VEHICLE DESIGN PORTFOLIO

CONCEPTUAL DESIGN AND COMPUTATIONAL ANALYSIS OF AERODYNAMICS AND COOLING SYSTEMS

LARA MERICAN

DESIGN SUMMARY

INTRODUCTION

This portfolio presents the **aerodynamic analysis** of a **conceptual, urban MPV/minivan.** This minimalistic design is aimed at optimising aerodynamics by **reducing drag, improving airflow efficiency and minimising energy consumption**.

METHODOLOGY

The aerodynamics of the car was assessed using **Computational Fluid Dynamics (CFD)** analysis. This involved a simulation conducted on ANSYS Fluent at **30.528 m/s wind speed** to evaluate **drag, lift, pressure and airflow behaviour**.

KEY CFD OUTCOMES

0.36
DRAG COEFFICIENT

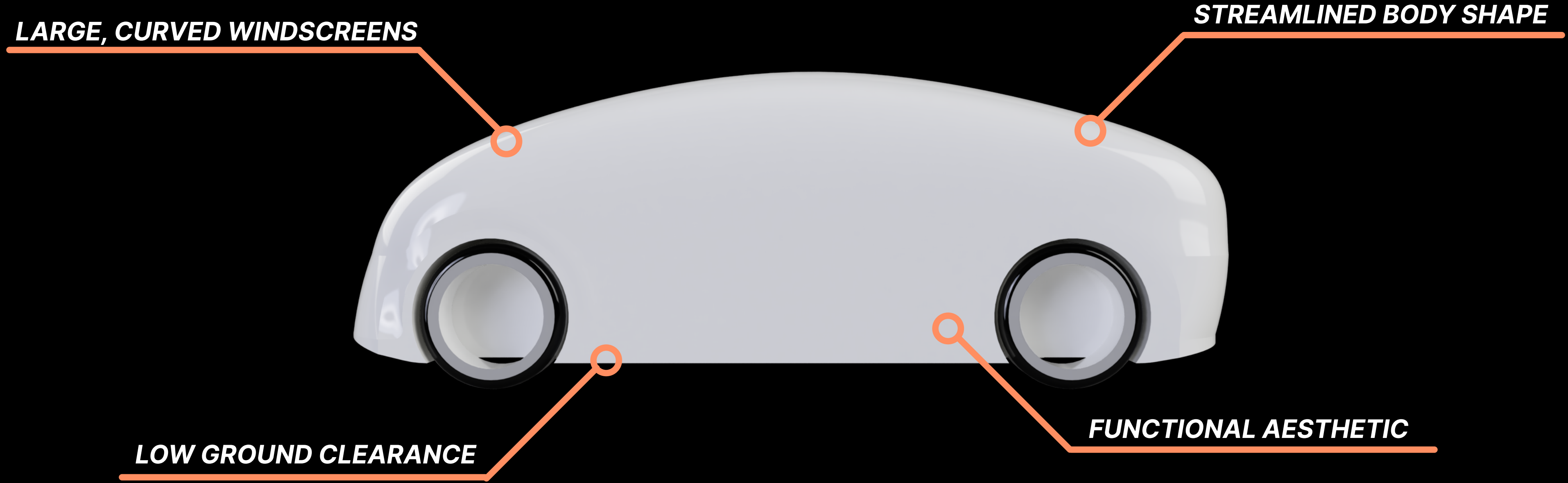
2.94
DRAG FORCE (N)

0.0285
FRONTAL AREA (m^2)

0.50
LIFT COEFFICIENT

4.08
LIFT FORCE (N)

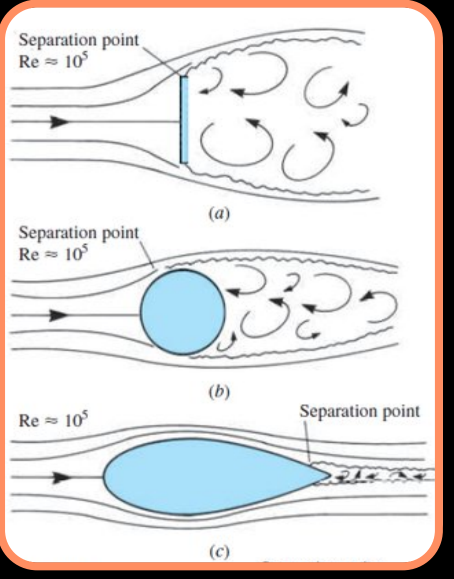
KEY DESIGN FEATURES



DESIGN RATIONALE: FEATURES

STREAMLINED BODY

- Features inspired by **"the most aerodynamic shape in the world"** – the teardrop shape
- **Continuous curvature:** Aims to **reduce air resistance** by minimising flow separation
- **Gradual roofline taper:** Aims to **reduce wake turbulence** at the rear, improving aerodynamic efficiency

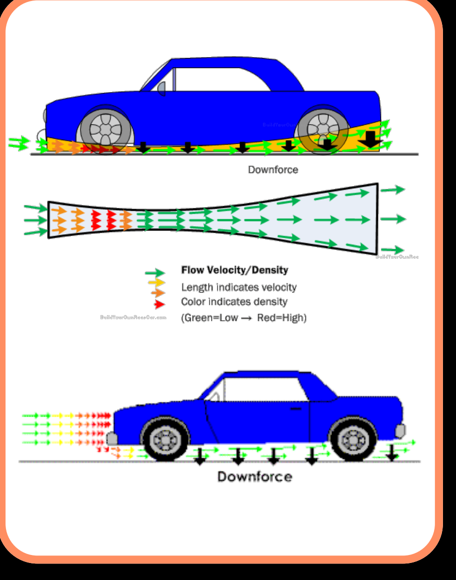


PANORAMIC WINDSCREENS

- **Large and curved**: Optimises airflow to move smoothly over the surface
- **Seamless connection**: No gaps between the windscreen and roof to prevent disruptions and promote laminar flow

GROUND CLEARANCE

- Low ground clearance reduces drag force
- **Reduced air:** Less air underneath the car reduces lift and turbulence
- **Lower centre of gravity:** Improves stability of the car, especially at higher speeds



FUNCTIONAL AESTHETIC

- **Smooth surfaces:** Reduces energy consumption while aligning with urban electric vehicle trends
- **Spacious form**: A compromise between optimising aerodynamics and allowing for ample interior room

DESIGN RATIONALE: EXISTING VEHICLES

These vehicles were chosen as **benchmarks** due to their size, type and purpose which results in a **similar aerodynamic performance**. They have **varying dimensions and drag coefficients**, giving valuable insight to optimising aerodynamics for an urban MPV.

VOLKSWAGEN EUROVAN

0.45
DRAG COEFFICIENT

2.92
FRONTAL AREA (m^2)

4.74 × 1.84 × 1.90
LENGTH X WIDTH X HEIGHT (m)

MERCEDES BENZ VITO

0.34
DRAG COEFFICIENT

3.18
FRONTAL AREA (m^2)

4.90 × 1.93 × 1.91
LENGTH X WIDTH X HEIGHT (m)

CHEVROLET VENTURE

0.35
DRAG COEFFICIENT

2.60
FRONTAL AREA (m^2)

5.10 × 1.83 × 1.73
LENGTH X WIDTH X HEIGHT (m)

KEY TAKEAWAYS

- The Volkswagen Eurovan has the **highest drag coefficient**, probably due to its **boxier shape**.
- The Mercedes Benz Vito has the **lowest drag coefficient**, despite it having the **largest frontal area**. This reflects its streamlined body which contributes to aerodynamics.
- The Chevrolet Venture's **low height** contributes to a **lower frontal area** and hence a lower drag coefficient.

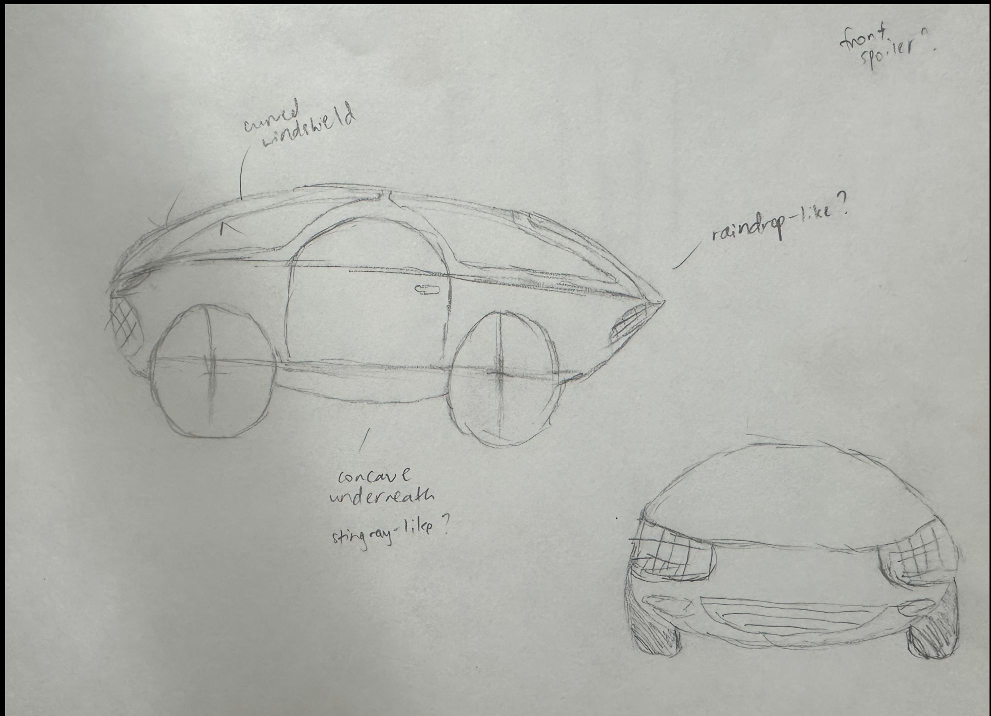
SPECIFICATION AIMS

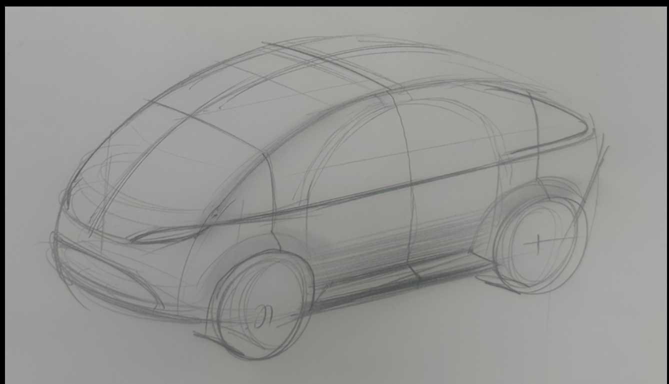
These real-world vehicles give an approximate idea of the dimensions and specifications of my design.

- **Dimensions**: 4.92 × 1.88 × 1.82 approx.
- **Frontal area**: 2.60 - 3.00
- **Coefficient of drag**: Ideally lower than 0.34

CONCEPTUAL DESIGN DEVELOPMENT

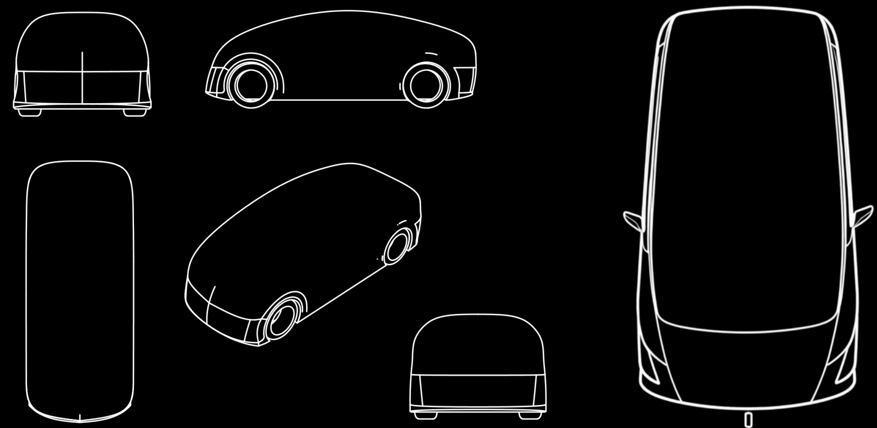
INITIAL SKETCHES

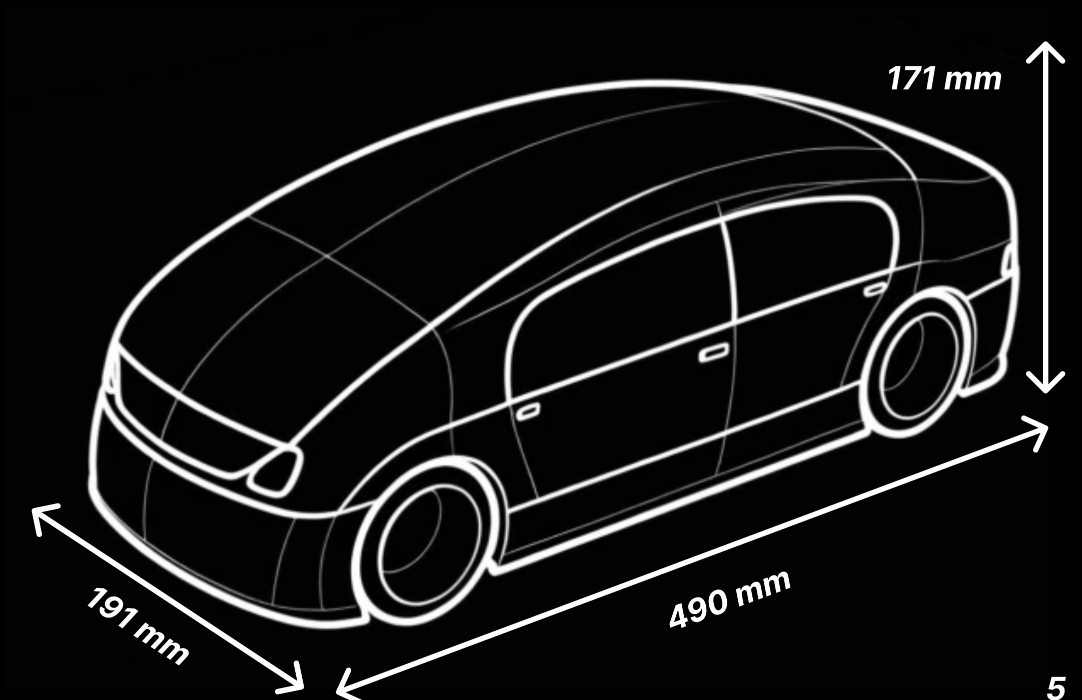




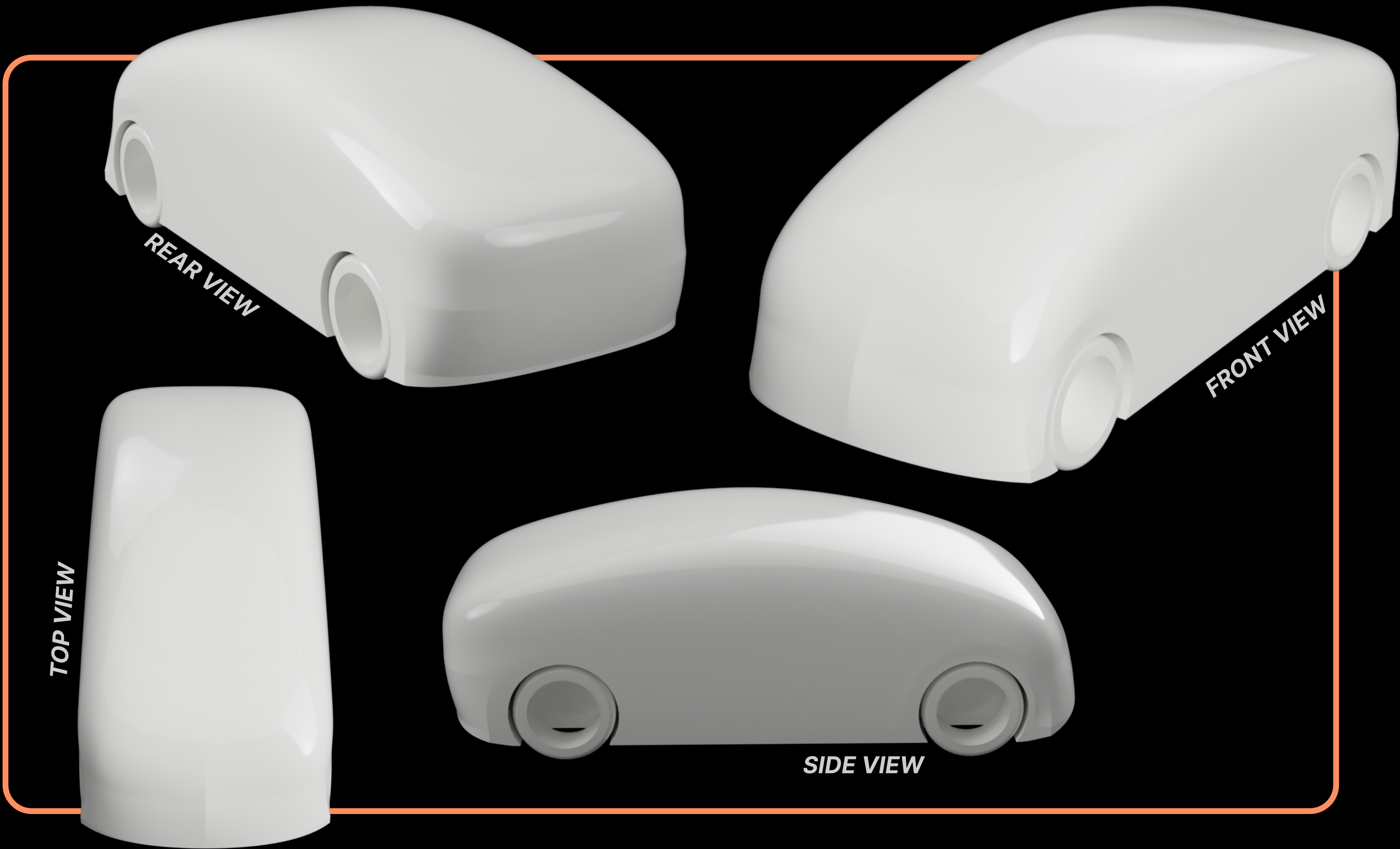
Sketched by professional Automotive & Transportation Designer, Boris Fabris

REFINED SKETCHES





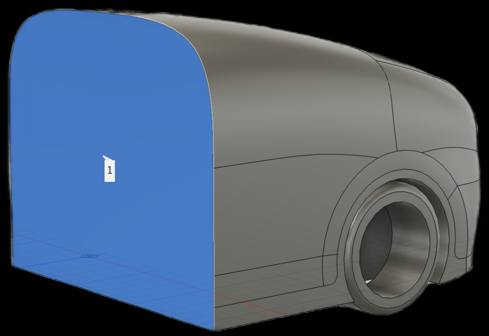
LOW-FIDELITY 3D CAD MODEL



FRONTAL AREA MEASUREMENT

METHODOLOGY

Frontal area describes the exposure area to wind forces at the front of the vehicle. In order to find the frontal area of the car, **cross-sections were made and measured in Fusion 360**.

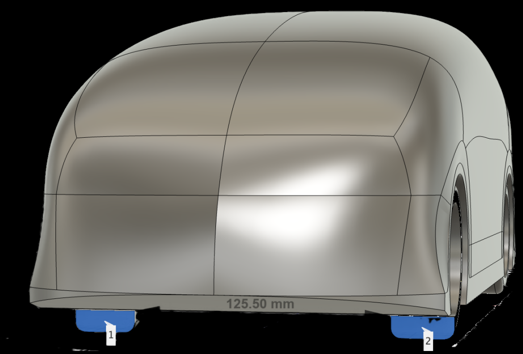


1 CAR BODY

- Cross-section was made at the tallest part of the car
- Cross-section area: 27930 mm^2 = **0.02793 m^2**

2 WHEELS

- Cross-section was made halfway through the wheels
- Cross-section area (1 wheel): 286.94 mm^2 = **2.8694×10^{-4} m^2**
- Area (2 wheels): $2.8694\times10^{-4}\times2$ = **5.7388×10^{-4} m^2**



TOTAL FRONTAL AREA

Generally, a l**ower frontal area reduces drag**, however it also depends on many other factors. For a family car, there must be a **compromise between spaciousness and frontal area**.

$0.02793 + 5.7388\times10^{-4}$ = **0.02850388 m^2**

0.0285

FRONTAL AREA (m^2)
to 3 significant figures

CFD SETUP

COMPUTATIONAL DOMAIN

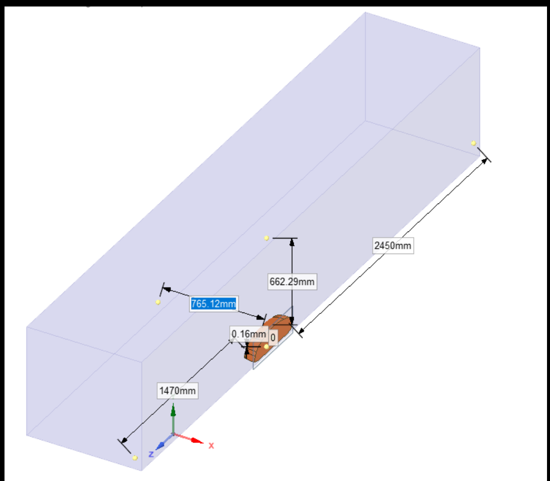
The following dimensions were used for the enclosure:

- **Upstream**: 3 times the length of the car (490×3 = **1470 mm**)
- **Downstream**: 5 times the length (490×5 = **2450 mm**)
- **Width**: 4 times the width of the car (191.281×4 = **765.12 mm**)

$$\text{Blockage ratio} = \frac{\text{Frontal area of car}}{\text{Cross-section area of enclosure}} \quad \ldots\ldots\ldots \quad (1)$$

$$\text{Enclosure width} \times \text{Enclosure height} = \frac{\text{Frontal area}}{\text{Blockage ratio}} \quad \ldots\ldots\ldots \quad (2)$$

- Using the **standard blockage ratio of 5%**, height of the enclosure can be found by rearranging equation (1)
- The cross-section of the enclosure can be found by product of the width and height, hence giving equation (2)
- **Height**: Frontal area, divided by the blockage ratio multiplied by width of the enclosure (28500/(765.12×0.05) = **mm**)

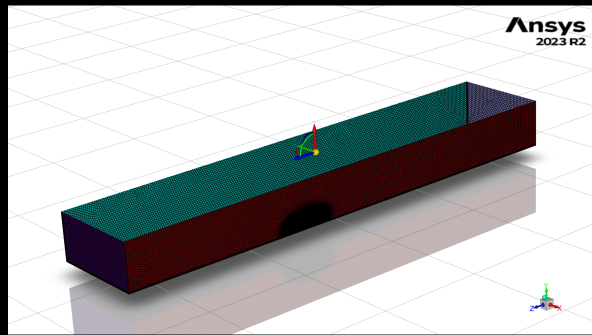


INITIAL BOUNDARY CONDITIONS

- Enclosure material: Air
- Car shear condition: No slip
- Inlet velocity: 30.5 m/s, normal to boundary
- Outlet gauge pressure: 0
- Road shear condition: No slip
- Wall shear condition: Specified shear of 0

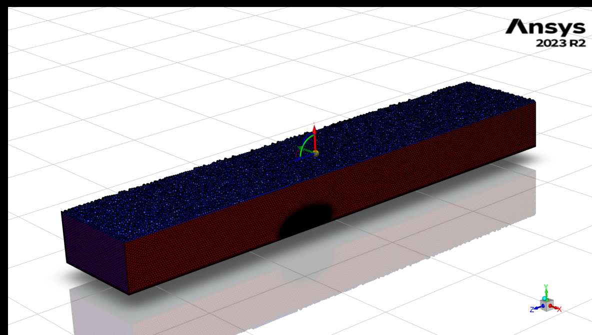
MESHING

Meshing allows for an accurate simulation by **discretising** the vehicle into well-defined cells.



1 SURFACE MESH

- Nodes: 277420
- Edges: 4577
- Faces: 545714
- Cells: 0

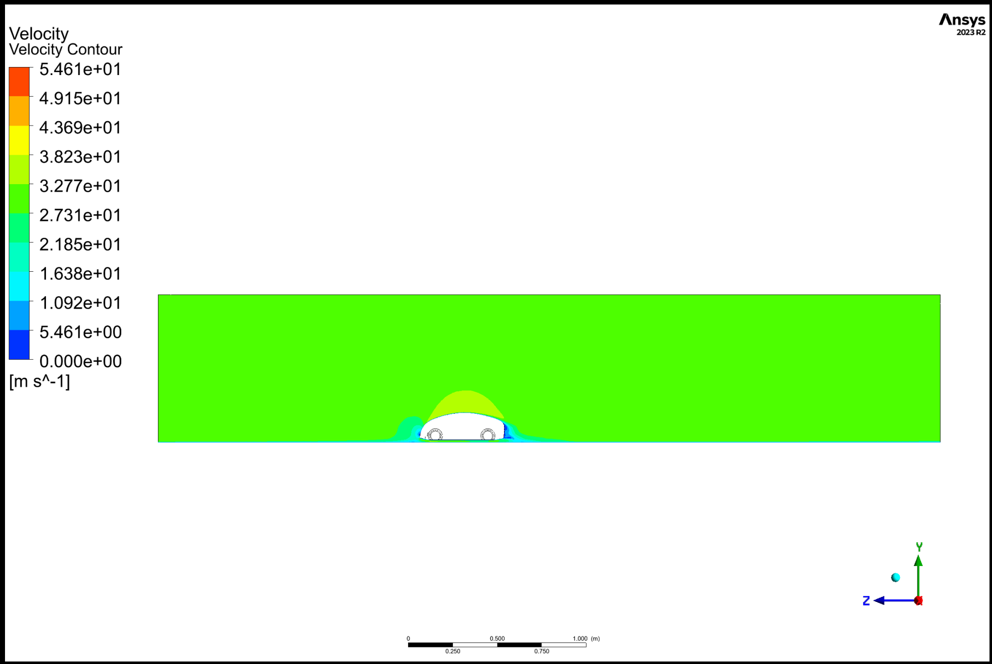


2 VOLUME MESH

- Nodes: 9367352
- Edges: 4577
- Faces: 11961247
- Cells: 2091160

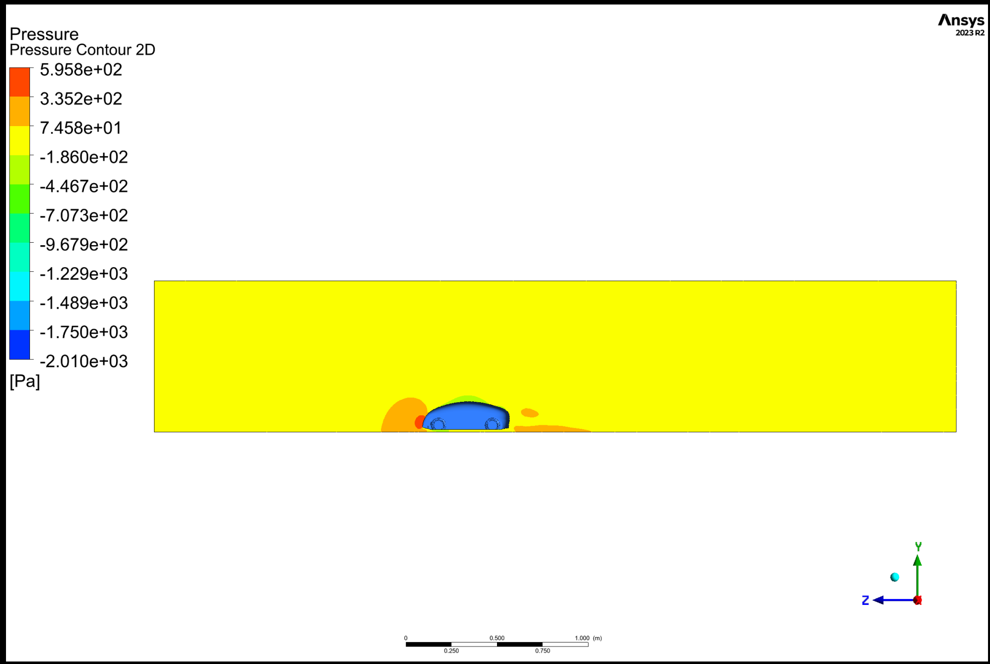
CFD OUTPUTS

2D VELOCITY PLOTS



- Shows **airflow speed distribution** across vehicle
- Relatively **small recirculation zone**, suggesting good aerodynamics
- Majority of airflow is **attached to the vehicle body**, minimising turbulence
- Velocity gradients indicate **smooth airflow**
- **Potential to reduce wake region** to enhance aerodynamic efficiency

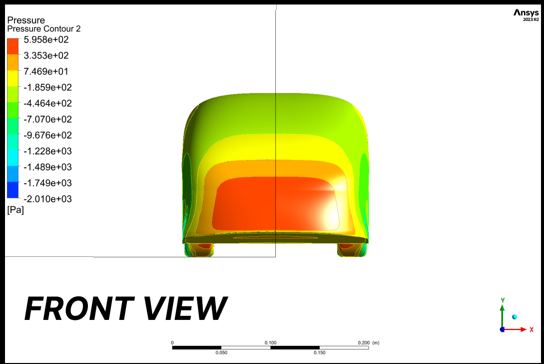
2D PRESSURE PLOTS



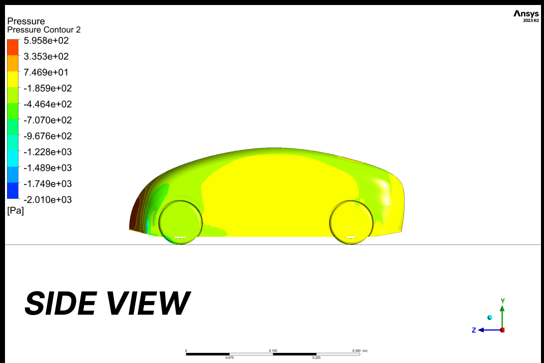
- Shows **pressure distribution** along vehicle's surface
- **High pressure zone at the front** indicates aerodynamic resistance
- **Low pressure zone at the back** indicates potential for drag reduction improvements
- Small pressure differentials suggest **minimal lift**
- Pressure distribution is generally uniform along the body, which contributes to **stability**

CFD OUTPUTS

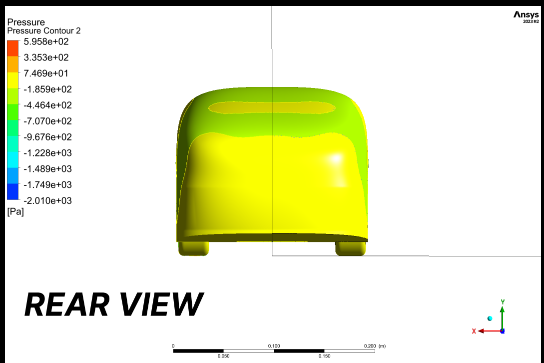
3D PRESSURE PLOTS



High pressure zone on the frontal surface **increases drag** but also ensures **stability**.

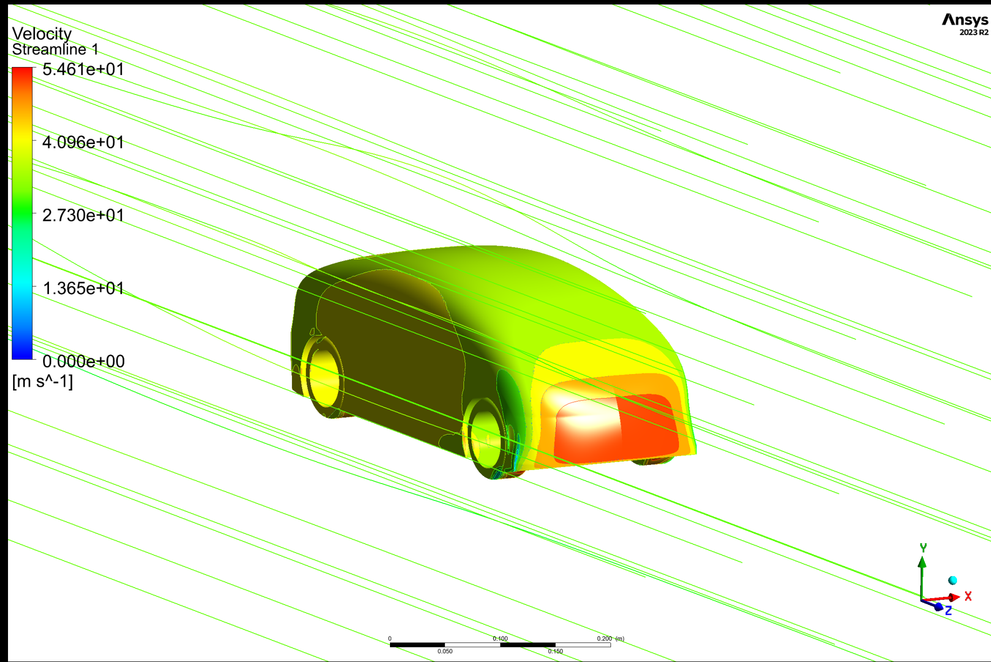


Gradual pressure drop along body **reduces flow separation**, enhancing aerodynamic efficiency.



Low pressure zone on the back indicates **wake formation**, a primary drag source (can be seen in 2D velocity plot).

3D FLOW TRAJECTORIES



- Shows **airflow streamlines** across vehicle
- Streamlines show **smooth airflow over vehicle body**, with minimal separation
- Green streamlines indicate **consistent laminar flow**
- **Flow is well-guided around body** reducing turbulent wake

RESULTS EVALUATION

DRAG COEFFICIENT: *0.36*

Using the drag coefficient equation:

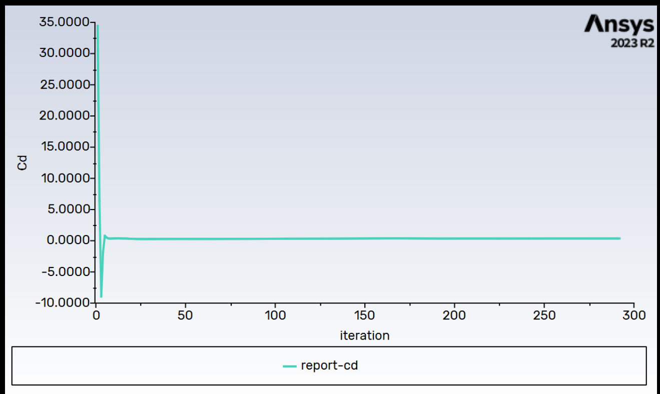
$$C_d = \frac{2F}{\rho v^2 A}$$

$F = \text{Drag force (N)}$
$\rho = \text{Air density } (kg/m^3)$
$v = \text{Air velocity } (m/s)$
$A = \text{Frontal area } (m^2)$

$$= \frac{2 \times 2.94}{1.225 \times 30.5^2 \times 0.01425}$$

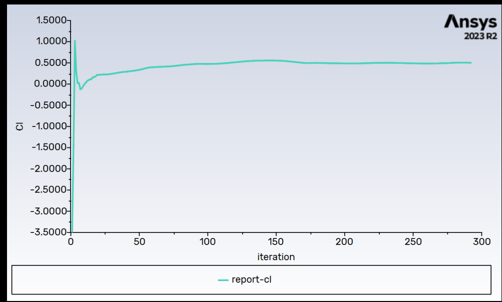
$$= 0.362$$

(3 significant figures)



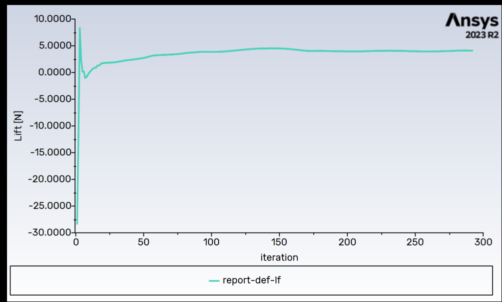
Moderate drag coefficient value suggesting a balance between aerodynamics and stability. Further improvements can be made to reduce the coefficient.

LIFT COEFFICIENT: *0.50*



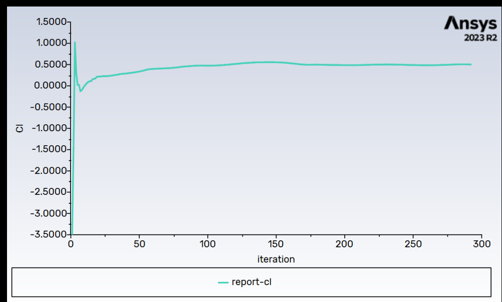
Positive lift coefficient may be undesirable and cause unwanted lift, possibly causing instability in the vehicle.

LIFT FORCE: *4.08 N*



Lift force is higher than drag force. This may cause instability. Modifying the shape may be necessary to reduce upward forces.

DRAG FORCE: *2.94 N*



Relatively low drag force, which indicates minimal resistance. Shows that the current design is effective, but with room for improvement.

RESULTS & IMPROVEMENTS

SUMMARY OF RESULTS

The aerodynamic analysis indicates that the design meets some of the specification aims while highlighting areas for improvement.

- The drag coefficient (0.36) is **slightly higher than the target of below 0.34**, suggesting that while the shape is relatively streamlined, further improvements could enhance efficiency.
- The lift coefficient (0.50) and lift force (4.08 N) indicate **notable lift generation**, which **could impact stability**, particularly at higher speeds.

Comparing to the benchmark vehicles:

- The drag coefficient is slightly higher than the Mercedes Benz Vito (0.34) but close to the Chevrolet Venture (0.35)
- The frontal area falls within the expected range, aligning with the 2.60 - 3.00 m^2 target
- Dimensions are within expected ranges

Overall, while the design is **aerodynamically competitive with existing MPVs**, **further refinements are needed** to optimise drag reduction and stability.

FUTURE IMPROVEMENTS

REFINING BODY SHAPE

Further streamlining could help reduce the drag coefficient to below 0.34. For example:

- Increased roof taper to reduce flow separation and vortex formation
- Reduce abrupt change in geometry at the back to minimise pressure

REDUCING LIFT-INDUCED INSTABILITY

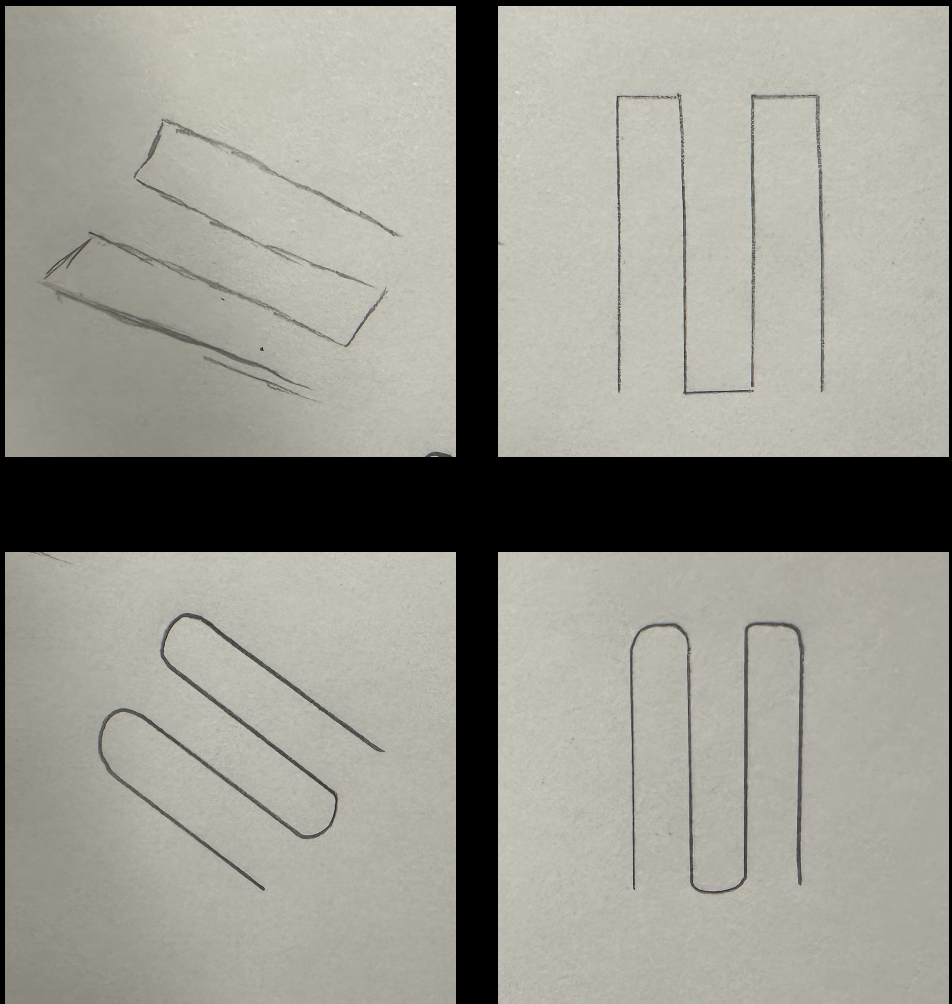
- A rear or roof-mounted spoiler at the back can prevent excessive pressure differences
- A front splitter could redirect airflow to reduce underbody airflow

OTHER POSSIBLE FEATURES TO CONSIDER

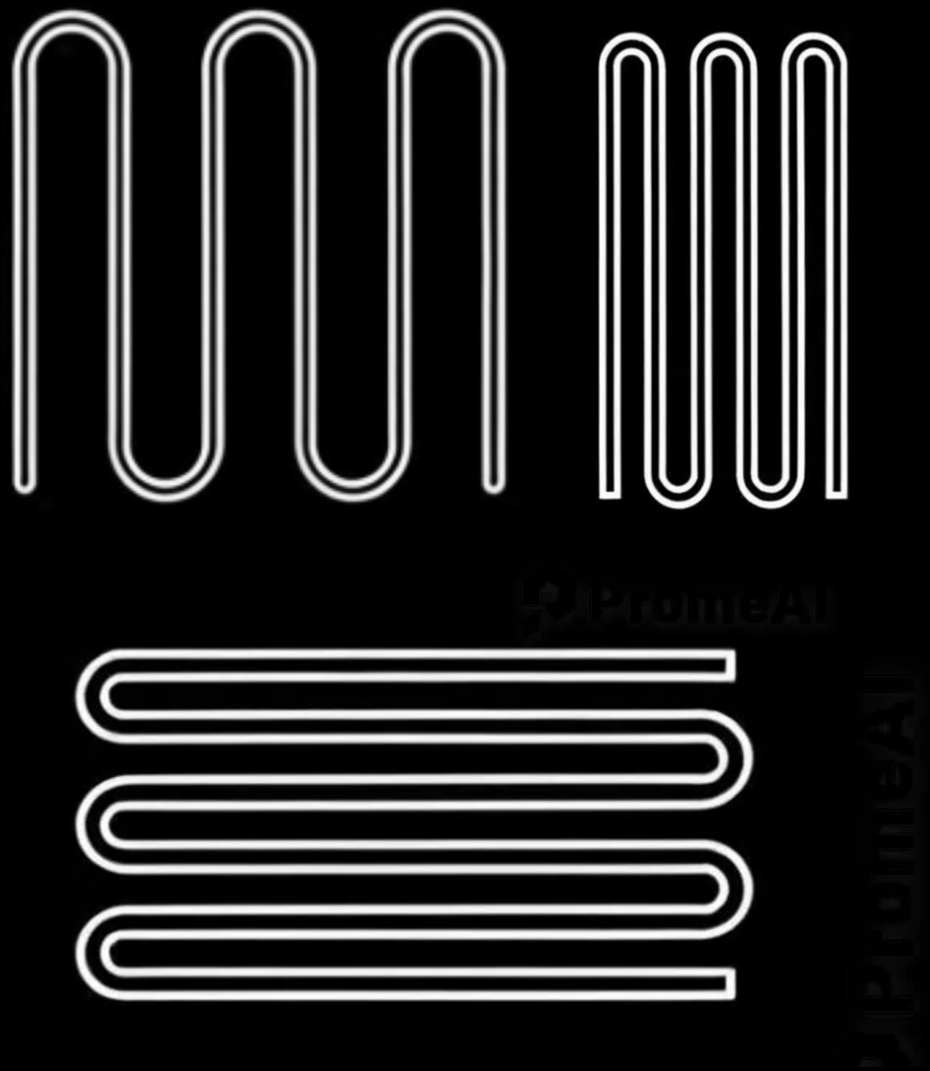
- Rear diffusers to guide airflow efficiently and reduce turbulence
- Aerodynamic wheel covers to reduce turbulence from rotating wheels

CONCEPTUAL PIPELINE DESIGN

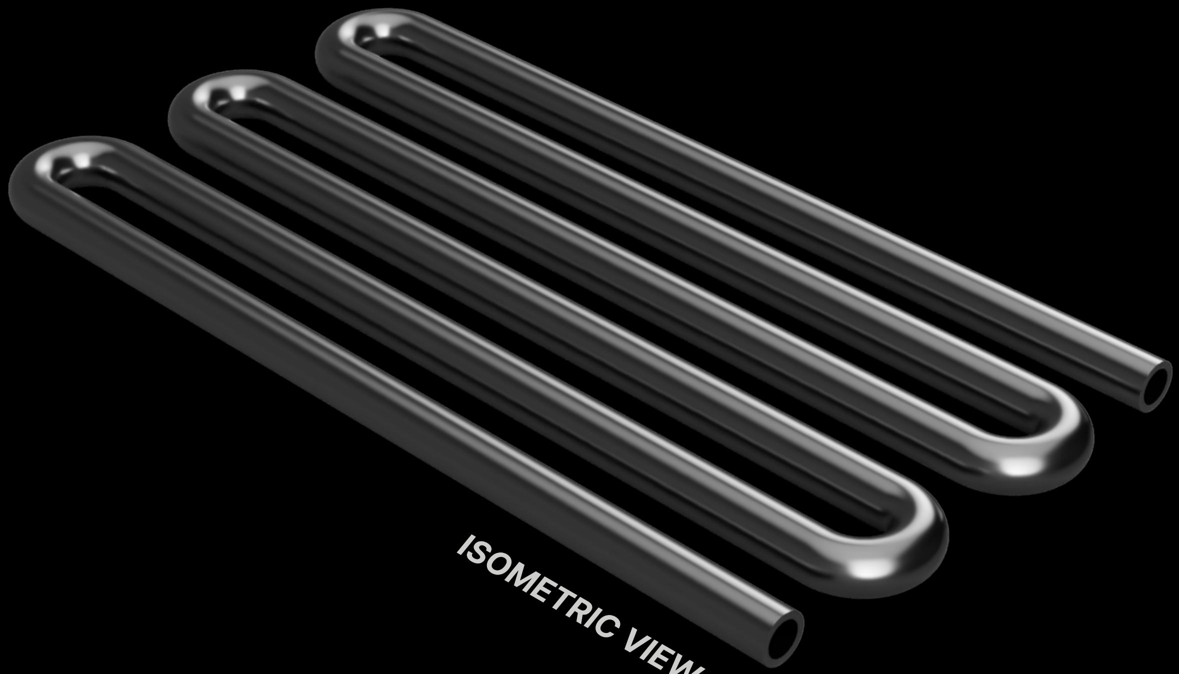
INITIAL SKETCHES



REFINED SKETCHES



3D CAD MODEL



ISOMETRIC VIEW

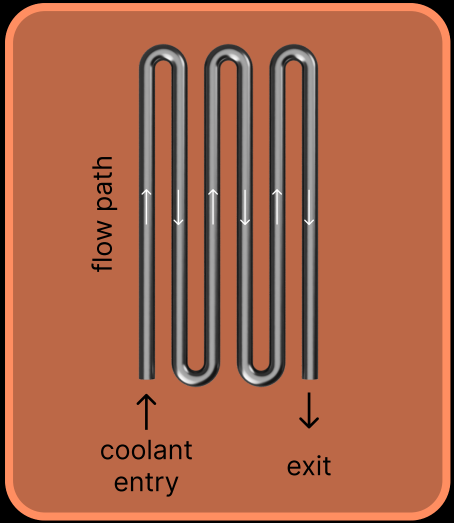
TOP VIEW

DESIGN RATIONALE

To cool a simple battery pack, the pipeline design aims to focus on: **efficient heat transfer & minimising pressure loss**.

SERPENTINE DESIGN

- Maximises surface contact for heat transfer
- Allows for a large portion of the coolant to stay in contact with the battery cooling plate, enhancing thermal exchange
- Parallel pipes allows for uniform cooling distribution, lower flow resistance and prevention of flow stagnation

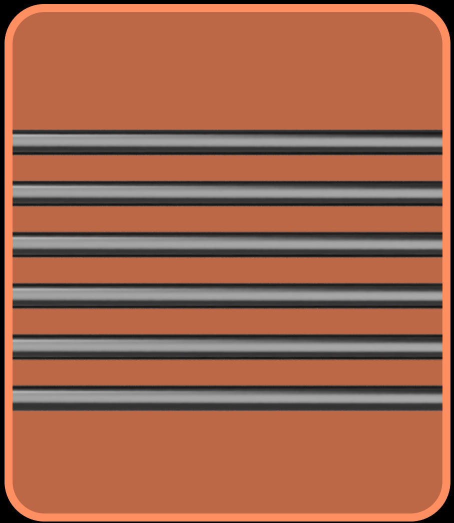


SMOOTH BENDS

- Rounded U-bends reduce sudden changes in velocity, minimising turbulence
- Pressure drop is reduced and pressure loss is minimised

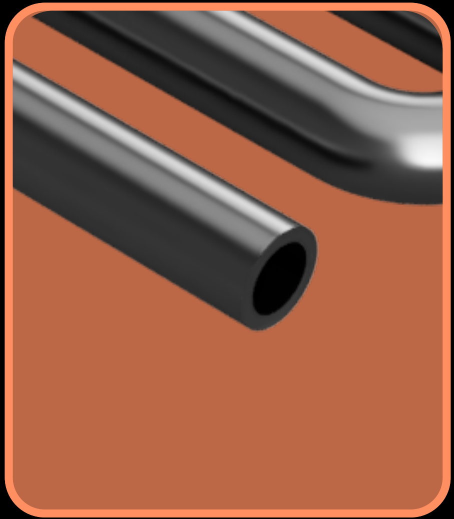
FLOW DISTRIBUTION

- Evenly spaced tubes ensures uniform cooling distribution across the battery
- A controlled moderate flow rate will ensure that the liquid absorbs enough heat before exiting, hence preventing inefficient heating from excessive velocities



PIPE DIAMETER

- A uniform pipe diameter ensures steady flow – this avoids any unnecessary change to flow speed
- By optimising pipe dimensions and flow rate, a low Reynolds number can be maintained
- This prevents turbulence and reduces the power to pump the coolant



CONCLUSION

SUMMARY

The pipeline cooling system is designed with a focus on:

1. **EFFICIENT HEAT TRANSFER**
2. **MINIMISING PRESSURE LOSS**

The design has the following features:

- **Serpentine design shape**: To maximise coolant contact area
- **Smooth U-bends**: Reduces turbulence and pressure loss
- **Flow distribution considerations**: Ensures uniform cooling
- **Uniform pipe diameter**: Ensures steady flow

Additionally, the material should be a **high conductivity metal** such as aluminium or copper. This is to **enhance heat dissipation efficiency** – hence using a high conductivity metal means that it has **ideal thermal properties**.

FINAL CONSIDERATIONS

In practice, this design aims to:

- Enhance thermal management
- Improve system efficiency
- Improve longevity
- Lower energy consumption
- Enhance sustainability

NEXT STEPS

DEFINE PIPELINE DIMENSIONS

The pipeline size is dependent on the size of the battery. As an initial guide, the bend radius of the pipe would be 2 or 3 times the diameter of the pipe and the space between pipes would be twice the bend radius.

CALCULATE PRESSURE LOSS & HEAT TRANSFER

Determine the Reynolds number and pressure drop to validate the system's thermal efficiency.

CFD ANALYSIS

Conduct CFD simulations to analyse the coolant flow, turbulence effects and heat transfer. This can then be compared with the theoretical calculations.

REFERENCES

Agatie, C. (2022) Volkswagen Eurovan Westfalia MV Weekender Is Still Going Strong After Almost 30 Years. 18 October 2022. autoevolution. https://www.autoevolution.com/news/volkswagen-eurovan-westfalia-mv-weekender-is-still-going-strong-after-almost-30-years-201582.html [Accessed: 24 February 2025].

Anon (n.d.a) 2005 Chevy Venture Review & Ratings | Edmunds. https://www.edmunds.com/chevrolet/venture/2005/review/ [Accessed: 24 February 2025].

Anon (n.d.b) Best family cars 2025: top choices for you and your children. https://www.whatcar.com/best/family-cars/n27171 [Accessed: 24 February 2025].

Anon (n.d.c) Car Aerodynamics Basics, How-To & Design Tips ~ FREE! https://www.buildyourownracecar.com/race-car-aerodynamics-basics-and-design/4/ [Accessed: 24 February 2025].

Anon (2025) Mercedes-Benz Vito. Wikipedia. https://en.wikipedia.org/w/index.php?title=Mercedes-Benz_Vito&oldid=1274860842.

Anon (n.d.d) Riwal888 - Blog: New Opel Astra J GTC wins Red Dot Design Award. https://riwal888.blogspot.com/2012/07/new-opel-astra-j-gtc-wins-red-dot.html [Accessed: 24 February 2025].

Anon (n.d.e) The Mayfield Company Homepage - Volkswagen Vehicle Drag Data. http://www.mayfco.com/volks.htm [Accessed: 24 February 2025].

Anon (n.d.f) Used 1993 Volkswagen EuroVan MV Specs & Features. Edmunds. https://www.edmunds.com/volkswagen/eurovan/1993/st-4037/features-specs/ [Accessed: 24 February 2025].

Anon (n.d.g) Used 1993 Volkswagen EuroVan MV Specs & Features | Edmunds. https://www.edmunds.com/volkswagen/eurovan/1993/st-4037/features-specs/ [Accessed: 24 February 2025].

Anon (n.d.h) Vehicle Coefficient of Drag List - EcoModder Forum Wiki. https://ecomodder.com/wiki/Vehicle_Coefficient_of_Drag_List [Accessed: 24 February 2025].