THERMOFLUIDS: VEHICLE DESIGN

DE2 2023/2024

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1 TABLE OF CONTENTS

2 SUMMARY

The project aimed to design a minimalist and modern pick-up truck with a spacious driver's cabin, while maintaining competitive aerodynamic performance. The design process involved three iterations of sketching and Vizcom, resulting in the final concept. The dimensions of the concept were derived from the Ford F150 Lightning, which facilitated the creation of the CAD model. The CAD model was then subjected to a CFD analysis, which revealed the following aerodynamic characteristics:

- Lift Force: 567 N
- Drag Force: -768 N
- Drag Coefficient: 0.43

These values are within the typical range for pick-up trucks. However, the CFD analysis also identified a major aerodynamic problem: the formation of large vortices in the truck bed. This could be mitigated by increasing the height of the walls on both sides of the bed, which would reduce the lateral air flow into the bed.

3 Design Iterations

The initial design inspirations for this pickup were rooted in minimalism and functionality. The vehicle features a compact, boxy shape that maximizes space efficiency while maintaining a sleek appearance. The theme for this design was simplicity, with clean lines, a monochromatic colour scheme, and an absence of excessive detailing. This approach not only underscores the vehicle's utilitarian purpose but also lends it a contemporary, urban aesthetic.

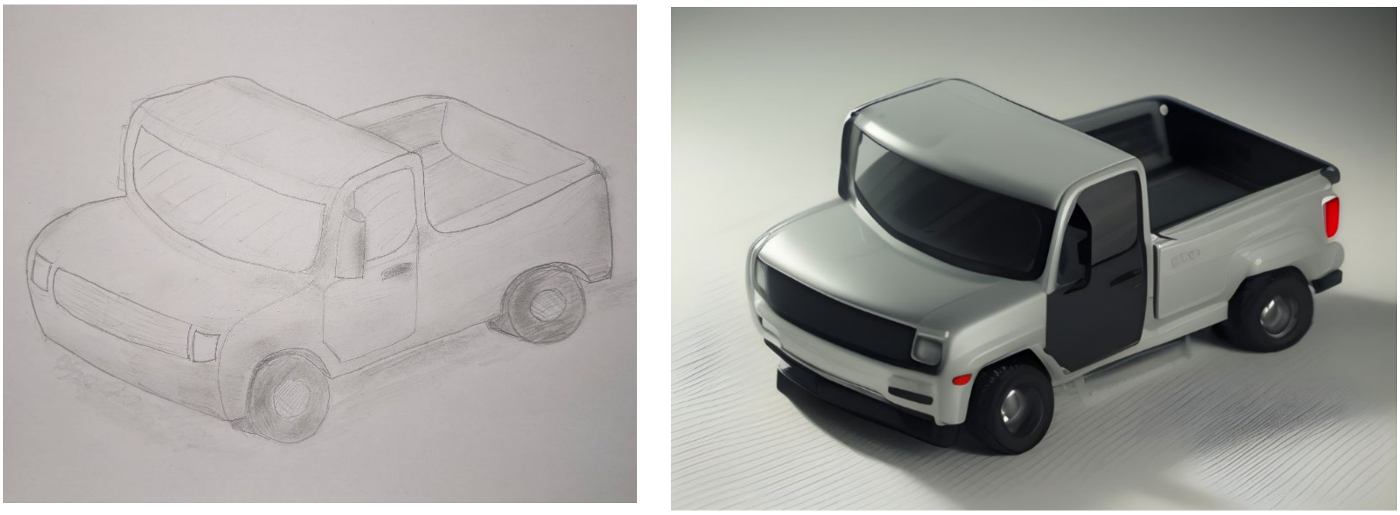

Figure 1 - the initial concept for the pickup.

While the principles of the design were good, the design resembles trucks produced in the last century and lacked modern appearance. Therefore, a second iteration of the design was devised.

Figure 2 - Second Iteration of the pickup design.

The second design while remaining rather boxy and still minimalist, has introduced modern features to the design such as the LED headlights and the air channelling features. However, the design lacks significant aerodynamic features. The windscreen is largely flat, and the bottom of the front bumper is likely to create turbulent flow. Additionally, the front of the bonnet of the truck is almost straight which can cause significant drag.

Figure 3 - Third Iteration of the Design.

A number of changes were made in the third iteration of the design. Firstly, the aerodynamics of the car were improved by adding a slant to the windscreen, rounding the front bumper, air channelling features at the front and lowering the driver's cabin. Secondly, the pickup was extended slightly to match the exterior dimensions of the Ford F150 Lightning, which is the most sold pickup in the US. (1) This was done in order to enable the use of the F150 blueprints for the CAD model.

4 CAD MODEL

The final CAD model is shown below, with the key aerodynamic features highlighted and annotated.

Figure 4 - Render overview of the pickup model in a real-life scenario.

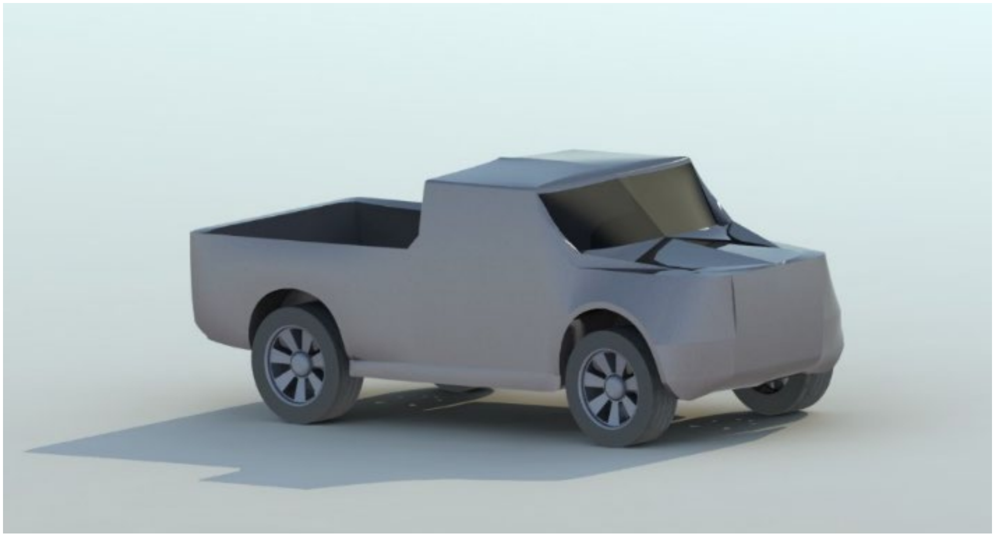

Figure 5 - Isometric view of the model.

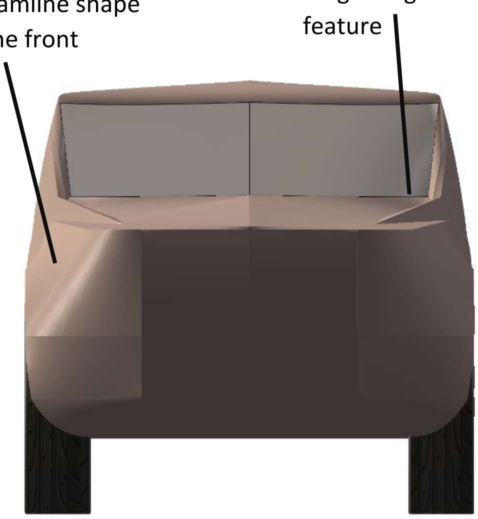

Figure 6 - Front view.

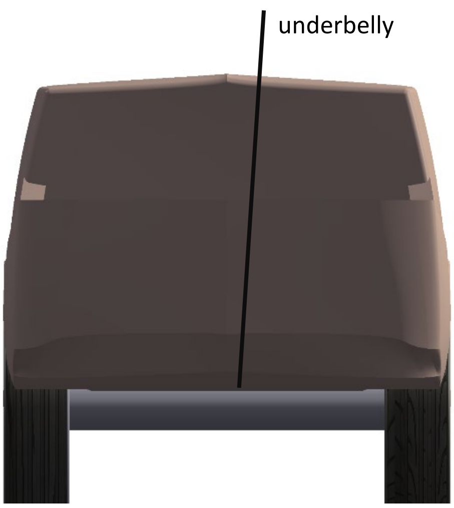

Figure 7 - Rear view.

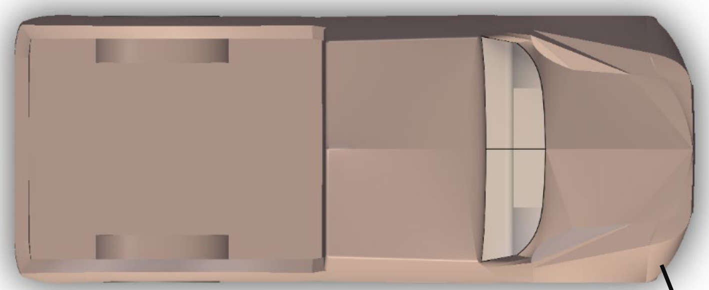

Figure 8 - Top view.

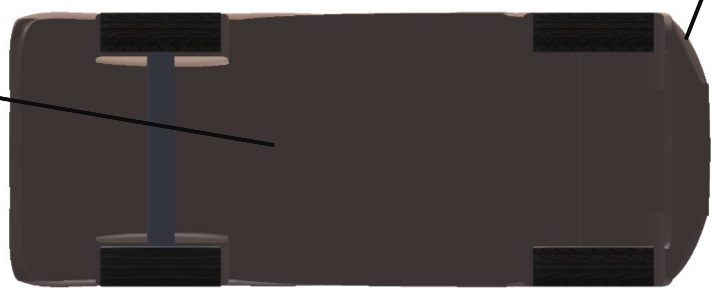

Figure 9 - Bottom view.

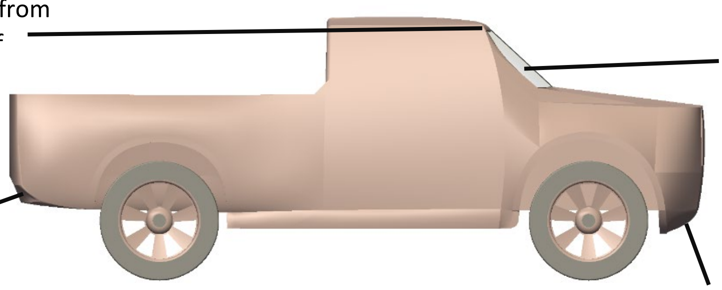

Figure 10 - Side view.

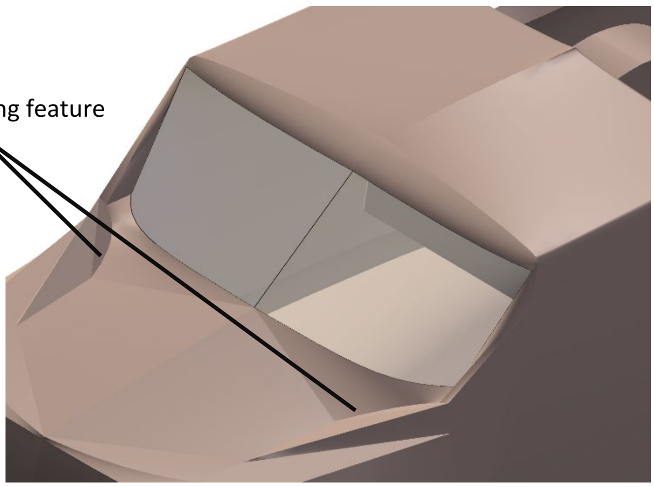

Figure 11 - Windscreen detail.

5 DRAG ANALYSIS AND PRELIMINARY CALCULATIONS

An initial drag calculation was performed to validate the design of the pick-up and determine any potential for improvement before proceeding to computational fluid dynamics (CFD) simulations.

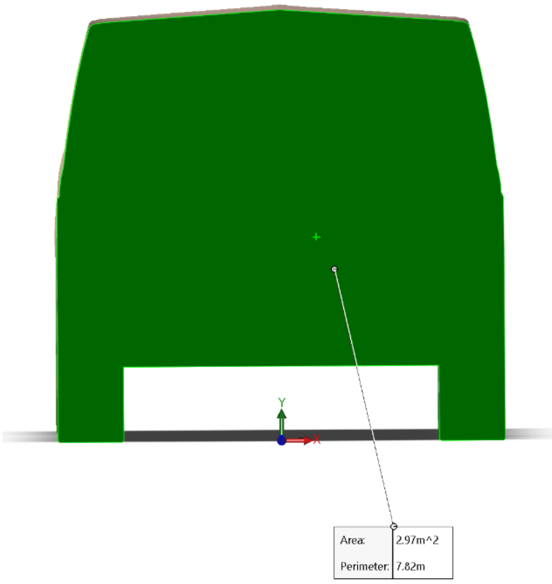

Figure 12 - The Frontal Area of the Pick-up Truck.

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

$$N_A = 5, N_B = 3, N_C = 2, N_D = 2, N_E = 4, N_F = 3, N_G = 3, N_H = 4$$

$$C_d = 0.16 + 0.0095 \times 23$$

$$C_d = 0.3785$$

Assuming the vehicle is travelling at 70 mph (the national speed limit), therefore $v = 31.290 \text{ m/s}$.

$$C_d = \frac{2F}{\rho v^2 A}$$

Where:
F is the drag Force (N),
ρ is the air density (1.225 kg/m^3)
v is the air velocity (m/s)
A is the frontal area (m/s)

It can then be found that the Drag Force, F is 670 N.

Therefore, the Power lost to overcoming drag, P can be found by $P = Fv$, which when computed gives a result of 20.1 kW.

The drag coefficient of the Ford F150 Lightning is 0.36 (2), and the preliminary calculations show that the predicted coefficient for my pick-up is very close to that. With that in mind, it was decided to proceed with the current design for the final CFD analysis.

6 CFD MODEL

6.1.1 Vehicle Data

Frontal Area: 2.97 m^2

6.1.2 Ambient Conditions

Thermodynamic parameters	Static Pressure: 101325.00 Pa Temperature: 293.20 K
Velocity parameters	Velocity vector Velocity in X direction: 0 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: -31.290 m/s
Turbulence parameters	Turbulence intensity and length Intensity: 0.10 % Length: 0.019 m

6.1.3 Physical Features Settings

Fluid Flow: On
Conduction: Off
Structural: Off
Electromagnetics: Off
Time dependent: Off

Gravitational effects: Off
Rotation: Off
Flow type: Laminar and turbulent
High Mach number flow: Off
Humidity: Off

Free surface: Off
Default roughness: 0 micrometre
Default wall conditions: Adiabatic wall

6.1.4 Mesh Settings

Cells	612235

6.1.5 Computational Domain Settings

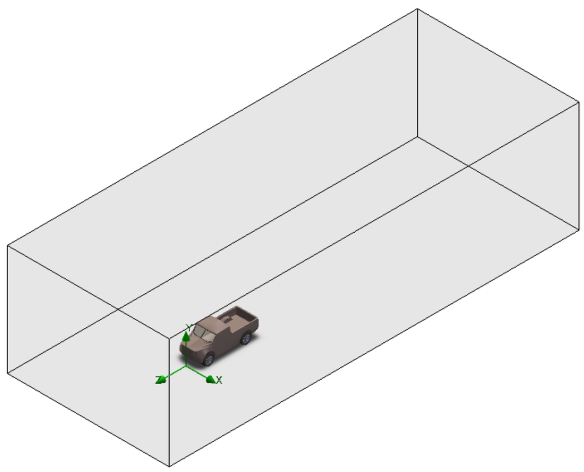

Figure 13 - Showing the computational domain.

6.2 RESULTS

Name	Unit	Value	Progress	Criteria	Delta	Use in convergence
GG Force (Y) 1	N	567.160	100	66.0519302	3.89118628	On
GG Force (Z) 2	N	-768.102	100	159.206883	3.47940406	On
Drag Coefficient		0.4312679	100	0.0893902164	0.00195358817	On

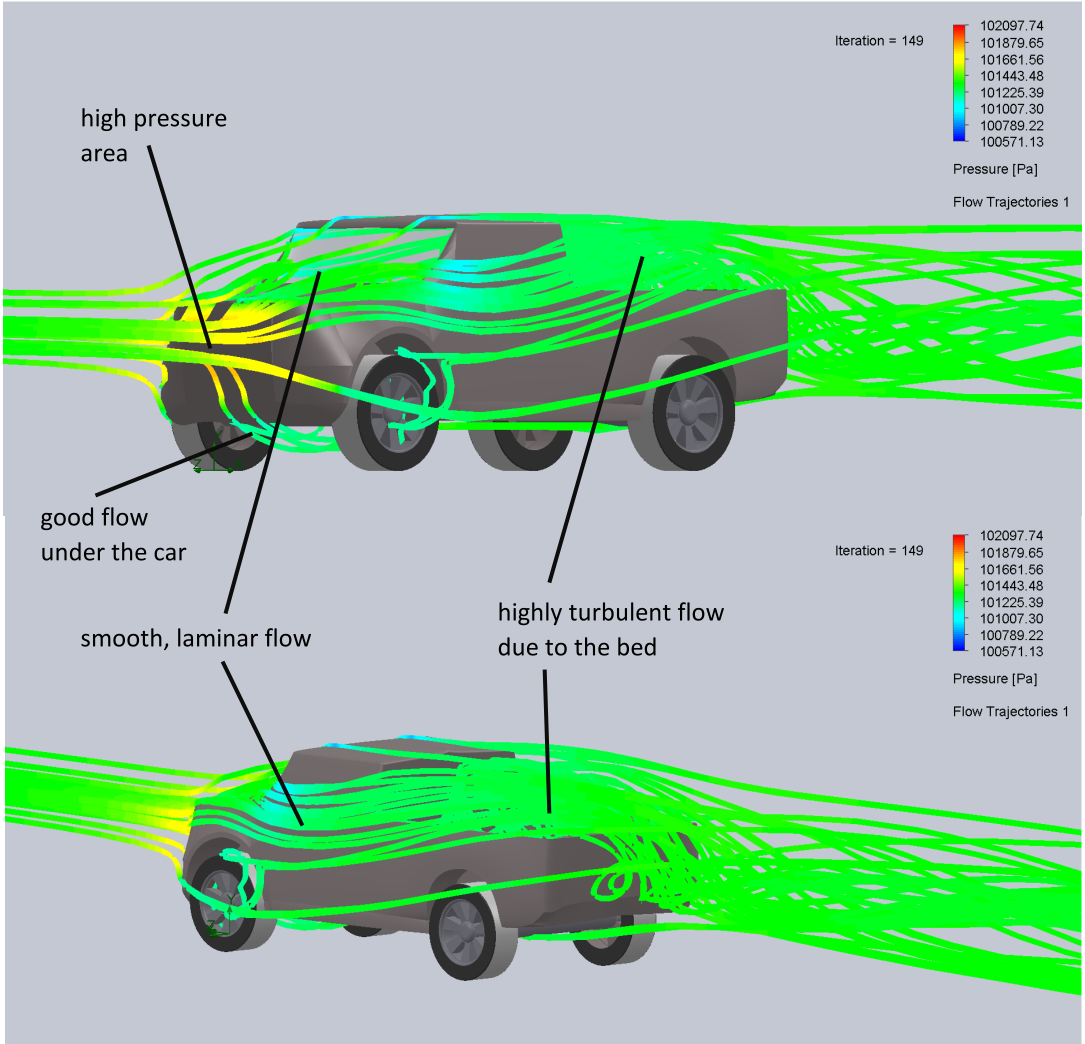

Figure 14 - 3D Flow Trajectories

Initially, the flow remains close to the vehicle and flows in mostly a laminar way. Although there is an area of high pressure at the front of the car, it is where the grill/air intake would usually be located. The main issue highlighted by the plot is the large amount of turbulent flow in the boot of the pickup. This turbulent flow creates additional drag as well as can be dangerous for any items stored there which might get blown away.

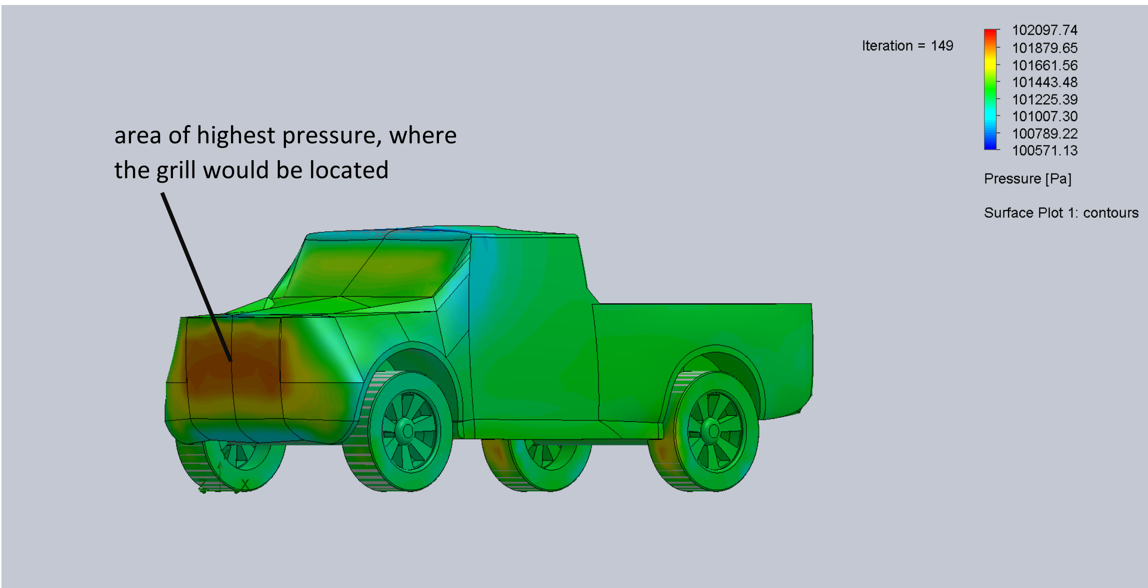

Figure 15 - 3D Front and Side Pressure Plot

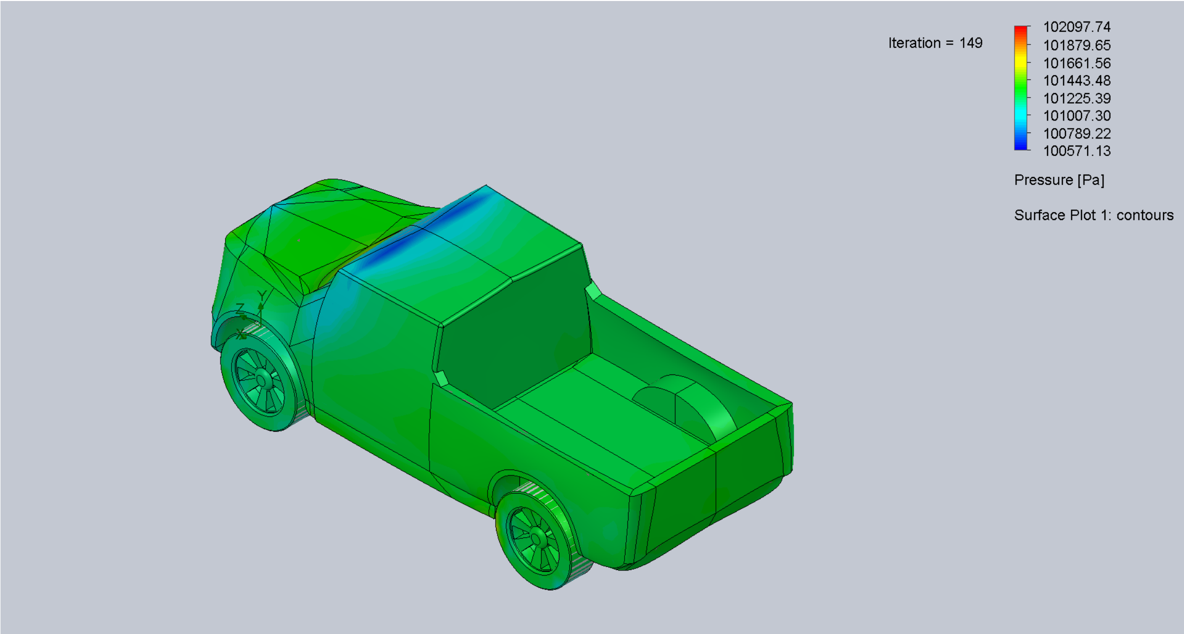

Figure 16 - 3D Rear and Side Pressure Plot

The highest pressure experienced by the vehicle is at the front. It encompasses the area where the grill would be placed, therefore in real operation the pressure there would be lower due to some of the air being taken into the engine. Overall, the range of pressure exerted on the car is around 1500 Pa, meaning the pressure change between different areas of the car is relatively small.

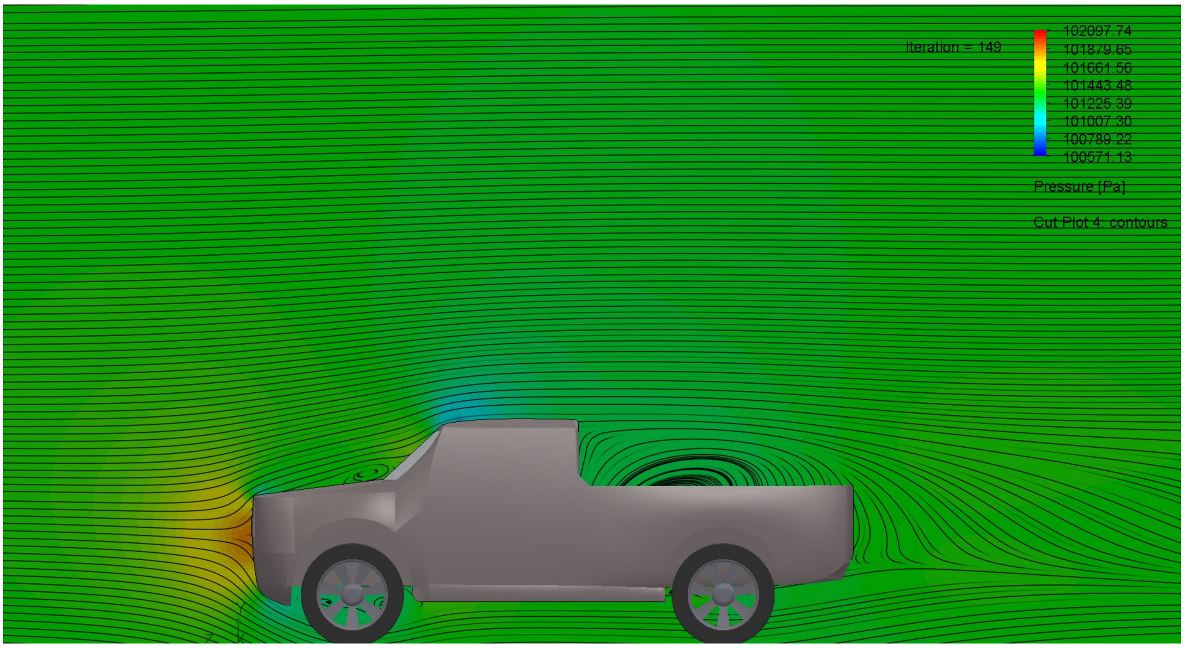

Figure 17 - 2D Pressure Plot

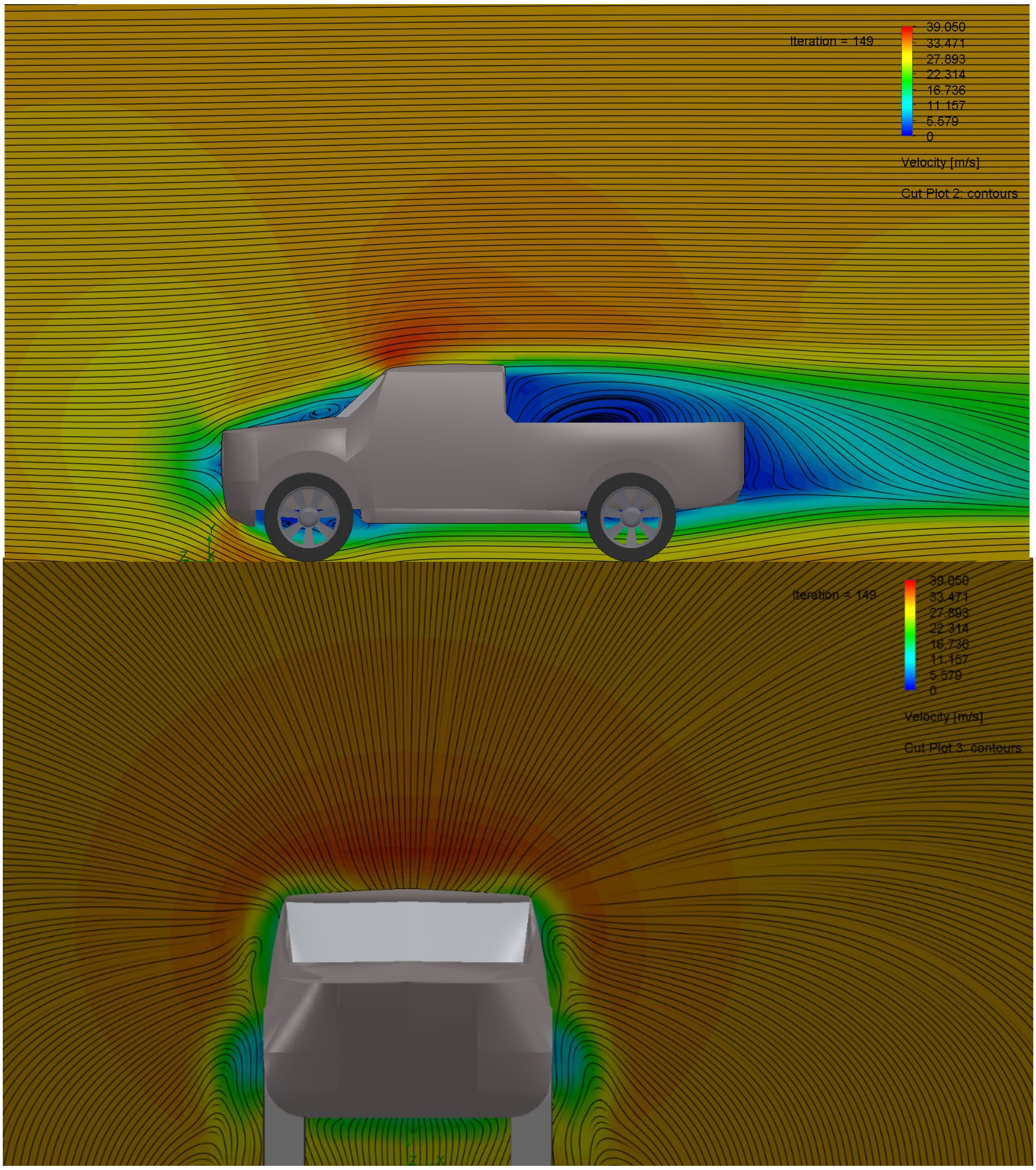

Figure 18 - 2D Velocity Plots

7 Discussion and Conclusion

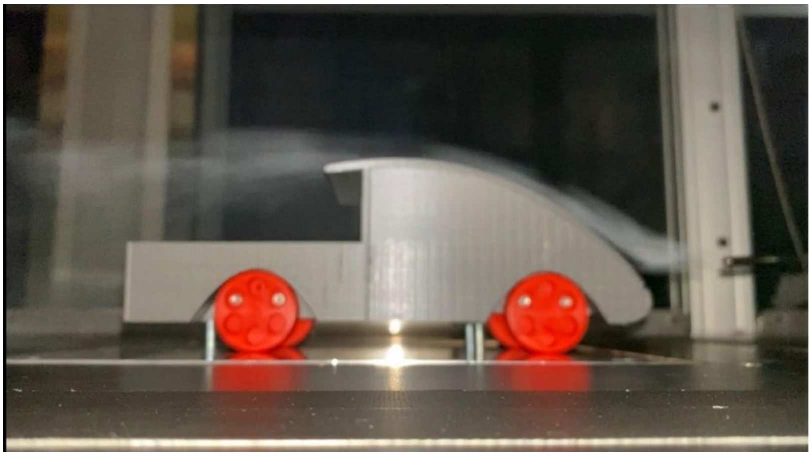

Figure 19 – Side view of the pickup archetype in the wind tunnel.

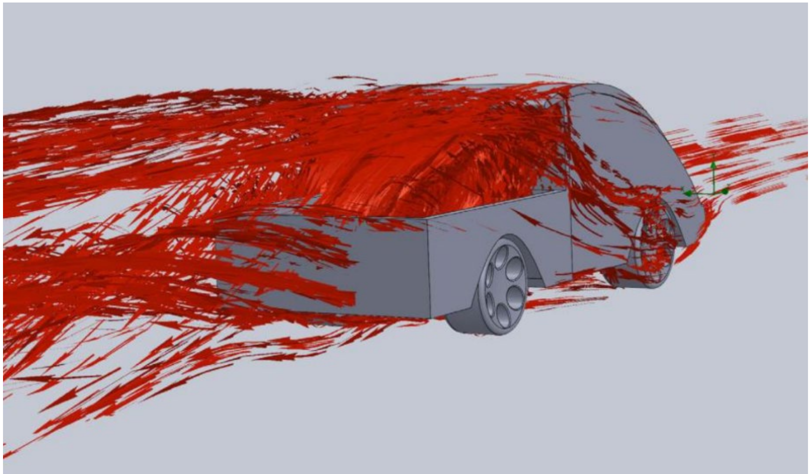

Figure 20 - Rear view of the flow trajectories of the pickup archetype.

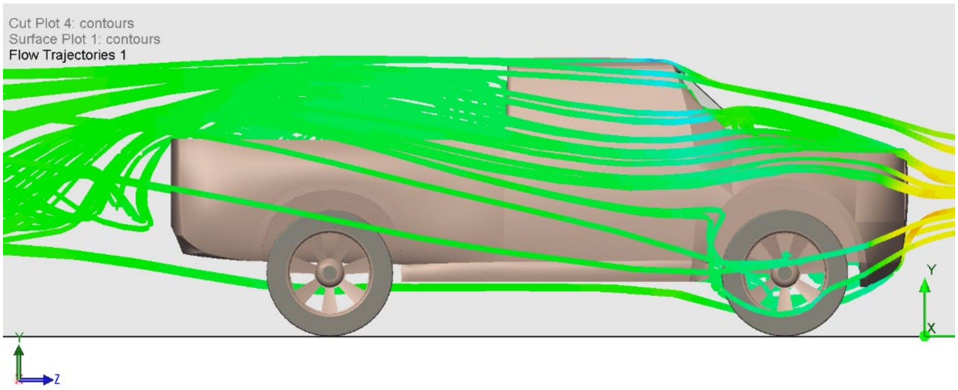

Figure 21 - Side view of my pickup with flow trajectories.

7.1 Comparison with wind tunnel Pick-up model

The drag coefficient of the archetype was found to be 0.437 while my truck has a coefficient of 0.431. Overall, the CFD and the wind tunnel drag analysis are largely similar, with the main differences pointed out below.

7.1.1 Recirculation of air in the bed area

In both models there is a large amount of recirculation in the area behind the drive cabin in the bed of the pickup. The air which is recirculating in both cases comes from the side of the pickup, while the air which has flown over the roof of the cabin does not interact with these vortices. This can be seen especially on the wind tunnel model where no vortices are formed, as the air only flows over the roof of the pickup. (Figures 20 and 21)

This problem can be solved in two ways. One of them is to add a taller wall on the sides of the pickup to prevent the air from entering from the sides into the bed compartment. The other is to create a retractable cover for the bed compartment to prevent the vortexes from forming there while the bed is empty. An example of such a solution can be seen in Figure 22. (3)

Figure 22 - Example Implementation of the taller walls of the bed as seen in the Tesla Cybertruck.

7.1.2 Air flow around the driver's cabin

With the archetype's front, it is quite difficult for the air flow around the sides, with most of it following the curvature and flowing over the truck. On my design the curved front allows air to flow to the sides more easily and in turn reduces the pressure experienced by the car at the front. Due to the poor calibration of the scale on the archetype it is difficult to see the pressure changes in the air flow.

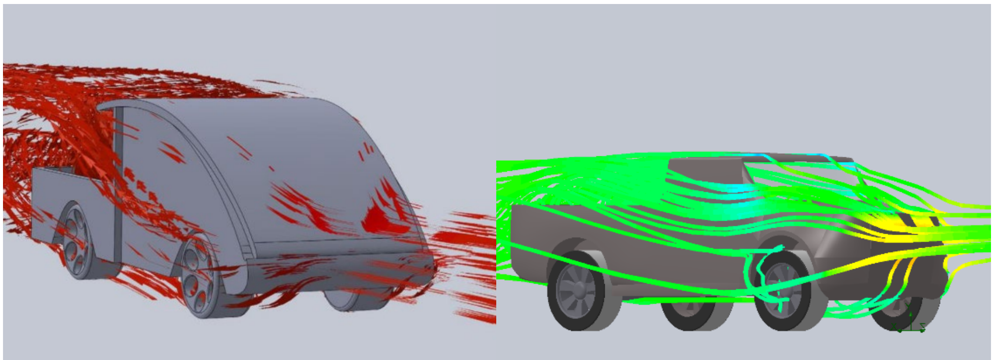

Figure 23 - The flow trajectories at the front of the archetype compared to my model.

7.1.3 Area of high pressure on the front bumper

The front bumper of my model shows an area of high pressure. Positioned where the grill would typically be for air intake, this design element serves a crucial purpose. If the grill was added to the model, the simulation would become more accurate, as this area of high pressure would not exist.

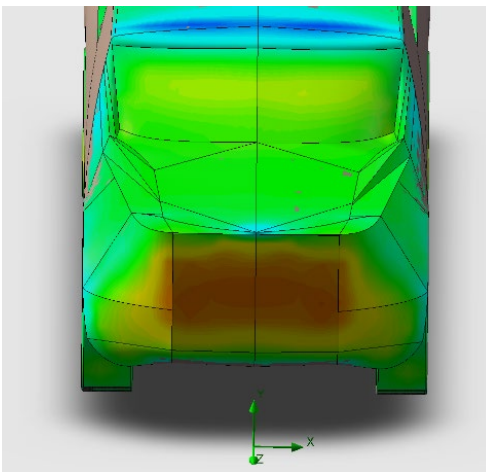

Figure 24 - Area of high pressure at the front of the pickup.

8 REFERENCES

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