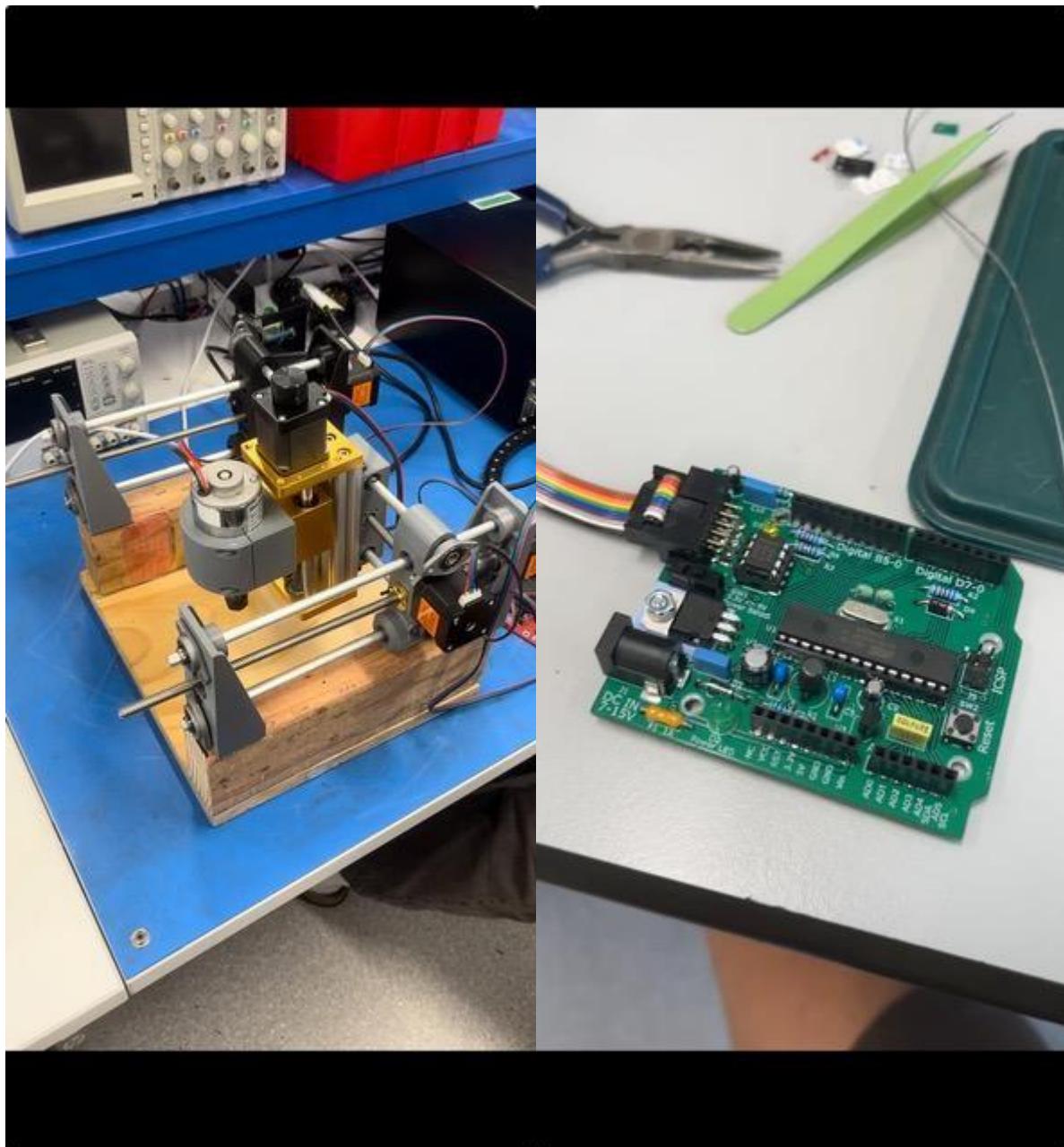


# Mo Balfour-Lochner – Project Portfolio

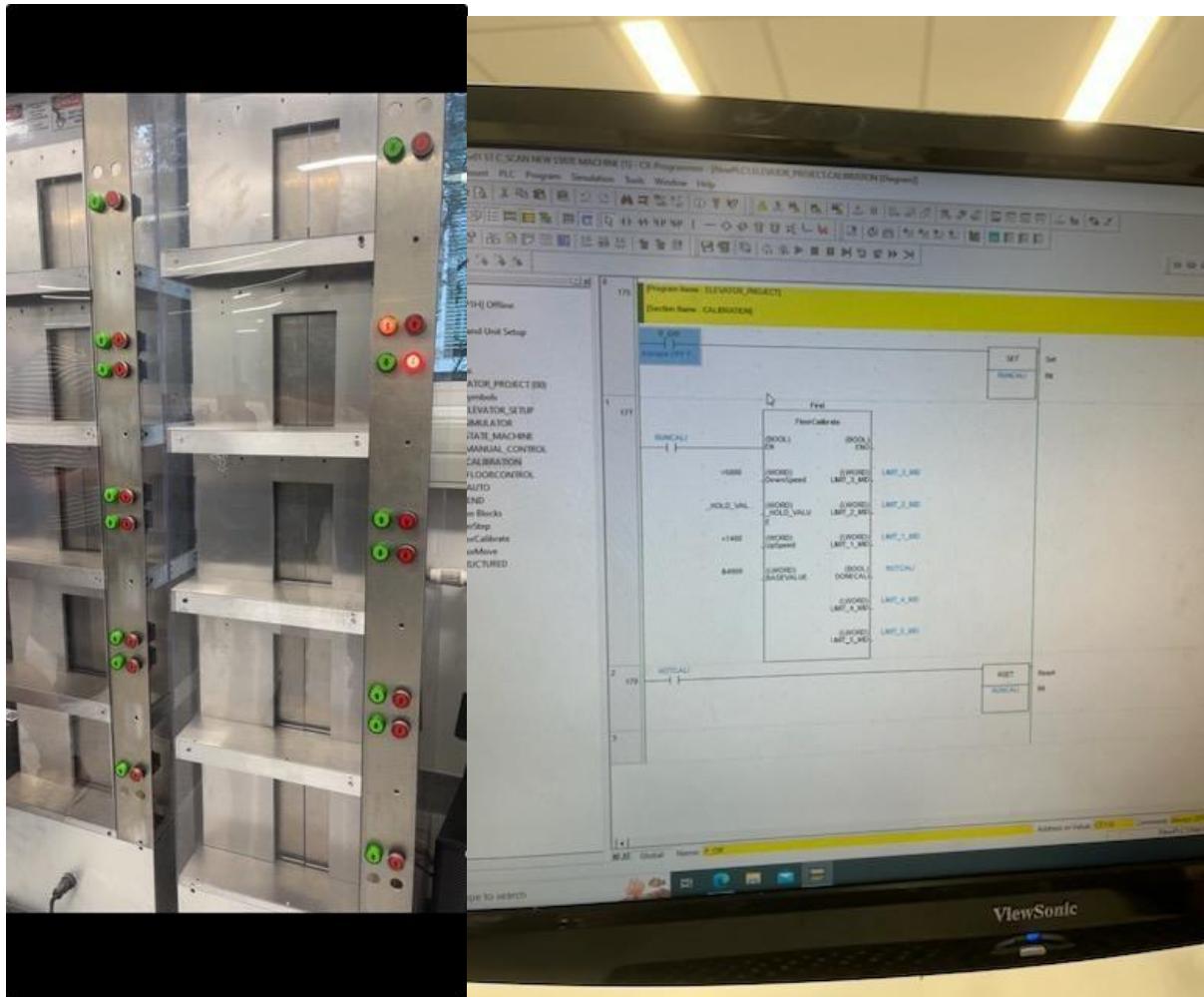


A few projects completed very early on in my journey to becoming a Mechatronics engineer were soldering up a USB to serial converter and designing, building and programming a desktop CNC mill. Photos of these can be seen below.



Last year I completed two main mechatronics related projects. In the first we were required to write a program for a functioning elevator using a combination of the Ladder Logic and Structured Text programming languages. An Omron CP1H PLC was used as the controller to interface with a physical model elevator and its necessary actuators and sensors. All the code was written on the CX Programmer software. Overall, this project went very well and although it was very difficult it was quite enjoyable. A photo of the model elevator and one of our ladder logic function blocks can be seen below. My group partner and I invested a lot of time into this project and in turn produced a near perfectly

functional elevator with no way to break the program. We received an A+ for this which was satisfying.



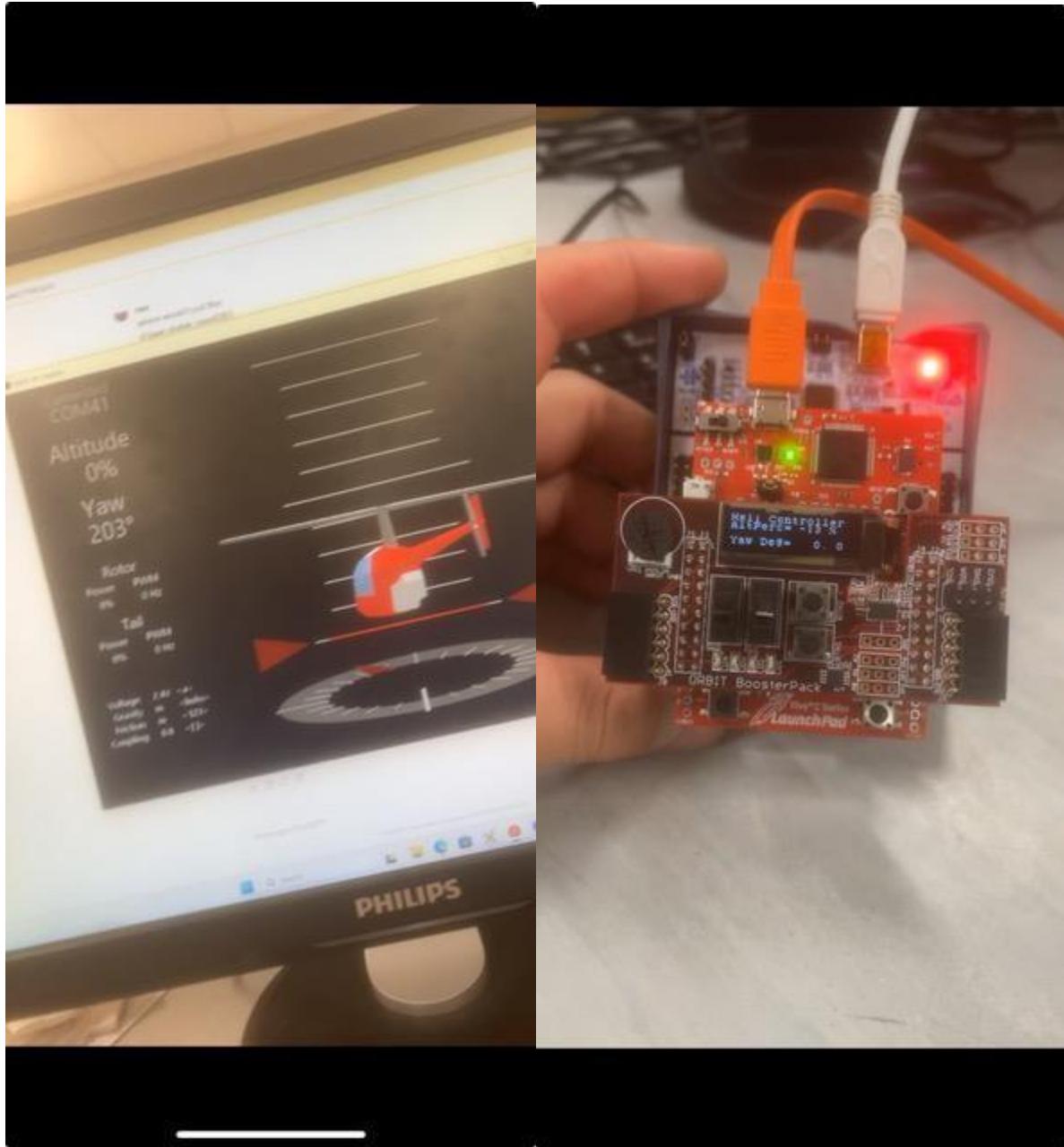
The second important project was a Line Following Robot. This project involved conducting electronic simulation, designing a custom circuit and PCB layout using Kicad, soldering up said PCB, programming an ATmega4808 microcontroller to control the robot, designing mechanical parts in CAD, and finally assembling and testing the robot so that it could follow a line course in the shortest possible time. A photo of our line following robot is shown below.



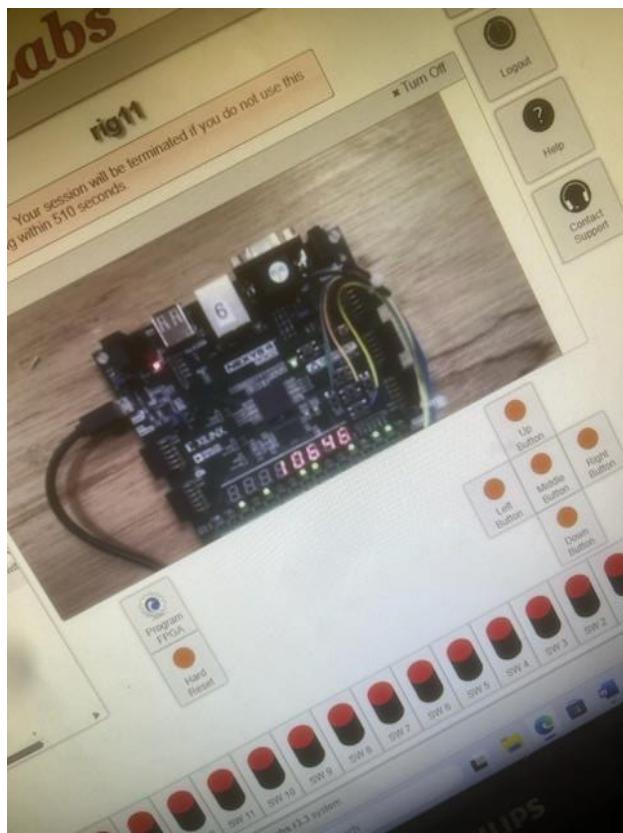
We decided to use our PCB as the chassis for our robot making it incredibly light weight and small. This was a good idea and stood out from the rest of the robots, unfortunately on the race day we had issues with the DC motors so it did not go as well as it could have. Despite this it was still heaps of fun and I learnt lots.

This year a few key projects have been programming a TIVA board to control an RC helicopter, designing and manufacturing an aluminium structure to break at a specified load, designing CMOS logic gates for unique Boolean expressions, using FPGAs to implement a reaction timer, designing a bespoke bearing and clutch system and lastly

Robocup, which involves designing and programming a fully autonomous weight collecting robot. Some photos of these things are shown below.



This project involved implementing a kernel (task scheduler), using interrupts and creating a state machine to control the various flight operations required.



The reaction timer project seen above involved using Vivado and VHDL to program a reaction timer onto an FPGA. The reaction timer needed to have a pseudo-random number generator to stop people from anticipating the start of the timer. In addition, an ALU and memory had to be implemented to calculate the average, max and min reaction times of the last three recorded times which then needed to be displayed. An error message also had to be displayed if the stop button was pressed during the countdown, this all required a complex finite state machine to be implemented.

Another project for this course was to design and analyse a CMOS inverter for a given logic expression. First, we simplified the expression using Boolean algebra operations and then produced an inverter gate with pull-up and pull-down networks to match the truth table of the simplified expression. The network was designed to factor in the lower charge carrier mobility of PMOS devices so that the overall switching times were still symmetric. The final design was implemented and analysed in a program called TINA. A photo of the expression simplification working and the final design are shown below.

$$48958410 | ((\bar{D}) + (D+B)) \cdot ((C \cdot C) \cdot (\bar{A}))$$

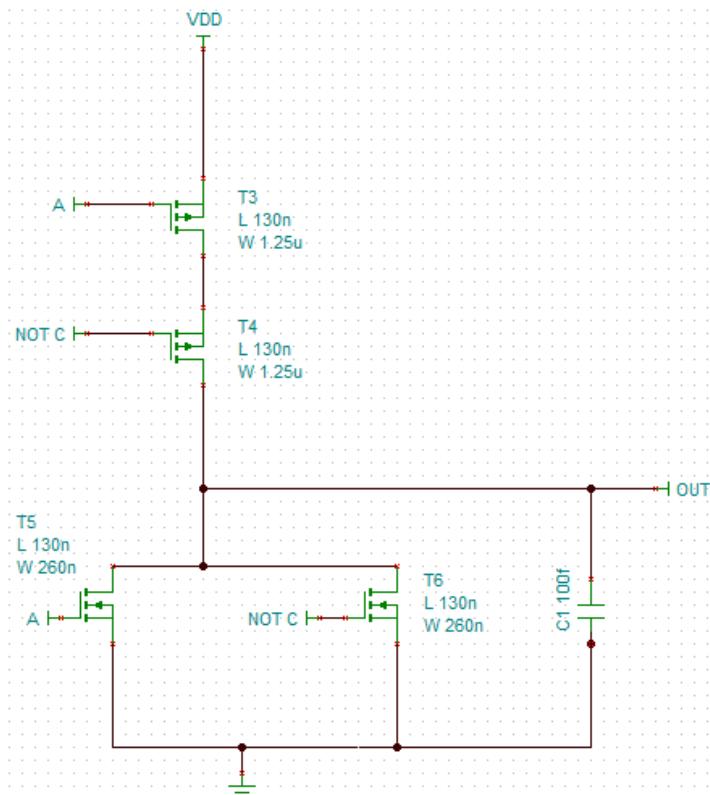
$$\Rightarrow (\bar{D} + (D+B)) \cdot ((C \cdot C) \cdot \bar{A}) \Rightarrow \text{Idempotent Law } C \cdot C = C$$

$$\Rightarrow ((\bar{D} + D) + B) \cdot (C \cdot \bar{A}) \Rightarrow \text{Associative Law } \bar{D} + (D+B) = (\bar{D} + D) + B$$

$$(1 + B) \cdot (C \cdot \bar{A}) \Rightarrow \text{Complement Law } \bar{D} + D = 1$$

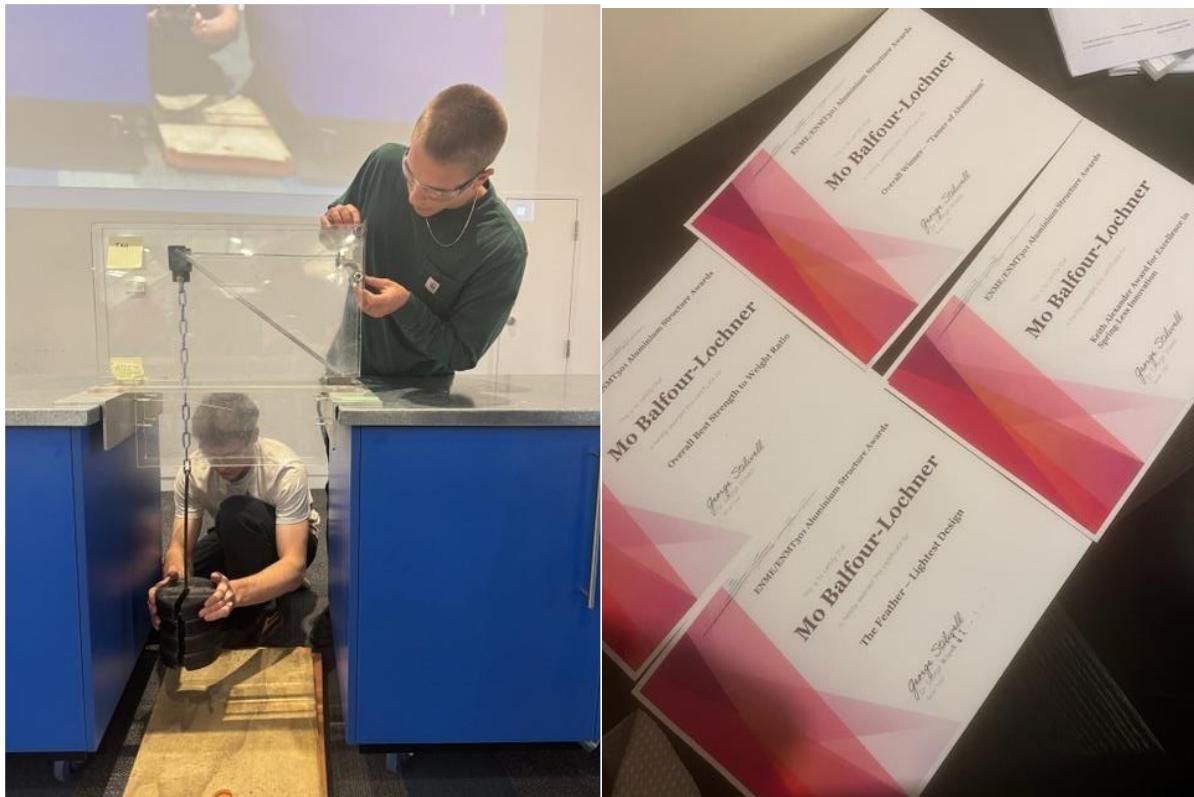
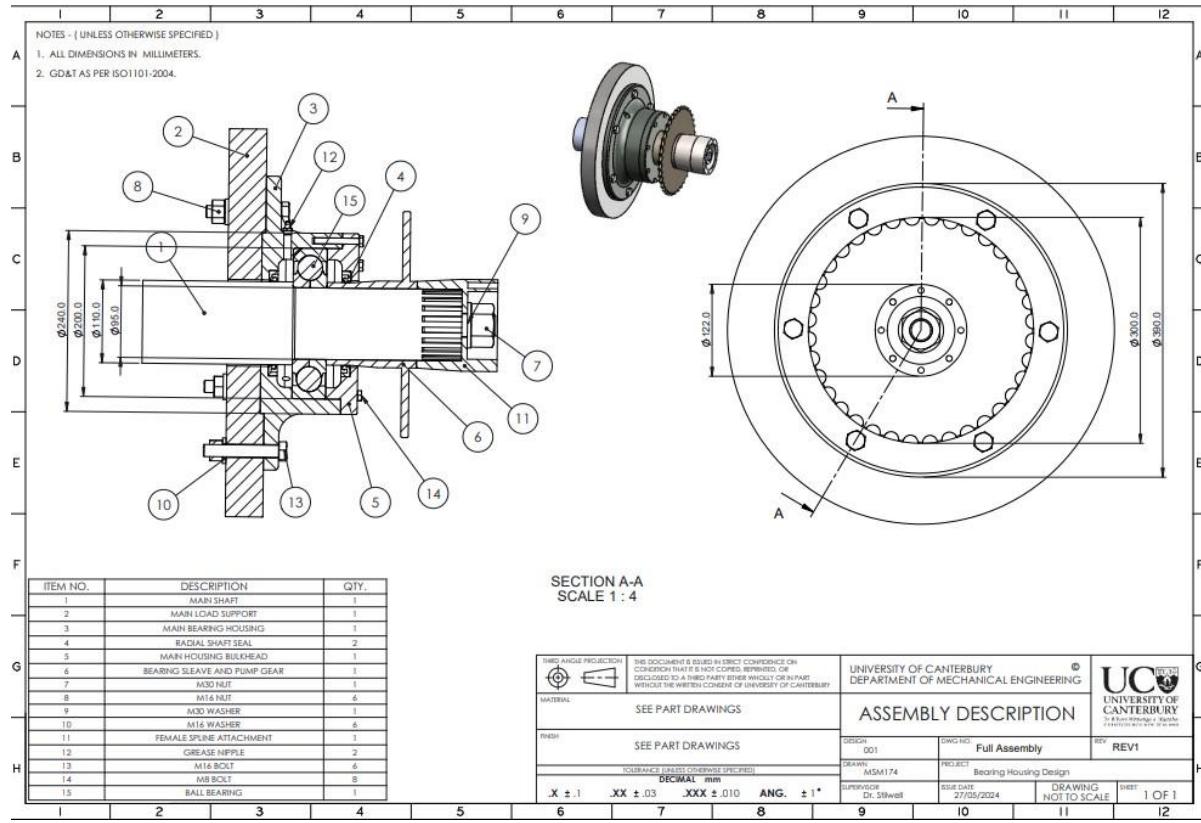
$$1 \cdot (C \cdot \bar{A}) \Rightarrow \text{Null Law } 1 \cdot B = B$$

$$\Rightarrow C \bar{A} \Rightarrow \text{Identity Law } 1 \cdot C = C$$



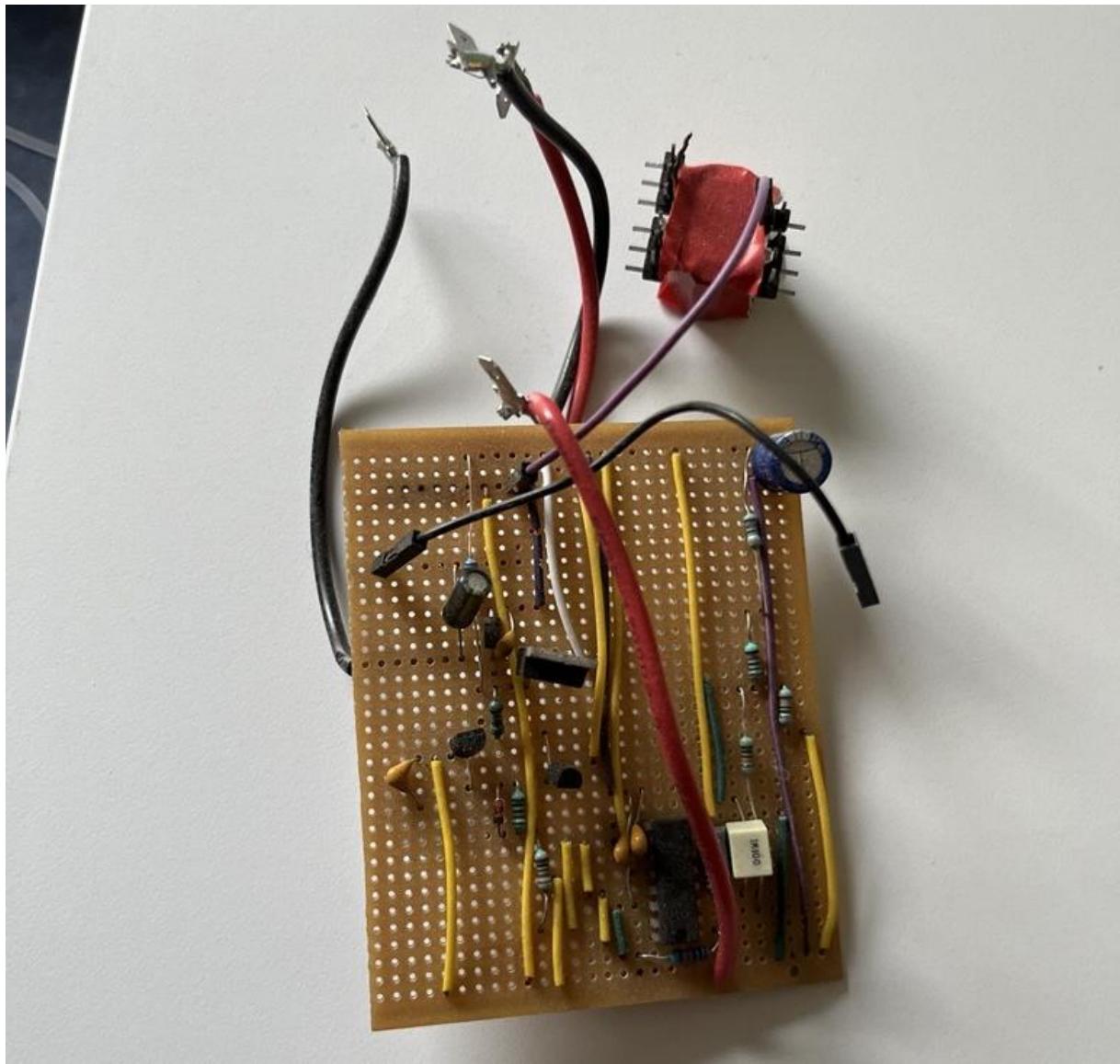
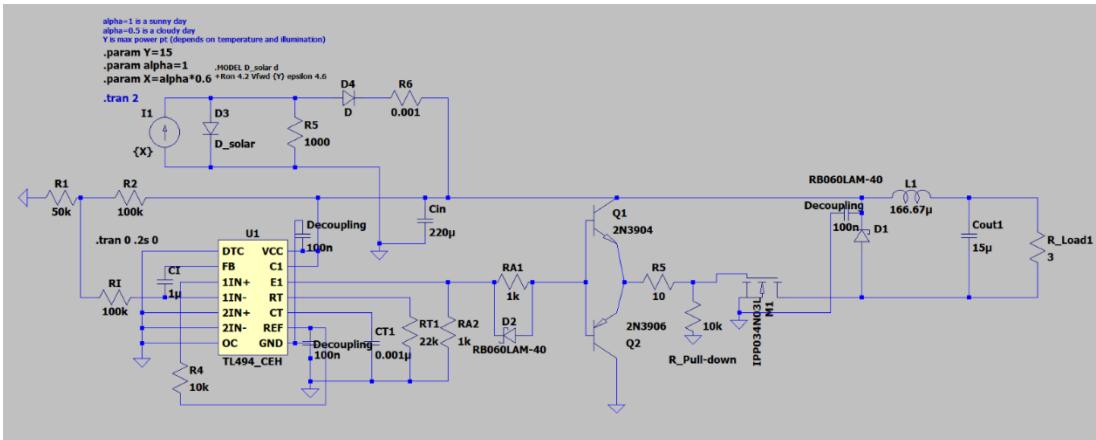
This year we also completed a project in which we had to design a bespoke bearing housing and clutch assembly for an example business venture. This involved carrying out calculations to determine suitable shaft diameters, bearing types, lubrication types and systems, clutch plate materials, number of plates, type of clutch etc. This was an interesting project as it essentially involved going through an entire engineering process from determining the client's needs to providing them with a well-engineered solution. I found this quite cool as it showed us that our growth as engineers and the real-life

applications of what we learnt. A drawing of our bearing housing design can be seen below.



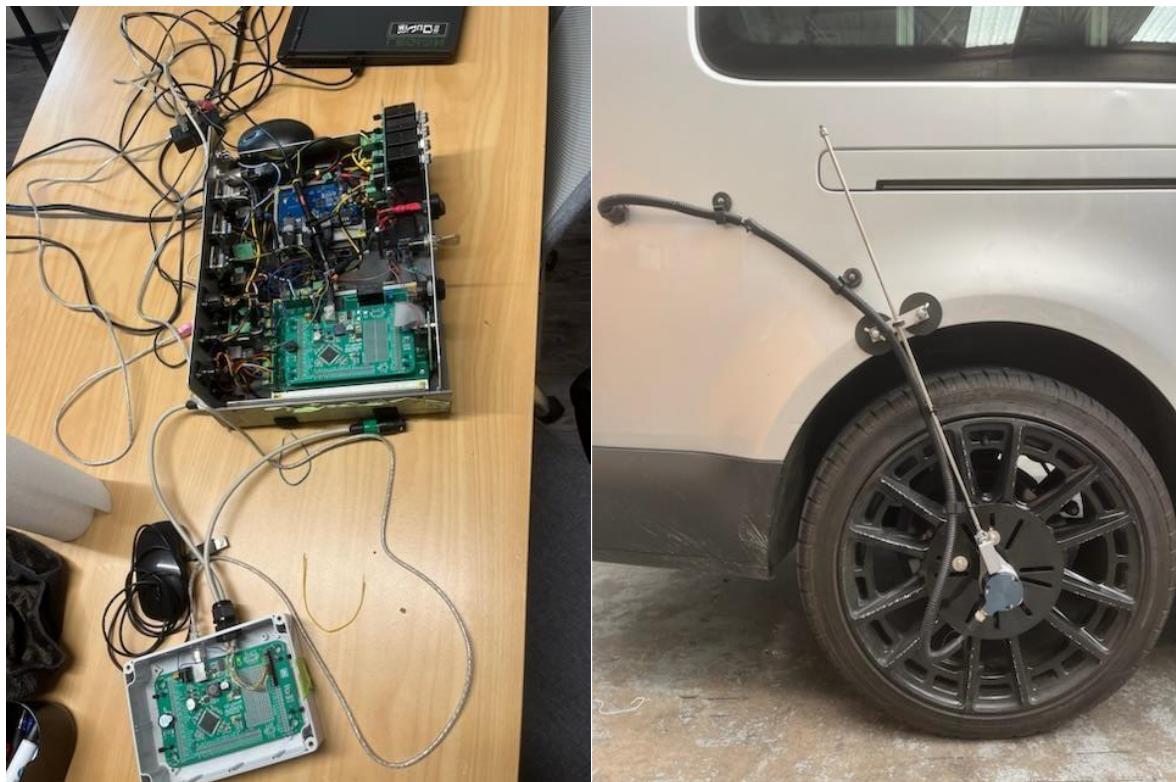
In the aluminium structure project, around 160 teams of two competed to design a structure that had to break at a specified calculated weight between 20 and 39 kg. My partner and I decided to use a 2-member structure to reduce the weight as strength to weight ratio was one of the things points were awarded for. As seen in the photo the structure has 3 pin joints however, the top support is an axially constrained roller bearing which had to remain within  $\pm 3$  mm of the specified dimensions, thus the structure also had to support its self-weight. Going with a 2-member structure made the calculations and analysis significantly harder as the system became very indeterminate. It also meant we had to be much more innovative with our design. I proposed using a rectangular beam for our compressive member made up of two pieces bent at right angles with teeth cut out of them so that they would slot (and glue) together nicely. In the end our design broke at the target weight, which was 36 kg and weighed only 52 g. We were the only successful 2-member structure, the only people to reach the highest strength to weight ratio which was 550+ (ours was 692.3) and therefore the only people to get a perfect score on the project. There were 6 awards given out and we won four of them (the two we didn't win were for the most catastrophic failure and for the heaviest design). Overall, this project was super satisfying as we took an extra risk compared to our peers, put in the extra work and it paid off!

I also completed a cool project in which myself and two others developed the required circuitry for an analogue motor driver. This was used on a small remote-control cart that was powered by a solar panel. The circuit needed to contain a buck converter, a push/pull emitter follower and a closed-loop feedback control system. The inductor required for the buck converter was calculated, designed and made to match the calculations. This circuitry meant that the output current and voltage were adjusted so that the maximum possible power was always seen at the motor – this is essential for operating under varying loads and the motors characteristics. We also learnt how to use LTSpice for design and analysis. A photo of the LTSpice model and the actual circuit are shown below.



Another project I was involved with was during my internship last summer. I was tasked with redesigning the circuitry for one of the daughter boards used in a modular road

surveying system. This involved using Kicad and knowledge of circuit design to restructure the current design and fix a few issues the company was having with the board. I was also tasked with identifying why the high-accuracy odometer, attached to the survey vehicles wheel to trigger data collection, was jittering and then provide a solution to stop this from happening. Finally, I was tasked with setting up an NFS server so that one of the boards used for development could be programmed from any PC in the office without any physical connection between them. This was awesome as the work that I was responsible for had a direct effect on the company and system thus, I could feel like the work I was doing was valuable. A few photos of this are shown below.

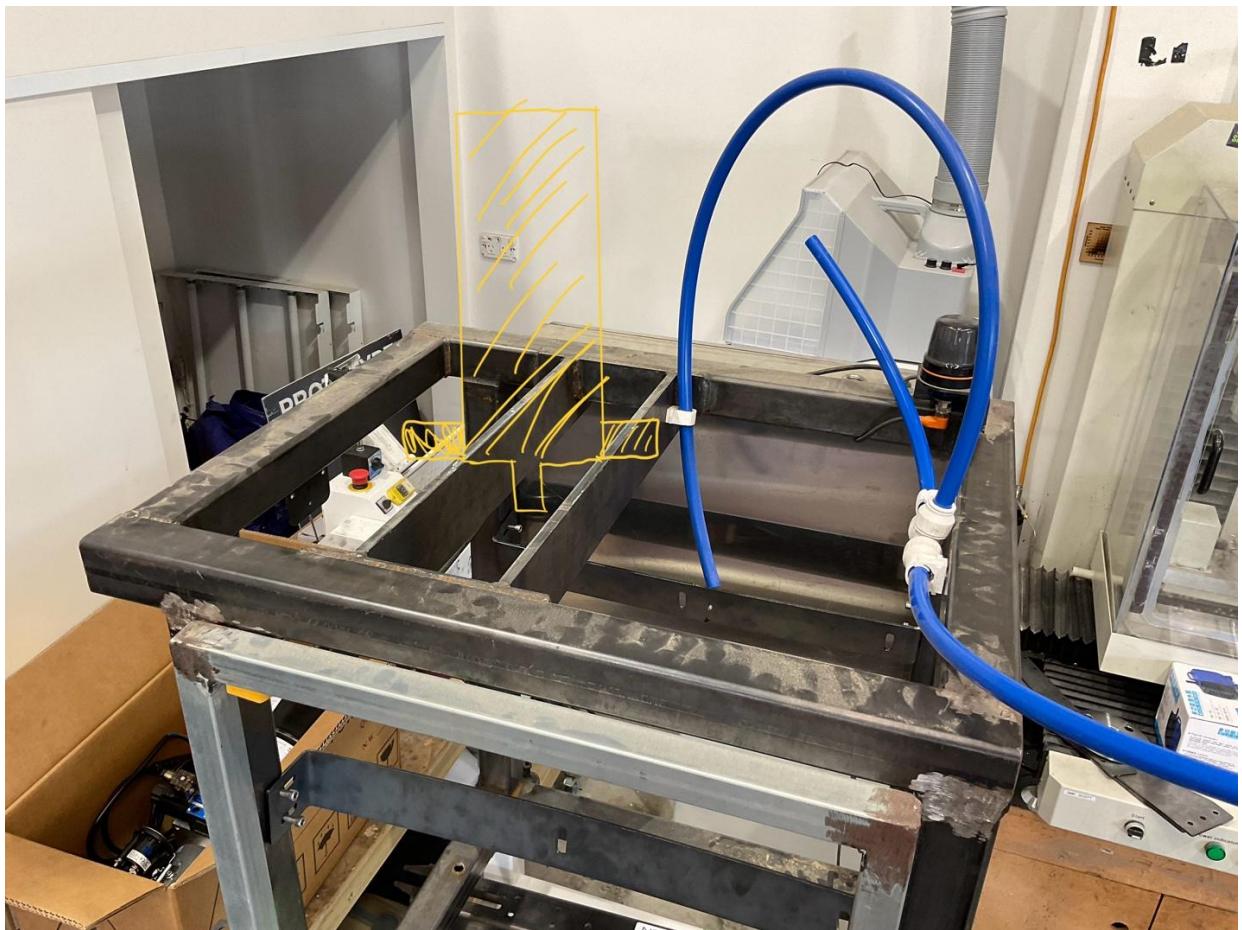


My latest project has been designing and building a small-scale injection molder for my summer internship with SPS Automation.

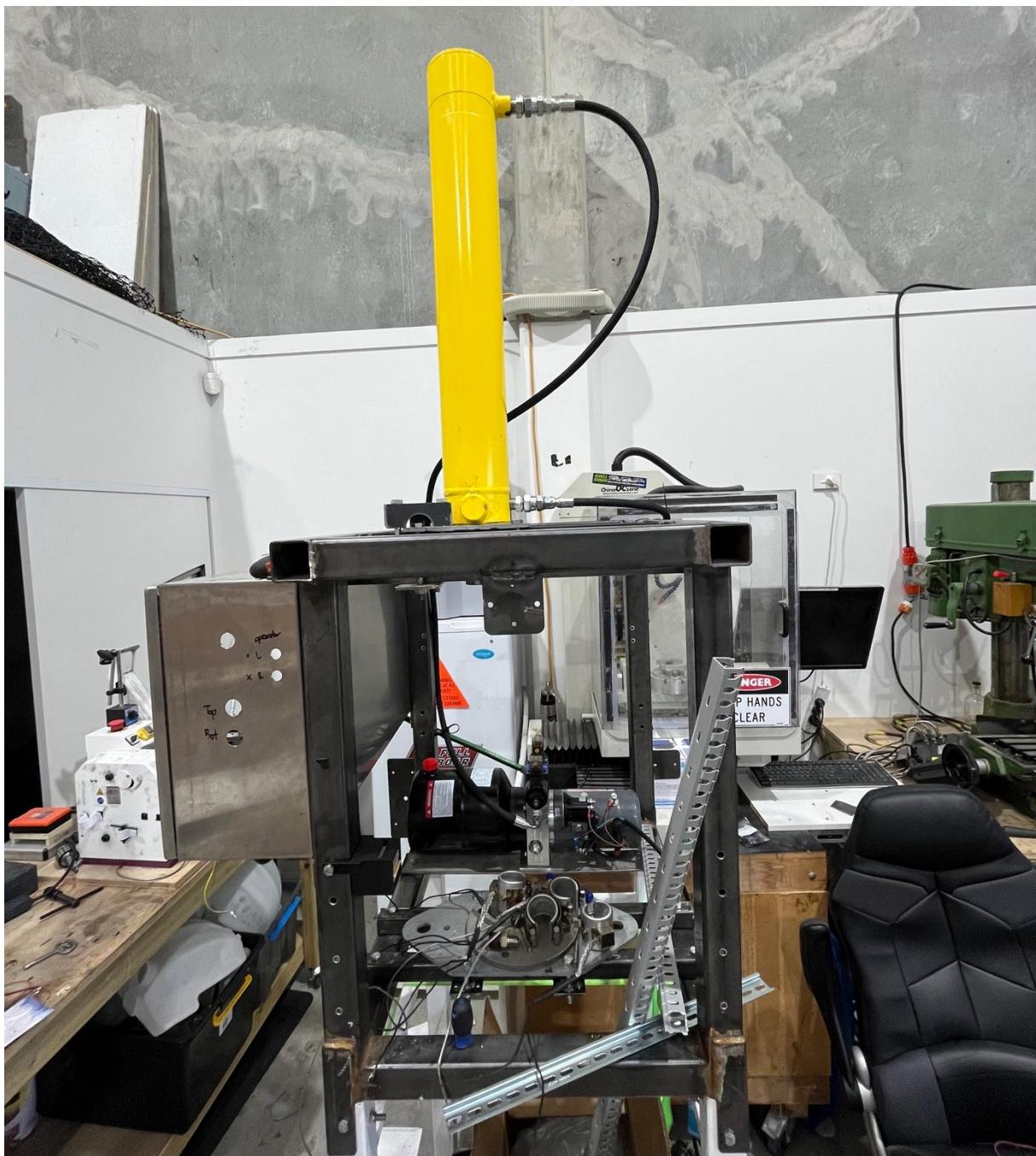
This was completed the summer before my final year of engineering and involved myself and one other intern completing the entire engineering process on our own project. It felt great to have control and freedom in the project over things such as how we wanted the design to work, how much it should cost, when each part of the project should be completed, what sort of (safety) features it should have and how it should be powered. I think getting used to thinking about these things is an invaluable lesson that I have taken from the project. A few photos from the setup are shown below.

As can be seen, the frame was mostly made up of welded steel frame section meaning that I also got to learn how to TIG weld a bit better which was fun.







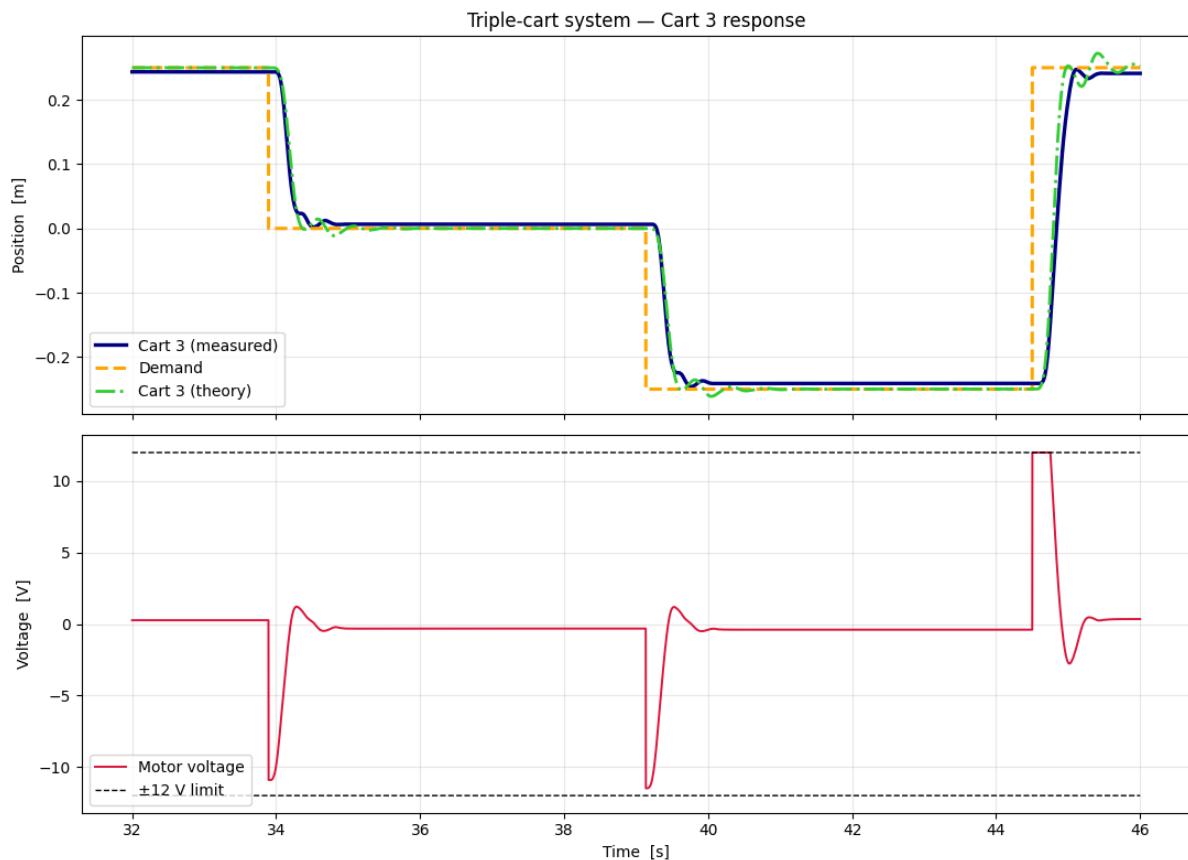
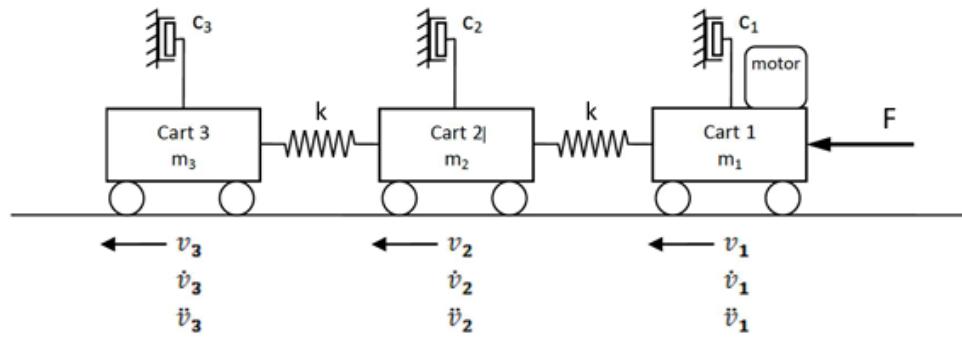
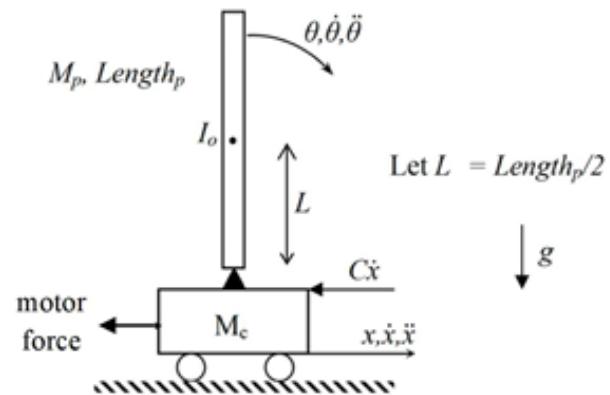


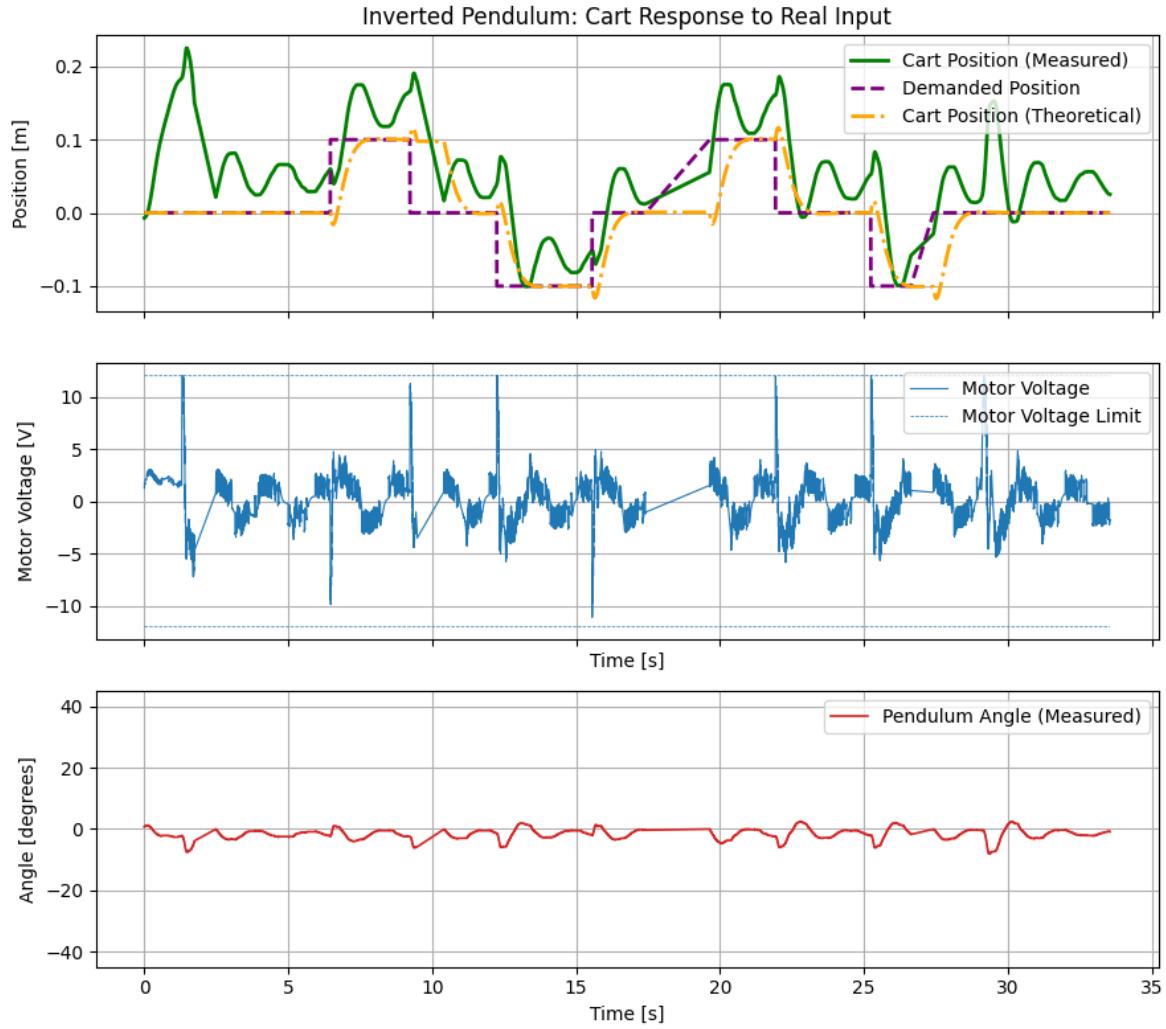


Band heaters were used in combination with a custom machined 316 stainless steel heating chamber. A 316 stainless steel ramrod was also used with a very fine tolerance used on the last 50 mm to ensure it made a good seal with the chamber. A Bucher hydraulic power pack and 20 Ton hydraulic ram were used to get the driving force required to squirt out the molten plastic.

Since my summer internship at SPS Automation I have completed various interesting university projects. The first involved writing python scripts to implement control systems needed to stabilize an inverted pendulum and track and control the motion of a triple cart

SMD system. Diagrams of the physical test systems as well as some plots showing the responses achieved using the linear quadratic regulator (LQR) method are seen below.





In a second project, I created a Neural Attenuation Field (NAF) neural network used for 3D image reconstruction of X-rays. This involved using known geometries from the cone-beam CT (CBCT) scan data to cast rays from the X-ray source through each pixel on the detector plane. The rays were discretized into a sequence of sample points which could then be passed through a positional encoding function. The encoded points are then passed through our network which predicts a scalar attenuation coefficient for each point, the distance between the sampled points as well as the attenuated values were then used to compute the overall attenuation along a given ray using a discretized form of the Beer-Lambert law.

The resulting attenuation values were used to generate a synthetic projection image which could be compared against the true projection image at that point. From this a loss is calculated and used to update the network with standard backpropagation and optimization. This process is repeated until the network has a reasonable output. At this point the network represents a model of attenuation throughout the given 3D volume and can be queried to generate arbitrary slices of the volume. We were tasked with adding an additional more complex feature to the architecture of the network. For this I

attempted to implement multi-headed self-attention (MHSA) with residual connection as well as convolution in two separate models. The images below show an overview of the setup provided in the assignment brief as well as some code snippets and results.

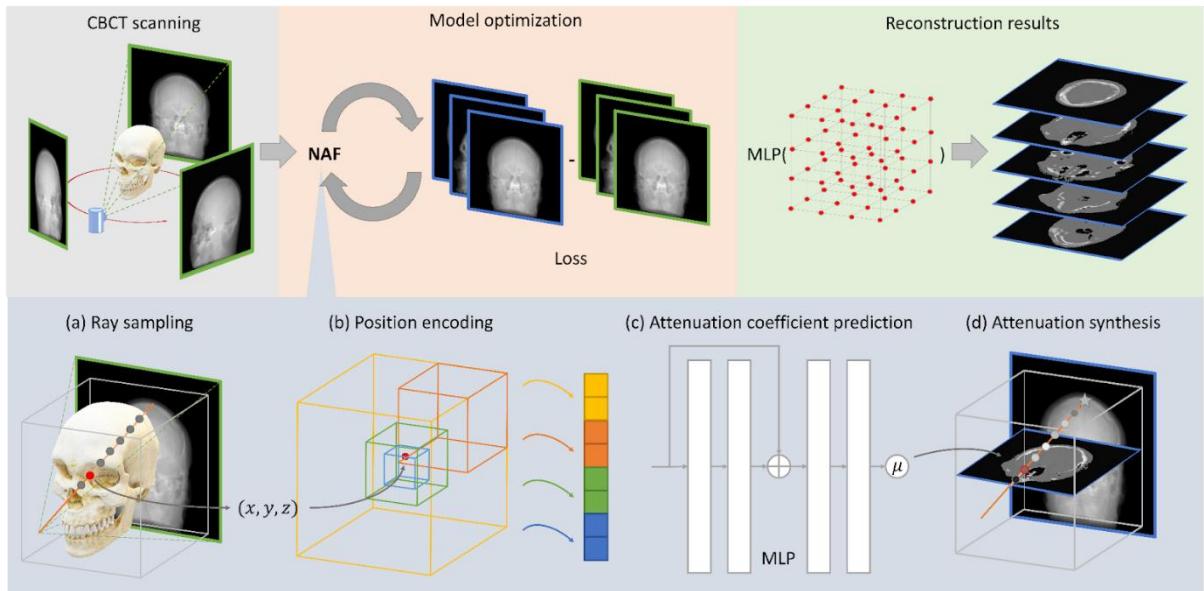


Figure 1: A overview image taken from the project brief credit to COSC440 and Dr. James Atlas.

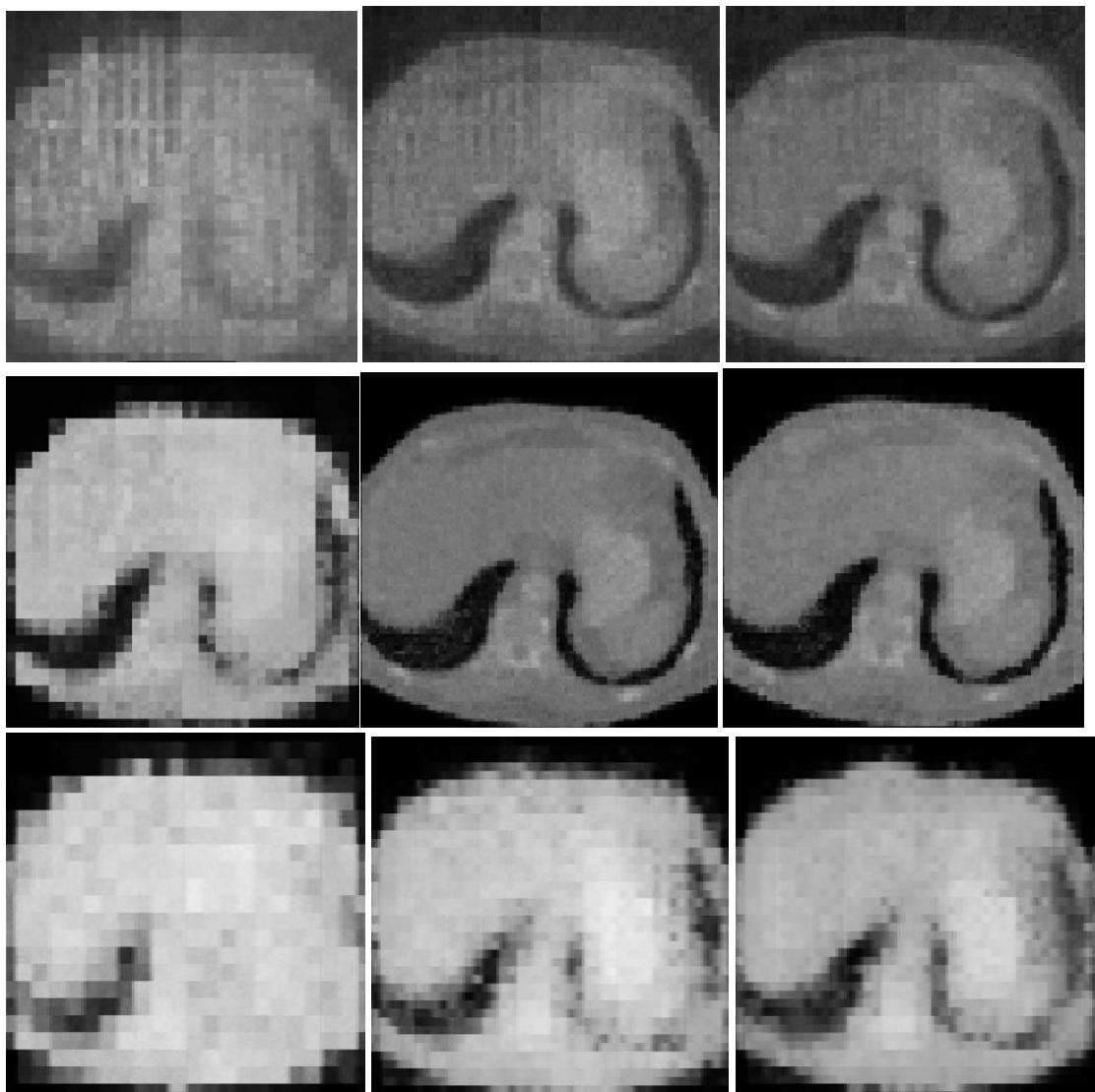


Figure 2: Reconstructions of the chest data set (birds eye view) output by the residual + MHSA modified model (top), the original model (middle), and the convolution modified model at different epochs.

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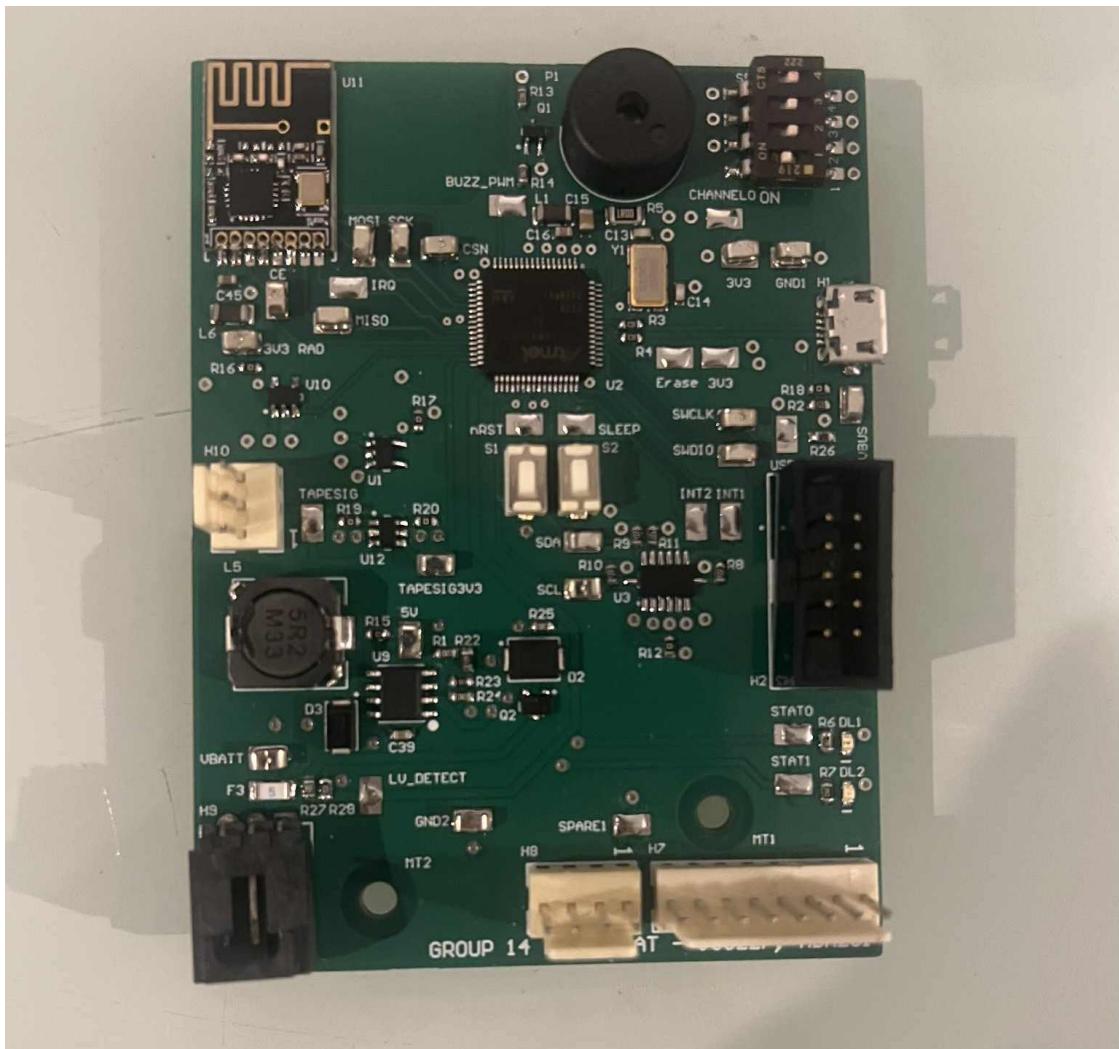
1  import tensorflow as tf
2
3
4  class ResBlock(tf.keras.layers.Layer):
5      def __init__(self, hidden):
6          super().__init__()
7          self.d1 = tf.keras.layers.Dense(hidden, activation="linear")
8          self.act = tf.keras.layers.LeakyReLU(0.2)
9          self.d2 = tf.keras.layers.Dense(hidden, activation="linear")
10
11     def call(self, x):
12         h = self.act(self.d1(x))
13         h = self.d2(h)
14         return x + self.act(h) # residual
15
16
17 class ModelAttnSoft(tf.keras.layers.Layer):
18     def __init__(self, encoder,
19                  hidden=64,
20                  num_blocks=3,
21                  n_points=192):
22         super().__init__()
23         self.encoder = encoder
24         self.n_points = n_points
25         self.hidden = hidden
26
27         self.fc_in = tf.keras.layers.Dense(hidden)
28
29         # attention block
30         self.ln_attn = tf.keras.layers.LayerNormalization(epsilon=1e-5)
31         self.attn = tf.keras.layers.MultiHeadAttention([
32             num_heads=2, key_dim=hidden // 2])
33
34         self.blocks = [ResBlock(hidden) for _ in range(num_blocks)]
35
36
37         self.fc_out = tf.keras.layers.Dense(1, activation=tf.nn.softplus)
38
39     def call(self, pts):
40         """
41         pts: [N, 3]
42         """
43         x = self.encoder(pts)
44         x = self.fc_in(x)
45
46
47         N = tf.shape(x)[0]
48         if tf.math.equal(tf.math.floormod(N, self.n_points), 0):
49             B = N // self.n_points
50             x3 = tf.reshape(x, (B, self.n_points, self.hidden))
51
52             attn_out = self.attn(self.ln_attn(x3), self.ln_attn(x3))
53             x3 = x3 + attn_out
54             x = tf.reshape(x3, (-1, self.hidden))
55
56         for blk in self.blocks:
57             x = blk(x)
58
59         return self.fc_out(x)

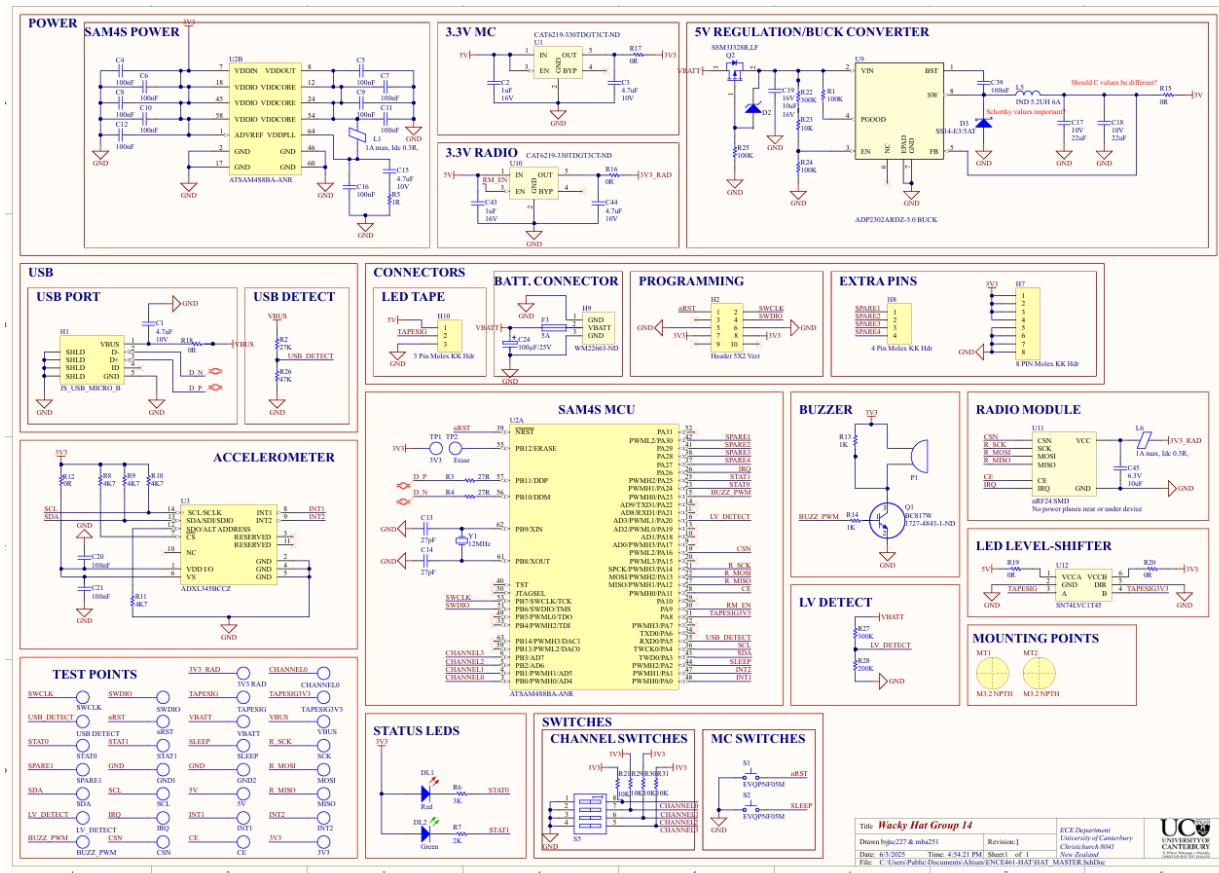
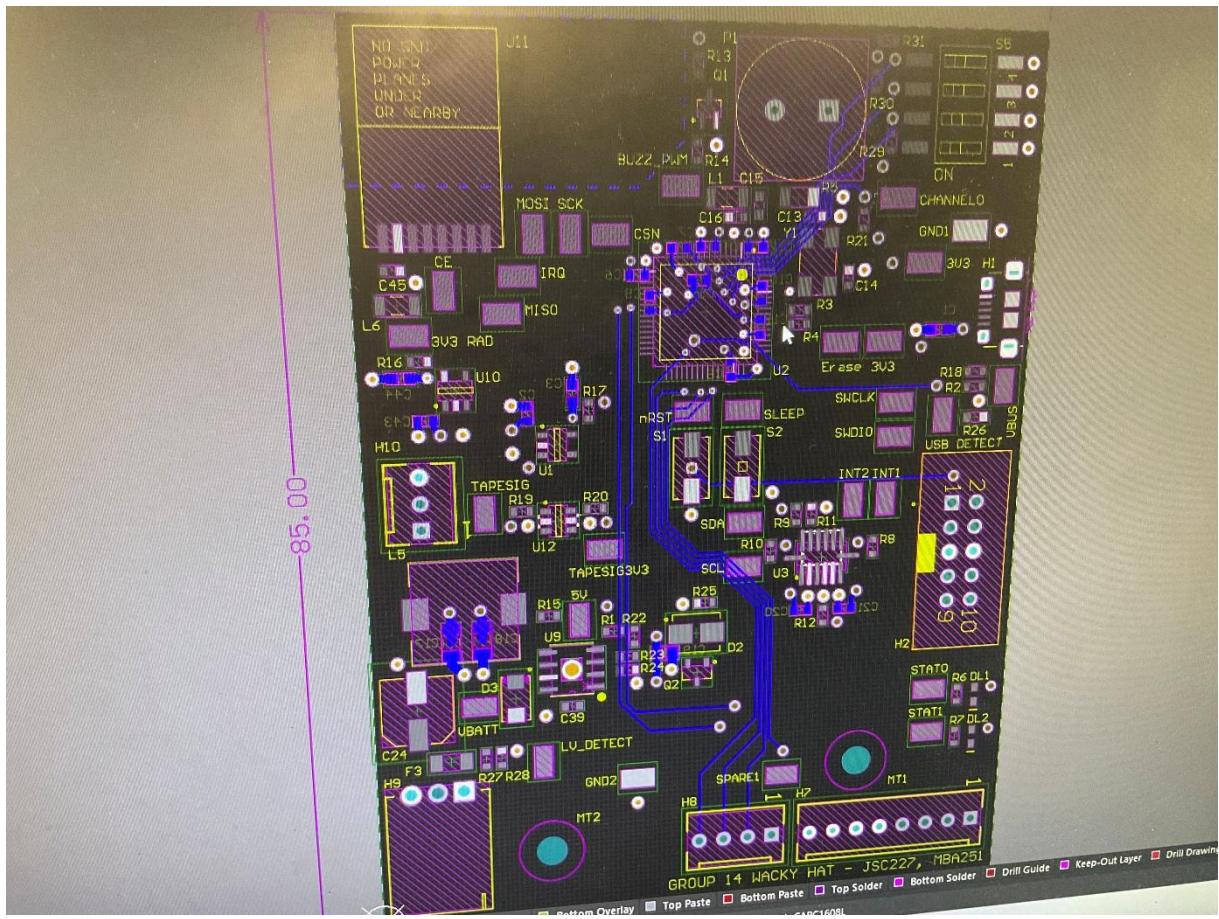
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A third project completed is known as the Wacky Races. In this project groups of four students produce a small scale radio controlled car and a corresponding controller which uses an accelerometer to determine the orientation of the controller and convert this into left and right duty cycles to drive the car in this direction. The controller is mounted to a hat so that the driver must steer with their head. Students are also encouraged to dress up and add “dastardly stuff” to their designs. The groups of four

split into pairs with one pair responsible for the car and one responsible for the hat, I worked on the hat.

The project started with a full design of the PCB schematic and physical layout using Altium. Once received the boards were then assembled using the university pick-and-place machines and oven. The boards then had to be boot-flashed and code was developed for reading the accelerometer data, transmitting duty cycles via radio and many other little things such as playing interesting noises from a buzzer on the hat when a bumper on the car is hit. Below are some photos of our hat PCB and schematic as well as my team on race day and me driving the car.







My latest and greatest project has been my final year project which I am completing on the University of Canterbury Motorsport (UCM) team. My role in the team this year is on the powertrain sub-team. I am responsible for the complete design and manufacture of our power transmission from motors to wheels. This includes gears, gearbox assembly and uprights (housing), motor mounting, spindle (interface to wheel). Some of the things I have been doing for this are:

- Research into gear theory
- Track days where we test on 2024's car, maintenance of the 2024 gearbox e.g. disassembly to ensure parts are still ok, oil changes etc.
- Writing python scripts for; determining valid gear configurations, optimal gear ratio (based on simulation of acceleration event at competition), gear analysis to check all parameters of gearbox design are suitable e.g. adequate backlash, centre distance spacing of planets for correct meshing, required profile shifts to ensure no undercutting of teeth.
- Manufacture of gears – this is done using an EDM wire-cut machine. 2024 was the first year that we produced our gears this way and it took around 3 months as the workshop staff were not trained on how to use the machine. This year I taught myself to use the machine and got permission to operate it myself allowing me to complete the gears in under two weeks. I also figured out how to directly import DXF's into the machine increasing the freedom of design as I can use the exact tooth profile that I designed whereas in 2024 they used an embedded gear generating tool on the machine which is less capable and does not allow for fine tuning of as many parameters.

- Analysis of gear pairs and overall gearbox using KISSsoft and KISSsys to determine FOS's, lifetime, forces on selected bearings, failure modes etc (includes dynamic simulation of geartrain).
- CAD models of gears, uprights, spindles, full assembly as well as engineering drawings for manufacture and sponsorship enquiries.
- Sponsorship requests and organisation of manufacture and processing e.g. heat treatment, material orders. I secured a fully sponsorship for isotropic finishing of the gears which should improve their lifetime significantly.
- Discussions with members of industry about technical design factors e.g. titanium 3D printing, gear material selection.
- Investigation of forces and load cases around rear uprights.
- Topology optimisation of titanium 3D printed uprights using nTop (software). As well as all the necessary post-processing to produce a valid, printable CAD part.

I am incredibly stoked on this project and love the feeling of working in a team with an overall goal in mind and deadlines to meet (although they are stressful!). Due to this I have been set on making the most out of my time working on the project from the beginning. This means I have been taking any opportunity I can to learn or do more and be involved. Some of the things I've done include:

- Helping with the chassis manufacture by priming and sanding plugs, helping with composites e.g. doing infusions as well as wet lays for the carbon fibre chassis.
- Getting involved in any extra-curricular club activities I can e.g. attending SouthMach, Two Rivers Motoring Extravaganza, E-Velocity and club information events.
- Setting up a minute taking system and taking minutes for all UCM full team and powertrain meetings as previously there was none.
- I will be designing and manufacturing the gearbox for UCM2026 later this year once 2025's is completed. This is atypical and is only happening because I am very keen to do it. It is also essential as the car is going to be four-wheel drive next year meaning six full gear sets will need to be produced (four plus two spare sets), the front upright (which will now have to house gearboxes) will need to be redesigned and optimised to allow room for the steering, and we will be advancing to an entirely different gearbox design which removes the need for a spindle and interfaces directly with custom carbon fibre wheels. There would not be enough time to go ahead with these changes if it is not started this year.

Below are some photos of the things mentioned above.



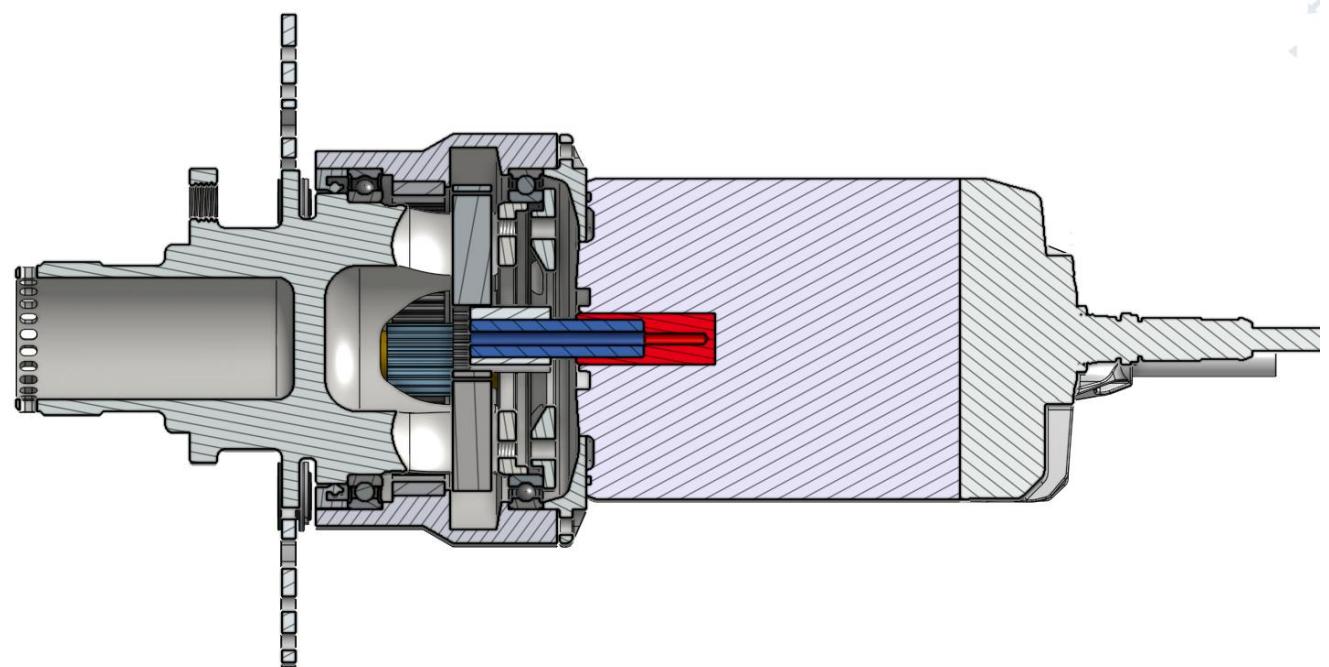
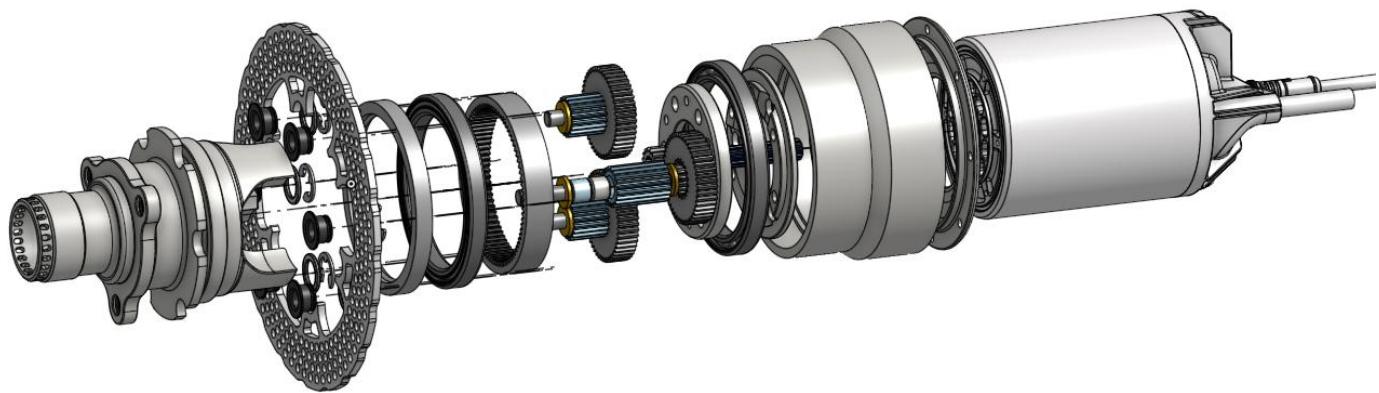
A photo of UCM24's spare ring gear that has been superfinished (isotropic finishing) and has since had a StealthCoat (TM) (Tungsten Disulphide) coating added to it. A process that I was able to get as a sponsorship deal for all UCM25's gears.

Research Papers

OneDrive > Mo - University of Canterbury > Courses > UCM > Research Papers

	Name	Status	Date modified	Type	Size
> Apps	18CrNiMo76_Mat_Datasheet	✓	4/10/2025 9:28 AM	Microsoft Edge P...	58 KB
> Attachments	18CrNiMo76_Mat_Datasheet_2	✓	4/10/2025 9:30 AM	Microsoft Edge P...	142 KB
> Courses	Design and analysis of compound steppe...	✓	3/22/2025 6:44 PM	Microsoft Edge P...	3,061 KB
> Kicad	ENG-18CrNiMo7-6_Datasheet	✓	4/10/2025 9:32 AM	Microsoft Edge P...	170 KB
> LFR Group_14	gears_vol1	✓	4/18/2025 11:23 PM	Microsoft Edge P...	29,855 KB
> Microsoft Cop	gears_vol2	✓	4/18/2025 10:47 AM	Microsoft Edge P...	28,428 KB
> PD_imported	JMD-PlanetAsmb-1998 (1)	✓	3/22/2025 11:31 AM	Microsoft Edge P...	498 KB
> Robocup_Chai	Master_Thesis_Design_of_a_Compound_...	✓	3/22/2025 6:48 PM	Microsoft Edge P...	9,546 KB
> Solidworks	MJH_Gearbox_Technical-Report	Cloud	3/20/2025 12:24 PM	Microsoft Edge P...	6,131 KB
Mo - University	NTNU Gearbox	✓	4/9/2025 10:58 AM	Microsoft Edge P...	59,818 KB
Apps	Sejoe14_profilerendeprojekt (1)	✓	3/20/2025 12:25 PM	Microsoft Edge P...	1,546 KB
Attachments	Sensitivity_of_General_Compound_Plane...	✓	3/22/2025 5:30 PM	Microsoft Edge P...	361 KB
Documents - l	Structured_Vibration_Modes_of_General...	✓	3/22/2025 7:30 PM	Microsoft Edge P...	648 KB
Microsoft Tear					

A screenshot showing a small collection of the research papers that I have used during my research and design.



*Exploded and section views of gearbox assembly.*

Gear_Config_from_paper - using Sejoe simplif.py												
	Zs	Zr	Zps	Zpr	module_sp1	module_p2r	A1	A2	ratio	Min	Assembly	Diameter
0	15	75	41	19		1		1	46	6	11.789	97.0
1	15	81	43	23		1		1	48	4	11.096	101.0
2	15	87	47	25		1		1	52	4	11.904	109.0
3	16	79	43	20		1		1	34	13	11.616	102.0
4	16	85	47	22		1		1	21	21	12.349	110.0
5	16	86	47	23		1		1	21	21	11.984	110.0
6	16	88	47	25		1		1	21	21	11.340	110.0
7	16	89	47	26		1		1	21	21	11.055	110.0
8	17	79	43	19		1		1	63	1	11.517	103.0
9	17	80	44	19		1		1	35	14	11.898	105.0
10	17	82	46	19		1		1	67	2	12.678	109.0
11	17	85	46	22		1		1	44	10	11.455	109.0

Required profile shift for z teeth: 0.01663318189490332

Computed center distances:

Zr: 82.000 mm

a\_sun\_planet: 31.500 mm

a\_planet\_ring: 31.500 mm

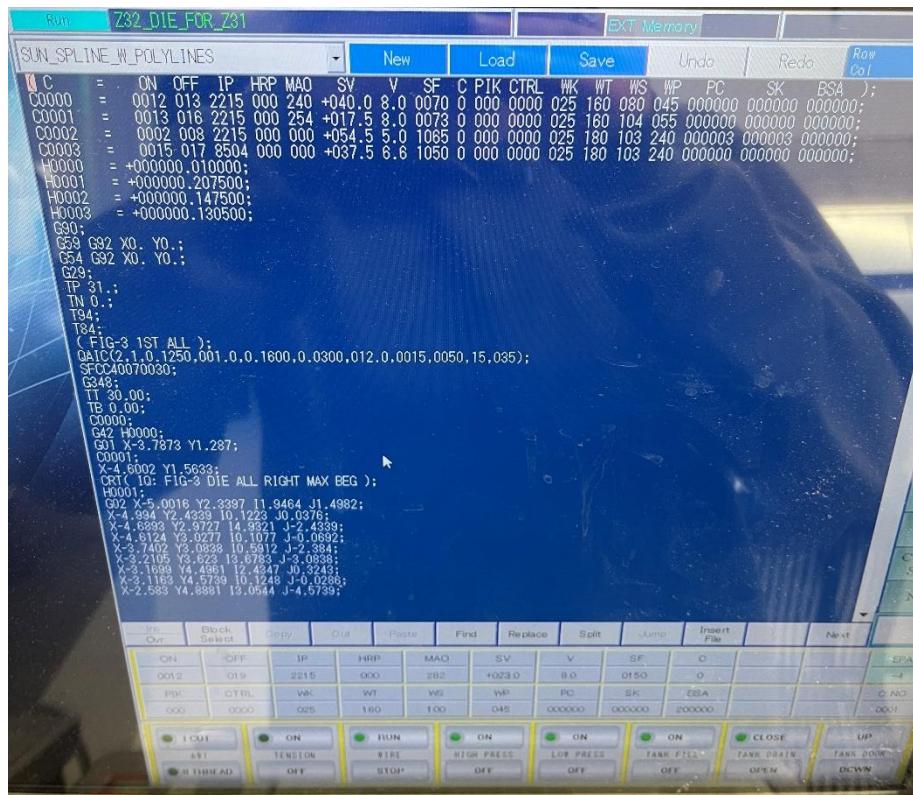
a\_total: 31.500 mm

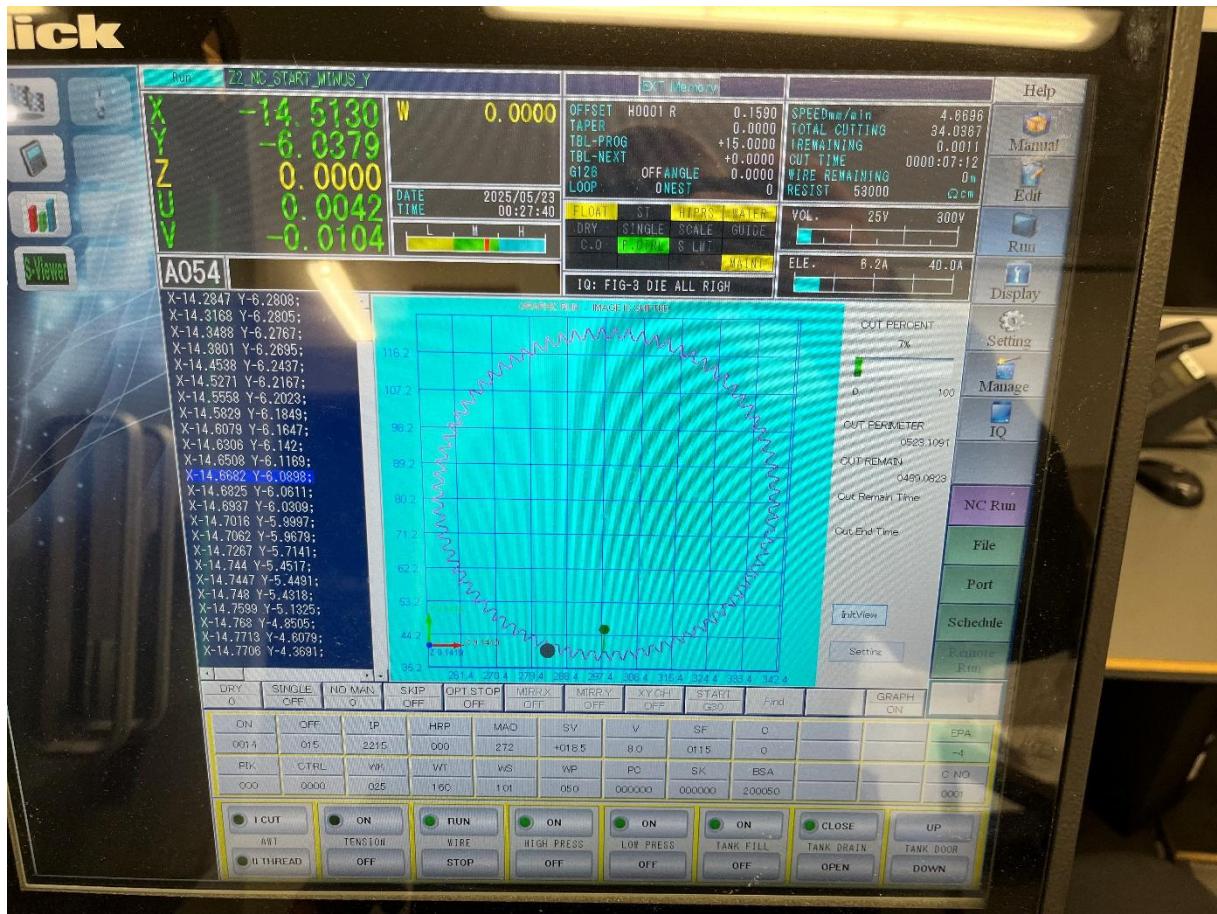
*Screenshots showing the output of my configuration finding script and my UCM codes folder with the files inside it, these files include an acceleration sim of the car to determine optimal gear ratio, a code that applies mathematical constraints found during my research that ensure valid configurations of numbers of teeth and modules etc. as well as a full gear analysis program for analysing gear pairs, their parameters and their interfacing.*





*Photos showing some of the small planet gears that I cut (top) using the wire cut machine pictured (middle) and a photo (bottom) showing this year's test stepped-planet compound planetary gear set (foreground) and 2024's test set.*

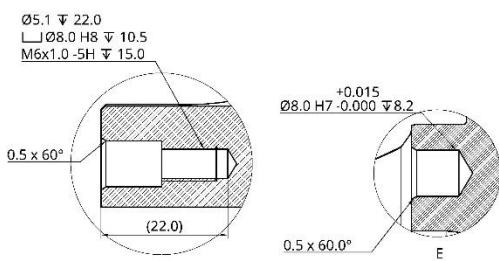
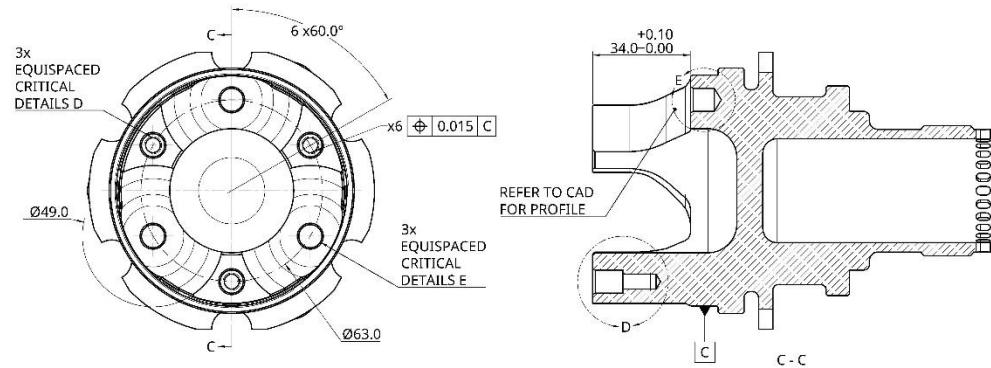




Some photos of machining paths and the corresponding G-Code I generated from my imported gear models to drive the wire cut machine as well as a photo of one of my stock pieces in the machine.



Photos of me suited up when preparing the plugs that are used for making the chassis molds (left) and a finished layup of the bulkhead ready for infusion (right).



QUANTITY: 2

<b>UCM</b> DRAFT	NAME: _____	SIGNATURE: _____	DATE: _____
RE-DRILL ALL SHARP RIBGES AND REMOVE BURRS APPROVED	IN: _____	IN: _____	IN: _____
MATERIAL: ALUMINUM - 7075	DESIGN: _____	TEST: _____	REAR SPINDLE
PRODUCTION: _____	TOOLING: _____	IN: _____	IN: _____
X ± 0.5	X.X ± 0.1	X.XX ± 0.05	ANG. ± 0.5°

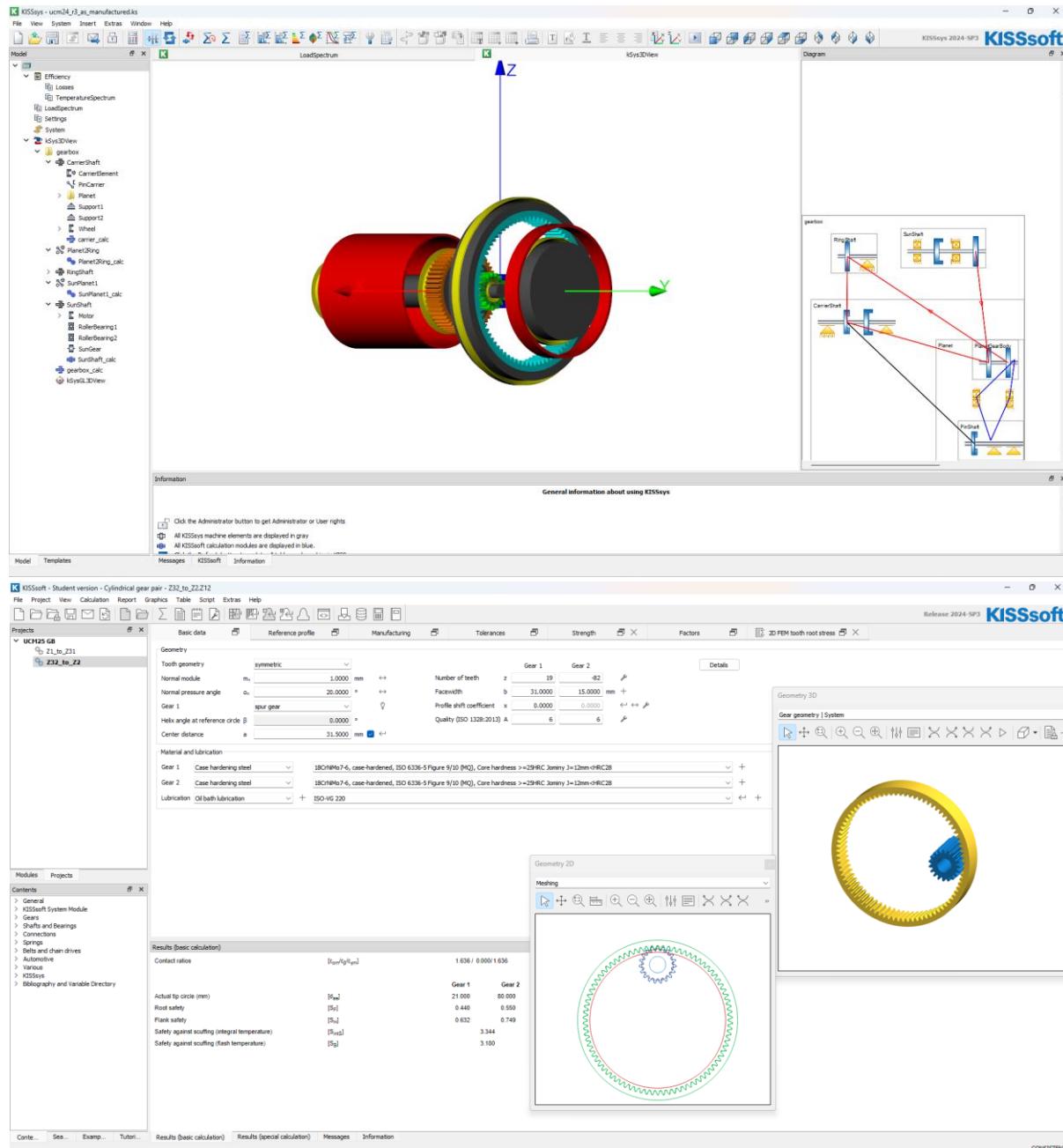
CONTACT DETAILS  
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02041647490

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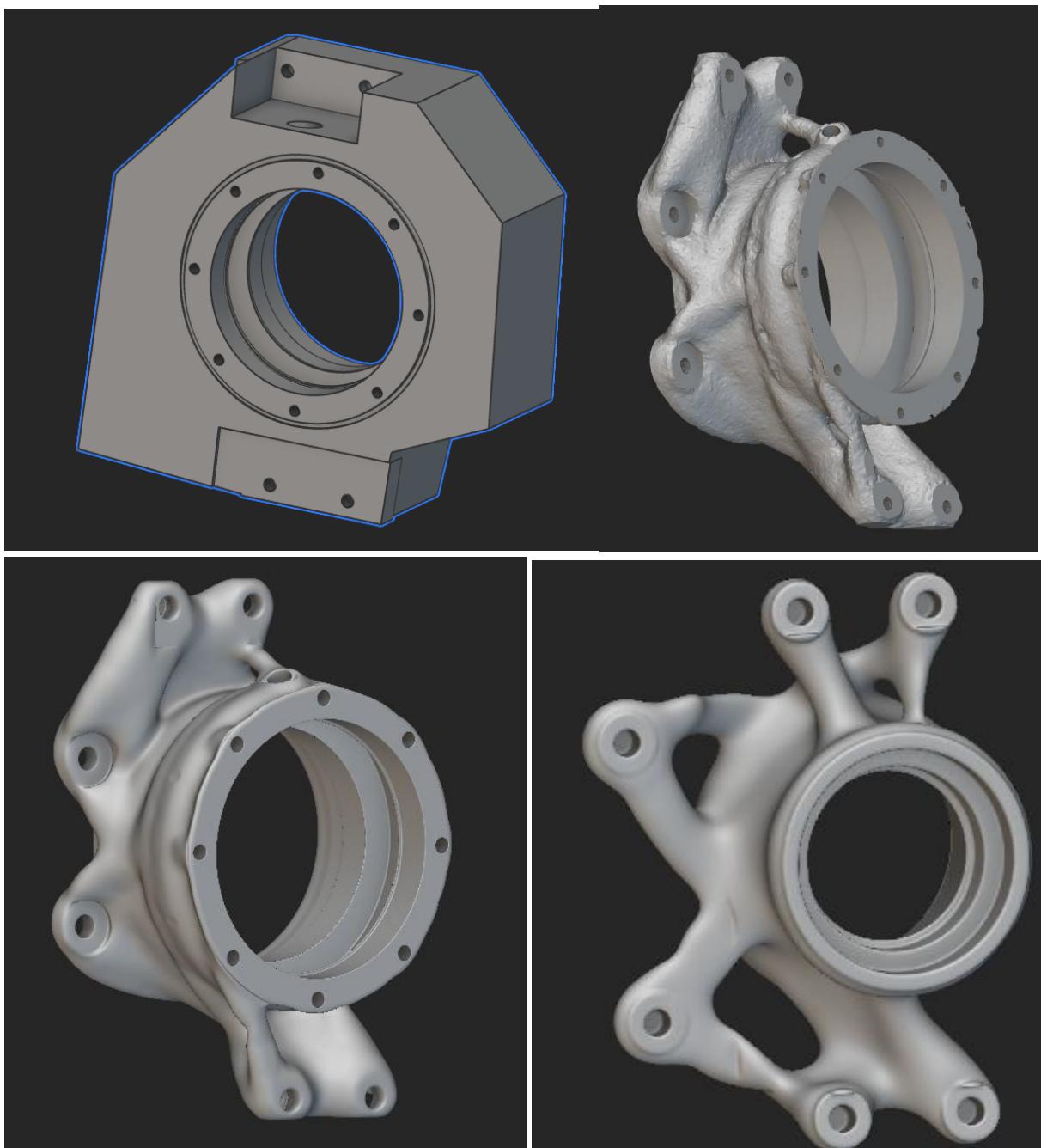
Photos showing a drawing I produced for the rear spindle followed by the finished physical product.



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Photos showing the KISSsys model of the entire stepped-planet compound planetary gearbox used for analysis of the gears and geartrain (top), a photo showing the ring to small planet gear pair model setup in KISSsoft – this is used for configuring the many gear parameters and running analyses (middle), a photo of the table of contents from the 64 page report that is generated for each gear pair using KISSsoft and details everything there is to know about them.



Some screenshots showing the models at various steps within nTop (the software I have been using for topology optimization and static FEA). Top left is the initial input model, top right is the topology optimization result, bottom left is the result once some initial clean-up has been applied, bottom right is a rough topology optimization on the front upright I ran as I have been assisting with their design.



*Some screenshots showing the topology optimised part once it has been exported from nTop as a .step file, imported to our CAD software (Onshape) and further refined.*

A personal project I'm excited to begin—likely toward the end of 2025—is developing my own mobile app. I'm really keen to teach myself the skills needed for app development, both because I find it interesting and because I know how useful those skills may be in

the long term. More importantly, I'm driven by the goal of creating an effective, free, and highly accessible way for people to learn languages. One of my long-standing goals has been to become proficient in Te Reo Māori, but I've never found a modern, widely available tool that supports this well—so I'd like to build one. I also want the app to support other languages, including German, which I'm continuing to improve myself. I've already started outlining the key features and design requirements, though I'll keep the details private for now. If we get the chance, feel free to ask me about it—I'd love to share more!