Unlimited 3.0 Deep-dive | 2021
WESTERN SYDNEY SOLAR TEAM

Western Sydney University acknowledges the Darug, Eora, Dharawal (also referred to as Tharawal) and Wiradjuri peoples and thanks them for their support of its work on their lands (Greater Western Sydney and beyond).

With respect for Aboriginal cultural protocol and out of recognition that its campuses occupy their traditional lands, Western Sydney University acknowledges the Darug, Eora, Dharawal (also referred to as Tharawal) and Wiradjuri peoples and thanks them for their support of its work in their lands in Greater Western Sydney and beyond.

We are Western Sydney Solar Team and our mission is to develop new innovations as well as leaders of the future to take a stand in the inevitable shift towards sustainable solutions. Our project is a multidisciplinary student led venture which encompasses all aspects including designing, manufacturing, and racing solar powered vehicles. We have a rich 10 year history and have placed top-in-class during the Bridgestone World Solar Challenge in 2017, 1st in the American Solar Challenge in 2018 and broke the record in

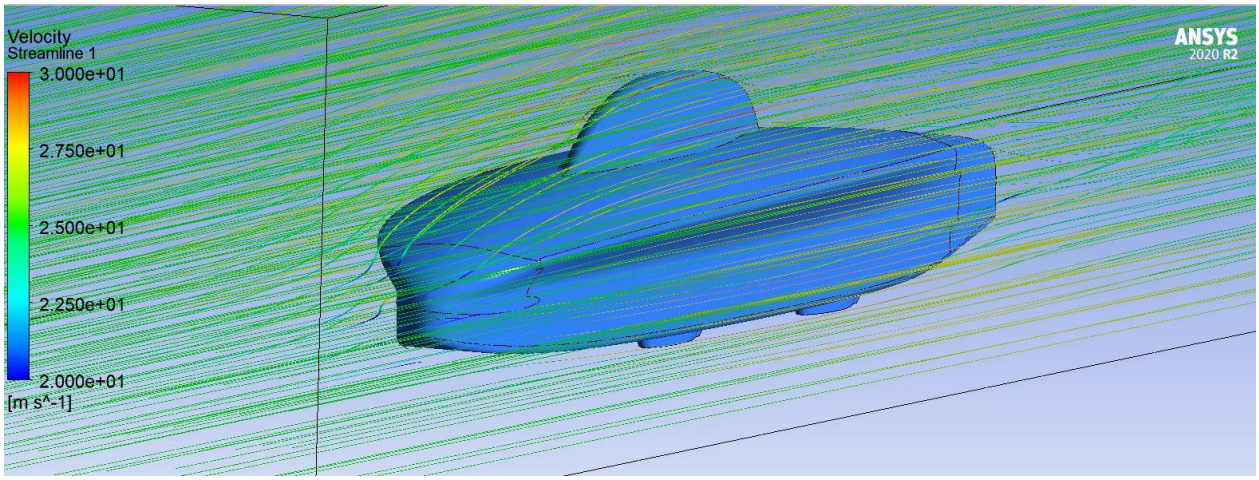
2019 for the lightest solar powered vehicle ever to race weighing only 116.8kgs.
Today, we want to embark on a deep dive into Unlimited 3.0 with you. We invite all questions to be asked using the chat function during our presentation, and will open up to Q&A during the 15 or so minutes of this session.

Intro to Unlimited 3.0

- Designed for the 2019 Bridgestone World Solar Challenge
- Uses 2.4 square meters of space-grade Gallium Arsenide Solar Cells
- Able to travel 400km on jut a 20kg Litium Ion battery
- Designed fully by team members and manufactured 80% in-house
- Lightest ever road-registered car in Australia at just 116kg!

So lets start by introducing the car that is going to be the focus of this session, Ted 3. Ted 3 is the WSU teams 4th vehicle and was built to compete in the 2019 Bridgestone world solar challenge. It is a 4-wheeled monohull or bullet shaped vehicle. It used 2.4 square meters of gallium arsenide solar cells, a marand designed high-efficiency motor and a 20kg lithium ion 1860 battery pack. It has a fully carbon fiber composite aerobody and chassis with a primarily machine aluminium suspension. It was able to travel around 400 km on just the 20kg of battery and can travel at approximately 70kmh on solar alone if expose to full sunlight. It was the first car the the team have made primarily in-house with nearly 80% of all components and nearly 100% of all composites being manufactured in house at our kingswood facility. The greatest achievement of this vehicle was that it broke the record for the lightest ever solar car to compete in the BWSC weight in at only 116 Kg race ready. It is also, as far as we know, the lightest road registered car in Australia.

Aerodynamics

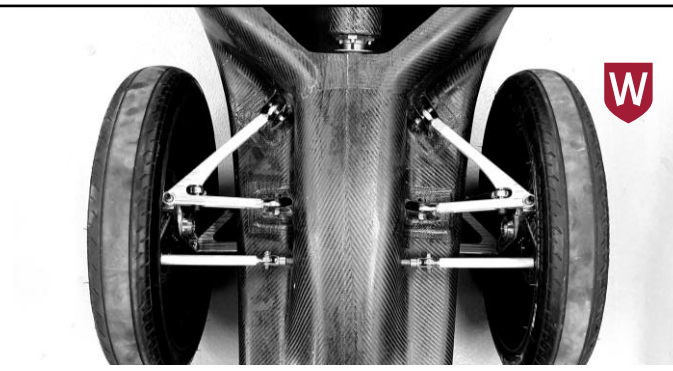


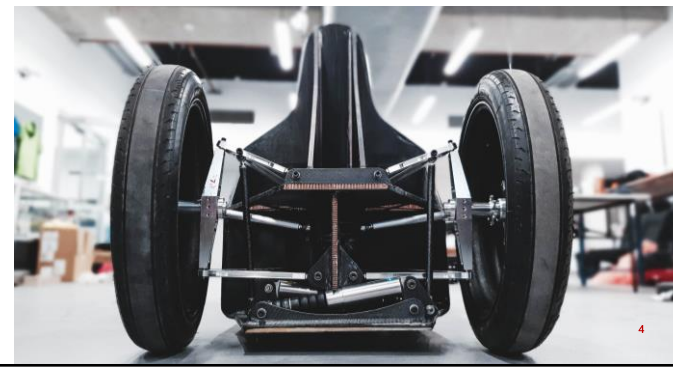
The first think I want to talk about is the aerodynamics of Ted 3. Solar cars in the 2019 race were split into 2 distinct classes, monohulls and catamaran. Ted 3 is a monohull shaped car, with all tyres and the driver encase in one single hull. Due to this, and the incredibly narrow track width of the front tyres, it has a very low frontal area. The bottom of the car is very flat and very low to the ground, around 50mm, reducing turbulence generated by exposed wheels. Since the car uses gallium arsenide solar cells, it only need 2.6 square meters of solar collector area. Compared other monohull cars at this event, ted 3 had no overhanging solar area ahead or behind the vehicle. It achieved the necessary solar area by flaring the car main body outwards near the top on either side of the driver. This created more solar area while still keeping the car as small as possible. It also creates geometry that helps stability under crosswinds. The car was designed with a 0 lift philosophy, where it produces as close to net 0 vertical force as possible. We did not want any downforce to increase rolling resistance or any lift that would make the car unstable at high speeds. Any lift or downforce creates associated drag, and this philosophy helps reduce straight line aerodynamic drag. The car is also designed to have extremely sharp trailing edges to reduce the amount of separation cause off the back of the car. To achieve this, both the end of the carbon aerobody and the end of the vacuum formed canopy have a 3d printed insert that created a razor-sharp trailing edge. All these design decisions combined; we believe to have created one of the most aerodynamically efficient solar cars at the 2019 challenge.

Chassis

A crashworthy driver tubs that weighs less that 15kg!

- Near perfect weight distributions and a very low centre of gravity
- Made entirely using carbon fiber composited
- Suspension mounted using incredibly strong carbon fiber ear mounts.
- Made to take 5 G Front, Top and Side impact loads
- 5-point safety harness and a integrated carbon-fiber roll hoop



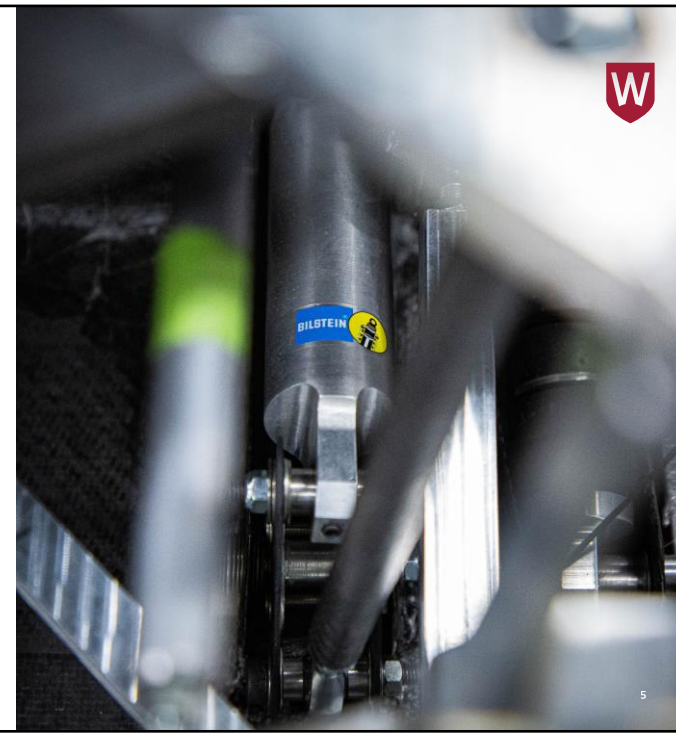


The chassis of ted 3 is very unique in that it is not a monocoque. Most other solar cars and all of our previous cars have been of a monocoque chassis, which the out skin/shell of the car is structural. However Ted 3 had the driver, suspension, motor and battery all in one package very close to the centre of the car and an aerobody that was very far away from all the loads. To create a monocoque in this configuration would have been very heavy and hence a separate chassis and aerobody were made. The aerobody, as seen from the outside is everything that is externally open to the air. This entire piece is non structural and only acts to deflect wind efficiently around the car. Using spars, this aerobody is connected to the main chassis, which is what you can see in the images on this slide. The chassis is designed to create a near perfect 50:50 weight distribution, with the centre of weight of the driver right in the middle of the car wheelbase. The battery is also located right behind the driver's back, separated by a firewall. All the mass held in the chassis is designed to be al low to the ground as possible, creating a very stable car at high speeds. The chassis tub is designed to take a 5G impact load front the front side and the top, while still keeping the driver safe. It have a 5 point racing harness and a fully integrated carbon roll hoop. In fact the whole chassis is made of composited. We use woven bi-directional pre-impregnated carbon fiber that sandwiches either nomex honeycomb or a foam core depending on the area. Any place a bolt goes through the composite, we ensure to have a foam core not nomex. We also use patches of unidirectional carbon fiber where we know strength in specific loading directions is needed. Even the suspension mounting points on the chassis are carbon fiber ears.

These have been tested on an Instron machine and have taken upwards of 25 tonnes of impact loads and high frequency without failing. The front have of the chassis is a moulded tub, where as the back hald consists of flat panel sheets that are waterjet cut to the perfect shape. All glue joins within the chassis are made using an aerospace grade adhesive called spabond. The final chassis tub alone weights just 15 kilos. This was a pretty incredible achievement. When we first measured this chassis, we really did know that we would have one competitive car on our hands.

Suspension

- Double wishbone suspension with transverse mounted shocks connected using bellcrank and a pullrod
- Optimised for low rolling resistance by running zero toe and chamber and minimising camber and caster gain
- Fully optimised suspension components CNC machine our of 7075-T6 Aluminium

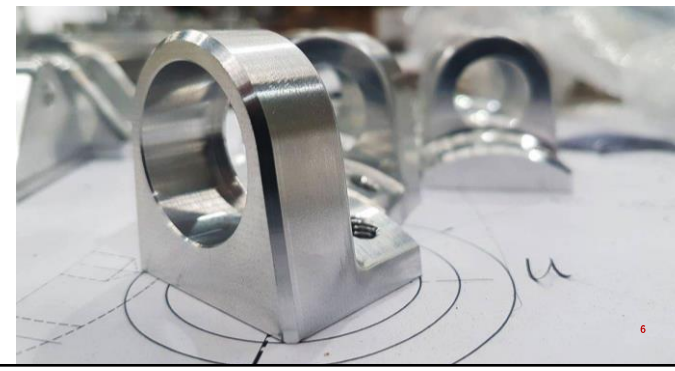


The front and rear suspension in ted 3 are of a double wishbone configuration. They have an upright joining them and use transverse mounted shocks and a bellcrank-pullrod system to connect them to the sprung mass. This was done for packaging reasons. The shocks at the front now fit sideways underneath the drivers knees, allowing the wheels to come closer towards the drivers legs, allowing for a narrower aerobody. It also allowed the design to achieve a near 1 to 1 motion ratio. The entire suspension geometry is designed to create as little rolling resistance as possible. The most important way to do so was using stiff shocks that don't waste too much of the cars energy while still providing a stable ride. We partnered with Bilstein to create these amazing one-off aluminium body shock absorbers. The rest of the suspension geometry is designed to have zero toe and chamber to reduce rolling resistance. Furthermore it is tuned to have as little chamber and castor gain as well as bump steer throughout the actuations while still fitting in the aerobody. After the geometry was optimised, the CAD designs were also optimised to sustain the loads and fatigue that it would experience. Through strict engineering control, we were able to safely optimise parts to a very tight safety factor, so that they could be as light as possible. All components were mased out of 7075-T6 aluminium or some composite rods. This created the best optimised and by far the lightest suspension system that the tam has every created!

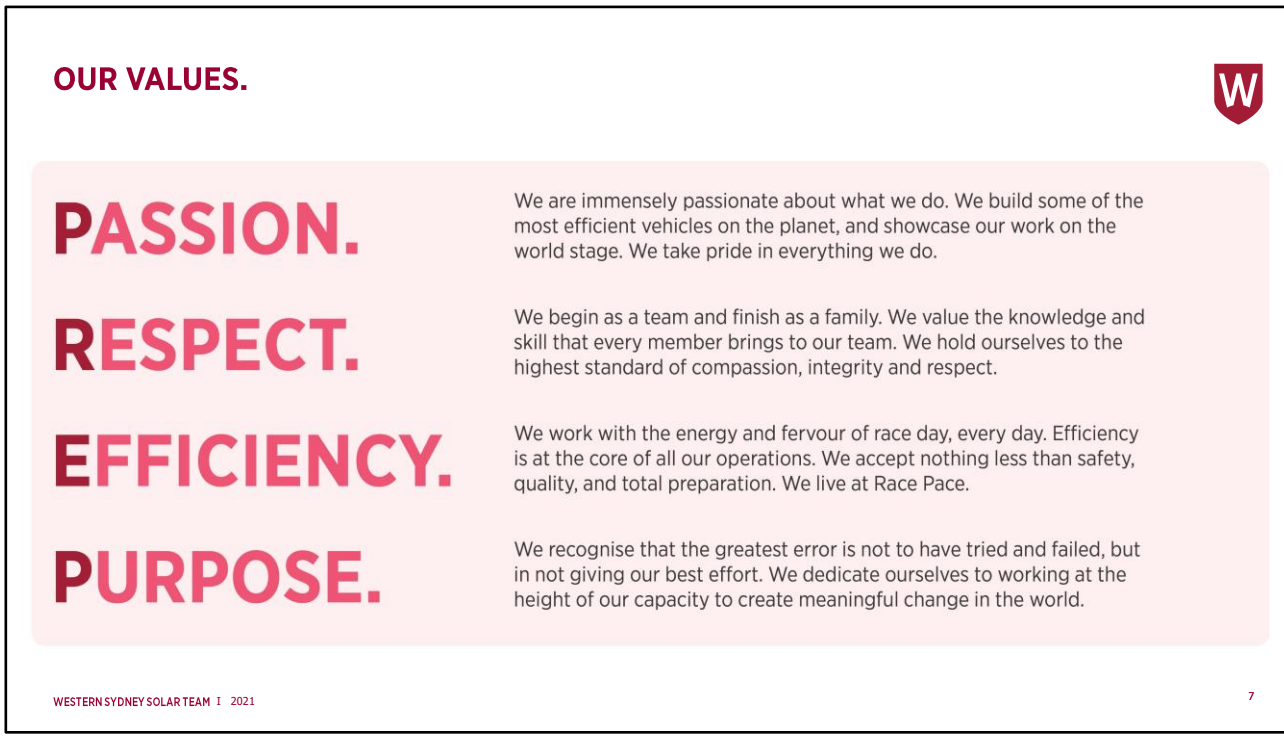
Systems and Interfacing

Amazing systems that don't work together are useless...

- Every single component in the solar car needs to work cohesively with many others.
- The slightest of errors in interfacing can cascade throughout the car and create massive issues
- Thorough engineering management strategies need to be employed to make sure the car works as one cohesive system.

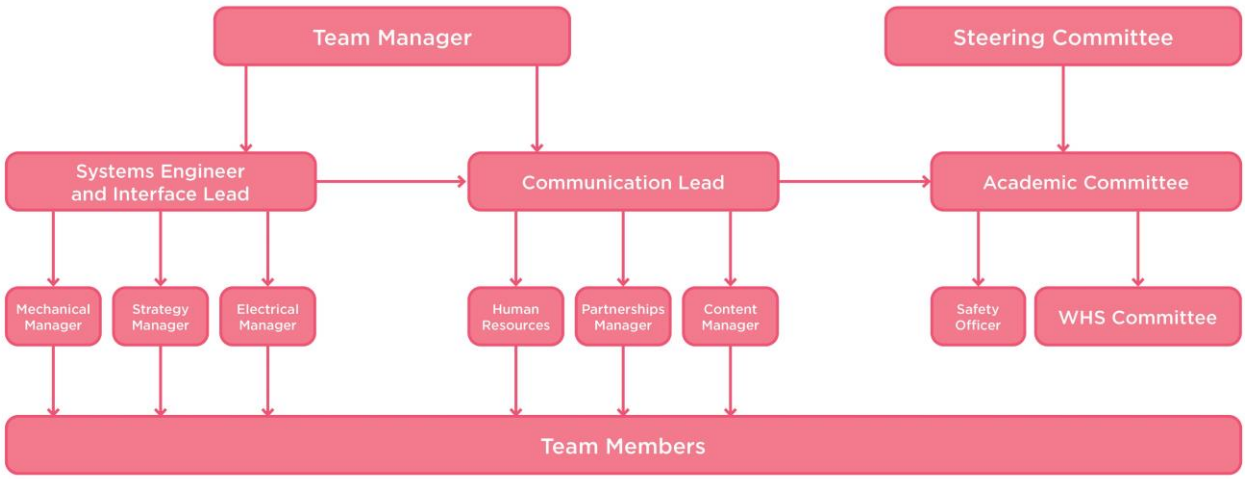


As you saw in the previous slides, every single sub system within the car was very deeply thought out and was optimised to be the best of what it could be. But there is no point in having amazing individual systems if they don't work together. Just as important is designing each system to interface with one another to work with and compliment each other. The aero team need to work with suspension to make sure there is enough clearance within the aerobody for the suspension. Suspension needs to work with chassis to make sure all the mounting locations are in the exact right location and strong enough. Chassis needs to work with electrical to ensure accommodations for all the wiring throughout the car. And electrical needs to work together with aero to ensure that the right formation of solar cells can be fit on the top surface of the car. These are just some examples, but you can see how this creates a complex web of interfacing that all needs to work perfectly. Even 1 mistake can stop the car from competing. To make sure that systems engineering and interfacing happens flawlessly, we needed to employ various measures of engineering management. I will now hand over to brad how will go into more detail about these.



Thanks Divyam. Before diving too deep into management strategies we use, I wanted to re-enforce the importance of clear and well defined values.
After the 2019 race cycle, our team saw big changes. Fortunately, lots of members had gone on to roles in their desired industry, but this did leave us with a skills gap. We worked hard on recruitment and were able to pull together a team of brilliant minds.
The first thing we did as a team, was define our values – This really set the foundation and culture in which we work. A strong set of values serves as an anchor point when you feel like the world is spinning around you. Times often get tough when trying to design, build and race a car in less than 18 months, but our values give us perspective, help us re-group and focus on the things that matter.

OPERATIONAL STRUCTURE.

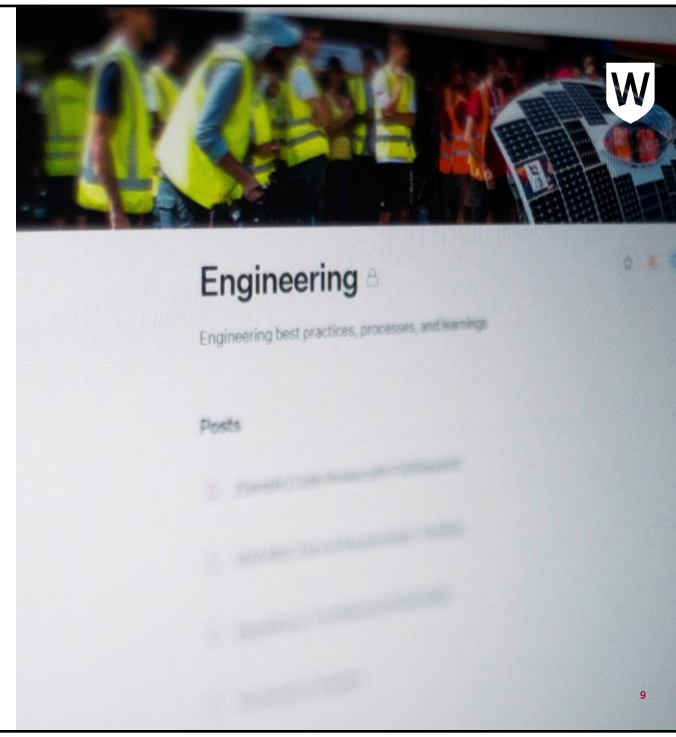


Here is something else we believe to be an important foundation to any team looking to achieve something great. A well laid out and clearly defined operational structure.
This is important for many reasons – It gives everyone involved a clear sense of identity, and shows them how their contributions tie in to the bigger picture. It also helps streamline work when your team members know who they can reach out to for help.

Engineering Management

File and knowledge storage

- Proper naming conventions help streamline file management.
- It is important to be able to step back in time, you may be able to discover justification for design decisions.
- The team always has access to whatever they need in a few clicks.



Many things we do are learned along the way. We are operating at the leading edge of technology and are often required to innovate to progress. In a fast paced environment, or any environment in fact, it is essential to have an archive of knowledge. There are many different solutions out there but we've found using the google suite works well for us.

We've set up google drive to store all of our vehicles finalised component in a parts library, as well as previous iterations of them so we can take a step back in time whenever we need to. File management is vital when you're creating a product to ensure ease of access between team members, also to ensure you're sending out the right files for manufacturing. Naming conventions play a big part in file management, and we have an excel library to make this more comprehensive for anyone on the team to find what they're looking for.

SLAB is a great piece of software too, and its what we use for knowledge storage and storing documentation. It is essentially an internal Wikipedia for our team. Every sub team is broken down as per the operations structure, and everything is labelled in a specific way to make this system easy to navigate.

Both of these tools are critical for our succession planning too.

Engineering Management

Effective communication and design reviews

- Communication is key to success, always.
- Constructive criticism needs to be given as well as it is taken.
- We have 3 different types of design reviews to widen the perspectives provided; Internal, Academic and External.

It might sound cliché, but communication is key to success. There are many different types of communication - verbal, virtual and constructive criticism are key players for us. The team uses google chat as part of the google suite to communicate virtually. During the most recent lockdown, this was essential to our progress. Google chat has been very useful for us as you can group conversations and even use a search function within the app if you need to.

Design reviews also play a big part in communication. They act as a platform for constructive criticism. We have a round table policy and no criticism is bad, in fact its very welcomed and encouraged as long as its constructive. We have three main types of design reviews, internal, academic and external.

Internal design reviews force us to communicate about what's important, with focus. We start the cycle as a team, and finish it as a family, so naturally we can get consumed with office banter.

Academic design reviews not only strengthen our partnership with Western Sydney University, but also give us great academic insight.

External reviews give us the chance to run our designs past people with very niche skillsets.

Engineering Management

Requirements Matrix and Trade-offs

- Do not miss this step! Always have clear objectives.
- We use the regulations as a starting point, but add our own requirements in as we see fit.
- Implementing trade-offs helps you develop philosophy and ask the right questions when needed.

Western Sydney University Solar Car 2023 Requirements Tracking - PART REQUIREMENT EXAMPLES

Requirement ID	Part No.	Requirement	Rationale	Priority	Owner	Verification Method
#0001	#0105 (steering wheel)	Shall withstand a torsional load of X Nm in use, FOS Y.	Driver is able to apply X Nm(link). FOS for failure-critical (material) is Y.	Mandatory	Dhyam	One unit is tested to failure. All production units tested to X Nm.
#0002	#0105 (steering wheel)	Shall weigh less than 100g.	Minimising weight is a system goal. Ted 3 Steering was 140g, minor improvement expected.	Highly Desirable	Dhyam	Computed weight to verify design. Measured weight to verify production units.
#0003	#0105 (steering wheel)	Shall be comfortable to use for extended time periods.	Driver comfort has tangible effect on driving efficiency. Minimal impact on performance is expected.	Desirable	Dhyam	Design approval from lead driver.

GUIDELINES

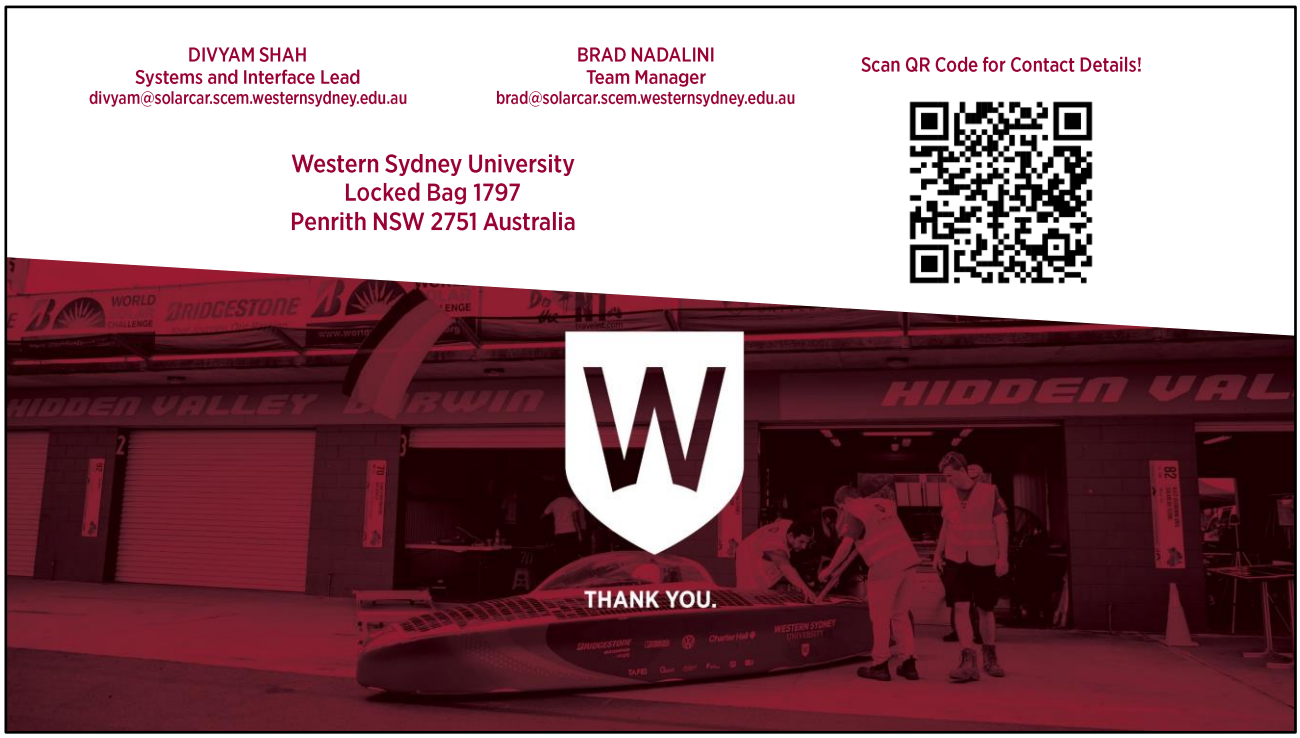
Purpose of Technical Requirements Tracking - Transfers large-picture expectations, into detailed and executable statements. Creates agreement between designer, manufacturer and other stakeholders on what the part is meant to do. Prevents confusion and extra work later on.
Requirements will be filled in 3 stages - General (on the 20/06 based on regulations and safety), System Level (overarching system requirements), Part Level (requirements specific to parts)
Requirement ID - Unique identifier for each requirement. Makes them easier to identify and keep track of.
Part Number - Each requirement must refer to a part, assembly or system in the car, each of which has a unique identifier, listed here. Each part/assembly/system may have multiple requirements.
The actual requirement - Exists at 2 main levels - Functional and Performance based. Functional requirements define exactly what the part is to do (for example - attach part a to part b while allowing it to rotate of x axis). Functional requirements then have performance requirements under them. They define to what level the functional requirement must be met. (for example they could include - load cases, tolerances, factors of safety, dimensional restrictions etc). Performance requirements are the majority of what this document will be tracking.
Coming up with requirements - Defining performance requirements may be difficult at first. Hear are some things to think about while coming up with requirements - how to make it safe, how to make it improve the cars overall performance, what contraints apply to it, what other components does it attach to, what rules and regulations does it have to comply with.
What makes a requirement well defined - requirements must be 'SHALL' statements. They should also be quantifiable and testable. The requirement should also fit within the scope of the project. (If there is absolutely no reasonable way of acheiving the requirement, it really needs to be reconsidered!)
Rationale - Should be a clear justification for why the requirement is what it is. It should clarify the intent of the part to all stakeholders. Having a good rationale for your requirement helps justify your design decisions later on!
Priority - Assigning a priority from the drop down menu helps put objectives of a design in perspective of one another. In helps decide what element of the design takes precedence over the other. This will be useful when two requirements conflict with one another. For example, if it is not possible to achieve both a target weight and a target factor of safety, the factor of safety (because it is of a higher priority) will take precedence.
Levels of Priority - Mandatory: Car cannot run without these validated. Failure will immediately endanger drivers life. Including Regulations Highly Desirable: Failure will not immediately endanger driver, but will endanger driver in near future and/or significantly impact performance. Will generally require car to be stopped and addressed. Desirable: Failure poses no safety risk. A failure of this nature should be addressed at next nominally available opportunity.
Owner - Name of whoever is responsible for the specific requirement. When someone has a question or wants more information about the requirement, they will know just who to ask!
Verification - is the most important stage of engineering, and the skill almost all graduates lack. Requirements must be verifiable; if it isn't, rewrite it. A method for the verification must be defined. It could include simple measurements, analysis results or full scale testing.

The last thing to talk about is our requirements matrix and trade-offs. This has been one of, if not the most important thing when ensuring what we are building is fit for purpose, safe and competitive.

What you see on the right is our requirements tracking document. It allows us to extract the race regulations into an organised system, and add our own requirements, which we believe enhance our vehicle. This is our engineering bible. We can tie the requirement into our parts tracking library, see the rationale behind the requirement, define its priority, see who created it and know how we can validate the requirement when we believe its met. We have a comprehensive guideline on how to use this matrix so anyone in the team can understand it.

Finally, we have our trade offs. At the start of 2020, we decided on some key aspects of the vehicle we believed to be critical. We then ranked them as a team and this now influences every decision we make – engineering or not. Those trade-offs are; Safety, Reliability, Performance, Working-Hours and Cost, ranked in that order from high priority to low.

Safety is first, we want to ensure everyone finishes the race in one piece. Reliability is ranked second and higher than performance – we rather have a car that runs slow but consistent, instead of one that's fast in short bursts before breaking down. Performance is third, although our team believes reliability is more important, we still obviously want a strong performer. Working-hours and cost are ranked last because they're the variable which are more easily controlled.



That marks the end of our deep dive into Ted 3 and also the management strategies surrounding. Divyam and I hope we've given you some good insight, and if you would like to know more please use the details on screen. We'd love to hear your questions, so Kartik, I'll hand over to you to kick off the Q&A!