Squid Sports Car

Vehicle Design Aerodynamics

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Summary

In the comprehensive aerodynamics report, the concept of a Squid Sports Car model, inspired by the natural streamlined shape of squid, is created, and its aerodynamic features are simulated, analysed and then improved.

The conceptualisation phase employed hand calculations for preliminary drag coefficient estimations, comparing the model against established drag coefficients of local features. This baseline allowed for the analysis of the drag coefficient (0.3215), drag forces (0.331 kN) and the required power (10.272 kW) to maintain a velocity of 31 m/s.

CFD simulations were meticulously performed, revealing a drag coefficient of 0.408007183. This was followed by generating detailed visualisations to pinpoint drag-inducing areas, including 2D velocity and pressure plots, 3D pressure distribution over the car body, and 3D flow trajectories.

Comparisons with wind tunnel tests and CFD tests of both a standard sports car and a pickup model were crucial for validating the accuracy of the CFD simulations and understanding potential areas for improvement on the Squid Sports Car. Insights from these comparisons directed efforts to reduce drag through design modifications.

A set of targeted design enhancements was proposed to reduce the drag further. The second version of the CAD model focused on a more streamlined shape, enhanced wheel shields, and a simplified rear design to decrease the likelihood of turbulent vortices and wake zones. The effectiveness of these modifications was evident in the reduced drag coefficient of 0.371, marking a decrease of 0.037 compared to the initial CFD results, not the 0.445 as previously mentioned, which appears to be an error in the document.

This significant reduction in the drag coefficient is a testament to the value of CFD analysis in optimising the design of vehicles for better aerodynamic performance. The document concludes with a forward-looking statement about the continuous improvement of the Squid Sports Car's aerodynamics through ongoing CFD analysis and iterative design refinements.

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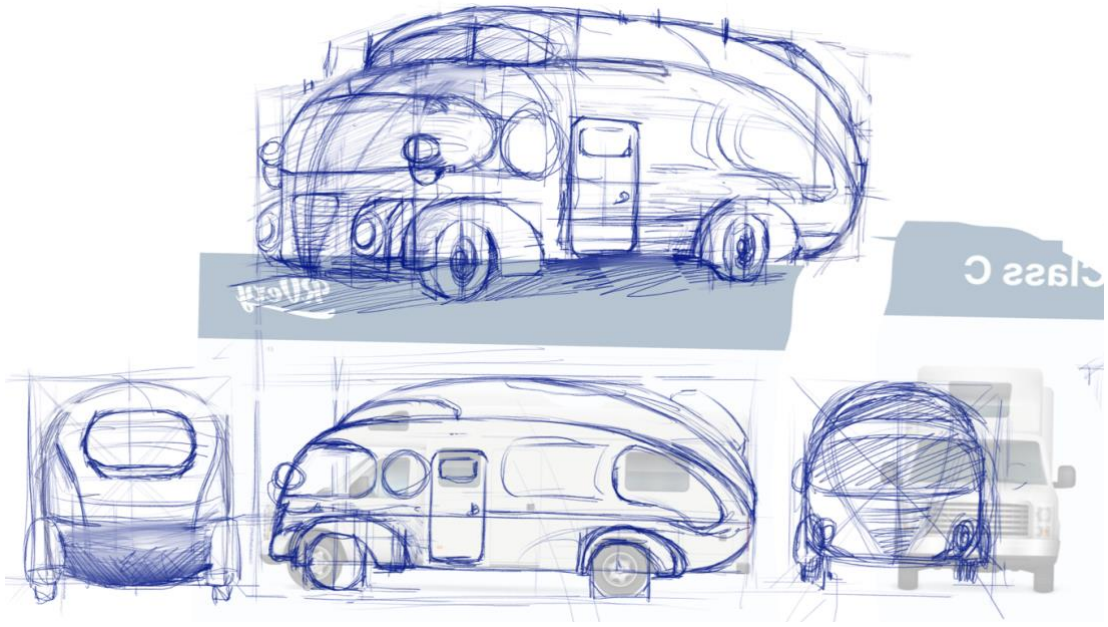
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Sketch Views of Concept

Initial Practices – Brainstorming and Sketching

The design process commenced with explorative sketches to enhance the conceptualisation of automotive aesthetics. Emphasis was placed on mastering perspective sketching, which is critical for understanding the structural aspects of contemporary vehicle design.

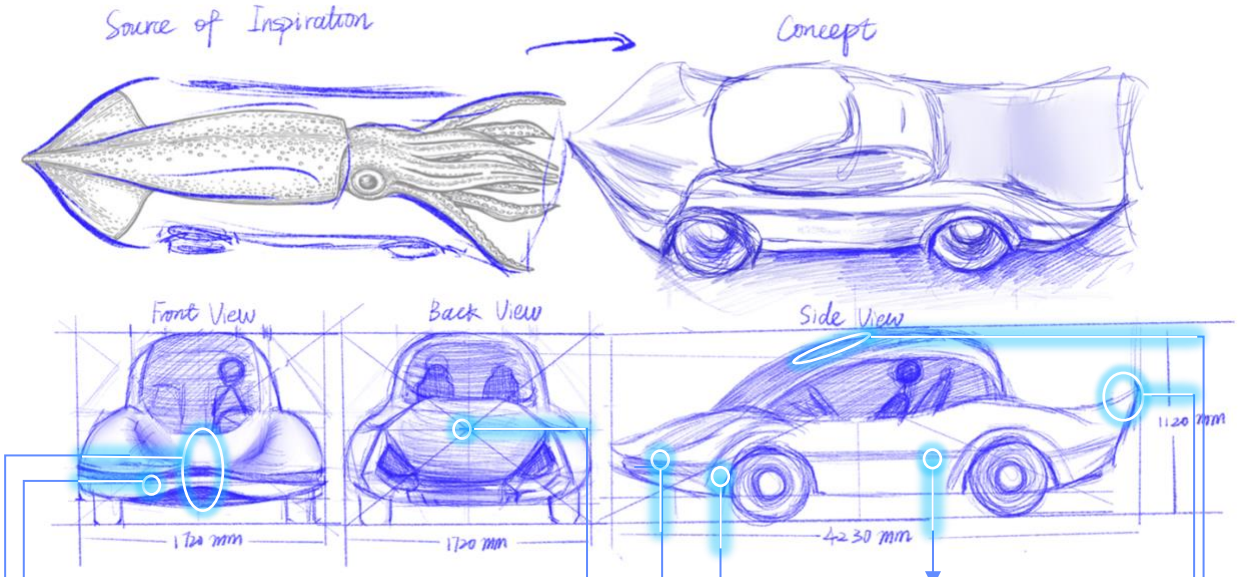
Subsequently, the design effort shifted towards reinterpreting a modern Class C RV with a vintage aesthetic. The objective was to synergise the classic motorhome style with current design trends, resulting in a vehicle that exudes old-world charm while embodying the aerodynamic advancements of today's RVs.



Conceptual Design Synthesis

In pursuing aerodynamic excellence, a new concept is generated and adopted. The conceptual design drew inspiration from the sleek form of marine fauna, with the squid as a focal point. The fusion of organic shapes and automotive engineering culminated in the following features:

- The front design, including the hood and bumper, was influenced by the squid's fin lobes, harmoniously blending form with aerodynamic functionality.
- The design of the windshield and roof took cues from the squid's head, optimising the vehicle's profile for reduced aerodynamic drag.
- The vehicle's rear elevation is a nod to the squid's tentacles, which are designed to emulate their natural curvature and contribute to its aerodynamic form.



The bumper's underside features a recessed area akin to an air splitter, accelerating airflow and generating downforce while reducing high-pressure

The bonnet features an aerodynamically favourable curve, reducing pressure drag by limiting vertical flat surfaces in direct contact with the airflow.

The rear design incorporates an aerodynamic uplift, akin to a spoiler, to reduce lift and augment stability at high speeds.

The bumper features a recessed contour that elegantly extends toward the rear, serving as a stylistic homage to the iconic Ferrari 308.

Wheel fenders are designed to protrude strategically, diverting air from the wheels and, thus, reducing drag.

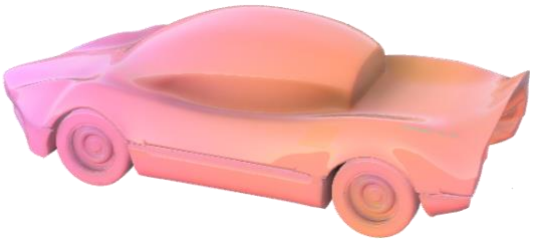
The rear end's upward tilt is reminiscent of a spoiler, designed to disrupt airflow and minimise lift at the rear, reinforcing high-speed stability.

Roof rails are contoured to extend from the hood in a streamlined fashion, aiding in reducing aerodynamic drag.

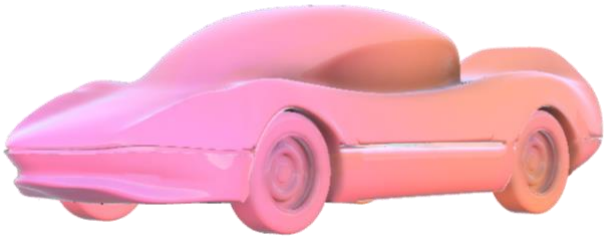
CAD Model (Assembly & Part)

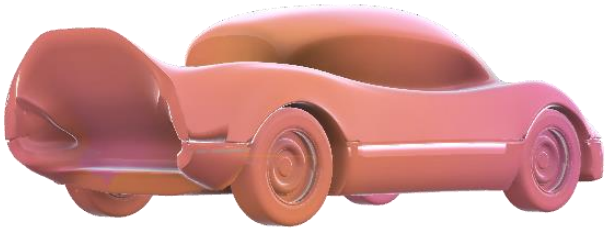
The CAD model has been developed from the blueprint, featuring a streamlined body that encapsulates the squid-inspired concept. Key aerodynamic features include an upward-tilted base and an integrated rear spoiler to enhance vehicle stability and reduce drag force



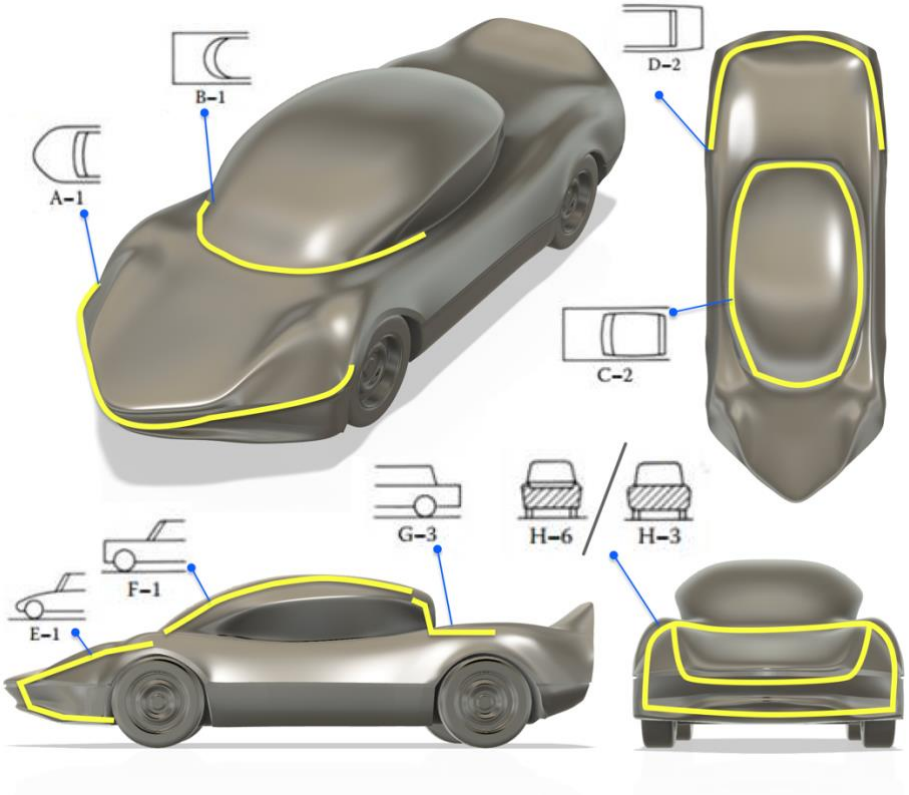
The undertray is modelled to be smooth, minimising turbulence and reducing drag. This design allows the air to flow more rapidly underneath the vehicle, decreasing air pressure and augmenting downforce for improved grip. The wheels are connected to the body via dual rods, merging into a unified structure and facilitating subsequent computational fluid dynamics (CFD) analysis



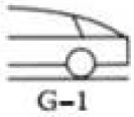
Preliminary Drag Analysis (Hand Calculation)

The preliminary drag analysis utilises a comparative approach, matching the vehicle's CAD model with established shapes to approximate drag coefficients.

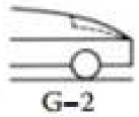




High cowl, low fender



Fastback (roofline continuous to tail)



Semi FastBack (with discontinuity in line to tail)

Employing the formula (employing H-6 configuration to estimate the worst situation):

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

Hence:

$$C_D = 0.16 + 0.0095 \times (1 + 1 + 2 + 2 + 1 + 1 + 3 + 6) = 0.3215$$

Velocity U_∞ = 31.0000 m/s, Area A = 1.751 m^2, density of air ρ = 1.225 kg/m, we get Drag:

$$F_D = C_D 0.5 \rho {U_\infty}^2 A = 0.331\ kN$$

Power to overcome drag:

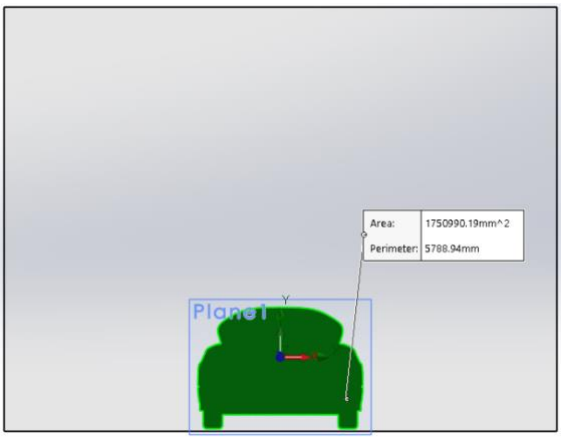
$$W = F_D \times U_\infty = 10.272\ \text{kW}$$

- The car's frontal shape straddles the categories H-6 and H-3 (shown above), hinting at potential inaccuracies due to their non-ideal drag reduction profiles. An evolution towards an H-2 category could enhance aerodynamics while preserving the squid-like aesthetic.
- Analysis suggests that the rear roof may need to be more aerodynamically optimised. Revisions to a G-1 or G-2 shape (shown above) or adding aerodynamic aids such as spoilers could reduce drag.
- The curved bottom front facilitates airflow beneath the car, potentially introducing lift at high speeds. Although this shape significantly cuts drag, stability at speed could be improved by incorporating aerodynamic modifications, such as spoilers, without compromising the design's drag efficiency.

CFD model

Data

1. Vehicle Data:
   Frontal Area: 1.751 m^2





1. Analysis of Mesh:
   Total Cell Count: 665,557
   Fluid Cells: 665,557
   Fluid Cells containing solids: 7,288

2. Additional Physical Calculation Options
   Heat Transfer Analysis: Heat conduction in solids: Off
   Flow Type: Laminar and turbulent.
   Time-Dependent Analysis: Off
   Gravity: Off
   Radiation: Humidity: Off
   Default Wall Roughness: 0 micrometre.

3. Material Setting
   a. Material Settings
      i. Fluids: Air

4. Initial Conditions

Table 1_ Ambient Conditions

Thermodynamic parameters	Static Pressure: 101325.00Pa 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: -31.000 m/s
Turbulence parameters	Turbulence intensity and length Intensity: 0.10 % Length: 6.689e-04 m

5. Engineering Goals
   Global Goals:

Table 2_ Velocity

Type	Global Goal
Goal type	Velocity (Z)
Calculate	Average value
Coordinate system	Global Coordinate System
Use in convergence	ON

Table 3_ Lift Force

Type	Global Goal
Goal type	Force(Y)
Coordinate system	Global Coordinate System
Use in convergence	ON

Table 4_ Drag Force

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

Table 5_ Drag Coefficient Equation

Type	Equation Goal
Formula	(2 * Drag Force)/(1.225 * 1.751 *(Velocity^2))*(-1)
Dimensionality	No units
Use in convergence	ON

6. Analysis Time

Calculation Time: 0: 38: 54
Number of Iterations: 407
Warnings: no warnings

7. Results:

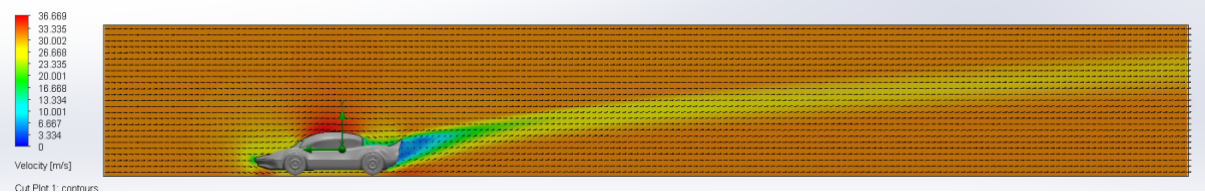
Table 6_ Outcomes

Name	Unit	Value	Progress	Criteria	Delta	Use in Convergence
Velocity	[m/s]	30.85477055	100	9.15089E-05	8.8126E-05	On
Lift Force	[N]	-27.3877683	100	0.986063756	0.151963789	On
Drag Force	[N]	-428.419624	100	0.405835768	0.375686835	On
C_D	[]	0.408007183	100	0.000386499	0.000357787	On

The CFD results indicate a higher drag coefficient than the preliminary analysis suggested, exceeding the sub-0.3 benchmark typical for modern sports cars. This is probably because of the vague structure description of the drag coefficient table, and my model has a more detailed design, such as the bumper area and the upward-tilted rear. Despite this, the preliminary analysis offers valuable insights for aerodynamic vehicle design enhancements.

Plots

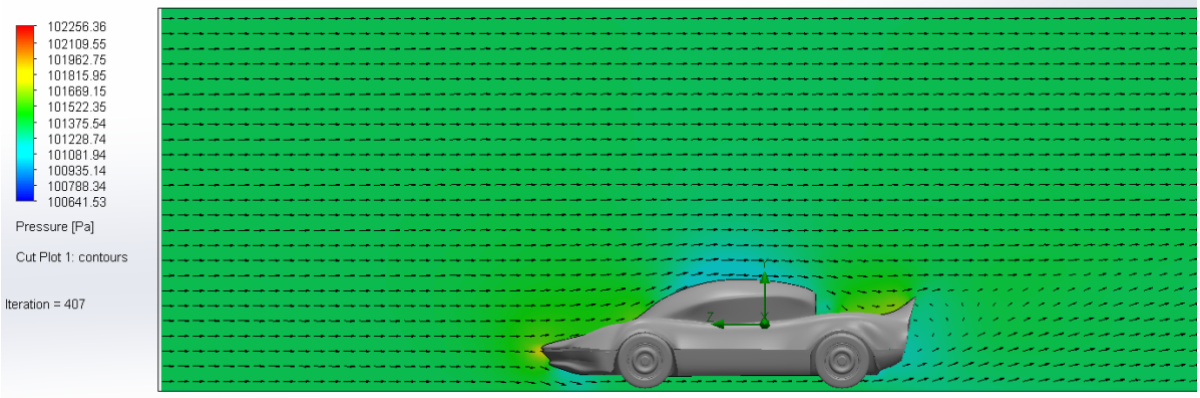
2D Velocity Plot



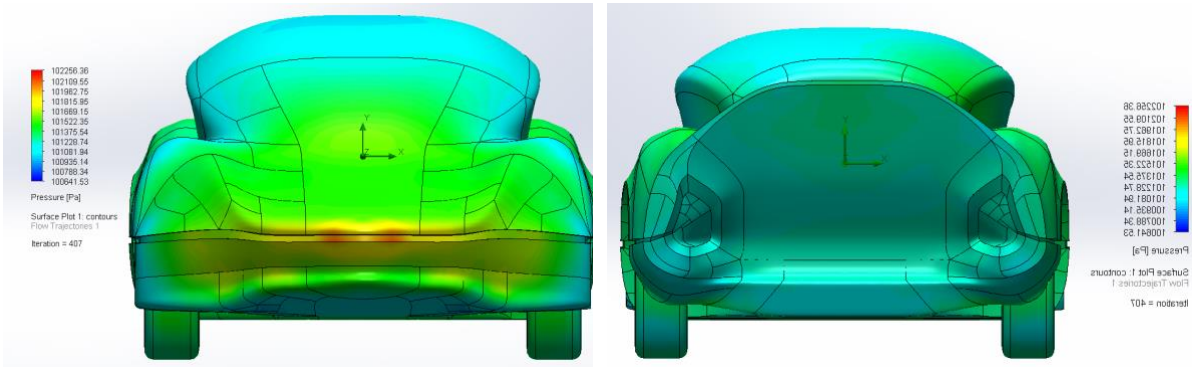
The blue zone, indicative of a wake area, is marked by low pressure and high turbulence and constitutes a primary drag source. The current design of the rear tail, which is angled steeply upwards to act as a spoiler, significantly contributes to this wake area by disrupting the streamlined flow.

To decrease drag, reconfiguring the spoiler to better conform to the natural airflow could be effective. Additionally, considering the principles of both the Bernoulli and Coanda effects, transforming the spoiler into an airfoil-shaped wing could prove advantageous. This design would leverage the Bernoulli effect by accelerating airflow underneath the wing, thus reducing pressure and creating lift (or downforce in automotive terms). Simultaneously, it would utilise the Coanda effect to encourage airflow to follow the wing's contour, enhancing downforce without excessively increasing drag.

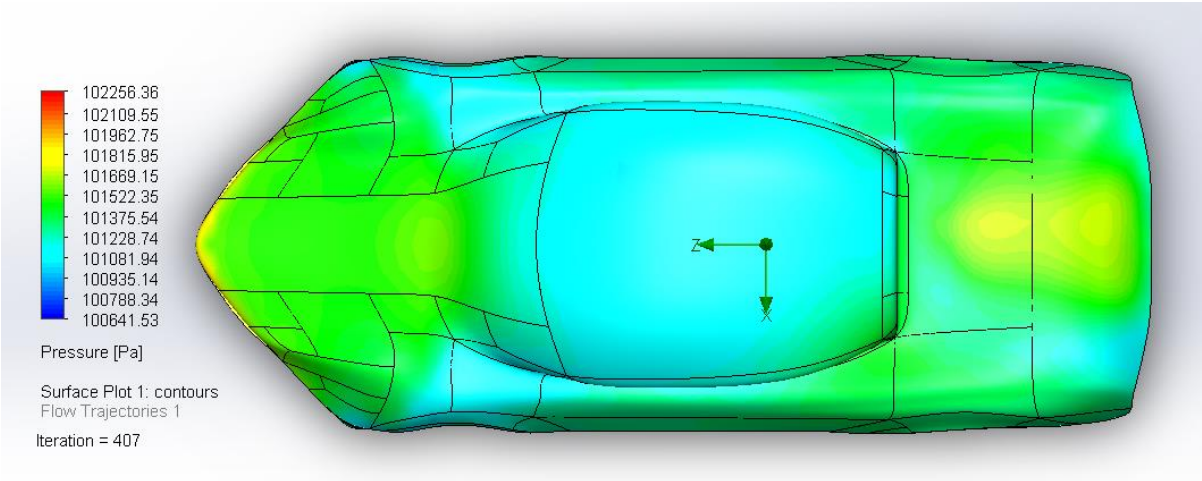
2D Pressure Plot & 3D Pressure Distribution



The graph demonstrates low-pressure regions due to the vehicle's aerodynamic, streamlined design extending from the front to the window roof edge.

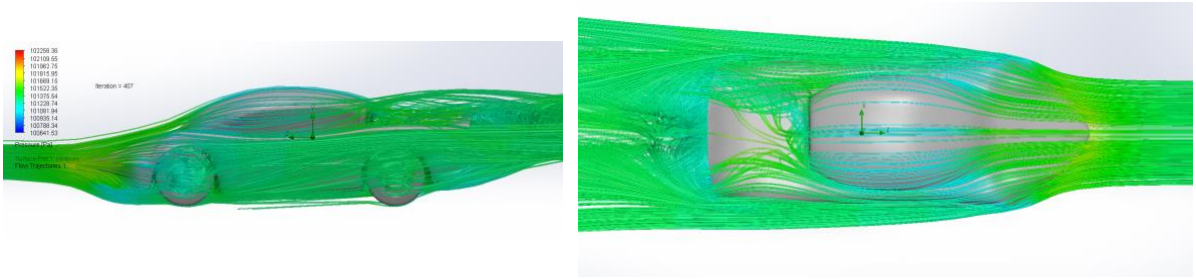


The red tip indicates a design shortfall in evenly distributing pressure at the forefront of the car, where it first encounters airflow. The splitter region generates a relatively high-pressure zone, enhancing downforce. This phenomenon is attributed to the Venturi effect, whereby fluid accelerates as it passes through a narrower section, leading to a decrease in pressure alongside the acceleration, thus contributing to increased downforce.

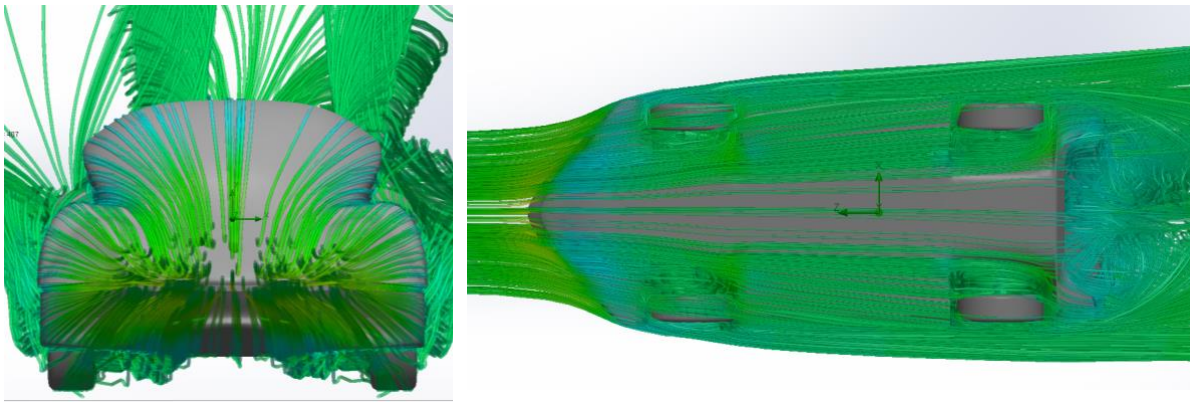


The yellow region in the rear zone indicates a high-pressure area, leading to increased drag force.

3D Flow Trajectories around the vehicle

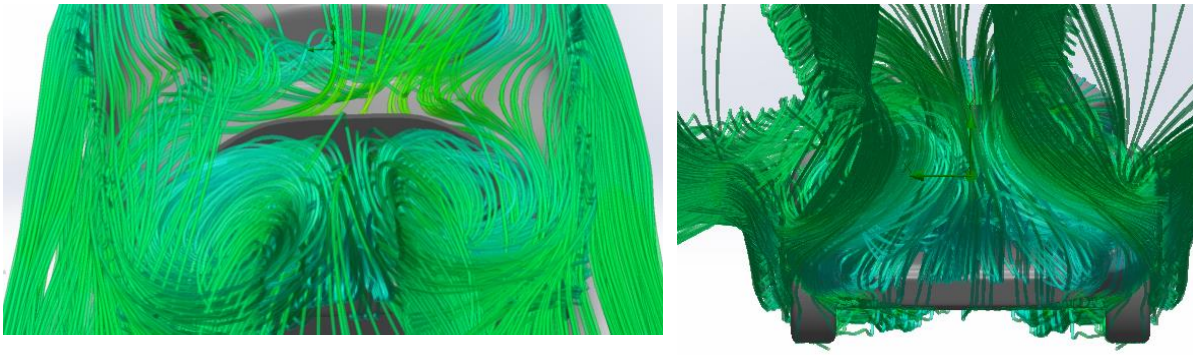


The design of the car's front end facilitates airflow towards the car's underside, inadvertently preventing the creation of a pressure differential necessary for generating downforce. This downforce is crucial for pressing the tyres against the ground, enhancing lateral grip, and improving cornering speeds. To mitigate this, front and rear splitters and side skirts can be installed to obstruct the air from flowing beneath the car, thus preserving the desired aerodynamic effects.



The illustration highlights the formation of vortices around the wheels, likely due to the wheel fenders' inability to fully shield the wheels from incoming airflow. This exposure can disrupt the smooth airflow around the vehicle, potentially affecting its aerodynamic efficiency.

Furthermore, the analysis points out that the excessive clearance at the car's front bottom allows too much air to flow downwards and enter the wheel housing. This influx of air acts as a barrier to the car's forward motion, reducing its speed and efficiency.

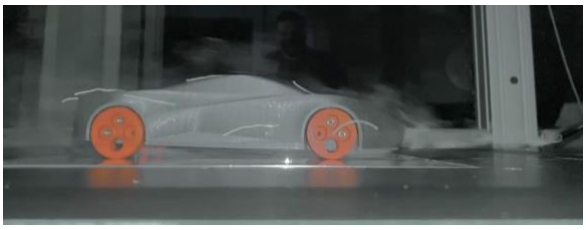


The area behind the rear window and the car's rear end is identified as a significant vortex generator, indicating a low-pressure zone contributing to drag. This issue may stem from the car's concave backlight and vertical rear window design, which disrupts the natural airflow path. Installing diffusers to guide airflow or mounting splitters on the rear fender to direct the flow upwards could alleviate this problem by optimising the air's path and reducing the turbulent zones.

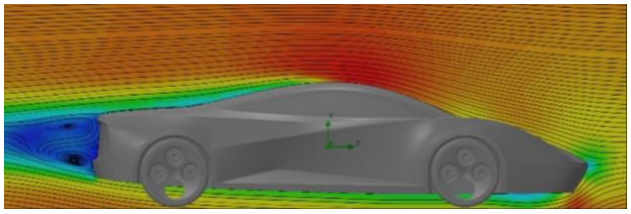
Discussion & Conclusion

1. CFD vs. Wind Tunnel Test Data Comparison

Name	Unit	Sports car Wind tunnel value	Sports car CFD value	Squid Sports car CFD value
Velocity	m/s	-30.833	30.552	30.85477055
Lift Force	N	0.983	1.316	-27.3877683
Drag Force	N	-0.966	0.0061	-428.419624
Cd	n/a	0.271886	0.37	0.408007183



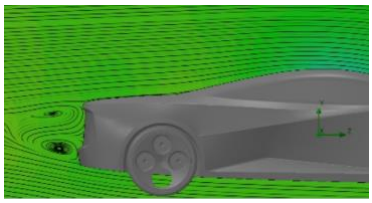
Sports car Wind tunnel test screenshot



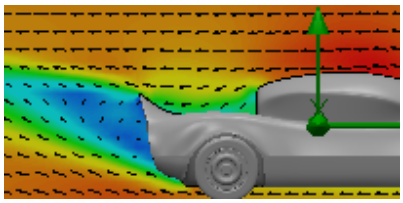
Sports car 2D velocity plot

The wind tunnel test revealed a 0.1 higher CD compared to the CFD analysis, indicating CFD's capability to approximate real-world conditions but with a tendency to idealise, leading to overestimations. This discrepancy may arise from factors like surface roughness or varying flow source positions not accounted for in CFD. The test also identified increased turbulence atop the car's roof and a pronounced wake area behind the vehicle.

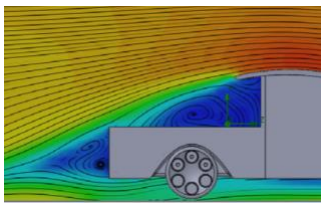
2. Model Comparisons
   - Rear window area velocity comparison



Sports car model



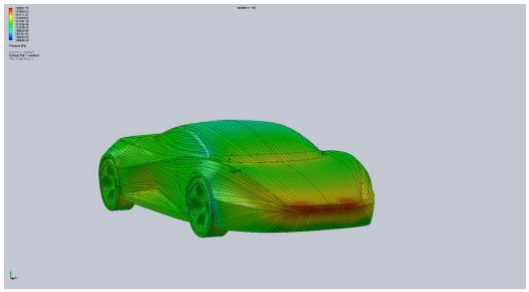
Squid Sports Car

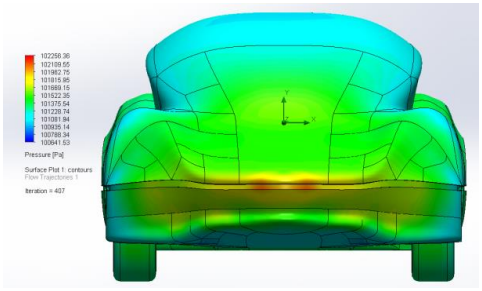


Pickup model

Upon examining the aerodynamic characteristics of the three models — the sports car, squid sports car, and pickup car — it becomes clear that a vertical rear window contributes to a low-pressure area and consequently a higher drag force. Additionally, the squid sports car's slanted rear end creates a triangular area similar to the pickup model, failing to reduce the rear end area by naturally streamlined shapes. In contrast, the sports car's rear end tapers more effectively, offering a smoother transition that allows the upper and lower airflow to reunite, further optimising aerodynamics.

   - Front bumper area pressure comparison



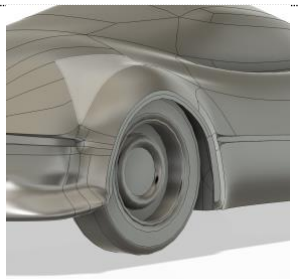
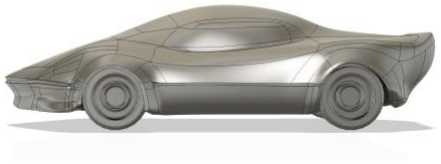


The comparison of pressure plots confirms my initial concept that designing the bonnet with an aerodynamically favourable curve—by minimising vertical flat surfaces in direct contact with airflow—can indeed produce fewer high-pressure areas, thereby reducing pressure drag.

Design Improvements Conclusion

1. Bump Area: To improve airflow, the design should be altered from a concave (H-6/ H3) shape to a convex (H-2) shape.
2. Top Back Area: A spoiler could be added, or the design could be changed to a G-2 shape while maintaining the squid shape to manage airflow better.
3. Bottom Rear Part: Adding a diffuser at the bottom rear part of the car is suggested to help smooth out airflow and reduce turbulence. The indented backlight area can be removed as it can cause turbulence.
4. Rear Window: Installing a vortex generator at the rear window would reduce the wake region and help the airflow to stay attached to the car's surface.
5. Wheel Shield: A wheel shield is recommended to protect the wheel from airflows that can cause turbulence and drag.
6. Bottom Front Part: A front splitter can deflect airflow, minimise drag under the car, and hasten air past the tyres.

The design revisions undertaken on the CAD model concentrate on areas critical for reducing the drag coefficient. These modifications are essential for improving the vehicle's aerodynamic profile and have been meticulously adjusted to ensure optimal airflow.

	Bottom Rear Part	Wheel Shield	Side Contour
Before			
After			

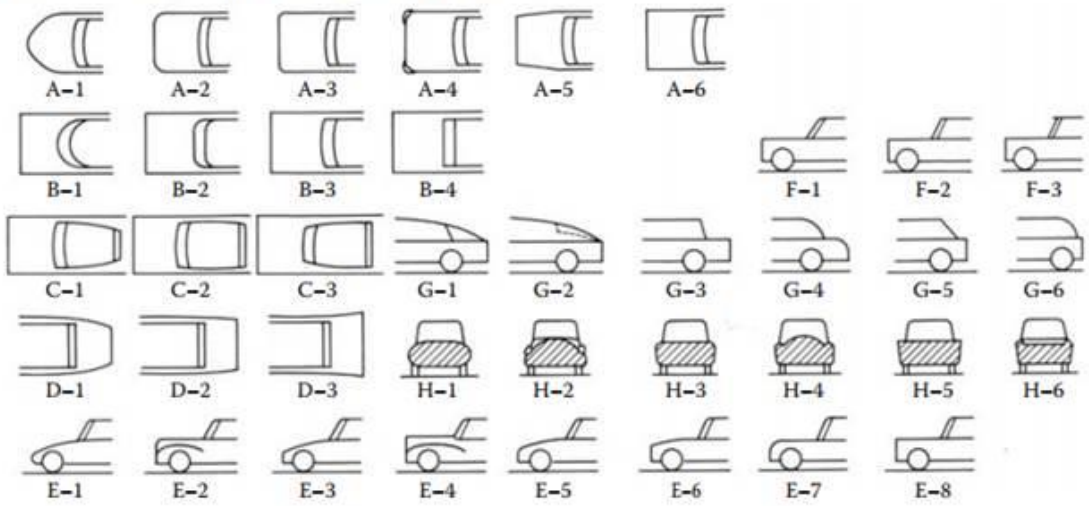
Name	Unit	1st model car CFD value	Improved model car CFD value
Frontal Area	M^2	1.751	1.637
Velocity	m/s	30.8549977055	30.9437324773482
Lift Force	N	-27.3877683	72.6576993038625
Drag Force	N	-428.419624	-364.49859564603
C_D	N/A	0.408007183	0.371305839448184

Reducing the drag coefficient by 0.445 is a significant achievement, demonstrating the effectiveness of the continuous analysis and improvements applied to the CAD models. With further refinement and iterations based on CFD results, there is a confident outlook that the Squid sports car will achieve even greater aerodynamic efficiency in future developments.

Appendix A

(The table is also shown in the lecture slide)

TABLE 6.2
Estimates of Automobile Drag Coefficient



A. Plan view, front end
A–1 Approximately semi circular (1)
A–2 Well-rounded outer quarters (2)
A–3 Rounded corners without protuberances (3)
A–4 Rounded corners with protuberances (4)
A–5 Squared tapering-in corners (5)
A–6 Squared constant-width front (6)

B. *Plan view, windshield*
B–1 Full wraparound (approximately semicircular) (1)
B–2 Wraparound ends (2)
B–3 Bowed (3)
B–4 Flat (4)

C. *Plan view, roof*
C–1 Well- or medium-tapered to rear (1)
C–2 Tapering to front and rear (maximum width at BC post) or approximately constant width (2)
C–3 Tapering to front (max. width at rear) (3)

D. Plan view, lower rear end
D–I Well- or medium-tapered to rear (1)
D–2 Small taper to rear or constant width (2)
D–3 Outward taper (or flared-out fins) (3)

E. Side elevation, front end
E–1 Low, rounded front, sloping up (1)
E–2 High, tapered, rounded hood (1)
E–3 Low, squared front, sloping up (2)
E–4 High, tapered, squared hood (2)
E–5 Medium-height, rounded front, sloping up (3)
E–6 Medium-height, squared front, sloping up (4)
E–7 High, rounded front, with horizontal hood (4)
E–8 High, squared front, with horizontal hood (5)

F. Side elevation, windshield peak
F–1 Rounded (1)
F–2 Squared (including flanges or gutters) (2)
F–3 Forward-projecting peak (3)

G. Side elevation, rear roof/trunk
G–I Fastback (roofline continuous to tail) (1)
G–2 Semi fastback (with discontinuity in line to tail) (2)
G–3 Squared roof with trunk rear edge squared (3)
G–4 Rounded roof with rounded trunk (4)
G–5 Squared roof with short or no trunk (4)
G–6 Rounded roof with short or no trunk (5)

H. Front elevation, cowl and fender cross section at *wind-shield*
H–1 Flush hood and fenders, well-rounded body sides (1)
H–2 High cowl, low fenders (2)
H–3 Hood flush with rounded-top fenders (3)
H–4 High cowl with rounded-top fenders (3)
H–5 Hood flush with square-edged fenders (4)
H–6 Depressed hood with high squared-edged fenders (5)

Source: Reprinted from Bolz, R.E. and Tuve, G.L. (eds.), *CRC Handbook of Tables for Applied Engineering Science*, 2nd ed., CRC Press, Cleveland, OH, 1973. With permission.
Note: Drag rating values in parentheses are for use in Equation 6.13.