Drag Reduction System Proposal Technical Report

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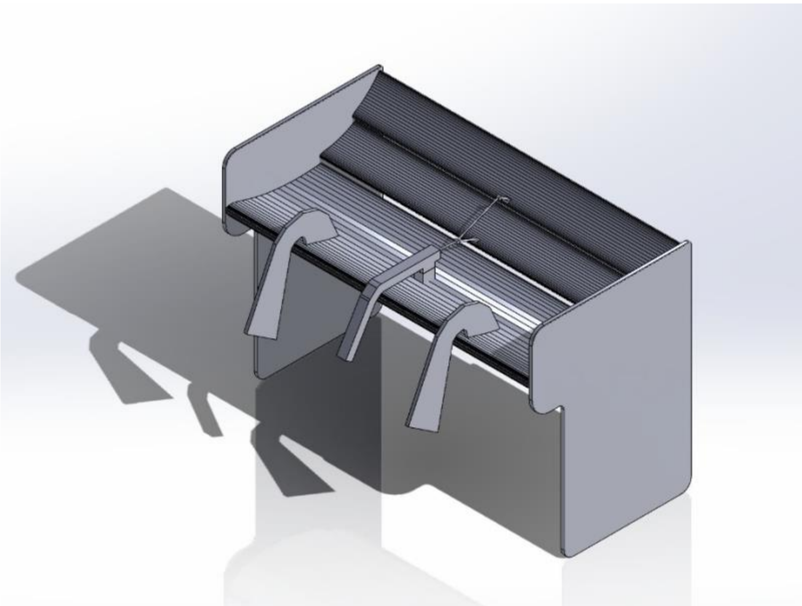


Contents:

Abstract:

The purpose of this report was to research and understand the advantages and disadvantages of a DRS (drag reduction system) and to develop our 2D aerodynamic analysis by creating our own DRS design. We made a 3 element wing with 2 actuating flaps, this system is capable of reducing the drag coefficient by a factor of 53%

Introduction:

A track has many different turns and corners that require high downforce to keep the car planted. This is to have enough traction to keep the tires gripping on the tarmac. All the while building a car with high downforce can be good, this can act as a significant disadvantage when battling side by side on straights due to the difference in drag. No matter how fast your car is around corners, if the opposing car is close enough behind and is faster on straights, they will overtake and become a nuisance in bendier sectors when overtaking is much more difficult.

To combat this, a system called Drag Reduction System can be implemented. A mechanism can be used with the rear wing that can open. The downforce required for turns is reduced as opening the wing allows the airflow to pass through. This results in a significant reduction in drag and much higher straight-line speeds.

Creating a mechanism for this can be difficult as finding the right balance of downforce and weight. A large wing with two flaps can provide more downforce but adds to the weight of the car, even with DRS open the weight of the wing and the mechanism can be very detrimental. A smaller wing with one flap has less weight will produce results with less downforce but higher straight-line speeds. Therefore, we must find the perfect balance by designing and testing within regulations of the Formula Student competition.

Since the purpose of writing up this report is to develop our understanding of vehicle dynamics and with our limited computational fluid dynamics skills we will be using JavaFoil a basic 2D aerodynamics analysis software to develop our DRS profile. Although limited in some aspects JavaFoil suits our needs as we can focus on the key principles such as lift and drag coefficients as well the pressure fields.

Research:

Event analysis [1]:

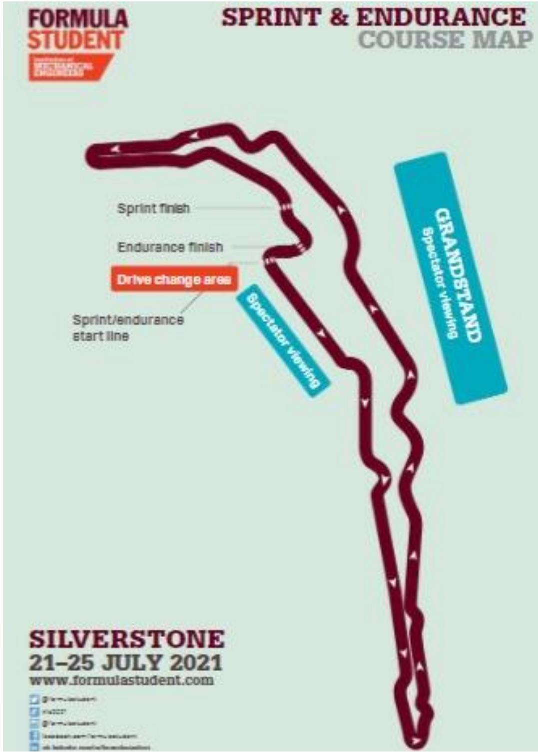


Figure 1

Skidpad Event

The event consists of two pairs of concentric circles in a figure of eight pattern. Cones are placed around the inside and outside of each circle creating a 3m wide path that allows the cars to maneuver around the course. This event mainly tests low speed aerodynamics and handling as it requires the car to travel the full circumference of a loop with an outer diameter of 21.25m and an inner diameter of 18.25m. The front and rear wing plays a massive part in keeping the car grounded to achieve as much traction as possible through the long left or right handers. This event requires the highest downforce and best suits the DRS mechanism to be closed as it produces the downforce needed for cornering.

Acceleration Event

This event consists of a 75m straight line that is 3m wide and measures how quick a team's car can cover that distance from a standing start. The event mainly tests how the drag of the car affects their acceleration. This event requires the lowest downforce and best suits the DRS mechanism open as it eliminates as much drag as possible to accelerate the car to its maximum velocity.

Autocross Event

This event consists of straights no longer than 80m, constant turns up to 50m diameter, hairpin turns with a minimum outside diameter of 9m, slaloms with cones spaced 7.5m to 12m out and few miscellaneous obstacles such as chicane, multiple turns and decreasing radius turns. This event tests how the car performs overall with its complex layout. It tests both handling and straight-line speeds and best suits the DRS mechanism open for the straights.

Endurance and Efficiency Event

This event consists of a track with the same constraints as the autocross event. The length of one lap is approximately 1km and the full event is 22km. This event tests how the aerodynamics of the car affects performance over a long period of time. As well as how the aerodynamics are set up, it is a test alongside the engine to see how efficient the car is. This event tests both handling and straight-line speeds and best suits the DRS mechanism open for the straights.

Trackdrive Event

This event consists of a track with the same constraints as the autocross event. However, the length of one lap is approximately 200m to 500m long. The times of two runs of 10 laps are taken down and as Tmax and Tmin. The formula to calculate the score is 150*((Tteam/Tmin)-1) where Tteam is the team's corrected elapsed time and Tmax is 2 times of the correct elapsed time of the fastest vehicle over all runs. This event tests handling, straight-line speeds, endurance and efficiency and it best suits the DRS mechanism open for the straights.

Rules & Regulations [2]:

Aerodynamic Devices:

T8.2.1 Height restrictions:

o All aerodynamic devices forward of a vertical plane through the rearmost portion of the front face of the driver head restraint support, excluding any padding, set to its most rearward position, must be lower than 500mm from the ground.

o All aerodynamic devices in front of the front axle and extending further outboard than the most inboard point of the front tire/wheel must be lower than 250mm from the ground.

o All aerodynamic devices rearward of a vertical plane through the rearmost portion of the front face of the driver head restraint support, excluding any padding, set to its most rearward position must be lower than 1.2m from the ground.

T8.2.2 Width restrictions:
o All aerodynamic devices lower than 500mm from the ground and further rearward than the front axle, must not be wider than a vertical plane touching the most outboard point of the front and rear wheel/tire.
o All aerodynamic devices higher than 500mm from the ground, must not extend outboard of the most inboard point of the rear wheel/tire.

T8.2.3 Length restrictions:
• All aerodynamic devices must not extend further rearward than 250mm from the rearmost part of the rear tires.
• All aerodynamic devices must not extend further forward than 700mm from the fronts of the front tires.
T8.2.4 All restrictions must be fulfilled with the wheels pointing straight and with any suspension setup with or without a driver seated in the vehicle.
T8.4.1 Any aerodynamic device must be able to withstand a force of 200 N distributed over a minimum surface of 225 cm2 and not deflect more than 10mm in the load carrying direction.
T8.4.2 Any aerodynamic device must be able to withstand a force of 50 N applied in any direction at any point and not deflect more than 25 mm.

Actuators:

Compressed Gas Systems

T9.1.1 Any system on the vehicle that uses a compressed gas as an actuating medium must

comply with the following requirements:

• The working gas must be nonflammable.

• The pressure inside compressed gas systems must not exceed 10 bar.

• Compressed gas cylinders/tanks may exceed the 10 bar limit, if a pressure regulator,

which limits the output pressure to a maximum of 10 bar, is mounted directly onto them.

• Gas cylinders/tanks must be of proprietary manufacture, designed and built for the

pressure being used, certified and labeled or stamped appropriately.

• Gas cylinders/tanks and lines must be protected from rollover, collision from any

direction, or damage resulting from the failure of rotating equipment.

• Gas cylinders/tanks and their pressure regulators must be located within the rollover

protection envelope T1.1.14, but must not be located in the cockpit.

• Gas cylinders/tanks must be securely mounted to the chassis, engine or transmission.

• The axis of gas cylinders/tanks must not point at the driver.

• Gas cylinders/tanks must be insulated from any heat sources.
• All used parts must be appropriate for the maximum possible operating pressure.

High Pressure Hydraulic Pumps and Lines

T9.2.1 The driver and anyone standing outside the vehicle must be shielded from any hydraulic pumps and lines with line pressures of 2100 kPa or higher. The shields must be steel or aluminum with a minimum thickness of 1 mm. Brake lines are not considered as high pressure hydraulic lines.

Other limitations:

Top Speed:
70mph to 80mph [3] & [4]
Top Speed on corners:
15mph-25mph [Reports 1,2 & 3]

The baseline 2014 Formula Student vehicle with no aerodynamic devices displays a drag coefficient of CD=0.71 and a positive lift coefficient of CL=0.21.

Case Studies:

Royal Institute of Technology Sweden – Aerodynamic Development of a Formula Student Race Car 2014

Calculations:

Top Speed
With no aero package a car with a 0.9m^2 frontal area, a drag coefficient of 0.85 and a max power of 85 kW has a theoretical top speed of 204kmh/126mph. With a maximum speed of 125kph/78mph and a frontal area of 1.2m^2 the maximum drag coefficient with an aero package is 2.76, although this value includes the front wing and undertray it is a very high drag coefficient suggesting that an aero package will not limit the top speed of a formula student car given the constraint of the relatively short straights which limit the top speed including the acceleration event.

Cornering:
Maximum cornering speed with a lift coefficient value of 1.7 vs no downforce for corners with radii varying from 4m to 30m (Formula Student Germany Course)

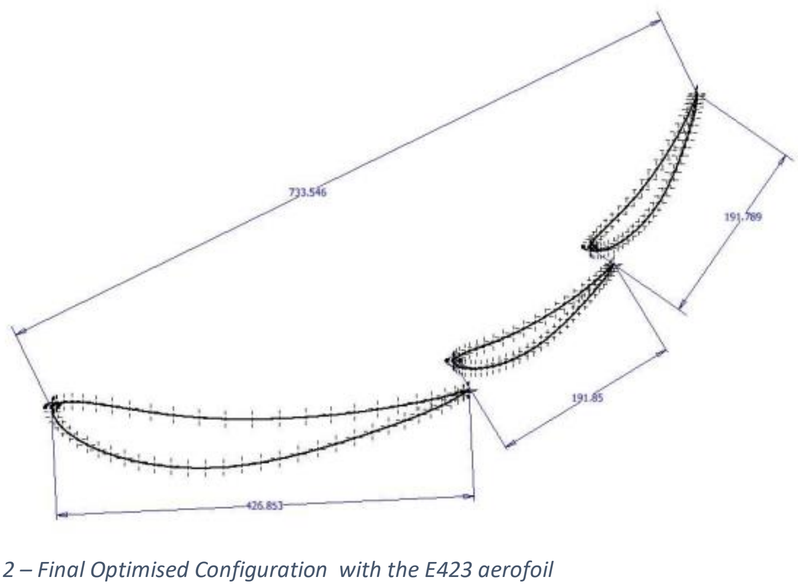


Figure 2 – Final Optimised Configuration with the E423 aerofoil

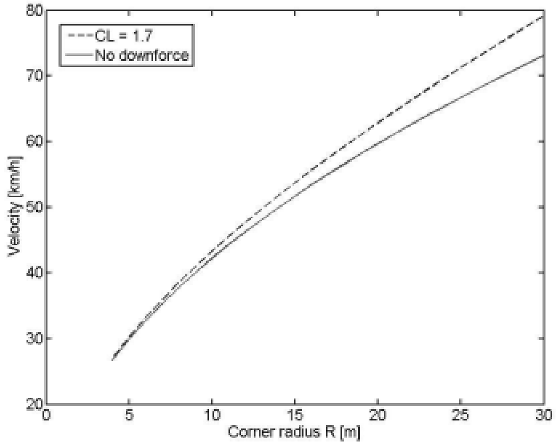


Figure 3

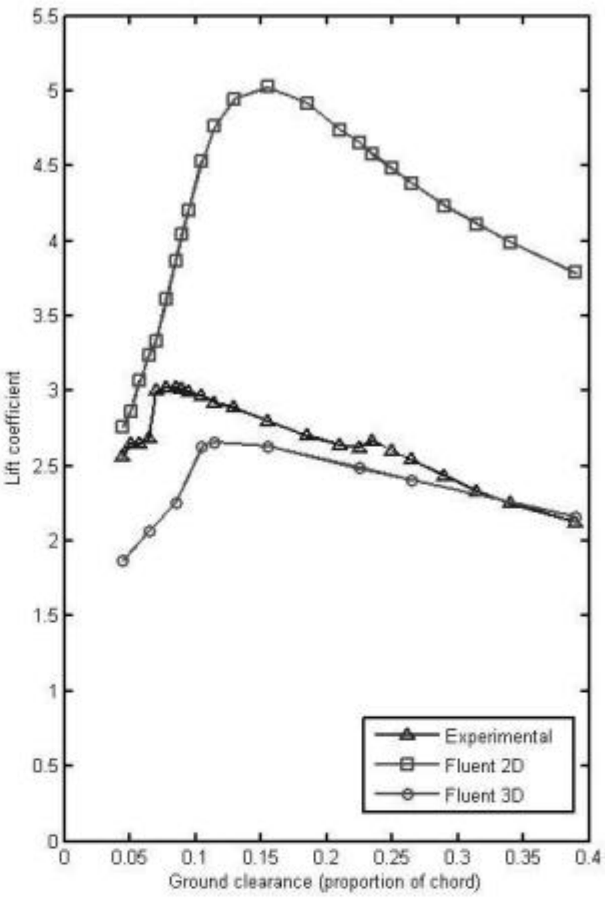


Figure 4

Figure 4 shows that 2D and even 3D simulation can vary from experimental values. JavaFoil according to it’s developers suffers from exactly this even when compared to other 2D software. If we were to manufacture and incorporate our DRS to the QMFS car further 2D and 3D simulations would be required before finalisation of the CAD.

University of Thessaly - Design and development of an Aerodynamic Package for an FSAE Race Car 2017

Final Models	Frontal Area(m^2)	Lift Coefficient(C_L)	Drag Coefficient(C_D)	Downforce(N)	Drag(N)	Ratio C_L/C_D
No Aerodynamic Devices	0.728	0.286	0.426	-38.42	58.42	0.67
Undertray & Sidepods	0.799	-0.668	0.532	108.87	81.24	1.26
Front & Rear Wings	1.019	-1.898	0.82	342.46	148.04	2.31

Figure 5

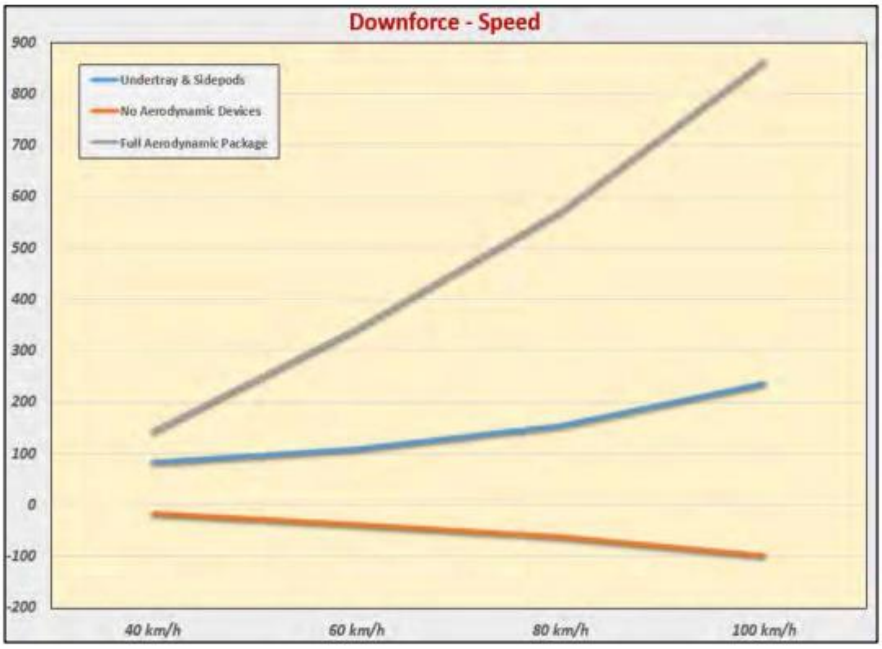


Figure 6

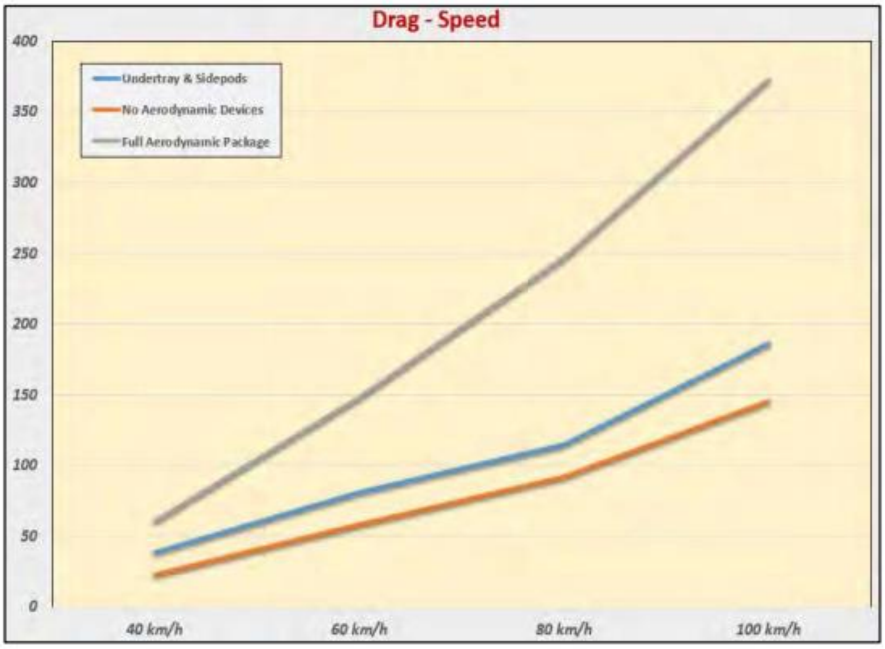


Figure 7

From Figures 5 ,6 & 7 we can see the clear advantage in terms of downforce of an aerodynamic package. The car analysed for this report would be dangerous for the driver and other competitors at and near its top speed due to the high lift force of 100N. The front and rear wings increase the CL/Cd ratio by a factor of 3.4x which is a significant improvement.

Aerodynamic optimisation of Formula student vehicle using computational fluid dynamics Frankie F. Jackson, University of Huddersfield 2018

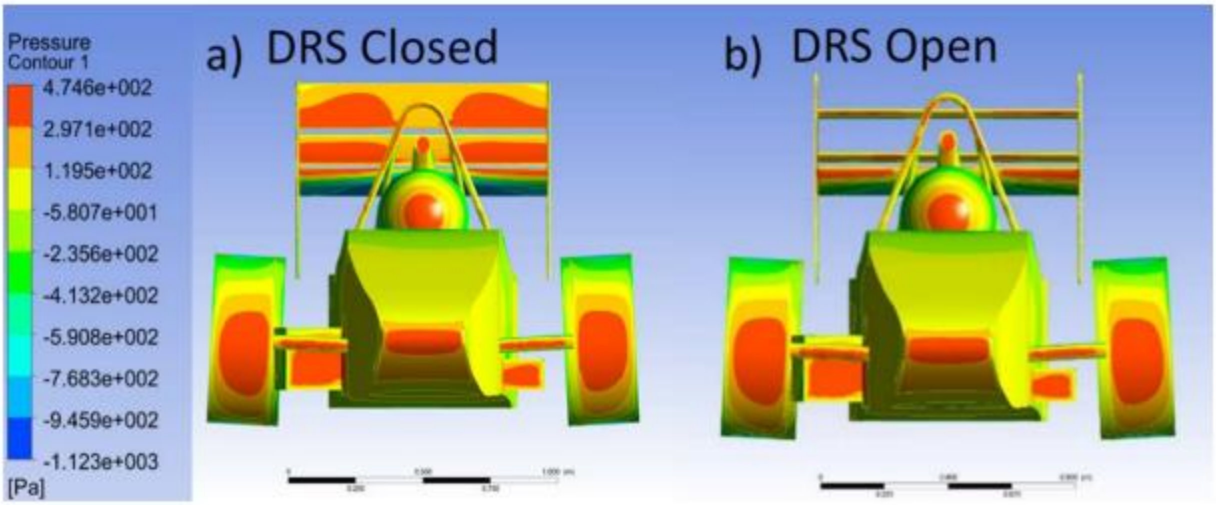


Figure 8

At 26,8m/s

DRS closed – Frontal Area: 1.18 m^2 CL:1.15 CD 1.21:

DRS open – Frontal Area: 0.99 m^2 CL: 0.26 CD: 0.79

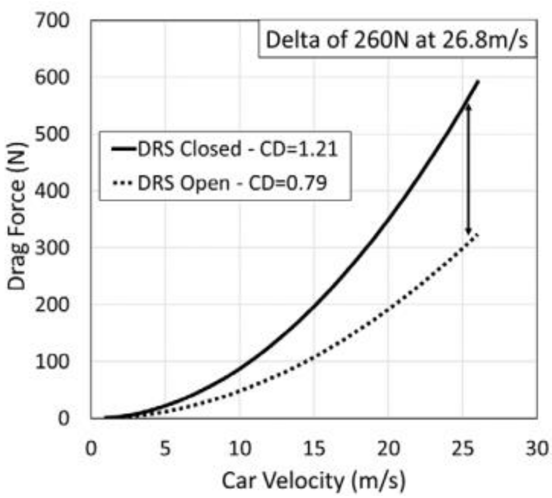


Figure 9

The resulting reduction in drag force was calculated to be 35% with the DRS open

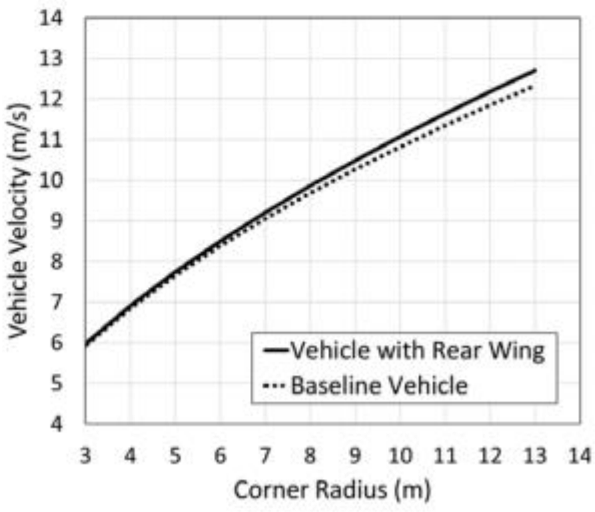


Figure 10

This graph suggests there is a relatively small increase in the maximum speed with the addition of rear wing which supports the data presented in the report by the Technical Institute of Sweden

Materials:
Aluminum – lower cost source and manufacturing process, simpler manufacturing process
Carbon reinforced polymer – greater stiffness to weight ratio, ~40%lighter for similar or greater strength depending on exact material choice
Fiberglass reinforced polymer – lower cost alternative to carbon fiber but less stiff and strong

Key Properties:
Light weight
Smooth (to reduce skin friction)
Satisfy the Rules
-Stiff /high Young's Modulus
High yield Strength in all directions (isotropic)

Manufacturing:

Carbon Fiber:
Complex processes can be performed by sponsors who have the experience and precise tooling required
Molds are constructed using vacuum forming or 3D printing for smaller components
Hollow inside, upper and lower surfaces constructed separately then glued together and bolted to end plates which are sandwiched with a stiff polymer or aluminum sheet.
Wet lay up is the most simple process and does not require expensive machinery.

Simulating the wing:
Solid works is a beneficial application which will be used to model and simulate the wing. Surface modelling is the most relevant approach to this aspect of the car and will therefore be utilized in designing the rear wing shape.
Testing the wing:
To test the effectiveness of the rear wing design, the Java Foil application will be most useful in determining whether the wing would produce advantageous results in reducing drag and increasing the streamlining properties. The application works by observing the geometry of the wing and then determines useful characteristics such as drag and lift data.

Actuators:

Subsystem (DRS actuator)

There are four main actuation types, which are electric, pneumatic, hydraulic, and mechanical:

- Hydraulic actuators can keep a high constant force and torque; however, the slow activation speeds and increased weight are a big downside.

- Pneumatic actuators are driven by air pressure rather than fluids, which means they are extremely fast, reliable, and consistent with linear motion. A disadvantage is that they can sometimes lose pressure due to excessive compression, which would decrease the effectiveness.

- Electric actuators provide extremely accurate control and positioning. This system is also requires minimal maintenance. However they are not explosion proof and are very sensitive to vibration.

- Mechanical actuators can be very cheap, however they contain many moving parts which are prone to wear. They are also heavier than the other options.

To decide which actuation fits best for the purpose, it is important to discuss the features such as weight, actuation speed, and cost.

- Cost: When talking about the cost, it is important to consider not only the material and devices that would be required, but also the manufacturing process. Electric actuators become expensive when we look for fast motion and light weight. However, pneumatic devices are cheaper. Nevertheless, the pneumatic actuation requires more devices, including an electro valve, an air compressed tank and braided hose.

- Actuation Speed: This feature is controversial. Both systems can be extremely fast if you are willing to pay the price. While it is true that all pneumatic systems are fast using Medium-High speed, electric systems are normally slow. Electric actuators designed for racing are necessary to be fast enough.

- Weight: This feature is similar for both electric and pneumatic. the electric actuators are heavier than pneumatic ones but summing all the pneumatic components the overall weight of the pneumatic version overcomes the electrical.

The hydraulic actuators can keep a high constant force and torque; however, the slow activation speeds and increased weight are a big downside. Pneumatic actuators are driven by air pressure rather than fluids, which means they are extremely fast, reliable, and consistent with linear motion. They can also consistently operate in extremely high or low temperatures, which would cause problems for the fluid-driven hydraulic actuators. A disadvantage is that they can sometimes lose pressure due to excessive compression, which would decrease the effectiveness. It is also important to keep the system well maintained, as air contamination increases the risk of damage.

Existing DRS Actuator Solutions

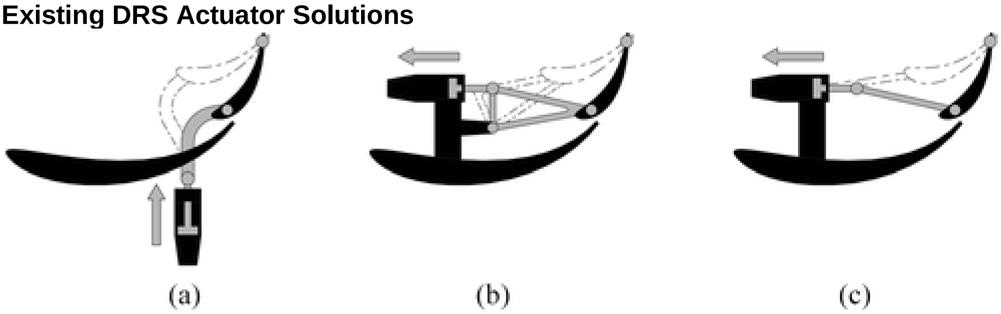


Figure 11. *Existing DRS solutions: (a) push-up type, (b) pod-rocker type and (c) pod-pull type. Closed configuration is shown in filled greyscale view, whereas open configuration is contoured by a dashed line.*

Push-up type In this system, the actuator sits inside a vertical pillar below the mainplane. This system is simple and economic because it requires only a link between actuator and flap, however, it creates aerodynamic disturbance under the surface of the wing. Another advantage of the push-up solution is the ease of access to hydraulic lines for maintenance.

Pod-rocker type In this system, the actuator and a part of the mechanism is included inside a pod, mounted over the mainplane. The actuator pulled on a rocker that increased the leverage of the piston, the rocker then is connected to the leading edge of the flap by link. Thanks to the rocker, this system requires a lower effort to the actuator, and it eliminates any aerodynamic disturbance under the mainplane, since the hydraulic lines pass through the endplate.

Pod-pull type This system is very similar to the pod-rocker solution, but here the mechanism is simplified. It is achieved by replacing the rocker with a single link. Actuator must be supplied with a larger pressure, but this is not a limitation, thanks to the high-pressure hydraulics in use in the vehicle gearbox.

Safety System

It is very important to have a fail-safe system to prevent the upper moving elements to remain open through the corners in case there is a failure in the system. The fail-safe system will consist of a three-way switching valve and air set. The valve positioner will operate as a three-way positioner and supplies air to one side of the piston only. A constant air pressure is maintained on the other side of the piston by the air set. Supply pressure is sensed by the three-way switching valve. If supply pressure drops below a pre-set value, the three-way switching valve will lock the air on the constant pressure which will lock the moving elements into a default closed position.

Aerofoil Analysis:

Calculations:

Coefficient of drag

$$C_D = \frac{2P}{\rho A v^3}$$

$$C_D = \frac{2(56.65\times10^3)}{1.223\times1\times37.6^3} = 1.717$$

Maximum drag coefficient for a top speed of 84mph/135kmh (5% margin)

Value in line with those calculated in cited reports

TECHNICAL SPECIFICATION

Length/height/width/wheelbase 2600/1440/1225/1545
Track 1200/1185
Car weight (approx.) 350 (kgs.)
Weight distribution (approx.) 157.5/192.5
Suspension Double A Arm Wishbone front and rear
Tyres 520/N/a/Hoosier front and rear
Wheels 7 front/7 rear
Brakes Area 198mm^2 front/Area Rear-285mm^2 rear
Chassis Steel Space frame
Engine Honda CBR600RR
Bore/stroke/cylinders/cc 67mm /42.5mm/4/600
Fuel system Manifold Port Injection
Max power/max torque 56.67kW@10,000 RPMrpm/60 NM Nm@9000RPMrpm
Transmission 520 Chain
Differential Drexler Limited Slip Differential
Final drive 3.85

Coefficient of lift:

An optimum range of -1 to -4 was chosen based on the literature review as not enough data was available to make the necessary calculaitons with the effect on max cornering speed minimal.

Since the downforce has a minimal effect on the maximum cornering speed we decided on using a range of drag coefficients based on the literature review with a cap of -4 as JavaFoil run accurate simulations beyond that. Our target range for Cd was -1 to -4

Aerofoil Profile

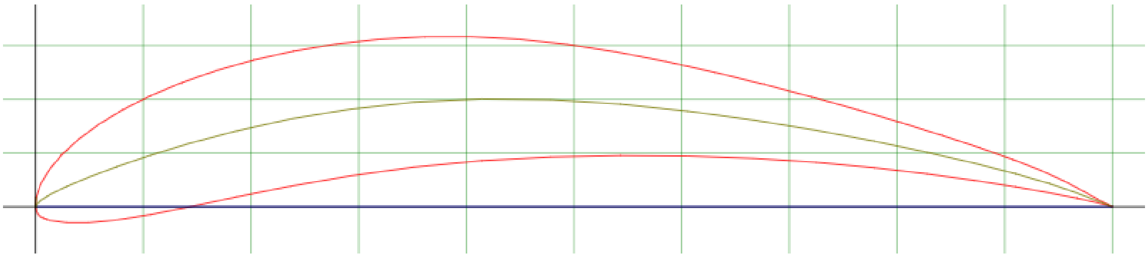
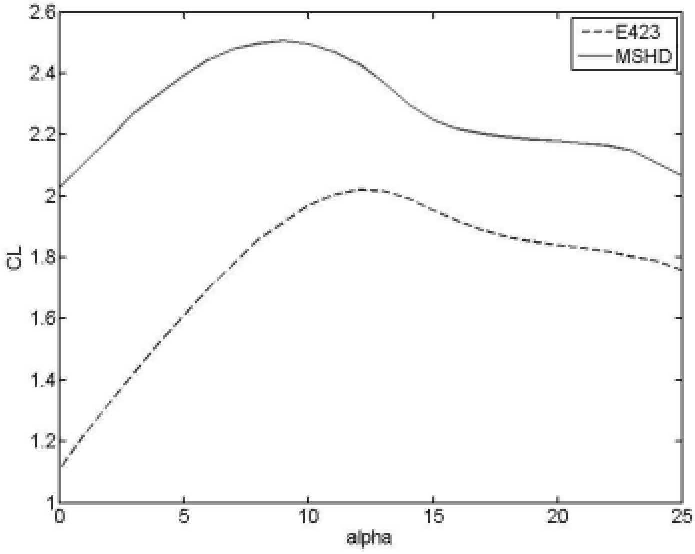


Figure 12 - Eppler E423 high lift aerofoil

This aerofoil was chosen due to its cambered design which allows for higher angles of attack without flow separation and a greater acceleration of the flow over the leading edge. This allows for a greater downforce while maintaining acceptable drag values. Aerofoils which are more chambered were available but had a much thinner trailer edge which would be difficult to manufacture especially with the high quality needed for the load tests. All three cited reports used the E423 aerofoil based on more in depth simulations further supporting our choice.



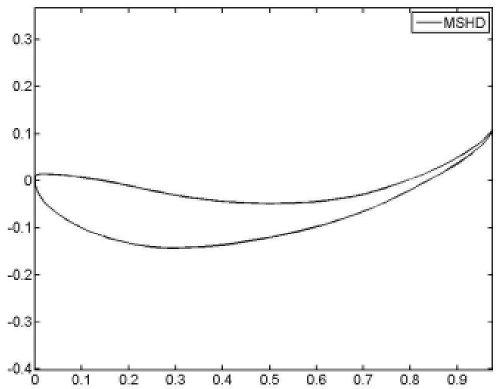


Figure 13 - Comparison of the lift coefficient between the E423 and MSHD aerofoils for different angles of attack
Figure 14 – Profile of the MSHD aerofoil

Number of Elements

3 elements were chosen due to the range in optimum Cl and CD values.

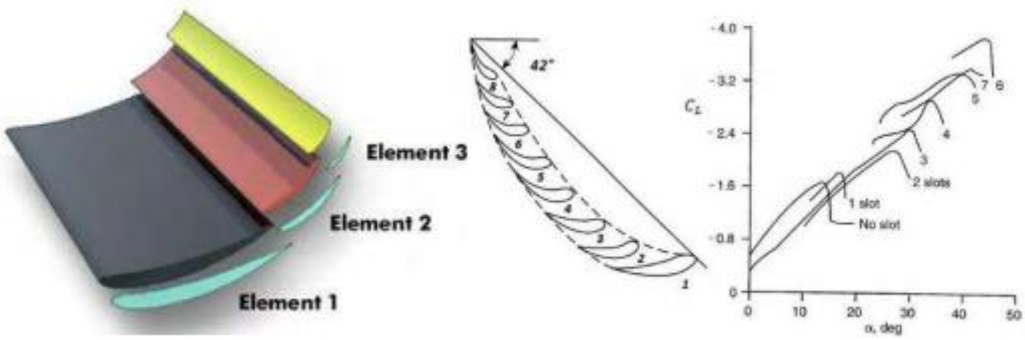


Figure 15 – number of elements optimisation

To make the optimisation process simpler the main factor that was adjusted was the angle of attack with the aerofoil and size ratios of the elements kept the same. The 2nd and 3rd elements are scaled to 40% of the 1st (most left in the figure 1) so that only 2 sets of molds have to be produced. The pivot point was set at the 1/3c and at the centre line for each element and was kept fixed relative to the element to be rotated for each change in angle of attack before all simulations.

To get a rough value for the angle of attack of the the 1st element the other were kept fixed at 25 and 40 degrees these values are from McBeath, 2006.

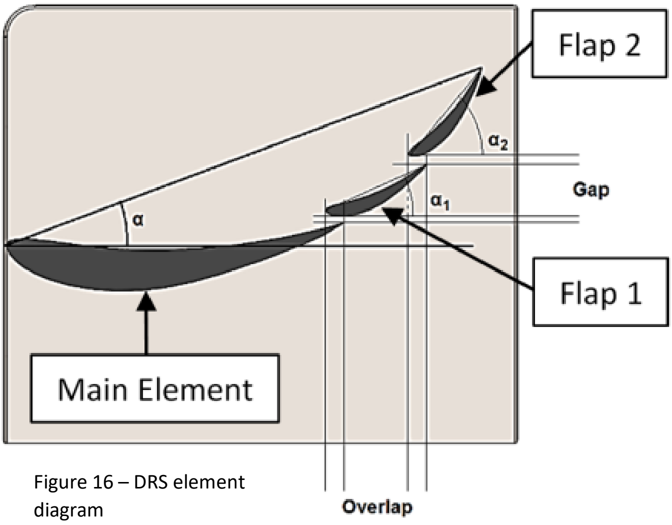


Figure 16 – DRS element diagram

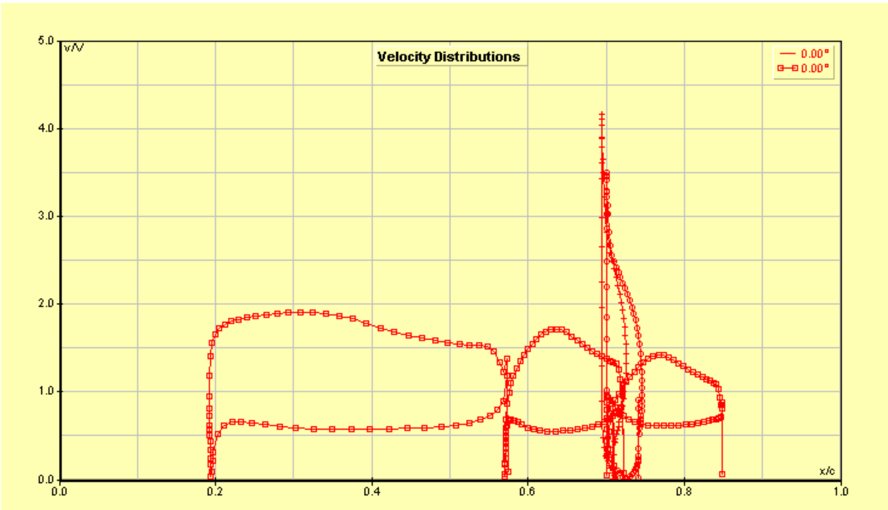


Figure 10 Velocity distribution at 70° angle of attack for the 3rd element with the 1st at 6° and the 2nd at 26°

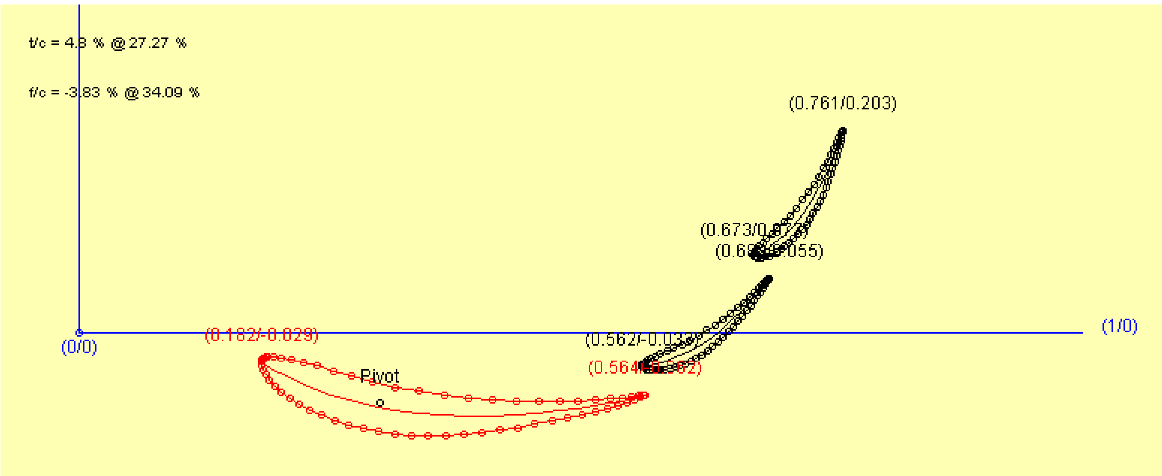
Angles of attack from 30° to 70° were suggested by the literature, to narrow this range simulations were run an increments of 5° for this range. The coefficient of lift decreased from 40° with spikes in the velocity and pressure values seen at greater angles suggesting inaccurate simulations

These were redone with the optimised angles of attack for the other elements.With a rough value for the 1st element the others were optimised with the 2nd element starting at 25 and the 3rd at 40 degrees.

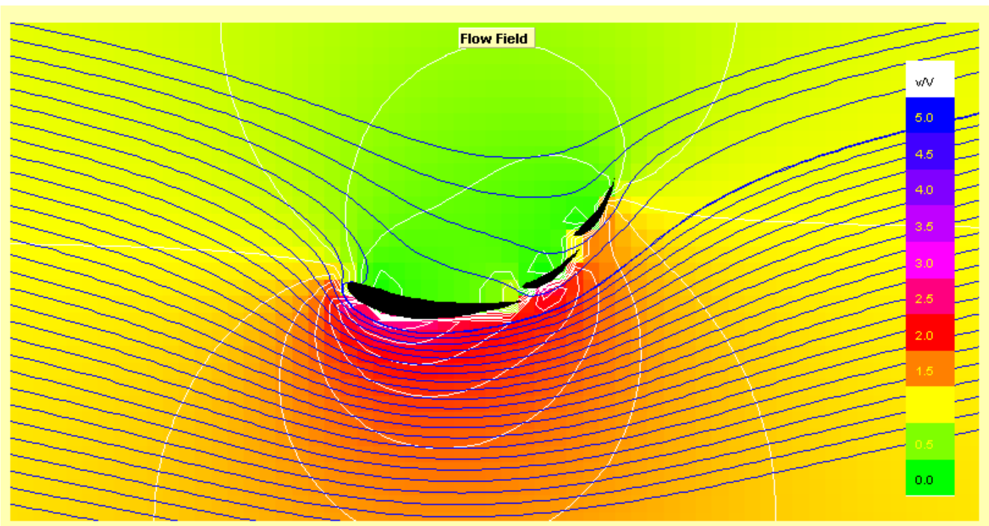
1st Element Angle of Attack Optimisation			
α	CD	Cl	CL/CD
-5	0.17762	-1.213	-6.82919
-4	0.15289	-1.274	-8.33279
-3	0.14030	-1.341	-9.55809
-2	0.12692	-1.414	-11.1409
-1	0.10813	-1.477	-13.6595
0	0.10243	-1.544	-15.0737
1	0.10052	-1.631	-16.2256
2	0.08419	-1.736	20.62003
3	0.08134	-1.825	22.43669
4	0.07510	-1.938	25.80559
5	0.07478	-2.026	27.09281
6	**0.07392**	**-2.107**	**28.50379**
7	0.08031	-2.18	27.14481
8	0.09161	-2.165	23.63279
9	0.09352	-2.196	23.48161
10	0.09533	-2.206	23.14067

2nd Element Angle of Attack Optimisation			
αS1	CD	Cl	CL/CD
-25	**0.06392**	**-2.107**	**32.96308**
-26	0.06328	-2.072	32.74336
-27	0.06473	-2.064	31.8863
-28	0.06887	-2.03	29.47582
-29	0.06921	-1.977	28.56524
-30	0.07064	-1.967	27.84541

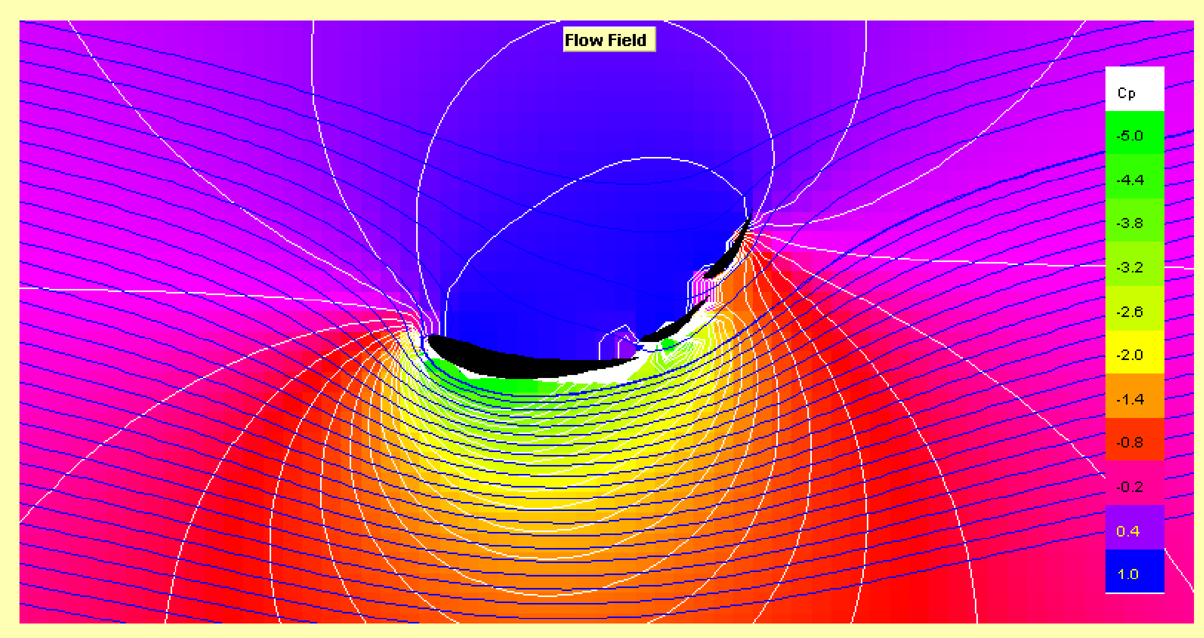
3rd Element Angle of Attack Optimisation			
αS1	CD	Cl	CL/CD
-30	0.06042	-2.03	28.50379
-31	**0.06275**	**-2.042**	**32.54183**
-32	0.06489	-2.041	31.45323
-33	0.06921	-2.051	29.63445
-34	0.07136	-2.082	29.17601
-35	0.07392	-2.107	28.50379
-36	0.07435	-2.11	28.37929
-37	0.07574	-2.142	28.28096
-38	0.0762	-2.152	28.24147
-39	0.07812	-2.159	27.63697
-40	0.07943	-2.168	27.29447
-45	0.08027	1.966	24.49234
-50	0.08425	-1.828	21.69733
-55	0.9356	-1.725	1.843737
-60	0.11864	-1.611	13.57889
-65	0.12348	-1.663	13.46777
-70	-0.88248	-1.566	-1.77454



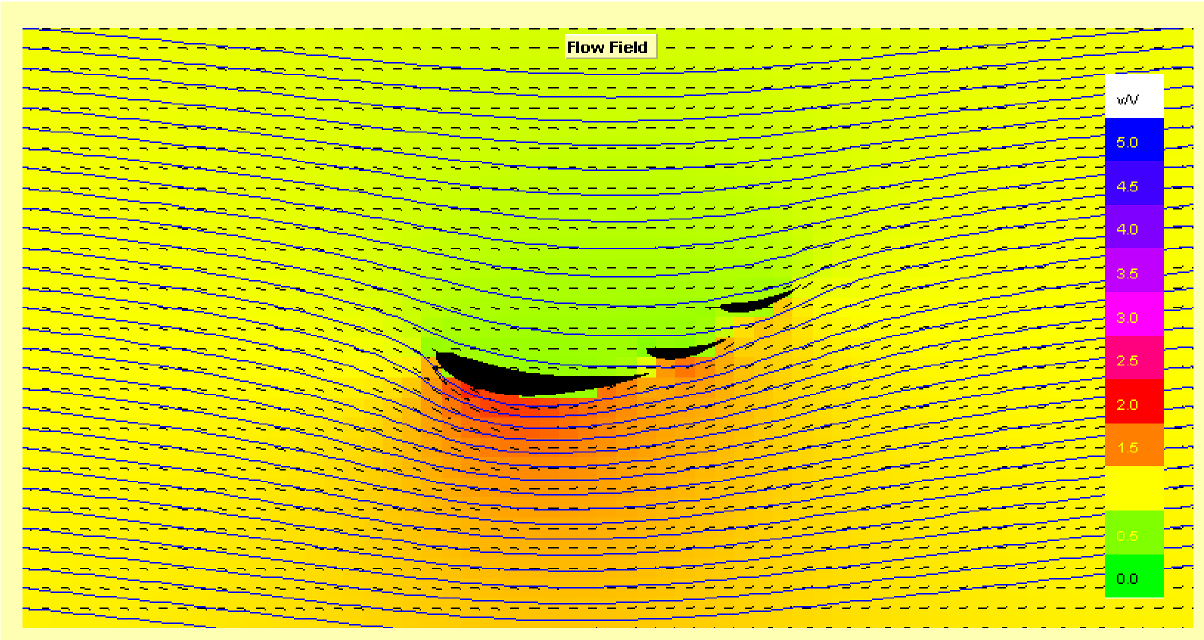
Final Configuration:



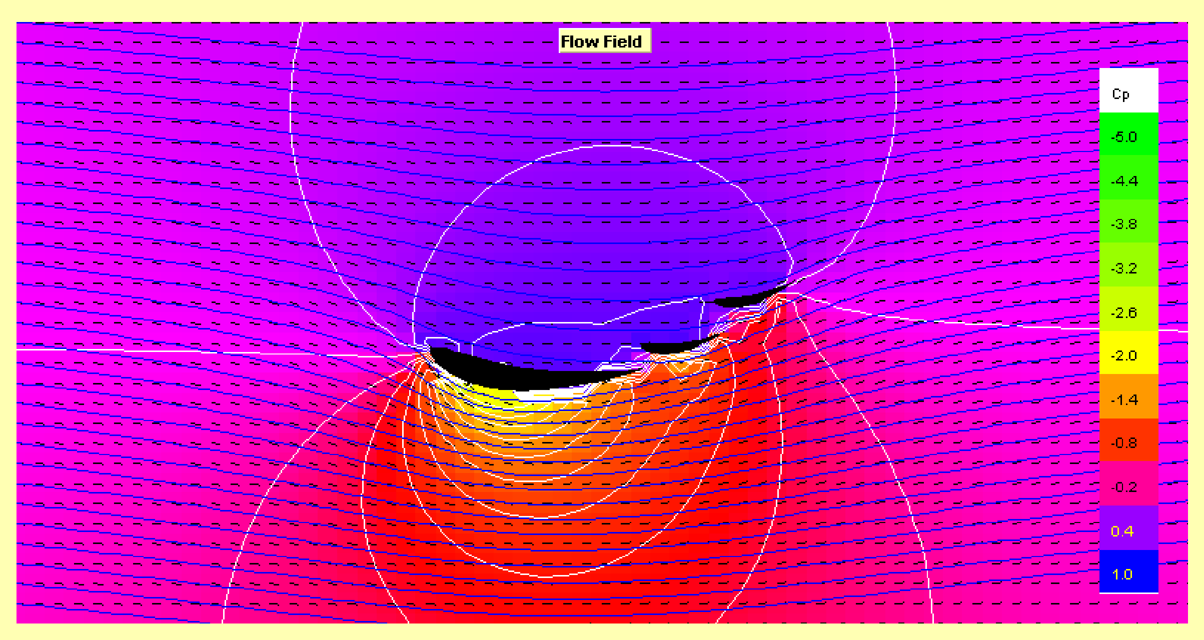
DRS closed (v/V) lift coefficient of -2.009 and drag coefficient of 0.06652



DRS Closed pressure coefficient lift coefficient of -2.009 and drag coefficient of 0.06652



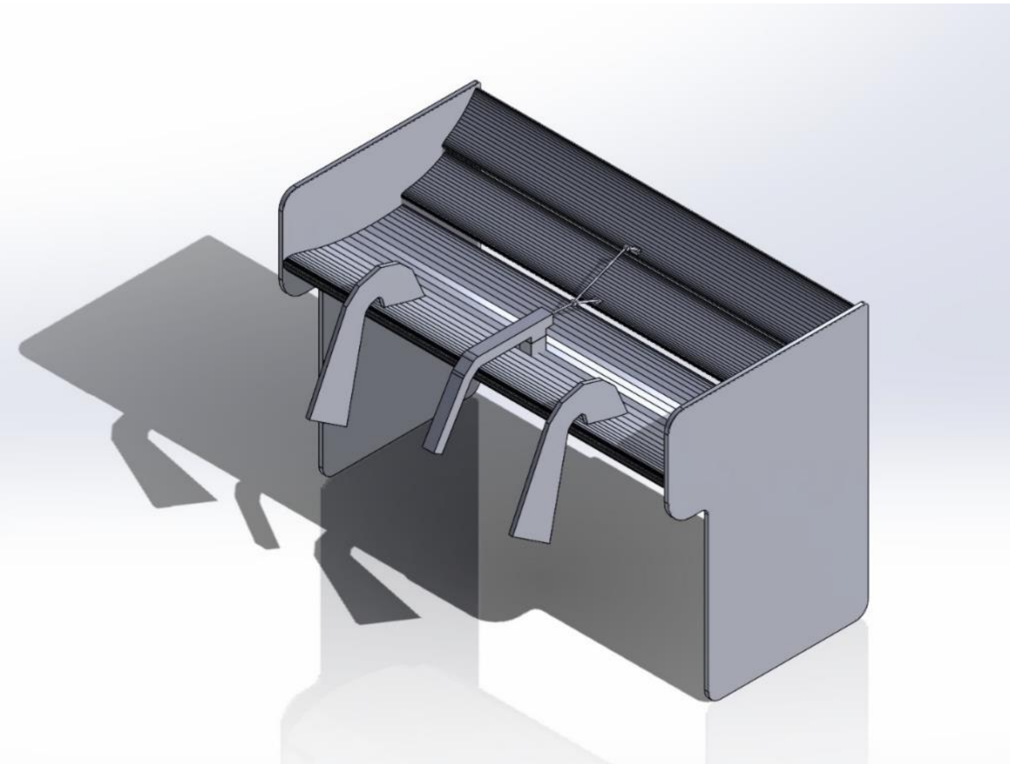
DRS open (v/V) lift coefficient of -1.415 and drag coefficient of 0.03109



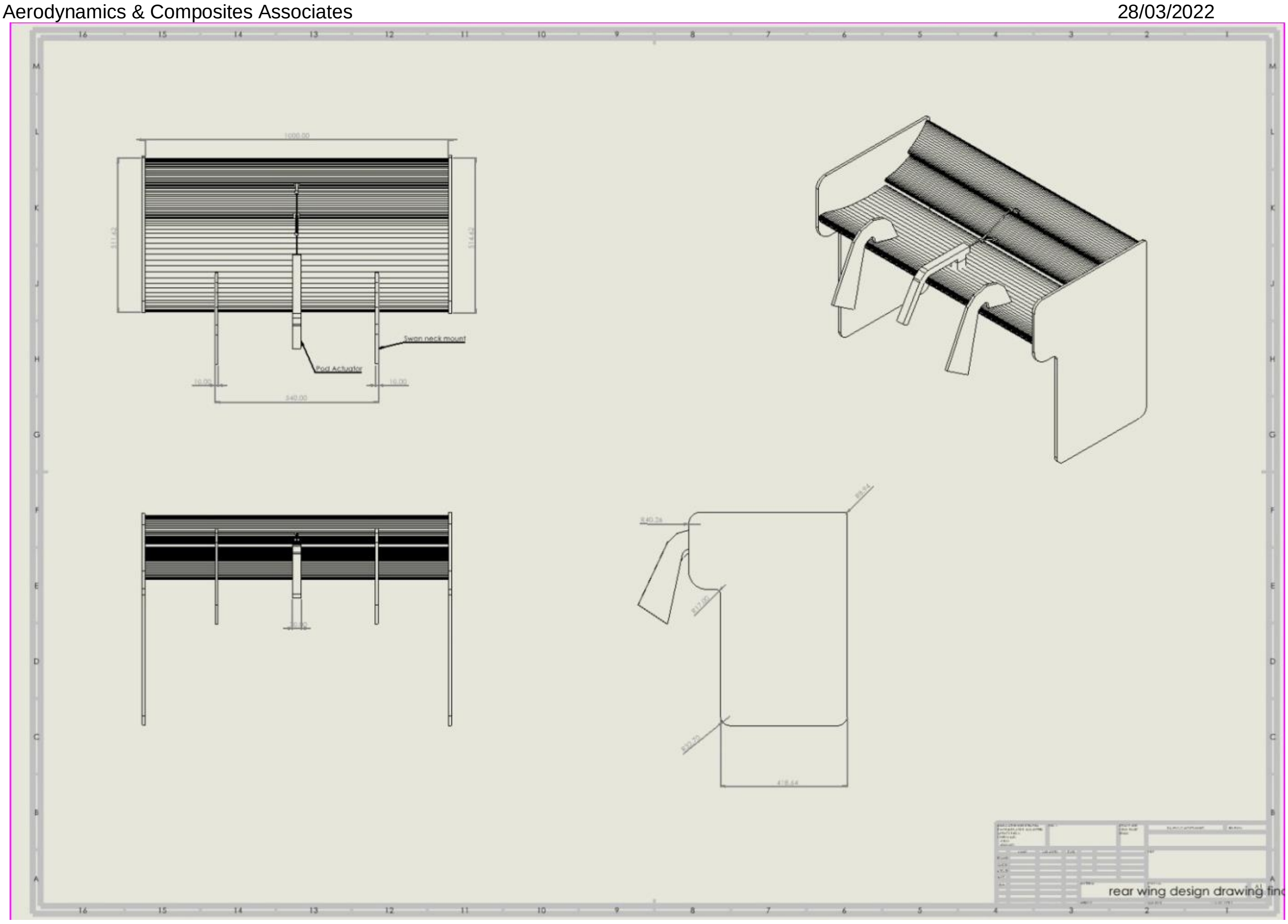
DRS Open pressure coefficient lift coefficient of -1.415 and drag coefficient of 0.03109

Max speed with DRS closed = 209kmh/129mph
Max speed with DRS open= 354kmh/220mph
Although these value are too high for the vehicle these values do not account for the inaccuracy in JavaFoil simulations and the drag of the rest of the car

Final Design:



Engineering Drawings:



Element	Chord Length (mm)
1	307.94
2	123.18
3	123.18

Improvements:

Improvements in general
If we were to do this project again, we would spend a lot more time on the aerofoil analysis, to test out different element shapes, gap changes and element numbers. This would allow us to optimize the aero package of the rear wing and to gain more experience using the software itself. We would also research on how different endplate shapes would affect the airflow, and which would be better suited for our design concept

Design changes for an EV
For an EV vehicle is it important to keep the overall weight as low as possible, since the weight of the batteries can be a huge downside. This would improve the agility of the car around the corners, and thanks to the torque of electric vehicles, the acceleration on corner exit will also be improved. The weight

can also be added higher compared to ICE vehicles, as the centre of gravity is already low thanks to the position of the batteries.

Another design change that can be made is that higher downforce levels can be added to an EV vehicle compared to an ICE car. This is thanks to the superior instant torque with EV vehicles, and also the circuit layout that does not allow cars to reach their potential top speed.

References:

[1] – Imeche Formula Student Rule Book Page 2022

[2] – Imeche Formula Student Rule Book Page 2022

[3] – University of Nottingham Formula Student 2021 top speed

[4] – Simscale

[5]- Burzoni, A., 2019. *An improved active drag reduction system for formula race cars - Mauro Dimastrogiovanni, Giulio Reina, Andrea Burzoni, 2020*. [online] SAGE Journals. Available at: https://journals.sagepub.com/doi/full/10.1177/0954407019862913 [Accessed 7 March 2022].

[6] - Collins, S., n.d. *DRS: The Drag Reduction System explained - Racecar Engineering*. [online] Racecar Engineering. Available at: https://www.racecar-engineering.com/articles/f1/drs-the-drag-reduction-system/ [Accessed 8 March 2022].

[7] -Slideshare.net.2017.*DRSFinalReport*.[online]Availableat: https://www.slideshare.net/SantiagoNapalLaguna/drs-final-report-71195080 [Accessed 8 March 2022].

Figure 1 – Sprint and Endurance Track Layout
Formula Student 2021 handout

Figure 2 - Royal Institute of Technology Sweden – Aerodynamic Development of a Formula Student Race Car 2014

Figure 3 - Royal Institute of Technology Sweden – Aerodynamic Development of a Formula Student Race Car 2014

Figure 4 - Royal Institute of Technology Sweden – Aerodynamic Development of a Formula Student Race Car 2014

Figure 5 - University of Thessaly - Design and development of an Aerodynamic Package for an FSAE Race Car 2017

Figure 6 - University of Thessaly - Design and development of an Aerodynamic Package for an FSAE Race Car 2017

Figure 7 - University of Thessaly - Design and development of an Aerodynamic Package for an FSAE Race Car 2017

Figure 8 - Aerodynamic optimisation of Formula student vehicle using computational fluid dynamics Frankie F. Jackson, University of Huddersfield 2018

Figure 9 - Aerodynamic optimisation of Formula student vehicle using computational fluid dynamics Frankie F. Jackson, University of Huddersfield 2018

Figure 10 - Aerodynamic optimisation of Formula student vehicle using computational fluid dynamics Frankie F. Jackson, University of Huddersfield 2018

Figure 11 - Numerical Study on Aerodynamic Drag Reduction on a Rear Wing of a Formula Student Car MAHIM AHSAN 2021

Figure 12 – Airfoil Tools

Figure 13 - Royal Institute of Technology Sweden – Aerodynamic Development of a Formula Student Race Car 2014

Figure 14 - Royal Institute of Technology Sweden – Aerodynamic Development of a Formula Student Race Car 2014

Figure 15 - University of Thessaly - Design and development of an Aerodynamic Package for an FSAE Race Car 2017

Figure 16 - Aerodynamic optimisation of Formula student vehicle using computational fluid dynamics Frankie F. Jackson, University of Huddersfield 2018