside the test pieces including some initial designs of folded accumulator mounts and folded lid clamping-tabs. These samples were folded by the author at his place of work using a CNC press-brake.

In previous years folded aluminium has been used in the design for the pedal box for folding flanges. The pedal box thickness from 2023 featuring these folds was 4 mm thick and folded with no issues. However, upon folding the 2.54 mm thick lid clamping tabs and 6.35 mm thick accumulator mounts, both part designs experienced failures due to fracturing.

Figure 21 - Bent 6.35 mm thick 6061 T6 aluminium. Heated prior to folding on the left. Non heated prior to folding on the right

Figure 22 - Application of heat to aluminium prior to folding

It is believed in hindsight that the pedal box from 2023 was manufactured from a 5000 series aluminium that was more pliable compared to the 6061 T6 aluminium used for the 2024 accumulator materials, as the material choice for the 2023 pedal box is not documented.

Blow torches were found to help the 6061 T6 materials fold however this would have likely caused issues with the heat treatment of the material, and the accumulator mounts still had some visible fractures after folding as seen in Figure 21.

For the reasons of the material failure the accumulator container was redesigned by Kristopher Kerr to use only flat sections of sheet and off the shelf sections of extruded aluminium for the mounts and clamping tabs. Warping under welding was a concern initially and so small amounts of added clearance around the cells was included in the design, and appears to be an appropriate amount of clearance, from the reasonable sliding fit the cells had with the accumulator container.

5.3. Tractive System Stack

The tractive system stack (TS stack) is an assembly of the motor controller, DC to DC converter (DCDC) and the 12 V low voltage battery. Due to the open-ended design of FSAE this is not the only method of retaining these components and it is possible to mount these components individually if a team wanted. The advantage of the tractive system stack design is that it is modular and only requires the removal of 4 bolts and disconnection of electrical connections to remove the components from the car as a whole assembly.

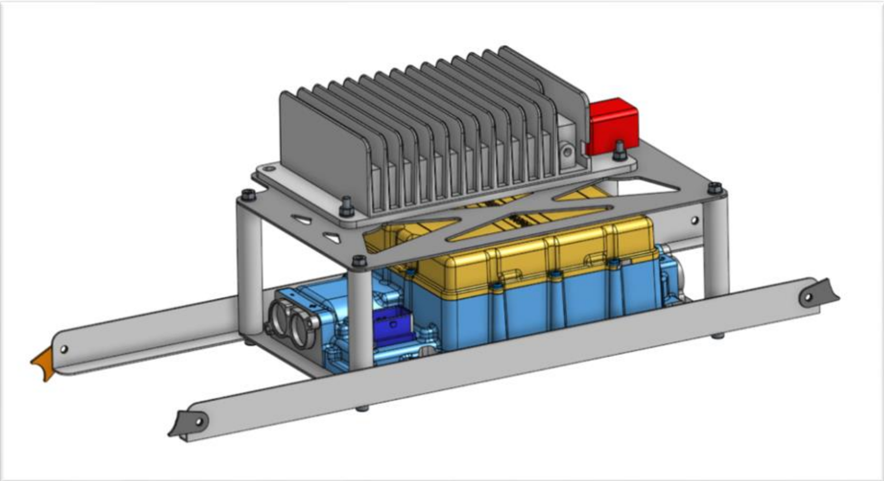


Figure 23 - Onshape model of NU24 tractive system stack

NU24's TS stack design by the author iterates on the design of NU23's TS stack through improvements in weight and necessary changes to component locations, and a change of low voltage battery. The motor controller and DCDC components are located such that they enable the lengths of high voltage DC cables to have clearance as they exit the human interface panel (HIP) node. The change of design from the 2023 CEN to be split into the 2024 HIP and CEN combination resulted in the moving of the high voltage electrical connections and caused the tweaks to the motor controller and DCDC to be necessary.

NU23's low voltage battery was a 12 V, 9 Ah sealed lead acid (SLA) battery weighing 2.55 kg. The use case for this battery is intended to be in things such as alarm systems and wi-fi installations as an uninterruptable power supply. Throughout 2023 the battery used was ran flat sometimes down to 7 V and took considerable damage to the lifespan of the battery. This caused issues during testing of low voltage systems especially at the track, as the battery would drain quickly and limit the amount of low voltage system testing possible. The charging of the battery was often overlooked and was forgotten prior to track days and was charged using bench power supplies with no control systems to slow charge rate or maintain battery health.

As SLA batteries are quite heavy and an established trend in motorsports is to use lithium-based batteries for motorbikes and cars alike, the author researched a locally available battery to replace the SLA battery and settled on a Super Start Batteries (SSB) 4-LH4LK lithium battery. Considerations to be made when choosing a low voltage battery include the max discharge rate (cold cranking amps or CCA), energy capacity (typically measured in Ah at 20 hours), connector type, packaging requirements and weight. The LH4LK battery has bolted electrical connections compared to the SLA battery's spade connectors, which aids to remove a potential point of failure due to vibrations that could risk the disconnection of the spade terminals from the SLA battery. The LH4LK battery also weighs 0.5 kg in comparison to the SLA battery used in NU23 and was the easiest 2 kg removed in the development of NU24.

Weight reduction from the metal structural components of the TS stack occurred primarily in the horizontal sheets of aluminium used for mounting the motor controller and the DCDC. According to measurements taken from Onshape, the top sheet was able to have its weight reduced from 403 g to 312 g and the bottom sheet from 432 g to 276 g. Total weight change of structural parts went from 1.185 kg down to 0.981 kg. The designs for weight reduced horizontal plates used triangulation between bolts to retain structural soundness, however this was not tested through FEA. Rigidity of the frame is of similar magnitude to NU23's TS stack frame. An example of the top horizontal sheet used for holding the DCDC and low voltage battery in NU23, vs the top horizontal sheet used for holding the DCDC only in NU24 demonstrates the triangulation methodology used for distributing applied loads directly from point to point in Figure 24.

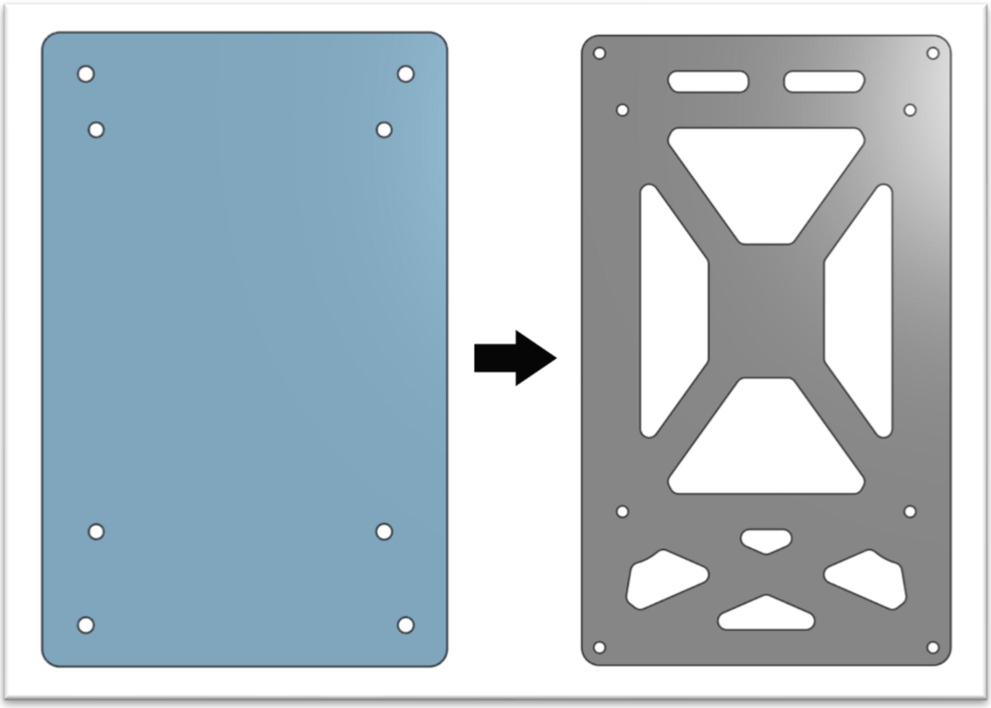


Figure 24 - Triangulation comparison of tractive system components

5.4. Suspension

The suspension of NU24 is of new geometry and construction method in comparison to the suspension arms that were used by both EV.Three and NU23. The suspension geometry was designed by Justin Li in late 2023 and documentation is available in his final year project report. The author contributed to the suspension design of NU24 by deciding the construction method of the a-arms and by choosing the spherical bearings used in the a-arm outboard joints.

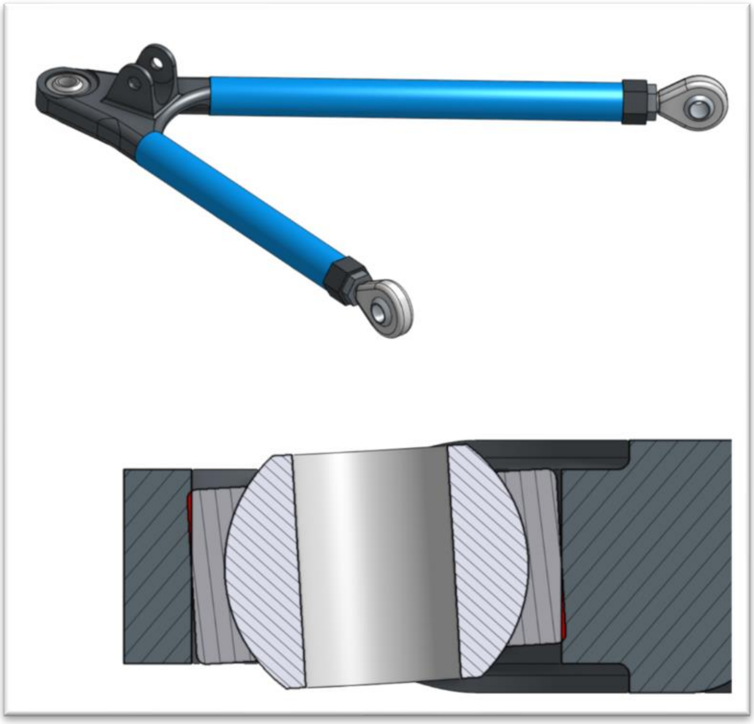


Figure 25 - NU23 suspension arm example

As seen in Figure 25, construction method for NU23's suspension arms used a CNC machined outboard part for both upper and lower control arms, that incorporates the spherical bearing pocket, as well as the coil-over pickups if necessary

The design used for the construction of NU24's suspension changed the CNC machined bearing pocket to remove the sections of coil-over pickups, and tubes ends that were present in NU23's design, resulting in a single bearing pocket with minimal features, that could be turned on a lathe. To make up for coil-over pickups, laser cut steel tabs were used as part of the welding assembly. It was thought by the author at the time prior to manufacture that this part being turned on the lathe made it simpler to produce, which is technically true, however only the bearing pocket becomes simpler to manufacture. An example of the CAD design for NU24's a-arm's is shown in Figure 26.

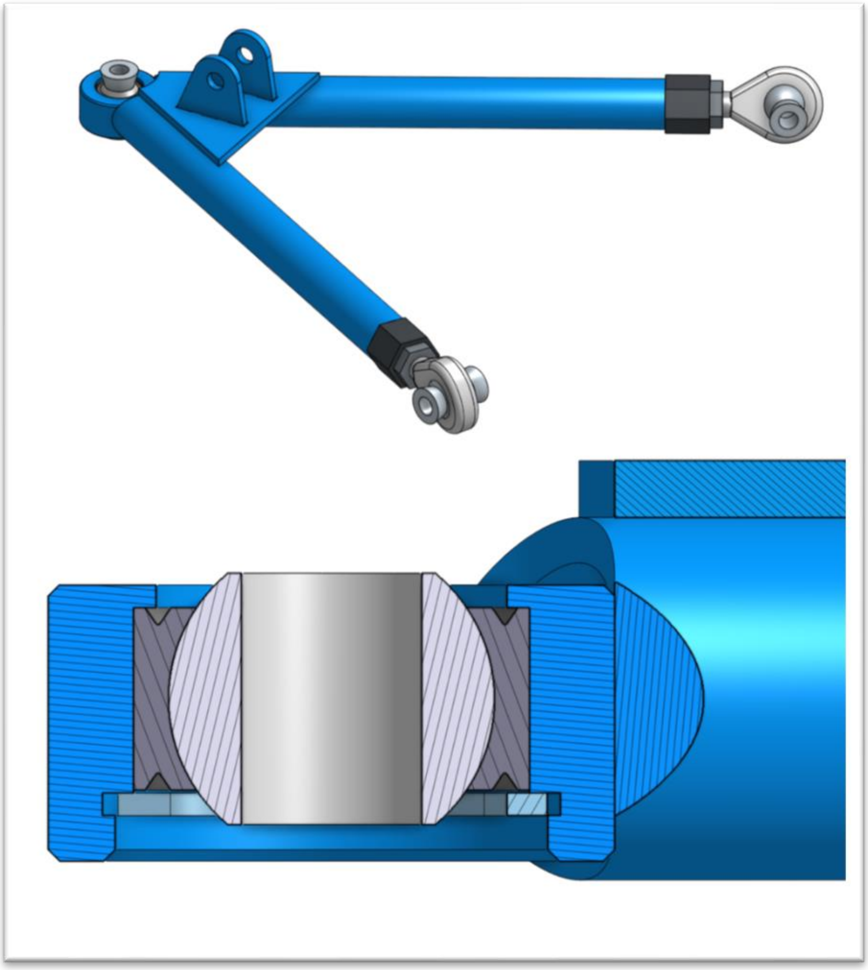


Figure 26 - NU24 suspension arm example

The suspension component design was negatively affected when taking into consideration the whole assembly of parts need to create a single a-arm. Instead of a single CNC milling program that made 1 complex part, with a-arm tubes being simple cut-to-length tubes, the simplified bearing pocket design necessitated extra machining for every a-arm tube to be cut-to-length, notched against the spherical pocket, and notched against the matching a-arm tube. A net increase in number of parts requiring machining occurred and increased the number of operations in the manufacture of the components.

Asides from complications during individual component manufacture, this design also poses risks in the welding of an a-arm. Due to the small size of the spherical bearing pockets, when welding the a-arm tubes to the pockets, it requires more precision in welding than the NU23 design, or else risk sending the welding arc through the bearing pocket. Regardless of the chance of melting the bearing pockets, welding directly onto the side of them localises the stresses of welding closer to the bearing pocket and has a greater effect on distorting the bearings out of round. In comparison, NU23's suspension had simpler welds with better managed heat flow of the weld, further away from critical geometry of the bearing pocket.

Positive design changes did occur, in the form of addition of an added shoulder to positively retain the spherical bearings from being pushed through the top of the bearing pockets under compression of the suspension. NU23's suspension did not have this and relied entirely on the friction and bonding achieved through press fits and bearing compound. NU24's bearing pockets also incorporate a circlip on the bottom face to prevent spherical bearings falling out of the a-arms in the opposite direction.

Choice of spherical bearing was a design decision made early in the development of suspension for NU24. In previous years metric spherical bearings had been used for the suspension design, however due to part availability and pricing, NU24 uses imperial spherical bearings for the outboard ends of the a-arms. At the time spherical bearings for NU24 were being researched for purchase, most suppliers had little to no stock of motorsport grade M8 sphericals. As a result, prices for metric sphericals had increased dramatically compared to the more commonly stocked imperial sizes. Some retailers even had stated that they could not obtain any more sphericals until the manufacturer had swapped over production tooling for manufacturing a run of sphericals.

As a result, the author had to research similarly sized sphericals for use in NU24's suspension. Stocked by NU Racing's preferred supplier of bearings is the NMB range of spherical bearings, in imperial at the time. The spherical bearing selected for NU24 was the NMB ABWT-5V, as it met or exceeded the ratings of the sphericals used in NU23 and was of similar enough geometry to be usable with metric fasteners, requiring only the remanufacture of the bearing spacers to suit the slightly changed dimensions.

Two kinds of spherical bearings are commonly available. A regular kind exists, where the outer housing has chamfered edges, allowing for easy press fitting into a spherical pocket. A "staked" kind also exists, also known as "v-groove", where the spherical has square edges, and a v-shaped groove machined out of the flat circular faces near the outside edge of the housing. This results in a lip that can be “staked” using bearing-specific tooling (pressed between 2 die) to roll the outside lip over, retaining it permanently to a bearing pocket.

As NU Racing expected to drive NU24 with the suspension un-painted for a while before getting it painted or powder-coated, the sphericals must ideally be removable from the a-arms due to the possibility of using an oven for the powder coating process, where masking components becomes more difficult due to the limitations in masking materials at elevated temperatures. Removable sphericals are also desirable for the recycling of components on a year-to-year basis. For these reasons the spherical bearing pocket included the necessary features to retain the sphericals without needing to stake a v-groove bearing. Ultimately NU24’s suspension was painted, not powder coated.

However, due to availability of parts at Statewide Bearings, and the necessity of the sphericals to get the car to meet the rolling-chassis goal and deadline, v-groove spherical bearings were purchased for a non-v-groove retention method, as regular chamfered sphericals were not available on demand.

Fitment of v-groove sphericals into holes with tolerances machine to suit press fitted components did not work well. Issues arose in the press-fitting of the square edged sphericals were the lip of the sphericals would get caught and deform. The fix this for NU24, the tolerances of the spherical bearing pockets were opened to a sliding fit. In hindsight, with the retention of the shoulder lip and the circlip, a sliding fit for the sphericals retained with bearing compound would have been a suitable solution for installation of either the regular chamfered sphericals or the less favourable v-groove sphericals. The author recommends this combination of sliding fit with shoulder, circlip, and bearing compound retention going forward, as it provides the most serviceable and recyclable installation of sphericals within the suspension that NU Racing has had in recent years. However, NU23’s CNC milled design of the complex outboard piece is a preferred design due to all the complexity of the assembly being absorbed into a single machined controlled process.

6. NU24 Body-kit

The body-kit for NU24 is a single-piece plus nosecone combination of fibreglass parts designed to enclose the car and driver space of NU24, while affording space for sponsor/industry partner logos and the mandatory FSAE stickers for car compliance, and FSAE's sponsors.

The author undertook an ENGG3200 course in semester 1 of 2024 running during the 'Part A' duration of the author's FYP. The scope of the ENGG3200 course was to design and order the plug for NU24's body-kit, and as such that is outside the scope of this FYP report and is not detailed.

The work the author did during the manufacture and installation of the body-kit to the car, as well as team management for this project is documented here as a contribution to their FYP.

To create the fibreglass body kit for NU24, the general steps were as follows:

- Order a polyurethane coated foam plug "positive" shape of the body kit.
- Shape, sand and fill the plug to a 1200 grit finish.
- Clean the plug and apply corflute flanges for the mould.
- Use wax for a physical separation barrier and PVA blue for a chemical separation barrier for the following mould making process.
- Create chopped strand fibreglass moulds, piece by piece ensuring suitable draft angles for mould separation.
- Cure and remove moulds before repairing any imperfections.
- Individually layup the body kit on individual mould pieces using woven fibreglass, and assembly the moulds together to lay fibreglass across the seams, creating one piece.
- Add extra stiffening to the body kit where necessary, and cure.
- Remove the moulds from the body kit and sand the body kit to prepare for paint.
- Design and weld mounting tabs for the quick release attachments to the body kit.

- Fit the body kit to NU24 and trim/grind all edges to a smooth finish.
- Paint the body kit and apply stickers as needed.

To create the body kit is an in-depth process involving lots of unique techniques that are not well documented within NU Racing. The entire project of designing and creating the body kit could not have been done without the assistance of Professor Bill McBride with every step of the process, for which the author is incredibly grateful for his help. Part of the goal of this engineering report is to try to impart the knowledge needed for NU Racing to replicate the process of manufacturing a fibreglass body kit without the need for as much external assistance as needed in 2024 and previous years.

For creating a completely original body kit from fibreglass reinforced polymer, the process requires at a minimum a complete set of moulds from which the body kit can be formed in and released from. In 2024 the author reached out to NU Teams industry partner ‘RPC Technologies’ to inquire about recommendations for obtaining a set of moulds. Upon recommendation from RPC Technologies, the author inquired purchasing a set of moulds from ‘APTEC Composites’. A response from APTEC Composites informed the team that they do not manufacture foam plug positives and instead create ready-to-layup medium-density fibreboard negatives (moulds) for one-off part productions, however they can produce ready-to-layup fibreglass moulds for mass produced parts. A very rough quote estimated a set of MDF moulds at $2500/m^2$, or around $16000 for a set of moulds to suit NU23’s shape. In comparison to the foam plug process used in 2023 and 2024, the foam plug is around $4400 and involves the consistent time and labour of multiple NU Racing students for around 2-3 months to finish the plug and produce a set of fibreglass moulds. The mould making process costing around $1100 in fibreglass and resin (also used for the body kit itself), and $200-$400 in consumable equipment. Due to concerns around costs the author chose to opt for the foam plug process.

The author would like to personally thank Professor Bill McBride for his continued help with the NU24 body kit project, useful demonstrations of technique, descriptions of processes, and useful tips with everything to do with composite manufacture. The author would also like to thank Tim Kerr, Lachlan Fisher, Alec Chapman, John Jones, Hugh O'Brien, and Fergus Menzies for their significant contributions to the body kit project and dedication to helping the author complete the body kit project on such a compressed timeline.

6.1. Plug Preparation

Preparation of the surface of the plug is the most important step in the body kit production for the end quality of the finish of the body kit. The process of creating a mould from a plug and a body kit from a mould is a process that carries through the surface finish of the plug throughout the entire process, meaning that the surface finish of the plug is very indicative of the surface finish of the body kit, at the point it is removed from the moulds. To ensure that the body kit does not require extra body filler that adds weight, or extra sanding down to exposed fibreglass that then needs to be sealed, it is key to ensure a good finish on the plug.

The foam plug used by NU Racing to produce the body kits for both NU23 and NU24 is a foam plug produced by '3D Carving' in Victoria, Australia. For a body kit with final dimensions as large as NU23 and NU24's body kits, the process of creating the plug involves the CNC machining of 2 large, expanded foam blocks that are then glued together. Once the shape of the foam plug is completed then a 2-part polyurethane coating is sprayed on the plug that adheres as a liquid, after which it cures into a hard polymer coating. After this process of enclosing the plug in polyurethane, it is sent out for delivery. Delivery of NU24's plug was taken at EC building nearby the large roller door.

The process of shaping the plug to remove these imperfections is the single longest series of steps involved in the body kit production process used for the NU23 and NU24 body kits. Hand shaping the body kit is a time intensive process that does not strictly count as 'engineering' and can be seen as having a large opportunity cost when compared to allocating team resources to other things more critical to the function and performance of the car. For this reason, and financial concerns, the author recommends that for 2025 the team uses the moulds produced for NU24s plug to produce a new, lighter body kit for NU25 using more optimised and well tested manufacturing techniques, to skip the entire process of plug preparation and mould manufacture.

Many of the processes of producing the body kit are a learned skill and as such the author recommends keeping a small team of 3 to 6 people working on the production processes for the body kit project, ensuring they are consistently available. Including more people than this can introduce complexities in trying to teach students the skills needed for each of the processes and will reduce the end quality of the plug surface or increase the time needed to achieve an equivalent result.

6.1.1. Identifying Surface Imperfections

The CNC machining process of the expanded foam is a process that involves loose tolerances, and many types of surface imperfections that are present in the foam carry through to the polyurethane coating process. Although the polyurethane coating wets the foam and smooths out on its own, not all surface imperfections can be eliminated, and smooth flowy high points and low points will be present on the resulting plug. For a professional finish on the body kit that is typically desired, it is important to smooth out these surface inflections through the sanding and filling process to obtain a result with visually pleasing reflections. During the process of applying the 2-part polyurethane coating to the body kit drips tend to occur around overhanging edges where runs of polyurethane collect before curing. Examples of issues in the plug on arrival can be seen in Figure 27.

Figure 27 - Issues in surface of plug on arrival

The process of identifying surface imperfections is a learned technique that a student will likely improve at through practicing it repeatedly on the plug. As such having 1 or 2 people dedicated to learning to identify surface imperfections in the plug is recommended rather than involving many untrained people in identifying the high and low points. Multiple methods exist for identifying high and low points, whether by hand or by using tools.

For using the hand to identify high and low points, a keen sense of touch is needed. By running the hand across the body kit in a grid-like pattern in at least two directions, a person can feel for changes in slope in a local area, indicating the transitions between troughs and peaks. Recommendations by Professor Bill McBride suggest that using the palm of the hand is ideal for this process due to the fingers being an unreliable indicator of the shape of the body kit. However, the author's own experience for using their own hands to feel for low spots found that gently squeezing extended fingers into a flat area, like reaching for a handshake, was their preferred technique. Using their fingers and palm laid upon the plug, the author was able to feel the movement of their fingers normal to the surface of the plug and feel a finger's movement relative to the other fingers in contact with it, essentially replicating the style of motion of a contour gauge.

Tools such as rules are very useful for identifying the true shape of surfaces of the body kit. The most obvious use of a rule is to check the flatness of a surface that is intended to be flat, such as the rear face of NU24's ducktail-like rear edge. Checking for visible light between the edge of the rule and the plug will indicate low spots, whereas having edges of the rule offset from the plug will indicate presence of a high spot lifting the ruler at some point along its length. Asides from checking for flatness, metal rules can also be used to check geometry that is curved to ensure that on a large scale, the surface has a continuous curvature with no inflections. To do this, bend the rule to match the curvature of the plug and hold it down tangent to the surface of the plug at two points far away from each other. By looking through the gaps present like checking for a flat surface with a rule, a person can identify low spots or high spots. More details on this technique are detailed in section 6.1.4.

When a low spot is identified, the method of identifying it used by the author was to draw around the area on the plug using a whiteboard marker as seen in Figure 28. Later in the filling and sanding process, these low areas would be filled with 1 of 2 fillers depending on the depth of the imperfection. When identifying high spots, drawing hash-style (#) marks on the plug can be used to mark areas to be sanded down. Generally sanding down the polyurethane coating is not recommended as in many areas, especially vertical facing sharp edges, the coating can be thin. Sanding through the polyurethane coating is a risk to consider when sanding down high points and doing so will require using Selleys Araldite to seal up the exposed foam, adding to the amount of labour. Repairing exposed foam is detailed in section 6.1.3. Instead, it is preferred to build up low areas to become flush with high areas.

Figure 28 - Markers used to identify high and low spots on plug

In the process of shaping NU24's plug, many cycles of identifying low and high spots, filling and sanding were done. Nearing the end of shaping the plug, often identifying surface imperfections was done to spend time when waiting for Araldite or body filler to cure.

6.1.2. Shaping (Filling and Sanding)

After body imperfections are identified, the next step in preparing the plug is to fill low spots using body filler. In 2024, Upol branded Dolphin Glaze body filler was used for shallow low points (up to 3 mm), and Evercoat branded Rage Gold body filler was used for larger depth imperfections. Early in the shaping process of NU24's plug Supercheap Auto branded filler was used at one point, however perhaps due to user incompetence or expired hardener, the majority of applied Supercheap Auto branded filler did not set, even after multiple weeks. In general, the Dolphin Glaze filler should be ready to sand after at most 45 minutes depending on hardener-to-filler ratio and ambient temperature but is typically ready to sand after 20 minutes. The Rage Gold filler followed similar cure time frames to the Dolphin Glaze.

When mixing filler to be used on the plug, always follow the directions of the package. Both Dolphin Glaze and Rage Gold use a red coloured hardener agent that mixes with the filler itself to activate the chemical reaction that hardens the filler into a hard polymer. The colour of the mixed filler is influenced by the amount of hardener used, so keeping visual note of the filler colour can assist in gaining a feel for how consistently the filler is being mixed with the correct amount of hardener. Mixing fillers must be done quickly and must result in an even colour distribution to ensure complete setting of the filler.

Whenever mixing Dolphin Glaze, always work in small batch sizes less than two 50 cent coins in size. Dolphin Glaze is a fast-setting filler that has very short working times around 3 to 4 minutes at most, and batches in sizes more than this must be quickly applied or otherwise it will become waste. Whenever mixing any filler, always use a fresh surface and a clean stirring utensil. In the process of shaping NU24's plug, thick paper study planners were used as a mixing surface, where sheets can be disposed of after a single batch. Plastic scrapers from Bunnings were used to mix and apply the filler, and acetone was used as a cleaning agent with paper towel to clean the plastic scrapers immediately after a batch of filler was applied.

When working with acetone and body fillers it is important to work in a well-ventilated area to avoid inhaling excess fumes. The composites lab in EC building was used for the entire plug shaping process in 2024 and has extraction fans used to remove fumes from the room.

The application of the Supercheap Auto branded filler was done in very thick areas across most of the plug without having sanded the plug or identified any low spots, as seen in Figure 29. This is an example of exactly what not to do when shaping a foam plug. When first applying filler to an area of the polyurethane coating, the surface must always be prepared by sanding with sandpaper, with a grit rating equal to or lower than 300 grit. The surface of the polyurethane coating is smooth upon arrival and filler will not adhere properly. Applying layers of filler across entire parts is generally a process only seen in metal panel repair or on fibreglass panels where weight is not critical. In this style of application, only a few millimetres are deposited, in a very even coating. This process does not make sense for the polyurethane coated plug as sanding down to the polyurethane through such a thick layer of filler will risk sanding through the polyurethane coating, exposing the foam.

Figure 29 - How not to apply filler to a plug

Large amounts of filler applied to anything can result in air trapped in the filler through mixing the hardener with the filler as seen in Figure 30. These air bubbles might not reveal themselves until sanding through the surface layer of the cured filler. To fill these air bubbles, use a paintbrush with fine bristles to agitate and remove the dust made by sanding, to clear out the holes. After that, using Dolphin Glaze it is possible to fill in these pinholes.

Figure 30 - Air bubbles in filler caused by aggressive mixing

When applying the filler, ensure to be precise and quick in application. It is always more time efficient to apply slightly too much filler than to apply too little. As soon as clumps begin to form or the viscosity changes noticeably, that batch of filler can no longer be used for anything other than bulk fill, as dragging clumps of filler through already an area that is not yet cured will result in creating deep troughs in the uncured filler, requiring another batch to repair.

The sanding process involved in the shaping of the body kit uses sandpaper grits including 80, 120, and 240 grit. Both 80 grit and 120 grit sandpaper are very rough and remove material quickly, while also resulting in relatively deep scratches in the plug. Sanding is a process that produces a lot of polymer dust; therefore, it is critical to always wear appropriate lung protection when dust may become airborne. These grits should only be used for roughing the shape of the plug. 240 grit sandpaper is also a grit suitable for shaping but is gentler and can be used to fine tune the shape of the plug. To avoid wasting sandpaper, do not place blocks with sandpaper face down on top of areas where dust collects, and avoid prematurely sanding filler before it is set. A fingernail can be used to gently test if filler is set enough to sand.

When sanding large convex areas, always ensure to use a cork block or a speed-file to ensure sanding is being done using a flat surface, to avoid uneven application of the sandpaper that would otherwise create low points. Constantly check the shape of the area being sanded using your hands to avoid sanding too far. To get a smooth transition from a filled area to the polyurethane coating, it is possible to visually check the transition between the two, as it should appear to have a feathered edge as the filler gradually reduces in thickness and opacity. Sanding convex areas is a much easier and faster process than sanding concave areas, and is a contributing factor to the decision behind using a mostly convex plug to produce moulds, in comparison to manufacturing mostly concave moulds from scratch.

When sanding concave areas, sanding using a hand to back the sandpaper can be useful. If an area has tight concave radii, rolling the sandpaper into a tube of a matching diameter can be used to get consistent radii along that section of the plug, or a single finger can be used to back the paper. Areas of note on NU24’s plug where these techniques were used are around the front coil-over covers, around the human interface panel (HIP) window, and around the base of the rear shroud.

Figure 31 – Help sanding

6.1.3. Repairing Exposed Foam

Multiple parts of the plug are bound to result in exposed foam due to multiple reasons:

- The 2-part spray on polyurethane coating did not bridge over an area.
- The polyurethane coating split or cracked due to an impact.
- Thin vertical facing edges such as the cockpit opening are easy to sand through.

- Larger areas may become thin enough to lose stiffness of the coating, and may need to be removed and repaired.

It is important for all foam to be sealed away from the polyester resins used in the layup process of mould making, or else it is possible for the resin to seep through and bond with the foam, resulting in damage to the moulds and difficulties in removing the moulds from the plug. To seal exposed foam the general process is as follows:

- Remove the grey polyurethane coating around the area if it is too thin. Cut out the coating using a Stanley knife until the exposed edge of the coating is at full thickness for that area (approximately 0.7 to 1.2 mm).
- Pull out about 2 to 3 mm deep of foam from the exposed foam and from around the border of the exposed polyurethane.
- Fill the area using Selleys Araldite 5 Minute Epoxy Glue. Ensure that the Araldite adheres properly to the back of the polyurethane and covers the foam fully.
- Once the Araldite is cured to at least similar hardness to a thumbnail, fill in the rest of the hole using body filler (typically Dolphin Glaze).

Removing thin sections of the polyurethane coating is necessary to avoid having issues sanding through the coating bordering the newly repaired area. Removing the foam and trying to get the Araldite epoxy to fill the inside of the hole is recommended as the Araldite has very different hardness/toughness properties compared to the fillers used and the polyurethane. Sanding down the Araldite is difficult and it is likely that when sanding across Araldite and a neighbouring material, the Araldite will resist sanding and cause the surround material to sand down and cause a low spot. Therefore, keeping the Araldite confined to the inside of the hole while ensuring proper bonding on all surfaces is very important. After the hole has been sealed by the Araldite, filler is used to build up to the level of the intended surface for that area.

Areas requiring repair may include long cracks such as those seen in Figure 32. Using a drill bit to round out the edges of the crack can prevent stress concentrations and therefore the propagation of the crack.

Figure 32 - Crack in the polyurethane coating

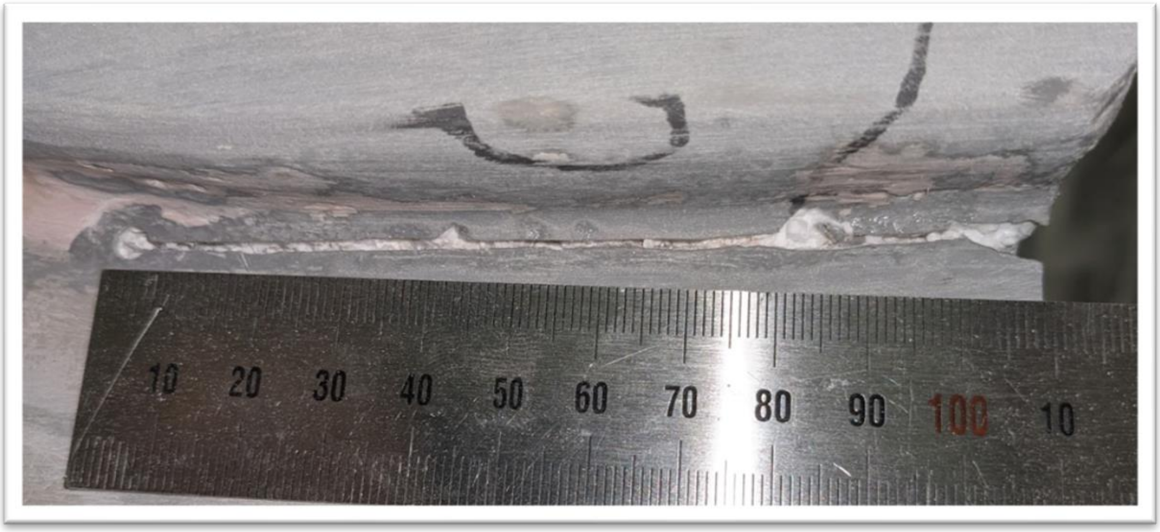


Figure 33 - A knife has been used to open up the exposed foam area

6.1.4. Bonnet Low Point Issue

During the identification of low points on the plug for NU24, it was found that the ‘bonnet’ area forwards of the cockpit opening of the plug had a very large and deep low point spanning about 30x80x1 cm. This kind of low point is not something that a team should be concerned about when ordering a plug as the issue was the result of an oversight in the modelling of the plug in Onshape. This kind of error is preventable, and the author recommends using Onshape's curvature analysis tools to inspect the curvature of the surfaces comprising the plug model. These tools are available by clicking an icon in the bottom right corner when inside of a part studio. Useful tools include 'zebra stripe' reflection projections which can visualize how light bounces off the surface of the plug, and a tool that plots the curvature (inverse of radius) in a grid like pattern in 3-dimensional space across the inspected surfaces.

Resulting from the author's mistake, repair to the shape of the bonnet was necessary, using unique methods for filling in large areas. The process for filling in such a large uniform low spot as the bonnet involved the following steps:

- Prepare the surface with sanding to ensure good adhering of the filler.
- Apply a single strip of filler the longest length of the low spot (front to back on NU24's bonnet). Use Rage Gold for this.
- Use a rule and a filler resistant film to lay the rule down to shape the strip of filler, without the filler adhering to the rule. Hold the rule down at its far ends to ensure the rule is tangent to the plug.
- Repeat the previous steps at multiple points perpendicular to the first long strip of filler, to make a grid-like pattern.
- Fill up the areas between the grid-like pattern.
- Sand back to a smooth finish. Use Dolphin Glaze for this.
- Inspect with the rule to ensure smooth and symmetrical distribution of filler.

When using the rule to shape the filler, using a filler resistant film is necessary to prevent the filler from adhering to the rule. The author is unsure of the material of the film used for this process as the author was not present when the process of repairing the bonnet low spot was started. Most of the shaping to fill the bonnet was done by Professor Bill McBride. The red film shown in Figure 34 is likely located in EC basement somewhere, and reaching out to Professor Bill McBride is recommended if it is needed and cannot be found.

Using the rule to measure the distance between the edge of the filler and the nearest body line was done to check for the approximately symmetrical distribution of filler. The techniques described in section 6.1.1were used to check for high and low spots in the filler, and to repair the pinholes caused by air mixed into the filler. The result of filling in the bonnet can be seen in Figure 35.

Figure 34 - The first strip of bog for repairing the bonnet low point

Figure 35 - Result of filling in the bonnet low point of the plug

6.1.5. Nose Radius Issue

According to T.7.2.4 forward facing edges of bodywork exlcuding aerodynamic devices (which is just the body kit), must have a minimum radius of 38 mm. When modelling the body kit the author was aware of this rule however did not check the radius of the nose prior to ordering. This is a preventable issue similar to the issue of the bonnet of the body kit, as detailed in section 6.1.4 that can be identified and prevented in the modelling process through the use of tools for inspecting the curvature of surfaces.

3D prints of various included angles of 40 mm radii were used to check the curvature of the plug, and identified that the nose of the plug was too sharp and therefore non compliant. Options to remedy the radius of the nose included either removing material to then re-seal the foam and build up a rounder nose, or to add material around the nose area until it built up to a round nose. When removing material and then filling back up to a rounder nose, a smaller area needs to be shaped by hand. To prevent a larger area from potentially becoming mishapen, the author chose to remove the material first and build the nose back up.

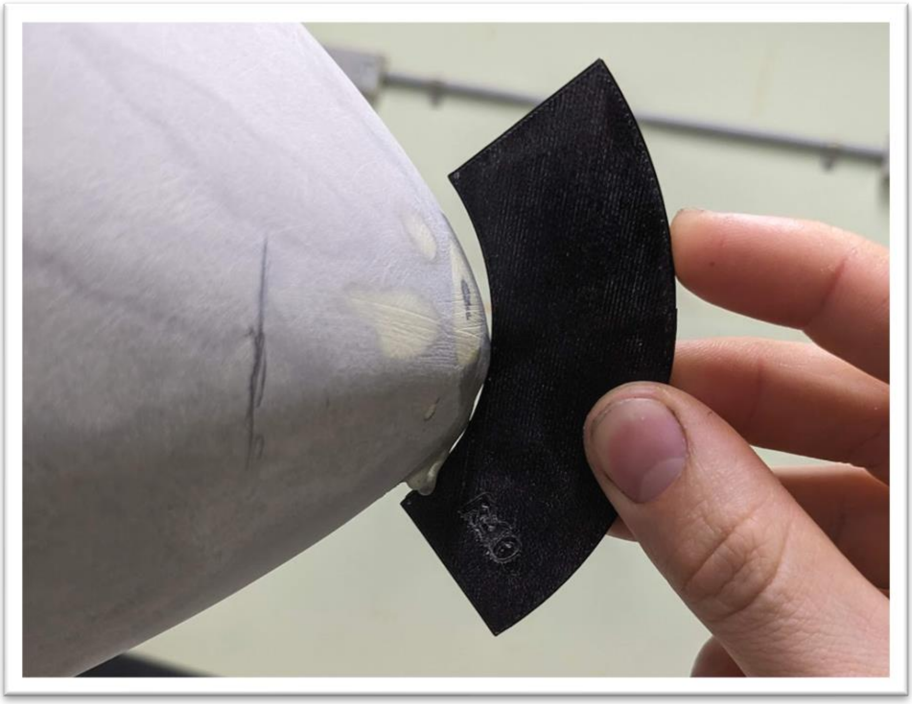


Figure 36 - Radius gauge demonstrating issue with nosecone radius

Using the 3D printed gauges as seen in Figure 36, a border was drawn around the nose tip where the geometry was still compliant, which was used to cut out the section of non-compliant nose geometry as seen in Figure 37. The repair methods for exposed foam described in section 6.1.3 were used to seal off the foam, followed by filling the nose back up with Rage Gold filler followed by sanding and Dolphin Glaze filler.

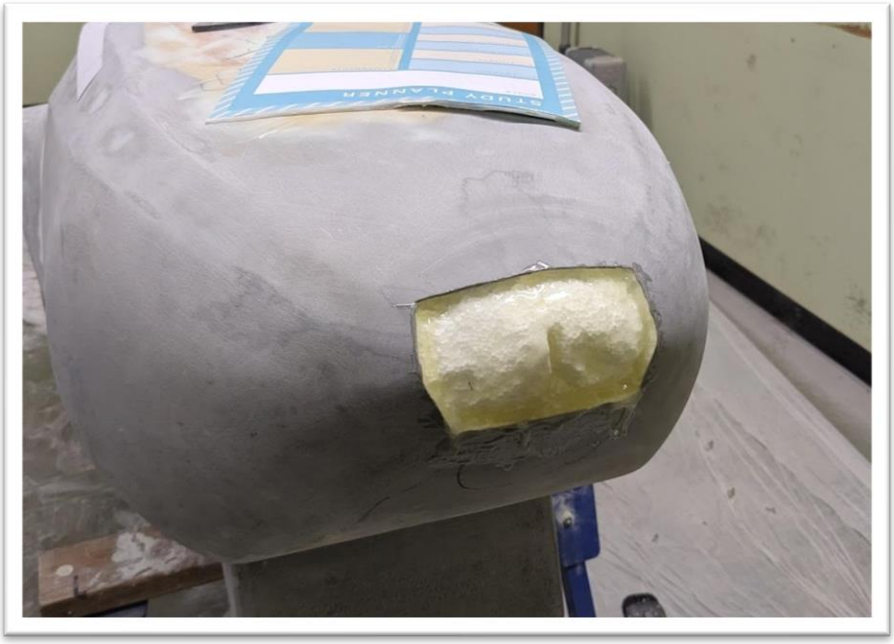


Figure 37 - Section of nosecone of the plug removed and sealed with Araldite

6.1.6. Smoothing the Plug

Once the shape of the plug has been refined to a point that the author/project lead considered acceptable, the plug was able to be sanded to a 600-grit finish. To smooth out the surface of the plug, it is important to progress through the grits of sandpaper available. By progressing through the grits, the deep marks of the previously used grit become shallower. If a large jump in grits (i.e. from 240-grit to 600-grit) was used, it would result in slower progress compared to following a clear progression of grits, due to the slow rate of material removal by the 600-grit sandpaper. The process of sanding up through the grits from 240, 400, to 600-grit is a process that only takes approximately 1 day, given the labour of 2 people.

At the time of sanding Bunnings Wallsend supplied 400-grit sandpaper that was used as an intermediate grit; however, this may no longer be available. Effort should be made by future teams to find suitable intermediate grits from another supplier to replace the 400-grit no-longer sold.

When sanding up through the grits on the plug, all sanding is done dry with no lubrication, as lubrication is unnecessary. This is different compared to sanding done on the moulds which is wet sanded.

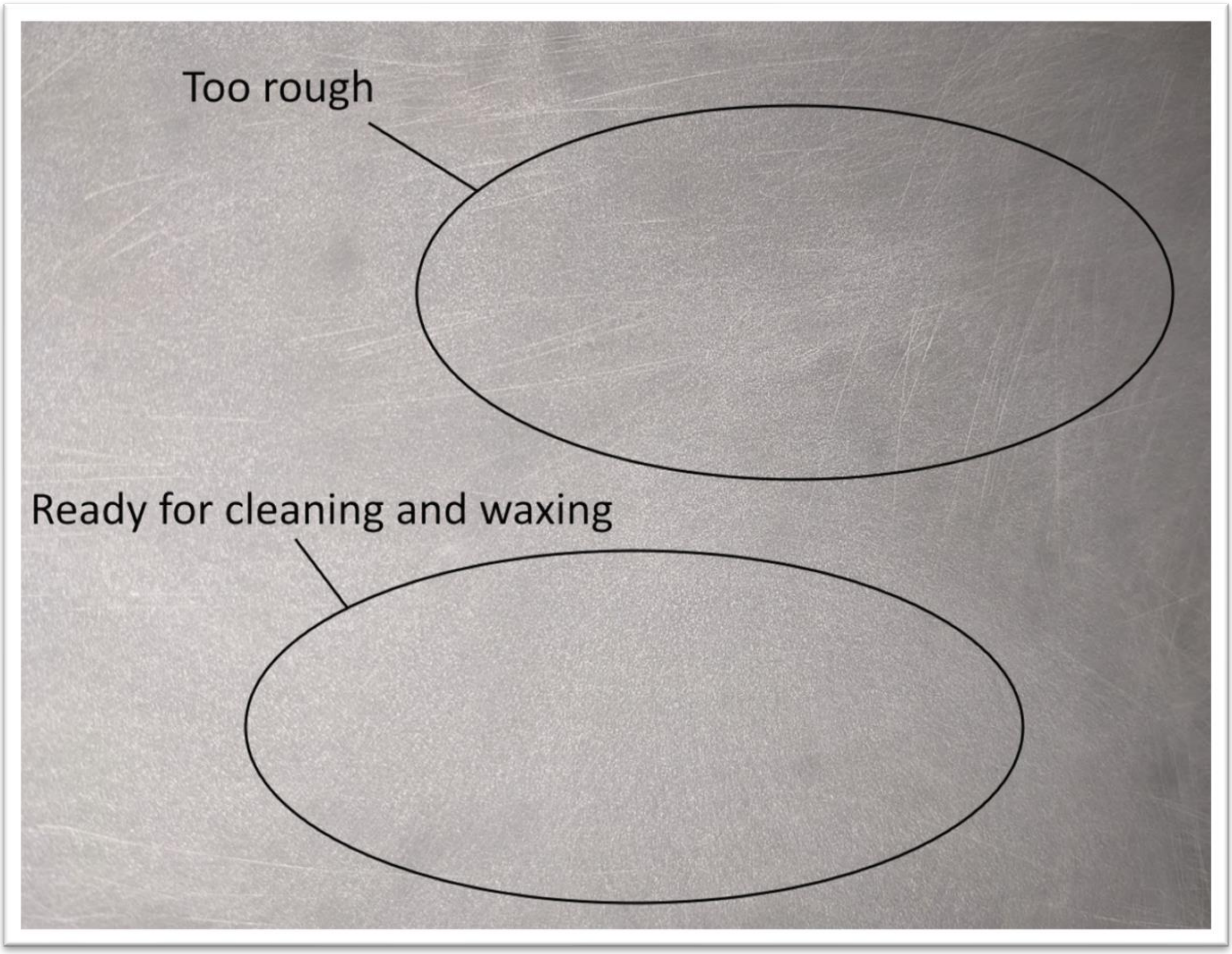


Figure 38 - Visual comparison demonstrating a sufficient 600-grit finish

To identify areas that have not been sanded up to the current grit, the roughness of the surface can be inspected by dragging a cloth or the back of a hand over the area in question. Rougher surfaces will provide more drag, to a noticeable level when compared to a higher grit.

Sanding up to 600-grit will not provide a completely visually smooth finish, however an example of what was considered reasonable to continue with from NU24's plug is shown in Figure 38.

6.1.7. Surface Preparation for Moulds

To prepare for mould making, the now smooth surface of the plug must be thoroughly cleaned, followed by using a resin resistant wax to provide a mechanically smooth surface to prevent applied gelcoats and resins from adhering to the plug. Cleaning the surface of NU24 was done with paper towel and acetone to remove all dust and fingerprints from the plug. Continue cleaning the plug until all paper towels wiped on the plug show no signs of picking up any dust and appear clean, followed by a final wipe-down of all surfaces.

Figure 39 - TR-108 mould release wax

Wax used for NU24’s plug was TR-108 mould release wax as shown in Figure 39. Application of this wax is done through circular movements, alternating the direction of rotation to ensure the wax fills all surface imperfections in the plug from each possible direction. Application can be done through the included applicator pad, however the applicator pad included in this tin disintegrated through usage, and most wax was eventually applied using a kitchen cloth equivalent to a ‘Chux Wipe’. This TR-108 wax is then immediately buffed off from the plug using circular motions with a fresh cloth. Once the TR-108 wax was buffed, a 30-minute wait period is recommended by the instructions to let the wax set, however due to working on a compressed timeline, the 2024 team let the wax set for up to 10 minutes per layer, for a total of 6 layers. This reduced wax-setting time did not seem to have unfavourable consequences as mould removal was a relatively easy process.

Of note is that prior to applying PVA Blue (a process described in section 6.2.3), a final layer of wax was applied to the area where gelcoating was about to commence, followed by the usual buff and cure.

6.2. Mould Work

Design of moulds typically only has considerations to make regarding geometry, as the procedure of mould layup is well established with moulds created through the known layup procedure being both stiff enough to hold their shape and light enough to handle without assistance. The established layup method used for NU24's moulds was recommended by Professor Bill McBride, and worked without significant issue.

6.2.1. Mould Design

As the body kit shape for NU24 was a design where at least two surfaces on it directly oppose each other, it is impossible to create a single piece mould that is cleanly removable from the plug and from the resulting body kit. Therefore, decisions must be made regarding the separation of the moulds along certain locations to create a multi-piece mould.

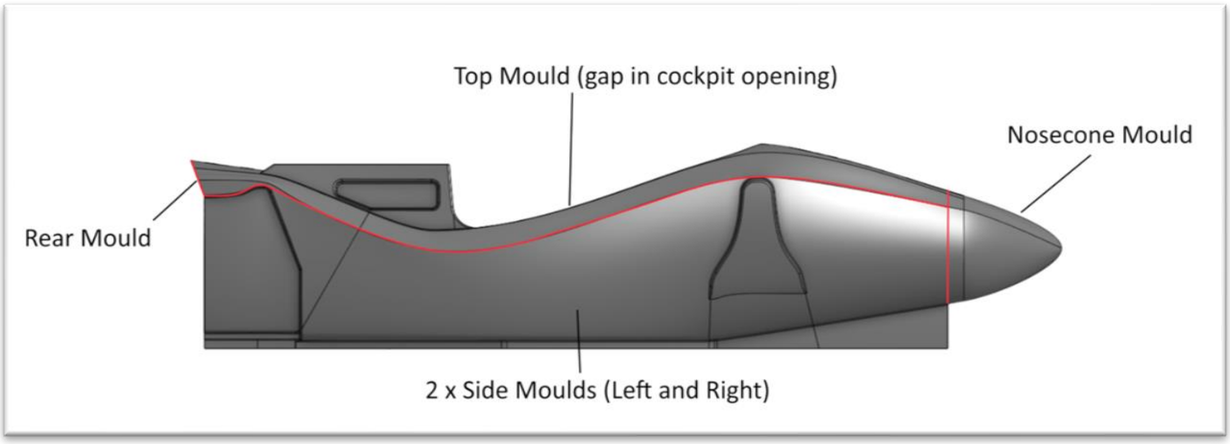


Figure 40 - Description of mould locations and flange joints

The splits in the moulds for NU24 occur at the locations of red lines shown in Figure 40. The pieces making up the NU24 mould include:

- 2 side moulds, ending the front edge at the nosecone, and ending the top edge at the bodyline passing above the coil-over covers.
- 1 nosecone mould ending at the vertical plane defined by the front of the base of the plug.
- 1 rear mould, covering only the back portion of the ducktail.

- 1 top mould, covering the entire area between the sides, nosecone, and rear moulds. This top mould only included layup over geometry that needed to be captured, plus a 50 mm extra border of fibreglass and resin to add stiffness.

Draft angles are the measured angle between surfaces of a part of a mould, and the intended direction of removal of the mould. It is necessary to keep draft angles in mind when choosing where to split moulds, to ensure each mould can properly release from the plug and part.

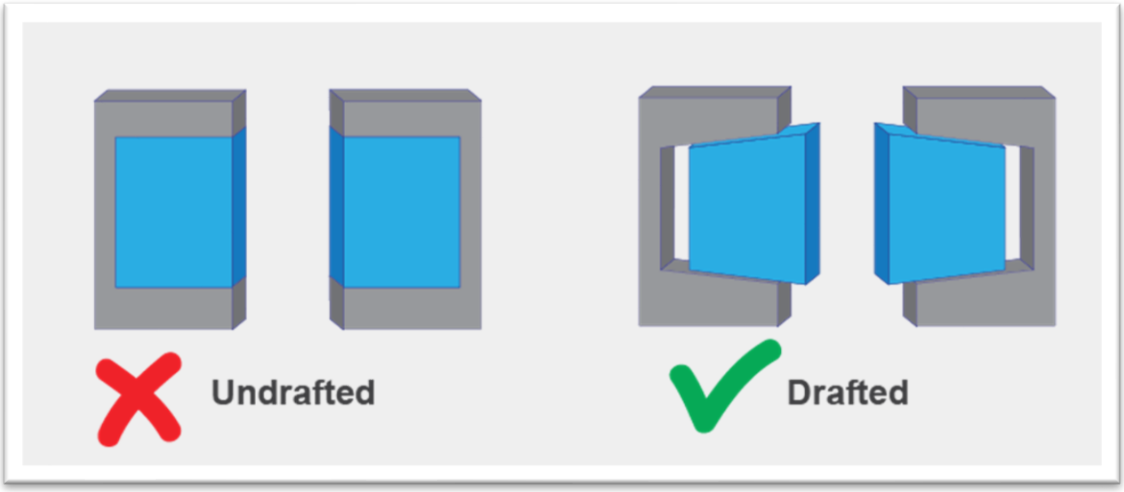


Figure 41 - Draft angle visual (3 Space, 2024)

Each of the mould pieces for NU24's body kit had a flange at the seams where the mould pieces met. These flanges would later be drilled through so that once taken apart, the mould pieces could be put back together with bolts ensuring their correct relocation with each other.

The order of mould pieces made started with the nosecone, as it was a small and simple piece useful for practicing the layup techniques on. Once the nosecone mould had cured, the top mould piece was made. This was due to it being easier to install the temporary mould flanges by supporting them from the underside instead of the top. Once the top had cured, the two sides of the body kit mould were made in 1 day. The final mould piece that was made was the rear mould, made in approximately 1-2 hours.

6.2.2. Creating Mould Flanges

To create the flanges in the moulds, layup must be done over an already existing temporary flange that can later be removed. Once the flange of one mould piece has been created and that mould piece left to cure, the temporary flange pieces can be removed, and the next mould piece can lay upon the previously laid mould.

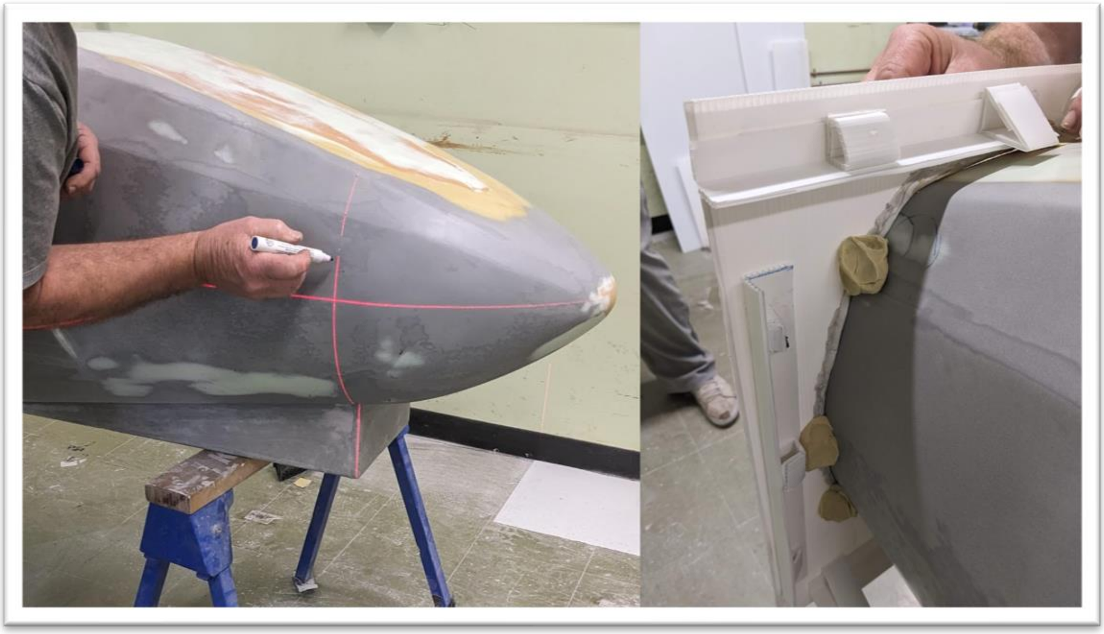


Figure 42 - Laser level used to plot nosecone flange location (left), support of nosecone flange (right)

Temporary flanges were made from corflute as it is resistant to being adhered to by polyester resins used in the layup process. Corflute is also able to bend and twist along the length of the flange, allowing the author to design a flange that had access to layup the fibreglass into the small gap between the flange and the top of the front coil-over covers, by orienting the flange 45 degrees to horizontal at this location. Creating the temporary flanges involved cutting paper templates that would be held up to follow the geometry of the intended path of the flange. These templates were then used to transfer the path that needed to be cut into the corflute sheets. Corflute was cut such that the tubes of the corflute ran start-to-finish along the length of the flange. This allowed the use of a heat-gun to heat and bend the corflute to permanently match the shape of the bodyline it was to follow as seen in Figure 43. Orienting the corflute in this direction also makes it more difficult to accidentally create a crease in the corflute, which would make it difficult for it to accurately trace the path of the smooth bodylines. When creating the flange for the nosecone, a laser level was used to draw a line along the plane where the flange would sit, to enable accurate location of the flange front to back as seen in Figure 42. The author recommends using the laser level to only mark the vertical lines, and a string to mark the horizontal line across the top of the plug. This is due to how the nosecone flanges for NU24's moulds ended up crooked, as their location was not marked as correctly or neatly as could have been. The nosecone flange corflute for NU24's moulds was also made as two pieces, however the author recommends in the future making nosecone flanges from a single piece of corflute, as aligning two distinct pieces adds unnecessary difficulty, and a single piece can still be removed prior to layup of the other mould pieces, by peeling it back and cutting it off with a knife. To join the two pieces of corflute that made NU24's nosecone flange, name-brand cello-tape was used as it is also a resin resistant material.

Figure 43 - Corflute flange piece that has been heated to conform its shape

To adhere the corflute flanges to the waxed plug, plasticene was used. Plasticene is a resin resistant material that does not adhere to the polyester resins, just like the corflute sheet. Plasticene was initially jammed into the exposed edges of the corflute sheet that would mate with the plug. To apply an even layer of plasticene along the length of the corflute, a plasticene extruder was provided by Professor Bill McBride. The extrude consisted of a tube with a screw-operated plunger that would force plasticene from a hole in the end of the tube. The plasticene in the edges of the corflute would adhere the flange weakly to the plug, while plasticene chunks were placed beside the corflute on the side opposite of the side being used for layup. An example of how plasticene was used to hold the flanges is shown in Figure 42. To clean up the edges of mould flanges where plasticene was used, a popsicle stick that had the end cut to a square edge was used to gently scrape along the excess plasticene and remove it, with an example of a scraped edge shown in Figure 44. It is difficult to remove all excess plasticene just by scraping it, so to wipe off the remaining plasticene smears, the TR-108 mould release wax was used to dissolve the plasticene and clean away the surfaces.

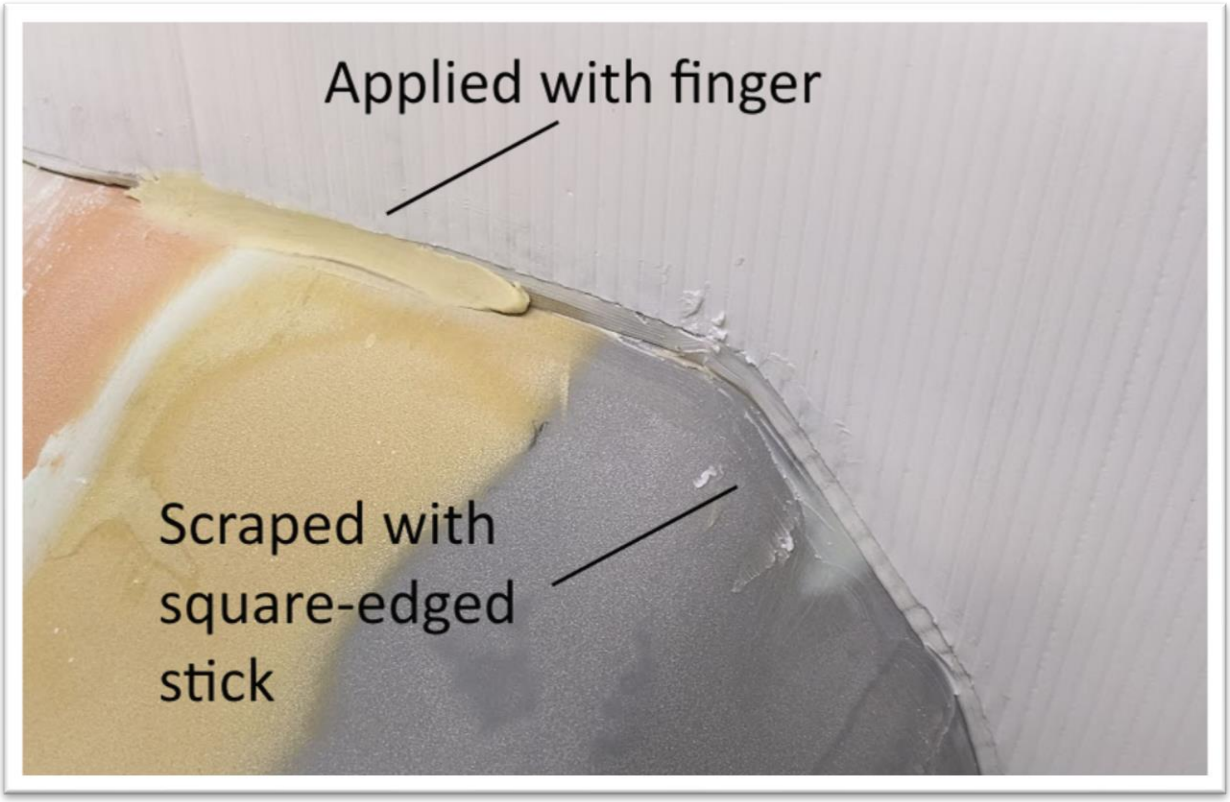


Figure 44 - Application of plasticene to the edge of corflute

Figure 45 is an image depicting the level of cleanliness necessary for a typical corflute flange and the plasticene adhering it. It is most important to ensure that the plug surface itself is very clean, whereas the corflute itself and be relatively covered with specs or smears of plasticene. Specs of plasticene on the flange surface itself could even be argued to be favourable as it will create a rough surface that better locates the flanges once the moulds have been released from each other and put back together. The blue coloration is discussed in section 6.2.3 as it is an applied release agent.

Figure 45 - A suitable finish of a flange for layup

6.2.3. Layup of Mould Pieces

The general process for all fibreglass and polyester resin layup involves the following steps:

- Re-wax the area prior to layup.
- Apply PVA Blue as a chemical release agent.
- Have a person dedicated to mixing up batches of gelcoat.
- Have a person dedicated to applying gelcoat to the areas being fibre glassed.
- Let gelcoat cure until it is sticky to touch but firm. Waiting longer is okay.
- Precut as much fibreglass as possible.

- Have a person dedicated to mixing up batches of polyester resin and applying it with a brush.
- Have a person dedicated to placing fibreglass on the gelcoated areas.
- Have 1 or 2 people dedicated to rolling in and consolidating the resin with the fibreglass.
- Once appropriate layers of glass are applied everywhere, wait for it to partially cure.
- If it is a mould, ‘green’ trim the fibreglass to form edges that are of the full thickness of glass.

Steps following this vary if a mould or the body kit itself is being created. When making moulds a single mould is created at a time and left to cure. As just described, many steps are involved in creating a fibreglass reinforced polymer, and this section will go into depth on each of the steps.

Re-waxing the area of a soon-to-be glassed area is necessary to ensure the area is both free of dust and has not been touched or scratched in a way that may compromise the mould-releasing effects of the wax. As mentioned in section 6.2.5 the TR-108 mould release wax must be applied and buffed off from the area immediately, followed by a 30-minute cure. For this application, the author recommends waiting the full 30 minutes for the wax to flash off and cure.

Figure 46 - PVA blue

PVA blue is a water-soluble chemical release agent that prevents chemical bonding of the gelcoat layer with the wax, and with the substrate beneath the wax. Figure 46 is an image depicting the jug of PVA blue used for the NU24 body kit project. PVA Blue is a runny deep blue liquid that dries quickly when applied as a thin film and exposed to air. Application of PVA blue was done by cutting a wedge from a waxed paper cup enabling easy dipping access into the bottom of the cup. PVA Blue is then decanted into the cup and a paper towel is used to soak up the PVA blue. Using the paper towel, smooth even wipes of PVA blue are applied to the area of the plug that will be glassed. It is not necessary to apply PVA blue to any resin-resistant surfaces such as corflute, cello tape, or plasticene. When applying the PVA blue, ensure to always apply keeping a ‘wet edge’ where you do not double back on any dried areas. Fibreglass layup is a process that captures surface geometry in fine detail, and dragging the paper towel across dried PVA blue will result in tearing up the dried PVA blue and leaving chunky smears of it that will be included in the finish of the moulds.

Figure 47 shows the body-kit outdoors of EC building under a gazebo, with an even layer of PVA blue and ready to be gelcoated.

Figure 47 - Nosecone area ready for gelcoat application

Gelcoat is a spray-on polymer that is applied as an even layer onto the surface area that is to be glassed. Gelcoat comes in multiple varieties, but the ones used for making the moulds and body kit are a red ‘tooling’ gelcoat used for making moulds, and a white spray gelcoat. Gelcoats are used to capture the fine surface geometry and to provide a smooth, finish that is capable of being lightly sanded to remove surface imperfections. Applications of gelcoat are made using a ’spatter gun’. The spatter gun used by the 2024 team was provided by Professor Bill McBride and consisted of a typical airgun for use with an airline and compressor, and a T-piece fitting along the nozzle of the airgun. This T-piece was used to attach a clear nylon tube. The mode of operation of a spatter gun is like that of a venturi injector, where airflow creates a low-pressure zone that draws up fluid from the nylon tube. Application from a spatter gun is rough, as it shoots blobs, and a motion that agitates the gelcoat in the cup and keeps the nylon tube in the gelcoat while also spraying easily must be used to get even coverage. Even coverage can also be ensured by first spraying an even coating across the whole part, moving along as soon as an area is covered in a visibly opaque layer of gelcoat, before spraying the remaining gelcoat evenly across the part at a pace inferred from the first full application. As the body of the spatter gun is an airgun, it is loud, and hearing protection is recommended, in conjunction with respiratory protection from airborne particles and vapours. Figure 48 depicts the author using a spatter gun to apply white spray gelcoat to a side mould prior to layup of the body kit. Gelcoat cures in an exothermic manner and avoiding skin-to-skin contact with gelcoat is recommended. Large amounts of gelcoat on the skin will need to be cleaned off with acetone to prevent skin agitation or burns. Application of gelcoat to parts of the plug and/or moulds will require at least 2 people, with 1 person to spray the gelcoat and 1 person to prepare it. Multiple smaller batches are needed to cover a large area such as a side mould, as the cups used to hold the gelcoat are limited in size.

Figure 48 - Using a spatter gun to apply gelcoat

Red tooling gelcoat is typically applied using a brush, and as such it has a thicker consistency than regular spray gelcoat. To make red tooling gelcoat sprayable, styrene monomer is used as a solvent to dilute the gelcoat back to a runny consistency by adding 0.5% to 1% styrene monomer to tooling gelcoat by volume (Trojan Fibreglass, 2024), however the percentage of styrene monomer added for use with the spatter gun was closer to 5%. Tooling gelcoat typically gives a harder surface finish than regular spray gelcoat and is better for sanding imperfections out of.

Gelcoat in industry is typically sprayed with a dedicated gelcoat spray-gun. Trojan Fibreglass sells a spray gun and the required assortment of supporting equipment to spray gelcoat this way, and the author recommends purchasing this if obtaining a spatter gun from Professor Bill McBride is not reasonable. Application of sprayed gelcoats is recommended by Trojan Fibreglass to be 0.8 mm at a minimum, which is approximately equivalent to 1100 g/m^2 to 1300 g/m^2 given a 1.0 mm thickness, based on a density of 1.1 to 1.3 g/cm^3. To measure out the appropriate amount of gelcoat and resins, gram-accurate digital scales are available from within the EC building composites laboratory. To measure areas of which gelcoat, glass, and resin are applied, a model in Onshape including rough geometry of the flanges was used to take estimates, as seen in Figure 49.

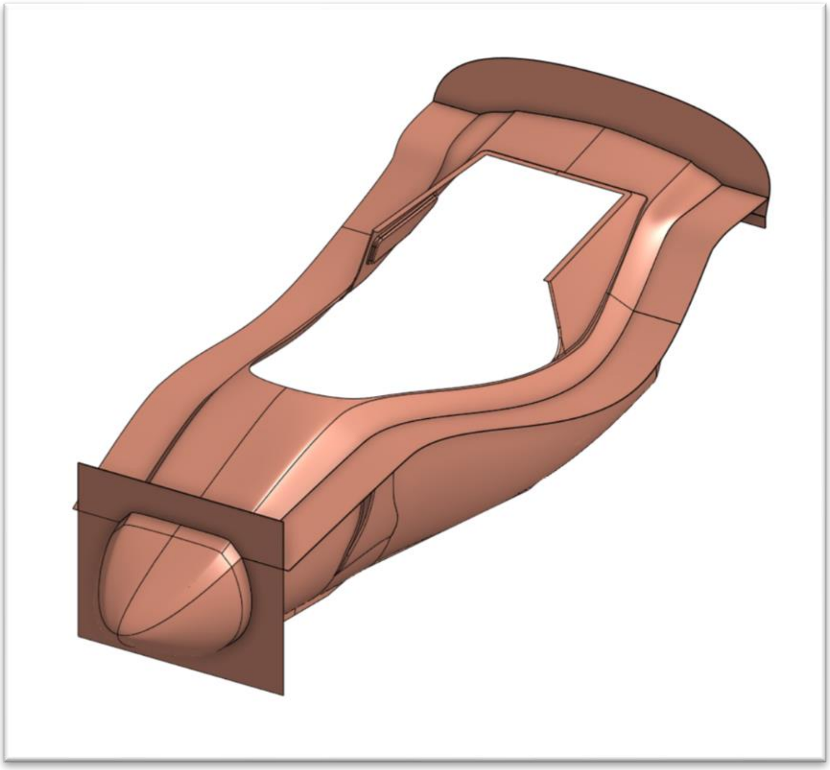


Figure 49 - Onshape model of plug surfaces with mockup of flanges

To activate gelcoat, it must be mixed thoroughly with its catalyst agent; methyl ethyl ketone peroxide (MEKP). MEKP is a colourless, highly toxic and flammable liquid. Eye protection and skin protection must be worn when working with bare MEKP. To mix MEKP catalyst into gelcoat, an amount of 2% by weight or volume is added to the gelcoat. This ratio can effectively be calculated as 20 mL/kg of MEKP to gelcoat, as it is intended for small adjustments to MEKP content to be made based on ambient temperature. To measure out the MEKP used for gelcoats and resins, a syringe can be used. Syringes for the catalyst and for styrene monomer will typically be used, and it is important to differentiate between the two syringes to avoid contamination. Warmer temperatures may need less MEKP, around 17.5 mL/kg, depending on desired working time. For polyester resins and gelcoat, the working temperature of the liquid material should be around 18 to 25 degrees Celsius, as per Trojan Fibreglass' recommendation. Gelcoat should be applied in a shaded area out of direct sunlight to prevent uneven or rapid curing. Mixing the gelcoat with the MEKP should be done very thoroughly to ensure that all edges of the cup have been scraped, and the MEKP is mixed in through stirring and up-and-down motions.

Once gelcoat has been applied, it will typically take 45 minutes curing at room temperature to result in a surface texture that is tacky, with no liquid like behaviour. It is important to ensure that the gelcoat has been given sufficient time to cure to at least this level, before applying the polyester resin and fibreglass, as the resin can react with the gelcoat, creating thin spots in the gelcoat that may cause rippling in the surface texture. To check if gelcoat is ready to glass over, the back of a knuckle can be used to check that it is tacky, in a non-critical area of the mould such as on the flanges. Gelcoat in a professional environment can be given up to a day to cure fully, as it can provide better end results, and if a team that is creating a body kit is not rushed, this is recommended.

The polyester resin used in the mould making and body kit making process is sold by Trojan Fibreglass. It is a golden brown, sticky and viscous liquid that is catalysed using MEKP, the same as the gelcoat. The mixing ratio of MEKP to resin is the same as the gelcoat's mixing ratio, 20 mL/kg of MEKP to resin.

The fibreglass used for the moulds of NU24 was a 600 g/m^2 chopped strand mat. This is a relatively heavy-weight fibreglass mat that is useful for creating relatively stiff fibre reinforced polymers. The ratio of resin to fibreglass for the moulds is 2:1 by weight. To achieve the structural rigidity necessary for the moulds, a minimum of 2 layers of chopped strand mat were used across the entire set of moulds, with 3 layers used in areas that would be prone to higher stresses when the moulds were to be released from the plug. These high stress areas are mainly concentrated around the bridging material of the top mould connecting the front to the back. This kind of allocation of material is the result of intuition rather than in-depth analysis.

To begin the glassing process, ensure a minimum of 4 people a present, with preferably 5 people present for the large pieces such as the sides and top of the moulds. Workload allocation is:

- 1 Person to mix resin as needed. Applies resin to the plug first, before others apply glass. Wets down bulk areas of glass loosely with resin.
- 1 Person to lay glass as needed.
- 2-3 people to roll and consolidate the resin into the fibreglass and roll the fibreglass to the shape of the plug.

The layup process begins with identifying areas that need to be filleted. Fibreglass, although conformable, has a minimum bend radius it is suitable for, in the magnitude of 5 mm radius for both convex and concave corners. To fillet corners of the moulds, a mixture of resin and talcum powder is made, which will be called filleting bog for this report. Start by mixing the resin with the catalyst to ensure even distribution of catalyst, followed by adding talcum powder to achieve a toothpaste like consistency. An approximate 1:1 ratio by volume will result in the desired consistency, but the author recommends starting with too-little talcum powder as more can be added in increments. Mixing of talcum powder with resin must be done quickly and thoroughly, however this will result in adding air into the mixture. Aerated filleting bog can result in bubbles around the gelcoat, and will not support the gelcoat in that area, meaning the brittle gelcoat will later crack off requiring repair. Application in 2024 was done with a popsicle stick, scooping it out of the paper cup. The author recommends in the future that filleting bog be applied through a piping-bag, which can be made in a makeshift manner by using zip-loc bags, and scissors to cut the corner of the bag. This should ideally make it difficult to trap air under the filleting bog and help pop bubbles as it passes through the nozzle of the bag. All sharp corners in areas that are to be glassed in an approximate 30-minute timeframe will need to be filleted.

Fibreglass used in fibreglass reinforced polymers is impregnated with a small amount of a bonding agent that keeps the fibreglass stiff for handling while it is dry. This bonding agent is soluble in the polyester resin, meaning that applying a stiff section of chopped-strand fibreglass mat to an area coated in resin will cause it to lose some of its stiffness, allowing it to be pressed into place and consolidated around the plug.

Figure 50 - Beginning of layup of nosecone mould

To begin the glassing process, the filleted and ready-to-lay areas now receive a brushed on generous coating of resin, ensuring no dry spots are present. It is harder to force the resin down to the surface of the fibreglass than it is to lay the fibreglass on a thick bed of resin and then redistribute that resin through the rest of the glass. Once a large enough area is covered in resin, a sheet of fibreglass can be laid down upon the bed of resin. At this point, thick brushes of resin are applied to the outside surface of the resin, in a stippling motion resembling tapping the glass down with the wet brush, to gently conform it to the shape of the plug.

Sections of fibreglass mat are not the same for the whole shape of the mould. It is possible to either cut a roll of fibreglass with scissors or to tear it by hand (with appropriate PPE). A cut edge will have a sharp neat edge, whereas a torn edge will have a feathered-out texture. Feathered edges of fibreglass mat are used for joining bordering pieces of fibreglass, as it results in a smooth transition between pieces. Sharply cut edges of fibreglass mat are used to make up the border of the moulds around the edges of the flanges. Fibreglass should be applied right up to the edges of the flanges, along with the gelcoat.

Once a piece of fibreglass is sufficiently stippled, the 2 people on standby with rollers can begin to roll with medium pressure across the fibreglass. Rolling is a technique that redistributes resin throughout the fibreglass matrix, ensuring all fibres are properly wetted out, while simultaneously forcing the fibreglass matrix down to conform to the shape of the plug. Two rollers used for the layup processes were provided by Professor Bill McBride. The roller tools were a steel-wire handle with a drilled through M10-M12 size of bolt as the roller itself. Fibreglass rollers are available for purchase from Trojan Fibreglass if necessary. Rolling is an important job to do thoroughly and quickly. As resin sets, its texture and viscosity changes which results in a tacky mixture. Rolling over a mixture like this will lift the fibreglass rather than consolidate it, resulting in air being caught underneath the fibreglass as attempts to roll it back down will undoubtedly be made.

With all roles in the layup operation under way, the process for fibreglass layup operates in a workflow where a ‘wet edge’ style of layup must be maintained. This means that as a layer of fibreglass has been consolidated, the second (and potentially third) layers of fibreglass and resin must be applied before previous layers set too much. This is to avoid the previously mentioned glass lifting under roller application. As a result, a stair-case style of glass layering will proceed across the whole part until the part has been completed, where a first layer of glass makes constant progress across the part, with the second layer being applied behind the progress of the first layer, as soon as suitable sections of first layer have been rolled.

Approximately 30 minutes to 1 hour after fibreglass has been laid down, a ‘green trim’ of the fibreglass flanges can be done. This green trim is to remove any frayed edges that may be present on the outer edges of the flanges if fibreglass sections used were not sufficiently well-trimmed prior to usage. To do a green trim, the resin must be in the right state of cure, and the mould edge is to be trimmed using tinsnips. Tinsnips have a cutting direction, where was material is intended to be placed on the side of the bottom jaw. For this reason, it is useful to have both left oriented and right oriented tinsnips for trimming the flanges.

When laying up against another existing flange it is important to wax and PVA blue the surface the same way that surface would be prepared as if it was a part of the plug.

6.2.4. Removal from Plug

Once the entire set of moulds has been manufactured, it is recommended to wait at least 1 week for the resins to cure to a stiff finish. In 2024, however, the author removed the moulds after approximately 4 days from final layup, and the moulds were structurally sound at this point, holding their true shape for the body kit production.

Before removing the moulds from the plug, it is necessary to drill through the flanges of the moulds to enable them to be bolted back together accurately later. Placement of bolts for NU24's moulds was approximately 20 cm between bolts, using M6 bolts and a 6 mm drill bit.

To remove the moulds from the plug, a hard but flexible plastic strip known as 'yellow-tongue' is used to jam between the mould and the plug. Removing the moulds from the plug is a mostly sacrificial process, and is likely to cause damage to areas of the plug. Areas of the top mould in 2024 included feathered edges running along surfaces around the cockpit opening and rear shroud. These feathered edges caused issues when trying to jam the yellow-tongue beneath them, which resulted in these surfaces being cut through using an angle grinder to cut the extra mould material back to a section of full thickness. Angle grinding of fibreglass produces airborn glass particles that are damaging to lungs and irritating to skin. Always ensure to only angle grind fibreglass with an established exclusion zone, appropriate PPE, in a very well ventilated environent, preferably outdoors.

The order that moulds were removed was the nosecone mould, followed by rear mould, side moulds, and top mould. Removing the nosecone mould first is important as it is possible to use the side and top moulds to provide leverage against the nosecone mould.

It would be extremely difficult to remove the nosecone mould first by just pulling and pushing it off. To properly remove it, a hole was drilled into the underside of the mould, followed by a cut angle-ground through to the edge of the flange as seen in Figure 51. A hacksaw blade was used by hand to finish cutting around the whole, as the angle grinder would potentially cut past the hole, bypassing its intended purpose as a stress relieving feature.

Figure 51 - Split in nosecone mould to enable release

This method of cutting a slit into the nosecone mould provided a way to pry the nosecone mould out of shape, by jamming yellow-tongue between the cut in the flange, and jamming yellow-tongue through the slit against the surface of the plug, separating it from the plug.

Removing the sides, top, and rear of the moulds is easier than removing the nosecone. Gently separating the front edge with yellow-tongue and sliding it down the length of the plug, while simultaneously lifting the mould from the plug gently will create a stress concentration in the sticky bond between the moulds and the plug. This peels the moulds off slowly in a controlled manner.

Figure 52 - Plug after moulds were removed from it

6.2.5. Mould Preparation for Body Kit Layup

Once moulds are freed from the plug, they must be washed to remove the PVA blue film that remains on the moulds. PVA blue is water soluble and can be washed away gently with a wipe and warm soapy water.

If application of the gelcoat was not perfect, or the gelcoat was not given enough time to cure, bubbles or rippled surfaces may be present on the mould surfaces. To repair imperfections in the moulds, Dolphin Glaze is suitable for 1-time uses. It is difficult to adhere Dolphin Glaze to the smooth insides of pinholes in a gelcoat surface. To promote adhesion, brush out contaminants in the holes (as seen in Figure 53) and use a small sharp steel object such as a knife blade or sewing needle to scratch the inside surface of the holes. Application of the bog should be done lightly as sanding using 'shaping' level grits can quickly wear through the gelcoat layer, exposing resin and fibreglass. Sanding of the moulds should be exclusively wet sanding to keep the surface lubricated and to prevent deep scratches forming. Do not use a grit any more aggressive than 300-grit.

Figure 53 - Using a brush to clear dust from pinholes

The cut in the nosecone mould must be filled to provide a smooth continuous surface. As it is in a location that is difficult to see, and surface finish here may be overlooked, using plasticene to bridge this gap is a viable option to save a small amount of time. The author chose to bridge the gap in the nosecone mould with Dolphin Glaze to provide a mildly structural and well-finished surface to glass over, in comparison to plasticene which may distort throughout handling of the moulds.

The entire set of moulds should be gently wet sanded at 600-grit to knock down any high points caused by pinholes in the plug that were not properly filled with wax. Following a thorough clean of the moulds, the same process of waxing the plug is applied to waxing the moulds.

6.3. Body-kit Shell Manufacture

In comparison to the mould layup which involves a minimum of 1 week of continued dedicated labour plus curing, layup of the body kit itself is a relatively quick process, that could be completed in 2 days, followed by curing. Layup of the body kit is initially done in individual moulds, which are then bolted together, and the body kit is then laminated across the seams of the moulds to form a single piece.

6.3.1. Layup into Individual Moulds

Layup of the body kit used two different styles of 300 g/m^2 fibreglass weaves in 2024. Varying the choice of weave for future designs is a recommendation, where different combinations may result in different stiffnesses, manufacturability, and resultant weight of the body kit. The choice of weaves for NU24's body kit was a recommendation from Professor Bill McBride, with a first layer of "double bias" mat and a second layer of "woven cloth" (also known as plain weave). This is opposed to the body kit for NU23 which used two layers of 300 300 g/m^2 double bias. The change to a second layer consisting of plain weave was recommended by Professor Bill McBride due to it's supposed better handling characteristics when glassing with it.

Before beginning layup, ensure that the moulds have been properly waxed according to the process described in section 6.1.7 with wax only being applied to the body kit surfaces of the moulds. After this, PVA blue is applied to those same surfaces. When letting the PVA blue dry, invert the nosecone mould to properly drain the flow of gases released by the PVA blue, as fresh air is needed to contact the PVA blue to dry it properly.

Layup into the moulds requires a gelcoat finished outer surface. Gelcoat used for the body kit was a white spray gelcoat. Having brightly contrasting gelcoat colours is useful for visually identifying the clear application of gelcoat with uniform distribution across the moulds. Spray gelcoat does not require thinning with styrene monomer prior to application and uses the same catalyst ratio of 2% by weight or volume. To gelcoat the moulds, it is important to avoid covering the flanges of the moulds, as this would result in a bond between the moulds. Therefore, masking tape is used to fully mask off the flanges of the moulds and is removed immediately after the gelcoating of a given mould is completed.

For the body kit glassing process of NU24's body kit, paper templates were made by the author in combination with effort from NU Racing chassis engineer John Jones. The paper templates were used to cut out pieces of fibreglass prior to beginning the layup process. These paper templates were made to a level of detail that was approximately 5 to 10 mm accurate of the borders of the body kit moulds. Templates of this level of detail are not necessary at all, and rough templates that visually cover the moulds in a roughly neat but generous manner would be fine. Pre-cutting the fibreglass for the body kit itself is highly recommended as it considerably smoothed the workflow when doing the glass layup. This contrasts with the mould layup, where glass can be eyeballed quickly without significant impact to workflow. It is preferable that a single sheet of fibreglass would be used to cover a large area, however if sheets must be placed side by side, it must be ensured that there is no stack-up of glass seams. This means that where a seam exists in the first layer, the second layer should smoothly glass over the top, without locating a seam in the same place. This is to prevent stress concentrations in weak locations of the fibreglass layup.

It is important to note early on when cutting the glass for the body kit that the first layer of glass continues right up to the edge of a given mould. The second layer of glass is cut to a shape that is approximately 50 mm offset from the edge of a flange. As a part of the joining process, a 100 mm wide strip of plain weave is laid across the joints, meaning that material must be removed from the glass of the second layer on the individually laid moulds, to prevent having a step in thickness of glass. The rear mould can be bolted to the top mould prior to laminating, saving laminating them as separate pieces.

Glassing the individual mould pieces is the same process as glassing the moulds, detailed in section 6.2.3 and requires the same amount of people to do so. Preferably, all people involved in mould fabrication are involved in body kit manufacture as the transfer of skills and practice is highly beneficial to the smooth operation of the glassing team.

Keep note of sharp corners in the moulds that may require filleting bog to laminate glass around them smoothly, as described previously in section 6.2.3. In NU24's body kit design, an area that was not to be a part of the final body kit – but was included in layup anyway – was the opening of the front coil-over cover. This opening was glassed over with a single layer of double bias purely just to lift the gelcoat with it and to prevent any hairline fractures from forming in what would be unsupported gelcoat. Hairline fractures in the unsupported gelcoat may have transferred to parts of the body kit that were intended to be kept.

6.3.2. Layup Across Seams

To join the body kit pieces and turn them into a single-piece body kit, laminating the individual pieces at the mould seams is necessary. Breaking down the work into individual pieces allows for better access to the moulds for the layup process and prevents back-breaking work of reaching over and laminating vertical surfaces of an upside-down body kit.

Joining the seams first begins with joining the mould pieces together through the drilled holes previously made in the flanges. The bolting of the flanges together should result in a positive interlock between the uniquely shaped flanges. Tightening the bolts by hand with a spanner may provide the best results for tightening the flanges together firmly without overtightening and damaging the fibreglass. Ensuring a tight fit with the bolts will seal up the corners of the mould better, preventing gaps from filling with filleting bog.

Laminating over the seams of the body kit involves the same process of glassing as all other glassing, however the resin filler used to apply a radius to the joints between moulds is a new mixture. By combining the polyester resin and the white spray gelcoat in a 1:1 ratio and mixing with the appropriate 2% by weight or volume MEKP catalyst, followed by the addition of talcum powder, a new mixture of a toothpaste consistency filleting bog is created. This mixture has more desirable properties for sanding than the regular plain resin/talcum powder filleting bog.

After applying the resin/gelcoat/talcum powder mixture, the pieces of plain weave joining across the mould pieces can be placed. Additional layers of plain weave may be placed in areas where stress may be a concern. For NU24's body kit this included strength concerns around the coil-over covers, cockpit opening, and the necked down section just forward of the ducktail.

6.3.3. Stiffening Reinforcements and Adding Handles

Under prior assumptions from the body kit of NU23, it was assumed that the body kit of NU24 would have a similar lack of stiffness. Therefore, stiffening strips to reinforce the body kit were added at multiple locations across the body kit. These locations included:

- A horizontal strip across the top of the ducktail.
- Vertical stripes on the rear edges of the front coil-over covers.
- Strips around the border of the rear shroud.

To stiffen these areas, a material called coremat is used. Coremat is a polymer foam-like substance that readily absorbs resin and can be ordered in several different thicknesses. The thickness used for NU24's stiffening was a 3 mm roll. Coremat is a relatively heavy way of adding stiffness to large panels without much curvature. If possible, it is preferable to remove large flat sections from designs by increasing curvature or by adding rolled edges or flanges to the design of the fibreglass part itself.

Figure 54 - Coremat additions for stiffening the body kit

To apply coremat, first soak it in polyester resin that has been activated with MEKP catalyst. The reinforcing mat can then be laid down onto the areas that need to be stiffened. Following this, a layer of plain weave about 3 times the width of the coremat is placed on top of the coremat and consolidated with resin. A second layer of plain weave about 5 times the width is laminated on top of the previous layer, with examples of complete coremat installations shown in Figure 54. This produces a well adhered and very stiff structure to reinforce sections of a fibreglass layup. Varying widths of coremat strips were used across the NU24 body kit.

The author estimates that the coremat additions to the body kit are responsible for at least 1 000 g of mass added to the body kit and may potentially be unnecessary. If resources permit the author recommends future teams to experiment with removing a body kit from the moulds without stiffening to examine the stiffness of the body kit to make better educated decisions on where reinforcements are necessary. Generally, strength concerns can be solved with extra layers of glass, and coremat is just a means of adding stiffness at the cost of weight.

In the handling of the body kit of NU24, removal of the body kit was done with the assistance of a total of 5 people. Once off the chassis, NU24's body kit could be handled by 2 people, 1 person at the front and 1 person at the back of the body kit. Handling the rear of the body kit involves a location that is quite natural to hold. Due to the thin fibreglass construction, rubbing hands against the edges of the fibreglass posed the risk of cuts and abrasions. The mitigate this risk, small handles of wood trim board were used to add thickness to the location most natural to hold.

To apply the handles, shaped and sanded blocks of trim board were soaked in a mixture of resin diluted with 50% added acetone as seen in Figure 55. This decreases the viscosity of the resin and promotes its absorption into the wood. A strip of 600 g/m^2 fibreglass chopped mat is used to act as a spongy layer to ensure full contact between the flat wood and the uneven fibreglass body kit.

Figure 55 - Handles used for NU24 plug

To hold the handles in place, woodworking clamps with resin resistant cello-tape were used to prevent movement as seen in Figure 56.

Figure 56 - Wood clamp used for holding handles to cure

The handles used for NU24's body kit did provide a smooth surface to hold from, however a thinner section of wood around 3 to 4 mm thick and 10 mm wide would provide the same effect at a reduced mass.

6.3.4. Layup of Nose Joint

To avoid having a visible air gap between the major body kit piece and the nosecone, a layup of a joint between them is made, that is adhered to the nosecone. This layup locates the major body kit piece across the outside of this joint when both pieces are on the car.

To create the joining flange, gelcoat is brush onto the frontmost edge of the main body kit piece while it is still in the mould. This gelcoat is then waxed several times prior to having PVA blue applied to prevent adhesion of the joining flange to the main body kit piece.

Regular layup methods apply to the flange, and 2 layers of 300 g/m^2 plain weave fibreglass are used to create the extension of the nosecone.

Figure 57 - Gelcoat applied in a 50 mm strip along the edge of the front of the main body kit

Figure 58 - Wax and PVA blue applied to gelcoat strip

Once the flange has cured to a solid state, with the moulds bolted together, drill through an out-of-sight area of the flange, preferably the bottom. Extend the hole all the way through the main body kit piece. Doing this on the left and right underside of the nose will be useful in the fitment process, as bolts can be used to join the nose and body kit at these points, meaning only tape on the top surface of the nosecone joint to the body kit is needed to accurately constrain them together.

Ensure thickness of the flange joint is thick enough in areas where mounting of the nosecone is done using fasteners, as burying a countersunk head of a bolt into the fibreglass provides a better fitment between the nosecone and body kit than a bolt that sits proud of the flange.

6.3.5. Repairs of Air Gaps

Corners on the body kit may be prone to trapping air in the layup process. These air pockets create weak points as the fibreglass is no longer supporting the outside shape of the body kit. To repair these areas, two methods can be used.

For larger air pockets, the fibreglass must be cut away with a knife. Using 80 grits sandpaper, the remaining sharp edges of fibreglass can be sanded down flush. A new piece of plain weave fibreglass can be laminated onto the affected area.

For small air pockets, a drill can be used to expose the inside of the pocket. Using a syringe, inject resin into the air pocket to bond the fibreglass through the resin to the rest of the body kit material.

Figure 59 - Air pocket requiring cutting out and re-laminating (left), air pocket suitable for drilling and filling with resin (right)

6.3.6. Removal from Moulds

Removal of moulds from the body kit is a delicate process. Techniques such as using the yellow-tongue plastic to pry the body kit from the moulds is necessary. Patience is required to avoid damaging the body kit in the removal process. If serious difficulty is had, there is potential to use water to dissolve the PVA blue, however this was unnecessary for NU24's body kit.

6.4. Mounting and Fitment

Mounting of the NU24 body kit is done through "Quik-Latch" multipurpose push button fasteners, with the nosecone mounted via countersunk hex-drive metric bolts and nyloc nuts. The unique fasteners used for the nosecone are available for purchase at Newcastle Hi-Tensile Bolt Company. To attach these fasteners to the chassis, metal tabs are modelled in Onshape in context of the body kit and the chassis. Jigs for welding the metal tabs were designed by Lachlan Fisher.

Figure 60 - Blurry image of bolt joining nosecone to main body kit piece

During the entire fitment process of the body kit and nosecone, bolts are used through the drilled holes in the nosecone flange through to the body kit main piece. This pins the two pieces together such that tape on the top surface of the two pieces can be used to accurately match the nosecone to the body kit for the fitment process.

Before marking, drilling, and applying all fasteners to the body kit, a marker is used by hand to trace where edges of the body kit must be cut. This includes removing material covering the coil-over opening, and the cockpit opening, the top edge of the rear shroud, and neat lines along the entire perimeter of the body kit.

The fibreglass of the body kit is then ground away using sandpaper or an angle grinder with a flap disc to produce a neat finish along all body kit edges. At this point, sanding of the inside of the body kit should be done. It is likely that many sharp bits of fibreglass are protruding from the inside surfaces of the body kit that risk stabbing drivers or people handling the body kit. Sanding the inside can be done with 80-grit sandpaper on a cork block. Sanding fibreglass creates airborne glass fibres. Ensure to wear all appropriate PPE, and work in a well-ventilated area with an exclusion zone.

Figure 61 depicts the initial fitment process of the body kit to NU24, part way through having it’s edges ground back to a neat perimeter.

Figure 61 - NU24 body kit partway through fitment process

Ensure the thickness of the joint flange between the nosecone and body kit is as thick as the head of the bolts used to fasten the nosecone to the chassis. This will allow for the countersunk heads of the bolts to sit flush with the outer surface of the flange, improving fitment of the body kit to the nosecone. A deburring countersink drill bit can be used by hand to gently countersink the heads of the bolts.

To fit the nosecone, adjustable 3D printed shims with a half-sphere are used to provide a single point of contact with the nosecone at each of the fastener locations. Using adjustable shims is necessary as accuracy of the finished body kit may not match the Onshape CAD.

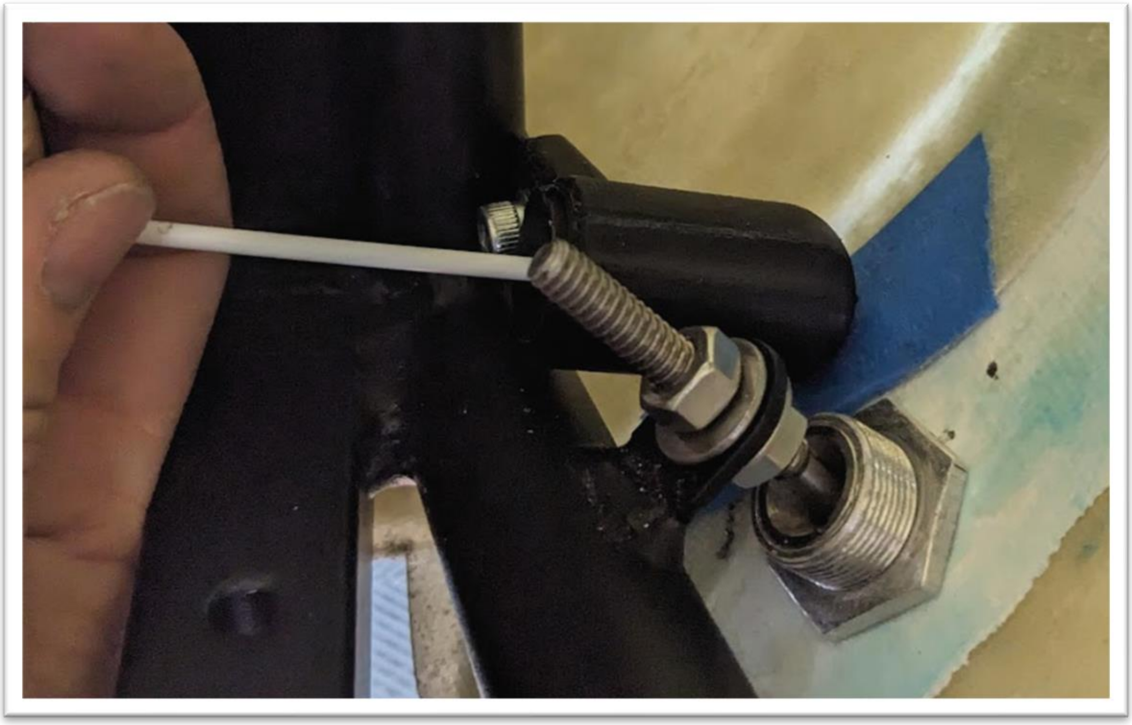


Figure 62 - Pen cartridge used to mark holes to drill for mounting on a piece of masking tape

The Quik-Latch fastener pins are installed across the chassis of the car, and then the body kit is placed on top of the car. Shimming the height of the body kit is used to sit it in the correct orientation. By pushing the pins to contact the body kit, a person inside of the chassis can mark the contact between pins and the body kit using a permanent marker. These markings are used for drilling out the holes needed for the push-button inserts that screw through the body kit using a thread and nut. By making the holes 1 to 2 mm oversize, the push-button inserts can rest freely to avoid putting distortion into the body kit, before being tightened down.

Adjustment of the gap between the body is done from within the chassis. Ideally 2 people are involved in this process. If the gap is reduced too far, it will become difficult to correctly connect the push-button insert to the pin, so the person on the outside should be regularly checking this throughout the fitment process.

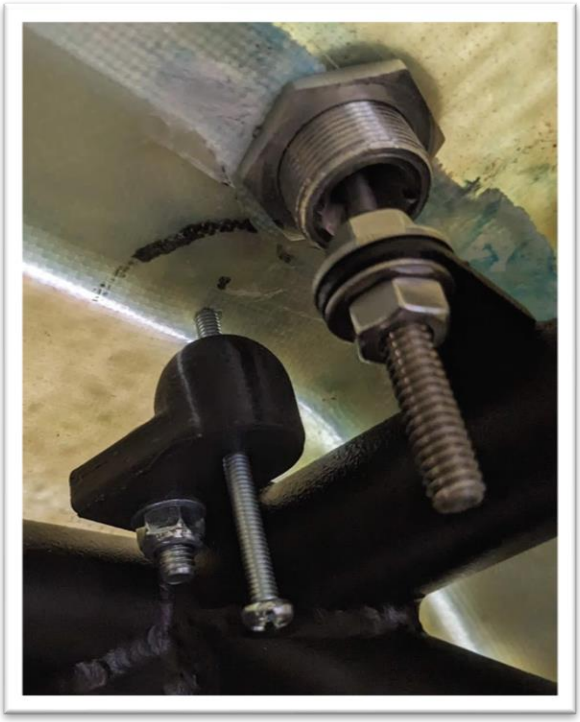


Figure 63 - Example of fitment of quik-latches (right) and nosecone adjustable prints (left)

Figure 64 - Second example of installation of quik-latch

6.5. Paint Preparation and Stickers

To prepare the body kit for painting, inspections of surface finish must be done to check for any areas of weak gelcoat. Areas of weak gelcoat could be caused by either prematurely glassing over uncured gelcoat resulting in ripples, or air bubbles from filleting bog or poor consolidation and application of fibreglass. To fix weak gelcoat, it must be cracked out and removed from the body kit. Areas that require filling can be filled with Dolphin Glaze. Sanding the body kit should be done with caution, using only 300-grit or higher sandpaper. In Figure 65 it is clear to see that NU24's body kit had many imperfections caused by air trapped in the filleting bog.

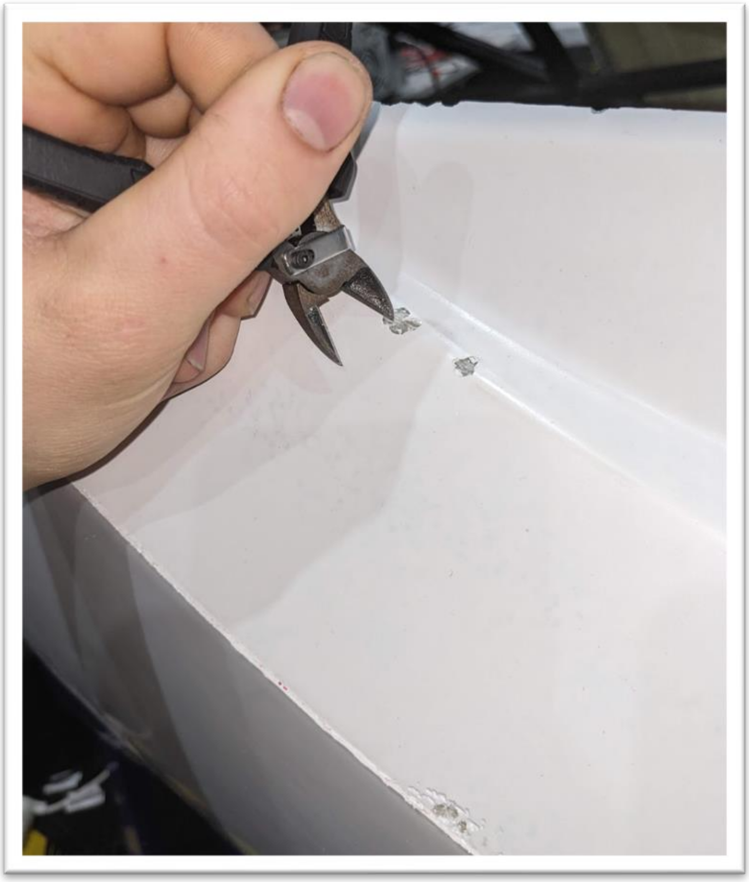


Figure 65 - NU24 body kit covered in flaky gelcoat that caused by air bubbles

Using 600-grit sandpaper, dry sand the entire body kit to a uniform finish as preparation for painting.

Painting in 2024 was done through Gourmet Bodyworks in Tuggerah. Approximate cost was $4 000. The result was a very professional finish and vibrant colours as seen in Figure 66. It is likely a large amount of cost was due to the imperfections still present in the body kit when it was submitted for painting, requiring costly labour.

Figure 66 - NU24 body kit being picked up from painting

FSAE requires several stickers across the car for compliance reasons. The stickers of importance for compliance are the “E03” stickers that identify the car number, as well as the FSAE competition sponsor stickers. FSAE publishes resources available to teams describing the dimensions of the sponsorship stickers and technical inspection stickers. The E03 identifications stickers are mandated to have 150 mm height text, 18 mm character spacing, and 25 mm black border. Check these values before ordering any stickers as they are prone to change at any point under new publications of FSAE rules.

The most important rule of the identification stickers that NU24 was not technically compliant with was the placement. The FSAE international rules state that “The numbers must not be obscured by parts of the vehicle” (SAE International, 2023). Stickers for NU24 were applied with the slick wheel and tyre combination on the car. However, the wet tyres on NU24 have a larger diameter, which partially obscured vision of the car numbers when viewed from a direct side view. This was not caught out during technical inspection; however future teams should take note to place competition regulated stickers with more care.

All stickers placed on vertical surfaces of the body kit were aligned using a laser level to ensure parallel alignment of all stickers for a professional and uniform look. Spacing of un-applied stickers was done with masking tape and blue tack to organise a cohesive aesthetic for the sponsorship sticker locations with even visual weight, as seen in Figure 67.

Figure 67 - Sponsor sticker application to body kit

6.6. Body Kit Recommendation Summary

The primary recommendations by the author regarding the body kit specifically for NU25 are described in section 8.9. This section will summarise the recommendations for improvements to the manufacturing process in general.

Consider investigating a process for alternate creation of plugs. Usage of a 3D printer for smaller scale moulds could be used as a validation test for the manufacture process of custom-made plugs.

Reach out to RPC Technologies for advice regarding potential adjustments to the processes described in this report. RPC Technologies specialises in fibreglass reinforced polymers and have the equipment and expertise to guide NU Racing into making better engineering decisions and processes with a variety of composite parts, not just limited to the body kit.

Consider using adjustments to the weaves of fibreglass used for the body kit, taking note of stiffness to weight ratio, and workability as the primary factors.

Investigate different amounts of coremat for stiffening the body kit. It may be desirable to produce a body kit with no extra stiffening, and to drive with it to investigate where added stiffness is truly necessary. Try different thicknesses of coremat and different widths of strips.

Consider removing the handles entirely from the back of the body kit, or at least use smaller wooden strips, as the ones in NU24’s body kit are larger than necessary.

7. Reliability and Performance Issues

This section is primarily a means to document some of the biggest known issues of the car that arose during both testing and competition. Although the author may not have been involved heavily with diagnosis or remedies for all these issues, it is important these are documented for the sake of the team's progression.

7.1. BMS Cell Voltage Irregularities

During the 2024 competition Autocross event NU24 had a battery management system (BMS) hard fault occur which forced the shut-down the car in the 2nd of 4 total autocross attempts, resulting in only having a single 'banker' lap recorded (a safe but slow time for the sake of ensuring *some* points in the event).

The fault that occurred which will be detailed further in the report submitted by Alec Chapman that cover's his work as the mechatronic team leader for 2024, and in Joshua Hayward's final-year-project report covering his work as EV drivetrain mechatronics engineer for 2024.

The BMS cell voltage irregularity that occurred is the symptom of 1 cell being read as under voltage followed by the next cell in sequence being read as above voltage, when the accumulator pack is under considerable load / power output. This creates a cell (voltage) delta fault from the BMS which then outputs that as a hard fault case to the shutdown circuit.

This was an ongoing issue, and multiple fixes were attempted such as replacing the suspect cells with brand new cells and attempting to bypass / bridge potential poor connections on the relevant CANAMON(s) in the accumulator. Despite this the issue still occurred at competition, and the temporary solution to prevent another hard fault occurring during endurance was to operate the bare minimum battery monitoring required by the competition rules in terms of cell under-voltage and cell voltage delta. This was done as the mechatronic team had collective high confidence in the accumulator cells as being within spec and the fault occurring due to bad voltage tap connections, or a faulty BMS unit.

The 2025 team should conduct extensive testing such as swapping segments, CANAMONs, voltage tap looms to the BMS, etc to progressively isolate the fault to any one of these components. There is the possibility that the BMS itself is faulty. Important to note is that the BMS validation tool located in the high-voltage work area in the TA building is likely broken and a new one may need to be purchased.

7.2. Powerbox Deflection

Part of NU24's changes from NU23 included the change from an EMRAX 188 electrical motor to an EMRAX 228 motor. This changed the peak available torque output from the motor from 100 Nm to 230 Nm. The gearing of the powerbox changed from 6:1 to 3.286:1 (10 tooth drive and 60 tooth driven to 14 tooth drive and 46 tooth driven) to achieve a target tractive wheel torque of ~750 Nm. This wheel torque was based on the tyre coefficient of friction and car mass and weight transfer to calculate the maximum longitudinal tyre force on the rear axle, and using the tyre radius, the maximum wheel torque before breaking traction.

The resulting peak chain tension based on the torque and sprocket diameter changed from NU23's 4866 N to NU24's chain tension of 8060 N. Multiplying the chain tension by the moment arm of the distance from sprocket to motor plate mounting bolt pattern produces a cantilevered moment reacted by the motor plate of 560 Nm for NU23's powerbox compared to 1040 Nm for NU24's powerbox, assuming both were operated at peak torque output.

This reacted moment at the mounting bolts is important as during testing of NU24 when implementing the first EMRAX 228 compatible powerbox, the maximum torque request from the pedal was gradually increased as a safety precaution during initial commissioning. As the maximum torque request increased there came a point where the motor contacted the chain guard of the powerbox. To do this the motor had to close a 5 mm gap between the motor's face and the chain guard's edge.

The peak motor output torque was limited from 230 Nm to 180 Nm for the 2024 competition to rule out the possibility of the motor contacting the scatter shield. For reference this resulted in a reacted moment at the mounting bolt pattern of ~814 Nm.

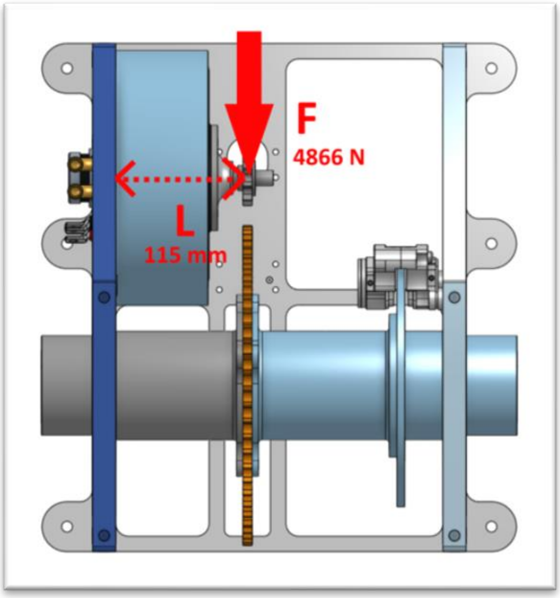


Figure 68 - NU23 powerbox primary forces

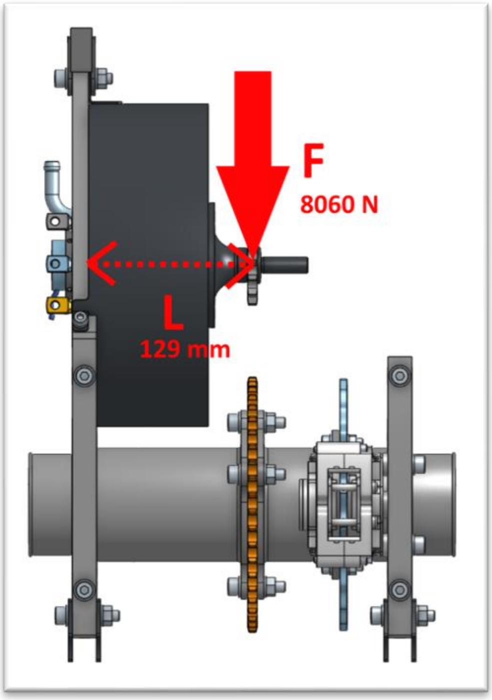


Figure 69 - NU24 powerbox primary forces

This type of potential clearance issue could have been identified as a potential issue earlier in the design process by doing the above simple calculation on the magnitude of bending moment reacted by the motor plate however this did not occur.

The current preliminary design for NU25's powerbox uses the same gearing ratio and motor and therefore same peak chain tensions, however the Drexler differential is driven from outside of the two bearing supports, meaning packaging of the motor uses a longer transfer shaft that is supported by a bearing nearby the sprocket, significantly decreasing the moment resisted by the plates at both the motor and the sprocket bearing support. At the centre of the sprocket support bearing the current moment arm is 31.5 mm compared to 129 mm of NU24's powerbox. The resulting moment for the NU25 powerbox at the sprocket support is 254 Nm, less than half that of the NU23 powerbox of 560 Nm. The reacted moment at the motor will be negligible and will effectively only transfer torque to the motor plate.

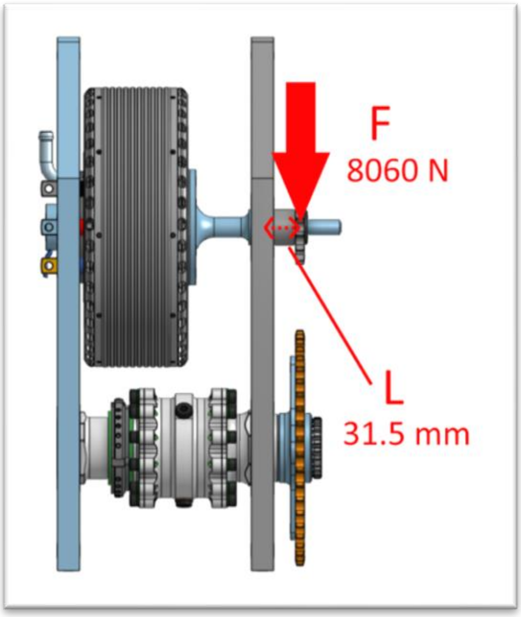


Figure 70 - NU25 powerbox primary forces

Recommendations for FEA regarding assemblies in the future is to include simplified models of large components to sanity check for the deflection of components and to be aware of the importance of clearance around critical components.

7.3. Electrical Quality Control

A very significant portion of time spent diagnosing issues on the car is spent chasing down problems with root causes linked to poor quality control of the manufacture or installation of electrical components on the car.

Issues may also arise where the nature of electrical components used are meant for relatively few connect/disconnect cycles compared to NU Racing's use case.

A common example of an issue on the car is caused by improper pinning of electrical looms on the car. This can be due to reasons such as a wire gauge being too small for a given pin size, copper strands being snapped off prior to pinning which produces a joint which is much more likely to fail, improper use of the pin crimping tool (especially with the fold over type of crimping seen in Molex Micro-Fit pins).

It is strongly recommended by the author that either the Wiring Loom Zero to Hero module be completed (which would be beneficial for all NU Teams members) or to at least host a 1-day class/lesson with all members of the NU Racing team early in the year including the mechanical team (it is not uncommon for mechanical team members to end up creating looms). Amongst any points covered in said class, the most important is the insist on every member to 'tug test' every crimp connection made on a loom, as it is an easy concept to grasp that ensures a base level of loom reliability.

For people creating a loom for the first time or using a pin and wire gauge combination for the first time, the author recommends using pliers to apply about 5 kg to 10 kg of tension to the crimp connection of a test wire to ensure that the pin, wire gauge, and crimp method is suitable for application. After this it is reasonable to just use bare hands to tug test the connections of the actual loom to avoid damaging the pin ends.

Even though electrical crimp terminations (pins) will have a range of wire gauge recommended for use, the author strongly recommends to always do a tug test even if operating comfortably within the gauge range of the termination, to rule out user error of the crimping tool/method.

It is worth noting that the Molex Micro-Fit female pins on the car are prone to opening under repeated cycles of connecting and disconnecting the connectors, and from pulling or pushing the connectors perpendicular to the direction they plug in. As a result, it is possible to have intermittent connection issues with these Micro-Fit connectors as the male and female pins make bad contact and ensuring that the mechatronic team for NU

Racing is aware of this issue is important. The author suggests that the pins on Molex Micro-Fit connectors be considered an inspection item every time these connectors are serviced.

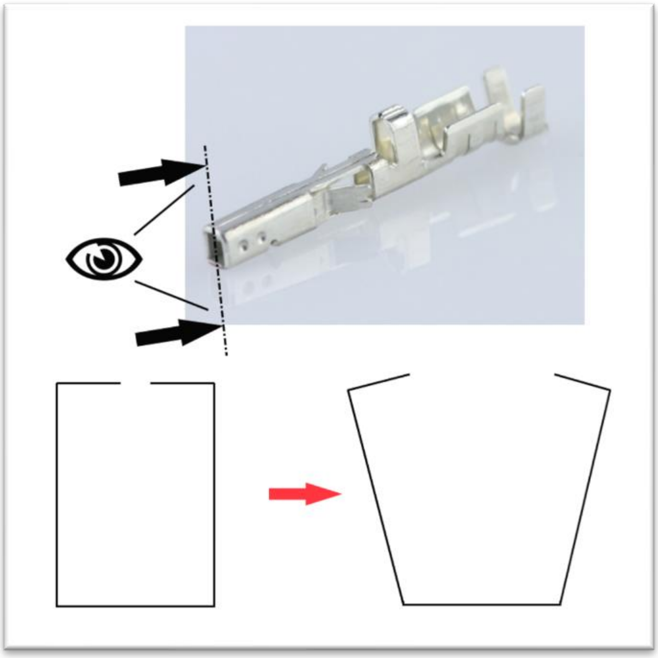


Figure 71 - Visual aid describing a failure mode of micro-fit pins (molex, 2025)

For as long as the team runs a Bender ISOMETER® insulation monitoring device (IMD) the team will need to keep note of this as the Bender units come with a PCB mount Micro-Fit connector as standard.

Where possible the team should make efforts to try to incorporate closed-barrel pin types (such as DT pins) to avoid this issue occurring in the first place.

7.4. EM Noise Interference

After the arrival of a replacement motor-controller for NU24 due to the failure of the first CM200DZ motor controller, the implementation of the replacement CM200DX motor controller had issues with the presence of electro-magnetic noise interference causing failures within the CAN BUS on NU24.

Detailed descriptions of the testing and diagnosis process will be included in the chief mechatronic engineer report from Alec Chapman and the tractive system electrical engineer FYP report by Joshua Hayward. This section is present for the documentation and explanation of the reasoning behind the necessity of the planned changes to the electrical node layout of NU25.

Initially issues in the implementation causing noise were present in the bench testing of the new CM200DX. The severity of the effects of this noise was very high causing CAN error frames when monitoring the CAN BUS of NU24 on a bench using a CANdaptor and CanKing software. Upon a video call with engineers from Cascadia Motion, the correct firmware was pushed to the CM200DX which remedied the majority of the noise issues and allowed NU24 to spin its motors for the first time in months.

Upon testing NU24 with the new motor controller, a testing day included the testing of running the loom from the dashboard electric node (DEN) to the central electrical node (CEN) along the right-hand-side of NU24. This was away from the shielded AC phase cables that run to the EMRAX 228 which were thought to be the source of the EM noise by the author. When driving NU24 with this loom layout the car faulted and had the CAN light on the dash flash indicating interruption of CAN communications.

Since the only loom that had been significantly relocated compared to the last drive was the DEN-CEN loom, and the team was wary of issues due to inducted noise, the DEN-CEN loom was relocated to its original location along the left-hand-side of NU24. This position resulted in no more issues in CAN communication. It is thought that the high frequency switching of the insulated-gate bipolar transistors (IGBTs) in the motor controller cause the noise in the high voltage lines, due to the matching of frequency of injected noise. There is potential that this high frequency switching induced the noise into the high voltage DC cables too, which were close to the DEN-CEN loom when the CAN communication went bad while driving.

8. NU Racing 2025 Design and Testing Plans

The budget for NU Racing in 2025 is on track to potentially be much less than in 2024 and as such the changes for designs are limited in scope and aimed to be low-cost upgrades where possible. The author suggests that across the board the team focuses on the validation of the methods used to generate the designs and on the validation of the performance of isolated subsystems.

Key changes suggested by the author are present in Table 6 with further detail explored in sections 8.1 to 8.11.

For designs of mechanical components for NU25 that are yet to be completed, the author suggests that function upon first implementation be considered priority over all other possible variables. From the designs handed over by the 2023 team, many oversights were made in the pursuit of removing weight from NU23, resulting in setbacks to manufacture timelines, and even performance in unforeseen ways such as the torque limiting that had to be applied to the NU24 powerbox, even after a second iteration was manufactured.

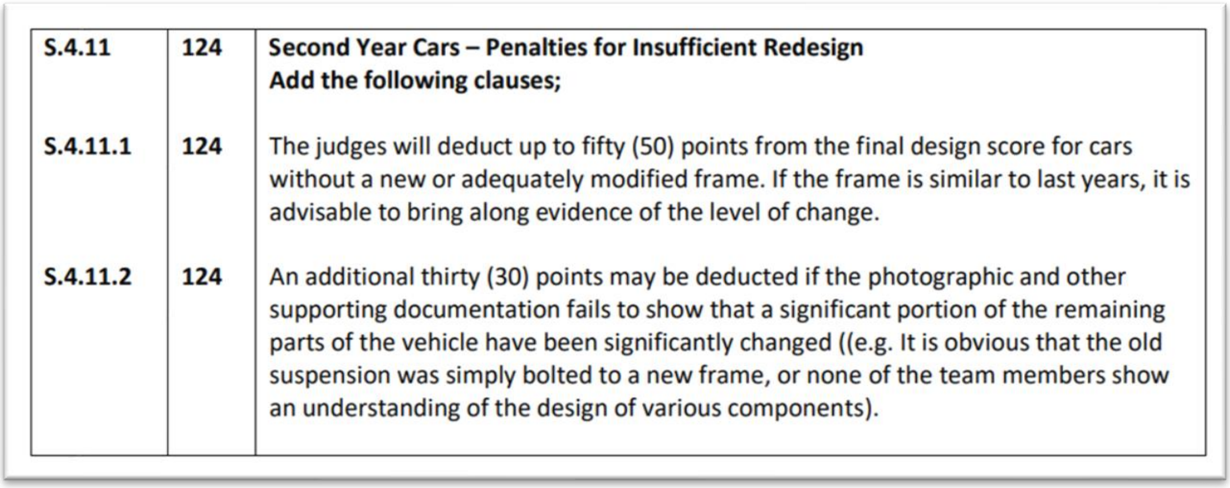
Deflection of components must be better understood in 2025, as the validation of the deflections of components and understanding the causes between variations of FEA results to real life will better inform design decisions moving forward and will also increase the scoring of the team's performance in the design event. It is not sound engineering practice to use unvalidated FEA practices to produce key components of a car capable of highway speeds.

Table 6 - Summary of changes planned for NU25

Subsystem	Issues	Priority	Fixes / Improvements	Plan for Implementing
Chassis	Unnecessary members. Must change to avoid point loss at competition.	Medium	Changed triangulation around driveshafts to remove 2 members. Changed front hoop to add 5 mm of height remaining withing body kit dimensions.	Approval, order and manufacture of already completed design.
Suspension	N/A	N/A	None. Re-use suspension.	Re-use.
Accumulator	Issues with BMS voltage taps / cell voltages. Volt meter is a bulky implementation.	High	Thorough testing of BMS voltage taps by swapping segments, taps and recommendations from Alec Chapman's chief mechatronics report. Add a voltage light indicator to replace the volt meter.	Testing under direction of 2025 lead mechatronics engineer and chief engineer. Low priority voltage light indicator circuitry still needs to be designed and tested thoroughly.
Powertrain	Spool "locked diff" design reducing performance in tight corners, reduces efficiency of drivetrain.	High	Implement Drexler FSAE specific chain driven differential. Move brakes outboard. Use driveshafts with U-joints manufactured by Drexler suitable for their differential.	Purchase of differential with driveshafts in progress. Powerbox design needs lightening and chain guard design completed. Revisions to transfer shaft and sprocket adaptor needed.
Steering	Needs mounting design suited for new front hoop shape. Could use more space for the DEN node to fit it's connectors.	Medium	Redo tube support design to match up to new front hoop.	Design to be similar to last year's design with same tube size and support plate design.
Aerodynamics	Could potentially lose 1-2 kg.	Low	Improvements to manufacture process including proper testing and documentation of the weights and stiffnesses of difference layup methods. Remove rear handles. Test out different methods of adding reinforcement / different widths of coremat.	Dedicated FYP or directed reading role. Re-use the moulds from 2024 to save on the time/labour spent on plug preparation.
Cooling	New radiator ordered in 2024 but did not have time to be tested and was therefore not implemented.	Medium	New radiator could potentially see it being suitable for cooling with a decrease in mass and smaller packaging.	Testing of new radiator. Significant revisions to the already designed radiator mounts for NU25 will be needed. Do not cantilever the pick-up bar like the existing design.
Pedalbox	PEN node on the pedal box is the most interacted/programmed/removed node from the car, and is in the least accessible location. Pedal box flexes under load. Brake fluid reservoir is in the travel path of the brake pedal. Pedal distance should be increased to better fit taller drivers.	High	Removed PEN node from pedal box. Relocate to chassis with loom running to pedal box sensors. Relocate or change brake reservoir(s). Increase stiffness of pedalbox along with better FEA practices. Move pedal faces up to 50 mm further away if possible. Add adjustment closer to driver to make up for increased pedal distance.	Thorough design and FEA work needed to ensure suitable stiffness. Conserve pedal ratio as it was suited to driver feel in 2023-2024. Manufacture as per 2023 and 2024 pedal box methods.
Brake Package	Almost failed brake test at competition. The team had not previously tested the car with new slicks on a warm day on asphalt. Many factors changed from 2023 to 2024 that could influence the result of the brake test.	High	MUST do real world testing of brakes on asphalt with the car completely skidding to a stop. Added second caliper to rear axle. Change of brake pad compound from 'Purple' to BP-28	Request track testing on the main circuit at SMSP when ready to do brake testing. Brake package design potentially return to 2023 rotor thickness.
Electrical	Noise injected by tractive system to control systems of car is definitely functional but less than ideal.	Medium	Further isolate low voltage systems from the unshielded high voltage DC cables.	Relocate CEN node to be opposite of the HIP node. Run looms far away from the HV DC cables.

8.1. Chassis

Attending competition with a reused chassis is grounds to be deducted up to 50 points as per the Australian FSAE rules addendum, as seen in Figure 72.



S.4.11	**124**	**Second Year Cars – Penalties for Insufficient Redesign** **Add the following clauses;**
S.4.11.1	**124**	The judges will deduct up to fifty (50) points from the final design score for cars without a new or adequately modified frame. If the frame is similar to last years, it is advisable to bring along evidence of the level of change.
S.4.11.2	**124**	An additional thirty (30) points may be deducted if the photographic and other supporting documentation fails to show that a significant portion of the remaining parts of the vehicle have been significantly changed ((e.g. It is obvious that the old suspension was simply bolted to a new frame, or none of the team members show an understanding of the design of various components).

Figure 72 - FSAE-A rules regarding second year chassis

To avoid a blatant penalty in the design event, a new chassis must be competed with each year, or up to 5% of the total competition score available may be deducted from the design event score. As such a bare minimum level of changes, which is not documented in any detailed capacity by FSAE, is needed to obtain high design event scores.

The chassis for NU24 performed without structural issues. This is due to the bare minimum requirements by FSAE's structural equivalency spreadsheet ensuring a suitable level of safety, energy absorption, and stiffness of any compliant space frame chassis. For this reason, it is difficult to make a chassis that will have obvious flaws in its dynamic performance without the use of stiffness measuring equipment and detailed suspension models. This is not to say that an FSAE chassis cannot have measurable favourable stiffness, weight distribution, or total mass, in comparison to another chassis. There is likely always room for optimisation of these aspects of a chassis.

To identify flaws in an FSAE tube frame chassis in other ways that do not require investments in expensive equipment, or time spent performing testing (which should be investigated regardless, as a method of validation), it is easiest to search for a design that has the minimum number of tubes possible, while still maintaining all the triangulation of nodes necessary for compliance, and to avoid loading tubes in bending.

The extent of changes to NU25's chassis are limited primarily by the financial situation of NU Racing in 2025. To save at least $4000 from purchasing a new body kit plug, the chassis must retain a similar enough shape to fit within the existing body kit geometry of NU24. Changes made to the chassis from NU24 to NU25 are therefore small optimisations to tube count with adjustments to some tube positions, to better accommodate taller drivers and to more clearly meet compliance with regards to a critical dimension of the accumulator container.

With NU24's chassis, the compliance issue detailed in section 5.1.8 necessitated the use of 4 additional tubes to triangulate the driveshaft opening at the rear end of the car. The biggest change to NU25's chassis will be the deletion of 2 sections of tube, allowing for the triangulation to change, increasing driveshaft clearance and reducing the mass of the chassis.

An adjustment to the front hoop of the chassis has been made, to widen the front hoop allowing for more leg room width wise, and to raise the top of the front hoop marginally, to allow a higher positioned steering wheel, contributing to clearance of driver's hands around the steering wheel and away from their legs.

In depth details on all changes made for NU25's chassis are detailed in the FYP report of John Jones.

8.2. Pedal-box

The pedal-box for NU25 will initially be the pedal-box from NU24. Improvements to the pedal box will need to be implemented in 2025 to demonstrate clear progression of driver ergonomics as a design event criterion, but also to better accommodate the range of drivers expected to drive NU25. In both 2023 and 2024, Zak Lobko – a successful Formula Ford driver – demonstrated the ability to drive NU23 and NU24 to their limit within a few laps at Sydney Motorsport Park and managed to secure driver positions as an auto-cross driver for NU Racing, with the likely chance to do so again in 2025. However, despite Zak's excellent driving ability, he is too tall to fit reasonably – much less comfortably – inside of NU Racing's cars. Without significant modifications to the chassis, adjusting the location of the pedal faces is the next easiest path to take.

Basic measurements taken with Zak in the car indicated that a target of 50 mm of further pedal position would seat Zak in a more reasonable manner, clearing his legs of where his hands must travel through when turning the steering wheel to make tight corners present across the type of tracks driven in Formula SAE-A.

To implement the NU24 pedal box into NU25, the mounting method must be carried over, which poses no issue other than the difficult to access pedal-box electrical node (PEN). The PEN interprets signals from the brake pressure sensors and throttle position sensors, incorporating the brake over travel switch (BOTS) into the shutdown-circuit too. Besides these well-established functions, the PEN was the node most often pushed with new code out of all nodes on NU24, due to the implementation of power limiting, and torque limiting at the PEN, detailed in the FYP report of Joshua Hayward. The PEN is also located below the height of the master cylinder reservoirs, on the underside of the pedal-box where it is prone to being dripped on with brake fluid. For these reasons the author suggests that the PEN node be relocated elsewhere, mounted to the chassis above the height of the master cylinder brake fluid reservoirs, to put it in a more serviceable and accessible location. This will enable the pedal box to make room for the relocation of master cylinders, condensing of size, or both.

It is difficult to validate the implementation of a pedal-box in meaningful ways other than to mark off the checklist of requirements for the design as compared to the delivered product. However, it is possible to do stiffness testing for the pedal-box assembly and its components, which would be useful for validating the structural finite element analysis (FEA) on such an assembly. In the past issues with pedal-box deflection and deformation have been had, through 2023 and 2024. To finally validate the FEA of the pedal-box would be a useful step towards more well-informed FEA practices within NU Racing.

8.3. Drivetrain

The drivetrain is the primary system of NU25 to see development in comparison to NU24. NU23 and NU24 both drove using a single electric motor using a chain to drive a spool rear axle – essentially a locked rear axle with independent suspension. Driving style using a locked rear axle like a go-kart or V8 supercar often relies on the lifting and slipping of the inside rear tyre in a corner. This is to reduce the negative effect that the inside wheel has by producing a backwards torque on the drive axle due to the difference in distance travelled by the inside vs outside row of tyres in a corner.

For a locked rear axle this is arguably the correct driving style, however this places compromise on the effectiveness on the loading of the tyres. Upon unloading of the inside rear tyre, it transfers load onto the outside tyres. As a tyre has an increased normal force on it, the peak lateral force it can hold due to friction increases at a slightly less-than proportional rate (Balkwill, 2018). This means that the efficiency of loading a tyre decreases with increased normal force. As a result, the peak amount of lateral acceleration of a car is decreased slightly with increased weight transfer.

As described, the supposed ideal driving style for a locked rear purposely increases the weight transferred onto the outside tyres, thus decreasing the potential lateral acceleration compared to a car that can hold all 4 tyres on the ground in that same corner.

This is the primary reasoning behind the recommendation of the development of a limited-slip rear differential based powerbox to be used by NU25. It is also notable that throughout testing of NU23 and NU24, recommendations by drivers align with suggesting the use of a limited-slip differential. FSAE has a long history of competition, and as such parts are available to market including FSAE specific differentials, including differentials designed and sold by Drexler. Drexler differentials use a chain driven design retained by 2 bearings, like the current design of the spools used by NU23 and NU24.

Preliminary designs are already in the works for implementation of the Drexler differential based powerbox. It is important to note that the chassis for NU25 shall be compatible with both the spool based powerbox of NU24 and the new Drexler powerbox design. This allows for earlier testing of NU25, by removing the Drexler powerbox from the critical path, while also allowing for direct comparisons before and after the installation of a limited-slip differential.

The author recommends that the 2025 team take advantage of the ability to do back-to-back comparisons of the spool and differential based drivetrains to validate the implementation of the Drexler differential it terms of lap times and energy efficiency.

8.4. Suspension

Changes to the suspension components of NU25 should be limited to the fine tuning of suspension parameters through the existing methods of tuning being:

- Adjustment of tyre pressures within manufacturer specifications and as per FSAE rules. Running higher pressures may improve tyre performance degradation due to compound temperatures that may or may not occur in endurance driving.
- Camber shims at upright bolt locations to adjust camber.
- Adjustment of rod ends to adjust toe settings.
- Spring stiffness, potentially including buying more sets of springs to fine tune with.
- Shock absorber settings.

This is primarily to limit the amount of necessary manufacturing on the critical path for NU25 and to bring forward the date of the first drive. In depth tyre analysis and therefore analysis for suspension systems has been lacking in NU Racing since the development of the suspension of EV.Three, and as such - no informed changes can be made. NU Racing needs to improve on this and work towards having well documented and standardised processes for tyre and suspension analysis.

Regarding validation, it is possible to do deflection and stiffness testing of the suspension arms themselves as the stiffness of suspension arms plays into the effectiveness of changing things such as spring rates and damper settings. This is due to suspension effectively being a mass-spring-damper system with the effective spring stiffness consisting of stiffnesses contributed by every component in the suspension assembly and the chassis itself.

In the future, designs should consider recommendations to suspension construction made in section 5.4.

8.5. Brake Package

All FSAE cars are required to pass a brake test at competition prior to entering any dynamic events. Requirements of the brake test are that cars can roll at a low speed and then lock up all brakes and all wheels and skid to a stop. No explicit wording on how far or how long a car must skid is available and thanks to the vagueness of the rules NU24 was able to compete, after having nearly failed the brake test.

Key changes to the brake system from NU23 to NU24 was the replacement of the rotors with a thinner and lighter design of custom rotor developed by Kieran Burgess. These rotors were tested at Sydney Motorsport Park for driver feel and temperature observations however they were not tested at any point throughout the year for that ability to lock all wheels. The ability to lock all wheels is important in both a safety and performance aspect since the maximum amount of controlled deceleration occurs on the edge of traction between the tyre and the ground, and therefore right before the wheels begin to slide or lock up.

Explicit brake testing should be a must for every year going forward, and efforts should be made to best replicate the 'worst case' brake test. This includes:

- Grippy warm and clean asphalt.
- Ambient temperature brake rotors.
- Track ready tyre pressures.
- New or near-new tyres.
- Brake uphill if the track is not level.

In 2024 the marshals performing the brake testing were requiring all teams to do the brake test on the pair of tyres they were going to drive on. This meant all teams were supposed to do the brake test on a new set of dry tyres. As a result of this and the range of changes to NU24 including but not limited to brake package revisions, mass distribution changes, changes to wheelbase, the car struggled to lock up both the front and the rear axle. Multiple attempts were required to pass the brake test, and the test was only barely passed with the car skidding for less than 20 cm.

As an aside, to pass the test, the tyres were inflated to 33 PSI using a Makita battery powered air pump, which were later measured using a dedicated air pressure gauge, which read approximately 20-25 PSI. For this reason, it is always recommended to use a dedicated air pressure gauge to measure the tyre pressure prior to driving to ensure they are always 14 PSI, unless otherwise specified by the team member responsible for tyre and suspension testing at that point in time.

Potential causes of issues with the brake package that may affect the production of braking torque include:

- The radius of the outside part of the rotor is both too small (95 mm compared to a minimum of 101.6 mm) and is wavy, effectively reducing the brake torque as the centre of pressure is decreased during the troughs of the wavy pattern (Wilwood, 2024).
- The PCD of the bolt pattern for mounting the GP200 brake calipers is too small (74.3 mm radius compared to a minimum radius of 79.5 mm to match the necessary minimum R101.6 mm rotor) (Wilwood, 2024).
- The thickness of the NU24 rotors is 5.0 mm, which barely meets the minimum thickness of 4.83 mm and is well below the 6.35 mm nominal rotor thickness recommended by Wilwood for the GP200 calipers (Wilwood, 2024).
- Temperatures of the rotors may be well above expected values as temperature testing used a flawed method of examining rotor temperatures after a braking event with a FLIR gun, resulting in rotor cooling prior to when photos with the FLIR gun could be taken. This may exceed the ideal temperature range of the ‘Purple’ pad compound. This is likely not relevant for a brake test at such low speeds as the FSAE brake test procedure but will be relevant for auto-cross and endurance events.

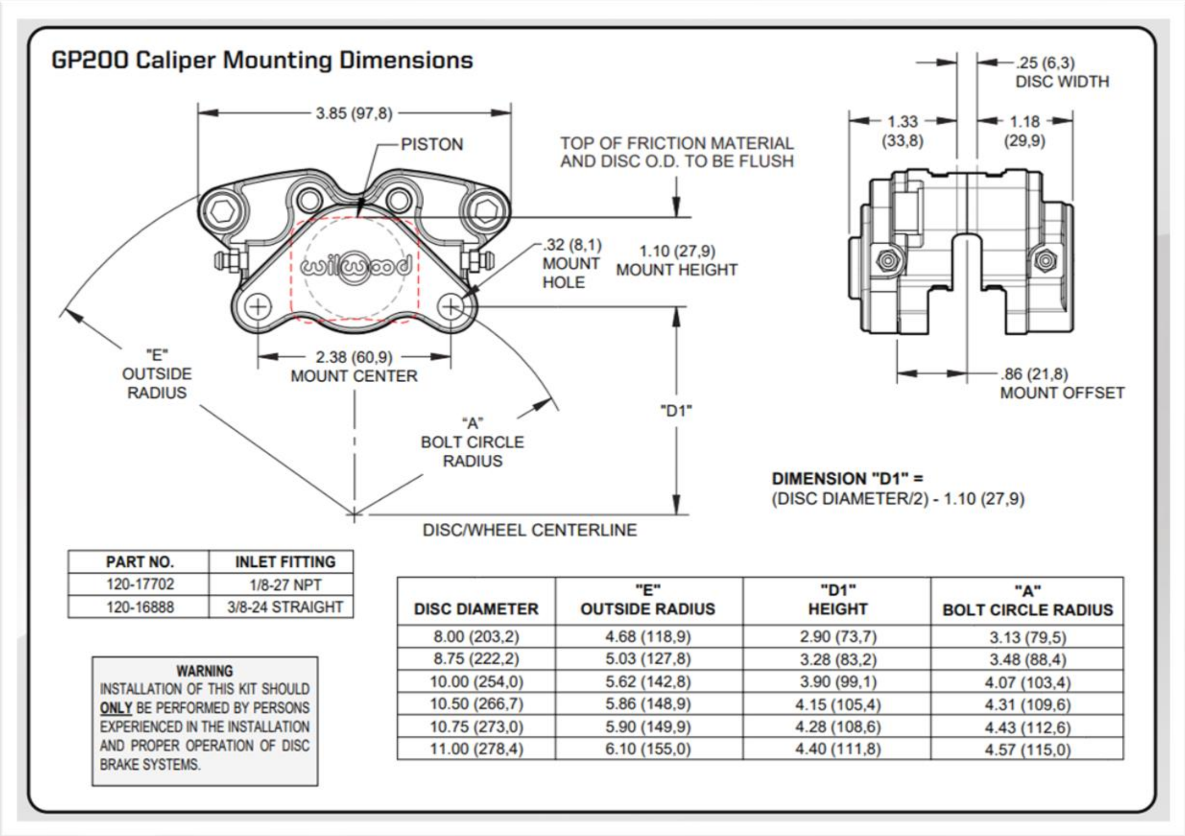


Figure 73 - GP200 caliper mounting dimensions (Wilwood, 2024)

Changes to be made to the brake package of NU25 include:

- Outboard brakes on the rear axle, going from 1 inboard brake to 2 on either outboard side. This will immediately double available braking torque on the rear axle.
- Change of brake pad compound from ‘Purple’ to ‘BP-28’.
- Change of rotors design. Design may need added mass or added outer diameter and should have added thickness back to 6 mm.
- Removal of wavy pattern from rotor if possible.
- Potentially move calipers 5.2 mm further out radially, resulting in 7% additional braking torque per caliper. This would however likely require new uprights on all four corners, a time and money intensive investment. All other proposed changes should be tested first.

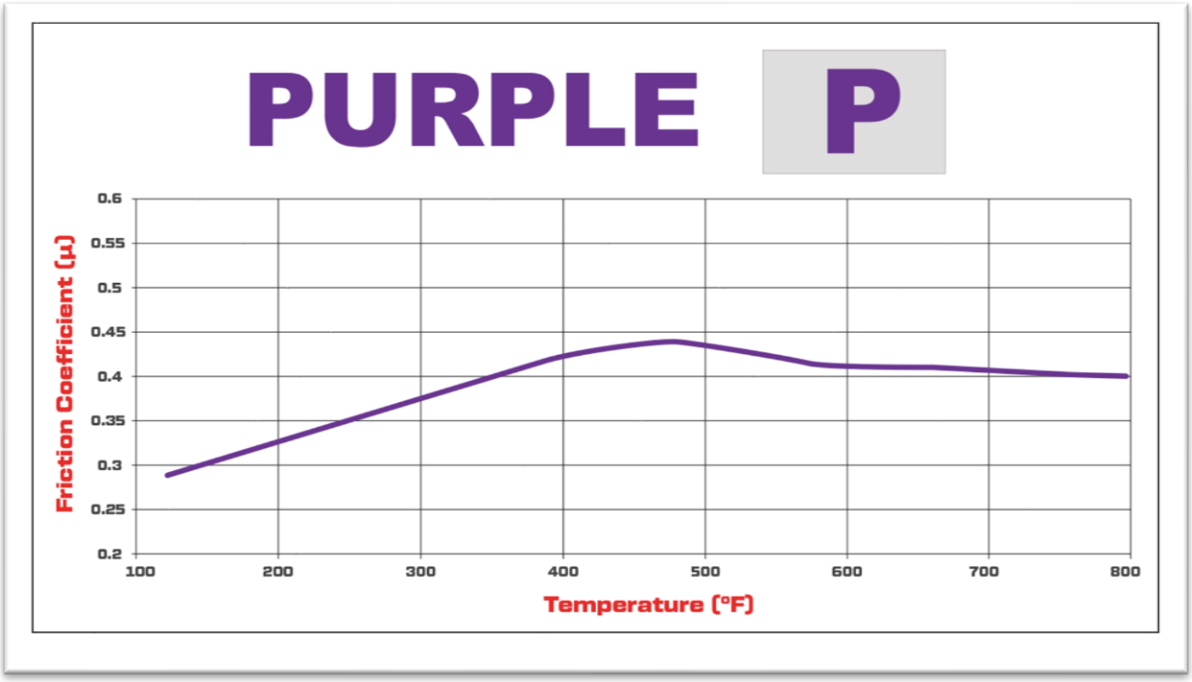


Figure 74 - "Purple" brake pad compound coefficient of friction properties (Wilwood, 2024)

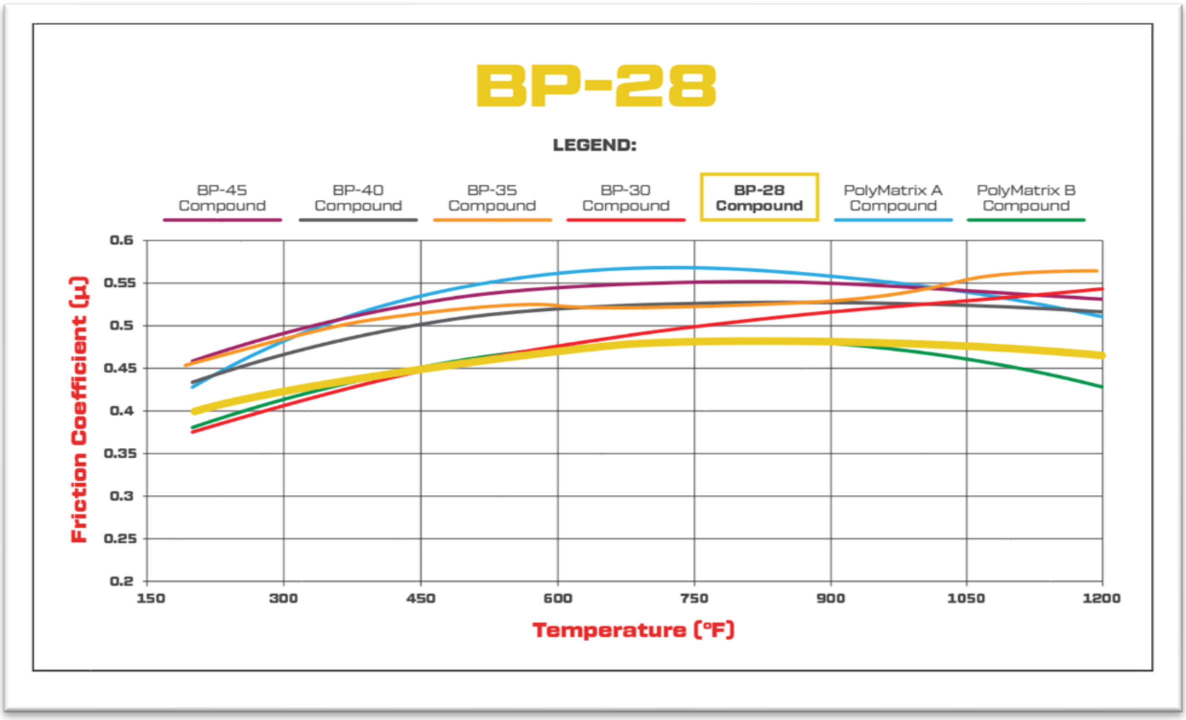


Figure 75 - "BP-28" brake pad compound coefficient of friction properties (Wilwood, 2024)

Brake testing outside of replicating the FSAE brake test can include thermal analysis using brake temperature sensors, which is useful to validate the selection of brake compound. If the dynamometer in EC basement is ever fixed, brake rotor testing could potentially be done using a custom setup to validate both temperatures and things such as friction losses due to pad contact.

8.6. Steering

Changes to the steering of NU25 should be extremely limited in scope and only include updates to the mounting of the steering system. This will include the necessary updates to the mounting of the steering gearbox due to the slight changes to the front hoop shape and may potentially include lightening of the aluminium blocks used to support the steering rack.

A notable issue with NU24 is the fitment of the dash electrical node (DEN) located on top of the steering gearbox, with its inputs and outputs facing the front of the car, passing through the gap between the steering support tubes and the front hoop. The gap that the connections pass through is quite small compared to the number of inputs and outputs, resulting in a crowding of connectors that have poor access by hand. Multiple revisions of the DEN PCB and PCB enclosure were made throughout 2024 to try to solve the fitment of the DEN node, however even the final version ran at competition was still difficult to access and disconnect plugs by hand. Contributing to the issue of hand access is also the problem of trying to place the PCB mount emergency stop and ready-to-drive buttons within arms-reach of the driver, which move the DEN PCB further away from the opening of the steering and chassis tubes, meaning a person’s hands must pass through that opening to reach the connectors to unplug the looms. Due to financial constraints for 2025, the limited changes to the chassis and body kit will likely see the bad access to the back of the DEN continue to be an issue. In the future with more drastic design changes, a revision to the steering assembly that does not use a 90-degree gearbox may result in geometry allowing better fitment of the DEN node.

Figure 76 - Parts of steering requiring attention for NU25

Changes to the steering of NU25 should be extremely limited in scope and only include updates to the mounting of the steering system. This will include the necessary updates to the mounting of the steering gearbox due to the changes to the front hoop shape and may potentially include lightening of the aluminium blocks used to support the steering rack. Parts suitable for updates in 2025 are depicted in Figure 76.

8.7. Inverter and Motor Cooling

As mentioned in section 4.2 a smaller radiator was purchased for NU24 with hopes of testing it and implementing it into the final build of NU24. Details on the specifications of the purchased radiator are available in Jayden Hardinge's final year project report.

The smaller radiator was the result of months of back-and-forth conversation with engineers at PWR Advanced Cooling Technology. The intended benefits of the smaller radiator was primarily a more mass efficient radiator that could reject heat in a similar manner to the existing radiator, while also having improved flowrates due to lesser constrictions within the radiator and attached inlets and outlets. Due to the late ordering of the radiator, it was received well after the cut-off deadline for testing it on NU24. Without ample time to test the radiator, priority for testing other systems such as the powerbox came first, as well as suspension set-up. As a result, the smaller radiator has not been tested in application on NU24.

The author recommends that temporary mounts be used to fasten the smaller radiator, and cooling tests through driving of NU24/NU25 in an endurance-style fashion be conducted. The use of the radiator is primarily important for endurance as the rise and plateau of coolant temperatures in NU24 and NU23 was only apparent over the duration of an endurance event or simulation.

If the radiator is to be considered suitable, new permanent mounting should be designed from scratch, incorporating the pickup bar, like the designs for NU23 and NU24 radiator mounts.

Further validation of the radiators would be preferable. An example of controlled testing using a dyno could be to use the different radiators over an endurance simulated via torque request signals exported from MoTeC data. This would be an ideal back-to-back style of test that eliminates many of the uncontrollable variables that driving NU24 and NU25 may be prone to. However, the dynamometer in EC basement as of writing this report is not functional. Another method to test the heat rejection of the radiators as well as the operating points would be to use a heated source of water (like the heat exchanger lab as part of MECH3695 – Heat Transfer), pumped through the existing car setup with in-line flowmeters to measure flow rates, while recording radiator inlet and outlet temperatures with thermistors. This method however would only be useful for determining steady-state operating points relative to ambient temperature. Using the dynamometer would give more accurate results for transient testing, as the amount of water used stays the same as NU24/NU25, conserving thermal mass, and the heat power flow into the water would be accurate to driving conditions, given suitable speed control of the dynamometer.

While technically driving NU24/NU25 with the smaller radiator is the easiest method to determine its suitability, the validation of heat rejection by the radiators is still useful information, and quantifying system parameters to better tune Brock Symons' coolant temperature script will help to provide better insight on future radiator choices.

8.8. Accumulator Cooling

Cooling of NU24's accumulator seems to be improved in comparison to NU23, observed through driver feedback. It is possible that the design change from painted steel to bare aluminium changed the thermal conductivity of the container in such a way that temperatures of cells were observably improved. Detailed analysis on accumulator cooling methods comparing the magnitude of heat removed by conduction to convection is a surprisingly overlooked task for a team that was critically thermally limited in 2022.

An endurance simulation was at one point completed in 2024 with no accumulator fans running due to a failure of the low voltage distribution (LVD) board in the accumulator, albeit at a reduced pace on a cold windy night. For this reason, the author suggests moving the power switching of the accumulator fans out of the LVD and onto another node such as the CEN. This would mean that 2 extra plugs would need to be disconnected in the removal of the accumulator from the car but would be 1 less system to have fail inside of the accumulator, preventing an undesirable time spent opening the accumulator in the middle of a track day.

Testing early in 2025 for turning off individual fans could reveal the necessity of the 'in-out' dual banks of fans. This was not testing in 2024 due to time constraints from limited driving time. Testing can include turning off 'in' fans, or 'off' fans, or any combination of individual fans. It may be best to do this so that the test conducted is across 4 driving sessions with the example of the following fan configuration rotated through from front to back.

- Frontmost: Both fans powered
- 2nd from front: LHS fan powered
- 3rd from front: RHS fan powered
- Rearmost: No fans powered

Rotating through this setup from front to back across 4 driving sessions will allow the driver to modulate pace to regulate the accumulator peak temperature and will demonstrate if certain cell locations are more sensitive to changes in cooling parameters.

Regarding a potential pouch-cell accumulator design, an accumulator made of aluminium may just be conductive enough to remove the heat from a battery pack using cells with much lower internal resistance than the existing '18650' cell types used in NU24. If a thermal model cannot be used with confidence to determine the necessity of active cooling, then an accumulator container with air cooling integrated into it may be desirable to prevent the necessity of manufacturing a container with cooling to replace an insufficient enclosed accumulator.

8.9. Body-kit

The body kit and aerodynamics package should be of low priority for NU Racing in 2025 primarily due to budget concerns. The completely custom '1-off' body kit, although required by FSAE rules to enclose the driver space, is a very costly item in terms of student time spent manufacturing it and the financial costs associated with the project. The body kit of NU24 is the 3rd most expensive part of the car, behind the Cascadia CM200DX motor controller and the custom fabricated space-frame chassis. Despite the very large associated time investment and financial costs, the body kit and aerodynamics package of EV.Three, NU23, and NU24 all provide little to no advantage when it comes to extracting performance from the car.

The planned changes to the body kit should be limited in scope to using the existing set of body kit moulds created by the 2024 team, as NU25 is designed to use the same shape of body kit. In an extreme case of being unable to allocate manufacture of a new body kit, re-using NU24's body kit is possible.

For proposed changes to the body kit, a new body kit would be manufactured using techniques that should be explored in isolation from the main product by doing test panels and stiffness testing of different fibre-glass layups, and fine tuning of reinforcing methods. For example, an engineer could do multiple test panels of the same layup with a reinforcing core-mat strip of varying widths and varying layers of glass atop the core-mat to secure it. This engineer could then do stiffness and deflection testing and identify the deflection at which the test panel fails, empirically noting a performance curve of the different layups.

If costs need to be saved, paint for a new body kit could be limited to a single colour reducing labour and potentially material costs.

Further improvements to the manufacture of the body kit may be investigated through reaching out to RPC Composites and asking for advice.

No aerodynamic research was done for the design of NU24's body kit due to an explicit exemption from the scope of work done by the designer, however for NU23 the aerodynamic and body kit lead Mitch Boots included detailed derivations of the coefficient of drag and coefficient of lift for his design of NU23's body kit. These values taken from Mitch Boots' work prompted the author to do an analysis of the effects of drag on the energy used by NU23 as a form of sensitivity analysis for potential changes in drag characteristics of future car designs.

From Mitch Boots' report, the drag coefficient was calculated as 0.33. The author of this report calculated the frontal area of NU23 as 0.602 m^2 as this figure was not present in Mitch Boots' report. Using formulas for drag force, and assuming an air density of 1.293 kg/m^3, the author wrote a script to calculate the estimated energy consumption used to combat the effects of air resistance by NU23.

- v : Velocity of the car. Calculated from motor RPM as this is directly linked to wheel speed and assuming no slip, ground speed. Effects of wind blowing is ignored. All wind speed assumed to match ground speed.
- ρ : Density of ambient air.
- A : Frontal area of car.
- C_D : Drag coefficient.

$$Drag\ force = F_D = \frac{1}{2}\rho A C_D v^2$$

$$Instantaneous\ Power\ to\ Combat\ Drag = P_{Drag} = \frac{Force \times Distance}{Time} = \frac{F_D d}{t} = F_D v = \frac{1}{2}\rho A C_D v^3$$

Also calculated is the power used to accelerate a point mass of 265 kg, to model the power used to accelerate the mass and inertia of NU23. Ideally the model for this would include the rotational inertia however this is limited to just a point mass.

- a : Acceleration of car. Calculated from gradient of velocity.

$$Force\ to\ Accelerate\ a\ Point\ Mass = F = m \times a$$

$$Instantaneous\ Power\ to\ Accelerate\ a\ Point\ Mass = P_{Accel} = \frac{Fd}{t} = Fv$$

Finally, power used by the tractive system is calculated.

- I : DC bus current through the motor controller.
- V: DC bus voltage measured at the motor controller

$$Instantaneous\ Power\ used\ by\ the\ Motor\ Controller = P = IV$$

The power exerted by the tractive system is integrated over time for all values of positive power output to calculate energy used by the tractive system.

The power required by the aerodynamic drag is integrated over time for all values to calculate the energy used by drag effects.

The power required to accelerate the point mass is integrated for all values of positive acceleration to calculate the energy used by the effects of accelerating the point mass.

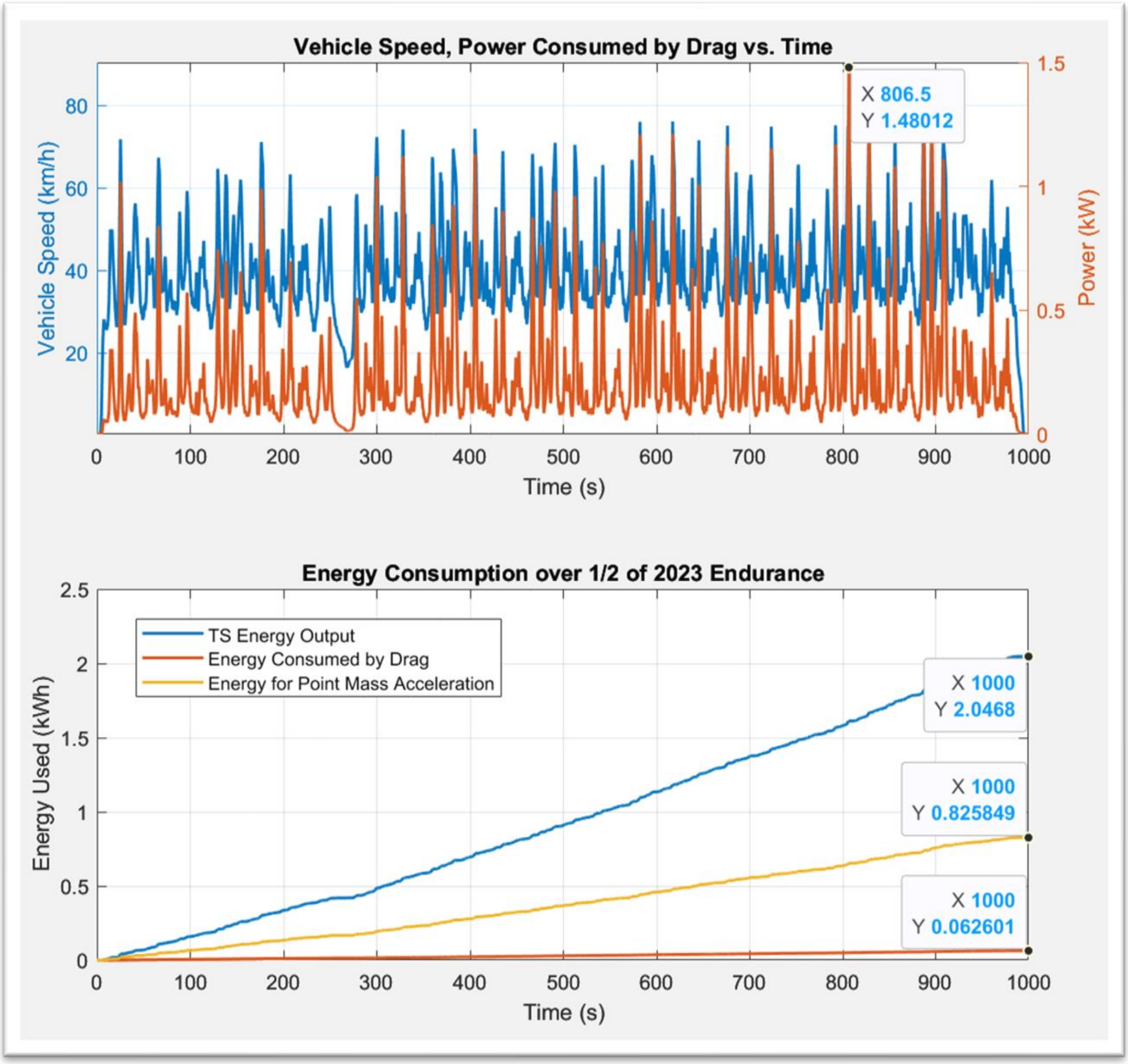


Figure 77 - Energy consumption analysis due to aerodynamic drag

Figure 77 shows an estimate that for NU23's 1st half of competition endurance driving, 0.063 kWh was used to overcome drag, 0.826 kWh would be used to accelerate a 265 kg point mass, and the tractive system energy usage was 2.04 kWh. The estimated energy uses are equivalent to a 3% usage for drag, and 40% usage for accelerating the mass, with the remaining 57% of energy usage allocated primarily to rolling resistance and partially to drivetrain inefficiencies.

These estimates can be used to calculate that the entire drag effect in terms of energy usage (not pace) has an equivalent effect of moving 20.2 kg of mass for endurance.

$$Equivalent\ mass = 265\ kg\ \times \frac{0.063}{0.826} = 20.2\ kg$$

Intuitively it should be hopefully clear to see that allocating resources to halving the amount of energy used by drag effects is insanely high compared to allocating resources to remove 10.1 kg of mass from a relatively heavy FSAE car. This statement is derived from the analysis of NU23, but it is likely that an analysis of NU24 would show similar conclusions. It is important to note that this analysis is only for the energy consumption results and therefore is only truly relevant for the efficiency event of competition, or for accumulator energy storage sizing.

Conclusions made are only regarding drag forces and do not include analysis of points reward from added downforce that may arise from resources invested in aerodynamics. This may suggest that in the trade-off for performance and competition points, the next logical direction aerodynamically is to increase the lift to drag ratio, and total drag but only if added vehicle mass and handling implications are considered in detail. The author urges the reader to note the lessons learned by the 2023 team by the improvement in driver feedback and reduction in vehicle mass made by the removal of the aerodynamics package that was present on EV.Three at the start of the year.

8.10. Further Address Electrical Noise

As explained in section 7.4 and in the reports of Alec Chapman and Joshua Hayward, NU24 had issues with electrical noise interference present in the low-voltage communication buses along the car due to noise created by the new Cascadia CM200DX motor controller. In its current state, NU24 now operates without significant issue from the noise, however based on the track day with the repositioned DEN-CEN loom, it is still possible for noise to create issues with the primary CAN BUS on the car. To combat the effects of noise on the low voltage lines of the car a few practices can be put into place that would assist with the issue.

More deliberate separation of the unshielded DC high voltage cabling from the rest of the low voltage system would be preferable as the location of the DEN-CEN loom that caused issues with noise was when it ran along/beside the unshielded DC high voltage cables. In comparison, running beside the shielded high voltage AC phase cables currently presents no identifiable issue for the DEN-CEN loom, and is the format that NU24 completed most of its driving in including at competition.

To implement more separation of the unshielded HV cables, the DC to DC (DCDC) converter on the top of the tractive system stack may be reoriented by 180 degrees to face the high voltage input of the DCDC to the right hands side of the car, pointed at the human interface panel (HIP) node. In doing this it will place all unshielded high voltage lines around the right hand sided of the car, behind the firewall. It is important to note that this will also locate the CAN BUS input to the DCDC near the highest concentration of the unshielded HV cables. As such, it is recommended that this is first tried as a temporary experiment to see if any adverse effects occur. It is always possible to retain the current orientation of the DCDC.

Extra separation can be done by relocating the CEN node for NU25 to be opposite the HIP node as this is further away from the noisiest part of the car and is a more serviceable location than NU24's CEN location. This location can also accommodate a larger CEN board in the future if any revisions need to be made to add functionality or reliability to this node.

Implementing shielded CAN BUS communication wires is a potential solution to further remove noise from the CAN BUS of the car. Shield the communication wires themselves is generally considered good practice in electrically noisy environments. Implementing shielded CAN wires would involve purchasing lengths of twisted and shielded 2 conductor wiring, with 22 AWG sized conductors to match and replace the existing 22 AWG CAN BUS wiring. Wiring like this is generally orders of magnitude more expensive than unshielded wires which most of NU24's looms are currently made from. Priority locations to implement shielded wiring would be best for the communication lines running closest to the unshielded HV cabling, and to the CAN BUS wires running to the DCDC.

8.11. Accumulator General

The accumulator for NU25 should remain almost identical to NU24's accumulator. There are few faults with the design of NU24's accumulator, namely the inefficient use of material of the "top plate" to restrain the cells, resulting in a heavy accumulator, as well as the inclusion of an old analogue voltage indicator. The analogue voltage indicator is entirely functional however a digital voltage indicator light would be a smaller implementation, providing packaging benefits in future accumulator designs. Modifying NU24/NU25's accumulator lid to suit a voltage indicator light would be a light manufacturing task, however implementing a light to replace a gauge is not critical path and can be forgone in 2025 if necessary.

Reducing mass of the accumulator would best be done through the implementation of a pouch-cell accumulator. This will be a development requiring extensive design and research efforts, and to remove it from the critical path it is suggested by the author that the pouch-cell accumulator begins development in 2025, for implementation at competition in 2026 at the earliest. Pouch cell battery packs have 2 distinct advantages, being that they are typically lighter overall, and they have less pack resistance. Lower pack resistance, as mentioned in section 8.8, can lead to lower accumulator temperatures, and may enable an accumulator design that does not require active air cooling.

Removing mass from NU24's accumulator is of low priority. The accumulator itself is already a valuable resource for the team as a competition compliant accumulator that has passed tech inspection in 2024, that has no pressing high priority issues.

9. Management at Competition and Team Documentation

9.1. Management of Team at Competition

Ensuring a smooth workflow of students amongst the NU Racing team at competition is critical to the efficiency of the team and can benefit the team as preparedness accelerates the technical inspection process. Making sure that critical work such as electrical plug-checks, bolt-checks, and tyre-pressure checks are done at suitable intervals will prevent surprises occurring that may cost a team performance or points at a FSAE competition.

As seen in Table 7 the author drafted up a day-by-day planner that informs everyone that attends competition of the following:

- What critical teams they are in.
- Backup people for critical activities such as charging, or backup drivers.
- What activities are on throughout the day.
- When they are needed for those activities.
- The state that NU24 should be in throughout the day.
- State of Charge for the Accumulator.
- When to charge.

The competition day planner is useful for leadership as a tool not only for communicating people’s responsibilities, but for planning out the exact state of the car at any point throughout competition, to ensure that the schedule is suitable for the team. It is important to note times that charging will be done, especially prior to acceleration and auto-cross events, as keeping a topped-up charge on the accumulator increases voltage, lowering the amount of current needed for a given power output, improving current limiting cut-ins that could decrease performance.

Table 7 - Example of day planner for 2024 competition

Thursday 5/12 Planner

Schedule		Required Teams	Team Members		Foodies
5:00	Breakfast		**BODYKIT**	**ACCUMULATOR**	**Lunch**
5:30			Wenham	Kris	Fletcher
6:00	**Cars Leaving**		Cameron	Daniel	Kas
6:30	Travel		Kris	**BOLT CHECK & WHEEL TORQUE**	Eliza
7:00	Arrive Gates Open		Jackson	Cameron	Jordan
7:30	**Bodykit on Stands** **Bolt Check**	**Bodykit** **Bolt Check**	Andy	Kris	
8:00	Team Rego Opens Tech Opens **Clean Bodykit** **Bodykit on Car**	**Bodykit**	**EV STATIC**	Brady	
8:30	Ready for Cost Event	**Push Bar**	Alec	**EV FUNCTIONAL**	**Shopping**
9:00	**Cost Event**	**Cost**	Lukes	Alec	Cameron
9:30	**Cost Event**	**Cost** **Push Bar**	Hayward	Lukes	Rishi
10:00	**Bodykit on Stands** **Accumulator out of Car**	**Bodykit** **Accumulator**	Jackson	Hayward	Andy
10:30	Ready for Accumulator Tech	**Accumulator**	**MECHANICAL**	Jackson	
11:00	**Accumulator Tech**	**Accumulator**	Fisher	**CHARGING**	
11:30	**Accumulator Tech**	**Accumulator**	Wenham	Daniel (ESO)	
12:00	Tech Closed **Accumulator in Car**	**Accumulator**	Johnny	Jackson	**Dinner**
12:30	Tech Closed **Accumulator in Car** **Plug Check** **Bolt Check**	**Accumulator** **Plug Check** **Bolt Check**	Cameron	Wenham (Backup ESO)	Zoe
13:00	Tech Reopens **Plug Check** **Bolt Check** **Bodykit on Car**	**Plug Check** **Bolt Check** **Bodykit**	**TYRE PRESSURES**	**PUSH BAR**	Diahn
13:30	Ready for EV Static Tech / Mech Tech	**Push Bar**	Cameron	Fisher	H-Dawg
14:00	**EV Static Tech**	**EV Static** **Bodykit**	Zak	Alec (ESO)	Holly
14:30	**EV Static Tech**	**EV Static** **Bodykit**	**BUSINESS**	Lukes	
15:00	**Mech Tech**	**Mechanical** **Bodykit**	Holly	Jackson	
15:30	**Mech Tech**	**Mechanical** **Bodykit**	Rishi	Wenham (Backup ESO)	
16:00	**NU24 in Pits w/** **Accumulator in at ~50%** **±10%** **& Bodykit on**	**Accumulator** **Bodykit**	**COOLING**	**COST**	
16:30			Jayden	Alec	
17:00			Wenham	Fisher	
17:30			**PLUG CHECK**	**DRIVER PREP**	
18:00	Tech Closes		Lukes	Zak	
18:30			Alec		
19:00	**Design Event prep**	**Design**	Wenham		
19:30	**Design Event prep**	**Design**			

9.2. Bill of Materials

For external orders particular to Hancock Speedway, NU Racing did not have a template for the bill of materials for parts being ordered. The author created a template to be used by the people or person ordering from Hancock Speedway or any other external company that does not explicitly provide a template to use. The BOM template was further updated to include an auto-generating part name by Lachlan Fisher, which can be used to fill in key details such as part name, thickness, quantity, material. This then generates the file name that can be copied and pasted to the associated DXF.

The BOM was successfully used throughout the year for several orders from Hancock Speedway by the author and by Lachlan Fisher.

An example of the BOM template is provided in Appendix D – BOM Template Example.

9.3. Technical Drawing Template Revision

The technical drawing template for the title block of engineering drawings produced by NU Racing during 2024 came with some slight issues that were easy to work around but added unnecessary menial work to the completion of engineering drawings. Things such as text alignment being off and oddly sized textboxes resulted in needing to update these auto-filled entries by hand.

The author created a new update to the title block template specific to the usage of NU Racing including fixing these issues as well as adding extra information useful to the team such as competition platform, system, and part number to tie in with submissions needed for the cost report to FSAE.

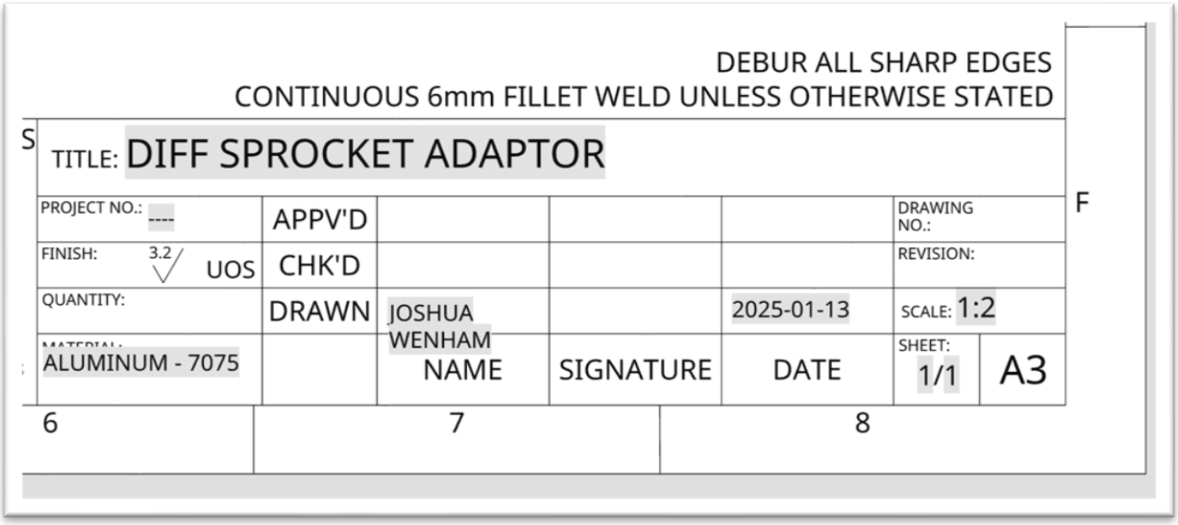


Figure 78 - Auto filled 2024 engineering drawing title block

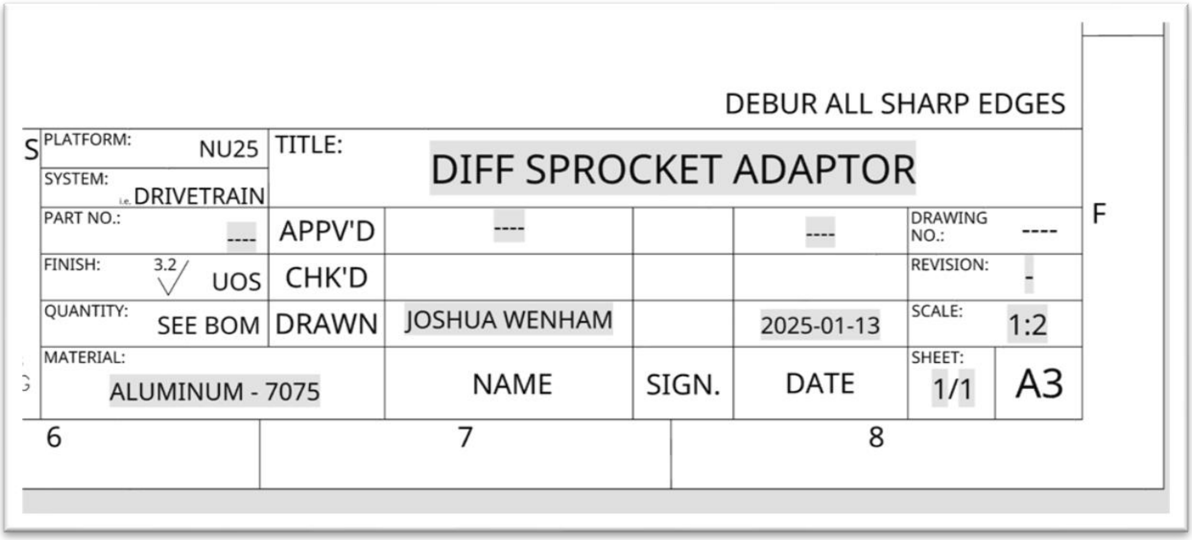


Figure 79 - Auto filled 2025 updated engineering drawing title block

Changes tied to the template also include the format of the alignment of dimension annotations and the default decimal accuracy being set to 3 decimal characters to bring to engineers' attention the added thought necessary for the general design and tolerancing of their drawings.

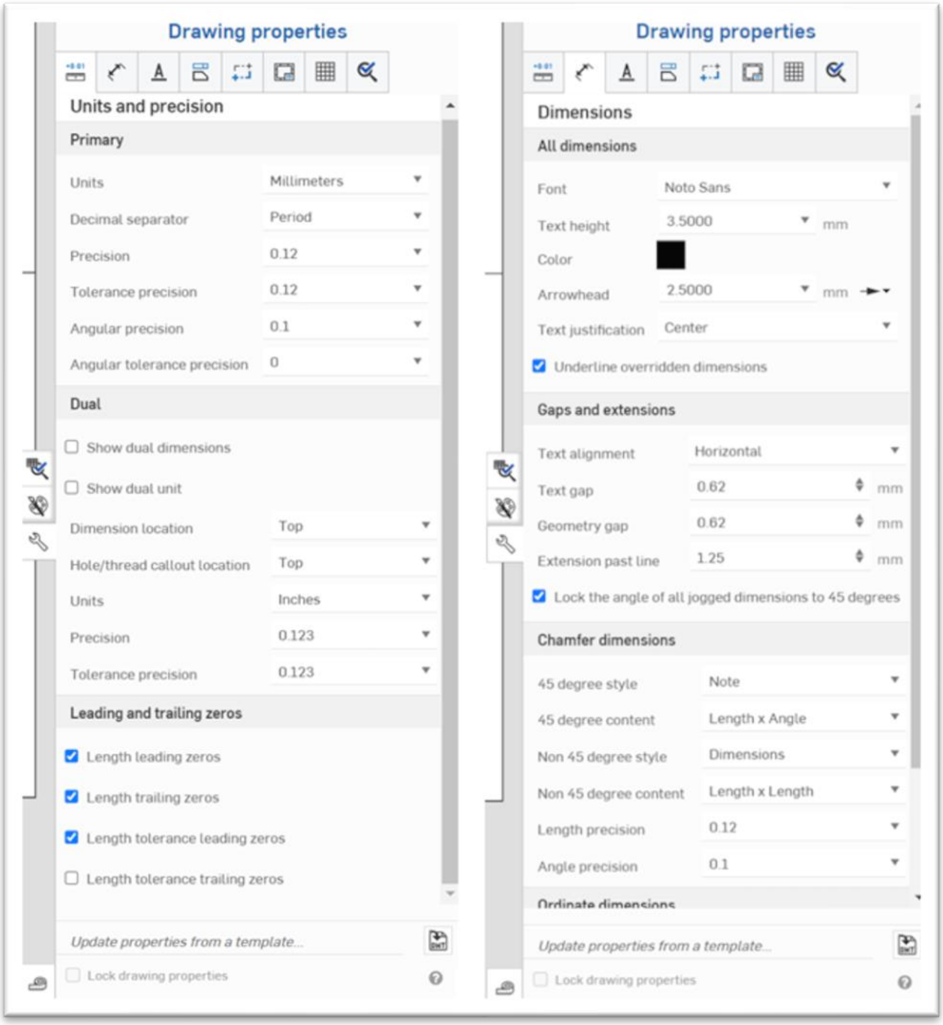


Figure 80 - Updates to drawing settings made to drawing template

9.4. Decision Matrix Template

A decision matrix is used to document the factors present in the decision-making process. The author created a decision matrix template for NU Racing to use to document key decisions going forward around the middle of 2024.

Even more useful than the matrix itself can be the worded arguments for and against each option for a potential decision as it explains in greater detail than just an array of numbers the intricacies of any one decision process. Pages dedicated to the worded arguments of an option are included in the template.

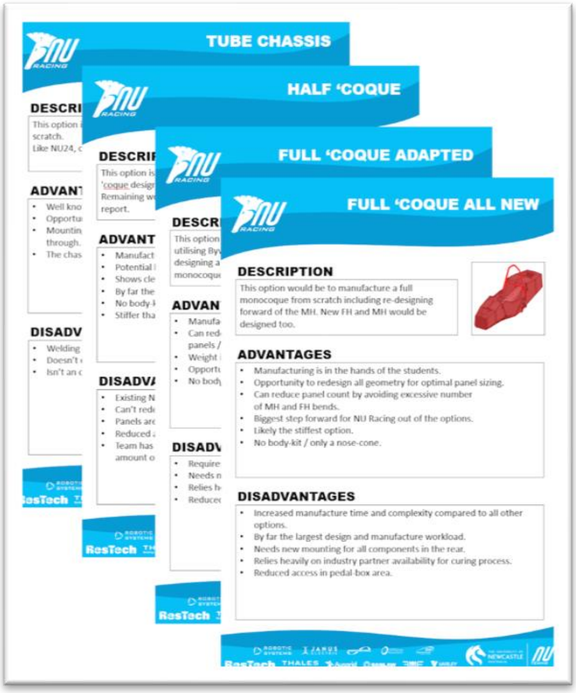


Figure 81 - Example of filled out sections of chassis selection decision matrix for 2025

Within NU Racing the actual application of a decision matrix is mostly limited to the documentation of a key decision. In 2024 the only decision matrix filled out was for the decision behind the future chassis to be used for 2025. The process of making the decision to use another space frame chassis was made through the meeting of Joshua Bywater and the 2024 leadership team. Ultimately the decision is made by the consideration of key factors present to the conversation, and the decision matrix is only used for the documentation of these factors. The decision matrix was not used in any capacity for deciding and was limited entirely to being a documentation tool, which is a valid purpose regardless.

The decision matrix document template can be seen in Appendix E – Empty Decision Matrix Template.

9.5. Laser/Water Cut Orders

A small project by the author was to create an ordering system for documenting and handling DXFs and engineering drawings to enable technical engineers to submit parts for manufacture through to the chief mechanical engineer, or chief engineer when need be. Asana is an online form and process handling software for creating workflows useful for file sharing and documentation.

In practice the system used for recording the submitted laser and water-cut orders was not useful. The workflow that the chief mechanical engineer for 2024 (Lachlan Fisher) ended up using was to export DXFs and .STEP files himself as he saw fit after the completion of design reviews. Attempting to get technical engineers involved with file handling creates issues of miscommunication and file versioning where outdated files need to be marked appropriately. Having the person responsible for ordering the manufacture of components do all exporting themselves reduces chances for issues to arise.

As such, the author does not recommend trying to create a system for handling any part manufacture related file sharing and instead suggests for manufacturing leads (such as chief/lead mechanical engineers) to adopt the method used by Lachlan Fisher.

10. Other Works

10.1. NU16 Front Uprights

NU16 is the final internal combustion engine car that NU Racing produced before swapping over to an EV competition platform. NU16 was used up until 2023 as a driver training car and got 7 years of driver training out of it before it was put out of commission by snapping a front upright.

As an exercise in learning to model and manufacture sheet metal parts the job of remanufacturing a set of front uprights was assigned to a junior member of the team. As they were not receiving course credit for the work there was no expectation for a deadline to be set, however a goal of approximately 1 months was given to have a design ready for submission to MEWS.

In the 1 month's period the junior had located an old CAD model of the uprights in Autodesk Inventor format. The model had flaws such as cuts in the sheet metal not normal to the surface of the flattened part. After being asked to remodel the part in Onshape, there was no tangible progress seen after that.

To get the parts manufactured the author modelled 3 of the 4 unique sheet-metal parts, after which the junior completed modelling the final part, being the lower turret.

The key change to the upright design was the increase of thickness of the 'turrets' that support the suspension pickups up to 2.5 mm from 2 mm.

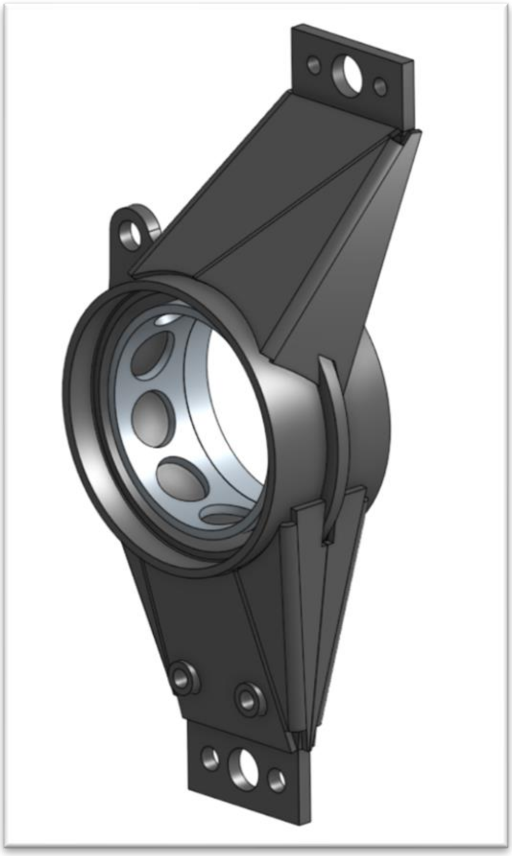


Figure 82 - CAD example of the modelled NU16 upright

Extra material was added to sections of material that ended close to fold lines. This is due to how when folding sheet metal in a press brake having the material not cover the full width of the tooling's trough will result in incorrectly formed folds. As a rule of thumb try to keep at least 8 times the material's thickness on either side of a fold line, though this may vary by material selection, fold angle, and tooling. Notches were included to indicate cut lines to remove the excess material after folding and the sheet-metal parts for the uprights were then submitted to Hancock Speedway alongside a set of folding drawings specifically for Hancock Speedway. These folding drawings are available in Appendix F – NU16 Upright Engineering Drawings.

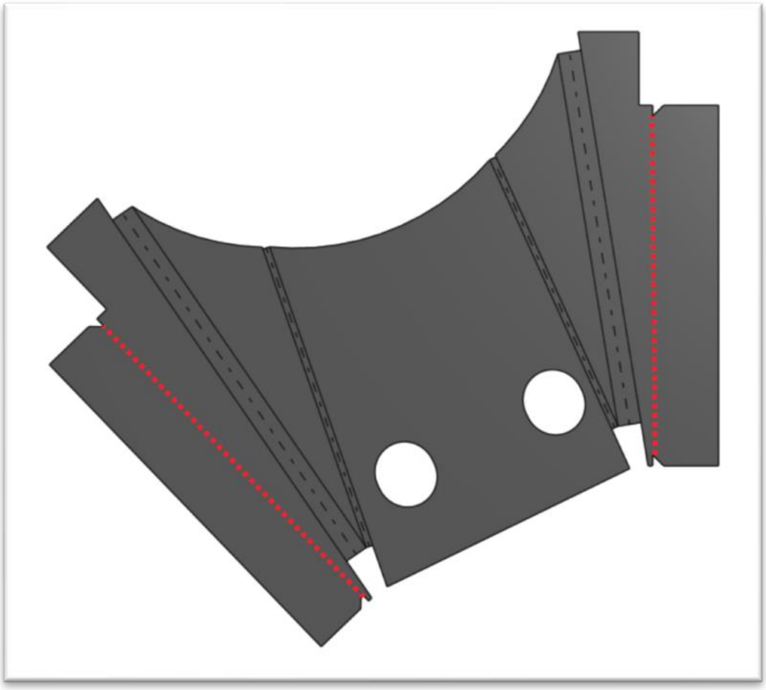


Figure 83 - Flat pattern of NU16 upright turret. Red dotted lines begin and end at notched areas indicating excess material to be removed after folding

Drawings for manufacture of the remaining turned parts were made by Lachlan Fisher including weldment drawings for MEWS to complete the rest of the manufacture.

The process of the material removal through the pre-notched locations of the cut lines was received positively by Lachlan Barrel of the MEWS workshop but the author did not hear opinions directly from the MEWS workshop machinists.

The uprights were put into use without issues, however later NU16 snapped a newly remade driveshaft and maintaining NU16 was then put on hold due to having to allocate resources to a then non-functioning NU24 motor controller.

10.2. NU23/NU24 Motor Phase Cable Cover

The phase cables running into the back of the EMRAX 188 used for NU23 and the EMRAX 228 used for NU24 are required to be enclosed such that a 6 mm rounded rod cannot touch any exposed high voltage, as per the FSAE rules. The author modelled an enclosure for the high voltage phase cables that would slide up the cables prior to connection and then cover would then fasten onto the side of the powerbox using bolts and tapped holes in the motor-plate of the powerbox.

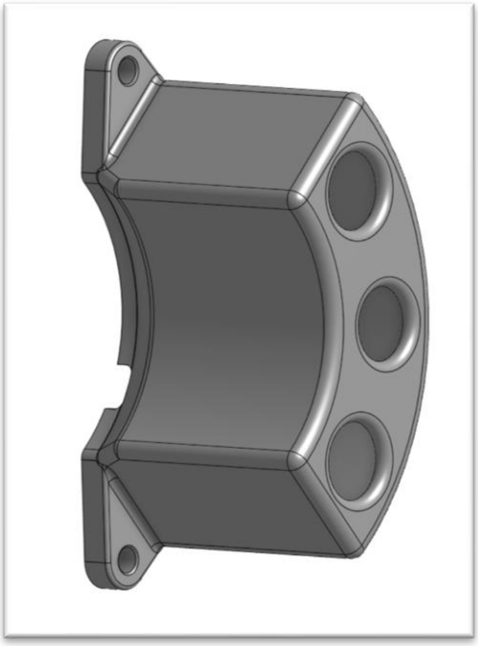


Figure 84 - Onshape model of NU24 EMRAX 228 phase cable cover

The cable cover was modelled using thickened surfaces that were mutually trimmed together to form a skin in the shape of the cover. The phase cable cover design is unique to each type of motor and functioned as intended during its use.

The phase cable cover design for NU24 should be compatible with NU25 as the motor selection is shared between the cars.

10.3. NU23 Brake Pedal Manufacture

In late 2023 the author used the Wazer water cutter in EC building's student workshop to water cut the brake pedal that was used for competition in NU23 and later reused for the pedal box of NU24 and taken to 2024 competition.

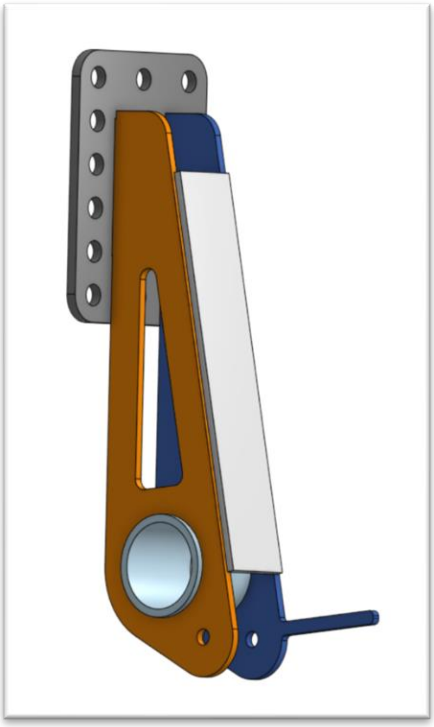


Figure 85 - Onshape model of brake pedal used for NU23 and NU24

The design for the brake pedal was created by Jye Hollier and the assembly, weldment and part drawings were created by the author for submission of manufacture to MEWS.

Drawings are attached in Appendix G – Brake Pedal Engineering Drawings

11. Conclusion and Recommendations

The 2023 NU Racing team set up the 2024 team for success with the development of their own NU23 car. The changes made by the 2023 team to align bottlenecks set up NU Racing to be able to iterate upon a solid competition platform for years to come.

The 2024 team was able to flesh out and make those designs into a reality, finding itself with the best performing car overall, with even better alignment of bottlenecks then ever had before. However, the manufacturing workload for 2024 was incredibly ambitious, and lessons have been learned to properly scope out workloads from the ground up, keeping ambitious developments parallel to testing and drive training.

Recommendations from the previous chief engineer Jye Hollier have been put into action with the design of NU25 being underway with most developments to the car being completely removed from the critical path. The 2025 team should hopefully have earliest drivable minimum-viable-product NU Racing has ever seen, setting them up to improve upon efforts to thoroughly validate the changes done to NU25 throughout the year.

NU24 and the 2024 team performed exceptionally well at competition, scoring the highest score NU Racing has had since entering the electric vehicle category. Although no event specific podiums were earned, the consistent scoring across all events demonstrates NU Racing's ability to uphold itself as a competitor in all events.

A section of this report directly addresses the future chief engineers of NU Racing, which should hopefully provide more insight for them into what sort of work they should be doing to best support the function and growth of NU Racing. The chief engineer role is historically a vaguely defined role within NU Racing and hopefully this report can assist is the clarification of the role for future final year project scopes.

Although vaguely defined, the chief engineer role is critical to the function of the team. The author recommends that future chief engineers work on fostering the professional development of all members of the team, especially those on the critical path. Recording team member's self-reflections on professional development and experience within NU Racing and taking onboard the recommendations of all members of the team would be beneficial for the chief engineer to be able to address any shortcomings of NU Racing that may reveal themselves, likely with assistance from the team leader.

A wholistic understanding of NU Racing, and the cars produced by the team is needed for the role, and it should be part of a chief engineers duty to see that their understanding goes towards the betterment of integration of systems on the car, while scoping out improvements for future years with realistic and well defined scopes, seeking to continue development of upgrades to the cars in parallel.

NU24 does have several issues as documented in this report, however the team leadership already slated for 2025 have been around for long enough to have witnessed these issues firsthand, with work already being done to remedy some issues and solve others. Detailed plans are laid out for the 2025 team regarding the development of each part of NU25 in this report, taking into consideration tight budgeting that may occur in 2025. The author has faith in the 2025 team to be able to strive for the highest levels of reliability NU Racing has seen, given the recommendations to drive NU24 and NU25 as much as possible to identify any remaining issues.

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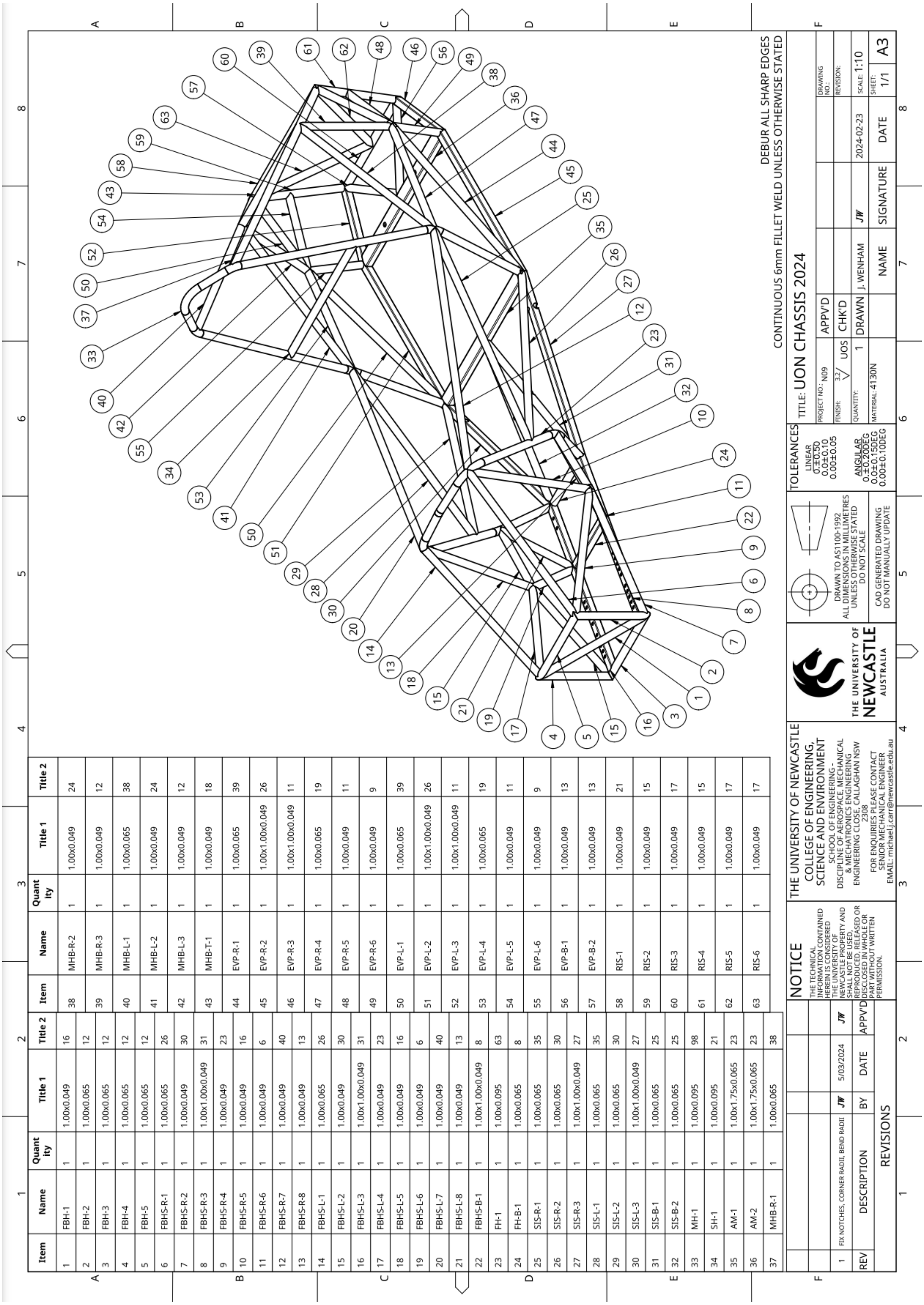
Appendices

Appendix A – Impact Attenuator Adherable Area Code

```
# IMPACT ATTENUATOR ADHESIVE AREA CALCULATOR
# JOSHUA WENHAM 02/09/24
#
# The purpose of this script is to enable quick calculation of Impact Attenuator adhesive area.
#
# The process is as follows:
#
# 1) Take a photocopy of the pre-crushed side of the impact attenuator being tested.
# - Scan at the highest DPI available.
# - Scan as JPEG.
#
# 2) Open the image in an image editing software.
# - paint.net is a reasonably good lightweight image editor. Gimp would work too. Both are free.
#
# 3) Rotate and crop the image to align with the rectangular borders of the image.
# - Crop close to the edge of the Impact Attenuator for maximum accuracy.
# - Orient the image to this orientation (for a competition standard IA):
#
# ---------------------- ^
# | | |
# | | Height
# | | |
# ---------------------- v
# <--------Width--------->
#
# 4) Save the image as 'IMPACTATTENUATOR.jpg'
# - Save it in the same directory as this script.
# - use .jpg NOT .jpeg
#
# 5) Enter the outer dimensions of the impact attenuator below:
IA_width = 200 # mm
IA_height = 100 # mm
#
# 6) Enter the grayscale threshold value from 0-255 below (typically 50-150 will work):
# - Note that a smaller threshold value will increase the amount of white present in the analysed image,
# and therefore increase the calculated adherable area.
threshold = 100 # out of 255
#
# 7) Run this script.
#
# 8) The script will save two images to the directory the script is in:
# - Image_Comparison.png (An image comparing the provided image with the B/W image used to calculate
# the adhesion area
#
# - IA_Adhesion_Area_Results.png (A pie chart to illustrate the results of the analysis)
#
#
==========================================================================================
======
# Import statements
import skimage as ski
import numpy as np
import matplotlib.pyplot as plt


# Importing image
image_raw = ski.io.imread('IMPACTATTENUATOR.jpg')

# Convert to uint8 (values 0-255)
ski.util.img_as_ubyte(image_raw)


# Convert the image to black and white
image_grayscale = ski.color.rgb2gray(image_raw)


# Convert the image to binary black and white, using a threshold of the grayscale values)
image_binary = np.zeros((image_grayscale.shape[0], image_grayscale.shape[1]), dtype='float64')
```

```
thresh = threshold/255.0

for row in range(0, (image_grayscale.shape[0] - 1)):
    for col in range(0, (image_grayscale.shape[1] - 1)):
        if image_grayscale[row, col] > thresh:
            image_binary[row, col] = 1

        else:
            image_binary[row, col] = 0


# Calculate the average value of the binary image. For a black and white image this will be equal to the
# number of white pixels divided by the number of total pixels
image_mean_intensity = image_binary.mean()

image_white_percent = image_mean_intensity*100

area_total = IA_width*IA_height # mm

area_adherable = image_mean_intensity*area_total # mm

area_blank = area_total - area_adherable

# Creating Pie-Chart Data for plotting
results = [area_adherable, area_blank]
pie_labels = [("Adherable:\n%d mm^2" % area_adherable), ("Empty Space:\n%d mm^2" % area_blank)]
pie_colours = ['']

# Plotting the results
plt.rc('image', cmap='gray')
dpi = 400

fig1, (ax1, ax2) = plt.subplots(2, 1)

ax1.imshow(image_raw)
ax1.axis('off')
ax1.set_title('Impact Attenuator\nPre-Crushed Surface')

ax2.imshow(image_binary)
ax2.axis('off')
ax2.set_title('Binary Image\nB/W Threshold = %d / 255' % threshold)

fig1.tight_layout()
fig1.savefig('Image_Comparison.png', bbox_inches='tight', dpi=dpi)

# ax3.set_title('Results')
fig2 = plt.figure()

plt.pie(results,
        labels=pie_labels,
        autopct='%.1f%%',
        wedgeprops = {"edgecolor": "black",
        'linewidth': 2,
        'antialiased': True}
        )
plt.title('Impact Attenuator Adhesion Area\nB/W Threshold = %d / 255\nWidth = %5.1f mm,  Height = %5.1f mm\n\n'
          'Adherable area taken as\n[Mean brightness of Binary Image (%%)] X [Total area (mm^2)]' % (threshold,
IA_width, IA_height))

plt.tight_layout()
fig2.savefig('IA_Adhesion_Area_Results.png', bbox_inches='tight', dpi=dpi)
```

Appendix B – NU24 Chassis Drawing



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3	FBH-3	1	1.00x0.065	12
4	FBH-4	1	1.00x0.065	12
5	FBH-5	1	1.00x0.065	12
6	FBHS-R-1	1	1.00x0.065	26
7	FBHS-R-2	1	1.00x0.049	30
8	FBHS-R-3	1	1.00x1.00x0.049	31
9	FBHS-R-4	1	1.00x0.049	23
10	FBHS-R-5	1	1.00x0.049	16
11	FBHS-R-6	1	1.00x0.049	6
12	FBHS-R-7	1	1.00x0.049	40
13	FBHS-R-8	1	1.00x0.049	13
14	FBHS-L-1	1	1.00x0.065	26
15	FBHS-L-2	1	1.00x0.049	30
16	FBHS-L-3	1	1.00x1.00x0.049	31
17	FBHS-L-4	1	1.00x0.049	23
18	FBHS-L-5	1	1.00x0.049	16
19	FBHS-L-6	1	1.00x0.049	6
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23	FH-1	1	1.00x0.095	63
24	FH-B-1	1	1.00x0.065	8
25	SIS-R-1	1	1.00x0.065	35
26	SIS-R-2	1	1.00x0.065	30
27	SIS-R-3	1	1.00x1.00x0.049	27
28	SIS-L-1	1	1.00x0.065	35
29	SIS-L-2	1	1.00x0.065	30
30	SIS-L-3	1	1.00x1.00x0.049	27
31	SIS-B-1	1	1.00x0.065	25
32	SIS-B-2	1	1.00x0.065	25
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34	SH-1	1	1.00x0.095	21
35	AM-1	1	1.00x1.75x0.065	23
36	AM-2	1	1.00x1.75x0.065	23
37	MHB-R-1	1	1.00x0.065	38
38	MHB-R-2	1	1.00x0.049	24
39	MHB-R-3	1	1.00x0.049	12
40	MHB-L-1	1	1.00x0.065	38
41	MHB-L-2	1	1.00x0.049	24
42	MHB-L-3	1	1.00x0.049	12
43	MHB-T-1	1	1.00x0.049	18
44	EVP-R-1	1	1.00x0.065	39
45	EVP-R-2	1	1.00x1.00x0.049	26
46	EVP-R-3	1	1.00x1.00x0.049	11
47	EVP-R-4	1	1.00x0.065	19
48	EVP-R-5	1	1.00x0.049	11
49	EVP-R-6	1	1.00x0.049	9
50	EVP-L-1	1	1.00x0.065	39
51	EVP-L-2	1	1.00x1.00x0.049	26
52	EVP-L-3	1	1.00x1.00x0.049	11
53	EVP-L-4	1	1.00x0.065	19
54	EVP-L-5	1	1.00x0.049	11
55	EVP-L-6	1	1.00x0.049	9
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57	EVP-B-2	1	1.00x0.049	13
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62	RIS-5	1	1.00x0.049	17
63	RIS-6	1	1.00x0.049	17

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37	MHB-R-1	1	1.00x0.065	38
38	MHB-R-2	1	1.00x0.049	24
39	MHB-R-3	1	1.00x0.049	12
40	MHB-L-1	1	1.00x0.065	38
41	MHB-L-2	1	1.00x0.049	24
42	MHB-L-3	1	1.00x0.049	12
43	MHB-T-1	1	1.00x0.049	18
44	EVP-R-1	1	1.00x0.065	39
46	EVP-R-3	1	1.00x1.00x0.049	11
47	EVP-R-4	1	1.00x0.065	19
48	EVP-R-5	1	1.00x0.049	11
49	EVP-R-6	1	1.00x0.049	9
50	EVP-L-1	1	1.00x0.065	39
52	EVP-L-3	1	1.00x1.00x0.049	11
53	EVP-L-4	1	1.00x0.065	19
54	EVP-L-5	1	1.00x0.049	11
55	EVP-L-6	1	1.00x0.049	9
56	EVP-B-1	1	1.00x0.049	13
57	EVP-B-2	1	1.00x0.049	13
58	RIS-1	1	1.00x0.049	21
59	RIS-2	1	1.00x0.049	15
60	RIS-3	1	1.00x0.049	17
61	RIS-4	1	1.00x0.049	15
62	RIS-5	1	1.00x0.049	17
63	RIS-6	1	1.00x0.049	17
66	MC-AM-1	1	1.00x1.75x0.065	25
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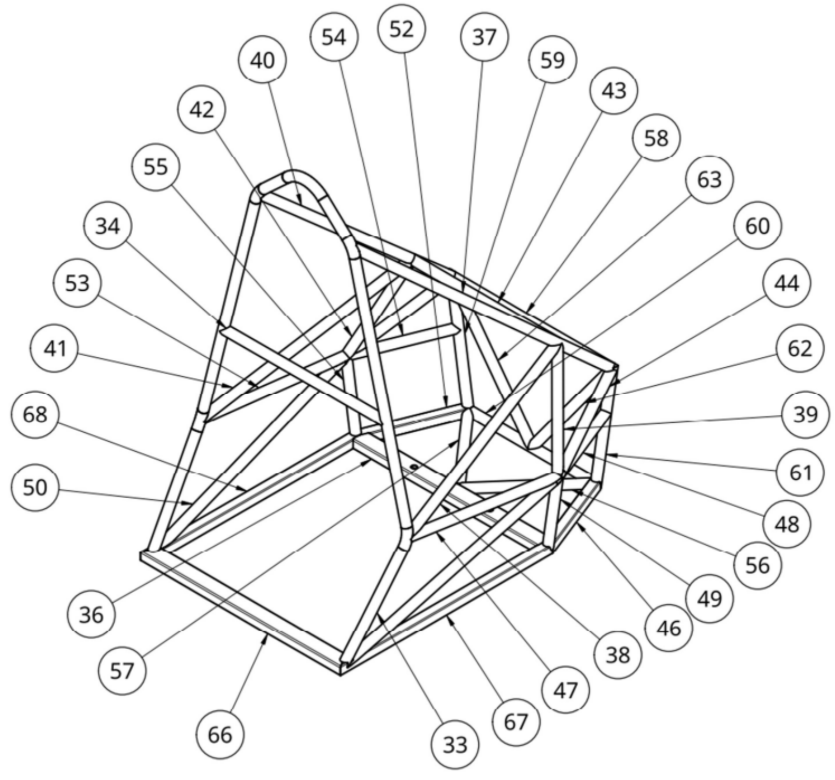
68	MC-EVP-L-2	1	1.00x1.00x0.049	27



DEBUR ALL SHARP EDGES
CONTINUOUS 6mm FILLET WELD UNLESS OTHERWISE STATED

REV	DESCRIPTION	BY	DATE	APPV'D

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TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.20DEG
0.0±0.15DEG
0.00±0.10DEG

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FINISH: 3.2 UOS	CHK'D				REVISION:
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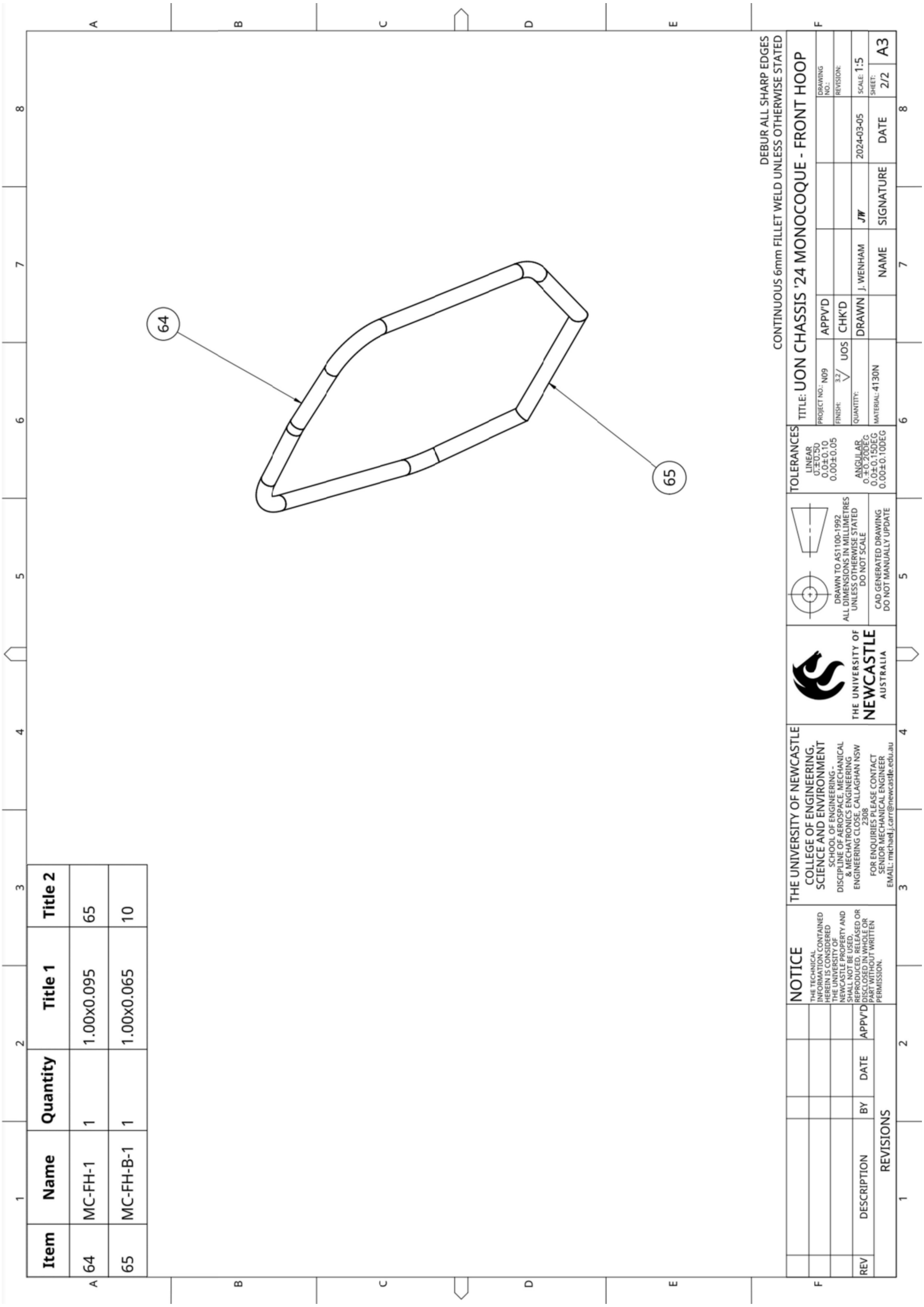

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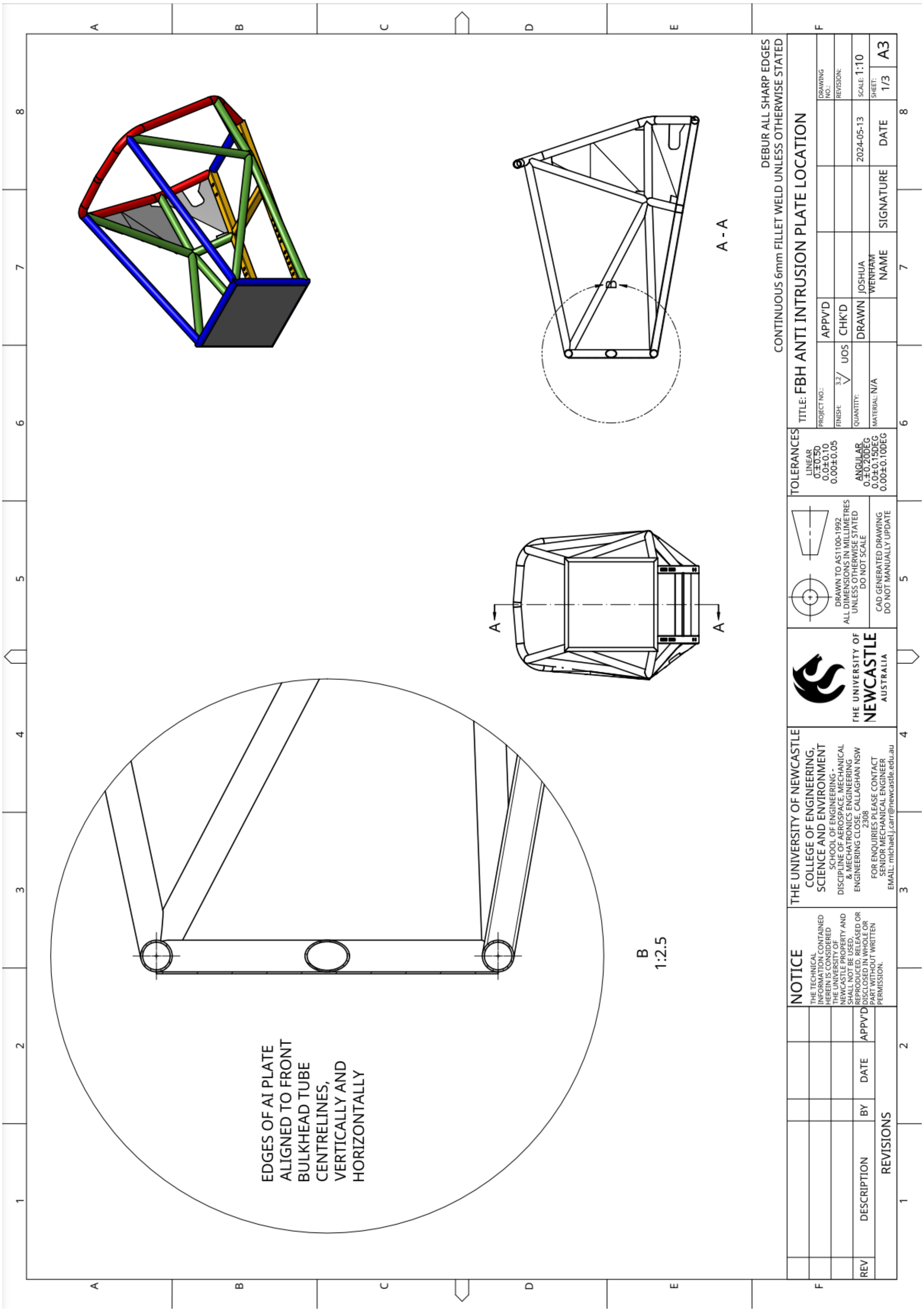
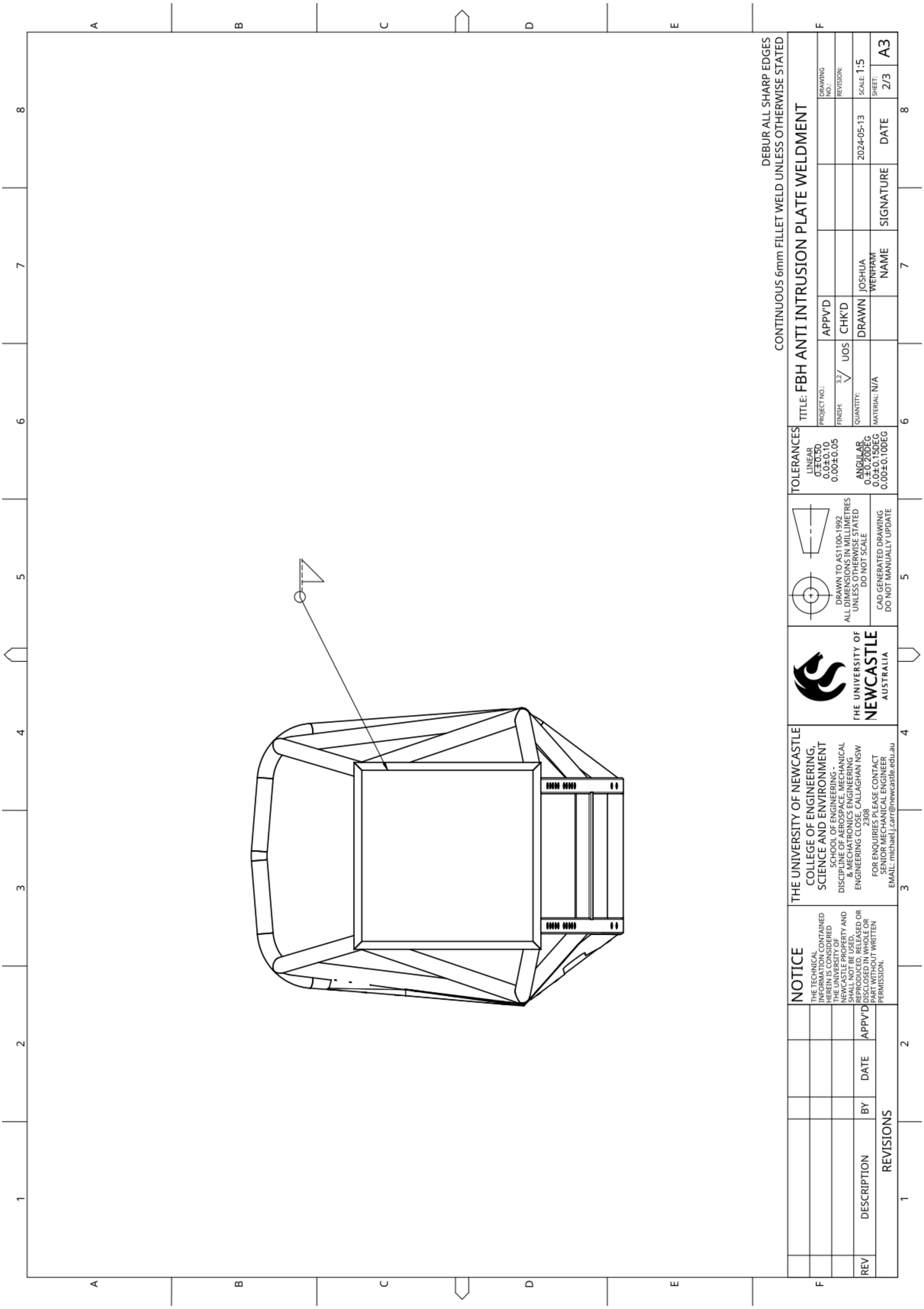
Appendix C – Anti Intrusion Plate Drawings

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DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
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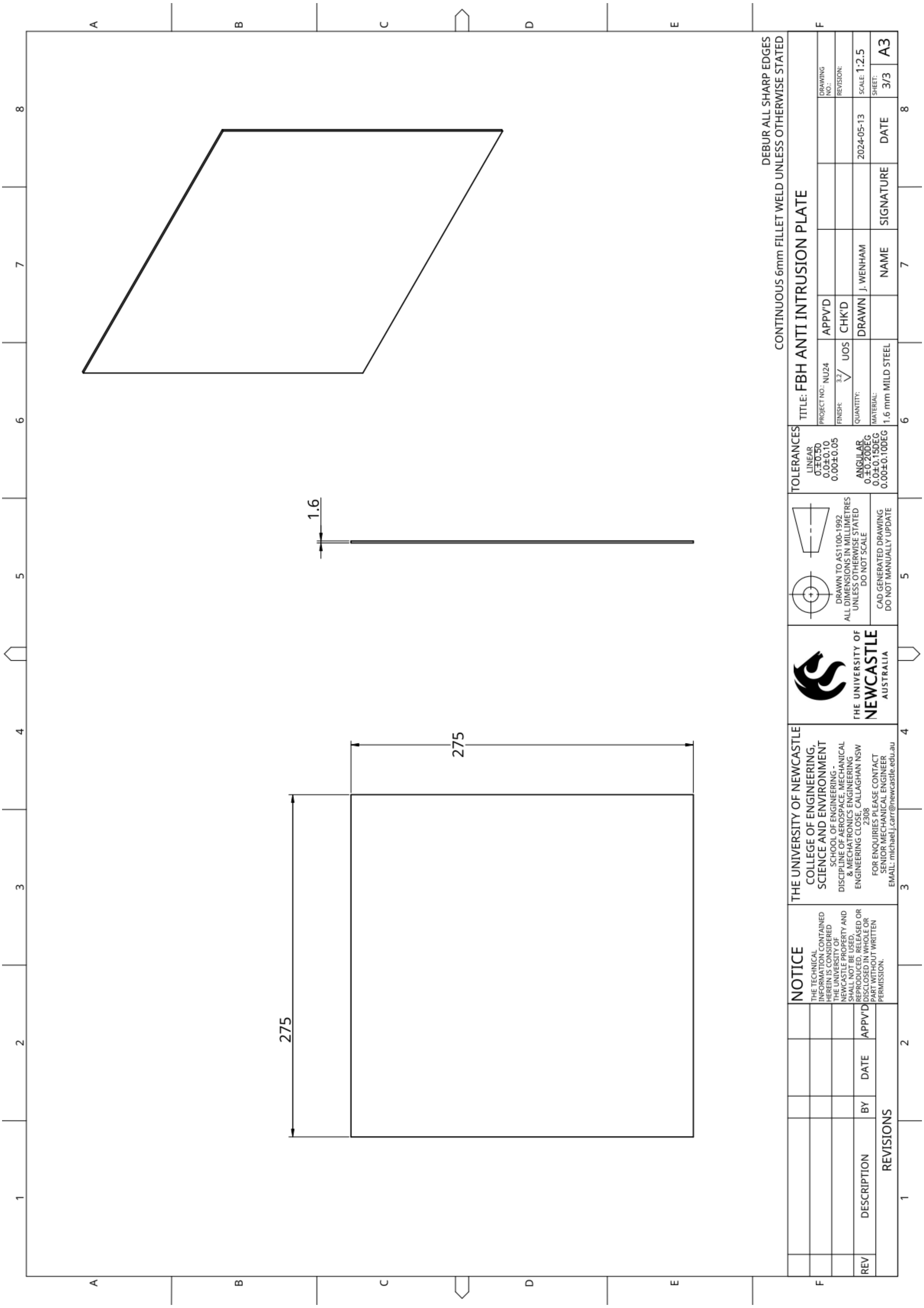


DEBUR ALL SHARP EDGES
CONTINUOUS 6mm FILLET WELD UNLESS OTHERWISE STATED
TITLE: FBH ANTI INTRUSION PLATE
PROJECT NO.: NU24
DRAWN J. WENHAM
2024-05-13
SCALE: 1:2.5
SHEET: 3/3
A3
MATERIAL: 1.6 mm MILD STEEL
1.6
275
275
NOTICE
REVISIONS

Appendix D – BOM Template Example

Name of Person Submitting Order	Signed	Order To:	Date Submitted For Order
JOSHUA WENHAM	JW	HANCOCK SPEEDWAY	28/03/2024

Part Number	Part Name	File Name	File Type	Material Thickness (mm)	Quantity	Section Type	Material	Finish	Requires Folding?
1	FLUF-F	1 - FLUF-F - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
2	FLUF-R	2 - FLUF-R - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
3	FLUR-F	3 - FLUR-F - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
4	FLUR-R	4 - FLUR-R - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
5	FLLF-F	5 - FLLF-F - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
6	FLLF-R	6 - FLLF-R - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
7	FLLR-F	7 - FLLR-F - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
8	FLLR-R	8 - FLLR-R - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
9	FCF	9 - FCF - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
10	FCR	10 - FCR - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
11	FCT	11 - FCT - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
12	RLUR-F	12 - RLUR-F - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
13	RLUR-R	13 - RLUR-R - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
14	RLUF-F	14 - RLUF-F - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
15	RLUF-R	15 - RLUF-R - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
16	RLLF-F	16 - RLLF-F - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
17	RLLF-R	17 - RLLF-R - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
18	RLLR-F	18 - RLLR-F - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
19	RLLR-R	19 - RLLR-R - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
20	RCF	20 - RCF - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
21	RCR	21 - RCR - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
22	RCT	22 - RCT - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
23	RCT-C	23 - RCT-C - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
24	RL UPPER PLATE	24 - RL UPPER PLATE - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
25	RL LOWER PLATE	25 - RL LOWER PLATE - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
26	FL UPPER PLATE	26 - FL UPPER PLATE - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
27	FL LOWER PLATE	27 - FL LOWER PLATE - 2.5 mm - MS - Quantity 2	.dxf	2.5	2	Sheet / Plate	MS	As Cut	No
28	COILOVER MOUNT RH	28 - COILOVER MOUNT RH - 2.5 mm - MS - Quantity 8	.dxf	2.5	8	Sheet / Plate	MS	As Cut	No
29	TIE ROD PLATE	29 - TIE ROD PLATE - 2.5 mm - MS - Quantity 4	.dxf	2.5	4	Sheet / Plate	MS	As Cut	No

Appendix E – Empty Decision Matrix Template

NU RACING DECISION MATRIX TEMPLATE

XX/XX/20XX

OPTION NAME

DESCRIPTION

Write about the general idea behind this option here.

INSERT PICTURE HERE

ADVANTAGES

- List the advantages of this option here.
- In a dot point format.
- Organise from best to most insignificant advantage.

DISADVANTAGES

- List the disadvantages of this option here.
- In a dot point format.
- Organise from worst to most insignificant disadvantage.

SCORING COMPARISON

CATEGORY	WEIGHTING (%)	OPTION A (X/10)	OPTION B (X/10)	OPTION C (X/10)	OPTION D (X/10)
TOTAL	100				

OUTCOME

OPTION CHOSEN

Write about the general idea behind this option here.

INSERT PICTURE HERE

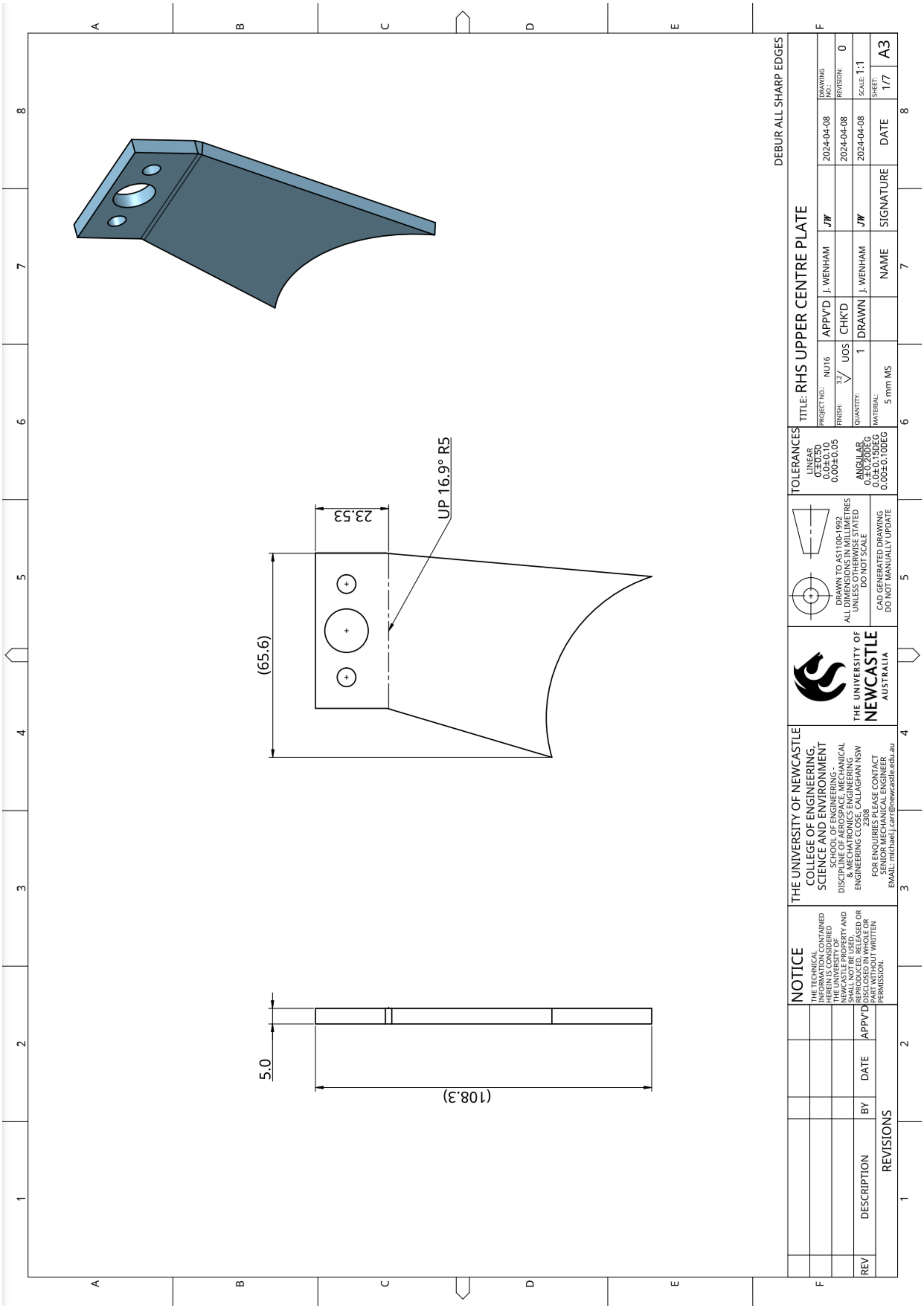
WHY IT WAS CHOSEN

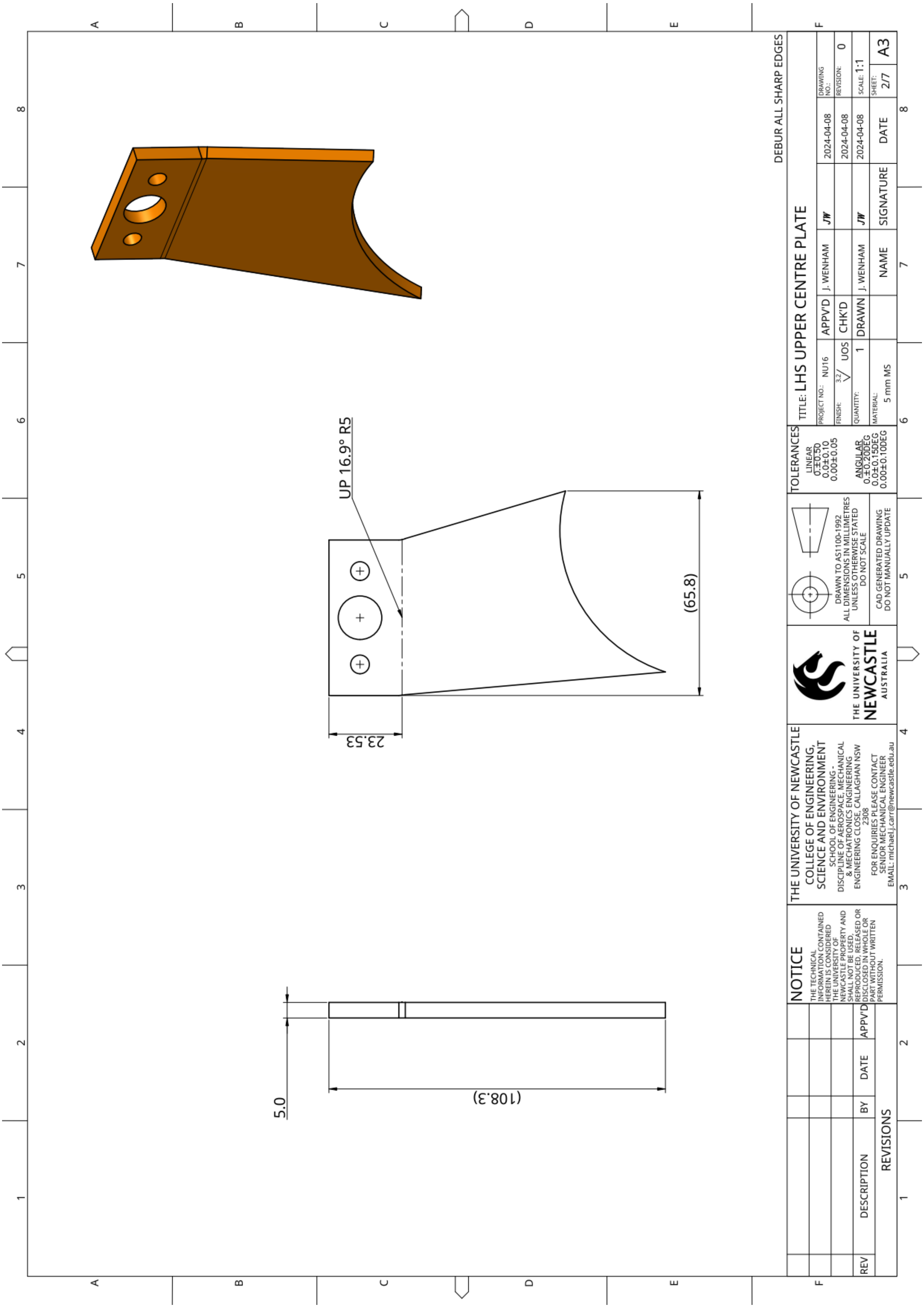
- List the key reasons why it was chosen (compared to the other options).
- Describe your expectations for the level of quality of the work.

ACTION TO BE TAKEN

- List the actions to be taken here.
- Allocate people to the work.

Appendix F – NU16 Upright Engineering Drawings




DEBUR ALL SHARP EDGES
TITLE: LHS UPPER CENTRE PLATE
PROJECT NO.: NU16
FINISH: 3.2 UOS
QUANTITY: 1
MATERIAL: 5 mm MS
APPV'D J. WENHAM JW 2024-04-08
CHK'D 2024-04-08
DRAWN J. WENHAM JW 2024-04-08
NAME
SIGNATURE
DATE
DRAWING NO.:
REVISION: 0
SCALE: 1:1
SHEET: 2/7
A3
TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.20DEG
0.0±0.15DEG
0.00±0.10DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES
UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
THE UNIVERSITY OF NEWCASTLE AUSTRALIA
THE UNIVERSITY OF NEWCASTLE
COLLEGE OF ENGINEERING, SCIENCE AND ENVIRONMENT
SCHOOL OF ENGINEERING -
DISCIPLINE OF AEROSPACE, MECHANICAL & MECHATRONICS ENGINEERING
ENGINEERING CLOSE, CALLAGHAN NSW 2308
FOR ENQUIRIES PLEASE CONTACT
SENIOR MECHANICAL ENGINEER
EMAIL: michael.j.carr@newcastle.edu.au
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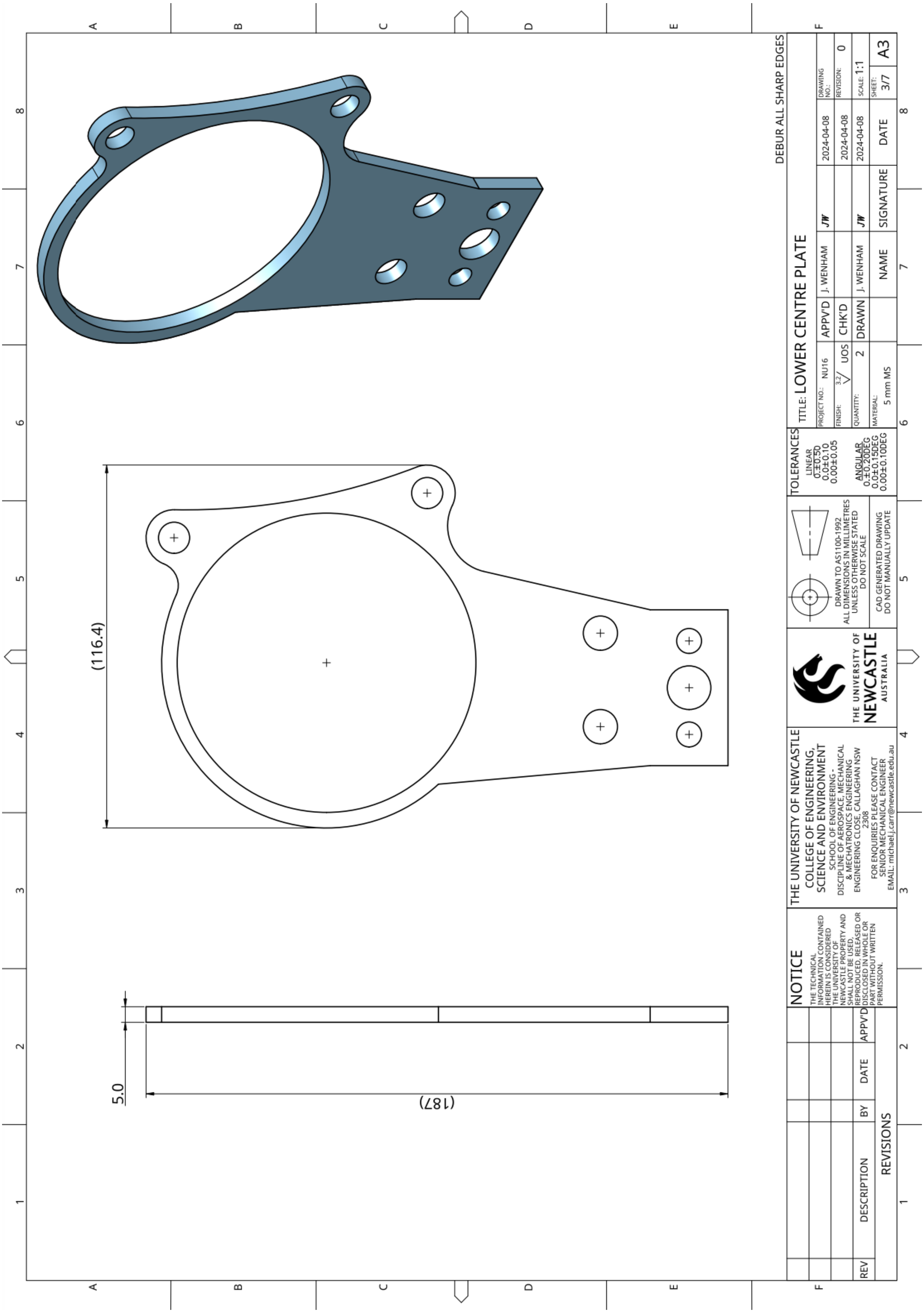
REV
DESCRIPTION
BY
DATE
APPV'D
REVISIONS
UP 16.9° R5
(65.8)
23.53
5.0
(108.3)


DEBUR ALL SHARP EDGES
TITLE: LOWER CENTRE PLATE
PROJECT NO.: NU16
FINISH: 3.2 UOS
QUANTITY: 2
MATERIAL: 5 mm MS
APPV'D J. WENHAM JW 2024-04-08
CHK'D 2024-04-08
DRAWN J. WENHAM JW 2024-04-08
NAME SIGNATURE DATE
DRAWING NO.:
REVISION: 0
SCALE: 1:1
SHEET: 3/7
A3
TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.200DEG
0.0±0.150DEG
0.00±0.100DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES
UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
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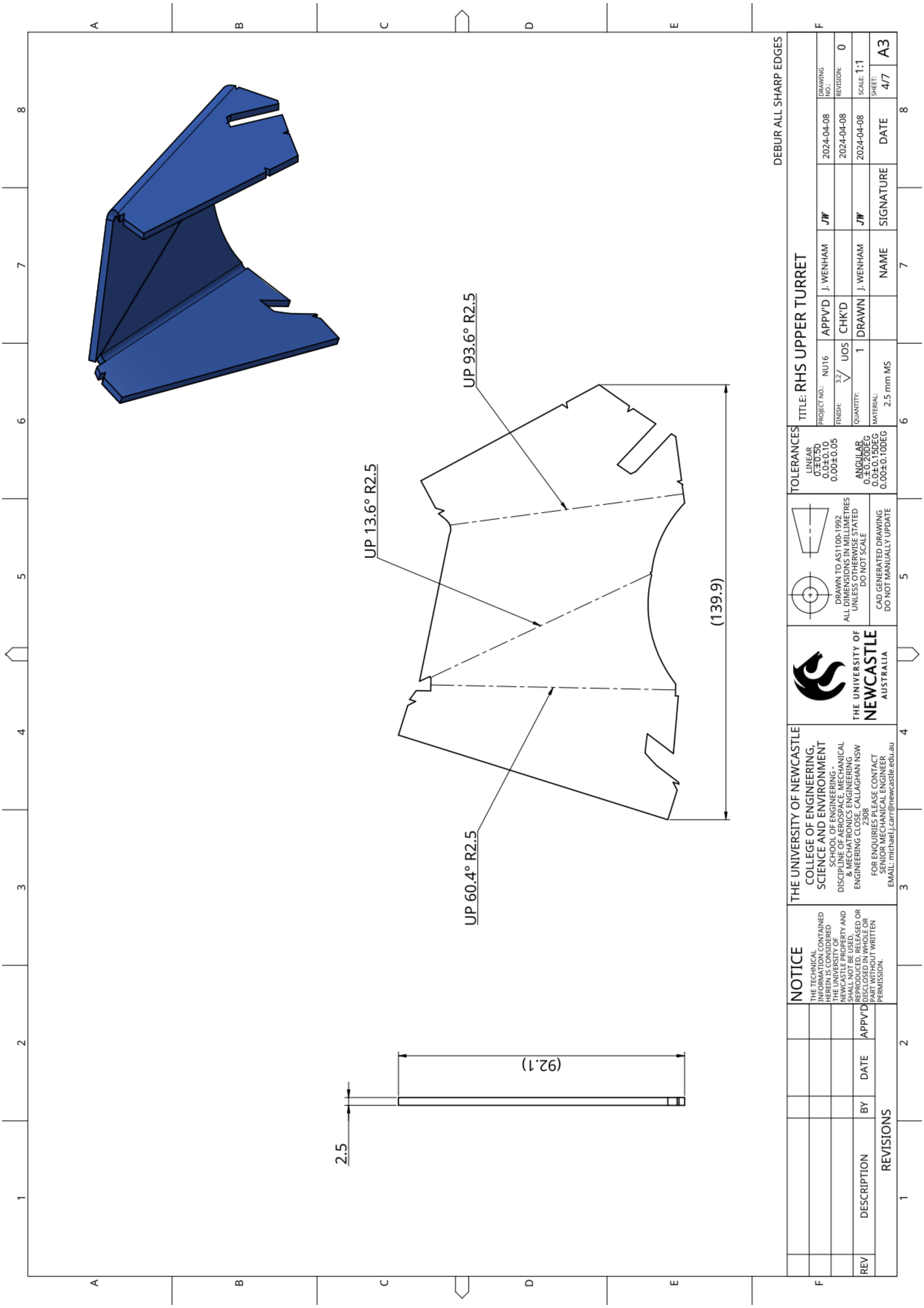
REV DESCRIPTION BY DATE APPV'D
REVISIONS
(116.4)
5.0
(187)


DEBUR ALL SHARP EDGES
UP 93.6° R2.5
UP 13.6° R2.5
UP 60.4° R2.5
(139.9)
(92.1)
2.5
TITLE: RHS UPPER TURRET
PROJECT NO.: NU16
APPV'D J. WENHAM 2024-04-08
CHK'D 2024-04-08
DRAWN J. WENHAM 2024-04-08
QUANTITY: 1
MATERIAL: 2.5 mm MS
NAME
SIGNATURE
DATE
DRAWING NO.:
REVISION: 0
SCALE: 1:1
SHEET: 4/7
A3
TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.20DEG
0.0±0.15DEG
0.00±0.10DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES
UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
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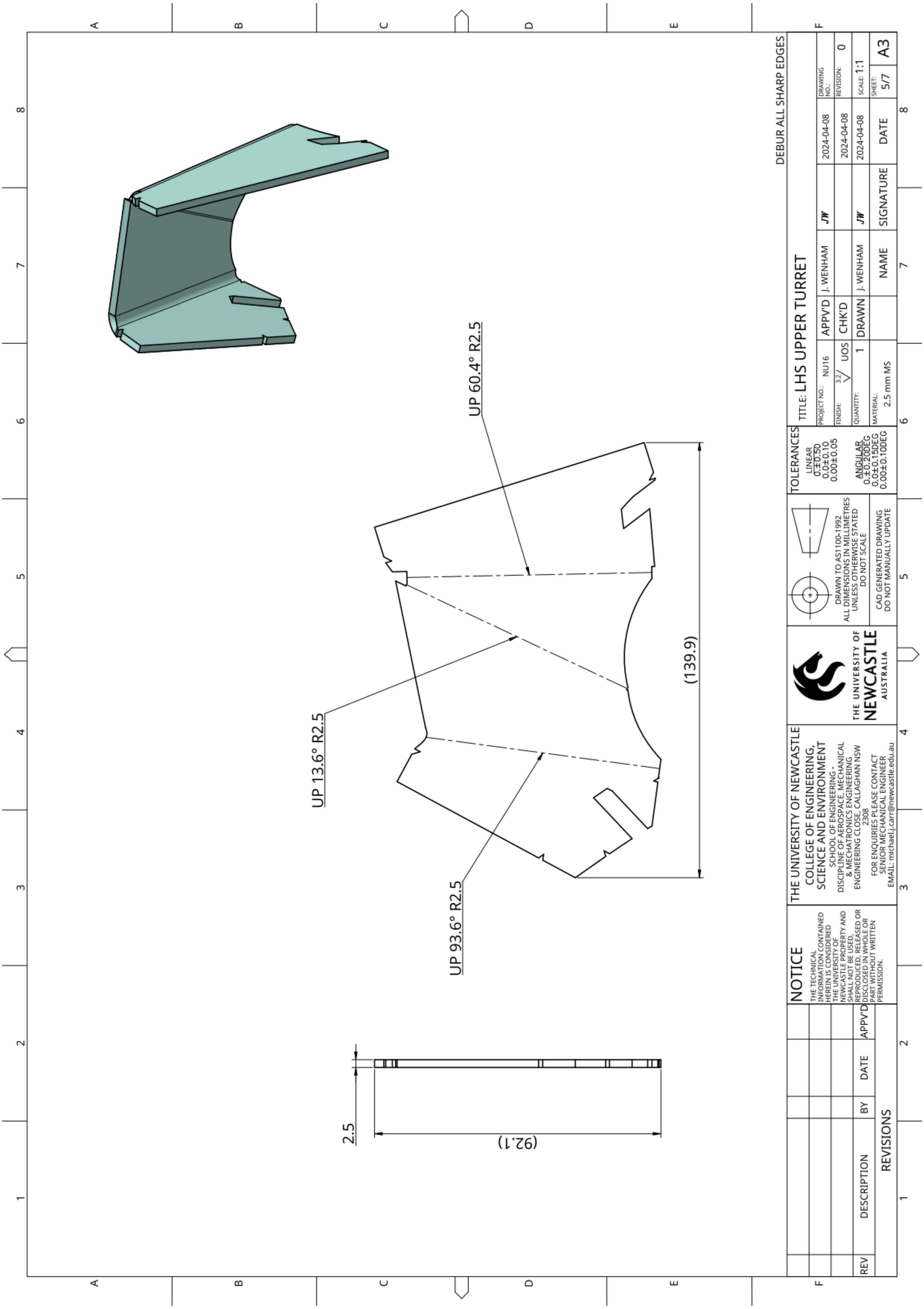
REV
DESCRIPTION
BY
DATE
APPV'D
REVISIONS


DEBUR ALL SHARP EDGES
UP 60.4° R2.5
UP 13.6° R2.5
UP 93.6° R2.5
(139.9)
2.5
(92.1)
TITLE: LHS UPPER TURRET
PROJECT NO.: NU16
APPV'D J. WENHAM 2024-04-08
CHK'D 2024-04-08
DRAWN J. WENHAM 2024-04-08
NAME
SIGNATURE
DATE
DRAWING NO.:
REVISION: 0
SCALE: 1:1
SHEET: 5/7
A3
FINISH: 3.2 UOS
QUANTITY: 1
MATERIAL: 2.5 mm MS
TOLERANCES
LINEAR
0.0±0.10
0.00±0.05
ANGULAR
0.0±0.15DEG
0.00±0.10DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
THE UNIVERSITY OF NEWCASTLE AUSTRALIA
THE UNIVERSITY OF NEWCASTLE
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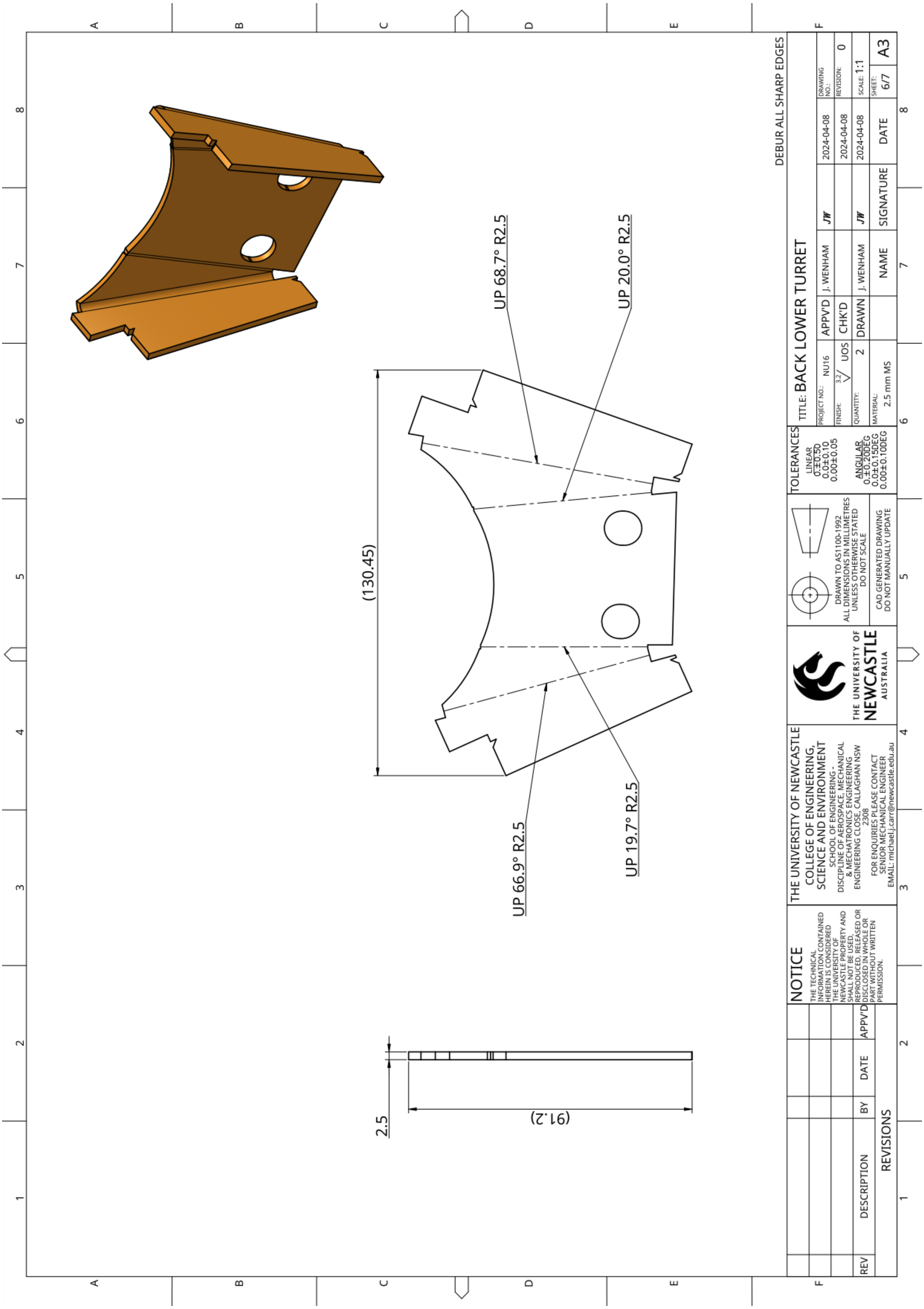
NOTICE
REV
DESCRIPTION
BY
DATE
APPV'D
REVISIONS


DEBUR ALL SHARP EDGES
UP 68.7° R2.5
UP 20.0° R2.5
UP 66.9° R2.5
UP 19.7° R2.5
(130.45)
2.5
(91.2)
TITLE: BACK LOWER TURRET
PROJECT NO.: NU16
FINISH: 3.2 UOS
QUANTITY: 2
MATERIAL: 2.5 mm MS
APPV'D J. WENHAM JW 2024-04-08
CHK'D 2024-04-08
DRAWN J. WENHAM JW 2024-04-08
NAME
SIGNATURE
DATE
DRAWING NO.:
REVISION: 0
SCALE: 1:1
SHEET: 6/7
A3
TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.20DEG
0.0±0.15DEG
0.00±0.10DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES
UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
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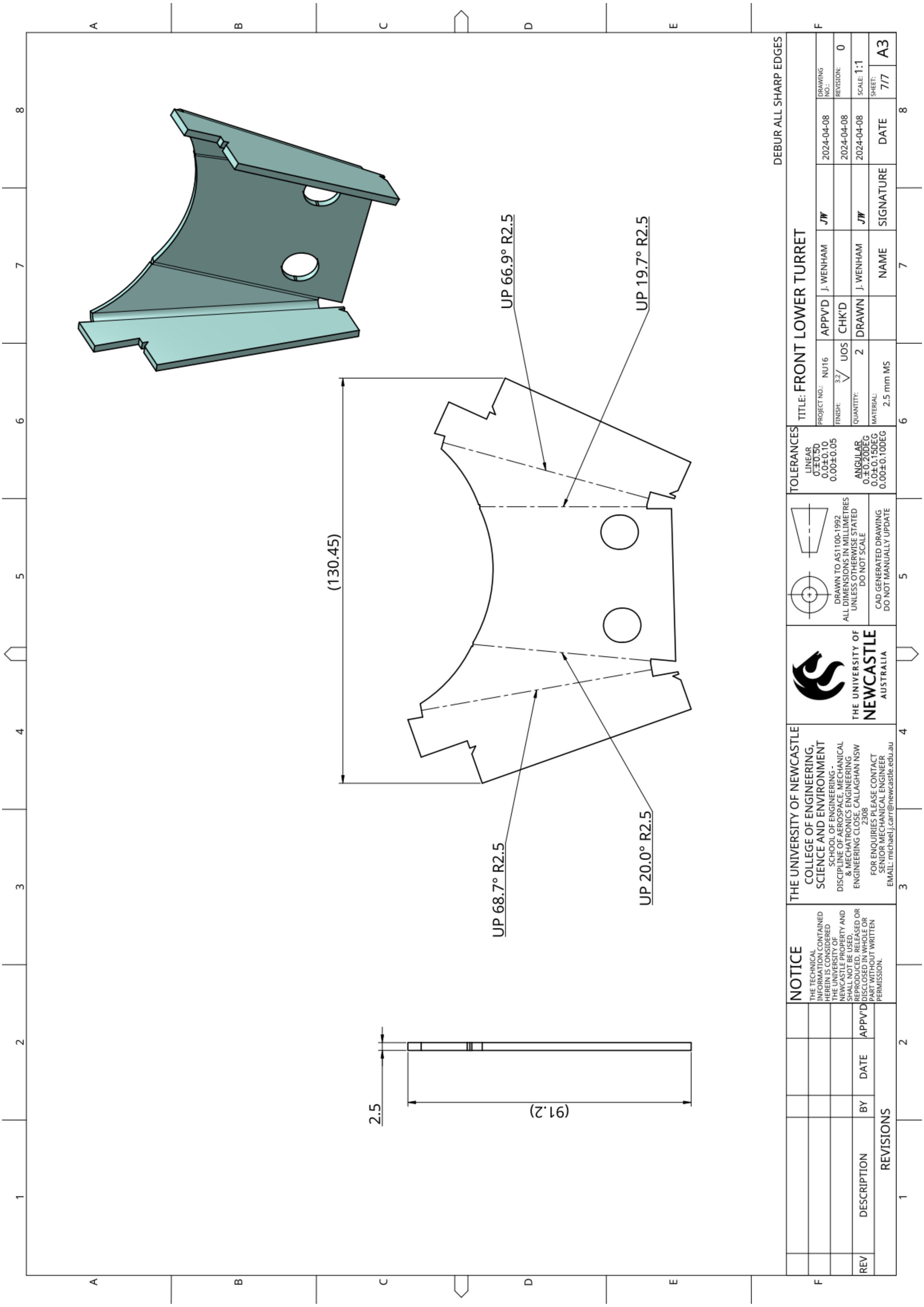
REV
DESCRIPTION
BY
DATE
APPV'D
REVISIONS
A
B
C
D
E
F
1
2
3
4
5
6
7
8


DEBUR ALL SHARP EDGES
UP 66.9° R2.5
UP 19.7° R2.5
UP 68.7° R2.5
UP 20.0° R2.5
(130.45)
(91.2)
2.5
TITLE: FRONT LOWER TURRET
PROJECT NO.: NU16
FINISH: 3.2 UOS
QUANTITY: 2
MATERIAL: 2.5 mm MS
APPV'D J. WENHAM JW 2024-04-08
CHK'D 2024-04-08
DRAWN J. WENHAM JW 2024-04-08
NAME SIGNATURE DATE
DRAWING NO.:
REVISION: 0
SCALE: 1:1
SHEET: 7/7
A3
TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.20DEG
0.0±0.15DEG
0.00±0.10DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES
UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
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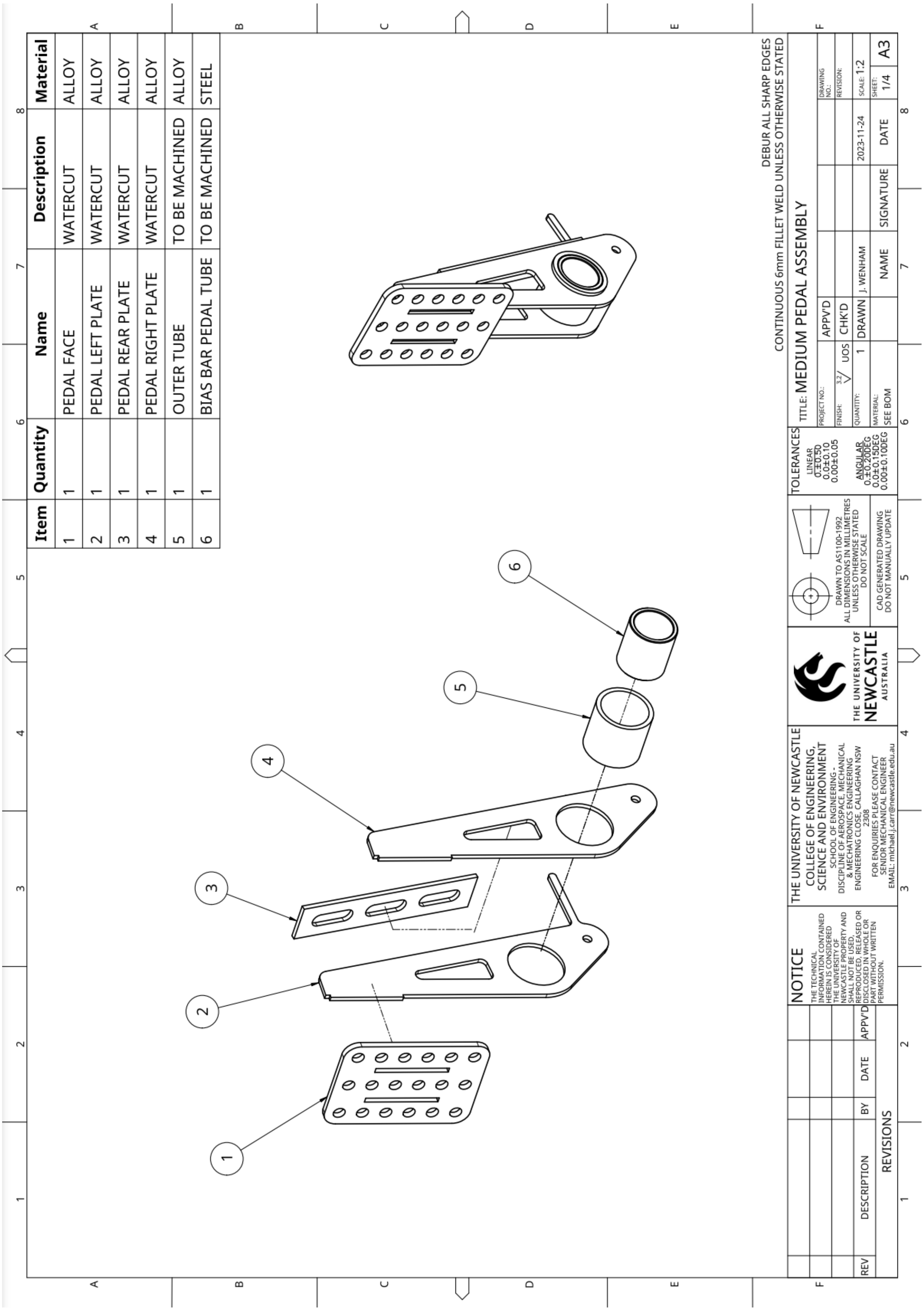
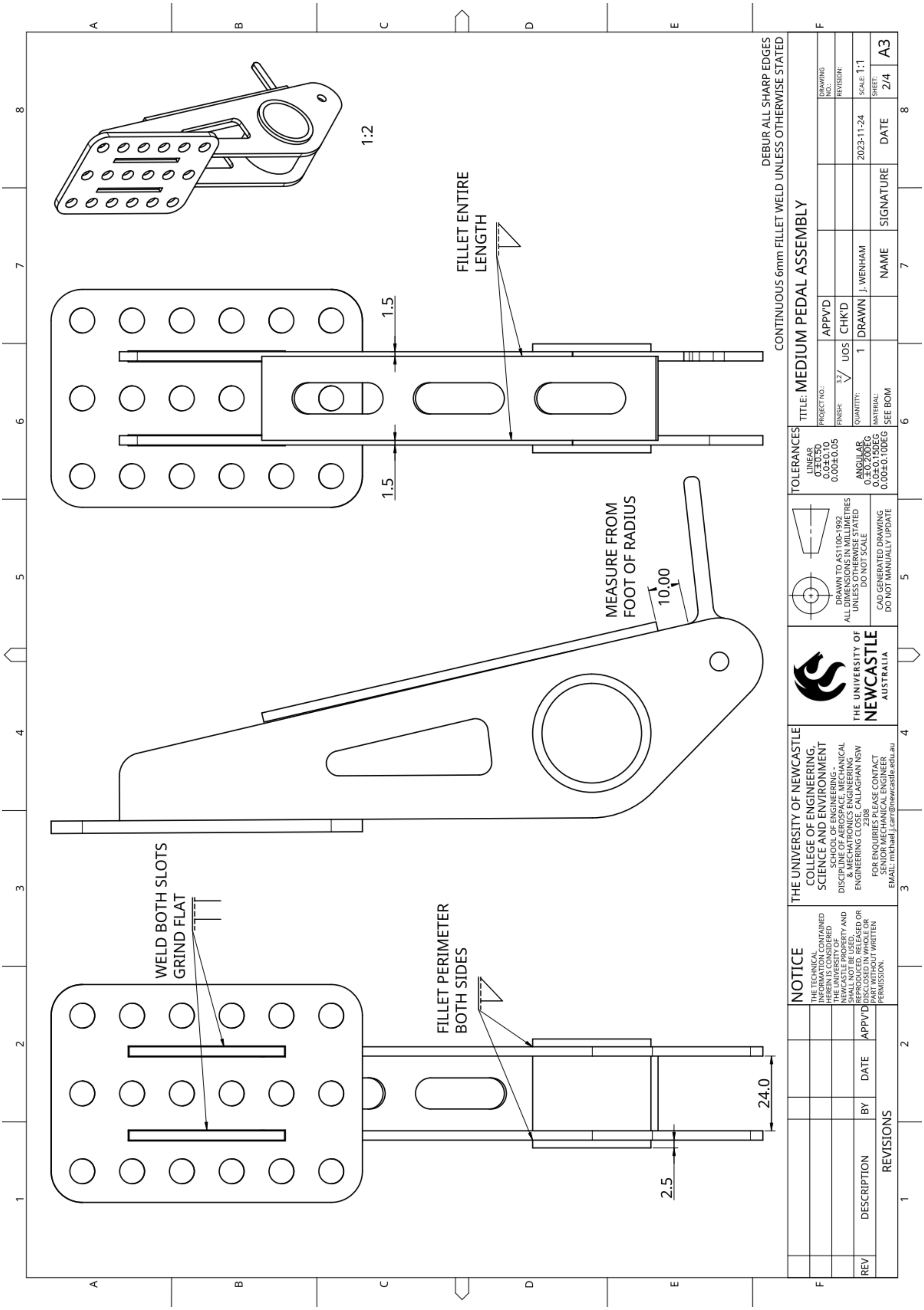
REV DESCRIPTION BY DATE APPV'D
REVISIONS

Appendix G – Brake Pedal Engineering Drawings




1:2
FILLET ENTIRE LENGTH
1.5
1.5
MEASURE FROM FOOT OF RADIUS
10.00
WELD BOTH SLOTS GRIND FLAT
FILLET PERIMETER BOTH SIDES
24.0
2.5
DEBUR ALL SHARP EDGES
CONTINUOUS 6mm FILLET WELD UNLESS OTHERWISE STATED
TITLE: MEDIUM PEDAL ASSEMBLY
PROJECT NO.:
DRAWING NO.:
REVISION:
SCALE: 1:1
SHEET: 2/4
A3
FINISH: 3.2 UOS
APPV'D
CHK'D
DRAWN 1 J. WENHAM 2023-11-24
QUANTITY:
MATERIAL: SEE BOM
NAME
SIGNATURE
DATE
TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.20DEG
0.0±0.15DEG
0.00±0.10DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
THE UNIVERSITY OF NEWCASTLE AUSTRALIA
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COLLEGE OF ENGINEERING, SCIENCE AND ENVIRONMENT
SCHOOL OF ENGINEERING -
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FOR ENQUIRIES PLEASE CONTACT SENIOR MECHANICAL ENGINEER
EMAIL: michael.j.carr@newcastle.edu.au
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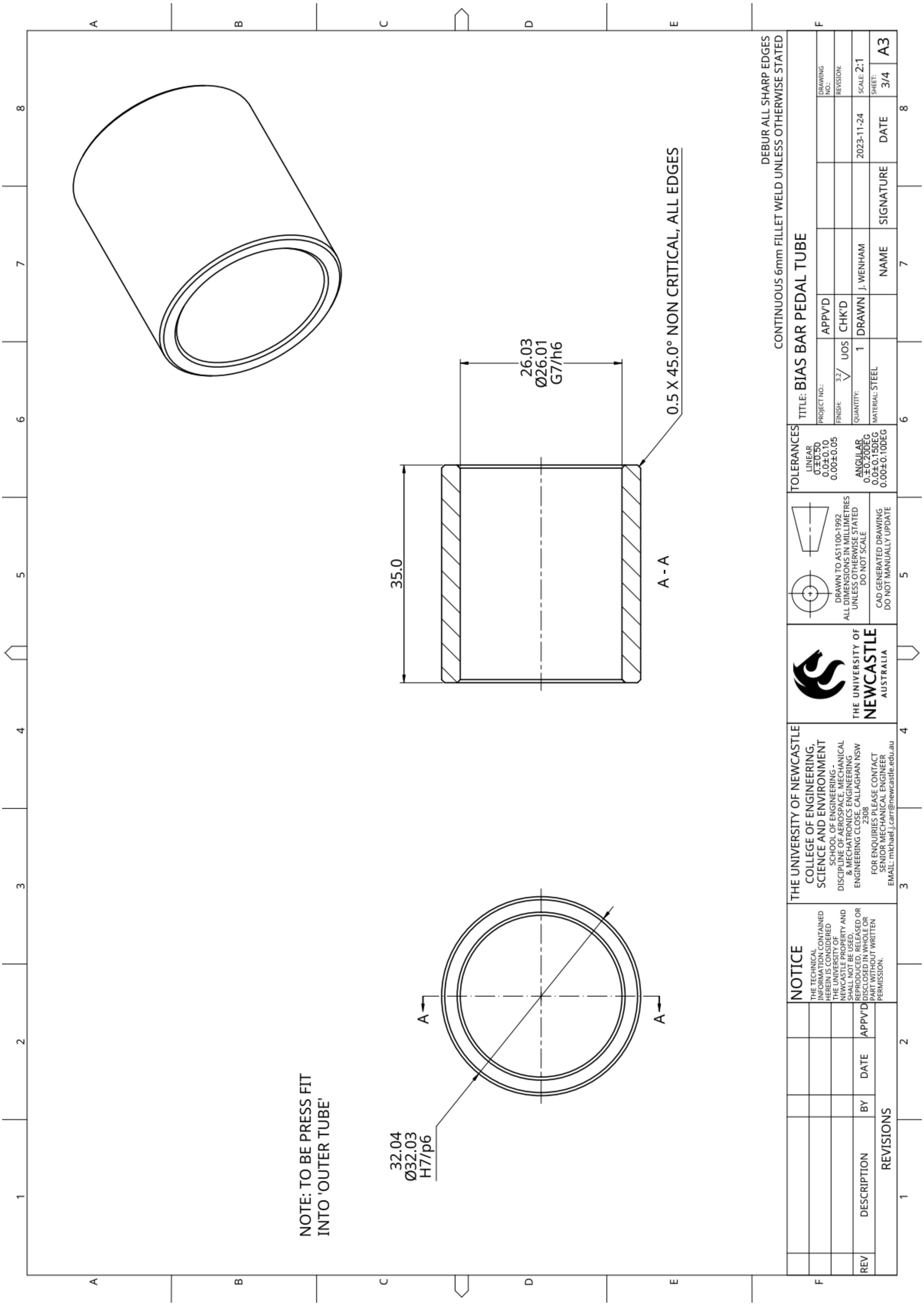
REV
DESCRIPTION
BY
DATE
APPV'D
REVISIONS


DEBUR ALL SHARP EDGES
CONTINUOUS 6mm FILLET WELD UNLESS OTHERWISE STATED
0.5 X 45.0° NON CRITICAL, ALL EDGES
26.03
Ø26.01
G7/h6
35.0
A - A
A
A
32.04
Ø32.03
H7/p6
NOTE: TO BE PRESS FIT
INTO 'OUTER TUBE'
TITLE: BIAS BAR PEDAL TUBE
PROJECT NO.:
FINISH: 3.2 UOS
QUANTITY: 1
MATERIAL: STEEL
APPV'D
CHK'D
DRAWN J. WENHAM 2023-11-24
NAME
SIGNATURE
DATE
DRAWING NO.:
REVISION:
SCALE: 2:1
SHEET: 3/4
A3
TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.20DEG
0.0±0.15DEG
0.00±0.10DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES
UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING
DO NOT MANUALLY UPDATE
THE UNIVERSITY OF NEWCASTLE AUSTRALIA
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SCIENCE AND ENVIRONMENT
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& MECHATRONICS ENGINEERING
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2308
FOR ENQUIRIES PLEASE CONTACT
SENIOR MECHANICAL ENGINEER
EMAIL: michael.j.carr@newcastle.edu.au
NOTICE
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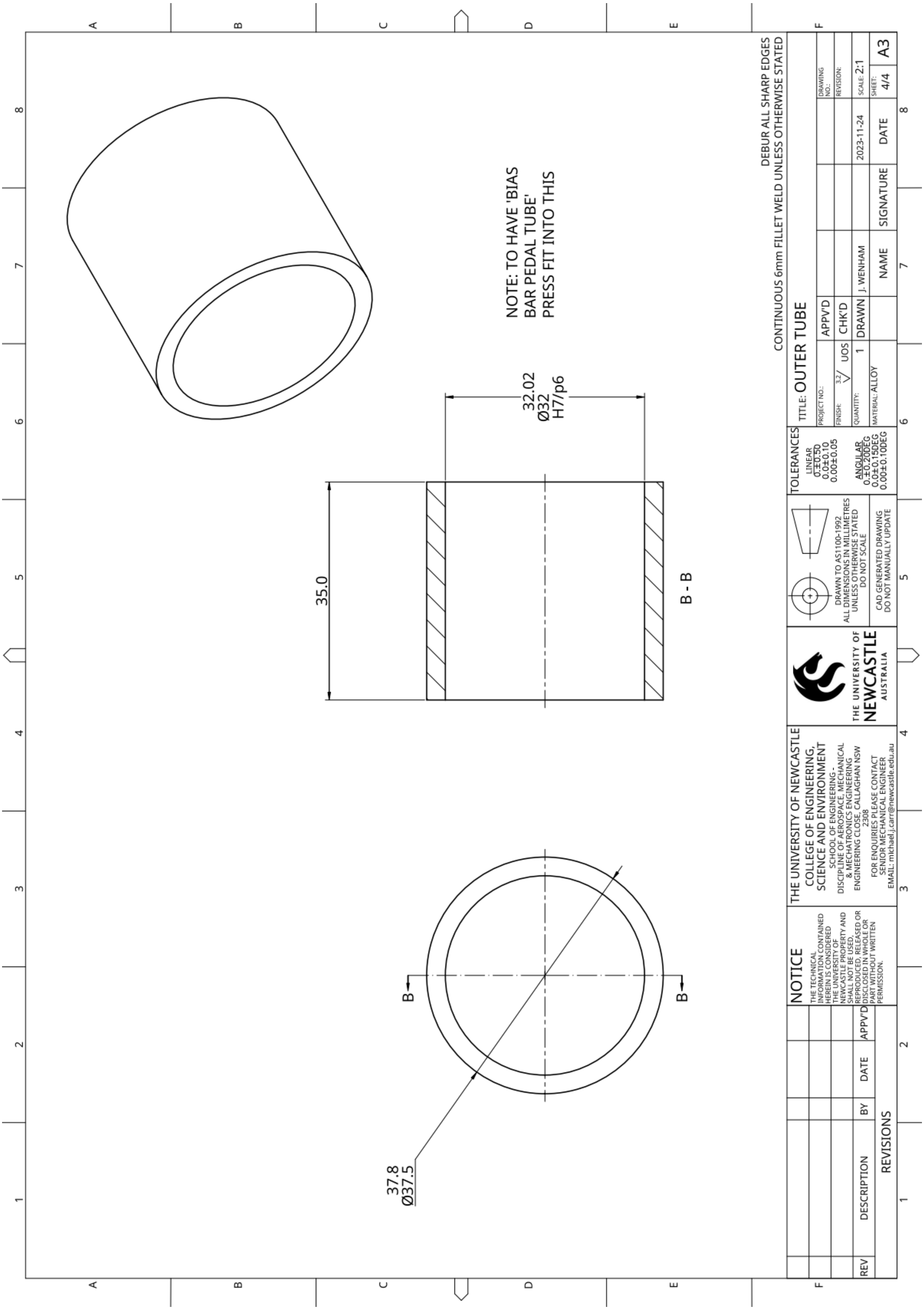
REV
DESCRIPTION
BY
DATE
APPV'D
REVISIONS


NOTE: TO HAVE 'BIAS BAR PEDAL TUBE' PRESS FIT INTO THIS
32.02
Ø32
H7/p6
35.0
B - B
B
B
37.8
Ø37.5
DEBUR ALL SHARP EDGES
CONTINUOUS 6mm FILLET WELD UNLESS OTHERWISE STATED
TITLE: OUTER TUBE
TOLERANCES
LINEAR
0.±0.50
0.0±0.10
0.00±0.05
ANGULAR
0.±0.20DEG
0.0±0.15DEG
0.00±0.10DEG
DRAWN TO AS1100-1992
ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED
DO NOT SCALE
CAD GENERATED DRAWING DO NOT MANUALLY UPDATE
THE UNIVERSITY OF NEWCASTLE AUSTRALIA
THE UNIVERSITY OF NEWCASTLE
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REV
DESCRIPTION
BY
DATE
APPV'D
REVISIONS
PROJECT NO.:
FINISH: 3.2 UOS
QUANTITY: 1
MATERIAL: ALLOY
APPV'D
CHK'D
DRAWN
J. WENHAM
2023-11-24
NAME
SIGNATURE
DATE
DRAWING NO.:
REVISION:
SCALE: 2:1
SHEET: 4/4
A3