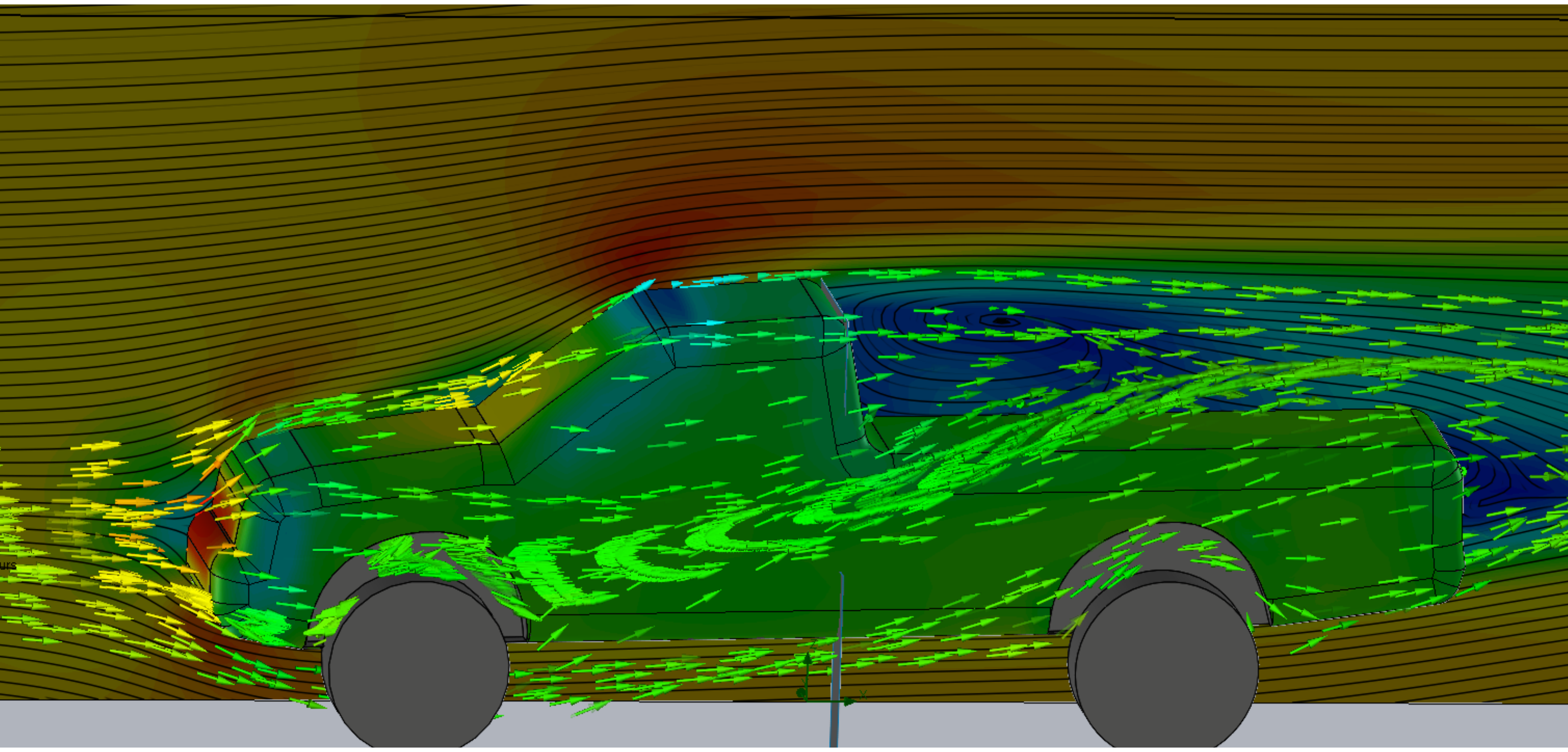
Vehicle Design Aerodynamics

DE2 Thermofluids assignment



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Technical Summary

This project explores the aerodynamic development of a modern pickup truck. Aerodynamics is crucial to the design of a vehicle. The improvements that can be made in aerodynamics allow for a better rider experience, improved fuel efficiency, and lower CO_2 emission.

This report explored the initial development of the vehicle through a series of sketching and CAD development techniques. These designs were then estimated by hand using a series of estimations for the drag coefficient based on vehicle characteristics. The CAD design was then imported into Solidworks 2023 as a Solid Body where the Flow Simulation add-in was used to produce a highly accurate CFD model for the low-fidelity design. The output of this model was then used to inform design changes that should be made to further improve the aerodynamic design of the vehicle.

Inspiration

Figure 1: Mitsubishi Raider LS (2007) NetCarShow.com

The design for the Car is based off the Mitsubishi Raider LS (2007) (NetCarShow, 2024). It's predecessor in 2006 won the Best-in-Class Vehicle Satisfaction Award.

This Mitsubishi brand is well known for producing reliable modern vehicles that are enjoyed by many owners across the world. The design was chosen for its minimal but effective design and its world-renowned reputation.

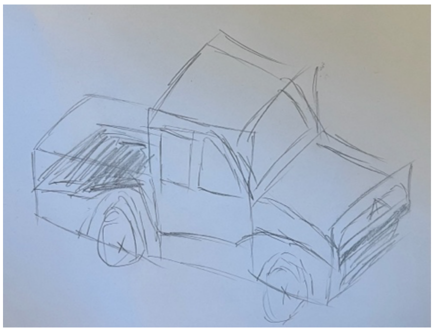
Although inspiration will be taken from this car design. The final concept will offer its own unique expansions towards a more modern abstract design fit for the 21st century. Other sources of inspiration were taken from Tesla's latest release of the Cybertruck. (Tesla, 2024). The car is also designed to be fully electric with current government schemes favouring this type of vehicle.

In the end, the CFD analysis showed that our initial assumptions were correct in creating a general-purpose pickup truck with a drag coefficient of $C_d = 0.362$. However, wind tunnel testing and CFD analysis also highlighted some flaws in the box design and three improvements were suggested to further increase the aerodynamics of the vehicle:

- Adding slants to the front of the bonnet
- Adding a natural curve to the sides of the vehicle
- Channel air at the front of the vehicle
- Addition of spoiler to rear

Sketching

The initial low-fidelity model was created using a series of sketches. These sketches later informed the CAD design.



This sketch was developed inside a workshop using reference images from NetCarShow. A "box" technique was used to segment the various components of the car including the passenger compartment, trunk, engine compartment, wheel arches, battery, and drive shaft.

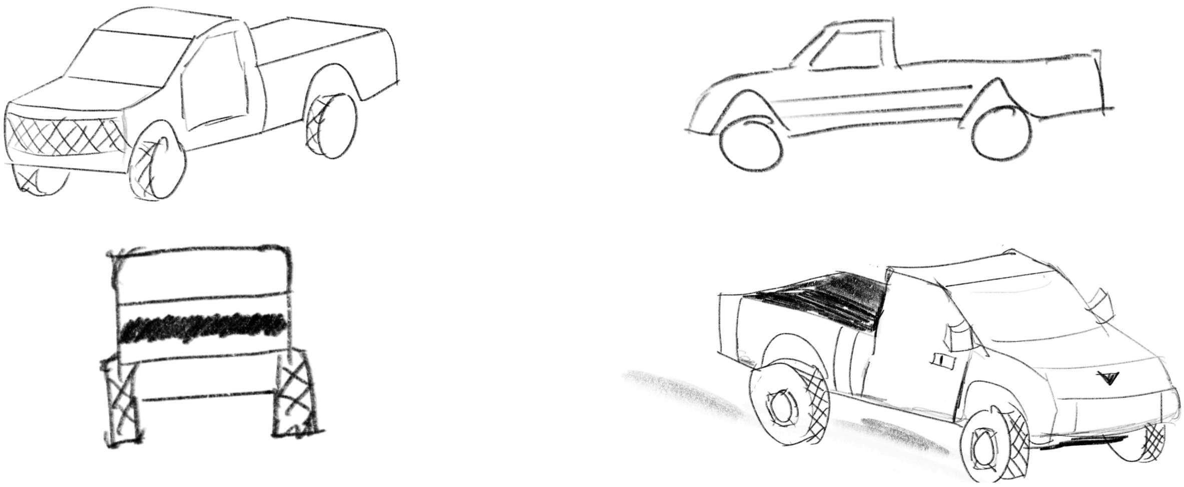
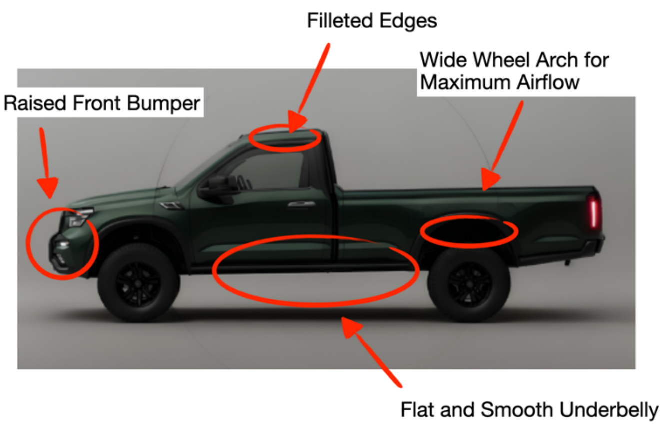


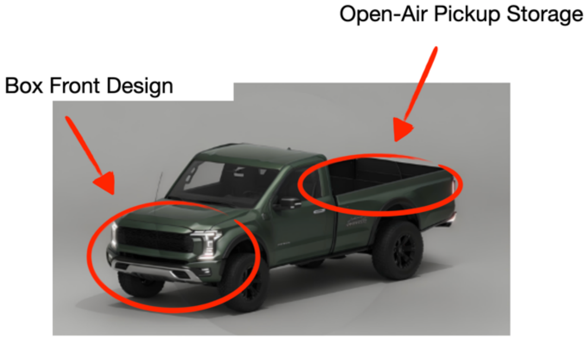
Figure 2: A series of rough sketches used to help depict design ideas.

Further views of the car were drawn outside of the session to provide to Vizcom (Vizcom, 2024) and to further develop the design thinking behind the idea. An abstract oblique design was favoured for a modern approach taking away from the generic filleted design seen in most pickup trucks today.

Annotated Vizcom (Vizcom, 2024) AI-Generated Imagery



Side View



Isometric View

Rear View

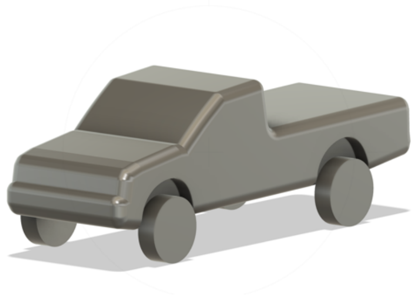
Front View

Figure 3: A series of AI-Generated Images from initial sketches

Vizcom (Vizcom, 2024) was provided with the original sketch views to generate high-fidelity design renders in Rapid time using artificial intelligence. The prompt used for the generation was “A modern green pickup truck”. The colour green was chosen to carry the Mitsubishi theme through to the new design.

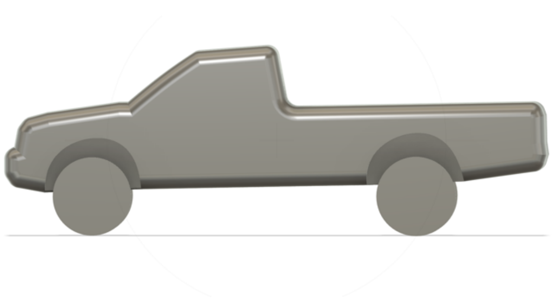
CAD Model

A CAD Model was developed in both Solidworks 2023 and Fusion 360. The simple solid model is a low-poly representation of the desired shape of the pickup truck that can be imported as a Solid Body into Solidworks 2023 Flow Simulation.

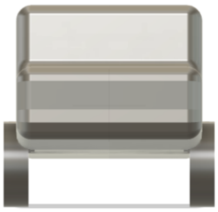


Isometric View

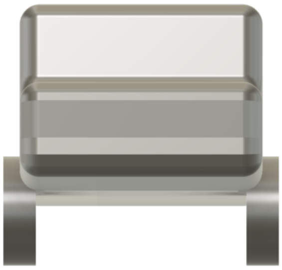
Top View



Side View



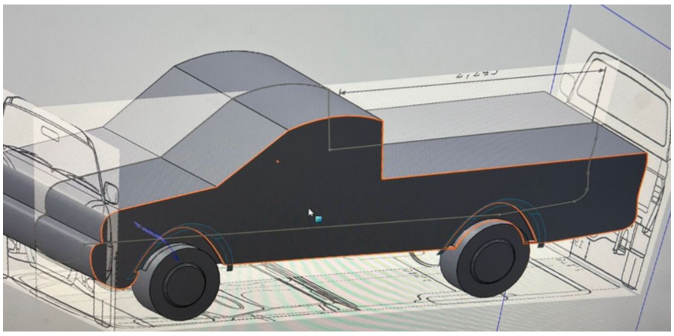
Front View



Back View

Bottom View

Figure 4: CAD Model from different views



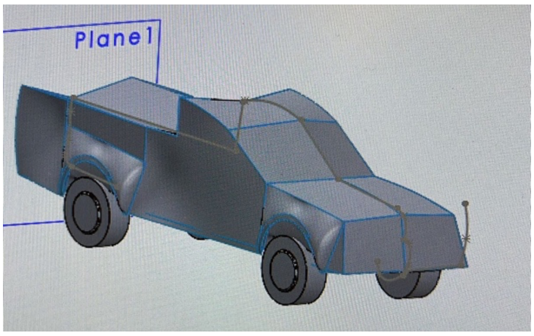
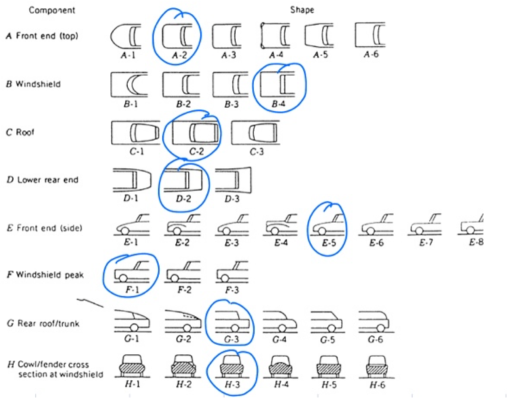


Figure 5: Further two rejected concepts developed using Solidwords 2023 using Surface Modelling

These rejected models were not taken forward as it was felt that the curved slanted nature of these designs did not reflect the modern box design desired for the futuristic vehicle.

Drag Analysis by Hand

The value for C_D was estimated using an equation given in DE2 E&D _ Drag notes (Hazeri, 2024). This allows us to compare the predicted value vs the calculated value in the CFD software to spot any potential CFD errors.



Component	Shape	N-Value
Front end (top)	A-2	2
Windshield	B-4	4
Roof	C-2	2
Lower rear end	D-2	2
Front end (side)	E-5	3
Windshield peak	F-1	1
Rear roof/trunk	G-3	3
Cowl/ fender cross-section at windshield	H-3	3

Figure 6: Drag Coefficent Vehicle Parameter Selection

$$C_D = 0.16 + 0.0095 \sum_{i=A}^{H} N_i \quad (1)$$

$$C_d = 0.16 + 0.0095(2+4+2+2+3+1+3+3) \quad (2)$$

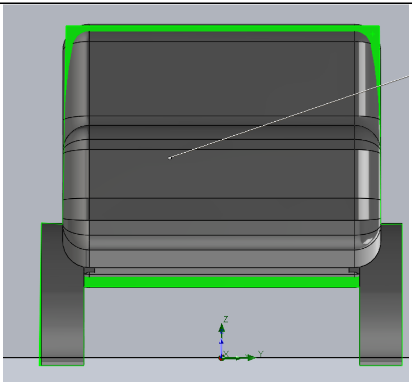
$$C_d = 0.35 \quad (3)$$

As this is similar to a BMW M 535i (0.37) . I can conclude that this approximation is appropriate.

Figure 7: BMW M 535i

The final calculated value of the CFD analysis for the drag coefficient was also found to be 0.362 and therefore an absolute difference of 0.012 confirms this is a fairly accurate estimation.

CFD Model

Area for Drag Coefficient Calculation		Mesh Details
	Frontal Area: $2m^2$	Cells: 668930 Fluid Cells: 668930 The mesh fluid cells exceed the recommended minimum number of field cells (600,000). Number of cells in X: 178 Number of cells in Y: 74 Number of cells in Z: 51

Physical Features	Ambient Conditions
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 micrometer Default wall conditions: Adiabatic wall Material: Air (Fluids) ***Air*** Path: Gases Pre-Defined Specific heat ratio (Cp/Cv): 1.399 Molecular mass: 0.0290 kg/mol	**Thermodynamic parameters** Static Pressure: 101325.00 Pa Temperature: 293.20 K **Velocity parameters** Velocity vector Velocity in X direction: 31.290 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: 0 m/s **Turbulence Parameters** Turbulence intensity and length Intensity: 0.10 % Length: 0.016 m

Vehicle Size

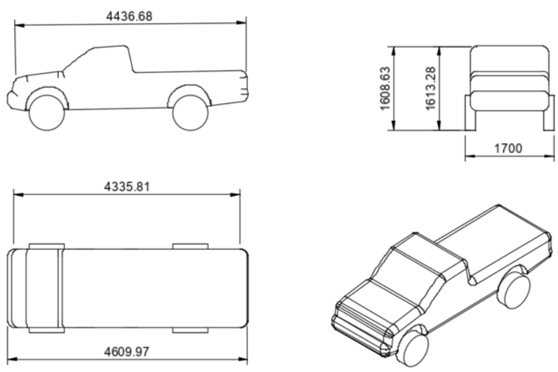


Figure 8: Technical Drawing with Overview Dimensions Added

Goals

Global Goals

GG Force (X) 1

Type	Global Goal
Goal type	Force (X)
Coordinate system	Global Coordinate System
Use in convergence	On

GG Force (Z) 2

Type	Global Goal
Goal type	Force (Z)
Coordinate system	Global Coordinate System
Use in convergence	On

Equation Goals

Drag Coefficient

Type	Equation Goal
Formula	(2*GG Force (X) 1)/(2*1.225*979.06)
Dimensionality	Force
Use in convergence	On

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

Where:
F is drag Force (N),
ρ is air density (1.225 kg/m^3)
v is air velocity (m/s)
A is the frontal area (m^2)

Figure 9: Drag Coefficent Calculation Equation from DE2 E&D _ CFD tutorial 2024 (Hazeri, 2024)

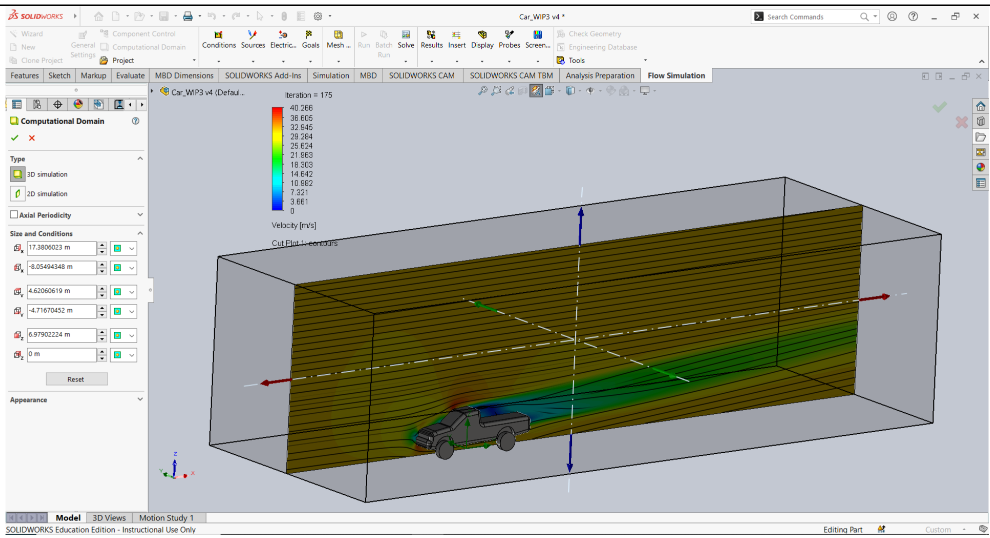


Figure 10: Computational Domain Visualisation in Solidworks 2023

Computational Domain
X min -8.055 m
X max 17.381 m
Y min -4.717 m
Y max 4.621 m
Z min 0 m
Z max 6.979 m
X size 25.436 m

Y size	9.337 m
Z size	6.979 m

Results

Name	Unit	Value	Progress	Criteria	Delta	Use in convergence
GG Force (X) 1	N	433.595	100	27.947669	2.2781793	On
GG Force (Z) 2	N	86.103	100	9.6224095	5.4187103	On
Drag Coefficent	N	0.362	100	0.0233023	0.0018995	On

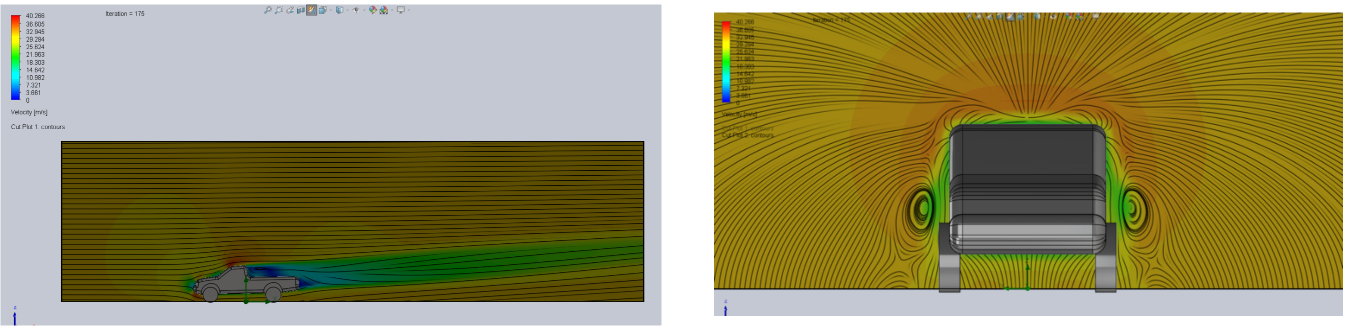


Figure 11: 2D velocity plot

The 2D velocity plots above clearly show there are areas of high velocity above and underneath the car but lower areas of velocity around the rear of the vehicle. There is also an elongated area of medium-speed velocity shown in green. The figure showing the front view shows a concentration of streamlines that indicates there could be some turbulence. This could be due to the drop in the body of the vehicle for the pickup truck storage. The recirculation zone in blue is large indicating there will be a considerable amount of turbulence.

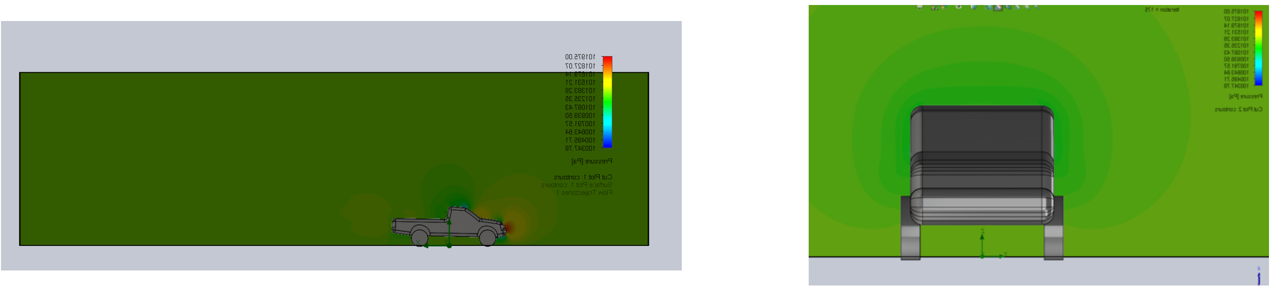
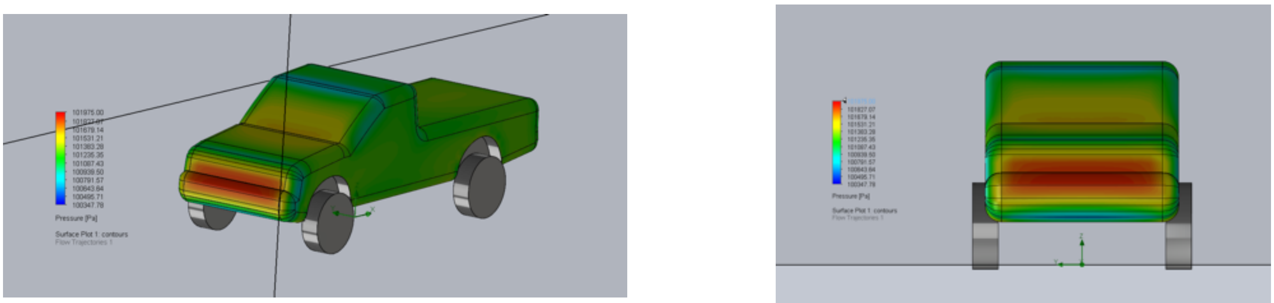


Figure 12: 2D pressure plot



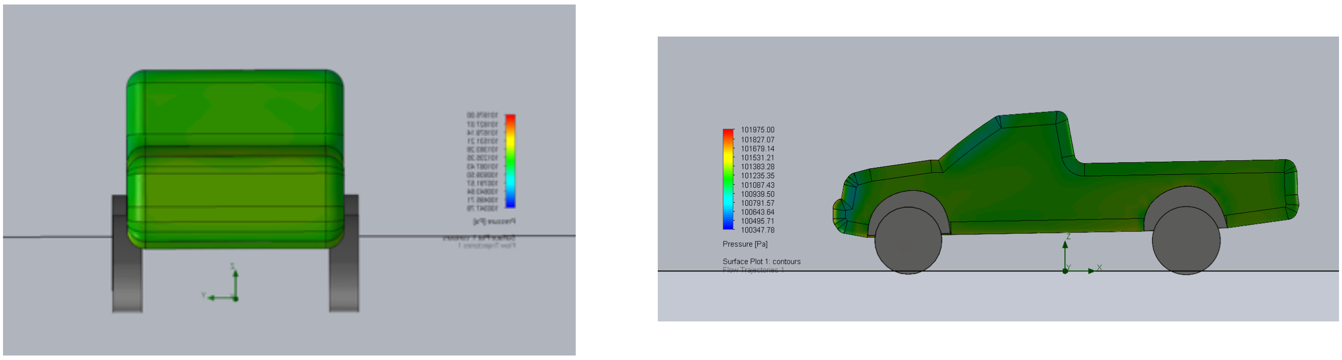


Figure 13: 3D pressure distribution plot for the isometric, front, rear, and side profiles,

The car shows a clear indication of high pressure towards the front of the vehicle. This will need to be eradicated before production of the vehicle. An opportunity to improve this may be additional air channelling implemented in the final design. There is a small patch of blue below the front of the circle indicating a lower pressure below the vehicle. The front windscreen bottom half is highlighted in yellow showing some moderate pressure being applied compared to the rest of the vehicle which is to be expected. The rest of the vehicle is highlighted in green indicating a standard pressure level at this stage of movement.

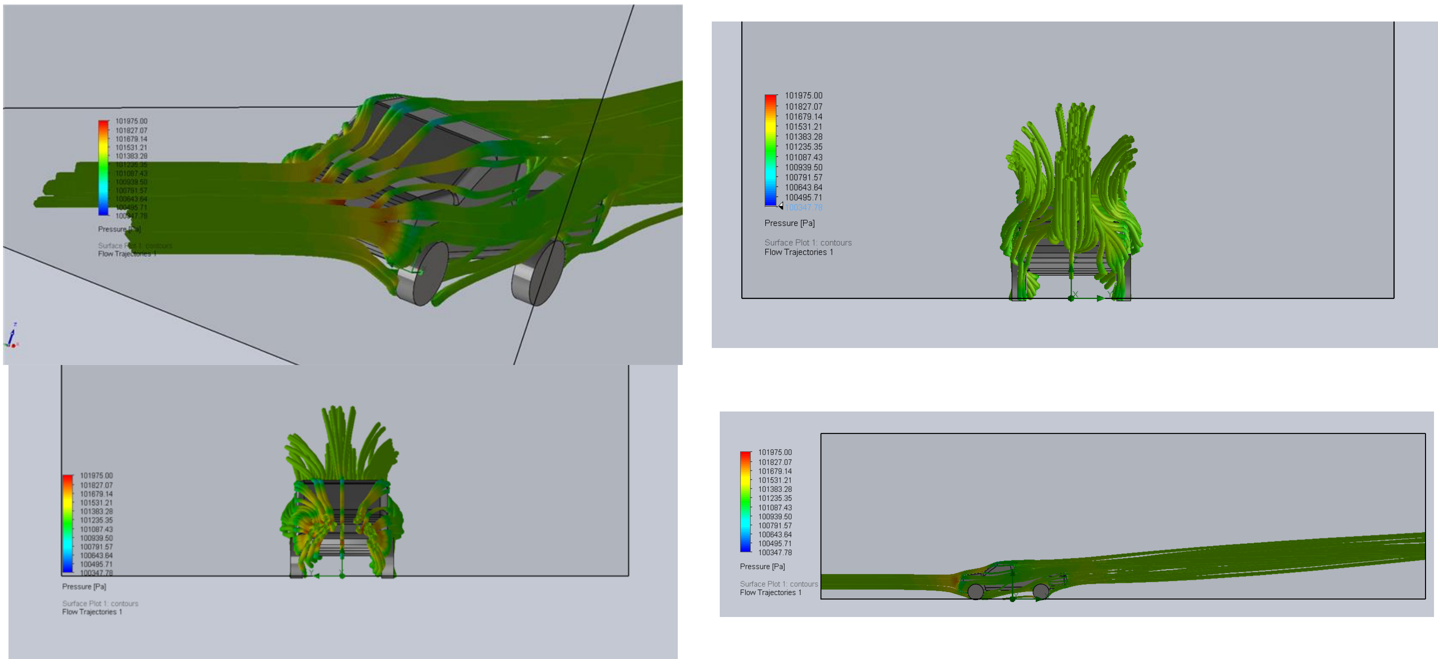


Figure 14: 3D flow trajectories around the vehicle

The 3D flow trajectories again indicate that there is high pressure on the front of the vehicle (stagnation point). Turbulent flow at the rear of the vehicle is made even more clear with clear four channels of shed vortices producing eddy currents. There is a more streamlined flow around the edge of the vehicle (thin boundary layer) however it does appear the fillet at the edge of the vehicle may be causing some distortion in this flow.

Comparison to Wind Tunnel

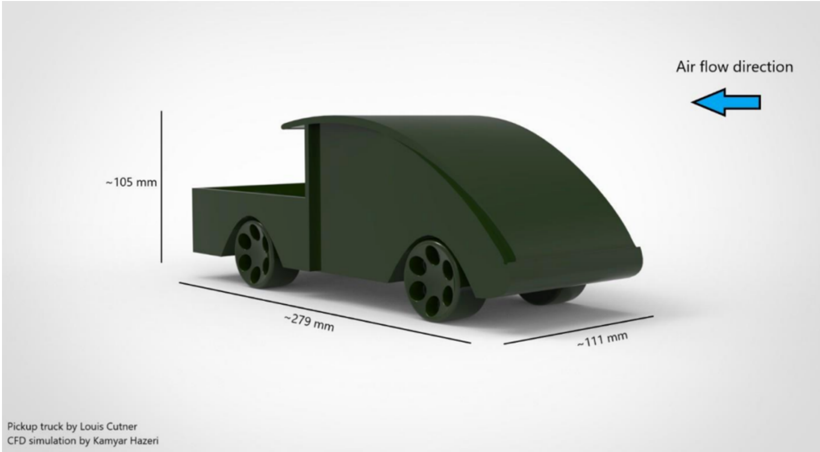


Figure 15: 3D Model of Pickup Truck tested

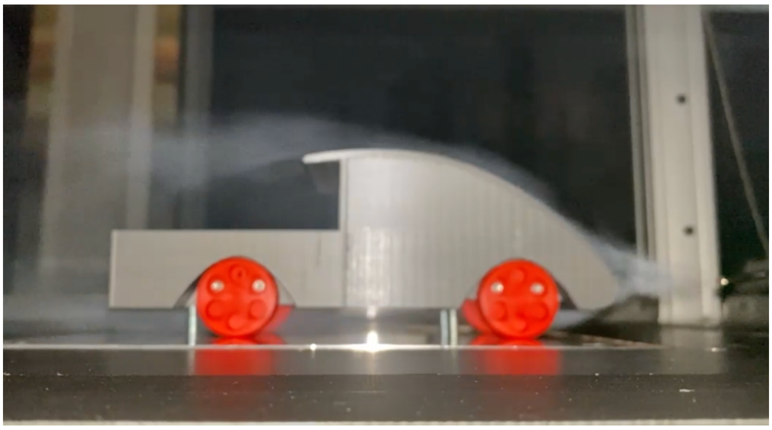


Figure 16: 3D Printed Model in Wind Tunnel

The result of the testing of this pickup truck resulted in a drag coefficient of 0.52 (C_D). This is considerably higher than the calculated value of the model designed for this report (by +0.16).

The streamlines of the wind tunnel test look very similar to the CFD 3D Flow Analysis which indicates that this is likely to be a correct estimation as well. In the wind tunnel it appears that there is some turbulence behind the “roof” of the vehicle.

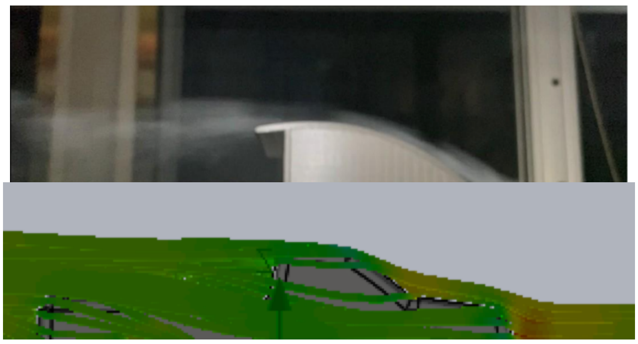


Figure 17: Comparison between Wind Tunnel and Simulated Model

Aerodynamic drag is clearly shown in both models by the storage box air gap behind the front of the car. The design outperforms the pickup truck model as it has a lower drag coefficient and drag force due to its more streamlined design compared to the high height of the driver cabin in the real-world test model.

Potential Improvements

The following solutions are proposed to further improve the aerodynamics of the next-generation pickup truck.

Adding slants to the front of the bonnet

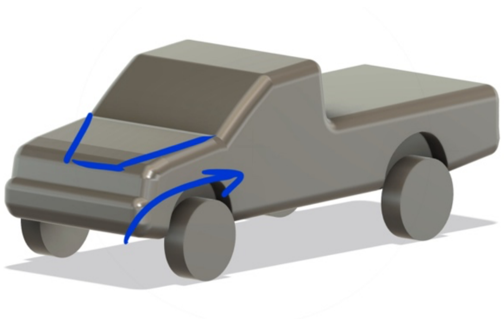


Figure 18

By adding slants to the front of the bonnet, the streamlines will be able to pass smoothly over the front of the vehicle reducing the pressure on the front of the vehicle. Turbulent flow is less likely due to a smoother surface.

Adding a natural curve to the sides of the vehicle

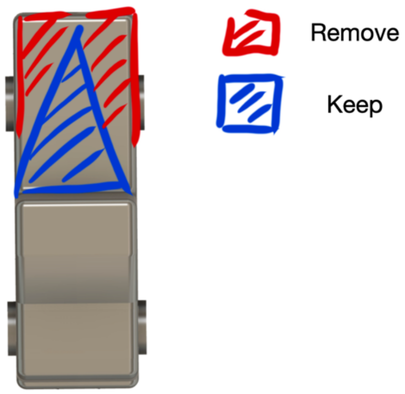


Figure 19

To produce a more streamlined flow at the back of the vehicle. A slanted storage box could be implemented to guide the flow in a more uniform manner. This has a clear disadvantage however of reducing the overall storage capacity and would also mean some items would not fit.

Channel air at the front of the vehicle

To reduce the pressure at the front of the vehicle. Air could be channelled through an air channel. The airflow will be directed up rather than into the window screen leading to improved efficiency of the car.

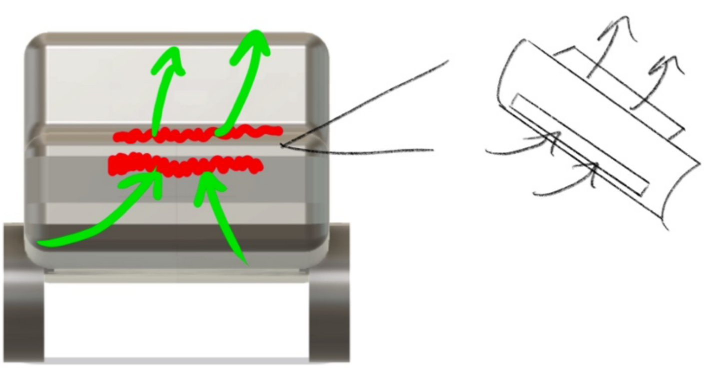


Figure 20

Addition of spoiler to rear

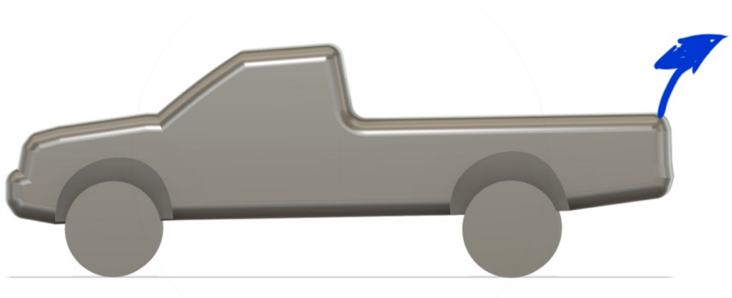


Figure 21

Spoilers would be effective at high speeds to make the car travel smoothly along a road. Additionally, it could help reduce the turbulent flow towards the rear of the vehicle.

Spoilers work by increasing downforce to allow for more grip at high speeds. The name comes from the fact that they "spoil" the airflow. (Cars.com, 2024)

Conclusion

The overall design of the original car was found to be aerodynamic with a drag coefficient of 0.362. With the inclusion of the above features, the drag coefficient should decrease by a small amount. This will result in a smoother ride and lower fuel consumption. The drag force will also decrease.

Using our estimation equation with the adaptions, we can predict the value will decrease to approximately $C_d = 0.32$.

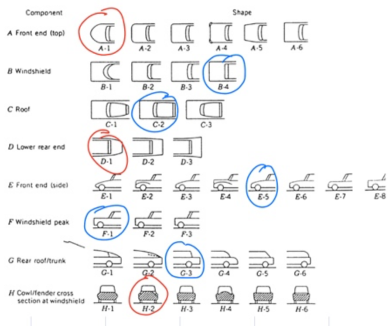


Figure 22: Adapted Estimation of Drag Coefficient with new features

Appendix

Cars.com. (2024). Retrieved from https://www.cars.com/articles/what-does-a-spoiler-do-424902/#:~:text=Spoilers%20are%20supposed%20to%20change,to%20reduce%20its%20negative%20effects.

Hazeri, K. (2024, February 18). *Blackboard*. Retrieved from Imperial Internal.

NetCarShow. (2024, February 01). *Mitsubishi Raider LS (2007)*. Retrieved from NetCarShow: https://www.netcarshow.com/mitsubishi/2007-raider_ls/

Tesla. (2024, February 21). *Cybertruck*. Retrieved from Tesla: https://www.tesla.com/en_gb/cybertruck

Vizcom. (2024). *Vizcom*. Retrieved from https://www.vizcom.ai/