

# 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.

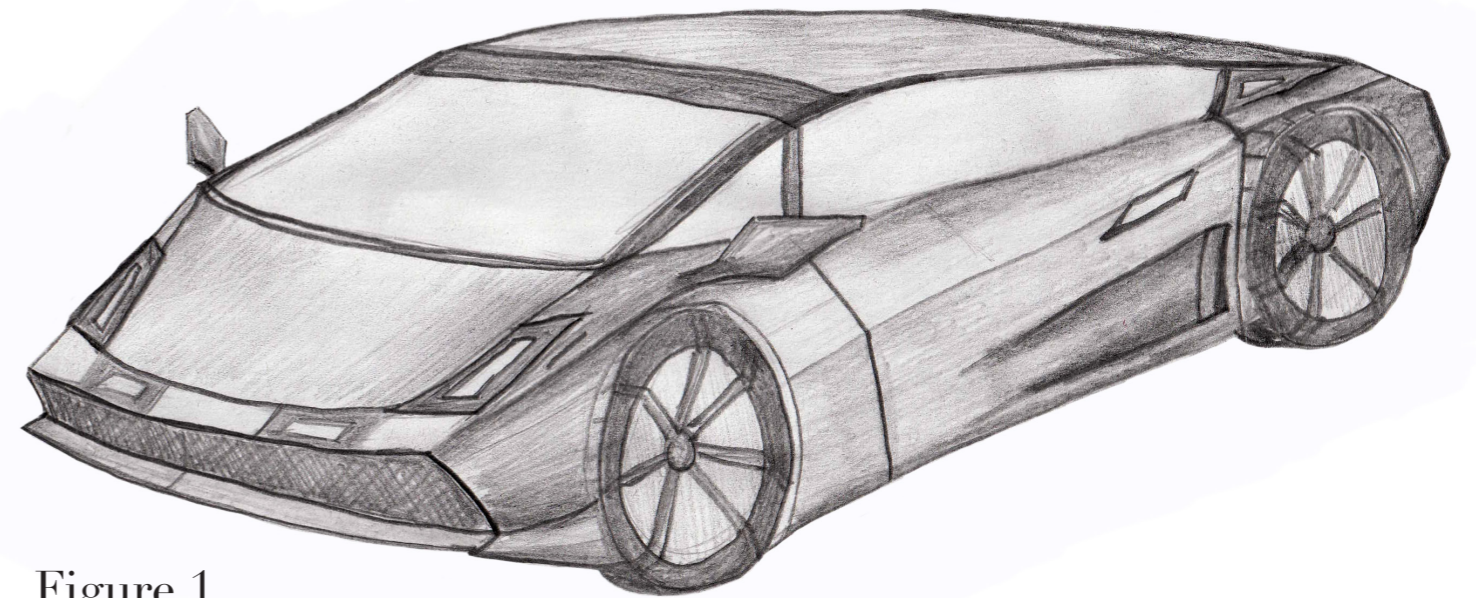


Figure 1

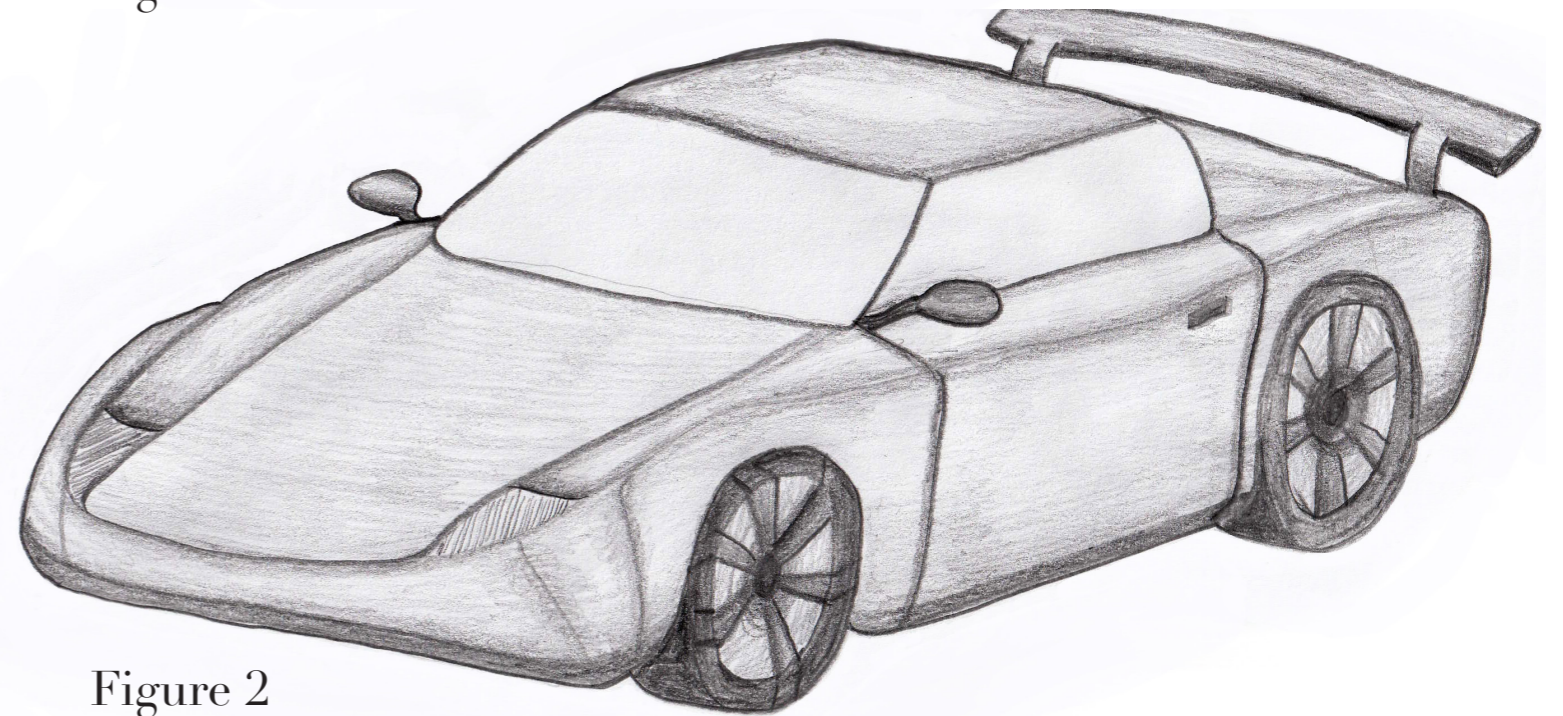


Figure 2

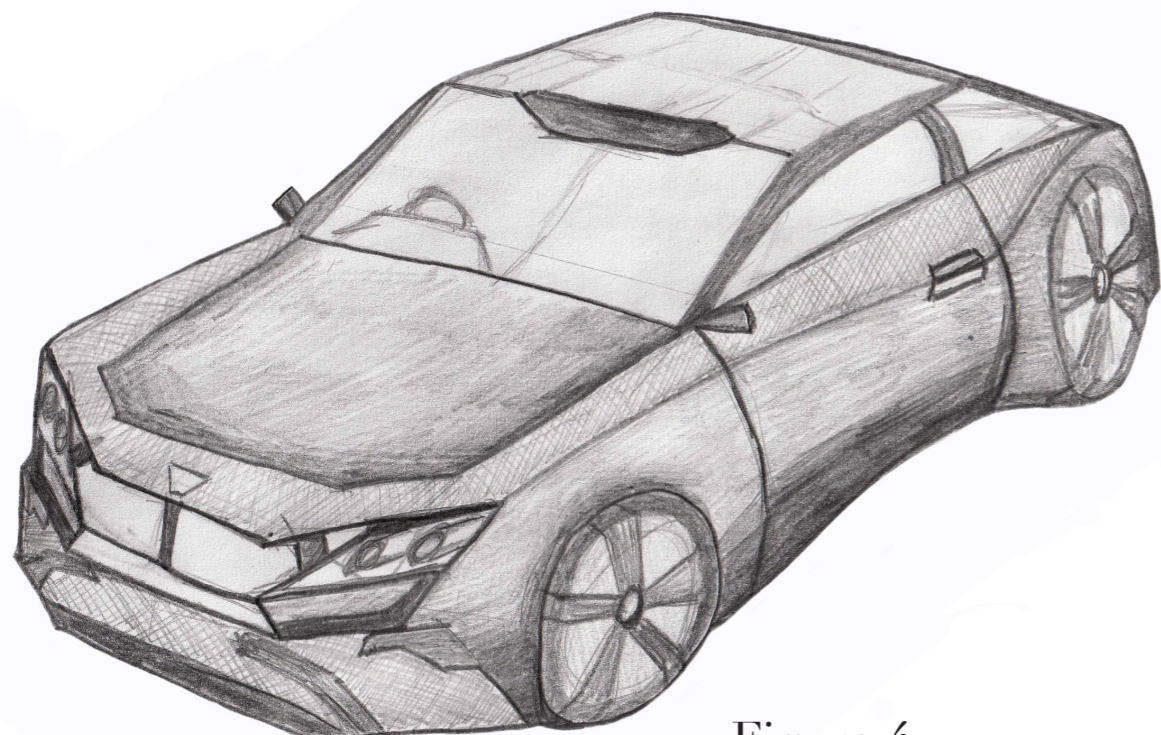


Figure 4

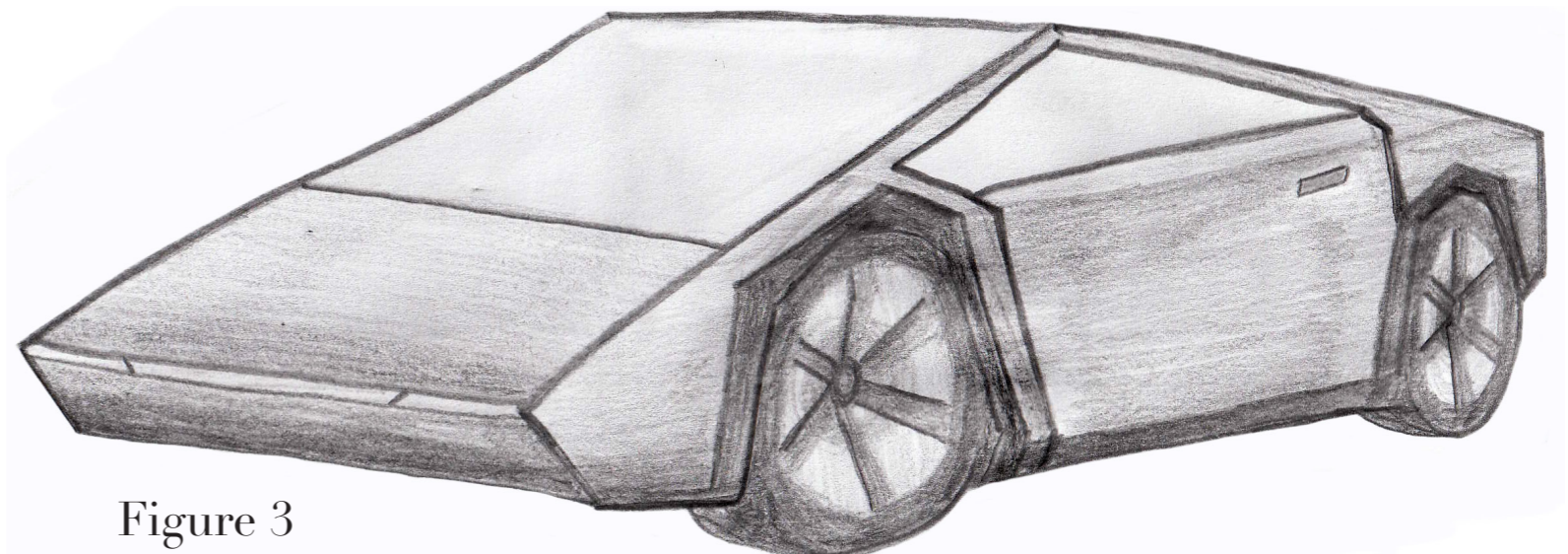


Figure 3

# 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.

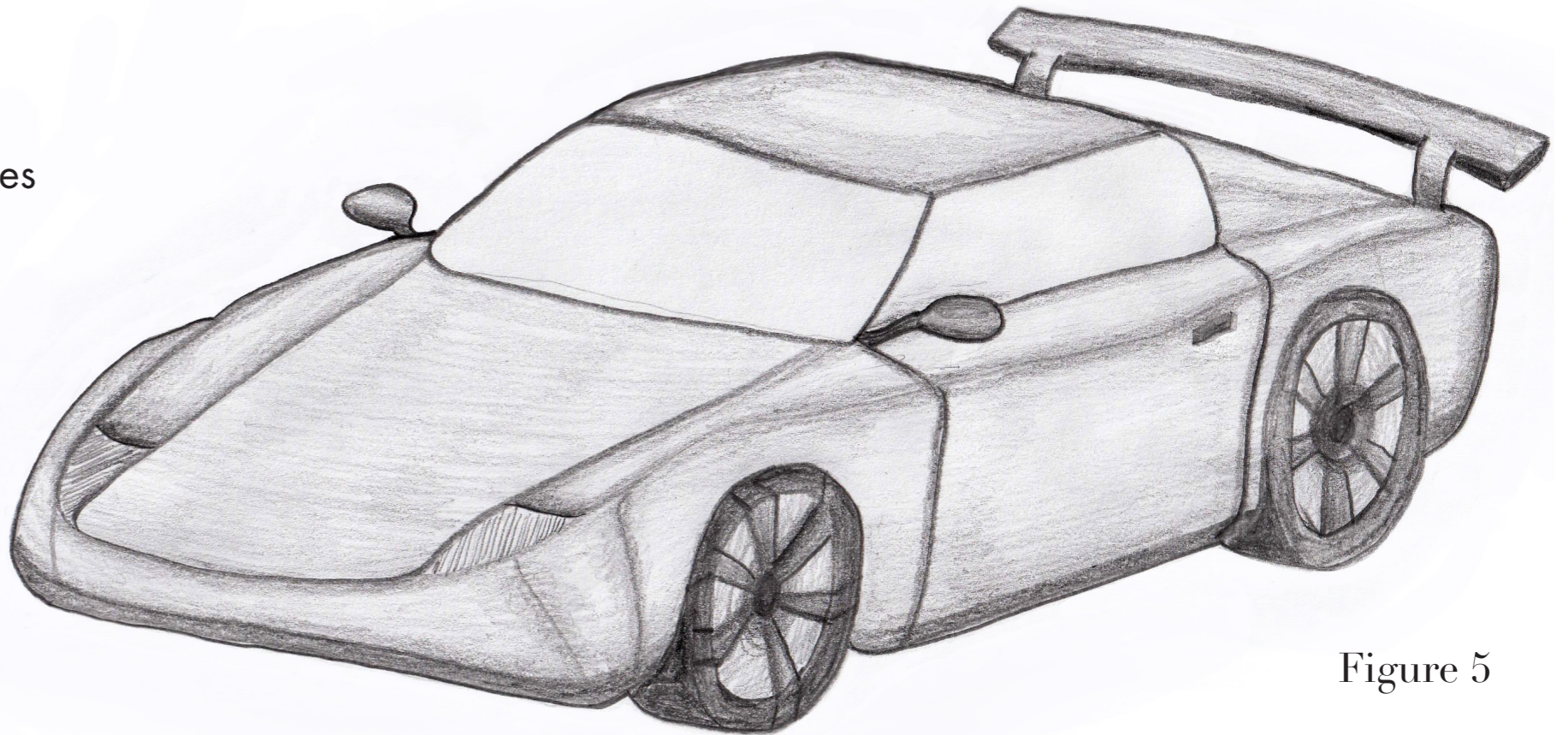


Figure 5

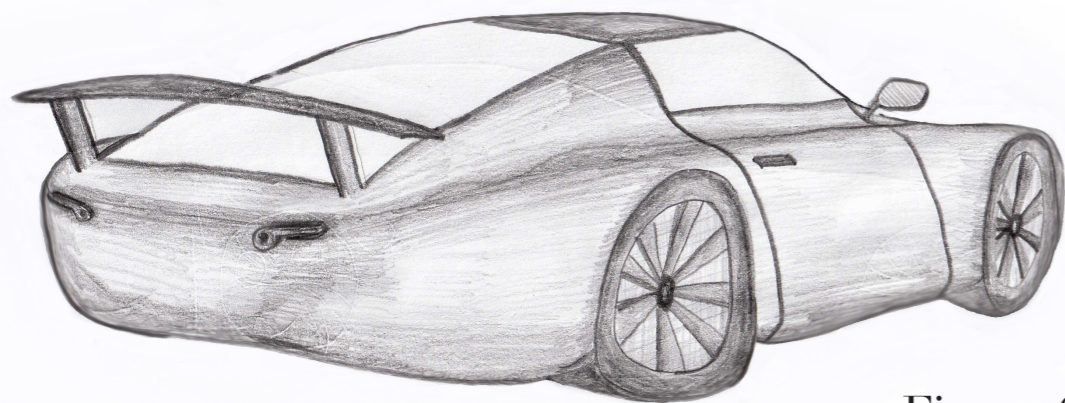


Figure 6

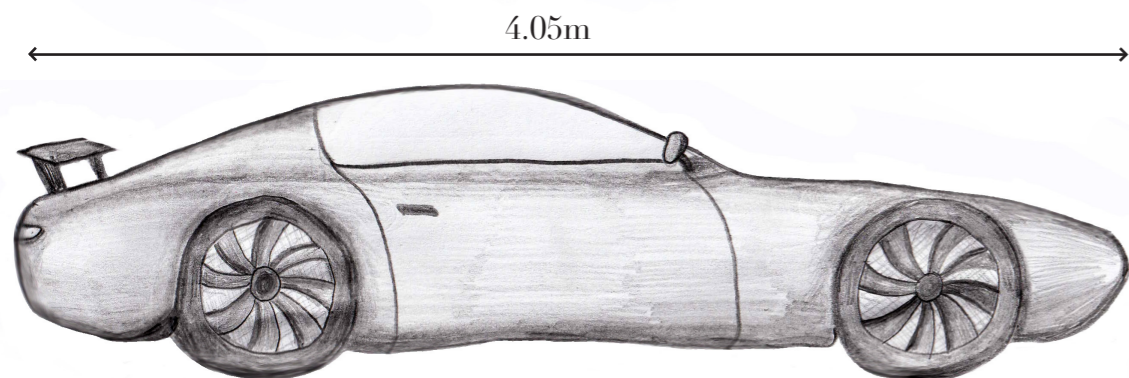


Figure 7

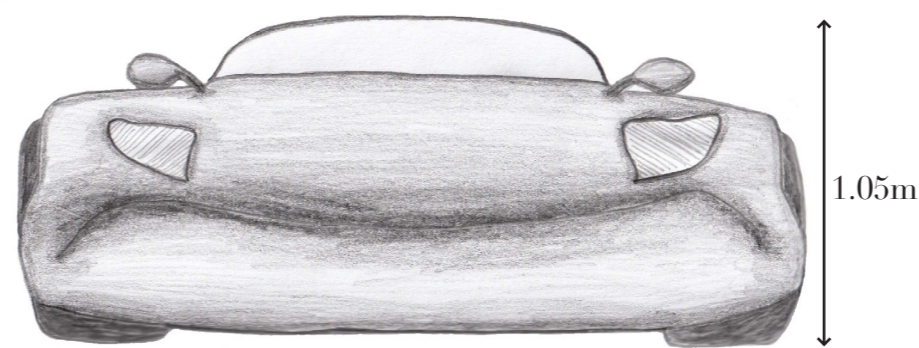


Figure 8

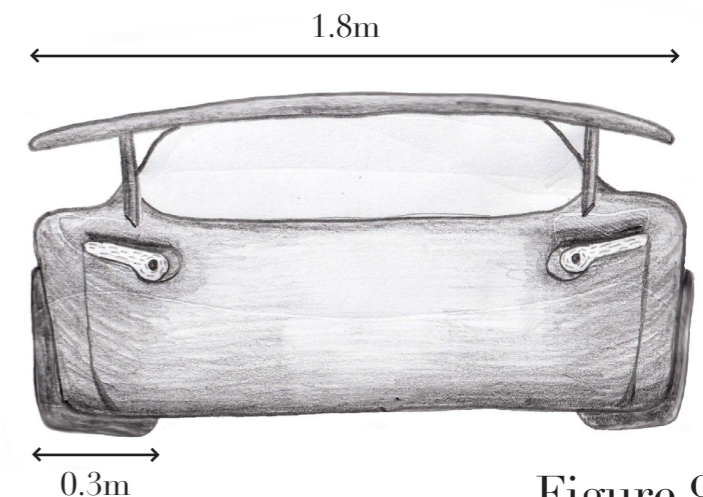


Figure 9

# Solid Model

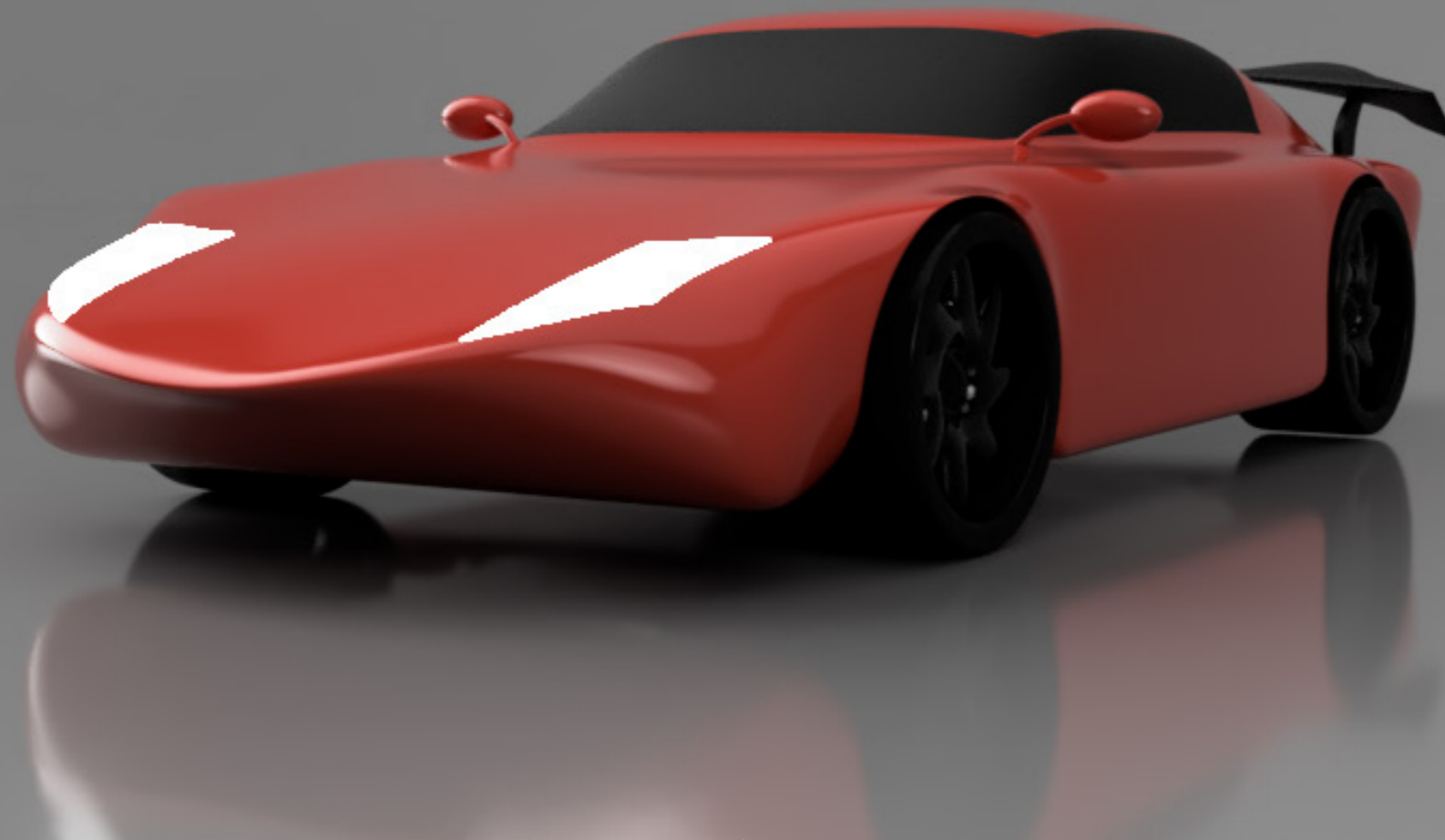
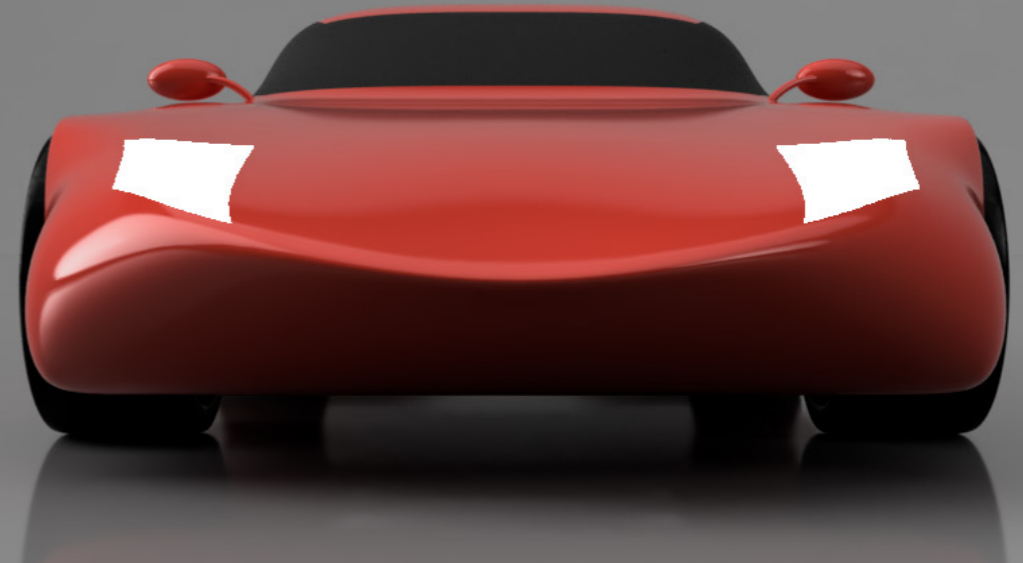


Figure 10. Overall View

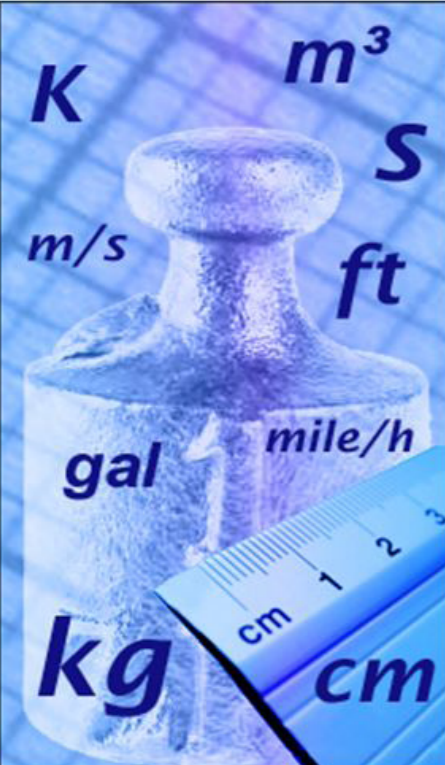
Figure 11. Rear View

Figure 12. Front View



# Wizard Settings

Wizard - Unit System



Unit system:

System	Path	Comment
CGS (cm-g-s)	Pre-Defined	CGS (cm-g-s)
FPS (ft-lb-s)	Pre-Defined	FPS (ft-lb-s)
IPS (in-lb-s)	Pre-Defined	IPS (in-lb-s)
NMM (mm-g-s)	Pre-Defined	NMM (mm-g-s)
SI (m-kg-s)	Pre-Defined	SI (m-kg-s)
USA	Pre-Defined	USA


Create new    Name: SI (m-kg-s) (modified)

Parameter	Unit	Decimals in results display	1 SI unit equals to
<b>Main</b>			
Pressure & stress	Pa	.12	1
Velocity	m/s	.123	1
Mass	kg	.123	1
Length	m	.123	1
Temperature	K	.12	1
Physical time	s	.123	1
Percentage	%	.12	1
<b>HVAC</b>			

< Back    Next >    Cancel    Help

Figure 13

Wizard - Analysis Type



Analysis type:  Internal     External

Consider closed cavities:  Exclude cavities without flow conditions     Exclude internal space


Physical Features	Value
Heat conduction in solids	<input type="checkbox"/>
Radiation	<input type="checkbox"/>
Time-dependent	<input type="checkbox"/>
Gravity	<input type="checkbox"/>
Rotation	<input type="checkbox"/>
Free surface	<input type="checkbox"/>

Dependency...

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Figure 14

Wizard - Default Fluid



Fluids	Path
<b>Gases</b>	
Pre-Defined	
Acetone	Pre-Defined
Ammonia	Pre-Defined
Argon	Pre-Defined
Butane	Pre-Defined
Carbon dioxide	Pre-Defined
Chlorine	Pre-Defined
Ethane	Pre-Defined
Ethanol	Pre-Defined
Ethylene	Pre-Defined

New...    Add    Remove

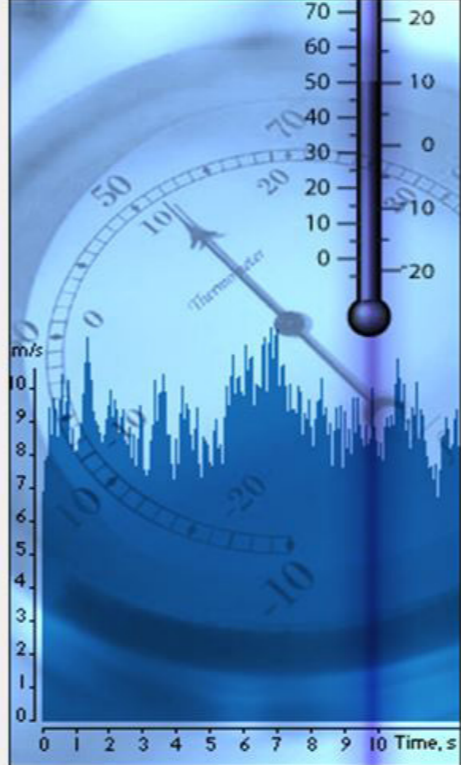
Project Fluids	Default Fluid
Air ( Gases )	<input checked="" type="checkbox"/>

Flow Characteristic	Value
Flow type	Laminar and Turbulent
High Mach number flow	<input type="checkbox"/>
Humidity	<input type="checkbox"/>

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Figure 15

Wizard - Initial and Ambient Conditions



Parameter	Value
<b>Parameter Definition</b>	
Parameter Definition	User Defined
<b>Thermodynamic Parameters</b>	
Parameters	Pressure, temperature
Pressure	101325 Pa
Temperature	293.2 K
<b>Velocity Parameters</b>	
Parameter	Velocity
Defined by	3D Vector
Velocity in X direction	0 m/s
Velocity in Y direction	0 m/s
Velocity in Z direction	-31.29 m/s
<b>Turbulence Parameters</b>	

Coordinate System...    Dependency...

< Back    Finish    Cancel    Help

Figure 16

# 2D Velocity and Pressure Distribution

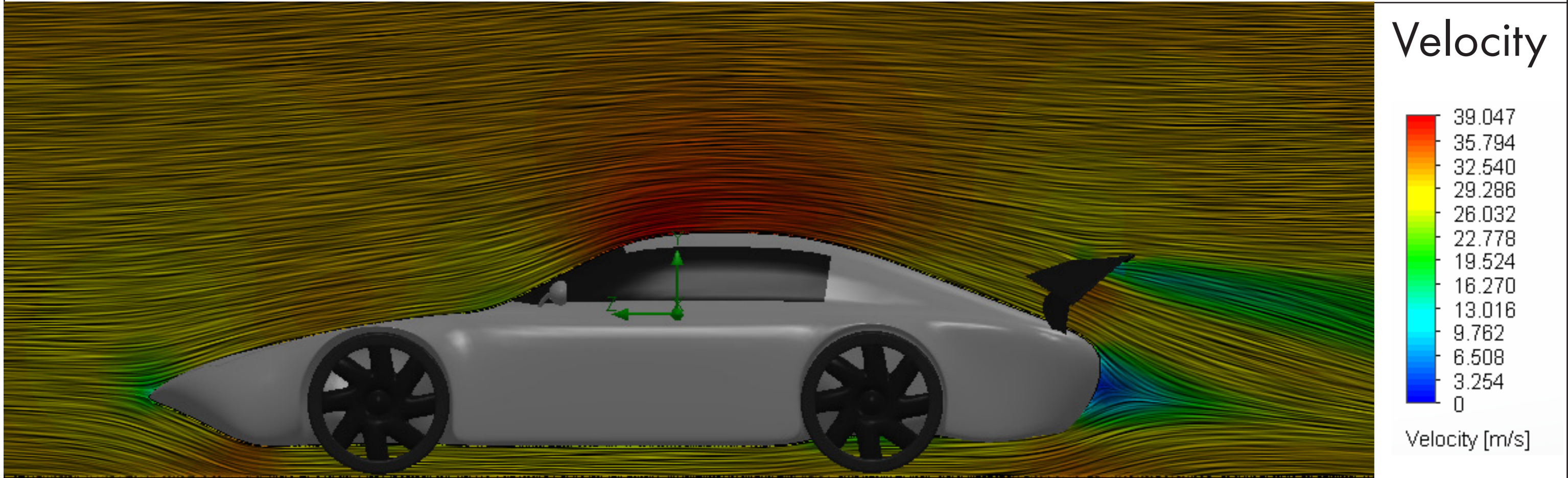
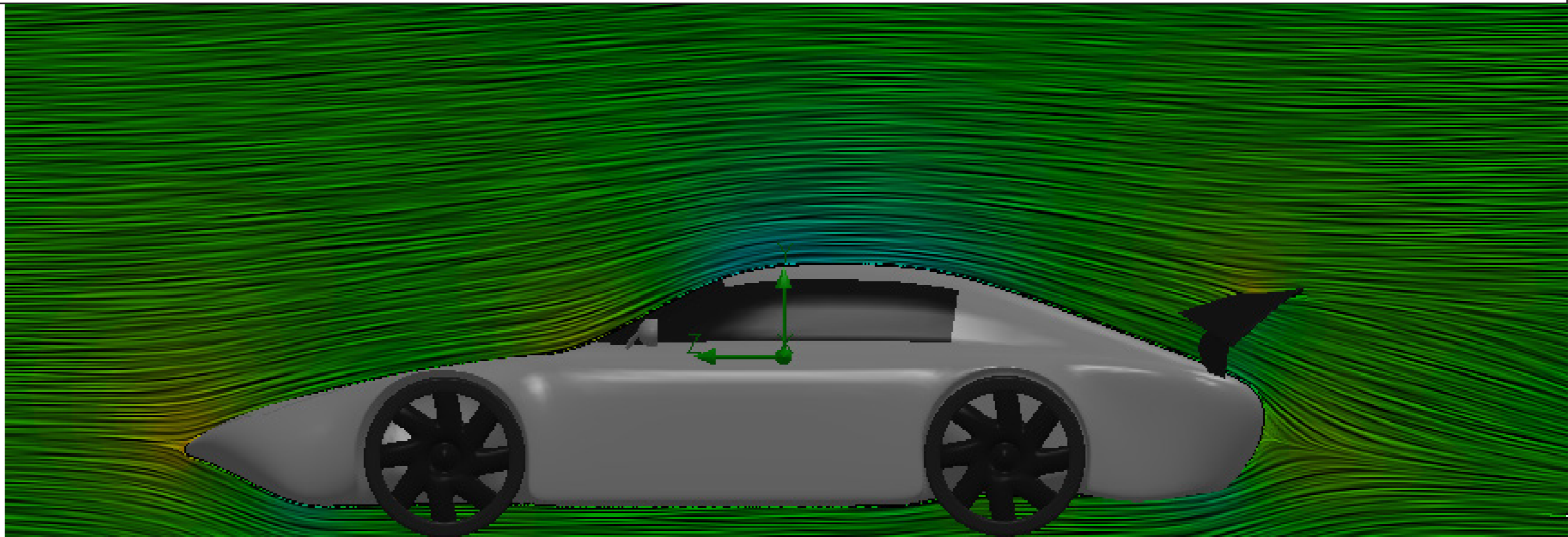
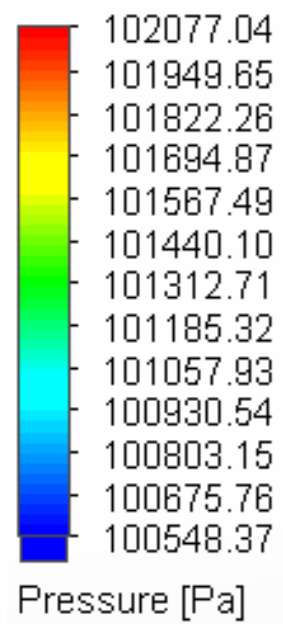


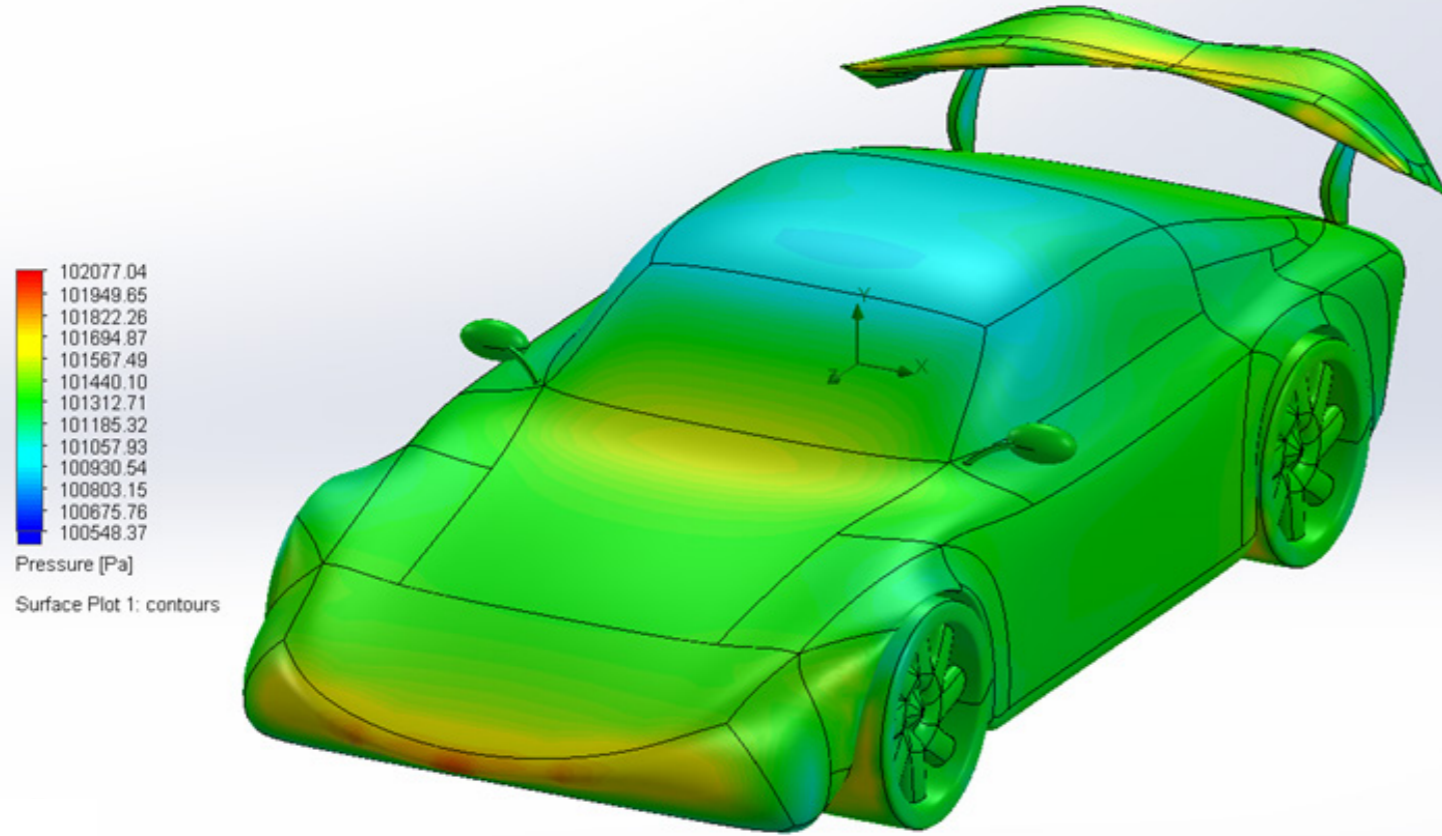
Figure 17

Figure 18

## Pressure



# Surface Pressure

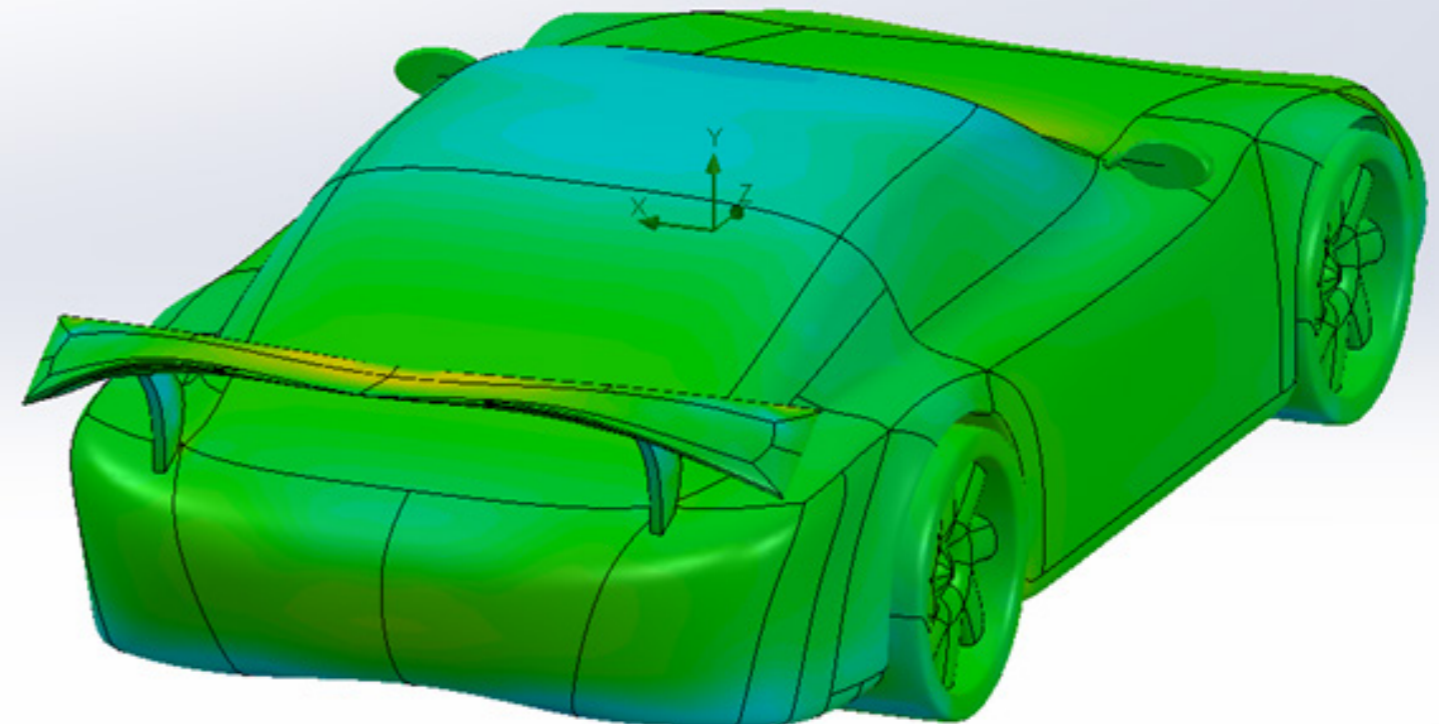
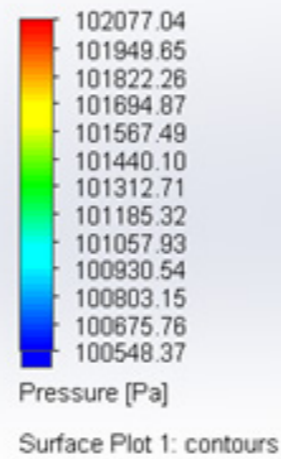
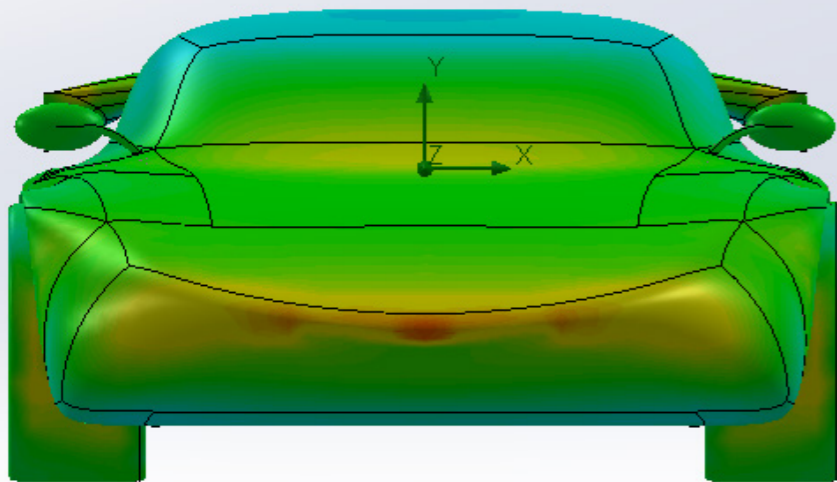


From the surface analysis it can be seen that the highest pressure is at the front on the car, but that the spoiler also has a higher pressure than most other parts of the car. This shows that it is effective as the air is pressing the car to the ground.

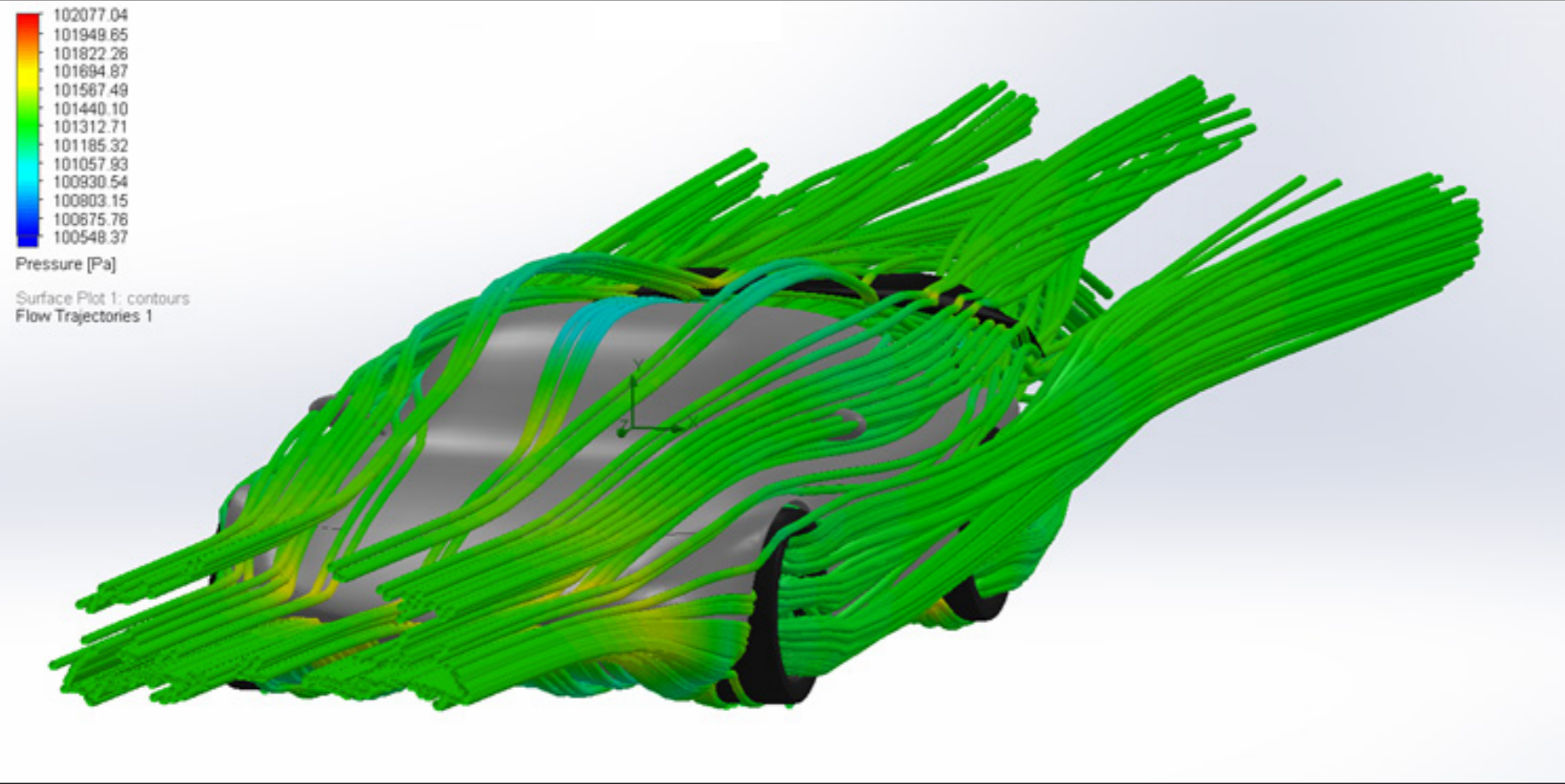
Figure 19

Figure 20

Figure 21



# Flow Trajectories

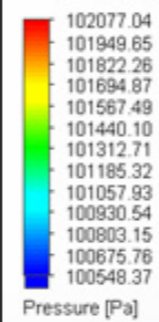
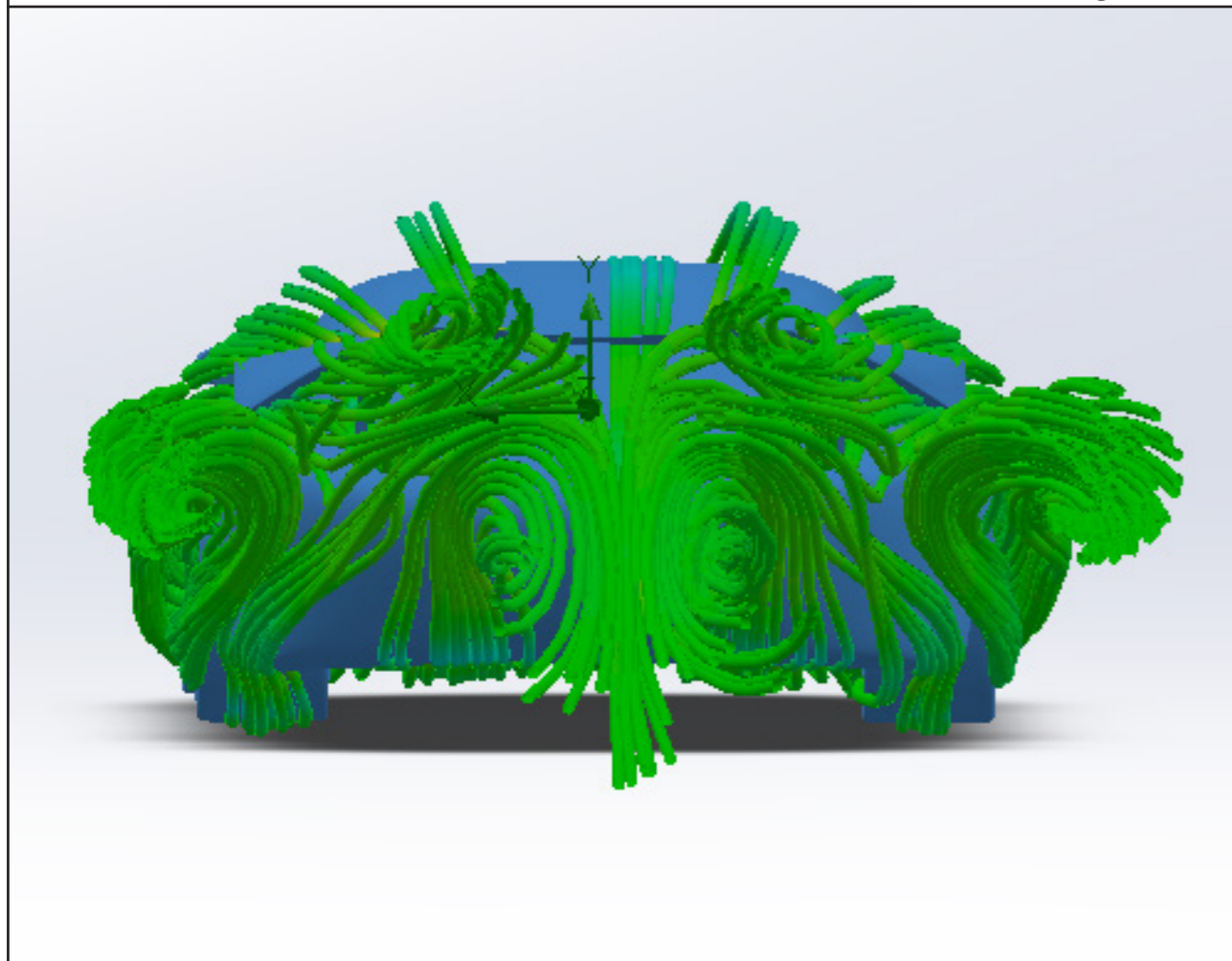


From the flow trajectories it can be seen that the air is forming some small vortexes behind the car, but that in general it passes smoothly over it.

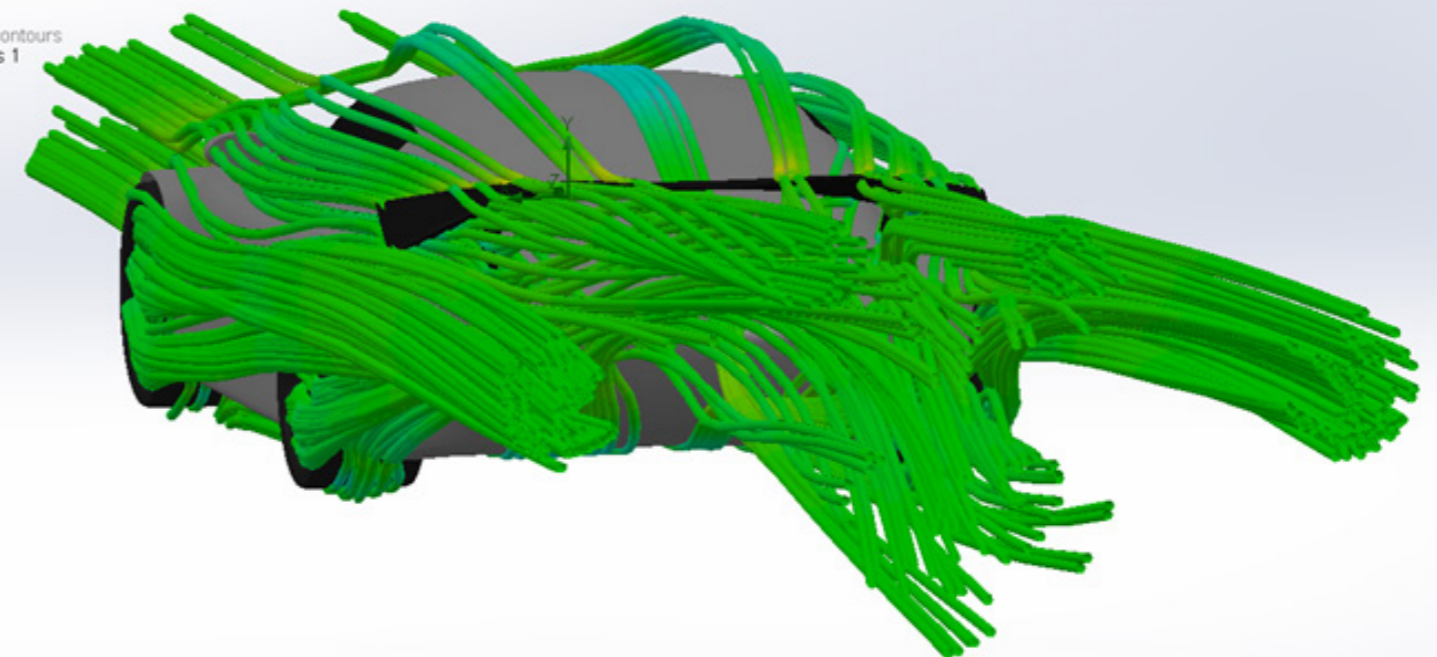
Figure 22

Figure 23

Figure 24



Surface Plot 1: contours  
Flow Trajectories 1





# 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.

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

$$\text{Force (Z)} = 288.672 \text{ N}$$

$$\text{Power} = \text{Drag} * \text{Velocity}$$

$$288.672 * 31.29 = 9032.55 \text{ W}$$

$$= 9.03 \text{ kW}$$

If the car drives for 1 hour at this velocity:

$$\text{Energy required} = 9032.55 * 60 * 60 =$$

$$32517180 \text{ J} = 32.5 \text{ MJ}$$

## Battery Capacity

As it is an electric vehicle, it has 300 V<sup>[1]</sup> electric motor voltage when travelling at 31.29 ms<sup>-1</sup>. The mass of the car is 1300 kg. Rolling Resistance Coefficient is 0.015<sup>[2]</sup>. 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

$$= 9032.5 / 0.6 = 15054.16 \text{ W}$$

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

$$= 50.18 \text{ A}$$

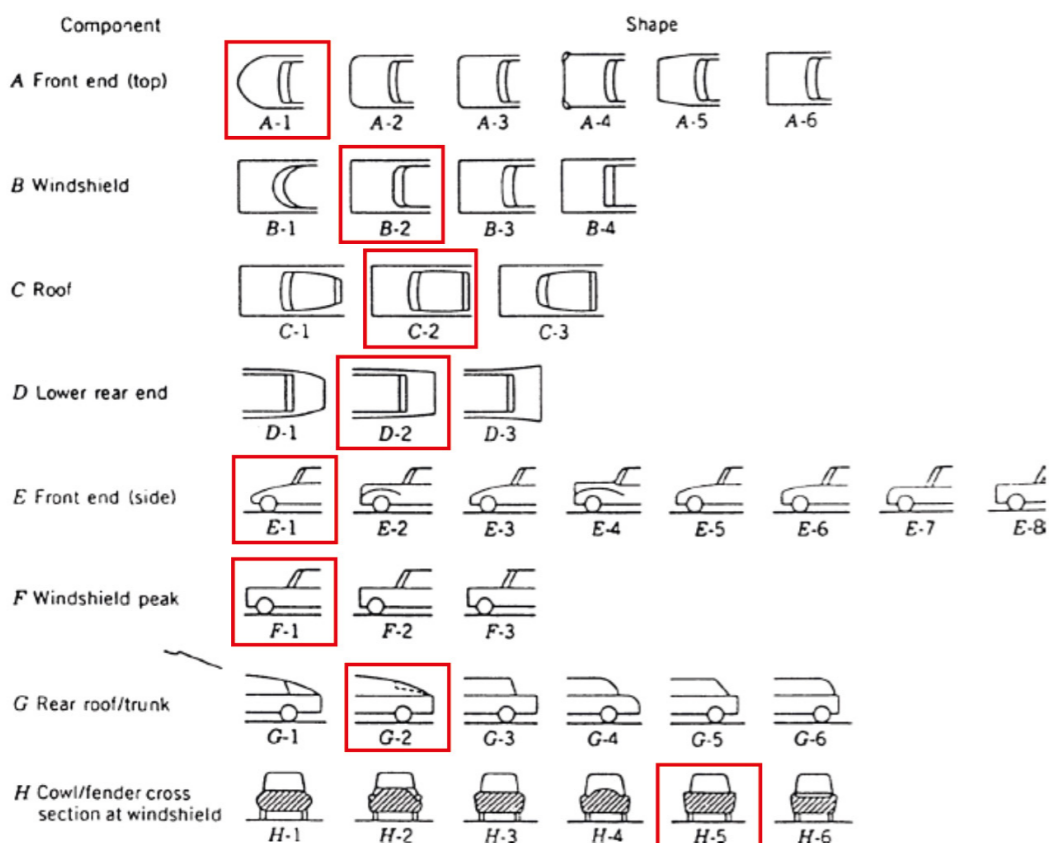
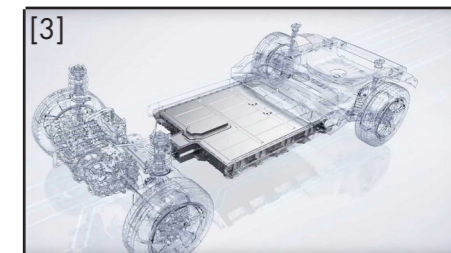
$$450000 / 31.29 = 14381.6 \text{ seconds}$$

$$\text{Time to cover 450 km} = 3.99 \text{ hours}$$

$$\text{Battery capacity} = 50.18 * 3.99 = 200.46 \text{ A h}$$

$$\text{Safety factor} = 2 \text{ so } 200.46 * 2 = 401 \text{ A h}$$

The battery capacity should be 401 A h.



## 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.

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

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

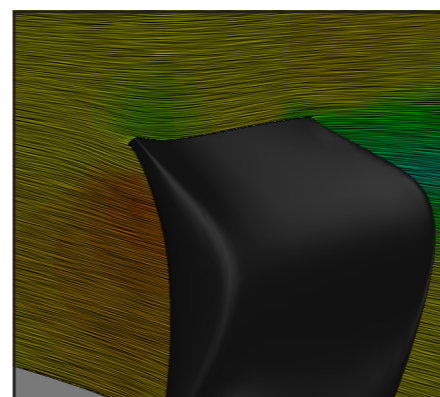
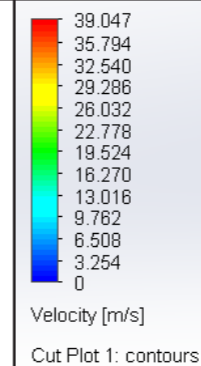
$$\Delta P = (1.225)(33^2 - 25^2) / 2$$

$$\Delta P = 284.2 \text{ N/m}^2$$

$$F = \Delta P * A$$

$$F = 284.2 * 0.4306$$

$$F = 122 \text{ N Down force}$$



[1] <https://auto.howstuffworks.com/electric-car2.htm>

[2] [https://www.engineeringtoolbox.com/rolling-friction-resistance-d\\_1303html](https://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303html)

[3] <https://www.myeve.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.

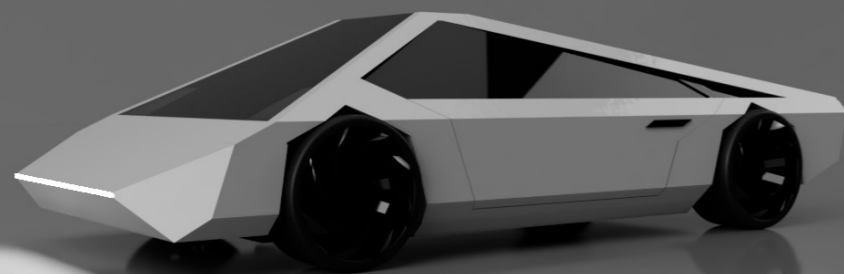


Figure 29

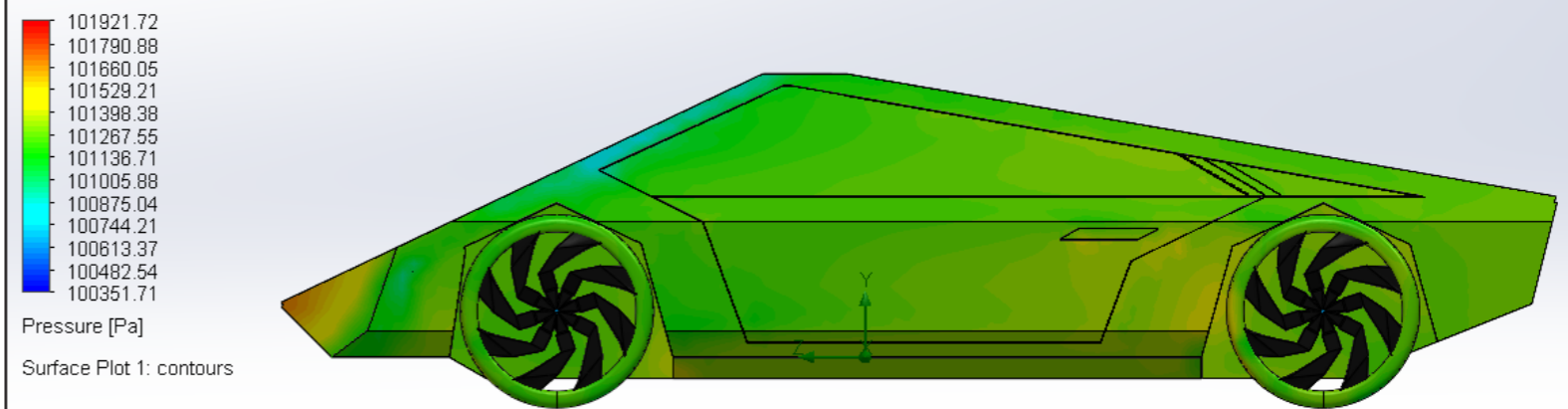


Figure 26

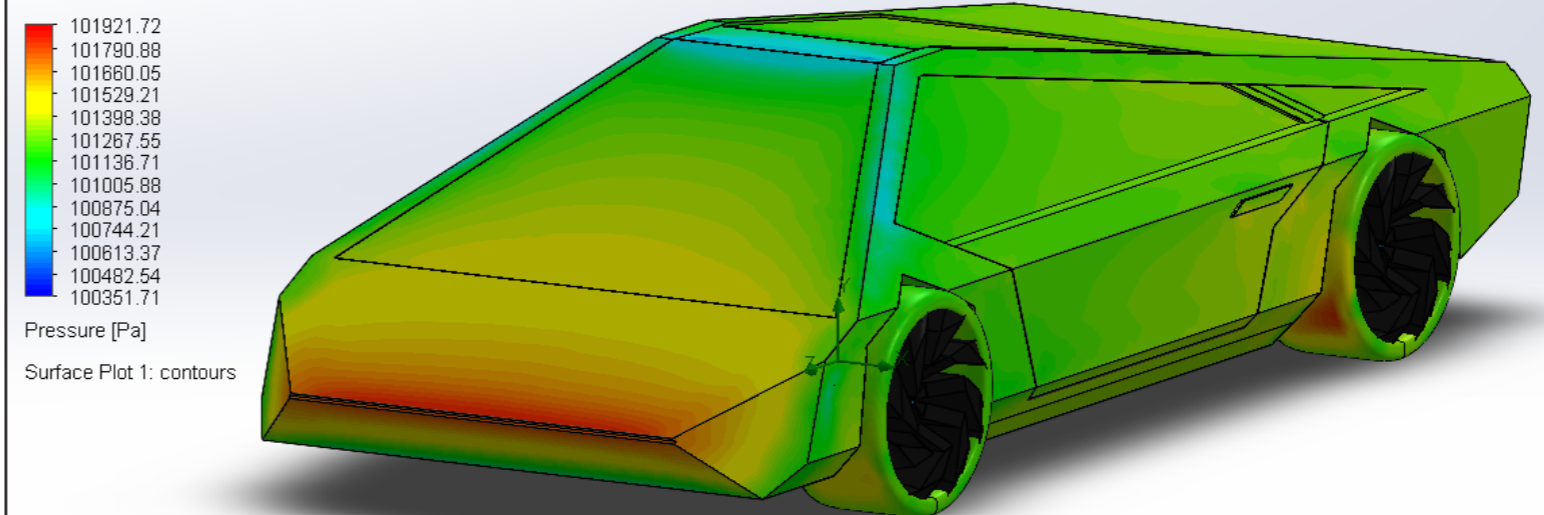


Figure 27

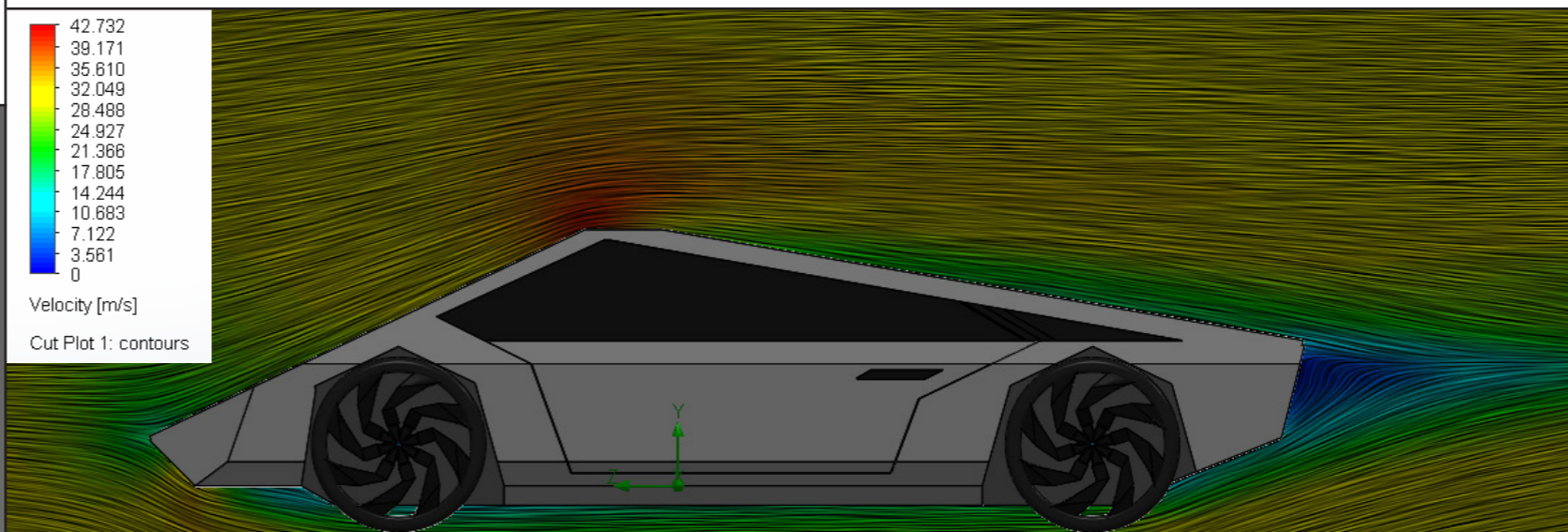


Figure 28