materials proceedings

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Investigation of Material Effects on Car Nose Geometry: Comparative Analysis of Ultra-High-Molecular-Weight Polyethylene, High-Density Polyethylene, Steel Sheets, and Aluminum Sheets on Drag Coefficient and Drag Force Through Computational Fluid Dynamics Approach †

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† Presented at the 2026 12th International Conference on Advanced Engineering and Technology, Incheon, Republic of Korea, 20–22 March 2026.

Abstract

To minimize the fuel consumption of an automobile, one of the parameters that car manufacturers modify is car geometry. Through aerodynamics testing, it is determined whether the final car geometry will produce a lower coefficient of drag. If the coefficient of drag is reduced, drag force will also be reduced, for coefficient of drag is parallelly related to drag force. Aerodynamic drag significantly impacts vehicle fuel efficiency and emissions, with the front-end geometry playing a critical role in flow separation and wake formation. This study investigates how material properties influence car nose design, focusing on the comparative effects of ultra-high-molecular-weight polyethylene (UHMWPE), high-density polyethylene (HDPE), steel sheets, and aluminum sheets on the coefficient of drag (C_D) and drag force (F_D) using a computational fluid dynamics (CFD) approach. In this study only the car nose or the front-end assembly will be modified and the rear end will not be change. The car type to be used is a sedan. There are six proposed car nose designs that undergo an air tunnel test. These include a flat hood nose design, a round nose design, a vented hood nose design, a streamline nose design, a sharp edge nose design and a pointed or triangular nose design. Using ANSYS CFD (computational fluid dynamics) the coefficient of drag will be determined through the simulation process. Based on the simulation results, the flat hood nose design and round nose design both with UHMWPE (ultra-high-molecular-weight polyethylene) produce the lower value of coefficient of drag. The round nose design produces C_D = 0.4011756 with F_D = 486.8655 Newtons and has a frontal area of 1.7828037 m^2, while the flat hood nose design generates C_D = 0.3406517 with F_D = 394.9720 Newtons and has a frontal area of 1.703730 m^2.

Keywords: ultrahigh-molecular-weight polyethylene; car nose; computational fluid dynamics; coefficient of drag; drag force

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Academic Editors: Jongwan Hu, Dongkeon Kim and Mosbeh Kaloop

Published: 19 August 2026

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1. Introduction

The escalating global demand for energy-efficient transportation has positioned fuel consumption as a paramount concern for automobile manufacturers. With road vehicles accounting for approximately 25% of worldwide energy-related carbon emissions, optimizing

vehicle design to minimize fuel use is imperative for both environmental sustainability and economic viability. One of the most effective strategies employed by engineers involves refining vehicle geometry, particularly through aerodynamic enhancements. By streamlining airflow around the vehicle, manufacturers can reduce aerodynamic resistance, which constitutes up to 70% of total propulsion energy requirements at highway speeds. Central to this effort is the determination of the coefficient of drag (CD), a dimensionless parameter that quantifies the vehicle's aerodynamic efficiency. A lower CD directly correlates with reduced drag force (FD), as expressed by the fundamental equation F_D=1/2 ρvˆ2 AC_D, where ρ is air density, vis vehicle velocity, and A is the frontal area. Consequently, even marginal reductions in Cd—such as 0.01—can yield fuel savings of 1–2% over a vehicle's lifecycle, underscoring the value of rigorous aerodynamic testing. Drag coefficient is one of the factors contributing to the increase in fuel consumption. Reducing this factor will result in lesser fuel consumption. According to Badiguer and Dindore [1], the car bonnet area can be altered to decrease the frontal area by 0.054 m^2 and reduce the attack angle by 2.36°, leading to a reduction in friction drag. Determination of the best geometrical front bumper design which reduces drag coefficient means a reduction in the fuel consumption which also means reduction in energy emission.

Aerodynamic drag arises primarily from pressure differences and skin friction along the vehicle's surface, with the front-end geometry exerting a disproportionate influence on flow separation, stagnation pressure, and wake turbulence. The nose or front-end assembly, including the hood, bumper, and grille, serves as the initial interface with oncoming airflow, dictating the formation of boundary layers and vortices that propagate downstream. Traditional designs, often constrained by manufacturing limitations of metallic materials like steel and aluminum, have historically prioritized structural integrity over fluid dynamic optimization, resulting in suboptimal CD values (typically 0.25–0.40 for sedans). However, advancements in polymer materials, such as ultra-high-molecular-weight polyethylene (UHMWPE) and high-density polyethylene (HDPE), offer enhanced flexibility, lower surface roughness, and reduced weight, enabling more innovative geometries that promote attached flow and delayed separation. Despite these potential benefits, there remains a paucity of comparative studies evaluating how material selection modulates the interplay between nose geometry and aerodynamic performance.

This study addresses this gap by investigating the effects of material properties on car nose design for a sedan-type vehicle, with a focus on the comparative impacts of UHMWPE, HDPE, steel sheets, and aluminum sheets on CD and FD. To isolate the front-end's contribution, modifications were confined to the nose assembly, leaving the rear end unaltered—a deliberate choice to mimic real-world incremental design upgrades without overhauling the entire vehicle architecture. Six distinct nose configurations were proposed and evaluated: flat hood, round, vented hood, streamline, sharp edge, and pointed (triangular). These designs span a spectrum of aerodynamic philosophies, from bluff bodies prone to early separation (e.g., flat hood) to more tapered profiles fostering laminar flow (e.g., pointed nose).

Employing computational fluid dynamics (CFD) via ANSYS Fluent software (https://ansys.synopsys.com/products/fluids/ansys-fluent, accessed on 1 August 2026), this research simulates airflow interactions under standardized conditions (e.g., 100 km/h inlet velocity), providing a cost-effective alternative to physical wind tunnel testing while enabling parametric exploration of material–geometry interactions. Preliminary simulations indicate that polymer-based variants, particularly the flat hood and round nose designs fabricated with UHMWPE, achieve the lowest CD values—0.3407 (FD = 395 N, A = 1.70 m^2) and 0.4012 (FD = 487 N, A = 1.78 m^2), respectively, highlighting up to 15% drag reductions relative to metallic baselines. By elucidating these material-driven effects, this work not

only advances theoretical understanding of bluff-body aerodynamics but also informs practical guidelines for automotive designers seeking to balance performance, manufacturability, and sustainability. Ultimately, the findings aim to contribute to the development of next-generation sedans with enhanced fuel efficiency and reduced emissions.

2. Review of Related Literature

Research has demonstrated that polyelectrolyte-grafted ultra-high-molecular-weight polyethylene (UHMWPE) is highly effective in reducing friction and wear. However, due to the impaired molecular structure and reduced material stability, the changed material exhibits diminished mechanical and tribological capabilities when exposed to a submerged, watery working environment. In order to improve the strength and water resistance of materials, carbon nanotubes (CNTs) were modified and utilized as a reinforcing agent. Both nanoindentation tests and macroscopic reciprocating friction tests have demonstrated substantial enhancements in mechanical and tribological characteristics. These improvements include a reduction in friction coefficient and wear rate to 0.0086 and 5.6×10^{-8} mm^3 (Nm)$^{-1}$, respectively, under saline-lubricated conditions. Furthermore, these properties remained relatively stable even after a 120-day saline pre-soaking period [2].

For a formula student car, the nose is the first point of flow contact and determines the flow direction, allowing other aero components to function efficiently. As a result, an optimized nose shape is critical for the vehicle's peak performance. Gradient-based optimization in the automotive industry has arisen in recent years, utilizing an adjoint technique. The adjoint solver is used to adjust geometry, such as a car's nose, to achieve the optimum possible shape in relation to other design variables. This study examines six different Reynolds number conditions: 8.15×10^5, 9.05×10^5, 9.96×10^5, 10.87×10^5, 11.77×10^5, and 12.68×10^5. The simulation setup is validated with the Ahmed Body's 30° slant angle [3].

This work develops a design assistance system that can be implemented into car side silhouette design tools to predict the drag coefficient of a specified silhouette. This activity is generally executed through two methods: wind tunnel testing and computational fluid dynamics (CFD) simulations. Owing to the substantial processing expense associated with these two methodologies, their application during the silhouette conceptual design phase in real time is impracticable. This paper develops a mathematical methodology for estimating the drag coefficient of a specific profile. Initially, the requisite quantity of silhouettes is produced by a generative design technique (silhouette sampling) to ensure their uniform distribution within the silhouette design space. Each profile is subsequently evaluated by computational fluid dynamics simulations, yielding their respective drag coefficients (CDs). A training dataset is constructed using silhouette shapes and their corresponding CD, culminating in a mathematical model that estimates the drag coefficient through principal component analysis (PCA) and subsequent regression or neural network techniques. The three processes are reiterated until a satisfactory level of a dependable mathematical model is achieved. Ultimately, three generative design test cases are demonstrated based on the mathematical model developed to forecast a specific profile [4].

A tool for optimizing aerodynamic shapes in complicated industrial flows has been developed, utilizing a hybrid method. The optimization technique integrates a stochastic genetic algorithm with a deterministic BFGS hill-climbing method. For each assessment necessitated by the optimizer, the Navier–Stokes equations utilizing the k–ϵ turbulence model are resolved using a commercial CFD software on an unstructured mesh encircling the shape to be optimized. Following numerous validation test cases, the method is effectively employed to optimize the rear of a simplified car model to enhance the computational efficiency of minimizing the drag coefficient [5].

Reducing fuel usage in road cars, for environmental and commercial reasons, is a concern for automobile makers. Thus, enhancing the aerodynamics of vehicle designs, namely minimizing their drag coefficient, emerges as a primary focus for automotive research institutions. Given that 40% of the drag coefficient is influenced by the exterior shape, predominantly in the rear geometry, a numerical optimization approach is proposed to explore creative low-drag automotive designs [6].

Aerodynamic drag is a primary impediment to the acceleration of a solid object in air. When a race car or road vehicle combusts fuel to accelerate, drag force acts in opposition, diminishing speed and consequently impairing fuel economy. Approximately 50 to 60% of total fuel energy is expended solely to counteract this detrimental aerodynamic force. To secure victory in a race, potentially determined by mere fractions of a second, racing automobiles require enhanced acceleration, achievable by minimizing drag force through form optimization for improved streamlining or reduced separation. The minimization of aerodynamic drag has emerged as a primary focus in vehicle aerodynamics. This article focuses on the analysis of aerodynamic drag in racing cars and various drag reduction measures, including rear underbody modifications and the redirection of exhaust gases towards the rear separation zones [7].

Drag reduction in automobiles is observed by the angle of windscreen slant. Drag reduction contributes to the mitigation of emissions. The angle of the windscreen influences the vehicle's height. The windscreen's curvature must be tuned to mitigate the cross-wind effect. The car's windscreen proportions are derived from literary sources and modeled using software. The impact of windscreen inclination on drag is analyzed using ANSYS Fluent. CFD analysis is conducted at an input velocity of 25 m/s, examining the impact of vehicle height on the drag coefficient. The pressure contours in the vehicle's frontal hood are analyzed by altering the inlet air velocity. The hood angle must be tuned to minimize drag. The findings indicate that a 32° back windscreen angle yields the lowest drag coefficient (CD) [8].

With a record-breaking drag coefficient of 0.168 (Cd), The Chery Aero has the lowest recorded coefficient of drag. The lower the coefficient of drag, the more effectively the vehicle will utilize its energy, providing drivers with a greater range and reducing their dependency on electrical charging or refueling when it is necessary [9]. Table 1 shows a list of cars with a low coefficient of drag value.

Table 1. List of cars with low coefficient of drag.

Car Model	Manufacturer Name	Coefficient of Drag
Chery Aero	Chery	0.168
Light Year 0	Valmet Automotive	0.175
Xiaomi SU7	Xiaomi Auto	0.195
Lucid Air	Lucid Group, Inc.	0.197
Mercedes-Benz EQS	Mercedes-Benz	0.200
Tatra T77A	Tatra	0.212
Porsche Taycan	Porsche AG	0.220
Mercedes A-Class Saloon	Mercedes-Benz	0.220
Tesla Model 3	Tesla, Inc.	0.230

According to NASA–Glenn Research Center, the drag coefficient is a quantity used by aerodynamicists to simulate the intricate relationships between drag and shape, tilt, and various flow conditions. This equation is essentially a rewrite of the drag equation in which

we solve for the drag coefficient using the other variables. The drag coefficient Cd is equal to the drag D divided by the following formula: density r times half the velocity V squared times the reference area A. Figure 1 shows the different shapes and their corresponding coefficient of drag [10].

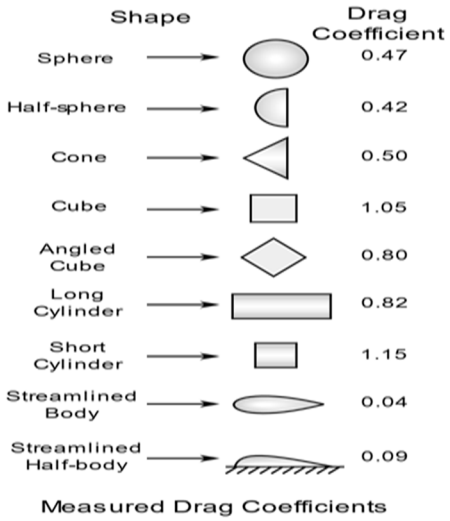


Figure 1. Shapes and their corresponding coefficient of drag [10].

The drag force determined for the car's initial design is 450 N (Figure 2), whereas it is approximately 408 N with the modified design (Figure 3). The shape of the car's bonnet alters, resulting in a 42 N force reduction. Figures 4 and 5 depict pressure contours for the initial and updated designs. The pressure obtained for the initial design is 520 Pa at the frontal end and 169 Pa at the rear end, while the pressure obtained for the modified design is 530 Pa at the front and 291 Pa at the back [3].

The difference between front and rear side pressure in Figure 4 is 351 Pa, while in Figure 5 it is 239 Pa. The pressure difference produced in the first design is significant when compared to the second design of the car. The pressure differential creates a resistive force that causes the car to move. Reducing this pressure difference results in reduced resistive force, which contributes to improved vehicle performance. As a result, we may conclude that the improved car design will have superior performance parameters to the original design. Figures 6 and 7 show velocity curves for the car's initial and updated designs, respectively. The highest air speed attained in each scenario is located atop the vehicle. For Figures 6 and 7, the velocity above the hood is 52 and 56 m/s, respectively [1].

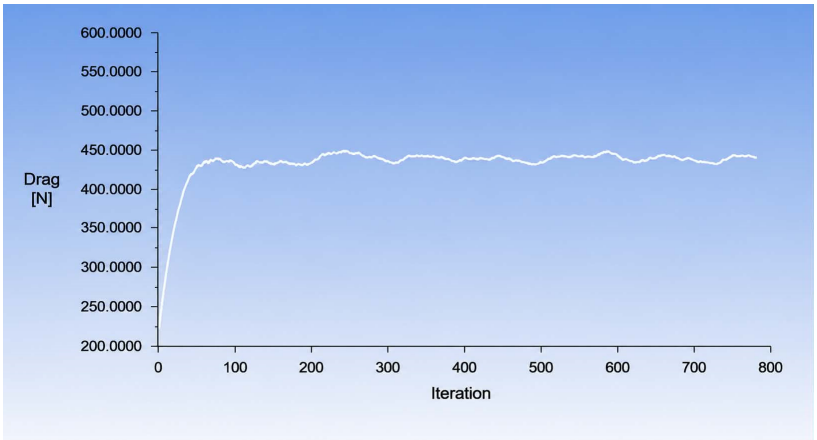


Figure 2. Drag force vs. iteration of initial design.

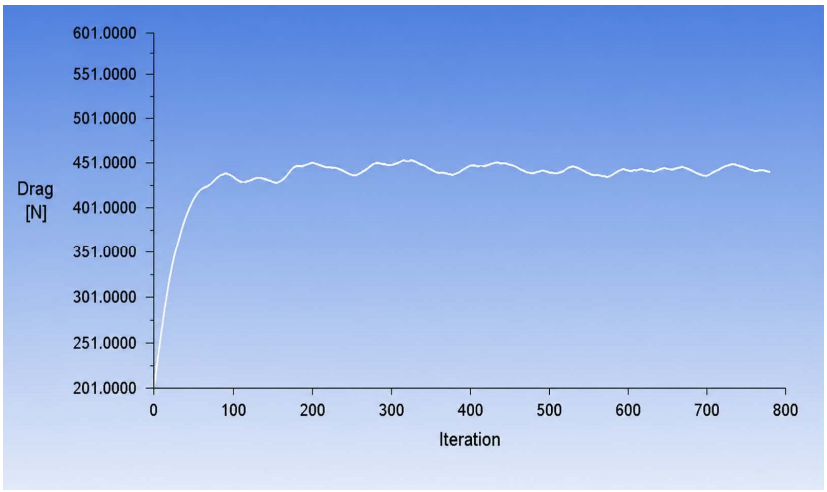


Figure 3. Drag force vs. iteration of modified design.

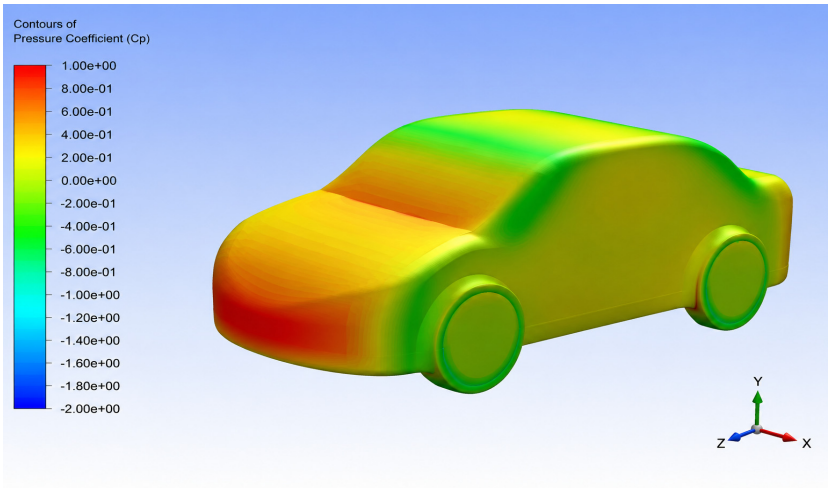


Figure 4. Pressure contours of initial design.

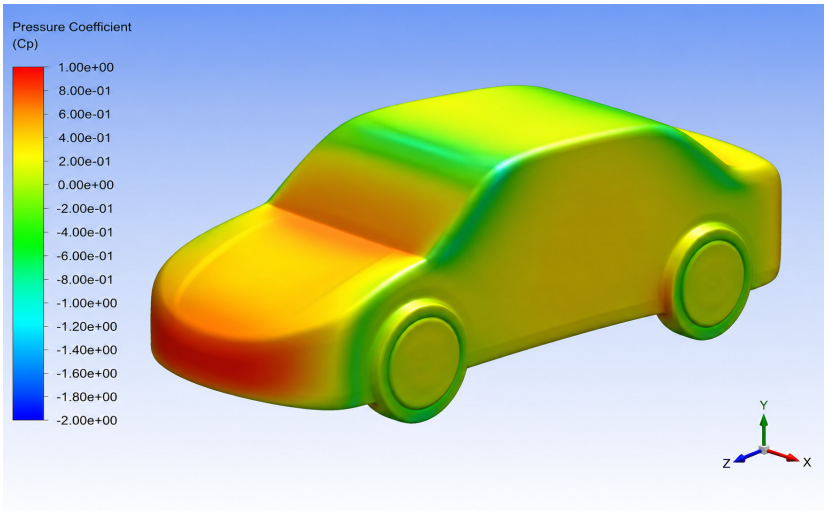


Figure 5. Pressure contours of modified design.

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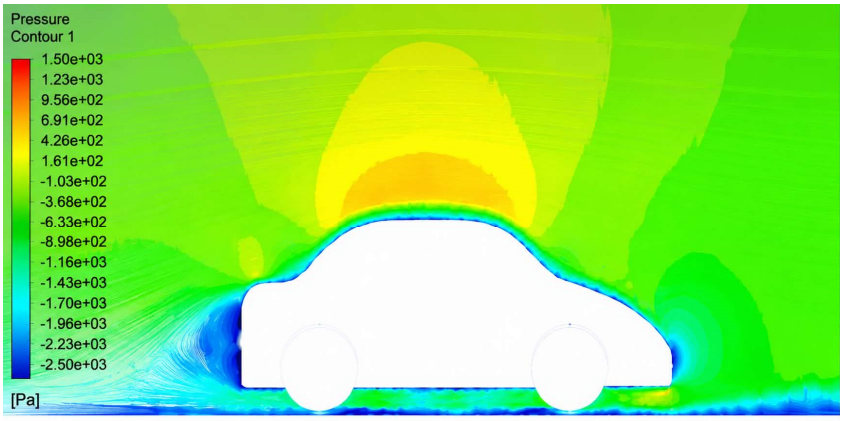


Figure 6. Velocity profile of initial design.

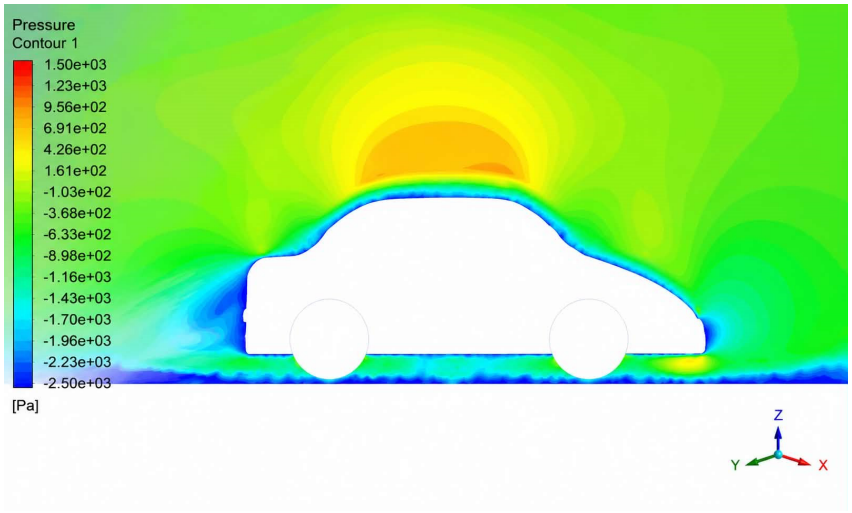


Figure 7. Velocity profile of modified design.

The shape and drag of bodies with low stiffness may alter during airflow. This problem applies to bodies such as flags, bands, banners, flapping sails, blades, and cables that vibrate due to the flow. This paper addresses laboratory measurements conducted to highlight the aerodynamic drag coefficient of a flag. The laboratory tests were conducted in an aerodynamic tunnel at various airflow velocities for flags with various dimensions constructed with textiles of varying roughness and stiffness. Rising airflow velocity lowers the drag coefficient value. Higher roughness materials have a higher drag coefficient. Furthermore, the edge type and fabric stiffness also affect the drag coefficient value [11].

3. Methodology

3.1. Phase 1: Materials to Be Used for Automobile Front-End Exterior Frame

Aluminum–magnesium (Al-Mg) alloys (5000 series) are ideal for the automobile sector due to their high strength-to-weight ratio, corrosion resistance, and weldability. However, when these alloys are processed at room temperature, their formability and surface quality suffer. Several investigations have been undertaken on these alloys to enable their application as car body materials. Recent data reveal that the formability of these alloys increases at temperatures ranging from 200 to 300 °C, resulting in improved surface quality in the final product. The goal of this paper is to evaluate and discuss recent advances in the heated forming of Al-Mg alloys [12].

Shangang Steel Group Company says that steel sheets for car bodies have qualities including plasticity, elasticity, and work hardening. Hot-rolled mild steel sheets are not

very hard, have a low carbon content, and are not very strong. Cold-rolled mild steel sheets are better for making things like mudguards, flooring, trunk hinges, and bumpers, for example. Hot-rolled mild steel sheets are used for outer panels, shells of parts, roof panels, trunk lids, engine hoods, inner and outer panels of doors, bumpers, mudguards, and other things.

High-density polyethylene (HDPE) is a versatile thermoplastic known for its high strength-to-weight ratio, chemical resistance, low moisture absorption, durability, and recyclability. While it is widely used in the automotive industry, particularly for components that benefit from its lightweight properties and ease of molding, it is not the most used material for the overall car exterior body frame (which typically refers to the structural chassis or body-in-white, often made of steel or aluminum). Instead, HDPE finds prominent application in non-structural exterior elements like bumpers, fenders, air dams, wheel arch liners, protective covers, and trims. These parts leverage HDPE's ability to reduce vehicle weight by up to 70% when combined with other materials, leading to lower fuel consumption and emissions [13].

Ultra-high-molecular-weight polyethylene (UHMWPE) is a high-performance thermoplastic characterized by its exceptional strength-to-weight ratio, low friction coefficient, high impact resistance, and excellent chemical and wear resistance. While UHMWPE is not a primary material for automotive exterior body frames (i.e., the structural chassis or body-in-white, typically dominated by steel and aluminum), it is increasingly explored for specific exterior components due to its unique properties. These include bumpers, fenders, underbody shields, and aerodynamic features like the car nose designs featured in our research, where low surface roughness and moldability can reduce drag [14].

Using information in Kurtz S.M. UHMWPE *Biomaterials Handbook*, Table 2 shows the average properties of ultra-high-molecular-weight polyethylene (UHMWPE) and high-density polyethylene for comparison (HDPE) [15].

Table 2. Properties of UHMWPE and HDPE [15].

Property	**UHMWPE**	**HDPE**
Melting Temperature (°C)	132–138	130–137
Molecular Weight (10^6 g/mol)	3.5–7.5	0.05–0.25
Specific Gravity	0.925–0.945	0.952–0.965
Poisson's Ratio	0.46	0.40
Modulus of Elasticity (Gpa)	0.5–0.8	0.4–4.0
Tensile Ultimate Strength (Mpa)	39–48	22–31
Tensile Yield Strength (Mpa)	21–28	26–33
Tensile Ultimate Elongation (%)	350–525	10–1200
Degree of Crystallinity	39–75	60–80
Impact Strength (J/m of notch)	1070	21–214
Wear Rate ($mm^3/10^6$ cycles)	80–100	380–400

Table 3 shows a comparison of the compressive strength and impact resistance of UHMWPE versus some common types of steel. It shows that UHMWPE has a low amount of compressive strength at 32 MPa but has a high impact resistance above the others with a value of 140 J/m.

Table 3. Comparison of the compressive strength and impact resistance of UHMWPE and some common types of steel [16].

Material	Compressive Strength (Mpa)	Impact Resistance (J/m)
UHMWPE	32	140
Carbon Steel (A36)	250	27
Stainless Steel (316L)	220	40
High-Strength Steel (A514)	690	40

Table 4 shows the comparison of the coefficient of friction of UHMWPE versus some common types of steel. It shows that UHMWPE has a low coefficient of friction at only 0.05.

Table 4. Comparison of the friction coefficient and chemical resistance of UHMWPE and some common types of steel [16].

Material	Friction Coefficient	Chemical Resistance
UHMWPE	0.05	Excellent
Carbon Steel (A36)	0.6	Poor
Stainless Steel (316L)	0.4	Good
High-Strength Steel (A514)	0.6	Poor

3.2. Phase 2: Design Development of a Car Nose

The developmental research design will be utilized by the researcher conducting this investigation. Establishing an empirical foundation for the development of instructional and non-instructional goods and tools, as well as new or improved models that regulate development, is the goal of a research design that is considered to be developmental in nature. The type of car that will be used is a sedan. All cars will have the same tail but have different front structures. The figures below also shows different figures able to generate a lower coefficient of drag, which will reduce drag force during car acceleration. Figure 8 shows the triangular nose design. Figure 9 shows the sharp edge nose design. Figure 10 shows streamline nose design. Figure 11 shows the flat hood nose design. Figure 12 shows the vented hood nose design. And Figure 13 shows the circular or round nose design. The proposed car nose design was developed through Auto-CAD.

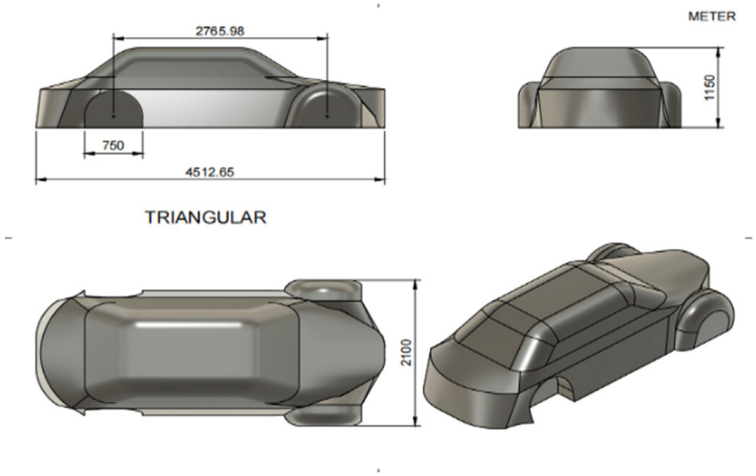


Figure 8. Triangular Nose Design.

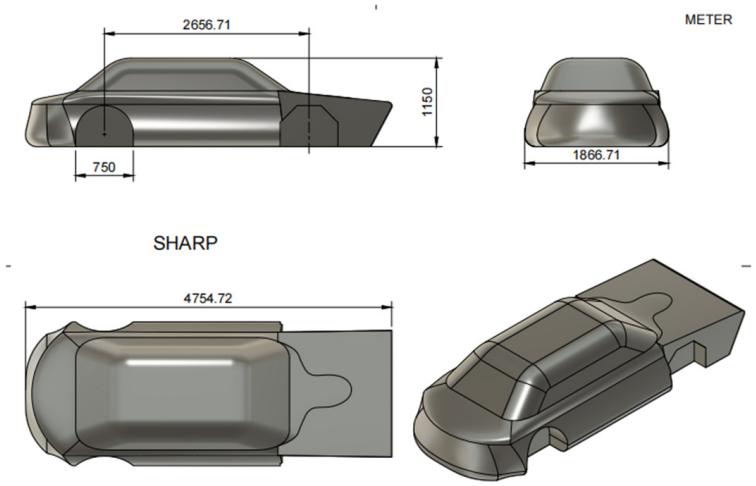


Figure 9. Sharp Edge Nose Design.

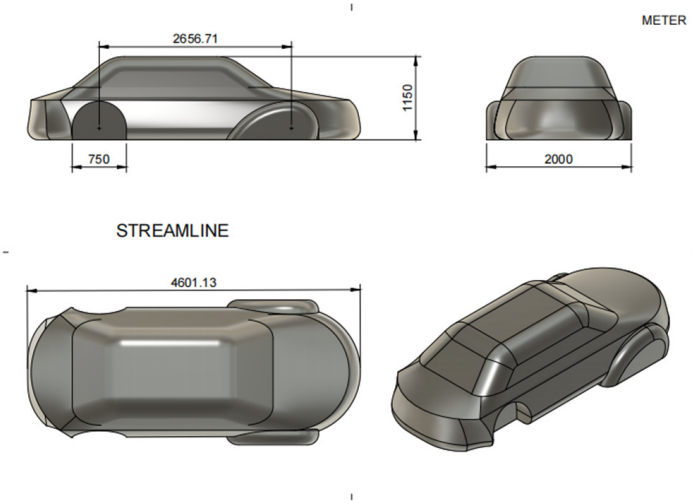


Figure 10. Streamline Nose Design.

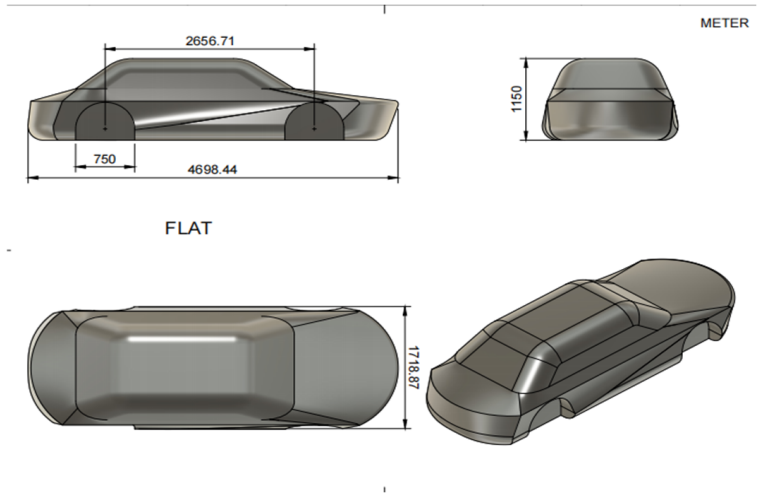


Figure 11. Flat Hood Nose Design.

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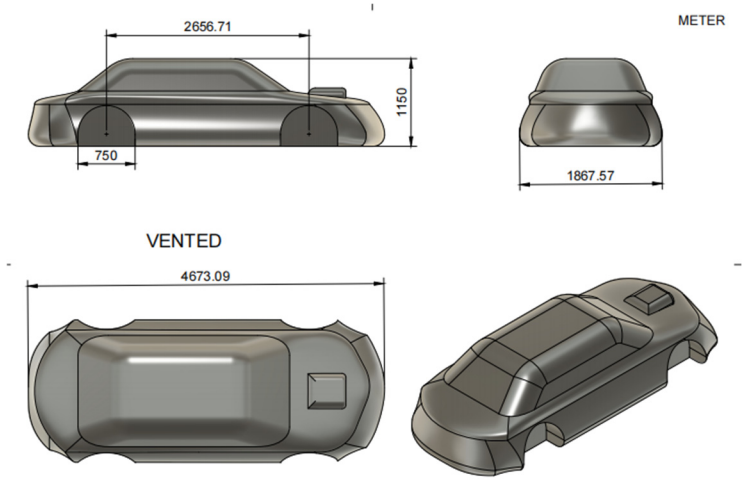


Figure 12. Vented Hood Nose Design.

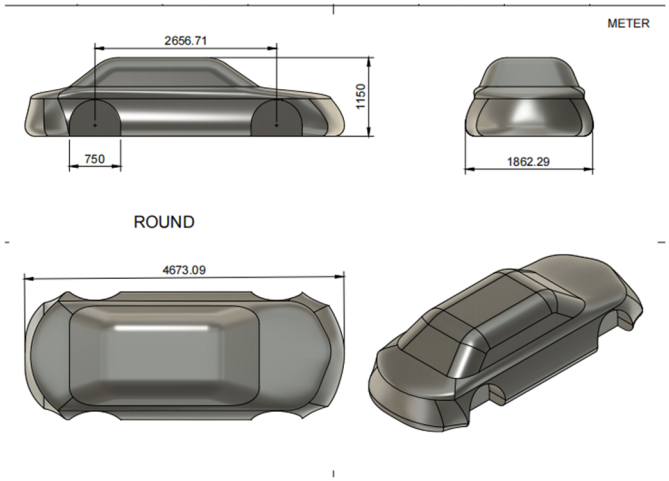


Figure 13. Round or Circular Nose Design.

3.3. Phase 3: Simulation of Air Tunnel Test to Determine Coefficient of Drag Using Computational Fluid Dynamics

To verify if the proposed design and material used by the researcher are reliable, the design will undergo a simulation process using computational fluid dynamics. This simulation process is almost the same in terms of actual testing, without involving high costs. Through this, the researcher will be able to prove that the concept is valid. Through simulation, different bumper designs will undergo aerodynamics testing to measure their corresponding coefficient of drag value, which contributes to the amount of drag force that affects the vehicle when accelerating; the higher the drag force, the more power the vehicle will need, which corresponds in parallel to fuel consumption.

Figure 14 shows the process flow of the simulation that will be conducted for the aerodynamics testing of the proposed car nose assembly. It will start with designing models of different geometrical car nose designs through Computer Aided Design. Then, the UHMWPE, HDPE, aluminum sheet and steel sheet will be attached to the car hood, bumper and fender, followed by its properties being specified. Mesh generation will be conducted for the different car nose designs to see if the assembled car's main body parts in the front area correspond to the desired shape. The next step will be CFD implementation: this process will include debugging, since the input design and parameters are all new; fine-tuning of the simulation process; and then, when precise and accurate data are acquired, a simulation run for an air tunnel test will be conducted through different speed and scenario

trials. Post processing, visualization and analysis of the data will be executed to determine what aspect of the proposed system can be improved. And lastly, since this study is a quantitative, all the obtained data will be saved for future reference.

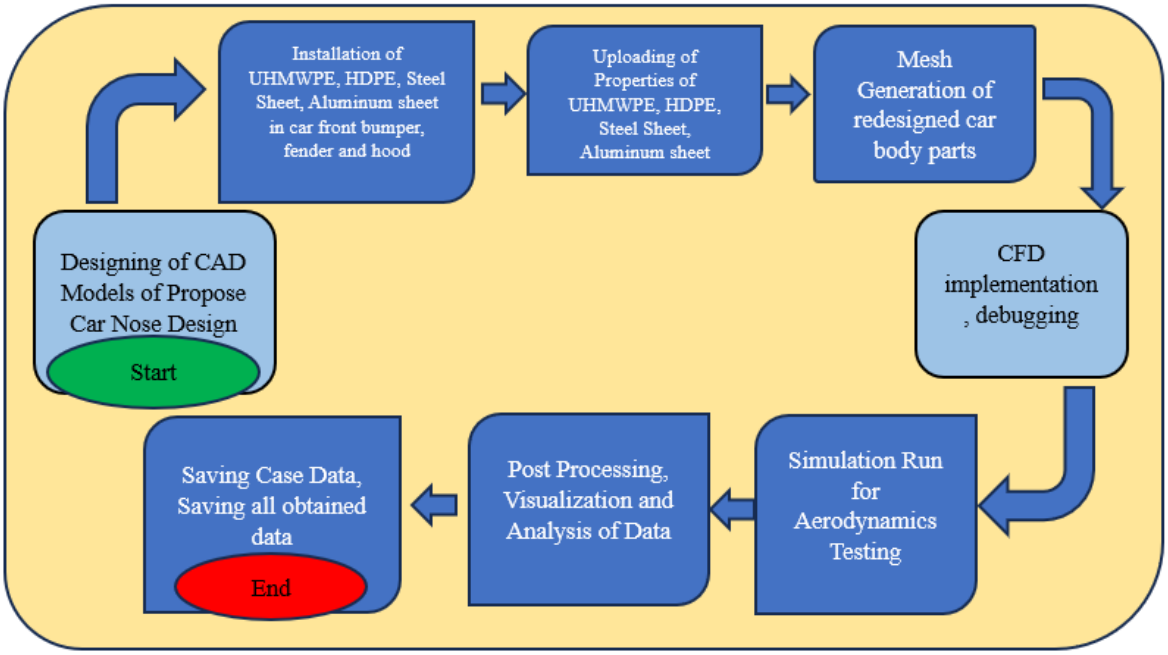


Figure 14. Process flow of the simulation.

Table 5 shows the CFD analysis comparing the thermal behavior of UHMWPE, HDPE, steel sheet, and aluminum sheet under identical airflow conditions. The models utilized high-quality honeycomb meshes and consistent turbulence parameters to ensure reliable and comparable results. Among the materials studied, aluminum is expected to exhibit the highest heat transfer performance due to its superior thermal conductivity, while HDPE is likely to retain heat longer because of its low thermal conductivity and high specific heat capacity. But the UHMWPE is expected to have high impact strength despite having the lowest density compared to the other four materials. The mesh quality and turbulence settings adopted in the simulations encourage confidence in the accuracy and stability of the numerical results obtained.

Table 5. Mesh statistics and boundary conditions.

Parameters	**Materials**			
	UHMWPE	**HDPE**	**Steel Sheet**	**Aluminum Sheet**
Material Property Inputs	Density—930 kg/m^3 Cp (Specific Heat)—1850 J/(kg K) Thermal Conductivity—104 W/(m K)	Density—970 kg/m^3 Cp (Specific Heat)—2500 J/(kg K) Thermal Conductivity—0.55 W/(m K)	Density—7850 kg/m^3 Cp (Specific Heat)—500 J/(kg K) Thermal Conductivity—50 W/(m K)	Density—2719 kg/m^3 Cp (Specific Heat)—871 J/(kg K) Thermal Conductivity—202.4 W/(m K)
Number of Nodes	6,345,235	1,177,526	51,176	51,176
Mesh Quality	Solid, Tetcel, Min Orthogonal Quality—0.15436595	Solid, Tetcel, Min Orthogonal Quality—0.15436595	Solid, Tetcel, Min Orthogonal Quality—0.087542862	Solid, Tetcel, Min Orthogonal Quality—0.087542862
Mesh Type	Honeycomb	Honeycomb	Honeycomb	Honeycomb

Table 5. *Cont.*

Parameters	Materials			
	UHMWPE	**HDPE**	**Steel Sheet**	**Aluminum Sheet**
Turbulent Intensity [%]	5	5	5	5
Turbulent Viscosity Ratio	10	10	10	10

4. Results and Discussions

The provided data details the coefficient of drag (CD), drag force, maximum air velocity, and pressure contour for various nose designs (vented hood, streamline, sharp edge, pointed/triangular, flat hood, and round) made from different materials (aluminum, HDPE, steel sheet, and UHMWPE). These were calculated using ANSYS CFD with a simulated air tunnel test at 120 KPH (33.33 m/s). Below is a summary of the results, organized by nose design and material, with key trends highlighted.

Summary by Nose Design and Material

1. Vented Hood Nose Design:
    - Aluminum: CD = 0.5484037, drag force = 665.556 N, max velocity = 61.79 m/s (222.444 KPH), pressure = 792.8 Pa;
    - HDPE: CD = 0.5324708, drag force = 648.7573 N, max velocity = 61.54 m/s (221.544 KPH), pressure = 792 Pa;
    - Steel Sheet: CD = 0.5543499, drag force = 672.7724 N, max velocity = 61.71 m/s (222.156 KPH), pressure = 791.6 Pa;
    - UHMWPE: CD = 0.5516444, drag force = 669.489 N, max velocity = 61.54 m/s (221.544 KPH), pressure = 792 Pa;
    - Trend: Steel sheet has the highest CD and drag force, while HDPE has the lowest. Maximum velocities are similar (~61.5–61.79 m/s), and pressures are close (~791.6–792.8 Pa).
2. Streamline Nose Design:
    - Aluminum: CD = 0.4484819, drag force = 572.7766 N, max velocity = 51.49 m/s (185.364 KPH), pressure = 740.2 Pa;
    - HDPE: CD = 0.4484873, drag force = 572.7835 N, max velocity = 51.49 m/s (185.364 KPH), pressure = 740.2 Pa;
    - Steel Sheet: CD = 0.4484528, drag force = 572.7394 N, max velocity = 51.48 m/s (185.328 KPH), pressure = 791.6 Pa;
    - UHMWPE: CD = 0.448453, drag force = 572.7396 N, max velocity = 51.48 m/s (185.328 KPH), pressure = 740.2 Pa;
    - Trend: CD and drag force are nearly identical across materials (~0.448, ~572.74 N). Steel has a higher pressure (791.6 Pa) compared to others (740.2 Pa).
3. Sharp Edge Nose Design:
    - Aluminum: CD = 0.6684503, drag force = 814.4334 N, max velocity = 64.49 m/s (232.164 KPH), pressure = 803.3 Pa;
    - HDPE: CD = 0.6678006, drag force = 813.6419 N, max velocity = 64.49 m/s (232.164 KPH), pressure = 740.2 Pa;
    - Steel Sheet: CD = 0.6676582, drag force = 813.4684 N, max velocity = 64.49 m/s (232.164 KPH), pressure = 791.6 Pa;

- UHMWPE: CD = 0.6676554, drag force = 813.465 N, max velocity = 64.49 m/s (232.164 KPH), pressure = 803.1 Pa;
- Trend: Aluminum has the highest CD and drag force, though differences are minor. All have the same max velocity (64.49 m/s). pressure varies, with aluminum and UHMWPE at ~803 Pa, steel at 791.6 Pa, and HDPE lower at 740.2 Pa.

4. Pointed/Triangular Nose Design:
   - Aluminum: CD = 0.4594982, drag force = 621.4773 N, max velocity = 48.19 m/s (173.484 KPH), pressure = 729 Pa;
   - HDPE: CD = 0.4579509, drag force = 619.3846 N, max velocity = 48.19 m/s (173.484 KPH), pressure = 740.2 Pa;
   - Steel Sheet: CD = 0.4579545, drag force = 619.3894 N, max velocity = 48.40 m/s (174.240 KPH), pressure = 728.9 Pa;
   - UHMWPE: CD = 0.4579544, drag force = 619.3893 N, max velocity = 48.20 m/s (173.520 KPH), pressure = 729 Pa;
   - Trend: Aluminum has the highest CD and drag force, but differences are small. Max velocities are similar (~48.19–48.40 m/s). Pressure is the lowest for aluminum and steel (~729 Pa) and slightly higher for HDPE (740.2 Pa).
5. Flat Hood Nose Design:
   - Aluminum: CD = 0.3717129, drag force = 430.9955 N, max velocity = 52.82 m/s (190 KPH), pressure = 744.6 Pa;
   - HDPE: CD = 0.3717296, drag force = 431.0148 N, max velocity = 52.87 m/s (190.332 KPH), pressure = 744.6 Pa;
   - Steel Sheet: CD = 0.3717295, drag force = 431.0146 N, max velocity = 74.46 m/s (268.056 KPH), pressure = 744.6 Pa;
   - UHMWPE: CD = 0. 0.3406517, drag force = 394.9804 N, max velocity = 52.17 m/s (187.812 KPH), pressure = 741.5 Pa;
   - Trend: HDPE has the lowest CD and drag force. Steel has a significantly higher max velocity (74.46 m/s) compared to others (~52–53 m/s). Pressures are similar (~741.5–744.6 Pa).
6. Round Nose Design:
   - Aluminum: CD = 0.4014669, drag force = 487.219 N, max velocity = 51.01 m/s (183.636 KPH), pressure = 718.4 Pa;
   - HDPE: CD = 0.4020199, drag force = 487.890 N, max velocity = 51.01 m/s (183.636 KPH), pressure = 872.5 Pa;
   - Steel Sheet: CD = 0.4014938, drag force = 487.252 N, max velocity = 51.00 m/s (183.600 KPH), pressure = 718.4 Pa;
   - UHMWPE: CD = 0.4011756, drag force = 486.8655 N, max velocity = 55.48 m/s (199.728 KPH), pressure = 718.4 Pa;
   - Trend: CD and drag force are similar across materials (~0.401–0.402, ~487 N). UHMWPE has a higher max velocity (55.48 m/s). HDPE has a higher pressure (872.5 Pa) compared to others (718.4 Pa).

Key Observations

- Coefficient of Drag (CD):
  - Lowest CD: Flat hood nose design with HDPE (0.3406517).
  - Highest CD: Sharp edge nose design with aluminum (0.6684503).
  - Across materials, sharp edge designs consistently have the highest Cd (~0.667–0.668), while flat hood designs have the lowest (~0.340–0.372).
- Drag Force:

- Lowest: Flat hood nose design with HDPE (394.9804 N).
- Highest: Sharp edge nose design with aluminum (814.4334 N).
- Drag force follows Cd trends, as expected, since drag force is proportional to CD.

- Maximum Air Velocity:
  - Lowest: Pointed/triangular nose designs (~48.19–48.40 m/s).
  - Highest: Flat hood nose design with steel sheet (74.46 m/s).
  - Sharp edge designs consistently show the highest max velocity (~64.49 m/s) across materials.
- Pressure Contour:
  - Lowest: Round nose design with aluminum, steel, and UHMWPE (718.4 Pa).
  - Highest: Round nose design with HDPE (872.5 Pa).
  - Pressures vary significantly, with sharp edge and vented hood designs generally showing higher values (~790–803 Pa).
- Material Impact:
  - Differences in CD and drag force across materials for the same nose design are generally small, suggesting material choice has a limited impact on aerodynamic performance in these simulations.
  - Notable exceptions: The HDPE flat hood has a significantly lower CD (0.3406517) compared to other materials (~0.3717), and the steel sheet flat hood has a much higher max velocity (74.46 m/s).

Selection of the two best nose designs with the lowest value of coefficient of drag and drag force

Figure 15 shows a graph of results for the coefficient of drag of aluminum sheet, steel sheet, HDPE and UHMWPE materials with respect to their different noses designs. The CFD was conducted to determine the nose design with lowest value for coefficient of drag and drag force with respect to the material that it utilized. We selected the two best nose designs according to its lowest coefficient of drag and drag force. The results show that the flat hood and round nose design with UHMWPE produced the lowest value of coefficient of drag and drag force. The flat hood nose design with UHMWPE produced a drag coefficient of 0.3406517 and 394.9804 Newtons of drag force, and the round nose design with UHMWPE produced a drag coefficient of 0.4011756 and 486.8655 Newtons of drag force.

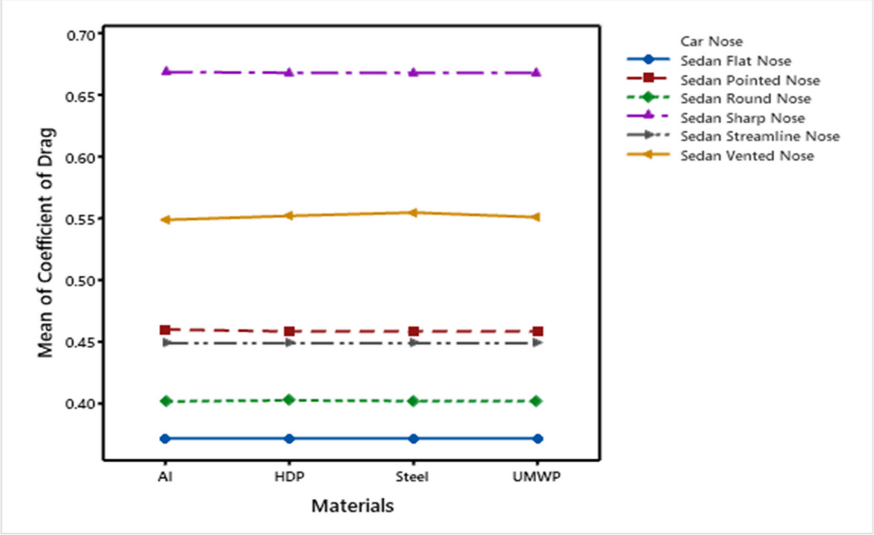


Figure 15. Line graph of the coefficient of drag of aluminum sheet, steel sheet, HDPE and UHMWPE with respect to different nose designs.

5. Conclusions

In wind tunnel testing, the material composition of a vehicle's exterior, particularly the front-end or nose assembly, has a considerable influence on aerodynamic performance, as measured by the coefficient of drag (CD) and drag force (FD). These characteristics are crucial for increasing vehicle fuel efficiency and lowering emissions because drag accounts for 50–70% of total resistance at highway speeds. Material selection influences surface properties such as friction coefficient and smoothness, which in turn influence airflow behavior, boundary layer dynamics, and flow separation. Ultra-high-molecular-weight polyethylene (UHMWPE) has a low coefficient of friction ($\mu \approx 0.05$) and promotes smoother airflow, delaying separation compared to traditional materials like steel, aluminum, or even high-density polyethylene (HDPE).

Lower dimensions in the frontal area resulted in a lower value of coefficient of drag. A smaller frontal area reduces the coefficient of drag because it decreases the surface area exposed to oncoming airflow, leading to less air resistance. The coefficient of drag (CD) quantifies how aerodynamic an object is, and a smaller frontal area minimizes the force of air pushing against the object, lowering the CD. For example, streamlined shapes with smaller cross-sections, like a sleek car or a tapered projectile, encounter less drag than bulkier objects with larger frontal areas. In this study the flat hood and round nose designs have a smaller frontal area dimensions. And as a result, a lower coefficient of drag value is generated.

Drag comprises pressure drag (from shape-induced pressure differences) and skin friction drag (from surface shear stresses). Skin friction drag, though typically 10–20% of total drag for sedans, is directly influenced by the material's surface roughness and coefficient of friction. A lower friction coefficient reduces shear stress ($\tau_w=\mu\ \partial u/\partial y$, where μ is dynamic viscosity and $\partial u/\partial y$ is the velocity gradient at the surface), promoting laminar flow and delaying the transition to turbulent flow, which can increase drag.

A triangle or pointed nose design in an air tunnel test can yield a lower velocity in velocity streamline analysis due to its streamlined shape, which lowers turbulence and permits smoother airflow, hence lowering local airspeed around the nose. However, it may not result in a decreased coefficient of drag (CD) because drag is determined by more than simply nose shape, including total body geometry, surface roughness, and downstream flow separation. While a pointed nose decreases frontal pressure drag, it may not maximize other drag components like skin friction or induced drag, particularly if the rear design or surface features produce flow separation or turbulence, resulting in a larger CD than expected.

Author Contributions: Conceptualization: J.C.P.B.; Data curation: J.C.P.B.; Formal analysis: J.P.H.; Funding acquisition: J.P.H.; Investigation: J.C.P.B.; Methodology: J.C.P.B.; Project administration: J.C.P.B.; Resources: J.C.P.B.; Software: J.C.P.B.; Supervision: J.P.H.; Validation: J.P.H.; Visualization: J.P.H.; Writing—original draft: J.C.P.B.; Writing—review and editing: J.C.P.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data used in this research was generated using ANSYS Fluent and Explicit Dynamics.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Badiger, G.; Dindore, A. Design Modification of Car Bonnet to Reduce the Frictional Drag. *Int. Res. J. Eng. Technol. IRJET* **2020**, *7*, 1724–1728.
2. Xu, J.; Han, T.; Zhang, C.; Luo, J. Superlubricating UHMWPE composites with functionalized carbon nanotubes reinforcement applicable to artificial joints. *Tribol. Int.* **2024**, *191*, 109142. [CrossRef]
3. Hoque, M.A.; Rahman, M.S.; Rimi, K.N.; Alif, A.R.; Haque, M.R. Enhancing formula student car performance: Nose shape optimization via adjoint method. *Results Eng.* **2023**, *20*, 101636. [CrossRef]
4. Gunpinar, E.; Coskun, U.C.; Ozsipahi, M.; Gunpinar, S. A Generative Design and Drag Coefficient Prediction System for Sedan Car Side Silhouettes based on Computational Fluid Dynamics. *Comput.-Aided Des.* **2019**, *111*, 65–79. [CrossRef]
5. Muyl, F.; Dumas, L.; Herbert, V. Hybrid method for aerodynamic shape optimization in automotive industry. *Comput. Fluids* **2004**, *33*, 849–858. [CrossRef]
6. Hucho, W.H. (Ed.) *Aerodynamics of Road Vehicles: From Fluid Mechanics to Vehicle Engineering*; Elsevier: Amsterdam, The Netherlands, 2013.
7. Hassan, S.M.R.; Islam, T.; Ali, M.; Islam, M.Q. Numerical Study on Aerodynamic Drag Reduction of Racing Cars. *Procedia Eng.* **2014**, *90*, 308–313. [CrossRef]
8. Vignesh, S.; Gangad, V.S.; Jishnu, V.; Maheswarreddy; Krishna, A.; Mukkamala, Y.S. Windscreen angle and Hood inclination optimization for drag reduction in cars. *Procedia Manuf.* **2019**, *30*, 685–692. [CrossRef]
9. Chery Makes Bold Claims About Latest Ultra-Slippery Concept. Available online: https://www.carexpert.com.au/car-news/chery-makes-bold-claims-about-latest-ultra-slippery-concept (accessed on 1 July 2026).
10. Drag Equation. Available online: https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/drag-equation/ (accessed on 1 July 2026).
11. Wilk, A.; Skuta, M. Laboratory tests of the aerodynamic drag coefficient of the flag as a body with low stiffness. *Task Q.* **2009**, *13*, 5–14.
12. Toros, S.; Ozturk, F.; Kacar, I. Review of warm forming of aluminum–magnesium alloys. *J. Mater. Process. Technol.* **2008**, *207*, 1–12. [CrossRef]
13. Why HDPE Has Changed the Automotive Industry. Available online: https://www.aimplas.net/blog/why-hdpe-has-changed-the-automotive-industry/ (accessed on 1 July 2026).
14. Ticona Engineering Polymers. *GUR UHMWPE for Automotive Components*; Celanese Corporation: Irving, TX, USA, 2022.
15. Kurtz, S.M. *UHMWPE Biomaterials Handbook: Ultra High Molecular Weight Polyethylene in Total Joint Replacement and Medical Devices*, 3rd ed.; Elsevier Inc.: Amsterdam, The Netherlands, 2016; pp. 1–6.
16. UHMWPE vs Steel: 5 Tips Which Material Is Better for Your Application? Available online: https://www.lijiuplastics.com/uhmwpe-vs-steel (accessed on 1 July 2026).

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