Thermo-Fluids:
Vehicle Design Aerodynamics

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Introduction and Concepts

My chosen vehicle archetype was a sports car, as I was interested in the evolution of the shape of the cars overtime, as they progressed from a very rounded styling, to more defined and with sharper edges.

My 4 concepts vary in their shape ranging from rounded designs, to very sharp designs as seen in figure 3, which takes inspiration from the Tesla Cybertruck.

I chose figure 2 to take forward as I expected it to perform the best in the CFD simulation, and as I was interested to see what effect the spoiler had on the down force of the car. I also liked it as I thought it resembled 1950's sports cars rounded shape.

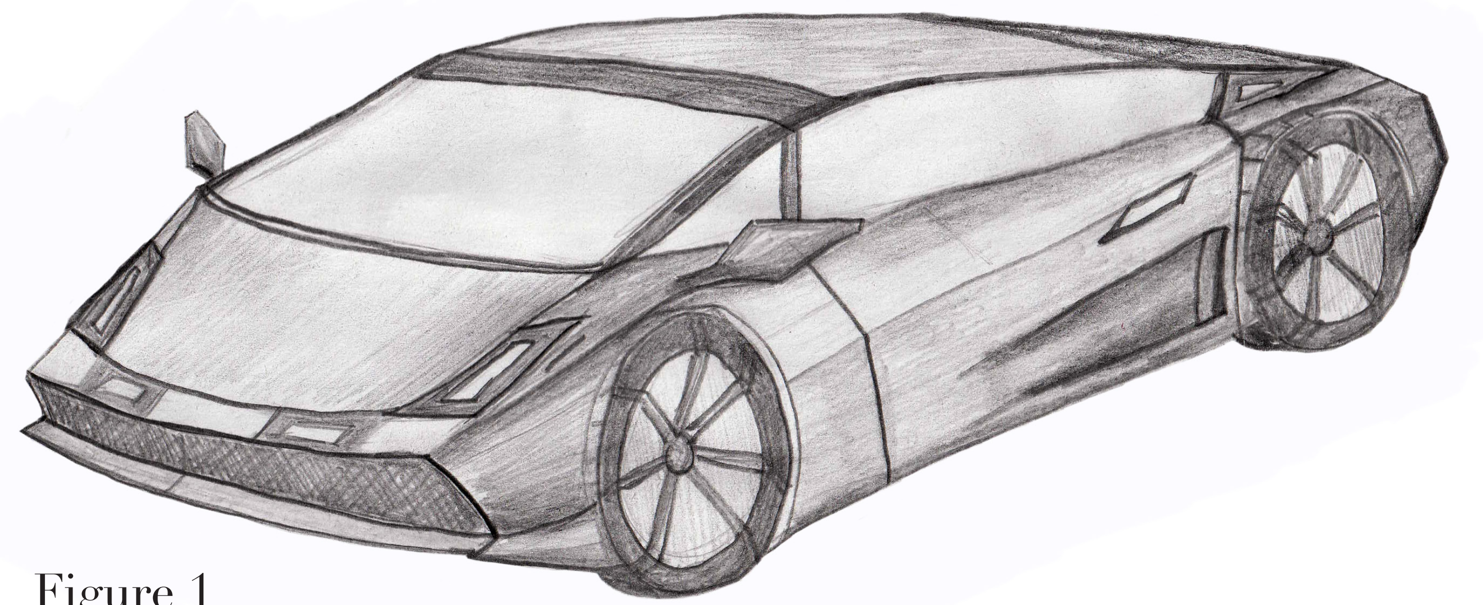


Figure 1

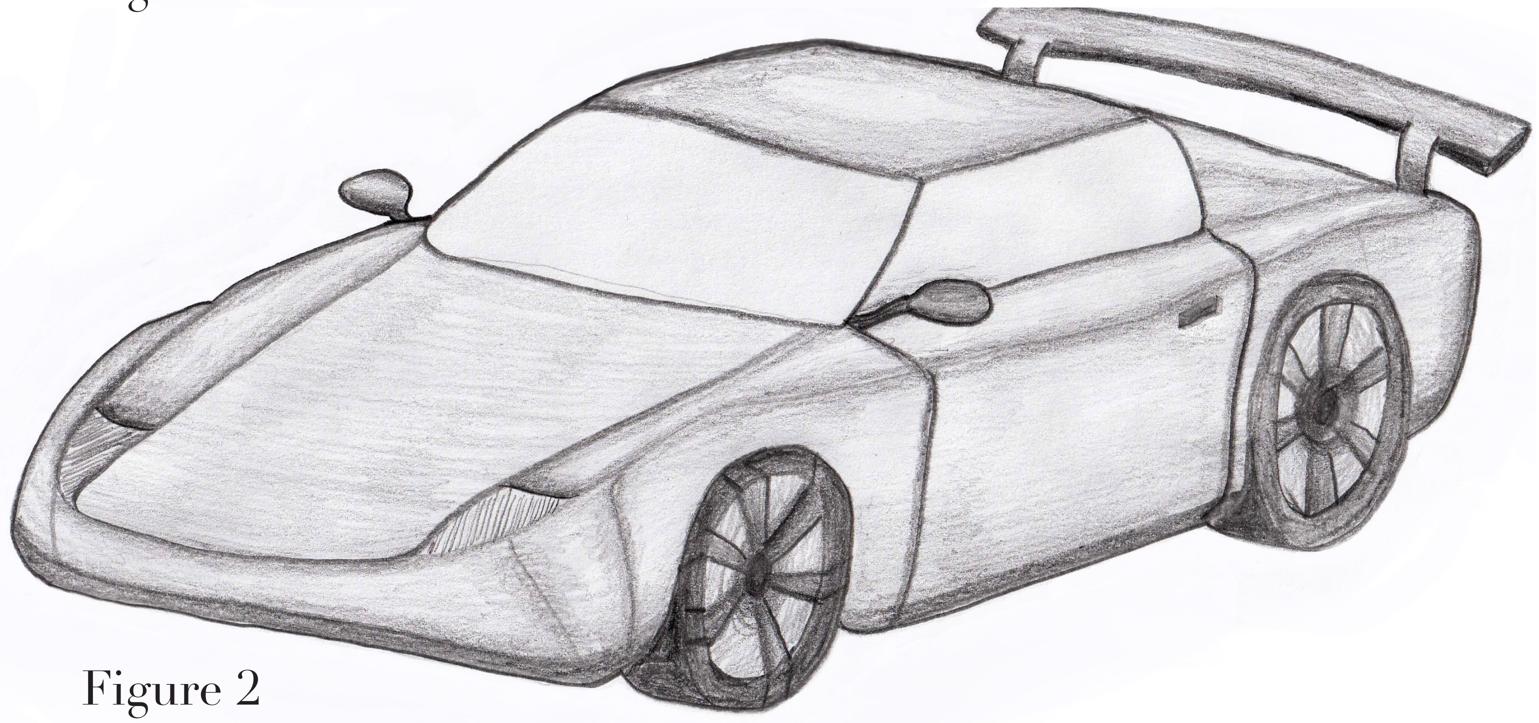


Figure 2

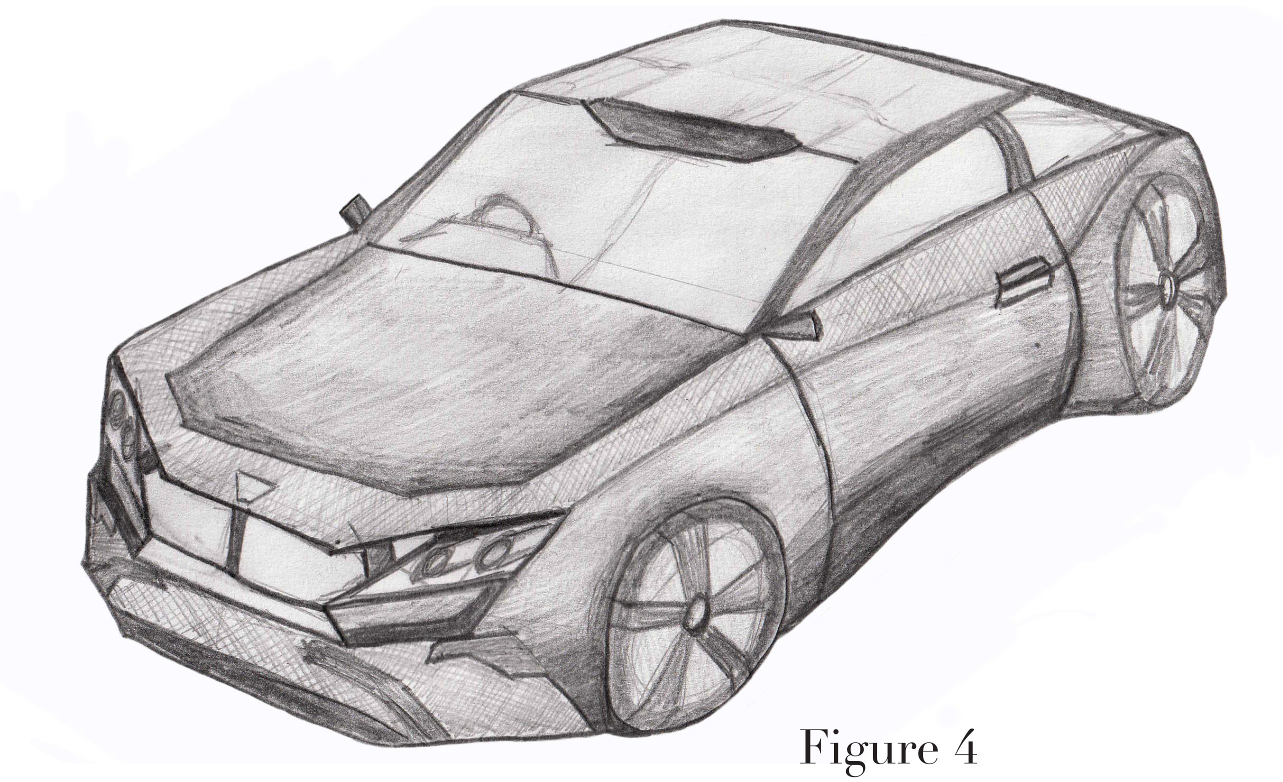


Figure 4

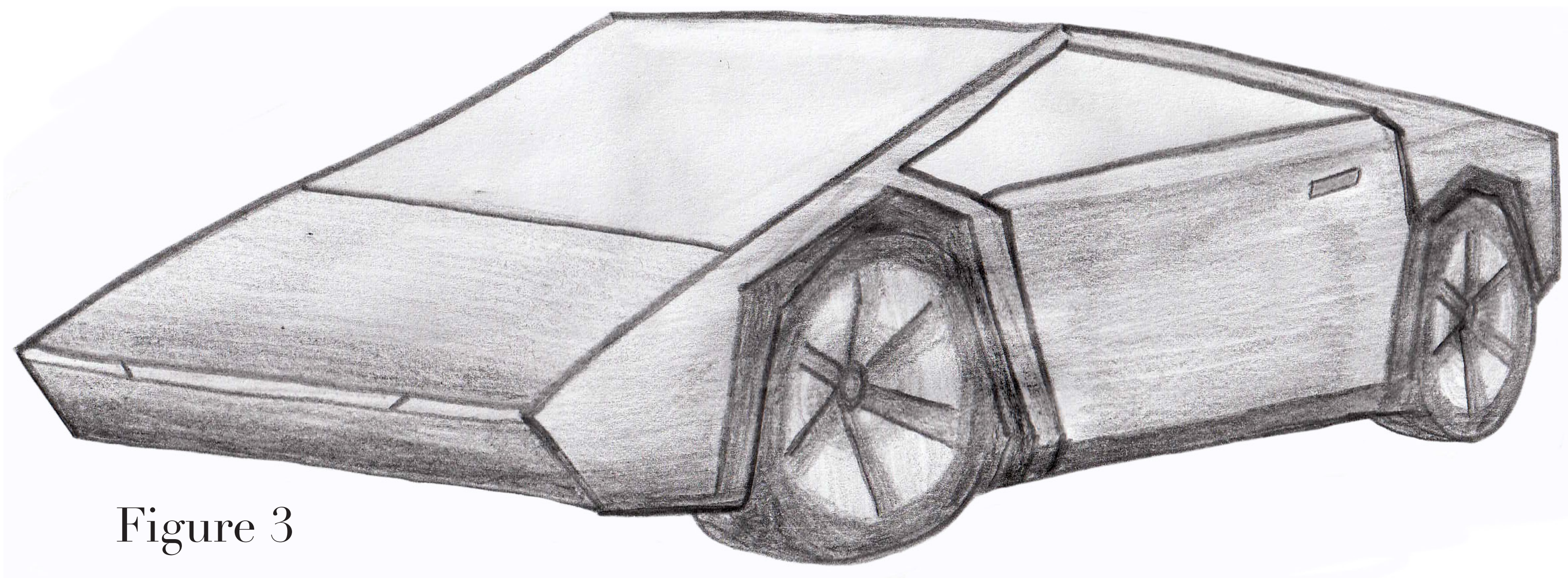


Figure 3

Concept Description

It has flush lights, door handles and an overall 'bubble' design with an added spoiler for down force, a common feature on modern sports cars to improve performance. The rounded design is even replicated in the tail-light shape.

A solid CAD model was produced, and then the flow simulation was carried out in Solidworks to visualise velocity and pressure and obtain a drag coefficient of 0.318, which when compared to the feature method calculation, gave a very similar figure.

Power to overcome drag, battery capacity and spoiler down force were calculated, and I also ran a flow simulation on the figure 3 car, to compare the differences between a rounded car, and one with sharp edges.

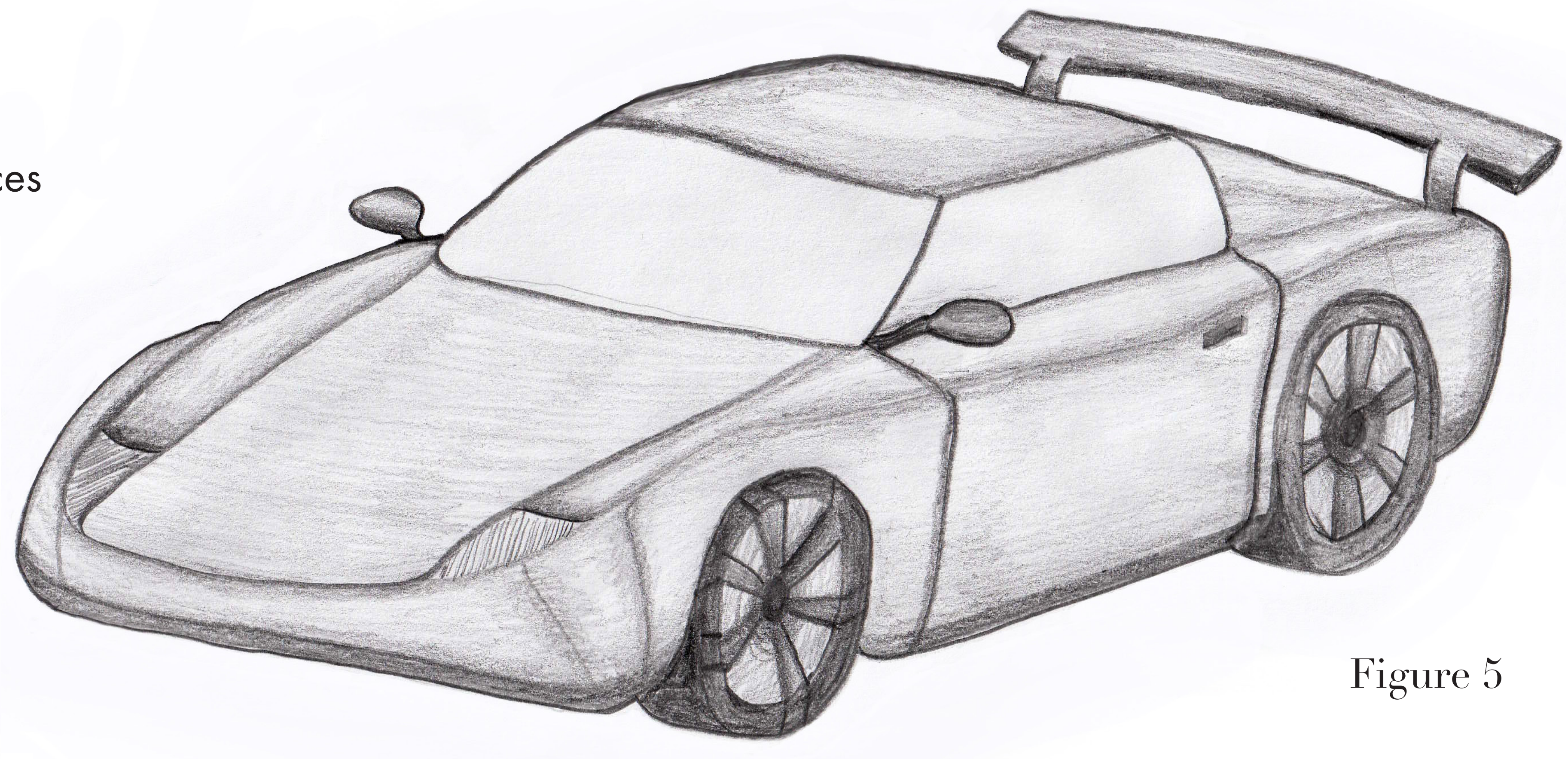


Figure 5

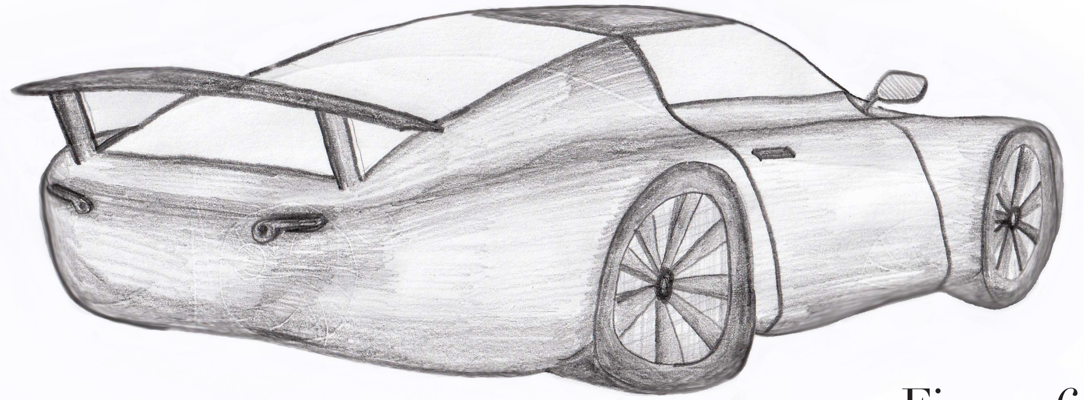


Figure 6

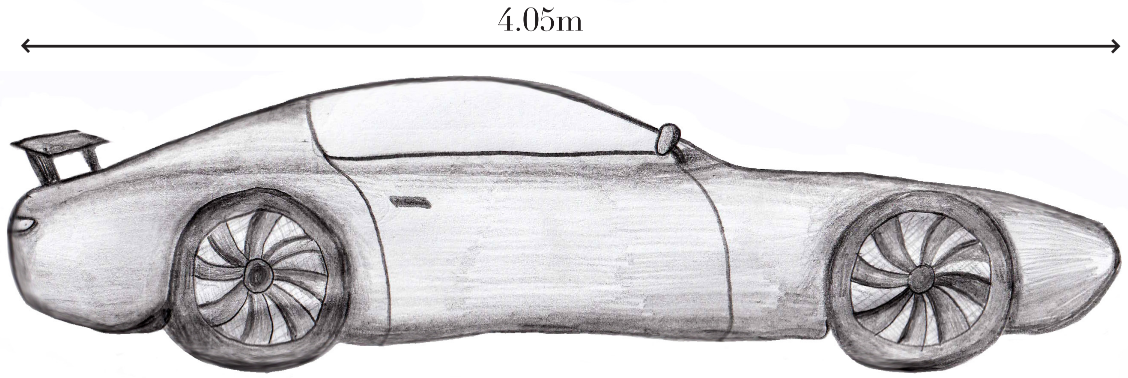
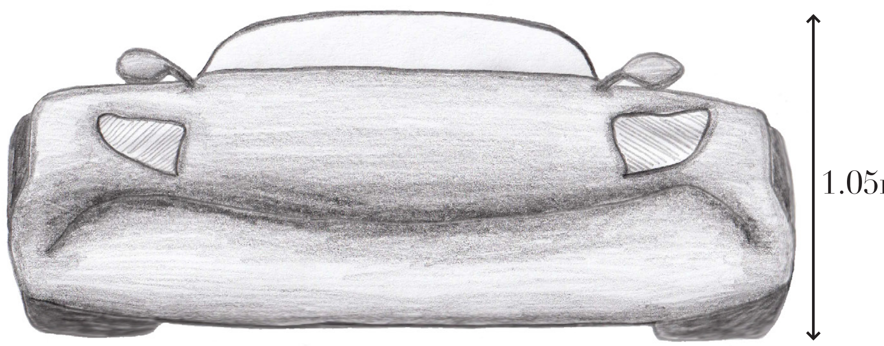


Figure 7



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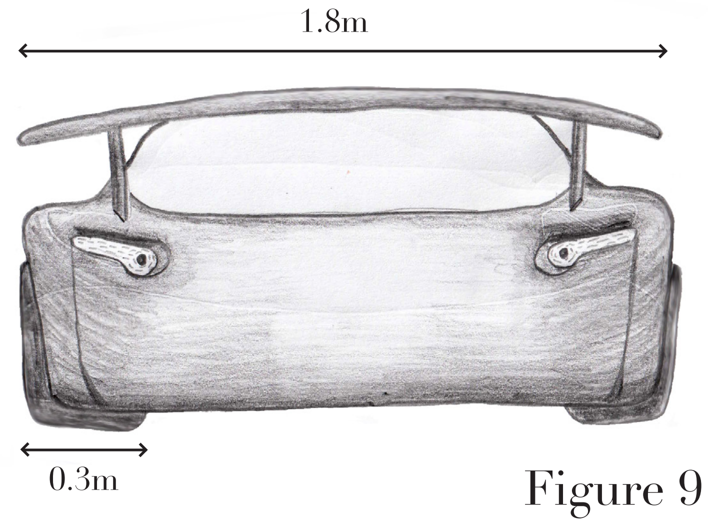


Figure 9

Solid Model

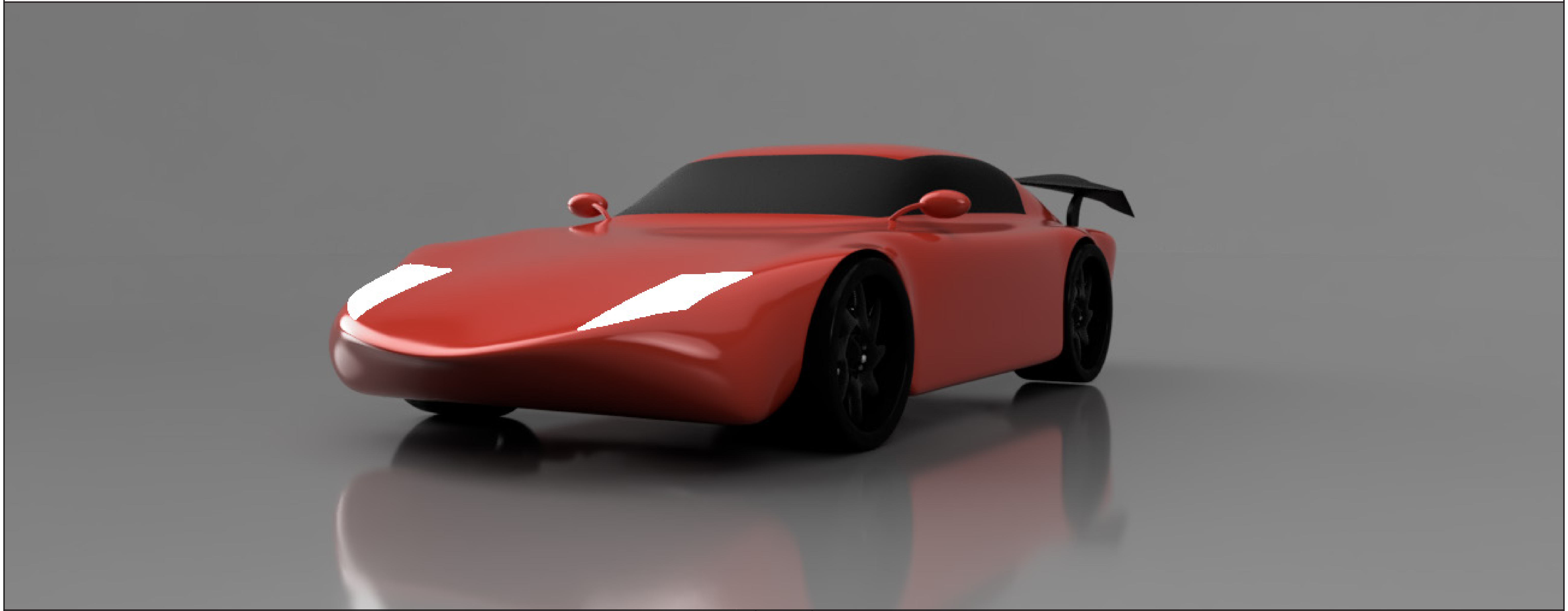


Figure 10. Overall View

Figure 11. Rear View

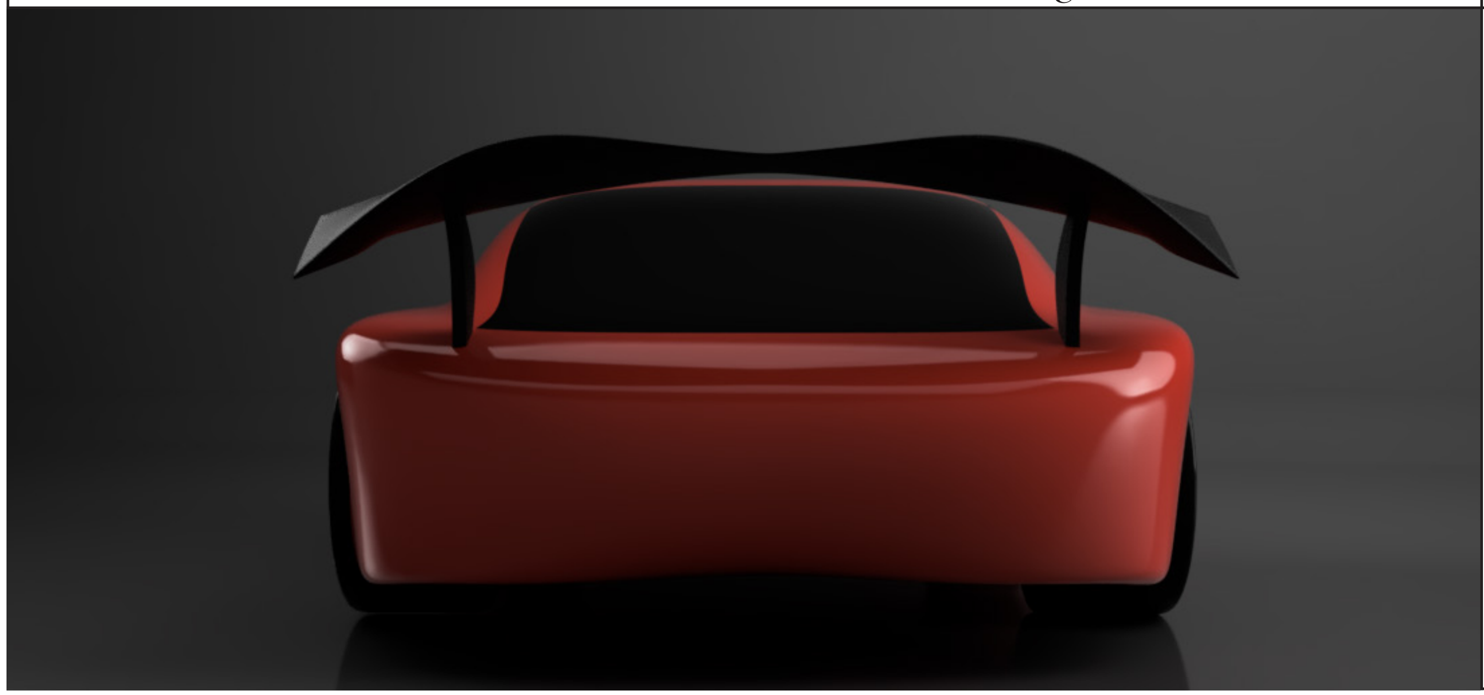
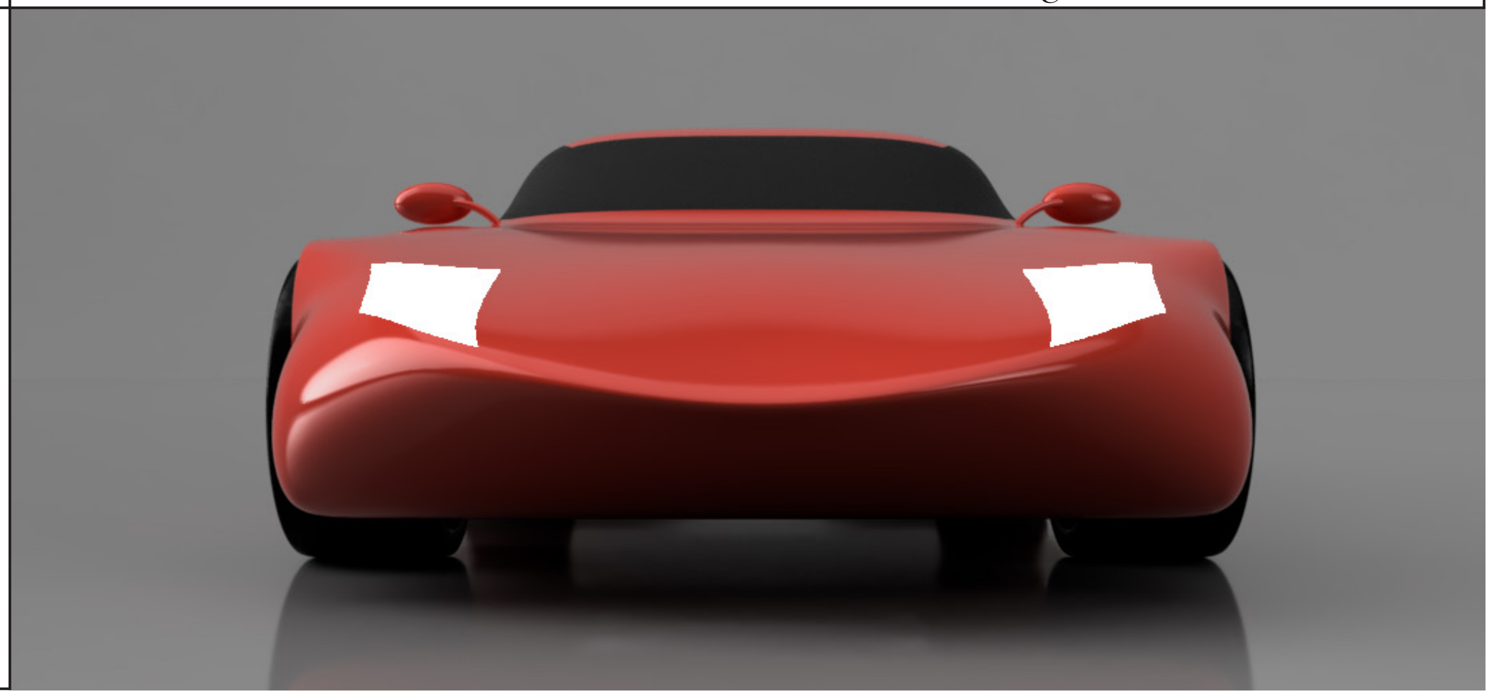


Figure 12. Front View



Wizard Settings

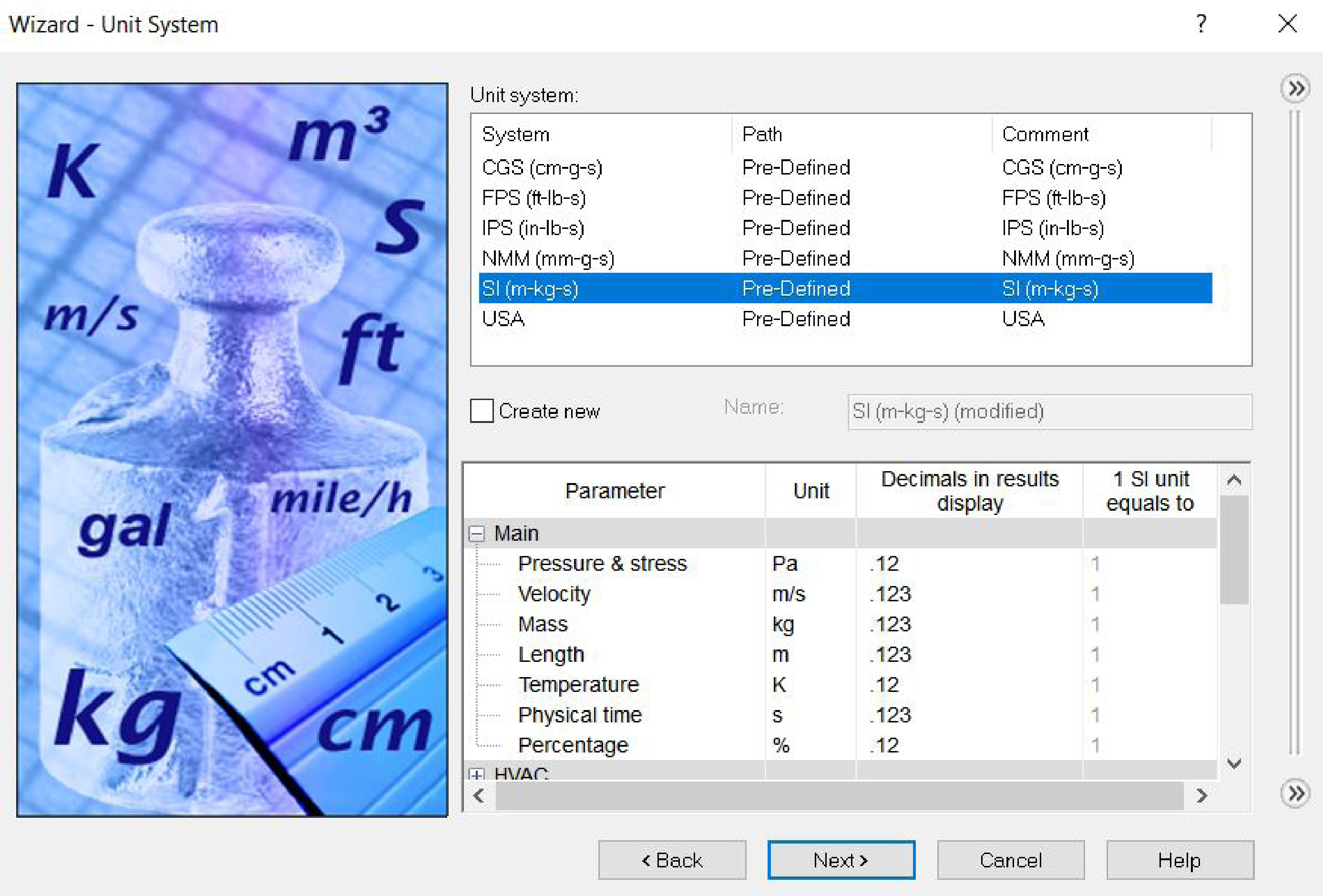


Figure 13

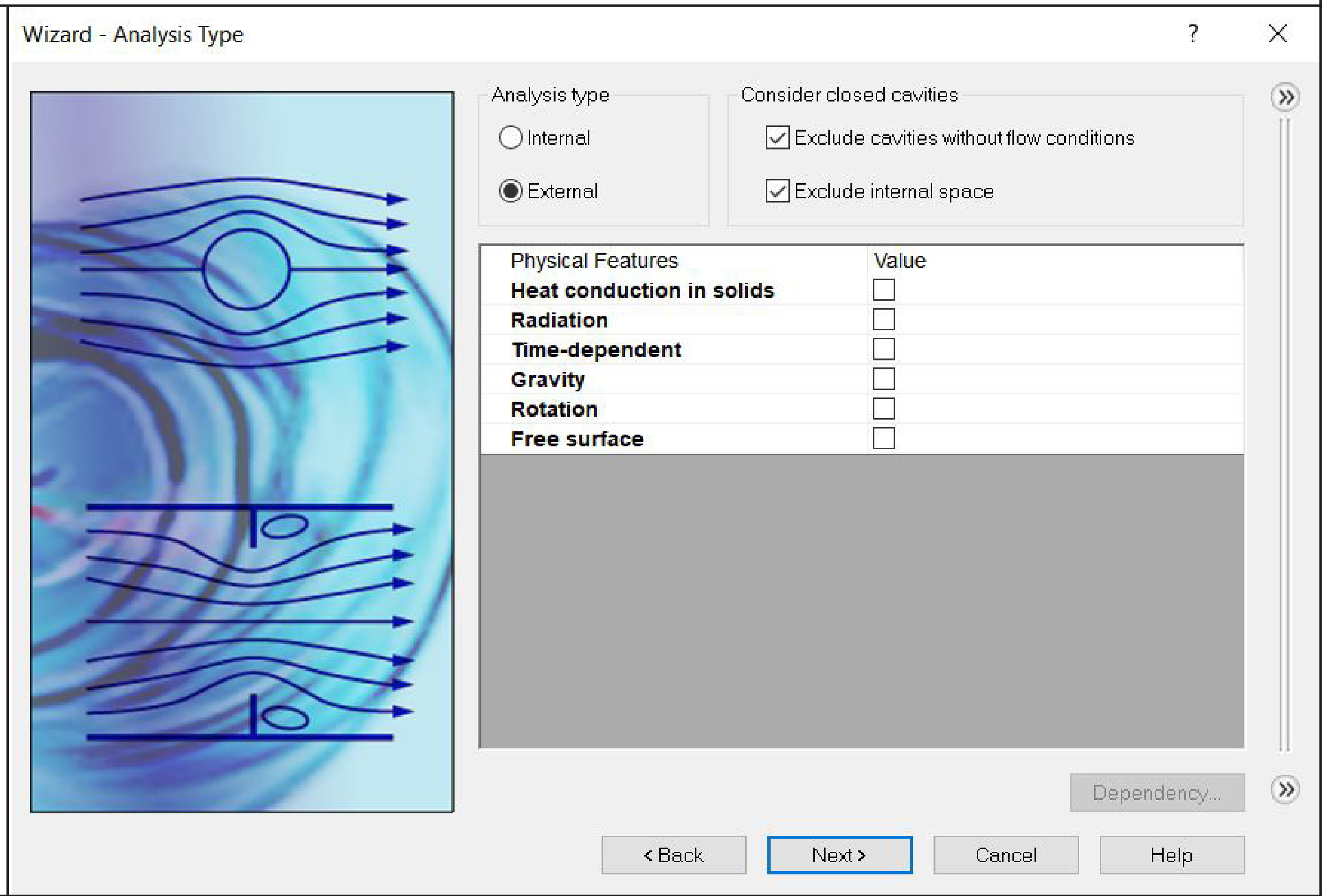


Figure 14

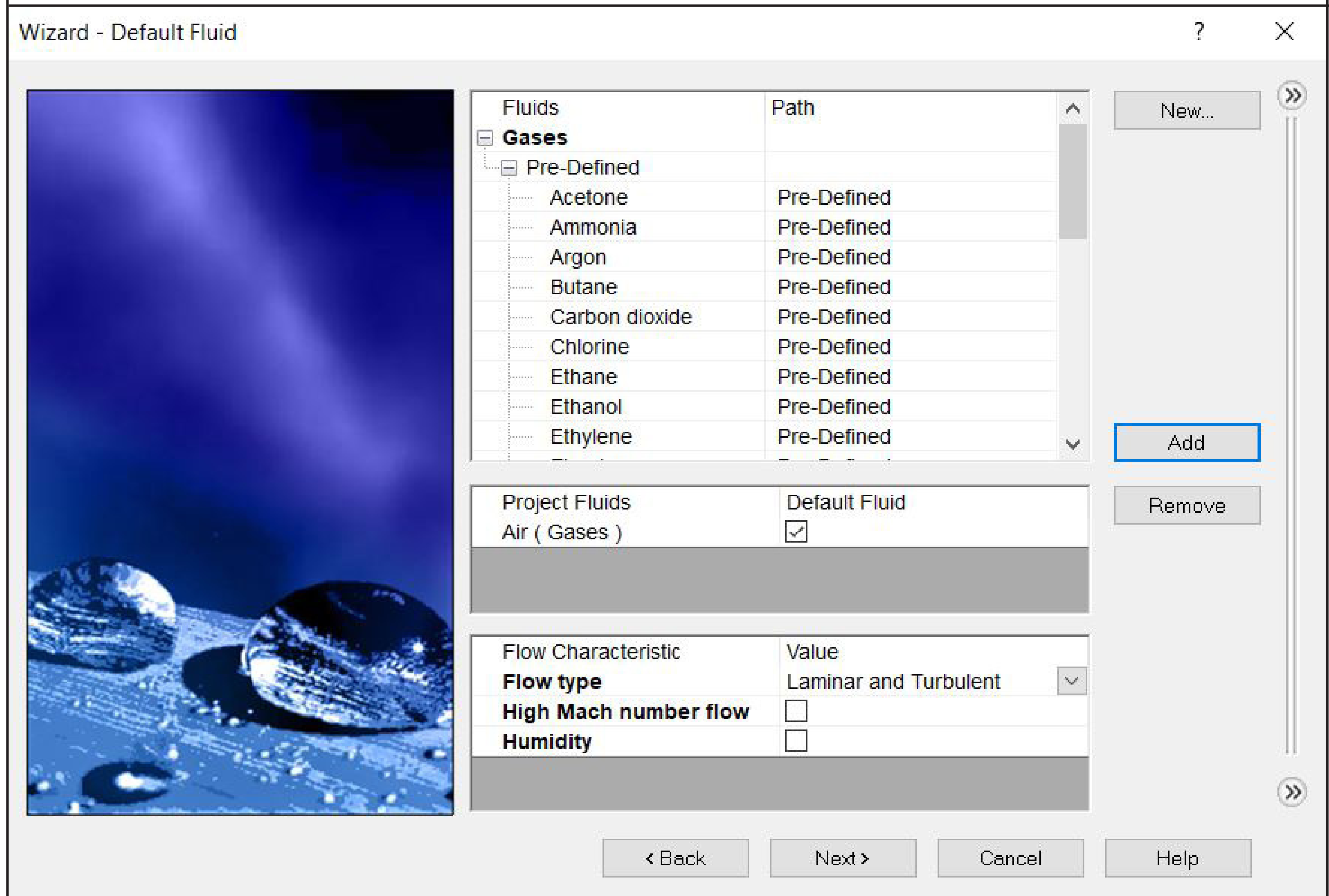


Figure 15

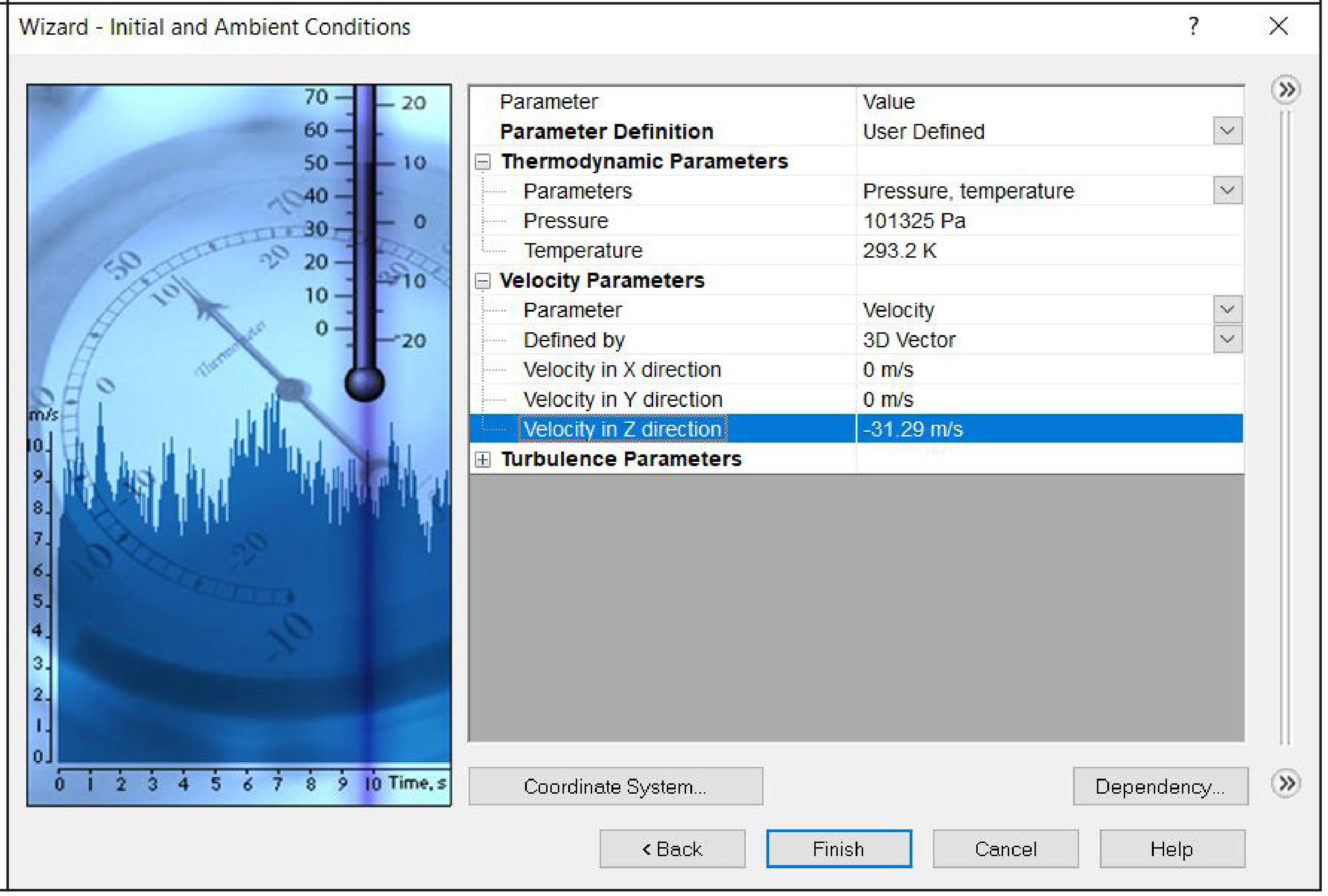


Figure 16

2D Velocity and Pressure Distribution

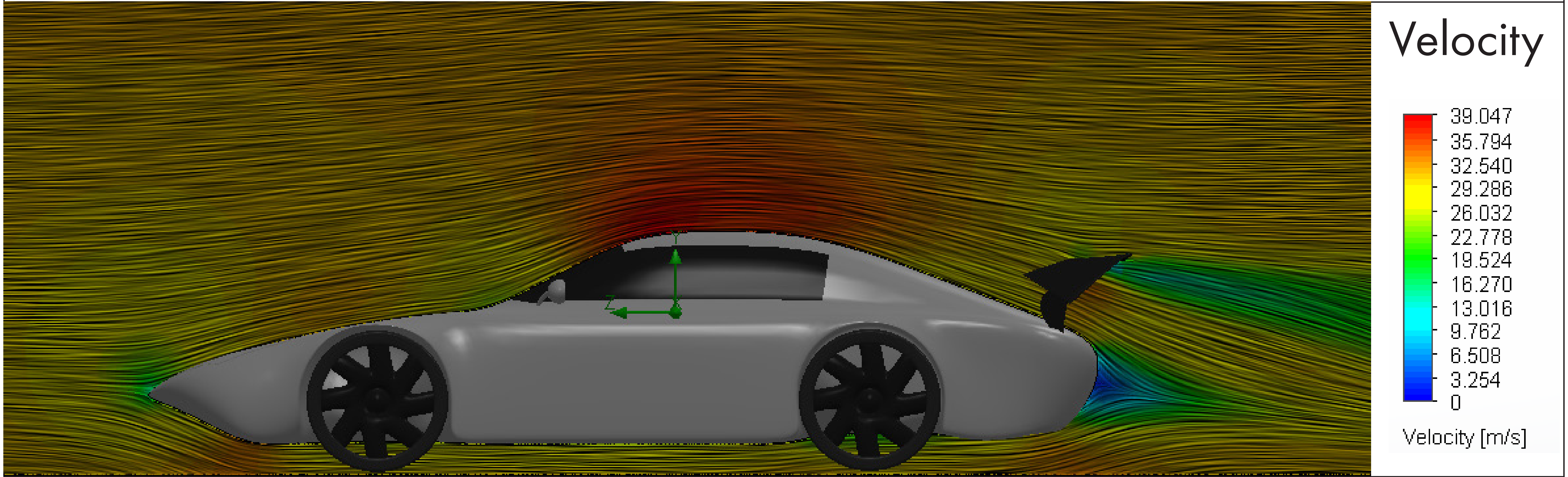
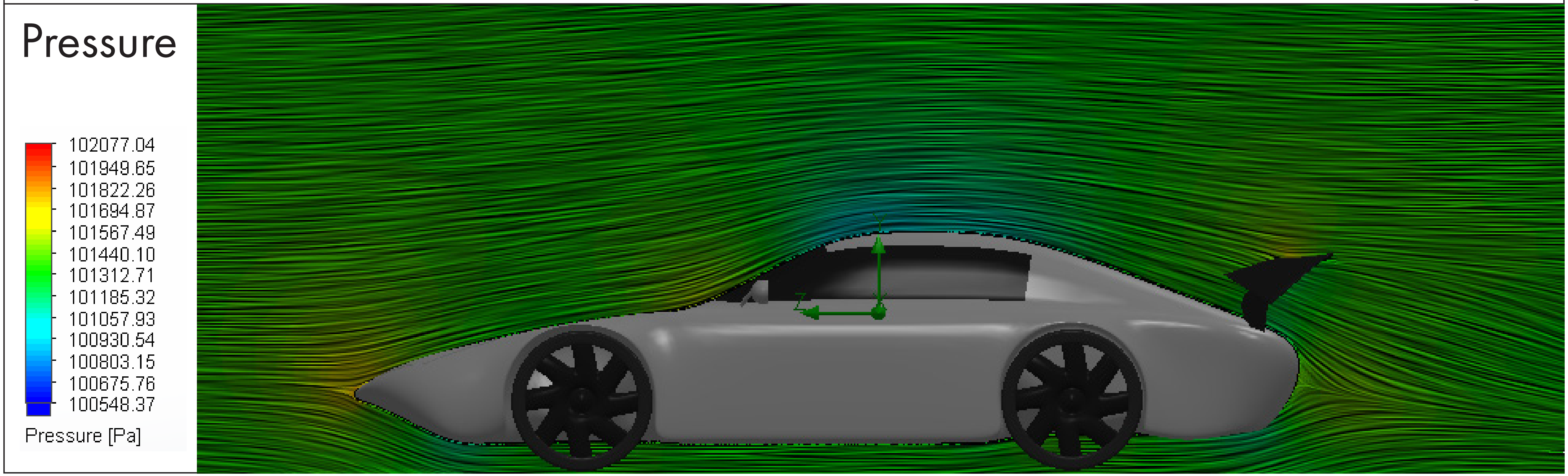
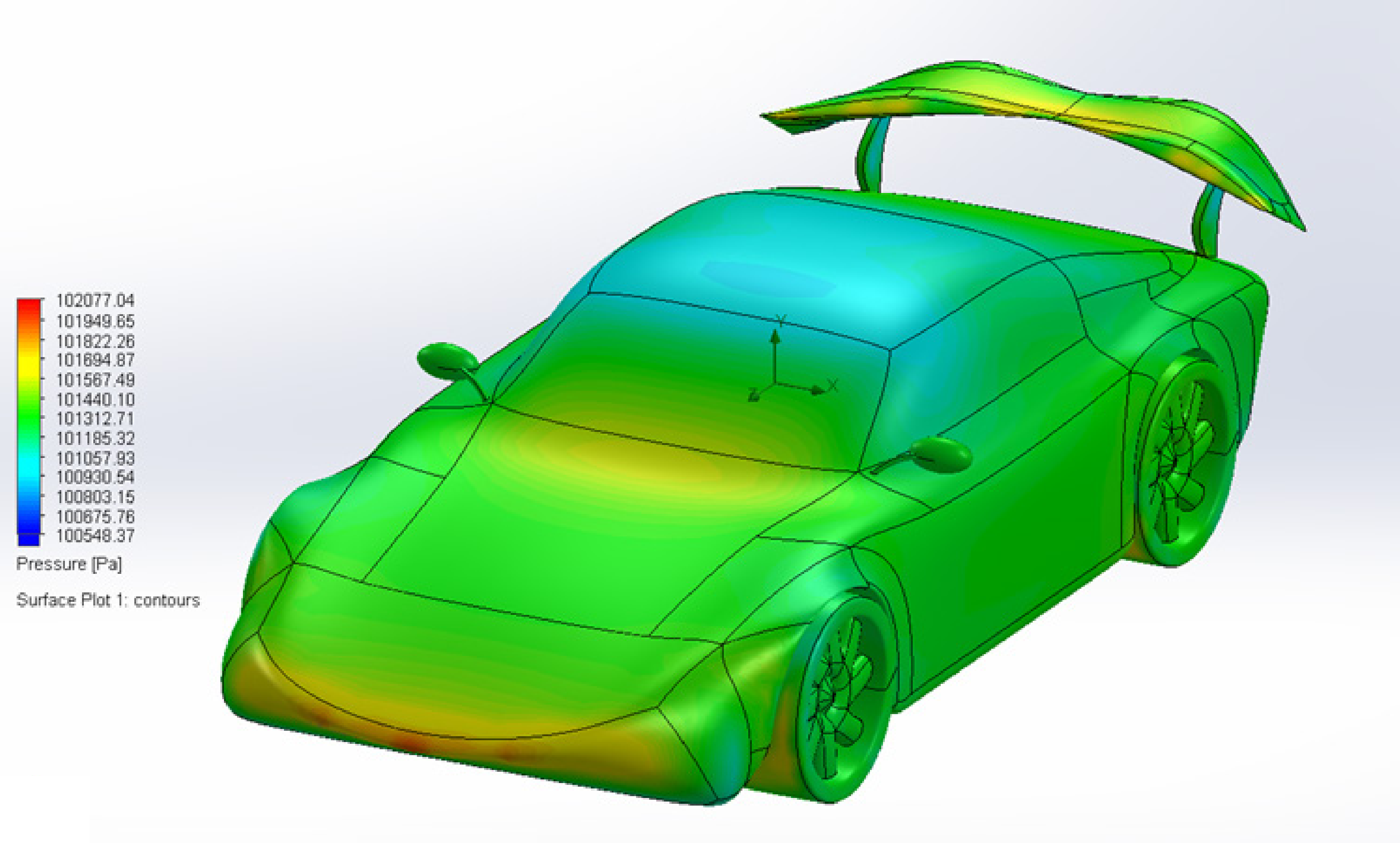


Figure 17

Figure 18



Surface Pressure



From the surface analysis it can be seen that the highest pressure is at the front on the car, but that the spoiler also has a higher pressure than most other parts of the car. This shows that it is effective as the air is pressing the car to the ground.

Figure 19

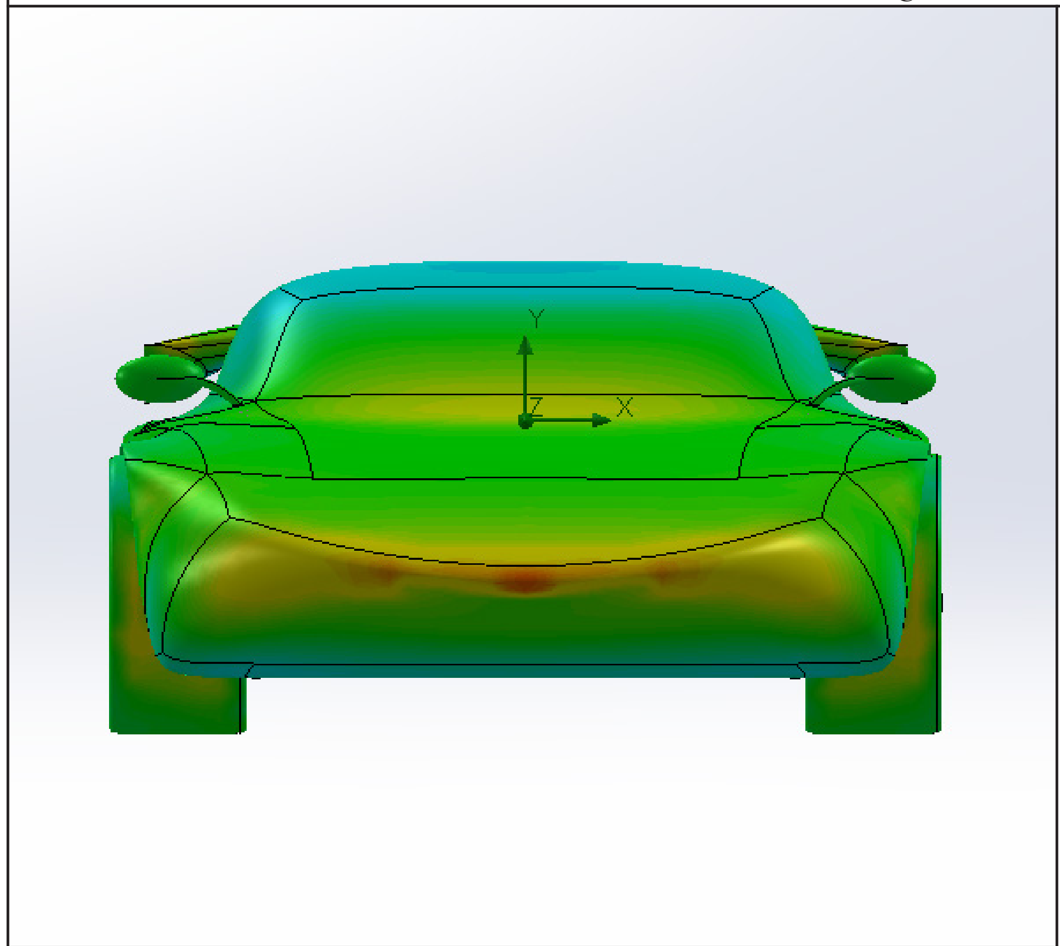


Figure 20

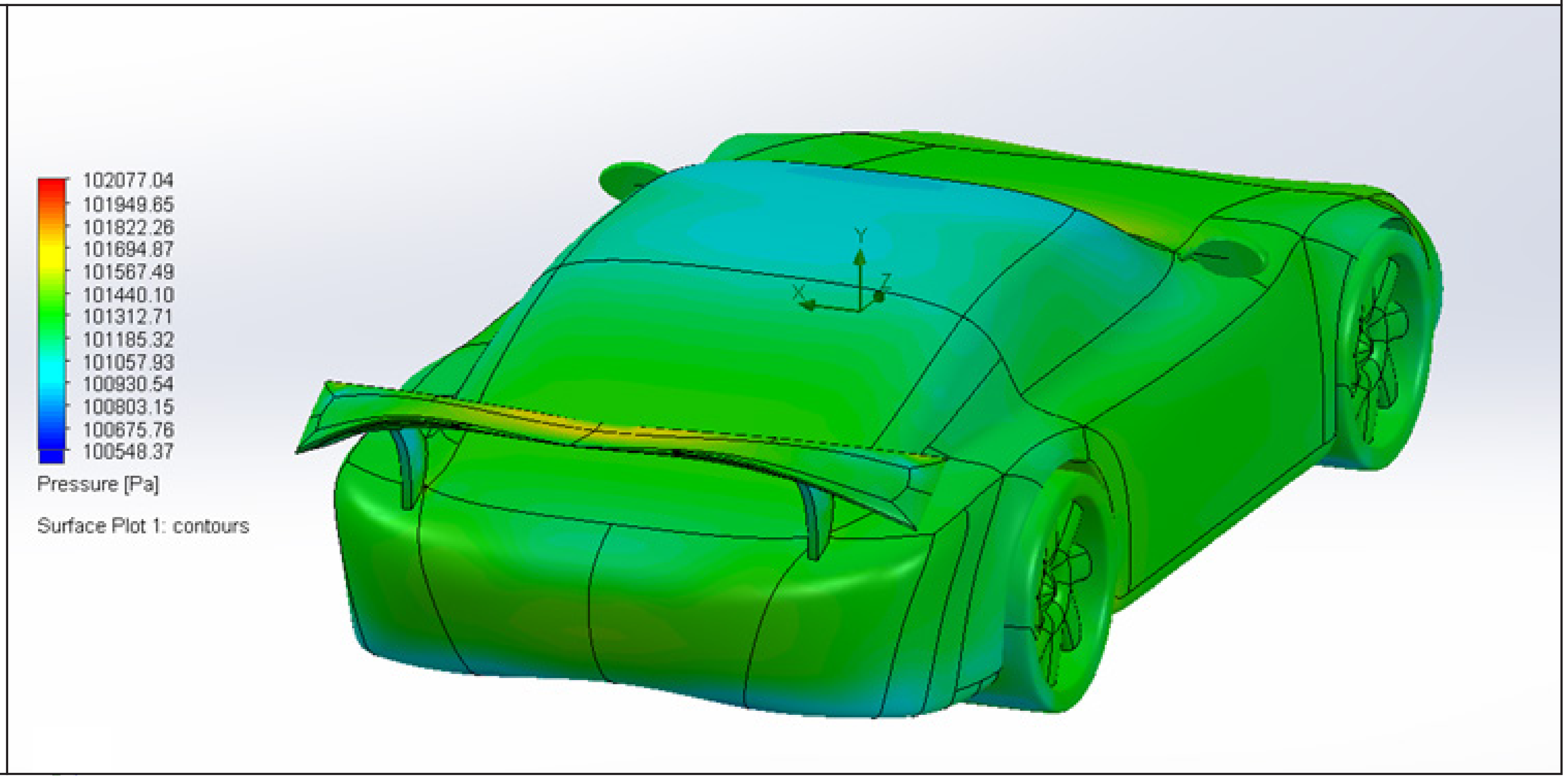
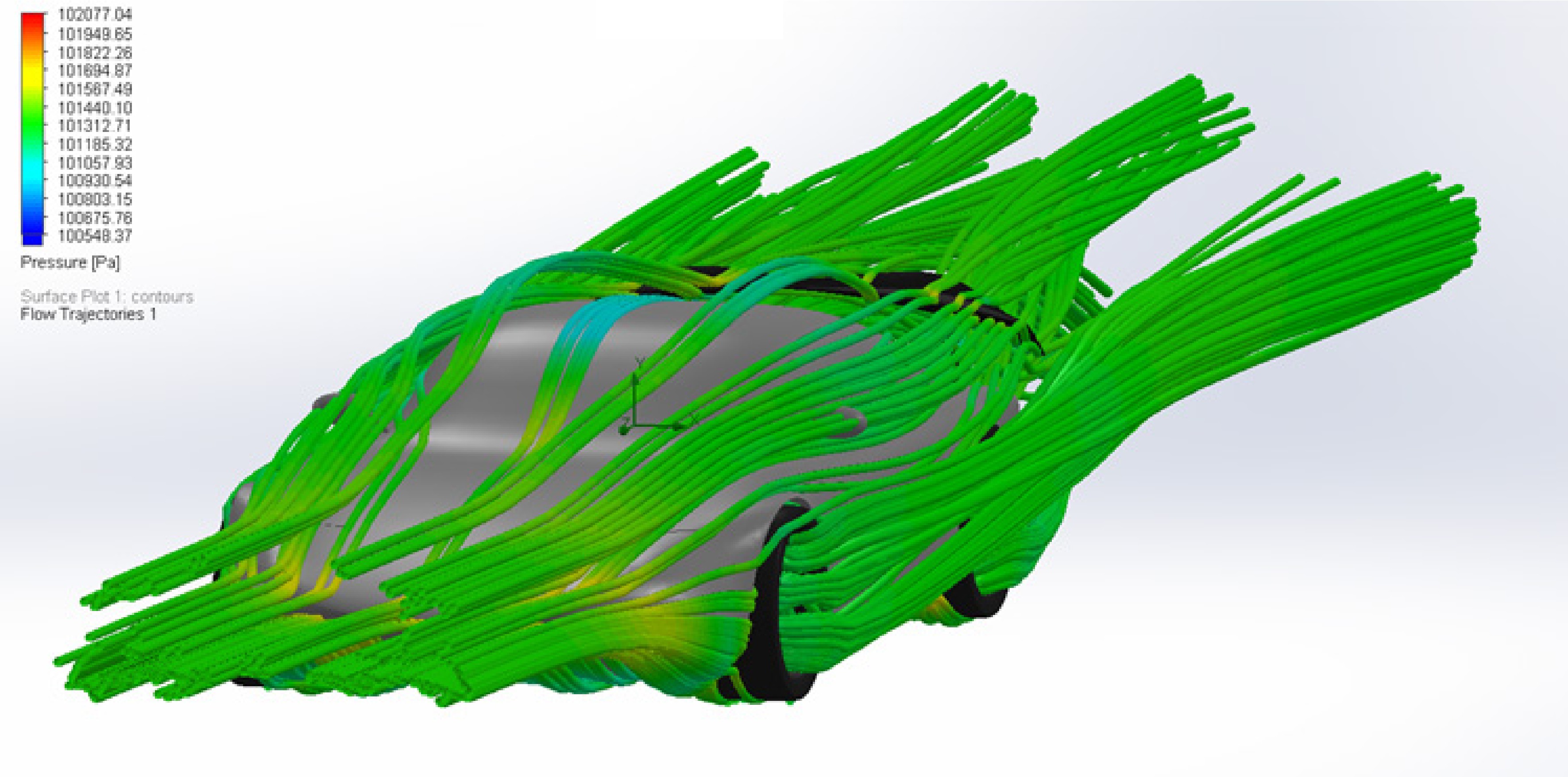


Figure 21

Flow Trajectories



From the flow trajectories is can be seen that the air is forming some small vortex's behind the car, but that in general it passes smoothly over it.

Figure 22

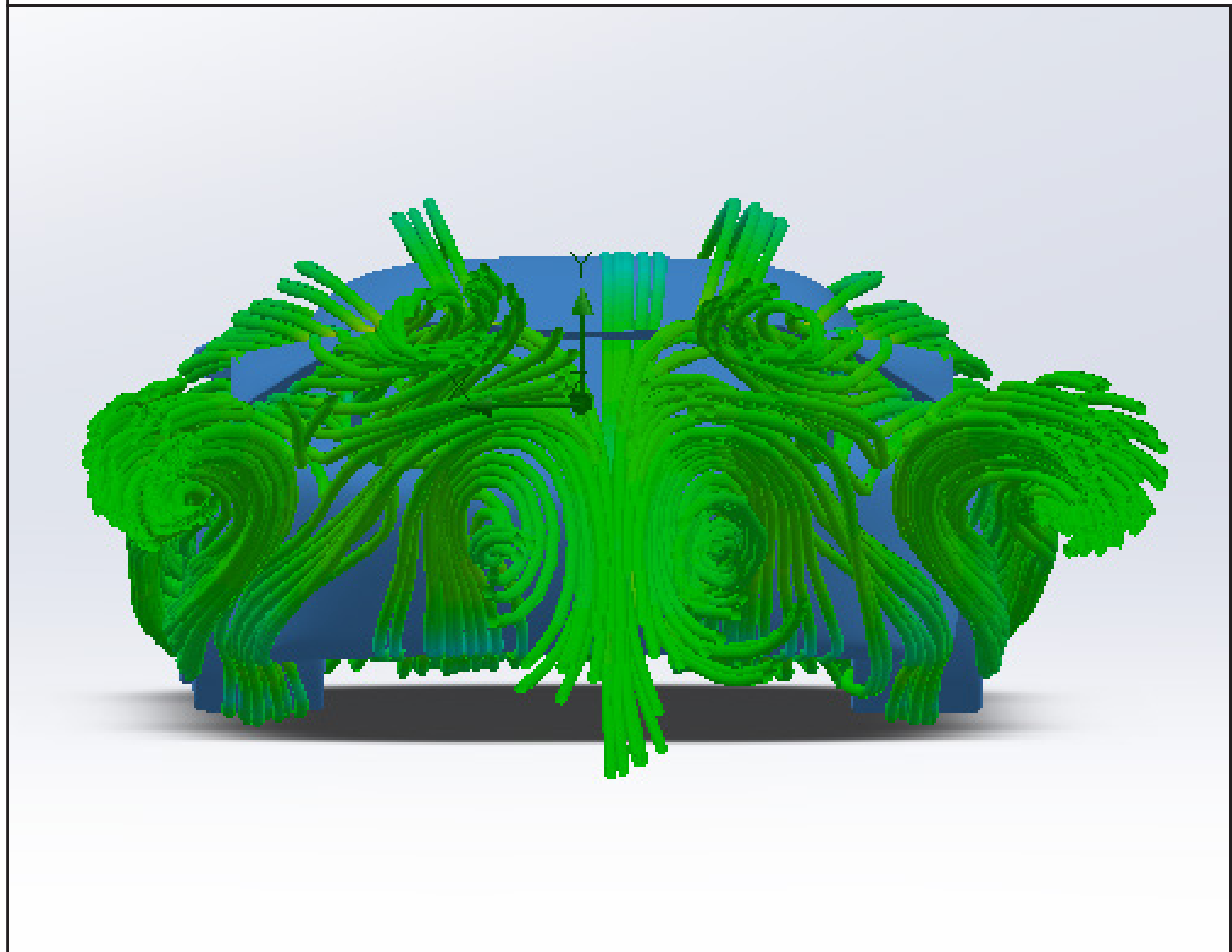


Figure 23

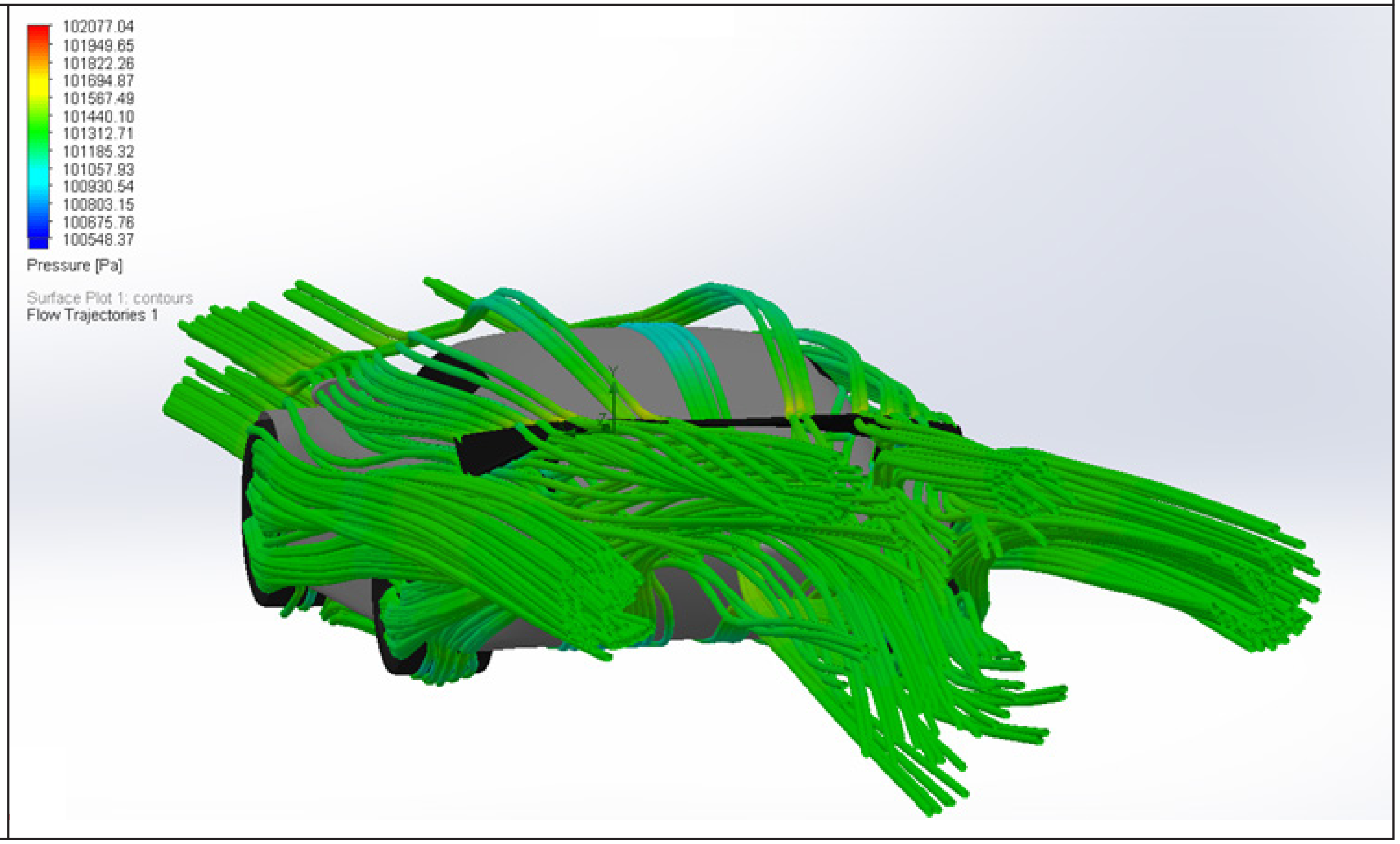


Figure 24

Drag Calculations

From the CFD, the drag force and down force values can be seen as well as the Drag Coefficient in figure 25. I then carried out 4 additional calculations.

Summary

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
GG Force (Y) 1	[N]	136.663	133.822	129.563	137.111	100	Yes	7.548	8.684
GG Force (Z) 1	[N]	-287.434	-288.672	-290.931	-287.237	100	Yes	3.693	39.660
DragCoefficient	[]	0.3161721	0.3175343	0.3159558	0.3200184	100	Yes	0.0040626	0.0436255

Figure 25

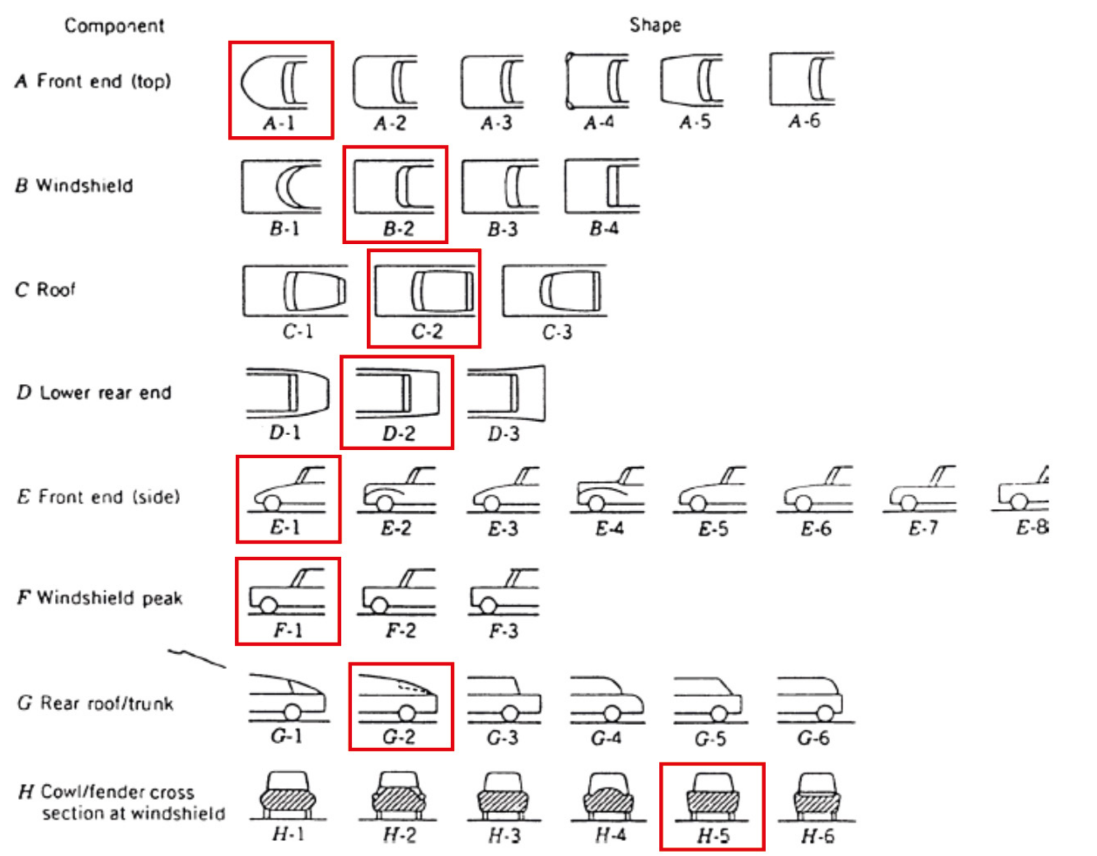
C_D From Feature Method

Although the drag coefficient had already been calculated by CFD (0.316), I explored the value for my car using the feature method:

1+2+2+2+1+1+2+4 = 15

$$C_D = 0.16 + 0.0095 \sum_{i=A}^{H} N_i$$

0.16 + (0.0095*15) = 0.3025 = C_D



Energy to Overcome Drag

Force (Z) = 288.672 N

Power = Drag * Velocity

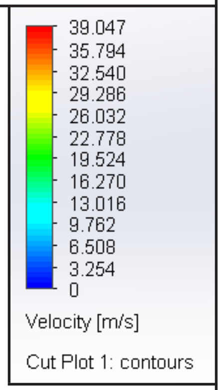
288.672 * 31.29 = 9032.55 W

= 9.03 kW

If the car drives for 1 hour at this velocity:

Energy required = 9032.55 * 60 * 60 = 32517180J = 32.5 MJ

Bernoulli's Equation



The down force on the spoiler can be calculated. If the area of the spoiler is known and the velocities on bottom and top are known.

$P_1 + \rho gh + \rho v_1^2/2 = P_2 + \rho gh + \rho v_2^2/2$

$P_1 - P_2 = \rho(v_2^2 - v_1^2)/2$

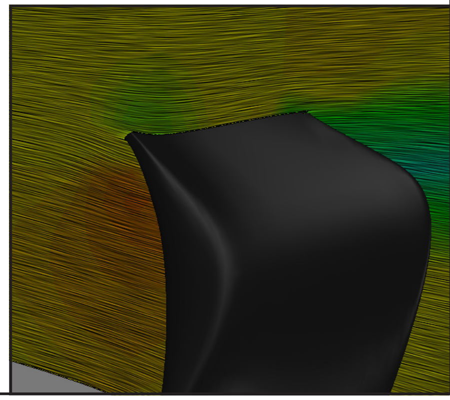
$\Delta P = (1.225)(33^2 - 25^2)/2$

$\Delta P = 284.2\ N/m^2$

$F = \Delta P * A$

$F = 284.2 * 0.4306$

F = 122 N Down force



Battery Capacity

As it is an electric vehicle, it has 300 V[1] electric motor voltage when travelling at 31.29 ms^{-1}. The mass of the car is 1300 kg. Rolling Resistance Coefficient is 0.015[2]. Looking at another sports car, the Bugatti Chiron, this can cover 450 km, so this should be the range for my car.

Ratio of aero resistance to total resistance:

288.672/((288.672)+(0.015*9.81*1300)) = 0.6

Power to overcome drag = 9031.5 W

Power to overcome total resistance

= 9032.5/0.6 = 15054.16 W

Current at 31.29ms^{-1} = 15054.16/300

= 50.18 A

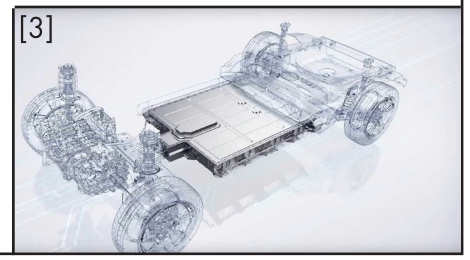
450000/31.29 = 14381.6 seconds

Time to cover 450 km =3.99 hours

Battery capacity = 50.18 * 3.99 = 200.46 A h

Safety factor = 2 so 200.46 * 2 = 401 A h

The battery capacity should be 401A h.



[1] https://auto.howstuffworks.com/electric-car2.htm [2] https://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303html [3] https://www.myev.com/research/ev-101/how-long-should-an-electric-cars-battery-last

Comparison

As I was curious about how the sharp edges on a car would effect the pressures and velocities on a car, I decided to create another sports car in Solidworks, that took inspiration from the Tesla Cybertruck.

When carrying out the flow simulation, it was clear to see that the pressures were much higher around the front bumper edge of the car. If you compare figure 26 to figure 19, you can see the difference between a curved front bumper and a sharp edged one.

Looking at figure 27, it can also be seen that at the rear of the car, there is an area of much lower velocity.

This is again down to the sharp edges, as the air is moving parallel to the car, and therefore after it gets to the back of the car, it is not going in the direction for the air off the top and the air off the bottom to meet, compared to the curved car as seen in figure 17 where the curved rear means the air is moving over the top and the bottom of the car in directions to meet each other sooner.

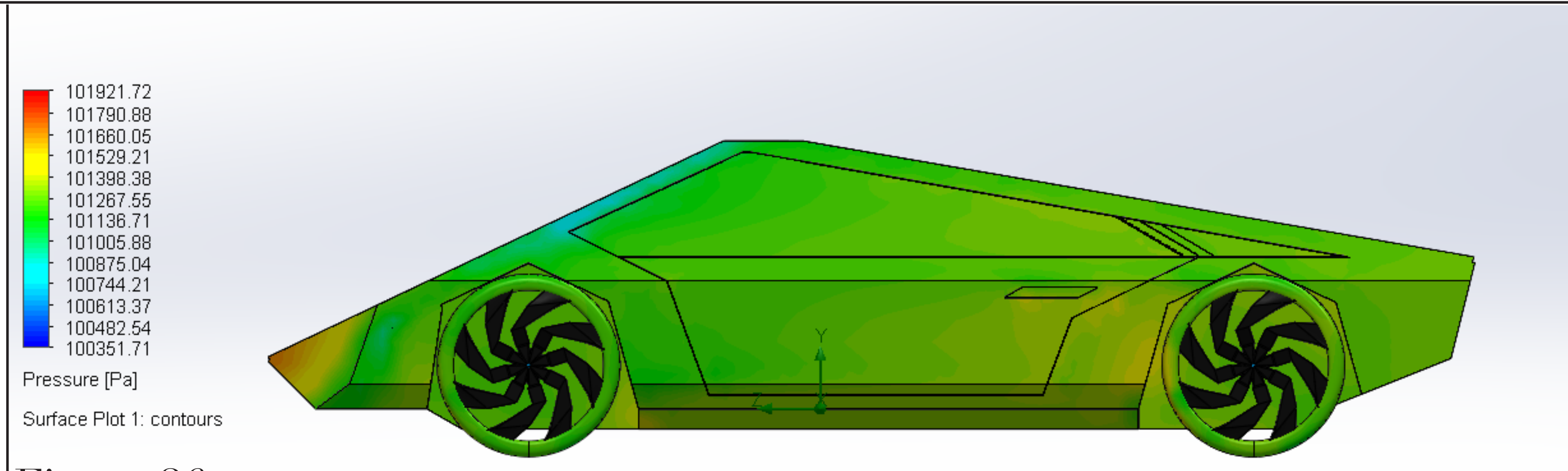


Figure 26

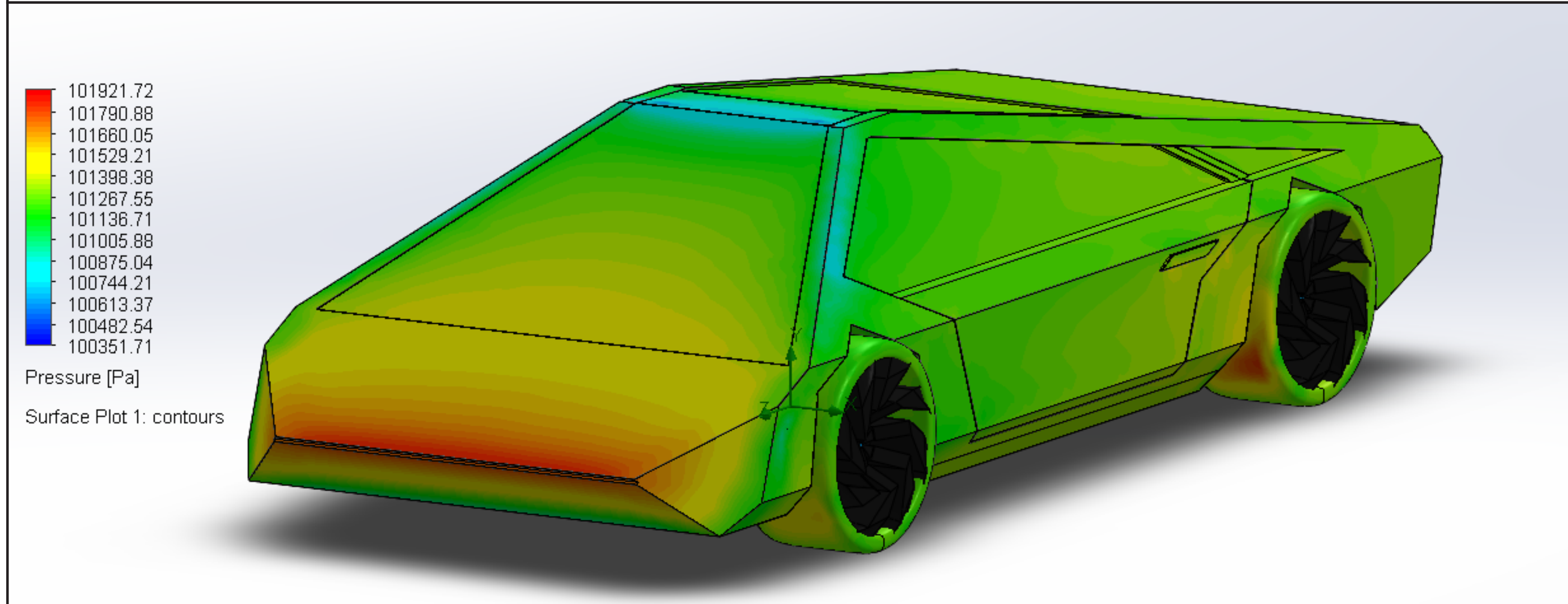


Figure 27

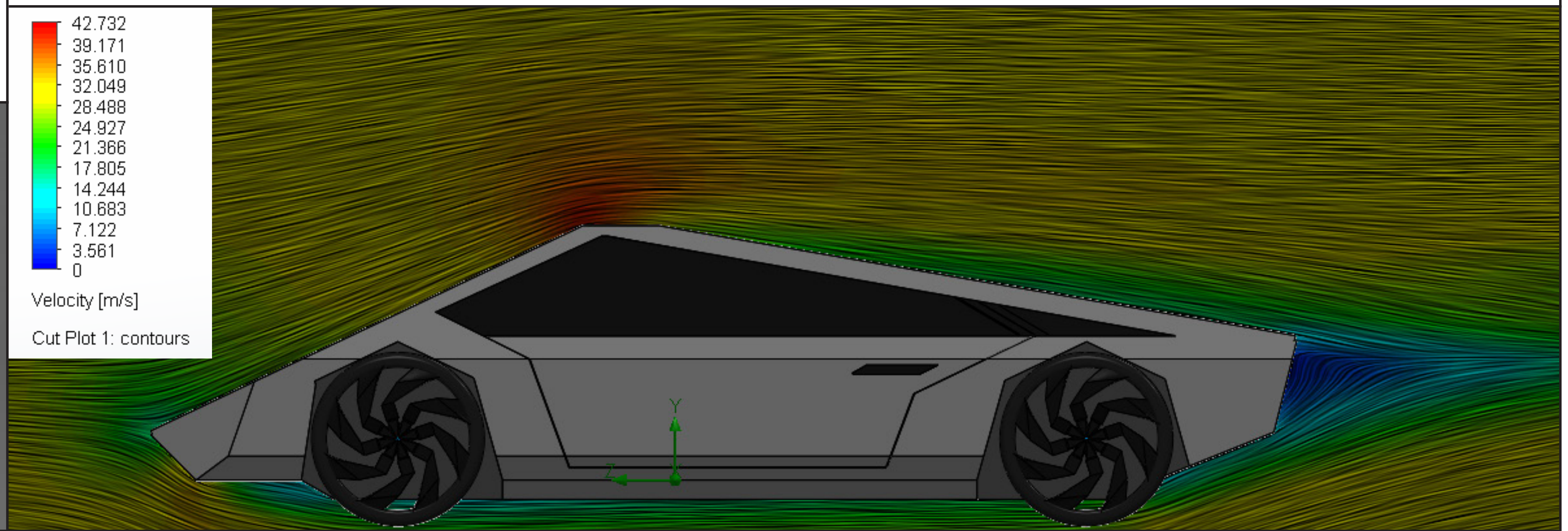


Figure 28

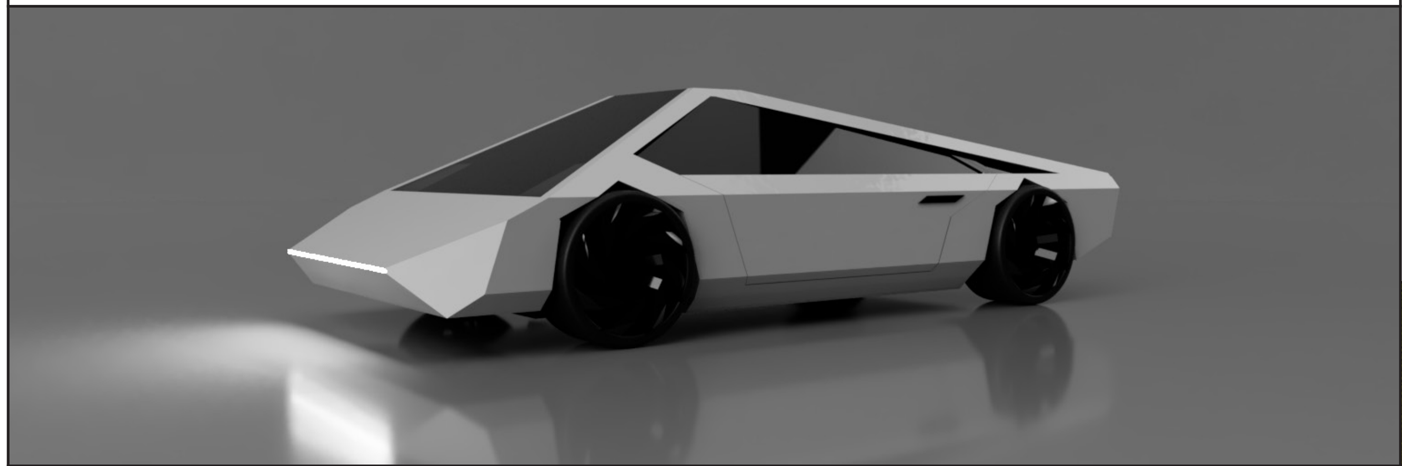


Figure 29