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Technical Report

Introduction to Automotive Engineering (ACHA4009)

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Contents

1	Introduction	1
1.1	Aims	1
1.2	Objectives	1
2	Impact of the topics	2
2.1	Materials	2
2.2	Sustainability.....	4
2.3	Aerodynamics	5
2.4	Computational Methods	7
2.5	Manufacturing	9
2.6	Maths in Engineering	10
2.7	Hybrids.....	11
2.8	Data Acquisition	12
3	Current state of the industry	13
4	Conclusion.....	14
5	References	15

1 Introduction

This technical report will look at 8 different topics selected from lectures that would have impacted the design and/or development of the Toyota Gazoo Racing Yaris that competes in the World Rally Championship (WRC) in the Rally1 classification. The topics that were chosen had the most impact on Research and Development (R&D) and cover a broad spectrum of the different regulations and standard that determine whether a car is suitable for the current automotive industry. Research was then completed on these design aspects and provided to show results.

This report will specifically look at the implementation of systems in the championship and the choices made to improve performance, reduce emissions, increase safety and future improvement.

1.1 Aims

To provide examples of how the Toyota Yaris GR that competes in the Rally1 WRC fits in today's standard of automotive design and to explain how different aspects of automotive design have an impact on the final production of a vehicle.

1.2 Objectives

To provide examples and evidence of how the Yaris GR fits in the current automotive sector and how regulation changes have an impact on the industry.

2 Impact of the topics

2.1 Materials

Choosing the materials used is one of the most important factors when designing and producing a vehicle, depending on the requirements of the part it may be structural such as the chassis or door to a cosmetic item like a wing mirror. The chassis of a vehicle needs to be produced from strong materials or alloy such as steel or aluminium as it has to be rigid enough to absorb and retain movements from the ICE and potential impacts. Components or parts may also be manufactured from plastic or fibreglass for cosmetic, cost or non-structural purposes such as door handles and wheel deflectors.

Typical values of Ultimate Tensile Strength, Yield Strength and Elongation.

Metal or Alloy	TS (MPa)	Ys (MPa)	δ - ψ (%)
Steels	1725	205	65-2
Iron	185-285	40-200	60-3
Aluminum	90	35	45
Aluminum Alloys	90-600	35-550	45-4
Copper	220	70	45
Copper Alloys	140-1310	76-1100	65-3
Nickel	320	58	30
Nickel Alloys	345-1450	105-1200	60-5
Titanium	275-690	140-550	30-17
Titanium Alloys	415-1450	344-1380	25-7
Molybdenum Alloys	90-2340	80-2070	40-30
Magnesium	160-195	90-105	15-3
Magnesium Alloys	240-380	130-305	21-5

Note: (MPa "Mega Pascal" is the unit of strength in International System and psi "pound per square inches" in Imperial System)

Figure 1 - Metal tensile strength chart (<https://qph.fs.quoracdn.net/main-qimg-66583d1159eeb1af4630118ef7003c2f-c>)

Figure 1 shows the typical values of the tensile strength, yield strength and elongation of different metals from Steel to Magnesium. Each metal consists of different properties making them suitable for different requirements. Steels have a very high tensile strength

meaning that more stress can be applied before the metal stretches and breaks whereas aluminium and copper have very low tensile strength making them brittle and unsuitable for high load. Picking the right material therefore is a vital aspect in automotive design as using the wrong material can both increase cost significantly whilst also reducing safety and performance.

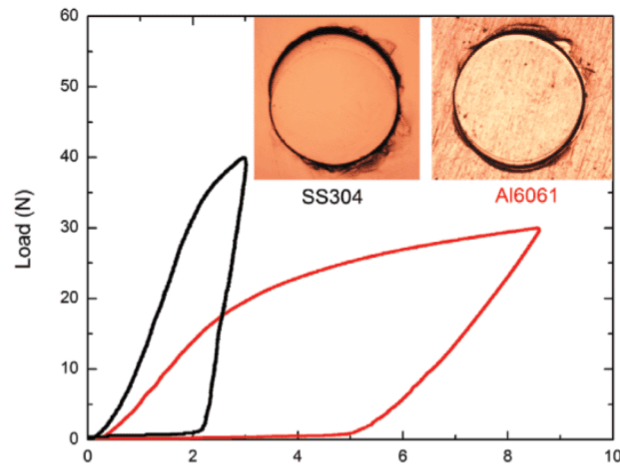


Figure 2: Load-displacement curves of SS304 and Al6061 samples. The flat indenter imprints on the test samples are inset.

Material	Yield Strength (MPa)		Ultimate tensile strength (MPa)	
	Indenation	Tensile Test	Indenation	Tensile Test
SS304	277±21	275	609±16	620
Al6061	231±18	241	301±9	300

Table 2: YS and UTS of SS304 and Al6061 measured using indentation and tensile tests.

Figure 2 - Steel & Aluminium tensile strength

Figure 2 gives us results of a tensile strength test performed on a small sample of steel and aluminium. It shows us that the steel can withstand more load before yielding than the aluminium that yields at a load of 30N.

2.2 Sustainability

In 2014 the current standard for Emissions known as Euro 6 came into effect, forcing manufacturers to produce new vehicles that complied with stricter limits on the volume of Greenhouse Gases (GhG) that were released upon combustion. The Yaris GR platform that competes in the Rally1 championship is based off of the Toyota Yaris released in 2017 that contains the G16E-GTS engine which complies with Euro 6 legislation. The table below shows the Euro 6 standards for Petrol and Diesel passenger cars.

Table 1 – Euro 6 Emissions limit

(<https://www.theaa.com/driving-advice/fuels-environment/euro-emissions-standards>)

Euro 6 Emissions Limits				
	CO	HC	NOx	PM
Petrol	1.0 g/km	0.10 g/km	0.06 g/km	0.005 g/km
Diesel	0.50 g/km	0.17 g/km	0.08 g/km	0.005 g/km

Since the automotive industry is under pressure to find alternative fuels for their vehicles due to the effects that Fossil Fuels have on the environment, sustainability has become an important factor in both the transport and motorsport sector. From the 2022 World Rally Championship (WRC) season the Fédération Internationale de l'Automobile (FIA) have decided to make the Rally1 their first championship to use 100% renewable synthetic biofuel supplied in partnership with P1 fuels that is compatible with existing Internal Combustion Engines (ICE). Figure 3 shows the process in which P1 fuel make the fuel that will be used from the 2022 WRC season.

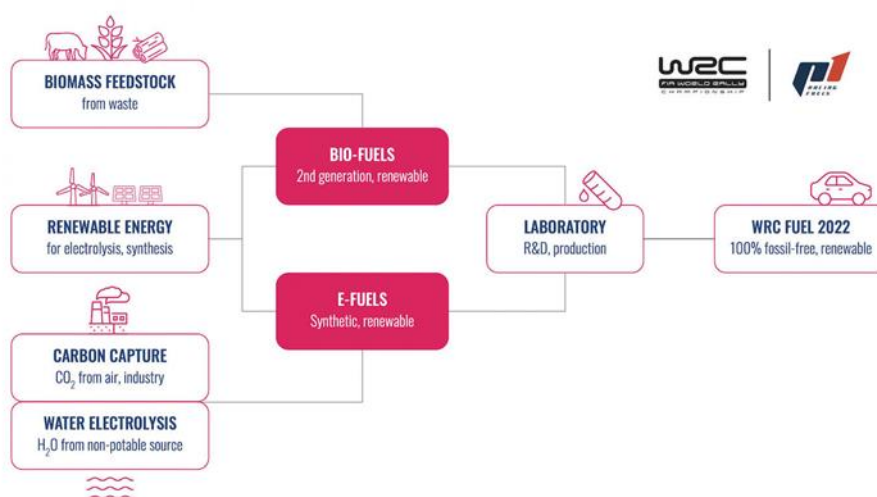


Figure 3 - P1 Fuels process

(<https://www.wrc.com/en/news/2021/wrc/fia-wrc-switches-to-100--sustainable-fuel-from-2022-p1-racing-fuels-as-exclusive-provider/>)

2.3 Aerodynamics

Aerodynamics is the study of how air flows in and around an object. When a vehicle is in motion, it interacts with the air molecules which exerts forces on the surfaces through pressure (Tudor, 2022).

Manipulating the aerodynamic effect on vehicles has become an increasingly important aspect of vehicle design in both road use and motorsport as it can increase performance and reduce fuel consumption by reducing the drag coefficient (Bhingare and Dhamale, 2019). The drag coefficient is a resulting force on a shape that directly opposes downforce, the more drag a vehicle produces due to its interaction with the air, the more work done is required for the same result. Figure 4 shows the effect of drag on a vehicle in terms of lift and downforce.

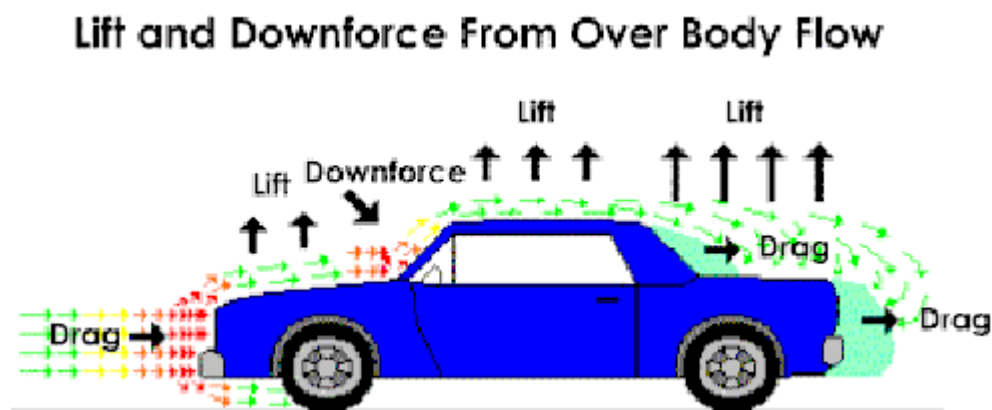


Figure 4 – Drag/Downforce flow (Tudor, 2022)



Figure 5 - Yaris GR vs Rally1 GR Comparison

Figure 5 shows a comparison of the bodywork between the road model of the Toyota Yaris GR (top) and the Rally1 modified GR Yaris (bottom). The Rally1 GR Yaris has a much wider body and a larger wing to aid in downforce and to redirect air around the car to aid performance and to cool components especially after the introduction of the Hybrid unit. The WRC introduced regulations for the 2022 season which prohibited elements such as the rear diffuser which decreases the amount of downforce that the car can generate.

2.4 Computational Methods

Computer Aided Design (CAD) and Computer Aided Engineering (CAE) are fundamental aspects of automotive engineering today. They allow us the tools to design parts and whole components for a specific application or several applications which we can then use software to simulate different conditions on the design or structure to analyse integrity and if it will perform under the required parameters. Components can be created using CAD software and made out of many different materials from steel to carbon fibre which allows rapid testing of designs without the need of prototype manufacturing (Noble, 2022). These designs can then be run in CAE software which can be set to apply loads in specific ways or to simulate the effects air has on the components for aerodynamic performance.

Many of the original component designs that were manufactured and available on the road model Yaris GR are created by smaller companies that design and manufacture components and systems to a specification set by Toyota. There are 5 tiers to the supply chain in the automotive sector in part design as shown in figure 6 below, each chain consists of different suppliers that cover things from brake calipers to pistons and gearboxes. Depending on cost, reliability and scale, an OEM may produce the part themselves or outsource it.



Figure 6 - CAD design tier (Noble, 2022)

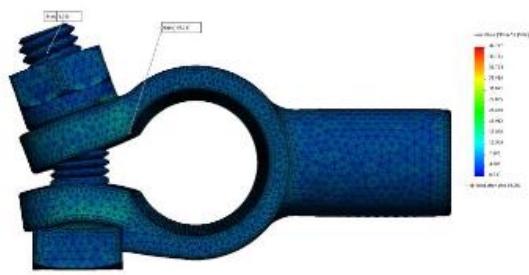


Figure 5. Von Mises stresses obtained for 500N load and 27°C

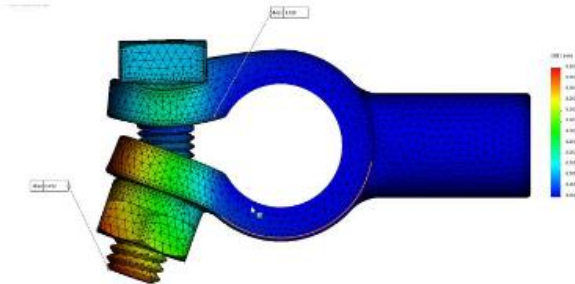


Figure 6. Displacements obtained for 500N load and 27°C

Figure 7 - CAE of a Tightening screw ((Stroia et al., 2020)

Figure 7 shows an example of how CAE gives results depending on the parameters set. In this case a load and a temperature were applied to the component resulting in a coloured diagram showing the stress forces. Areas that are blue show a low stress, however the red areas are the areas that are under the most stress.

Components that are produced go under this process depending on the requirements to see whether the structure, design and material are able to perform the task without being damaged or deform.

2.5 Manufacturing

Manufacturing decisions would have impacted the design of the Yaris GR as the materials Toyota decide on using for each component would have required different steps and production methods in order to produce them to the specification needed. There are many different manufacturing methods involved in the production of automotive vehicles and motorsport vehicles such as the Rally1 Yaris GR from casting which is a process in which a molten liquid is poured into a mould which then cools to produce the part required such as an engine block. Other methods such as Forging are typically used for components such as pistons which allow for improved strength properties and minimal wastage; however disadvantages include limitations in shape forming and the initial cost can be greater than other methods.

Manufacturing components is the most important part of developing a vehicle due to the cost involvement and due to finding out whether the CAE results will be consistent and correct in a real-world setting. Manufacturing components usually requires specialized tools and moulds that have been specifically designed to create those parts, getting any part of the design wrong or incorrect can be costly for a manufacturer if these tools need to be replaced or altered to produce a new specification part.

2.6 Maths in Engineering

Specifically looking at the damper system in the Rally1 Championship, many mathematical methods are used to find the rates of change over time. The damper system compresses and rebounds during loads exerted on the suspension which affects the oscillatory movement within the system. Depending on the amount of damping applied to a system, they can show different types of oscillations (Sutton, 2022). Being able to predict and map the damping system of the Yaris GR rally car allows for a more controlled drive as if the system is underdamped it would take longer for the car to reach equilibrium making it difficult to drive on terrain that is constantly changing, opposite to overdamping which is when the mass slowly returns to rest without overshooting.

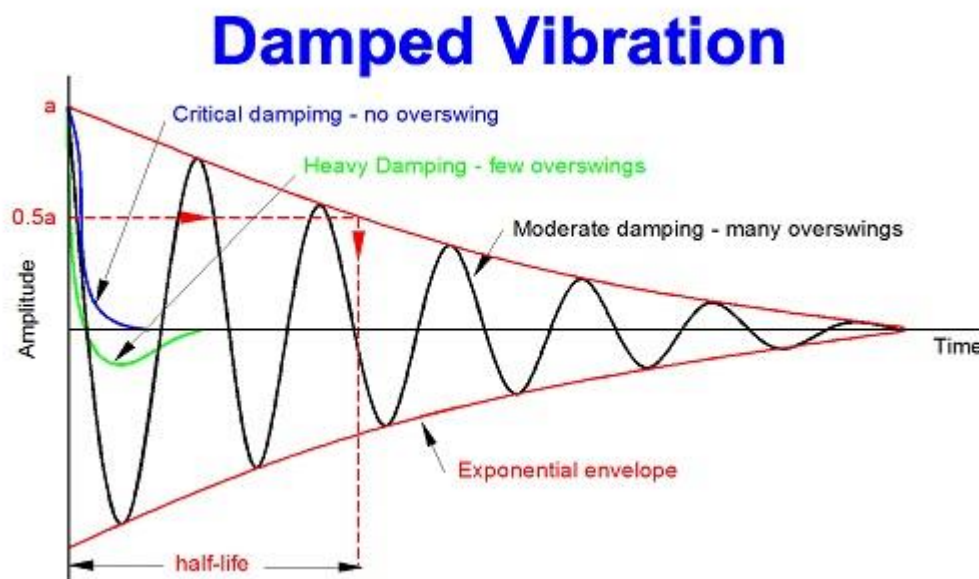


Figure 8- Damper Vibrations (<https://www.helitune.com/Knowledge-Base/Glossary/Damping>)

Figure 8 shows the 3 systems of damping and how the amplitude changes with time.

2.7 Hybrids

In 2022 the WRC introduced a regulation requiring all competitors to implement a hybrid system consisting of a battery and electric motor. The hybrid unit is standardised across the competition meaning all teams must use the same 3.9kWh battery supplied by Compact Dynamics which delivers an additional 100kW and 180Nm of Torque with the manufacturers ICE. The unit regenerates energy under braking via a Motor Generating Unit (MGU) which is then fed back to the battery to reduce fuel consumption and to aid in performance (WRC car tech specs & regulations: what we know so far – WRCWings, 2021).

2.8 Data Acquisition

Data acquisition is a vital part of the development of the Yaris GR due to competing in the WRC. Data recording instruments are connected to the Electronic Control Unit (ECU) of the car which allows the team to record data from acceleration, deceleration, spring & damper rates. This allows the teams to find how they can improve the setup of their car to increase overall performance or in certain sections depending on the strengths and weaknesses of their package. Access to this data also means that any issues that they may have had during a race or session can be troubleshooted and potentially be fixed by altering their setup or even designing parts that may perform better.

3 Current state of the industry

As alternative fuels and methods of powering vehicles continue to improve and increase in overall production, the current state of the industry seems to be improving from the state of unknowns due to the fossil fuel crisis. The WRC making the decision to incorporate these technologies into their championship after a history of using fossil fuels shows us that finding sustainable and greener methods is the direction that manufacturers should go, in both motorsport and automotive sectors as Toyota have shown with their Yaris platform.

4 Conclusion

In conclusion we can see that a lot of the design and manufacturing of the Toyota Yaris that competes in the WRC is a result of the decisions that were made by Toyota in the production of their road model. The different requirements from Aerodynamics to the ability to withstand forces exerted on different components is a major advantage that can be taken to competition if the right choices are made in development.

However, from limited data from Toyota on the details of the Yaris GR and the crossover to the Rally1 championship, inconclusive evidence of the parts that were either replicated for competition or not required or used due to regulations could not be fully explored.

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