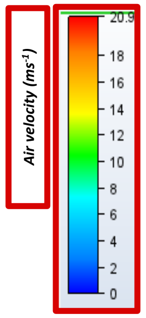
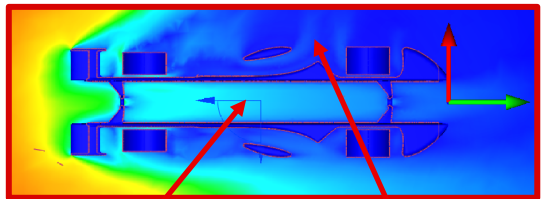
TESTING AND ANALYSIS

CFD ANALYSIS

CFD software proved to br invaluable tool throughout our design process, allowing us to quickly assess the aerodynamic performance of small alterations to our design. We used Autodesk CFD and created a wind tunnel simulation by making a 'box' around the car/component and then setting boundary conditions to produce the necessary environment, replicating air passing around the car at 20ms^{-1}.

We displayed the results on various intersection planes, which allowed us to easily see how the airflow around our car behaved, from several different angles.



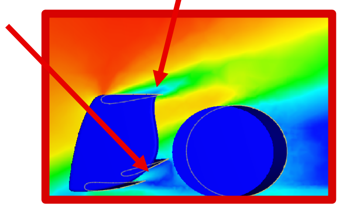


Speed of air through main flow channel is relatively slow and uniform throughout, reducing any downforce generated by the 'Ground Effect'

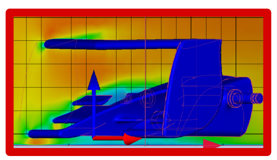
Faster flowing air (light blue) redirected out and around wheels, indicating that flow channels are effective.

Faster airflow between aerofoils, means little build up of pressure, however there are still areas of turbulence and flow separation behind the front wings.

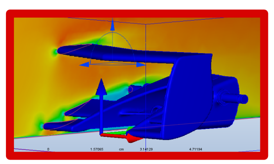
Little flow separation behind front wing and airspeed around it still relatively fast.



By using CFD, we were able to constantly refine our design, often helping us to reach an optimum compromise between two conflicting factors (eg: minimising drag on the front wing , whilst directing air around the front wheels).



Initial Trial with 3 aerofoils acting as a 'cascade', to direct air around the front wheels resulted in lots of flow separation behind the front wing.



Later adaptation with just two aerofoils and less flow separation, whilst still directing air over the wheels.

CALCULATING DRAG COEFFICIENT

Running the wind tunnel simulation also gave us a value for the drag force acting on the car body at 20ms^{-1}, which, alongside the frontal area obtained from Fusion 360, allowed us to calculate the car's drag coefficient. We would then be able to use this in our excel simulation, as well as compare it with our target drag coefficient.

Frontal Area (m^2)	0.0019717
Velocity (ms^-2)	20
Drag force (N)	0.06314
Density of fluid	1.225
Drag Coefficient	0.130706642

Car 1 had a drag coefficient of 0.13, lower than that of Car 2, so we expected Car 1 to perform better on track.

EXCEL SIMULATION

We created our own simulation on excel to run sensitivity testing, which allowed us to analyse the relative impact of different factors (such as weight and drag coefficient) on the lap time of our car.

The simulation revealed that weight was the most significant factor, as doubling it increased the lap time by 0.49s, compared to the 0.05s increase, which came from doubling the drag coefficient. This meant that keeping the mass of our car as close to the 50g weight limit as possible would be essential to a competitive lap-time and would therefore be a primary focus when designing the car.

The simulation also helped us predict the drag coefficient of our car would need in order to achieve our target lap time of sub 1.1s. Although we found that the drag coefficient had a relatively small influence on lap-time, in comparison to weight, we would still want to make our car as aerodynamic as possible. We put in different coefficient values, until the 20m distance on our simulation was reached at 1.1s, giving us a target drag coefficient of 0.13.

Lap time divided into 0.01s increments

We could change these variables to see how they affected lap time

Drag coefficient, acceleration and SUVAT equations used to calculate distance

Distance travelled in the 0.01s interval

Car Mass	0.047	Drag Force	1/2*Cd*p*A*v^2
Drag Coefficient	0.14	Distance	ut+1/2at^2 + previous distance
Frontal Area	0.001	Velocity	u(0) +at
Air Density	1.225	Acceleration	F-Fd/mass

Time (s)	Thrust Force	Drag Force	Resultant Force	Acceleration	Velocity	Distance
0.01	1.4	0	1.4	29.78723404	0.29787234	0.001489362
0.02	1.4	7.60842E-06	1.399992392	29.78707216	0.595743062	0.005957439
0.03	1.4	3.04335E-05	1.399969566	29.78658652	0.893608927	0.013404199
0.04	1.4	6.84745E-05	1.399931525	29.78577714	1.191466699	0.023829577
0.05	1.4	0.00012173	1.39987827	29.78464404	1.489313139	0.037233476
0.06	1.4	0.000190198	1.399809802	29.78318727	1.787145012	0.053615767
0.07	1.4	0.000273876	1.399726124	29.7814069	2.084959081	0.072976287
0.08	1.4	0.00037276	1.39962724	29.77930298	2.382752111	0.095314843
0.09	1.4	0.000486846	1.399513154	29.77687561	2.680520867	0.120631208
0.1	1.4	0.00061613	1.39938387	29.77412489	2.978262116	0.148925123
0.11	1.4	0.000760606	1.399239394	29.77105093	3.275972625	0.180196297
0.12	1.4	0.000920269	1.399079731	29.76765386	3.573649163	0.214444406
0.13	1.4	0.001095111	1.398904889	29.76393382	3.871288502	0.251669094
0.14	1.4	0.001285125	1.398714875	29.75989097	4.168887411	0.291869973
0.15	1.4	0.001490303	1.398509697	29.75552548	4.466442666	0.335046624
0.16	1.4	0.001710636	1.398289364	29.75083753	4.763951041	0.381198592
0.17	1.4	0.001946116	1.398053884	29.74582732	5.061409315	0.430325394
0.18	1.4	0.002196732	1.397803268	29.74049507	5.358814265	0.482426512
0.19	1.4	0.002462473	1.397537527	29.73484099	5.656162675	0.537501397
0.2	1.4	0.002743329	1.397256671	29.72886534	5.953451328	0.595549467
0.21	1.4	0.003039287	1.396960713	29.72256836	6.250677012	0.656570109
0.22	1.4	0.003350335	1.396649665	29.71595032	6.547836515	0.720562676
0.23	1.4	0.003676459	1.396323541	29.7090115	6.84492663	0.787526492
0.24	1.4	0.004017647	1.395982353	29.7017522	7.141944152	0.857460846
0.25	1.4	0.004373882	1.395626118	29.69417273	7.43888588	0.930364996

We checked the accuracy of our model by comparing simulated results with physical track times. The results were only out by +/- 0.01 seconds, making it a fairly accurate model.

Limitations of our simulation included:

- The assumption that the thrust force remained constant
- The fact that it didn't account for the inertia of the wheels
- The fact that the lap-time would also be dependent on other factors (for example the friction between the wheels and axels)

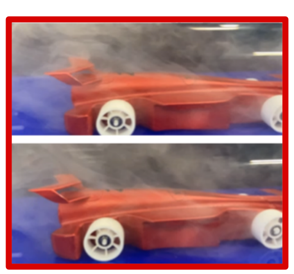
Moving forwards, we would like to integrate some of these elements into a revised model of our simulation in the future

LOW SPEED FLOW VISUALISATION & WIND TUNNEL

Low speed flow visualisation was used to analyse physical airflow around the car and determine the effectiveness of flow channels.

The flow channels in Car 1 proved to be effective, with air being directed through the sidepods and out around the rear wheels. The airflow also nicely followed the curvature of the main body, meaning we'd effectively used the Coandă effect to our advantage.

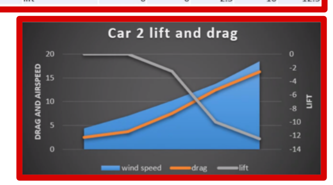
We were glad to see that for Car 1, our physical flow visualisation results mimicked that of our CFD analysis above.



Car 2 had a clear build up of flow behind the front wheels, as well as significant flow separation over the main body. There also seemed to be small vortices forming on the tips of our rear wing, which hadn't formed on Car 1, despite a very similar wing design. This could be due to the extra flow separation on the body of Car 2, changing the angle of the airflow which the wing came into contact with.

This testing helped us conclude that the aerodynamics in Car 1 were better, so this was the design we chose to focus on.

windspeed	4.4	7	10.2	13.8	18.5	wind speed	4.4	7	10.2	13.8	18.5
drag	2.5	5	7.5	12.5	15	drag	2.5	3.75	7.5	12.5	16.25
lift	-6.25	-9.5	-12.5	-12.5	-12.5	lift	0	0	-2.5	-10	-12.5



Wind tunnel testing allowed us to physically analyse the lift and drag experienced by both cars. We replicated track conditions by using a small scale wind tunnel and increasing wind speed up to 20ms^{-1}. We found that both cars shared similar drag coefficients across windspeeds, but noticeably, different lift values.

Car 1 experienced negative lift, thus, producing downforce at all speeds.

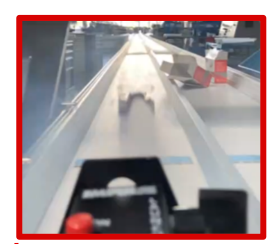
However, Car 2 only generated downforce at higher speeds, which meant that undesired lift would be produced during initial acceleration that would reduce its linear speed and could potentially cause a wobbly track run.

TRACK TESTING

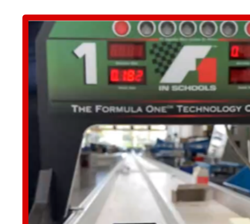
We outsourced wind tunnel, flow visualisation and track testing to UTC Scarborough, as unfortunately, due to COVID-19 restrictions, we did not have access to the necessary equipment. Although we could not conduct the testing personally, it still provided some incredibly valuable insights into the design and workings of our prototypes. We made sure, however, to hold a zoom call with the technician, post-testing, to discuss the results and learn about all the details and logistics of how the testing was actually carried out, so that we would have a more thorough understanding.

Track testing was a key part of the design process as it allowed us to:

- Test two designs and evaluate which model to develop further
- Identify component failures or areas for improvement, to allow for redesign and additional testing of the specific parts
- Evaluate methods of manufacturing, including adhesives, materials and logistics



Car 1 achieved a time of 1.011 seconds which was a promising result. However, as both test cars were slightly underweight we expect race times to be slightly slower. We were pleased to see that the superior performance of Car 1 was consistent with our virtual and physical airflow testing. Therefore, we chose Car 1 to develop further for Regionals.



Car 2 achieved a time of 1.062 which was slower than that of Car 1. We noticed that a possible reason for this was that it travelled a greater distance than Car 1 as it had veered to the side during its runs (as seen above). We concluded that greater flow separation, turbulence around the wheels, and an imbalance between lift and downforce had caused this.