# ENGINEERING PORTFOLIO

## F1 IN SCHOOLS™ WORLD FINALS

AUSTIN, TX 2016

INFINITUDE

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## OUR OUTLINE

At Infinitude, we believe that organisation is a key factor in success. From the development of the design, virtual to physical it is integral. Before work commenced on the design of the car, we devised an engineering blueprint. This was established to ensure consistent development and ensure we were efficient, logical, and focused on the job at hand. The blueprint also expanded how we collaborated with industry professionals, as we could demonstrate our intentions and timeframe clearly without scheduling clashes. We were commended from all of our collaborators on our organisational skills, and our logical approach as it led towards a smoother, bigger, and better development path.

PROJECT BLUEPRINT

F1 IN SCHOOLS™ WORLD FINALS 2016

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INFINITUDE

## LERS SCHEDULE

The Launch Energy Recovery System (LERS) used at the 2015 F1 in Schools world finals provided a winning edge for teams during racing. Knowing that LERS would be equally important in 2016, we devised a LERS development schedule that would ensure the design and manufacture of the LERS would satisfy our engineering goals. This schedule aligned the design of the LERS with the design of the car so they two were designed in parallel. This integration ensured the system would provide the maximum benefit.

## ENGINEERING PANEL

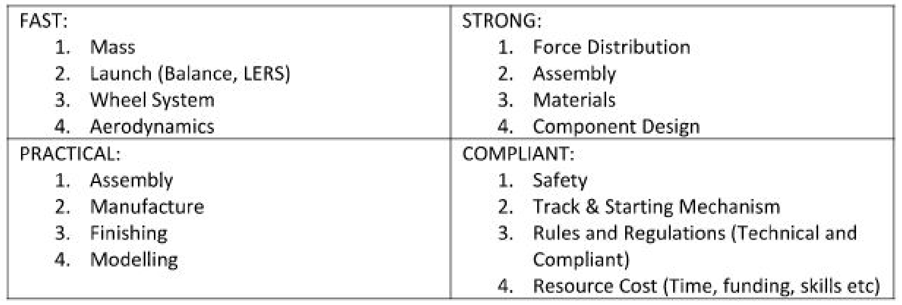
The experienced engineers assisting our engineering division has provided a strong supportive environment while developing our car. Coming from a school with a history of teams competing in F1 in Schools at a high level allows us to build upon the work of past teams. Working with Michelle Lennon, a third-year engineering student, we examined how this resource could be used most effectively. We created a panel of previous F1 in Schools™ competitors to provide feedback on our mechanical setup, the research and theories used, and the skills we had developed. The panel would also helped us to better understand the regulations clarification. The support from this panel helped guide our project and ensure we were using our resources, especially time, as effectively as possible.

## AERODYNAMIC SCHEDULE

As part of the project blueprint, we devised a schedule to track the development of the team's aerodynamic package. We developed this schedule in collaboration with Dr. Richard Smith, founder of Symscape, an advanced CFD technologies company. Working with Dr Smith, we learned of different ways we could test the aerodynamic performance of the car by reducing the variability of our current tests, as well as using new CFD programs.. One of these programs was CAEDIUM, an advanced CFD package. CAEDIUM allowed us to analyse the aerodynamics of the car in a dynamic fashion, modelling aspects of the race such as rotating wheels and gas release from the canister.

## CAR OBJECTIVE CRITERIA

We designed our F1 in Schools™ car with a very simple objective: to gain points for the team. We identified that we would gain points for the car's race speed, regulation compliance and engineering merit. Collaborating with Spencer Olds, a third year Aerospace Engineering student, we developed these areas into an evaluation sheet to use as a comparative tool between our components and prototypes. These criteria was developed around the four major areas that contribute to our car's performance: energy efficiency, structural integrity, practicality, and compliance. After parts were designed and tested, they were again evaluated against these criteria to examine their improving the car's performance. This method ensured there was no bias or mistake when selecting the best-performing design. The method also allowed us to quickly evaluate over 350 CAD designs to find the most effective design for the world finals.



| | |
|---|---|
| FAST:<br>1. Mass<br>2. Launch (Balance, LERS)<br>3. Wheel System<br>4. Aerodynamics | STRONG:<br>1. Force Distribution<br>2. Assembly<br>3. Materials<br>4. Component Design |
| PRACTICAL:<br>1. Assembly<br>2. Manufacture<br>3. Finishing<br>4. Modelling | COMPLIANT:<br>1. Safety<br>2. Track & Starting Mechanism<br>3. Rules and Regulations (Technical and Compliant)<br>4. Resource Cost (Time, funding, skills etc) |

## ENGINEERING GANTT CHART

A key component of our blueprint was the engineering Gantt chart. The Gantt chart was created to ensure we were meeting deadlines for our project elements. The Gantt chart allowed us to easily view deadlines for every element of the design process. The chart also helped us stay focused on the end goal, as it allowed us to efficiently start an appropriate next task when we had completed the previous one.

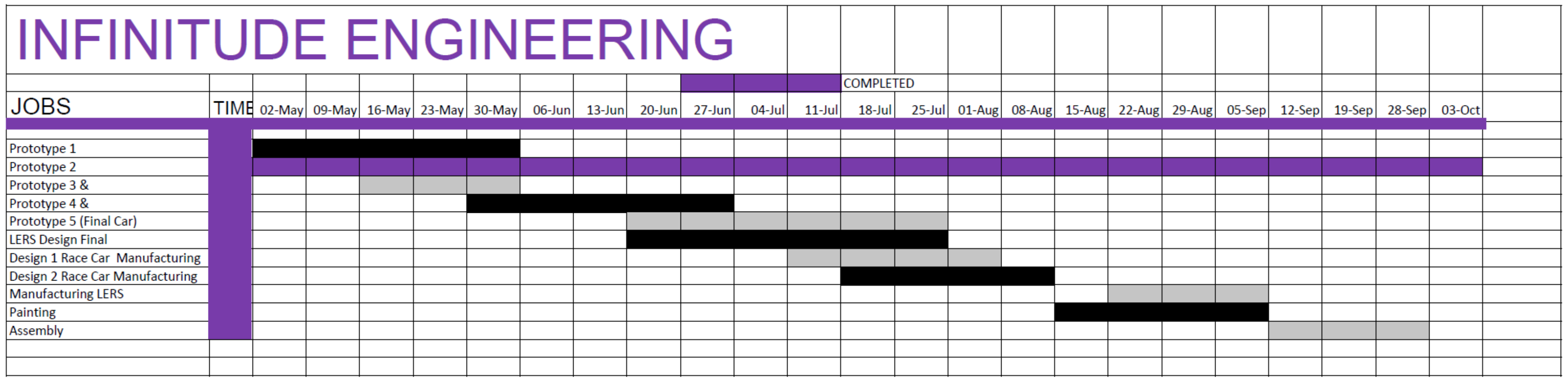
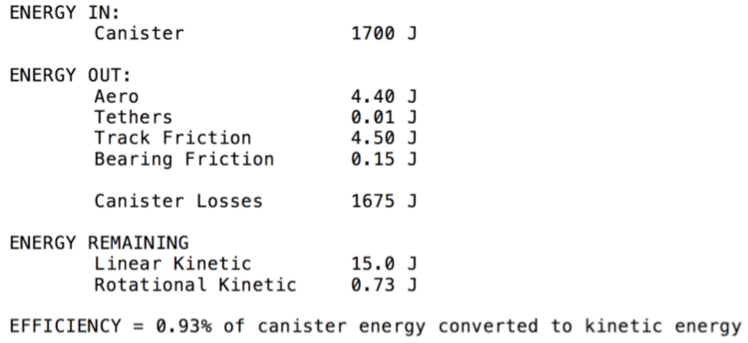


FIGURE 1: ENGINEERING GANTT CHART

# CANISTER EFFICIENCY

Following evaluation of our national final campaigns, we decided to look into the overall energy available for our vehicle during racing. The more of this limited energy we can use, the more efficient and faster our car will be. We believe F1 in Schools™ racing is now based on the efficiency of both car and LERS, so we investigated the energy exchange that occurs both during racing and at launch. We conducted energy calculations and found the pressurised CO2 in the canister contains 1700 Joules of potential energy. Conservation of energy states that this energy can not be created or destroyed, but can be converted into different forms, such as kinetic energy, or lost as frictional heating. Of particular interest was the linear kinetic energy of the car, which determines its speed along the track. Using data from the car design and previous testing, we found that of the 1700 J of energy in the canister, only 15 J is converted into linear kinetic energy. Working with Spencer Olds, a third year aerospace engineering student, we learned how to evaluate the energy lost due to aerodynamic drag on the vehicle. For a drag force of 0.115N, we calculated the energy lost by our car's aerodynamic drag would be 4.4J. With wheel system, tether and track friction amounting to another 4.6 J, this left 1675 J of energy lost during launch. This gave an efficiency rating of 0.93%, and so we undertook research into how we could make this process more efficient and harness more energy.

FIGURE 2: WORLD FINAL CAR SHOWING WEIGHT DISTRIBUTION FOCAL POINTS



```
ENERGY IN:
        Canister                1700 J

ENERGY OUT:
        Aero                    4.40 J
        Tethers                 0.01 J
        Track Friction          4.50 J
        Bearing Friction        0.15 J

        Canister Losses         1675 J

ENERGY REMAINING
        Linear Kinetic          15.0 J
        Rotational Kinetic      0.73 J

EFFICIENCY = 0.93% of canister energy converted to kinetic energy
```

FIGURE 3: ENERGY LOSSES BREAKDOWN

# THE DIVE PRINCIPAL

FIGURE 2: FIRST FRAME AFTER CANISTER PUNCTURE

FIGURE 2: FRAME OF CANISTER AT HEIGHT PEAK

To identify the biggest sources of energy loss during the launch, we examined testing conducted by the 2006 F1 in Schools™ World Champions. They conducted slow-motion filming of their car at launch, and showed that the rear of the car lifts during launch, causing the car to 'dive'. The diving effect occurs when the tipping moment exerted by the canister force exceeds the moment required to raise the rear wheels. The dive principle plays a large part in the canister efficiency, as it determines how efficiently the canister force is applied along the direction of the car's motion. In addition, the lifting of the rear of the car increases friction on the rear tether guide. Further evaluation led us to conduct our own research into how to reduce the magnitude of the dive. After extensive research, we found that the closer the centre of the canister force is to the centre of mass, the less tipping moment the canister provides and hence the lower the magnitude of the dive. After this had been established, we looked into ways we could design our body to raise the centre of mass.

?

DID YOU KNOW...

Over 99% of energy is lost at launch? Less than 1% of the total energy available converts into kinetic energy to propel the car.

# INERTIA

When a force is applied to an object, it experiences an acceleration. The resistance to this acceleration can be quantified as inertia. This inertia applied both to linear acceleration, where it is knows as mass, and to rotational motion. While reducing the mass of the car is a well known principle, we saw further potential for reducing the car's rotational inertia. Working with Peter Brown from SMR Automotive, we looked into ways we could reduce the rotational resistance of our wheel system. Working together, it was discovered that the two main resistances were the bearing friction and mass of the wheels. Through collaboration with Boca Bearings, we had access to very low friction full ceramic bearings. Using these bearings allowed us to reduce the rolling resistance and therefore the energy lost during the race. Working with Lyle Sutton, Maths Co-Ordinator, SACE Board SA, we learnt that moving mass further away from the centreline of rotation increases the rotational inertia. This research lead to our current wheel and axle system, which has both low friction and minimal rotational inertia.

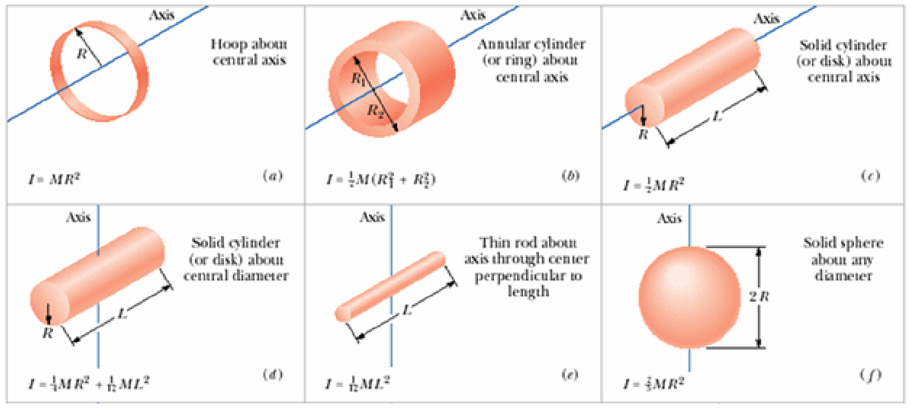


FIGURE 4: ROTATIONAL INERTIA OF DIFFERENT OBJECTS

# REACTION RACING

With over 110 points available in reaction racing, it is vital to the team's success that the driver has the best reaction time possible. Despite this, we felt that insufficient research had been undertaken by previous teams into how to improve reaction times. Initial research indicated that reflex and reaction time is mostly genetic, but can be improved through nutrition and training. We decided to research energy supplements. And found that the best three available energy supplements were Red Bull, GFuel and Powerade. After close inspection to ensure compliance with the competition regulations, we conducted testing on these three supplements. . Our testing showed GFuel as the best performer, as Red Bull had the effect of making the driver prone to false starts. GFuel also didn't cause negative physiological effects after the racing.

FIGURE 5: DRINKS COMPARISON

# 04

# CAR DEVELOPMENTS

## THUNDER

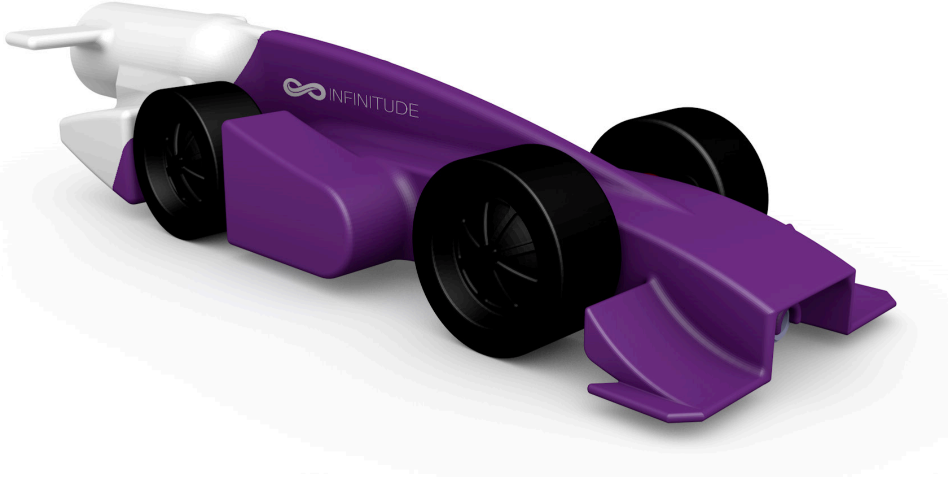
The Infinitude-WC-01 is based on the Negative Filter national competition car. The mechanical setup was the first design to include mass reduction pockets, which are still present on our final design. Another concept from this car that was carried through to the final design is the aeroskirt. The aeroskirt reduces the air escaping from the centre channel, therefore reducing the drag force. The mechanical setup features exposed suspension geometry, reducing the time needed to service the car.

**EVALUATION**

Although developed from a national championship car, the design had major structural integrity issues both in assembly and racing. The suspension geometry was a weak point of the design, as it created a large amount of contact friction with both the axle and the track. These issues, along with the fact that this design was created for outdated regulations, caused us to develop a new concept design.

**STATISTICS**

**Drag Coefficient:** 0.29
**Frontal Area:** 2183.447mm$^2$
**Drag Force:** 0.155 N/15.02 g
**Criteria:** 108/160 (67.5%)
**LERS Efficiency:** 3.6%



## FUSION

The Infinitude-WC-02 was the first concept to explore the freedom granted by the world regulations. The design featured an innovative wheel and axle system, designed to reduce the rotational inertia of the system. The system was designed to be self-aligning, to make the assembly of the car both easy and accurate. The canister efficiency system is a proven concept that was first used on this design. The system works by pressurising the canister gas in the chamber before the car is released. This system was designed to work efficiently with the launch systems designed alongside this prototype. This was our first design to achieve our target race time of below one second.

**EVALUATION**

Manufacture revealed that accurately machining the chassis was a major issue for this design; 42 machining angles were required to produce the physical geometry. The suspension geometry, although basic in design, was difficult to assemble, particularly with regards to aligning the bearings. Due to these technical and practical issues, this development path was not followed.

**STATISTICS**

**Drag Coefficient:** 0.36
**Frontal Area:** 1982.667mm$^2$
**Drag Force:** 0.162 N/16.51 g
**Criteria:** 97/160 (60.6%)
**LERS Efficiency:** 19.2%

## TYPHOON

Following research into concepts from the Eurofighter Typhoon, the Infinitude-WC-03 was developed. The mechanical setup featured an innovative yet proven catamaran design. The catamaran design allowed for better canister efficiency, as we could better position the mass to reduce the dive moment. This concept also sparked the development of the aeroduct. The aeroduct allowed us to reduce the drag created by the front wheel, as we could reduce the amount of air that broke laminar flow.

**EVALUATION**

Although a very solid mechanical setup, problems with the component alignment along with structural integrity issues meant that this design was unable to reach its potential. Compliance was also an issue as we struggled to ensure specification compliance. This made our LERS non-compliant and caused inefficiency.

**STATISTICS**

**Drag Coefficient:** 0.32
**Frontal Area:** 1822.49mm$^2$
**Drag Force:** 0.144 N/14.68 g
**Criteria:** 108/160 (67.5%)
**LERS Efficiency:** 21.3%

## BLACKBIRD

The Infinitude-WC-04 was the final prototype car developed by Infinitude. We decided to continue following using the catamaran design. Taking inspiration from the Williams FWC08, we designed an innovative double canister housing shape designed to smooth the fluid flow over the rear wing. Another innovative concept from this design was a new independant suspension geometry, which allowed us to maximise the benefit of the catamaran shape.

**EVALUATION**

Building on the prototype three concepts, we were able to achieve a balanced and effective design. The aerodynamic performance of the design is very close to our initial design goals, with the design creating less than 10 grams of force. Our independent wheel system also significantly reduced the rotational inertia of the wheel system, allowing for a faster and more efficient launch. This design was structurally very strong, but its incompatibility with the LERS reduced the potential efficiency of the canister.

**STATISTICS**

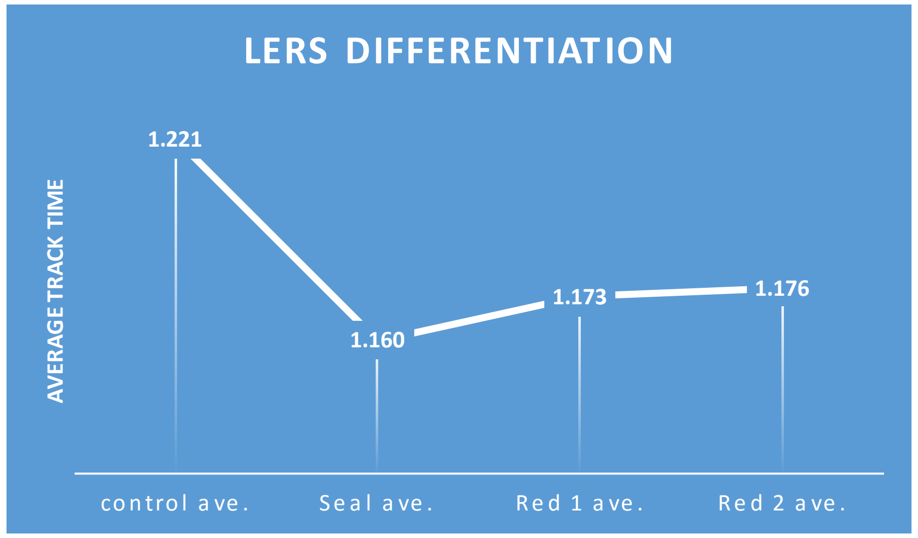
**Drag Coefficient:** 0.27
**Frontal Area:** 1707mm$^2$
**Drag Force:** 0.098 N/9.99 g
**Criteria:** 125/160 (78.1%)
**LERS Efficiency:** 6.25%

To minimise their race time, all car designs aim to minimise the energy lost from being converted into speed during the race, and maximise the energy gained from the canister. In a standard launch, 99% of the energy from the canister is lost, so any system to recapture this has the potential to dramatically increase our car's efficiency and speed.
In a standard launch, a large amount energy from the canister is lost, so any system to recapture this has the potential to dramatically increase our car's efficiency and speed.

## LAUNCH ENERGY RECOVERY

The LERS is a launch pod device that was first used in the 2015 World Finals, designed either to redirect the $CO_2$ released or temporarily contain the pressure. During the lead-up to the 2016 National Finals we experimented with a redirection-style LERS that lead to a decrease in race time of 0.03 seconds. During racing, we noted that that the launch mechanism recoiled in reaction to the $CO_2$, due to Newton's Laws of Motion. As theoretically determined and verified by race testing, a heavier LERS solved this problem and reduced the race time by a further 0.01 seconds. This LERS was successfully used at the 2016 National Finals. However, due to a regulation change we were unable to maintain our heavy LERS for the world competition.

We also experimented with vortex generators as a LERS modification, small fins that intentionally disturb the airflow. This created a 'funnel' of disturbed air, channelling a straight flow of $CO_2$ towards the car, rather than dispersing. Unfortunately the efficiency loss caused by obstructing the $CO_2$ flow overcame the benefit of the straighter flow, and the vortex generators were not used in our National Competition LERS.



## NOZZLE

The nozzle is launch device concept that attaches to the car, rather than the launch pod. It creates a temporary seal between the car and lers during launch, but also serves to direct and focus the $CO_2$ flow during the race. The nozzle works with a launch pod device to improve the performance gain from the seal. In this system, the shape of the nozzle is crucial design factor. The external surface of the nozzle was designed to be fixed at a contract diameter, so it could effectively interface with the launch pod device. However, internal interface between the nozzle and the firing pin caused issues in the early design phase. The small clearance between the solid plastic nozzle and the firing pin, required to create a pressure seal, created a large amount of friction during launch. To address this, the clearance was increased and the seal was instead created by a rubber o-ring.

Any nozzle design must also allow the $CO_2$ canister to be freely inserted and removed. We originally designed complex mechanisms to partially remove the rear wing structure but found that there were too many components, and the mechanism would not be strong enough to withstand the launch forces. To address these issues, we created two alternatives:

1. The first required the entire rear wing structure be removed to insert the canister. However this structure kept sliding off during races, so it was secured with a pin into the car body. This pin system was later found to non-compliant and the concept was discontinued.

2. The nozzle in the second design was formed of thin rubber formed into a conical shape. This rubber formed an effective seal with the firing pin while also allowing the canister to be inserted. A plastic shroud formed a secondary seal with a structure attached to the launch pod. This design was discontinued due to the difficulty in accurately machining the rubber nozzle

While a theoretically sound concept, the nozzle proved to be very difficult to manufacture and integrate with the car design. The concept was ultimately superseded by a simpler design, whereby the canister housing was extended beyond the rear of the $CO_2$ canister. This was coupled with a launch pod device to create internal and external seals with the canister housing. This reduced race times by up to 0.3 seconds, similar to the improvements seen with the LERS seal concept.

## LERS SEAL CONCEPT

During preparation for the World Finals, we further investigated the LERS concept and the mechanism by which it operates. We identified that further improvements could be made by forming a temporary 'seal' between the car and the launch pod, allowing pressure from the $CO_2$ canister to build before launching the car with a greater force. Through race testing, we found that the seal concept provided a 0.25 second advantage over the redirection LERS. This seal was established by having the LERS envelop the engine chamber on both the outside and the inside leaving a .3mm clearance.

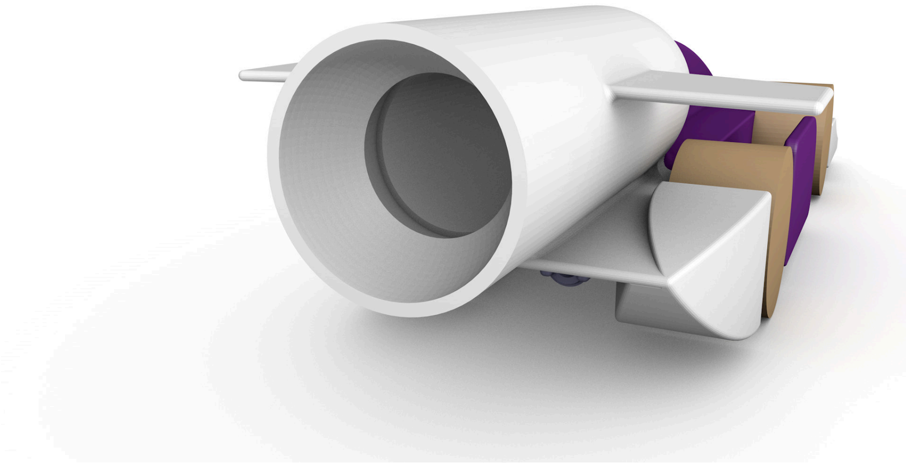


**FIGURE 6: NOZZLE ITERATION ONE**

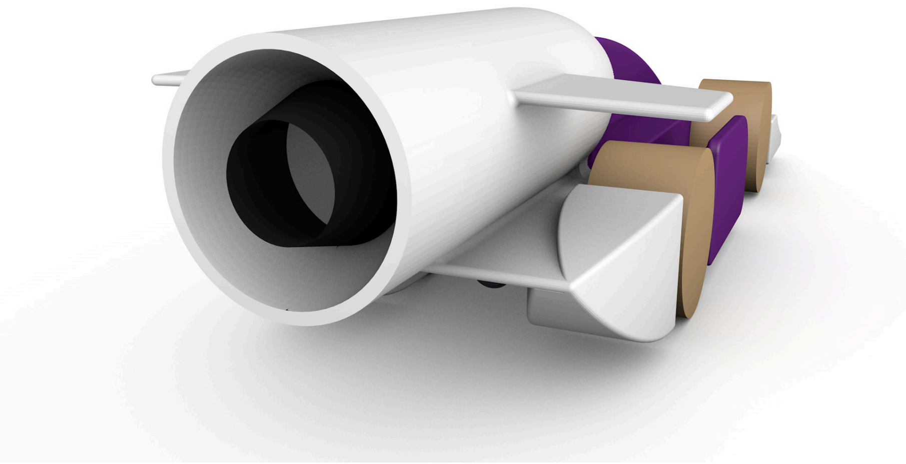


**FIGURE 7: NOZZLE ITERATION TWO**

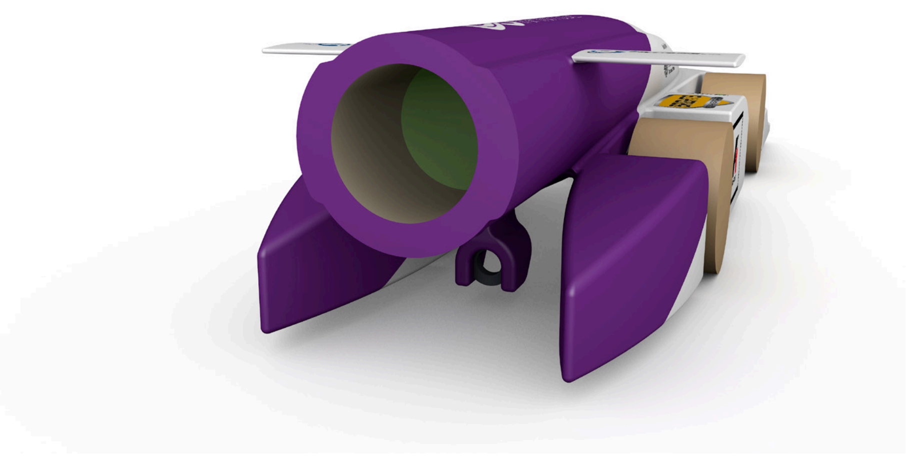
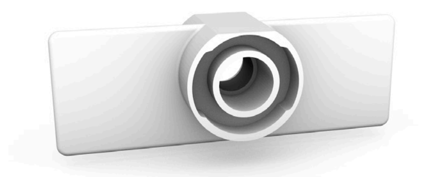
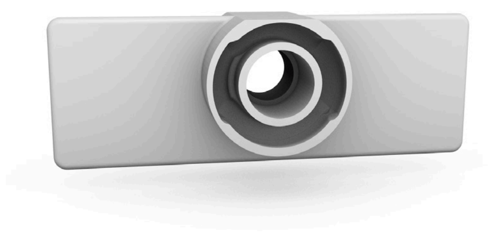


**FIGURE 8: NOZZLE ON FINAL CAR**

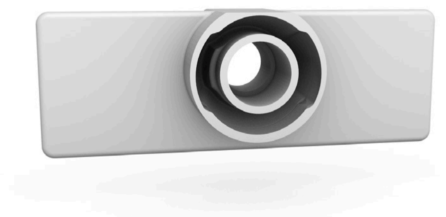
# LERS



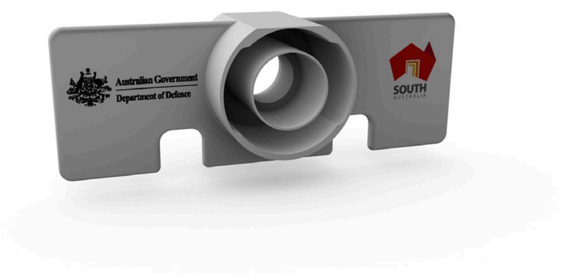
**ITERATION 1**
Our first LERS was designed around the concept of pressurisation. It was designed to reduce the energy lost by having the canister near the end of the car.



**ITERATION 2**
Our first redirection LERS was designed to reflect gas back onto the race car. It was designed to make the acceleration of the car more effective.

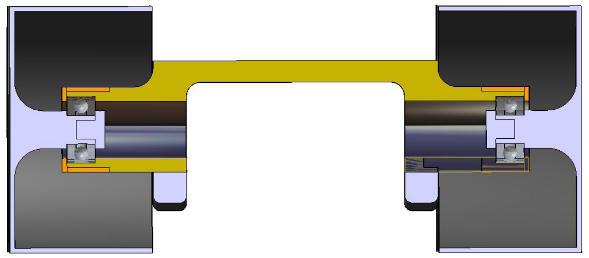


**ITERATION 3**
Our second redirection LERS was designed around the concepts of iteration two, but had the ability to be a manufactured by a three-axis CNC router.



**ITERATION 4**
Our final LERS is based around the concept of pressurisation. As it is designed for a 75mm chamber depth, it had a better effect on the acceleration than the previous two iterations.

## #1: LIVE INDEPENDENT

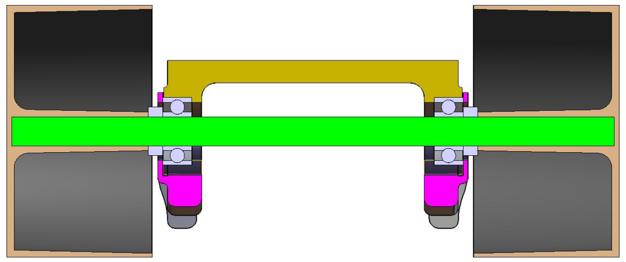


**DESCRIPTION**
This system aimed to reduce the rotational inertia. This was accomplished using a design that rotated the inner race of the bearing rather than the outer race. This was achieved by a bearing tube attached to the cross member that holds the outer race of the bearing centered across the wheel width. The rotating axle formed part of the rotating wheel assembly. Separate flanges were used to locate and secure the bearings and wheels.

**ADVANTAGES**
Low rotational inertia, minimal air disturbance, removable, self aligning, easy to maintain.

**DISADVANTAGES**
Difficult to manufacture, prone to wheel wobble when airborne, sensitive to transport loads.

## #2: LIVE DEPENDENT WITH CROSS MEMBER



**DESCRIPTION**
This system aimed to stabilise the wheels while having minimal impact on the frontal area. This was achieved by using a cross member similar to iteration one but contains a live axle passing through the catamaran.

**ADVANTAGES**
Removable, stable, easy to transport.

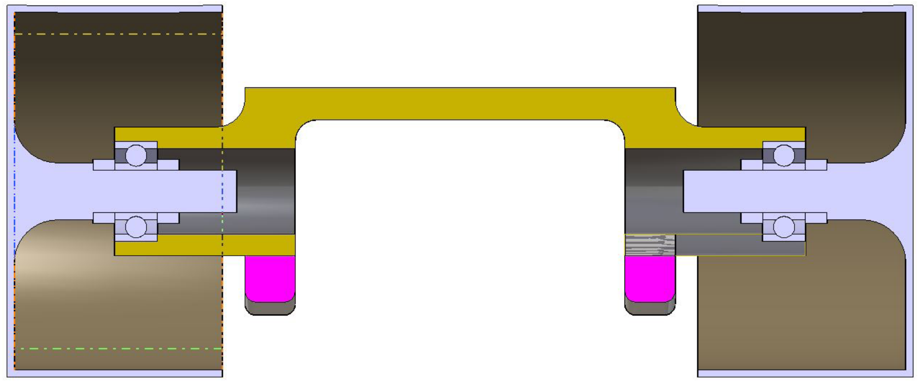
**DISADVANTAGES**
Exposed axle causes airflow disturbance, higher rotational inertia than iteration one.

## FINAL DESIGN

**DESCRIPTION**
The final design is a modified version of iteration two. The design removes the separate flanges and instead uses an interference fit to ensure the bearings are firmly fixed within the cross-members. The wheel flange has been modified into a tight-fitting tube that sits around the axle. This reduces the mass and provides an easy machining process.. Another inclusion are the spacers, small discs that are inserted on the axle between the wheel and the bearing and help keep the wheel from rubbing against the body of the car.

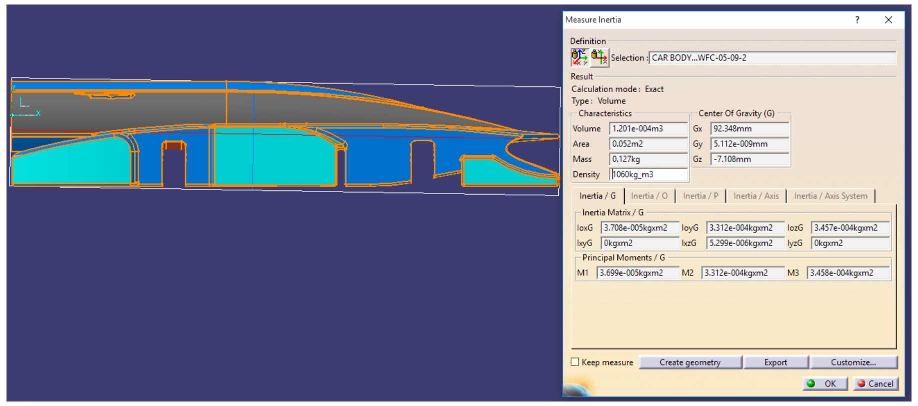
**ADVANTAGES**
Self aligning, removable, easy to align with respect to the crossmember, minimal rotational inertia, lightweight.

**DISADVANTAGES**
Difficult to manufacture, difficult to align with respect to the body, difficult to transport.



## CENTRE OF MASS

The positioning of the car's centre of mass relative to the centre of thrust affects its dive at launch. Using the inbuilt inertia and FEA tools in CATIA, we were able to measure the effect of varying this relative position.. We were then able calculate the torque required to raise the back wheels. After having the optimum torque number we needed to aim for, we could work out what needed to be changed to ensure our car didn't dive at launch.



Measure Inertia

Definition

Selection : CAR BODY...WFC-05-09-2

Result

Calculation mode : Exact

Type : Volume

| Characteristics | | Center Of Gravity (G) | |
|---|---|---|---|
| Volume | 1.201e-004m3 | Gx | 92.348mm |
| Area | 0.052m2 | Gy | 5.112e-009mm |
| Mass | 0.127kg | Gz | -7.108mm |
| Density | 1060kg_m3 | | |

Inertia Matrix / G

| | | | | | |
|---|---|---|---|---|---|
| IoxG | 3.708e-005kgxm2 | IoyG | 3.312e-004kgxm2 | IozG | 3.457e-004kgxm2 |
| IxyG | 0kgxm2 | IxzG | 5.299e-006kgxm2 | IyzG | 0kgxm2 |

Principal Moments / G

| | | | | | |
|---|---|---|---|---|---|
| M1 | 3.699e-005kgxm2 | M2 | 3.312e-004kgxm2 | M3 | 3.458e-004kgxm2 |

## CFD PROGRAMS

Computational fluid dynamics testing and analysis was heavily used during the car design process. CFD was used as it is the current method of testing the aerodynamic performance of various components. We used four programs to ensure we were able to accurately and efficiently evaluate our designs. Phonics F1 VWT was used for fast comparative testing and also provided accurate drag coefficient data. To visualise the flow around our car, Autodesk Flow Design and CFD Motion 2016 were used. These programs were particularly useful for analysing small drag-inducing details. For final prototype and direct componentry testing, Symscape Caedium was used. This provided extremely accurate and detailed data and flow visualisations, but took significant time and effort.

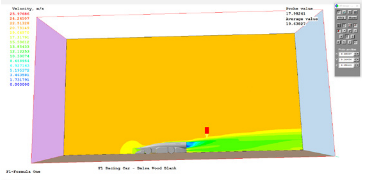
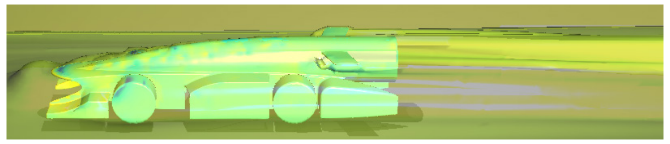


**FIGURE 9: CFD TEST IN PHOENIX F1 VWT ANALYSING THE AIRSPEED AROUND THE GEOMETRY AFTER TEST COMPLETION**

## ENGINE CHAMBER FLOW

When the canister chamber was deepened for the LERS interface, we wanted to ensure there would be no negative effects on the canister efficiency. Through collaboration with Symscape, we accurately modelled the gas flow out of the canister in Caedium. We found that the canister gas flows out in a 45 degree cone. This meant that the gas would collide with the inside wall of chamber, therefore causing less thrust loss as the air was not dispersed. We also found that the gas would directly enter the LERS design, making it more efficient, rather that waiting for the LERS to redirect the air back into the car.



## FEA TESTING

The use of Finite Element Analysis was vital, as we were forced to outsource both our 3D printing and most of our CNC operations. Despite this separation from the manufacture process, we still had to ensure all the parts of our geometry would survive the loads imposed during transport, scrutineering and racing. With the inbuilt FEA tool in CATIA, we could simulate real world forces, saving both time and money on manufacture.

## WHEEL SYSTEM

When engineering our running system, we were designing with two objectives: concentricity, for smooth running; and low rotational inertia, to ensure the wheel system accelerated without resistance. To ensure we met both of these requirements while remaining structurally sound, FEA tests were conducted on the wheels to test the minimum rim thickness required to avoid permanent deformation.

## LERS

The new world regulations reduced the size of the LERS exclusion zone relative to the national regulations we had previously followed. This reduced operating zone of the LERS reduced the volume available for LERS wall thickness, so we had to ensure the design and material used would still be able to withstand the force of the CO2 at launch. We identified the potential for the LERS to experience significant force and flexion as the car launched. It was vital to the performance of our LERS that it remained rigid and contained the pressure of the canister. FEA was used to identify and quantify the flexion that did occur for various designs., After running brief pressure calculations, we calculated the distributed pressure force required to simulate the real world launch of the car.

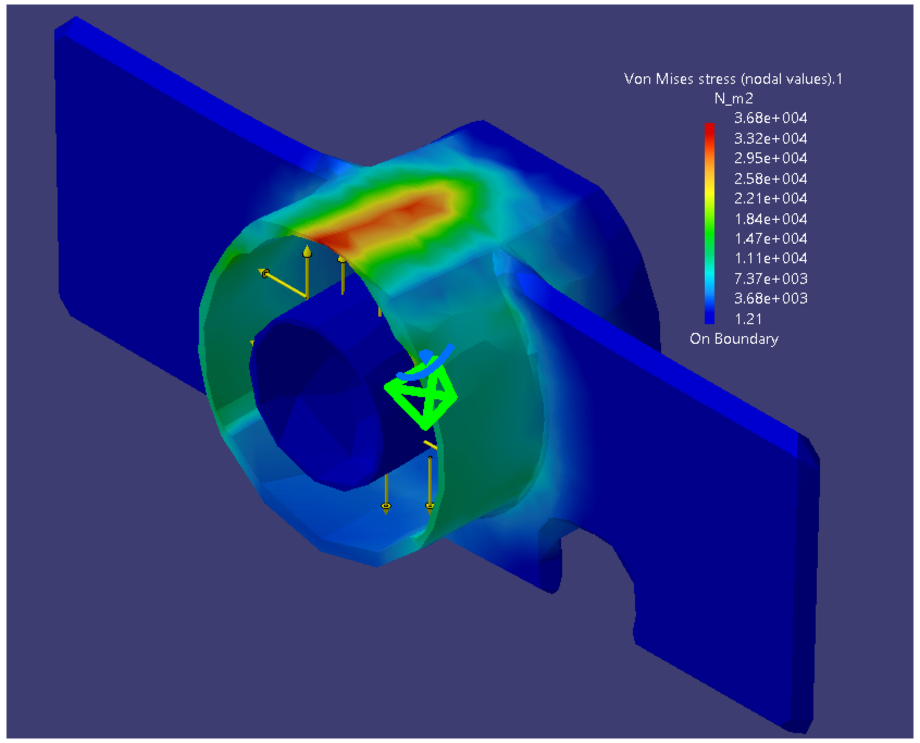


**FIGURE 10: VON MISES STRESS ANALYSIS WITH PEEK BASED LERS**

## REAR TETHER GUIDE ANALYSIS

We were initially unsure as to how to design the tether line guide system to meet the load bearing requirement of two Newtons. CFD and FEA testing showed that our initial attachment system, although a very strong aerodynamic design, created a huge bending moment, as the guide, and hence the force, was located rear of the mounting. Initial results showed the guide itself would not break, but the force throughout the chassis could cause the rear sing support structure to detach from the chassis. Modification of the design filled out the rear of the support, reducing the bending moment. The reduction in stresses can be seen in the FEA test results below.

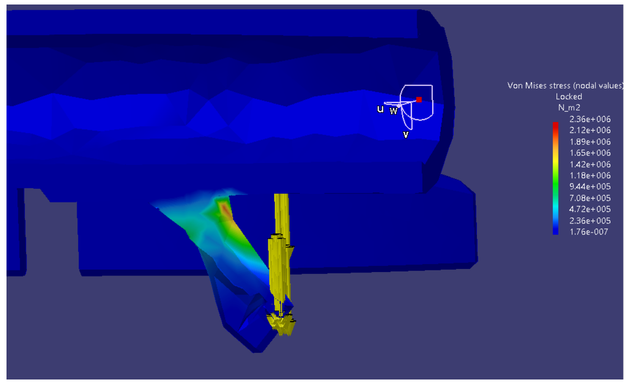


**FIGURE 11: ORIGINAL TETHER GUIDE CAUSING A STRESS POINT**

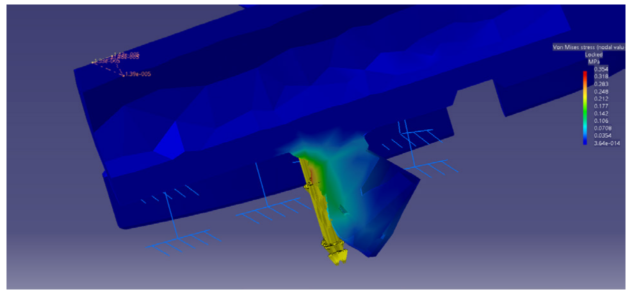


**FIGURE 12: NEW REVISED TETHER GUIDE SOLUTION**

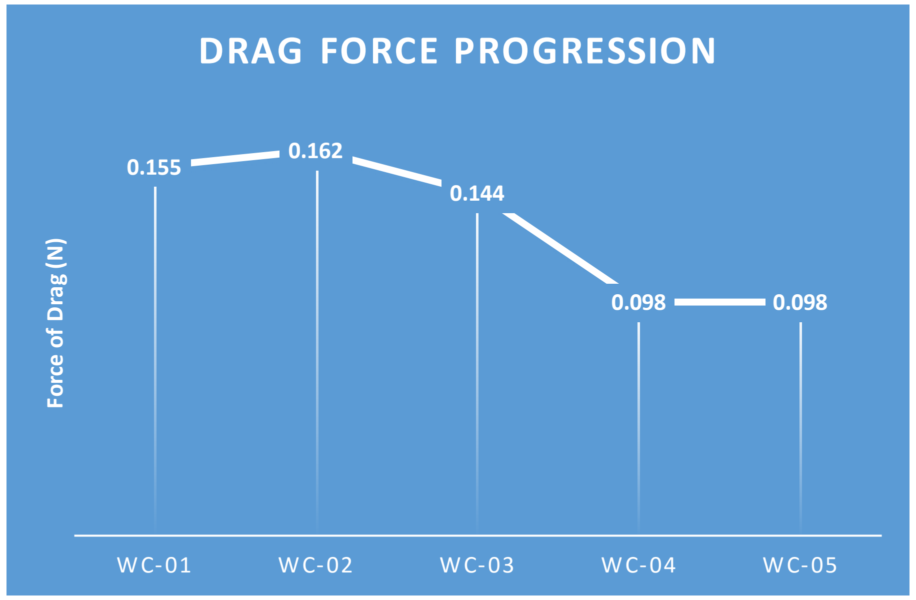


**FIGURE 13: DRAG FORCE PROGRESSION GRAPH**

## OVERVIEW

Post manufacturing tests has been a pivotal part in the development of our, LERS and suspension system. Testing in a physical environment has had a major impact on the design geometry because when in the physical world, more variables are introduced that could potentially reduce the accuracy of the results even the most sophisticated simulations.

## CHAMBER DEPTH TESTING

With the release of the 2016 F1iS Technical Regulations, new rules were brought in to restrict design placement on the X-axis. Rule T5.6 states 'When fully inserted, the CO2 cylinder must protrude a minimum of 5mm from the rear of the car, visible in the plan view.' As the penalty is 6 points for every car, a justification process of the LERS had to be undertaken. Changing the positioning of the canister changed both the centre of mass and the efficiency of our LERS. In the end, we needed to find a 0.06 second gain from the changed deepened chamber car and LERS for the to have an overall speed gain.

**RESULTS**

After 40 Test at each chamber depth was run, the gain of a deepened chamber was found to be worth 0.24 of a second. This was due to the pressure build up caused by the LERS along with the diving moment.

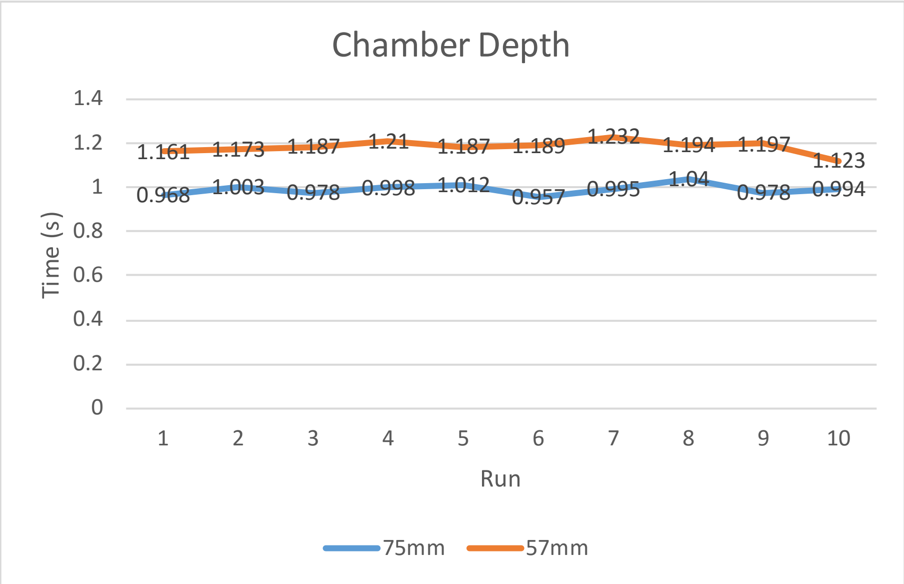
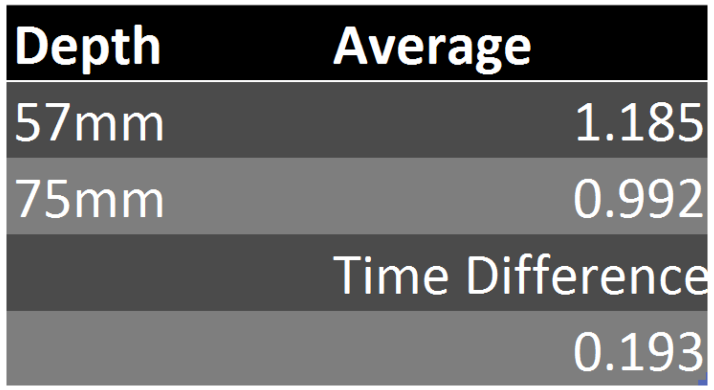


FIGURE 14: LINE GRAPH OF CHAMBER DEPTH TESTING RUNS



| Depth | Average |
|---|---|
| 57mm | 1.185 |
| 75mm | 0.992 |
| | Time Difference |
| | 0.193 |

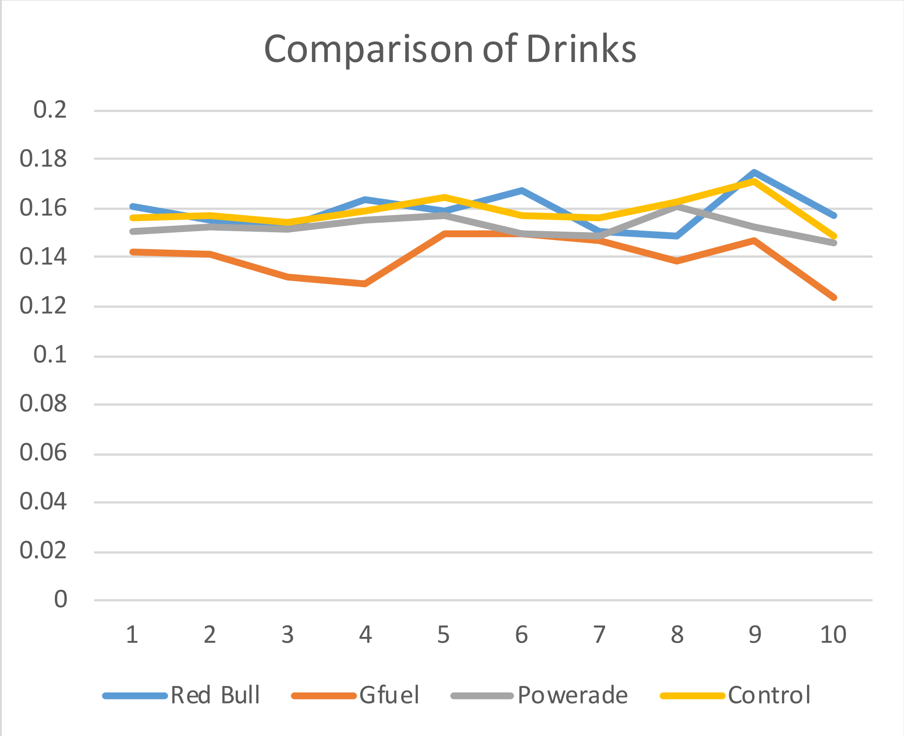
FIGURE 15: TABLE OF AVERAGES FROM CHAMBER DEPTH TESTING

## TIMING SECTORS

An important part of the F1 in Schools™ Challenge is understanding what has to be countered. Working out everything that happens in racing allows us to design a car to counter and exceed in every part of racing. Working with Dr. Warren Smith from UNSW ADFA, we devised a way of working out 3 important parts of the race, and how we can counter the losses encountered by each. After theoretical canister calculations were solved, we placed the intermediate splits in the rough positions calculated on the form, then test races were run with an established prototype to ensure the system was set up to the correct data points. From our data, we could calculate the average acceleration of the vehicle. The acceleration data we received allowed us to determine which launch systems were most efficient.

## REACTION RACING

To ensure the fastest and most consistent driver for infinitude was chosen, initial tests were ran to evaluate every person's reactive performance. To ensure accurate data 40 reaction times were recorded. After calculating averages and best times, we ran further reaction testing into the two best drivers, to find who could achieve the most consistent and fast times. From testing we established our driver was Jesse, as he had the lowest standard deviation, and fastest times. After further reaction time research was conducted, we looked into the effects of various drinks had on the body. Our test compared the gain/loss of Powerade, GFuel and Red Bull throughout the day. Our conducted tests proved that the energy formula of GFuel gave us the best reward, by improving reactions by up to 25ms. After results from a research partnership with OPSM, leading optometrists in Australia, we established that our reactions would be improved when wearing light blocking glasses. We ran comparative testing between Gunnar Optiks Amber Diffusion glasses, Polaroid Sunglasses and Clear lens glasses. As shown in the results, the gunnars provided the best benefit, reducing our average reaction times by 10-20ms.



## FOAM PAINT TESTING

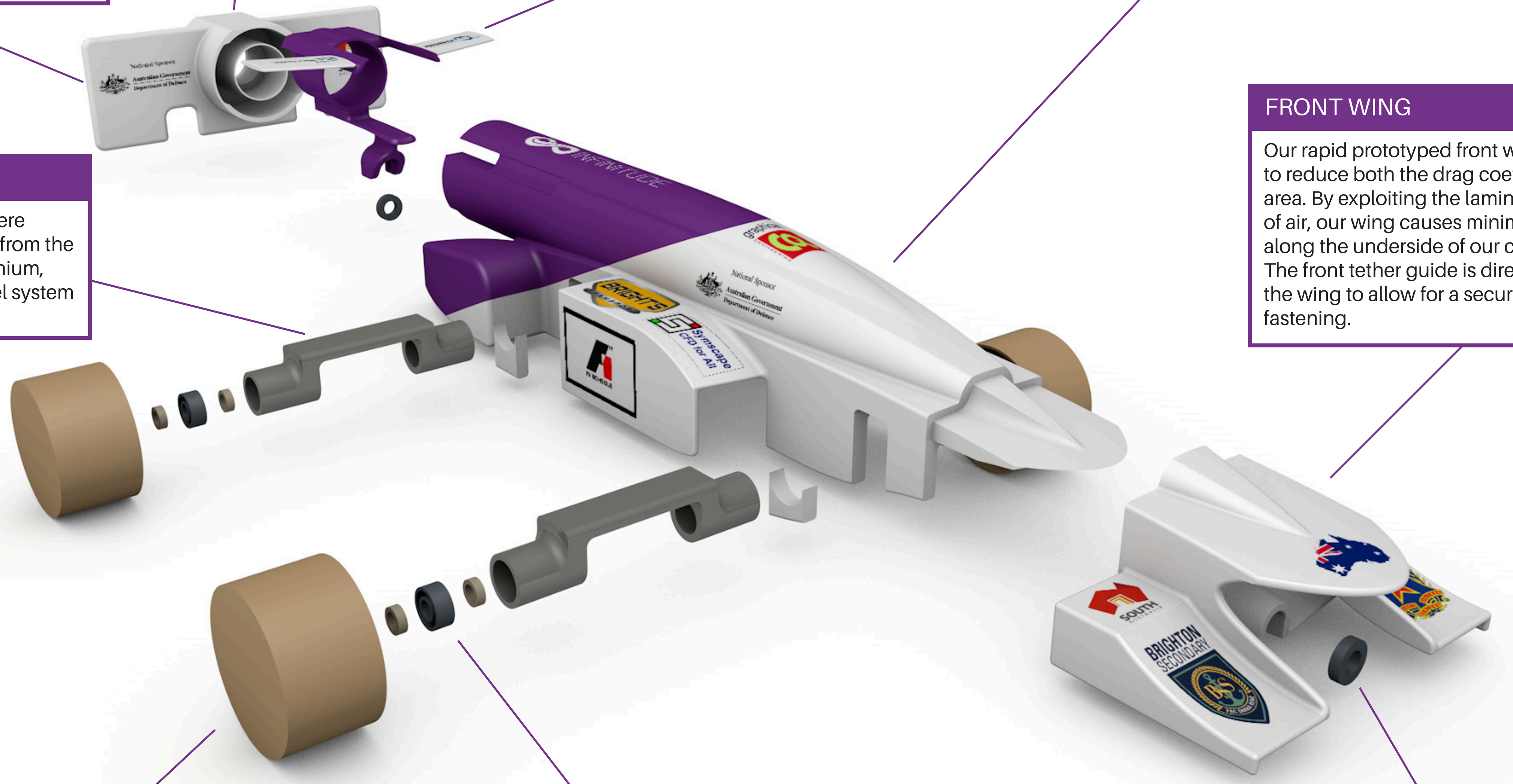
When we first tried painting the foam we did it the same way we would paint balsa, due to the pores in the foam we found it absorbed the filler and made our car much heavier. In order to use this method and still have our car on weight we would have to sacrifice the surface finish on the cars. With this in mind we set out to find a way of filling in the pores without adding too much weight to the car, we found two different methods of doing this. The first way is to get a foam sealant, this is a spray that corrodes the top layer of foam smoothing the next layer with the melted foam, we decided not to use this method as it makes the car's geometry dimensionally incorrect. The last method we discovered was to fill the car with a thin layer of putty as it is not as liquid as automotive primer so it isn't absorbed into the foam thus solving the weight absorption problem.

## LERS MOTION CAPTURE

When working on our LERS, we needed to see how the system both worked, and how it impacted the car. We decided to set up 5 1920x1080p 240FPS Slow Motion Capture cameras, that would give us an accurate recordings for our launch. Analysing our initial collected footage, we noticed the rear wheels would lift quite early on in the launch phase of the race. After we researched the moment of tipping, we could modify and film our designs to see gains or losses in this area. Later on in the development process, when designing and manufacturing the lers, we used these same technologies to determine which concepts worked and which did not.

FIGURE 16: FRAME TAKEN AFTER CAR LENGTH DISTANCE TRAVELLED

FIGURE 17: FRAME AT SIDE ANGLE TAKEN 8 FRAMES AFTER LAUNCH



## LERS

The low tolerance LERS machined from a hybrid of acetal and PEEK sits just 0.3 mm from the car body, creating a pressure seal with the car and launching mechanism containing the pressure from the CO2 canister during launch.

## REAR WING

Our rear wing was designed to slice through the air with minimal resistance, without disrupting the laminar flow. The support structure is designed to reduce the measured depth of the engine chamber to comply with regulations. We integrated our rear tether mount with our support structure to ensure both ease of assembly and aerodynamic performance.

## CHASSIS

Our chassis is designed to counter the tipping moment while still incorporating a highly developed aerodynamic package. Mass reduction pockets underneath both the sidepods and rear pods allowing for more flexibility in other aspects of the design.

## LERS ADVERTISING BOARD

The LERS advertising board allows us to innovatively market both our team and sponsors during the highly viewed racing.

## CROSSMEMBERS

Our car’s suspension crossmembers were designed to achieve maximum benefit from the catamaran. Manufactured out of aluminium, they ensured concentricity of the wheel system during assembly and racing.

## FRONT WING

Our rapid prototyped front wing is designed to reduce both the drag coefficient and frontal area. By exploiting the laminar flow properties of air, our wing causes minimal turbulence along the underside of our car, reducing drag. The front tether guide is directly connected to the wing to allow for a secure and aerodynamic fastening.

## WHEELS

Low friction PEEK wheels were machined professionally to ensure both concentricity and accuracy. Their lightweight design allows for minimal rolling resistance during initial acceleration and throughout the race.

## BEARINGS

Full ceramic $Si_3N_4$ ABEC 5 bearings supplied by Boca Bearings were used to ensure minimal resistance and friction, allowing the car to have a higher acceleration.

## TETHER GUIDES

Using a hybrid of Fuji Gold Cermet and silicon carbide fishing eyelets provided minimal friction and energy loss to the tether line.

# DESIGN FOR MANUFACTURE

When engineering the virtual geometry of the design, consideration for the manufacturing process had to be taken into consideration. As the cutters available to our team were limited, all of our inside fillets had to have a 1.5mm radius. Putting the radius on the virtual model allowed us to get accurate virtual testing results that matched the physical model being produced.

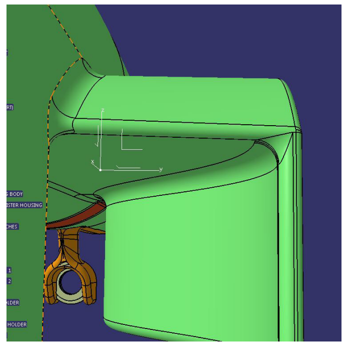


FIGURE 18: CONNECTIVE EDGE FILLET WITH A 1.5mm RADIUS

# HEALTH & SAFETY

Safety is key to ensuring the well being of team members involved in the manufacturing process. Taking onboard Australian Workplace Health and Safety regulations, we could prevent serious injury or sickness. Ways we achieved this included making safety operation procedures for every machine used by infinitude, wearing the correct safety gear in the correct circumstances and forcing breaks to reduce mental fatigue.

# FOAM BLOCK CONSIDERATIONS

With the foam block being relatively new to the F1 in Schools™ completion, we ran calculations and tests to make sure we got the best accuracy and finish possible. With the additional flexural and tensile strength, the foam is a stronger yet harder to machine material. After collaboration with Mark Cherrill, a former nanofabrication specialist for Mercedes AMG PETRONAS we devised a testing scheme to develop the manufacturing process. Together we evaluated the current pre-sets for the Balsa Blank, as together we thought this would be a good starting point. The setup is as follows, Feed rate 2250 mm/min, Spindle Output, 24000RPM, step over, 0.2mm. After running an initial car code with these feed rates, we evaluated the car's finish, and discovered that small points of the foam in the machine melting. As the router we use doesn't have a climate control or thermal control system to regulate the temperature of the bit, we turned down the federate to a more suitable setup consisting of a federate of 1850mm/m and a Step over of 0.1mm. This was enough to stop the melting of the foam and improved the overall finish of the design. Another thing we took into consideration was the rotation in the machine. With the first foam car we machined, we noticed our engine chamber bending out of shape. After heavy evaluation, we realised that the deformation of the blocks was being caused by the tailstock and the spigot. We overcame these problems by loosening the rear car stock when rotating on the 4th axis.

# TOLERANCE

Understanding that the manufacturing process isn't always 100% accurate, we were required to make sure that we met the F1iS Technical Regulations. Working with Simon Mee, founder of Applied Numeric Control, we discussed the importance of tolerance on geometry. He explained how different processes could cause different dimensional outcome, and how we have to take into account the limitations of accuracy available. After learning the importance of tolerance, we as an engineering division agreed that we should allow a 0.5mm tolerance on all components of the design, ensuring we met specifications.

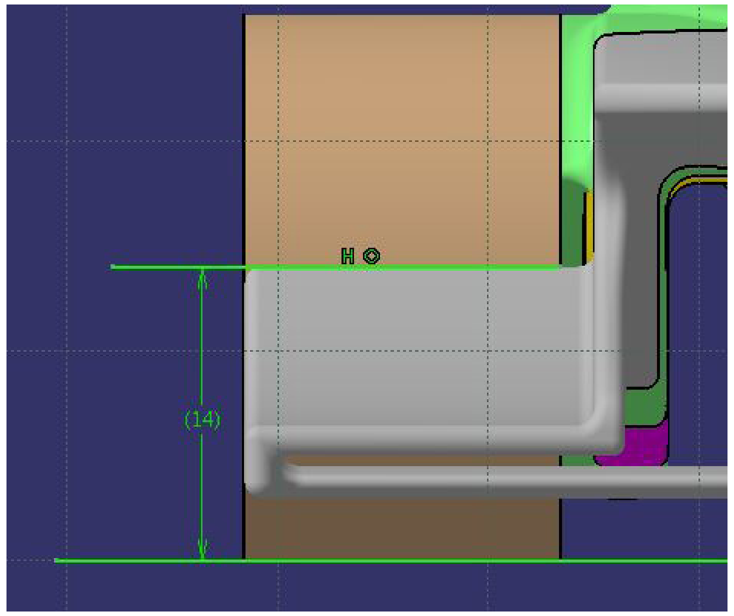
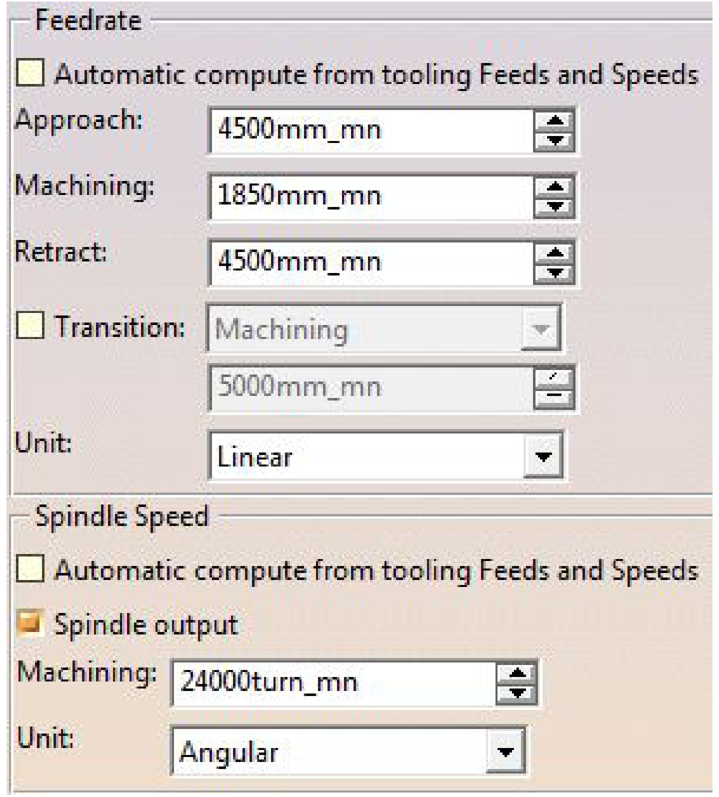


FIGURE 19: TOLERANCE DEMONSTRATION ON FRONT WING HEIGHT



Feedrate

☐ Automatic compute from tooling Feeds and Speeds

Approach: 4500mm_mn

Machining: 1850mm_mn

Retract: 4500mm_mn

☐ Transition: Machining

5000mm_mn

Unit: Linear

Spindle Speed

☐ Automatic compute from tooling Feeds and Speeds

☑ Spindle output

Machining: 24000turn_mn

Unit: Angular

FIGURE 20: TOOLING SETUP

# CAM PROCESS CHASSIS

Using the inbuilt Surface Machining tool in CATIA, we designed and used a simple but effective CAM Process. We found a significant advantage in using the the surface machining tool, as we could import our geometry without format change directly in CATIA, eliminating the random and systematic variables that could occur. CATIA also gave us the freedom to better control the CNC process (cycles) as we could make curved and 3rd dimensional limiting contours. This enabled us to better utilise the 4th axis as we could eliminate overlapping codes.

After code testing, we found the codes that achieve the best finish for our design.

To remove the initial material to speed up the manufacturing process, we used the roughing removal operation, as this would save machine time while improving overall accuracy. To further save time, we used a stepover and step down of 5 mm. To ensure geometric accuracy, we left a 2mm offset on geometry, as this would be removed in later codes.

To ensure safety in the manufacturing process we used 6mm finishing operations, removing the material in the way of the 3mm Cutter. This would also machine the parts of the design where a 3mm cutter is not required, saving more vital machining hours. To ensure no impact on surface finish, for cutter removal operations, a 0.6mm offset on geometry was used with a stepover of 0.6mm. Parts not requiring a 3mm cutter had no offset on geometry and a stepover of 0.3mm.

To ensure both an accurate and smooth surface finish, we used a 3mm long series ball nose cutter. Using a stepover of 0.1mm, we ensured no machining lines caused by tooling were left on the chassis when it was taken out of the machine. At the feedrate of 1850mm/m we could ensure the 3mm cutter had no issues with breakages.

TOP
- 6mm 0 roughing
- 6MM TOP FINISHING
- 3MM TOP FINISHING

3MM TOP FINISHING
- Tool Change.2 T2 D3 BALL NOSE
- Sweeping.2 (Computed)
- ZLevel.2 (Computed)
- Pencil.1 (Computed)

FIGURE 21 & 22: CATIA MACHINING PROGRAMS & OPERATIONS

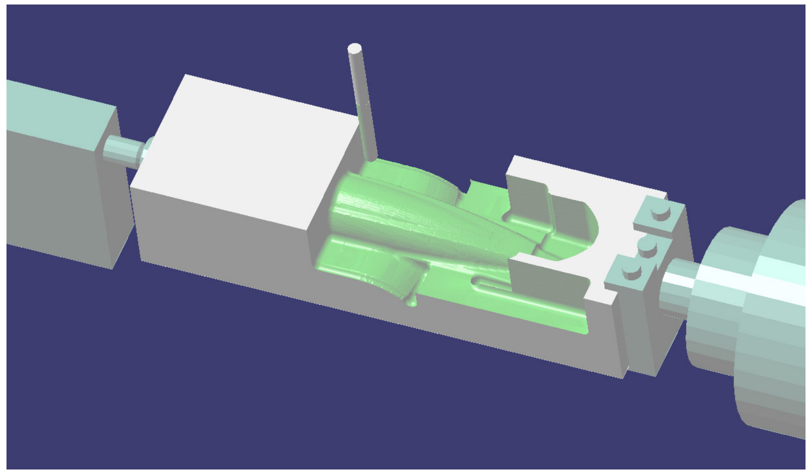


FIGURE 23: CATIA TOOLPATH GENERATOR

## ADEPT CIM CENTRE

We used the Adept CIM centre with DIGI-9 Lathe controller, when manufacturing the spacers and wheel sleeves for our final wheel and axle system, our final LERS and early wheel prototypes.
We manufactured the Spacers and Wheel sleeves using both the manual and cnc function that the lathe offers. This involved manually drilling the 3mm hole in a billet and then using the CNC function to turn it down to the correct diameter. We then parted them off at the right widths using the manual function.

The wheel prototypes were manufactured using a gang tooling fixture and the CNC function on the lathes. This involved turning the wheel down to the correct dimensions and turning the bearing tube as well. When turning the bearing tube we had to manually lubricate it to keep the tool from welding to the surface or grabbing and either snapping the tool, material or at the very least putting the offsets out. This involved watching the machine and spraying WD40 on the material, the reason we did it manually is our machines do not have an auto lubrication.

## FORMLAB FORM1+

We used the Formlab Form1+ to manufacture our wing, wheel and LERS prototypes. The Form1+ uses a 3D printing technique called stereolithography, which uses a laser to harden the resin, eventually creating the geometry. The end result is a clear structure that is more accurate than the Makerbot 3D printers due to a finer layer height and less thermal expansion. We used this machine for wing, LERS and wheel prototypes.

## GCC SPIRIT GLS

The GCC Spirit GLS is an industrial standard laser cutter which works by implementing a 60watt co2 laser and redirecting it using mirrors and a lens to cut material. The laser cutter both cuts and engraves materials allowing us to make jigs for measuring our car, key tags, engrave glasses and laser cut orthographics on acrylic.

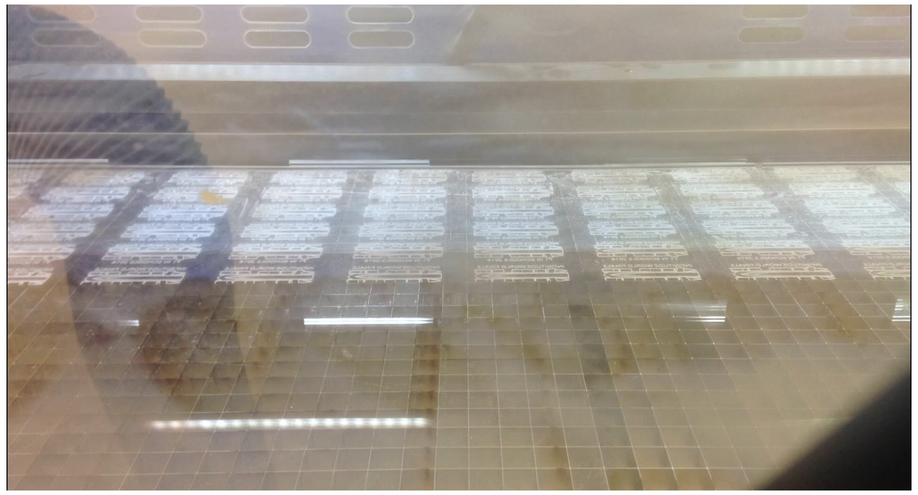


FIGURE 24: LASER ENGRAVING OF PROMOTIONAL KEYRINGS

## 3D PRINTING

3D printing is an additive process, unlike milling and lathing which are subtractive processes, this means they start with nothing and add material to produce the final product. They do this by heating a filament and layer by layer extruding it to the platform. This process does have its downfalls as the filament experiences thermal expansion when it is heated and cooled meaning that you have to scale the object bup before printing. Our team was fortunate enough to have 3 sources to 3D print from, TAFE SA, Objective 3D and Brighton Secondary school. We used these resources to print the skirt fills (prototypes from Brighton final from Objective 3D), the front and rear wings (Prototypes from Brighton and TAFE final from Objective 3D) and the LERS Prototypes (Brighton).

## PRE FINISHING

Before we could sand our car we had to assemble the front and rear wing geometry. This process was vital to do accurately due to measurement constraints. We accomplished this by using fine grit abrasive paper to remove small amounts of material accurately from both the chassis and wing support structures until they fit perfectly. During this process we used both the vernier and micrometer to ensure precision of the car's geometry.

## FINISHING

The first step is to use varying grits of abrasive paper to remove machining errors. Following this precise procedure we applied tamiya model putty to both the front and rear wing support structures where they met the body of the car, once dried we sanded the excess putty back to get a smooth surface finish. The next step is where our race and show car finishing process differentiated as our race cars needed to remain on weight whereas our show cars didn't have this restriction. Since our show cars didn't have to be at a certain weight we could afford to apply automotive primer at this stage. After applying automotive primer to our show cars we delivered all cars to Caddle Crash Repairs where we had white paint applied to the chassis, during this we ensured that no paint entered the crossmember mounts. After the paint dried we applied painters tape so only the purple sections of our car were exposed, leaving our car with the desired paint design.

## POST FINISHING ASSEMBLY

The post finishing assembly is where our car and wheel and axle system meet. This stage is crucial to our car's success as it determines the rolling resistance of the wheel and axle system. The advantage of our wheel and axle system is that the crossmembers and wheel assembly would have already been put together during the finishing of our car as the crossmembers can still be inserted into the chassis with the wheels on. Our wheel and axle system is assembled using jigs and takes 4 steps to finish, put the spacers bearings and axle tubes on the wheels, using the jig slid the bearing/ wheel assembly into the crossmember, glue on skirt fills, slid the crossmembers into the foam chassis.

FIGURE 25: PRE-PAINTING IN-SITUATION RENDER

FIGURE 26: APPLICATION OF FINAL COAT

FIGURE 27: PRE-ASSEMBLY IN-SITUATION RENDER

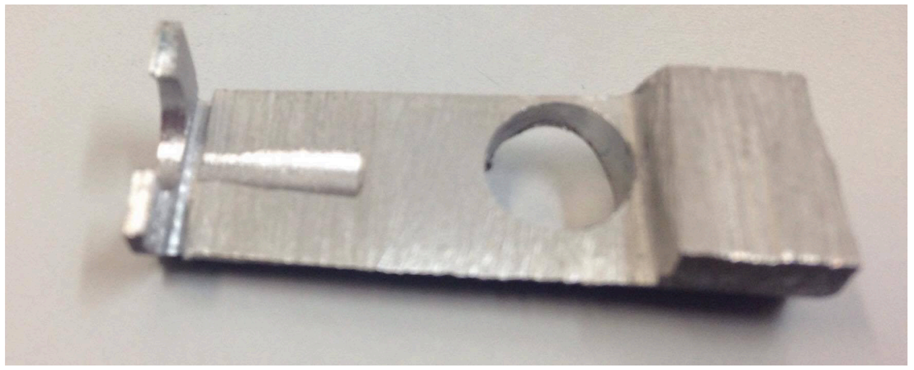


FIGURE 28: ASSEMBLY JIG