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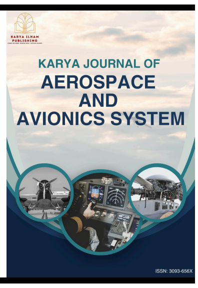

Aerodynamic Design Optimisation of UAV Fuselage to Minimise Drag

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ABSTRACT

Unmanned Aerial Vehicles (UAVs) are increasingly used for tasks such as building inspection, surveillance, aerial photography, and delivering essential supplies to remote areas. Due to their small size, UAVs typically operate at low speeds and require relatively high lift, which makes aerodynamic efficiency critical. While wings are the primary lift-generating surfaces, the fuselage also significantly contributes to the overall drag. Although the fuselage can provide some lift, this benefit is offset by increased drag. This study aims to design and evaluate UAV fuselage configurations that minimize the coefficient of drag. By optimizing fuselage geometry, the goal is to enhance UAV aerodynamic performance and efficiency.

1. Introduction

Unmanned Aerial Vehicles (UAVs), also known as drones, have become increasingly important in both industrial and research applications. Advances in autonomous systems, sensors, and lightweight structures have enabled UAVs to be widely used for aerial photography, infrastructure inspection, environmental monitoring, and the delivery of essential supplies to remote areas [6]. Their increasing popularity has also extended to recreational activities, including personal use and competitive drone racing. These developments highlight the growing demand and rapid progress of UAV technology in modern society.

However, a key challenge in UAV design is improving aerodynamic efficiency, particularly for small platforms that operate at relatively low speeds and require higher lift. Due to their size and limited power capacity, these UAVs must minimize drag to extend flight endurance and reduce energy consumption. While much attention has been given to optimizing wing structures, the fuselage remains a significant yet often overlooked contributor to total drag [9]. Previous studies have shown that propulsion system drag during forward flight, especially in VTOL UAVs, can significantly reduce overall aerodynamic efficiency [3]. Other research has investigated strategies such as riblet surface application to reduce skin friction drag, achieving measurable performance improvements (Drag reduction by riblets on a commercial UAV, 2022).

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Computational simulations have also demonstrated that optimized fuselage shaping can enhance aerodynamic performance across a range of UAV types [11], while fuselage cross-sectional design has been linked to both drag and acoustic emissions in multirotor configurations [10]. This study aims to address these aspects by evaluating the aerodynamic effects of different fuselage shapes, focusing on their influence on drag performance during forward flight.

This paper presents a comparative analysis of three fuselage designs with varying rear-end geometries, developed using SolidWorks and assessed through computational analysis. The main contribution of the study is to identify a fuselage shape that offers lower drag without compromising structural integration. The structure of the paper is as follows: Section 2 outlines the design methodology and computational setup, Section 3 discusses the results and provides detailed comparisons, and Section 4 concludes with key findings and implications for UAV design.

2. Methodology

2.1 Flowchart

To ensure the project progresses systematically and yields reliable results, a structured methodology is essential. Each decision in the design and analysis process plays a critical role in determining the accuracy and validity of the final outcomes. Figure 1 illustrates the overall workflow, beginning with software setup and component modelling, followed by the development of three fuselage designs. These designs are then analysed to evaluate aerodynamic performance. The recorded data is compared and assessed to identify the most efficient fuselage configuration in terms of drag reduction.

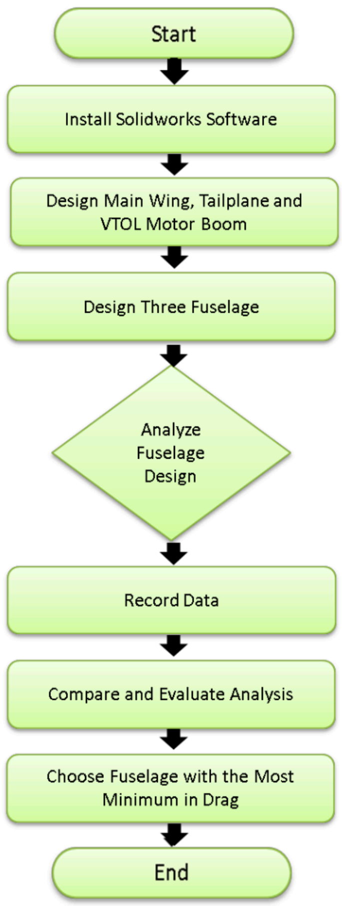

Fig.1. Methodology flow chart

2.2 Factors Affecting Drag Force

Drag is an aerodynamic force that acts opposite to the direction of motion of an aircraft as it moves through the air. It arises primarily from air resistance caused by both pressure differences and air viscosity. To ensure efficient flight, UAVs must be aerodynamically designed to minimize drag. Several factors influence drag, which can be broadly categorized into the shape and size of the object, its velocity, and the properties of the surrounding air [2].

The size of the aircraft directly affects the magnitude of drag it experiences. Form drag is largely determined by the cross-sectional shape of the object, while the planform geometry influences drag for lifting surfaces such as wings. As air flows around the UAV and its components, it splits and eventually rejoins; the smoothness and symmetry of this process affect the magnitude of resistance encountered. A less streamlined shape causes turbulent wake and greater drag, whereas a more aerodynamic shape facilitates smoother flow reattachment and reduced resistance [1].

In Figure 2, the swirling of air around the edges of a flat plate highlights the nature of form drag [5]. Minimizing form drag is a key design consideration, especially for small UAVs operating at low Reynolds numbers. Another critical component is skin friction drag, which is influenced by the surface texture of the aircraft. Smooth surfaces produce less aerodynamic friction than rough ones, making surface finishing an important aspect of drag control. Skin friction is typically included in calculations of the total drag coefficient.

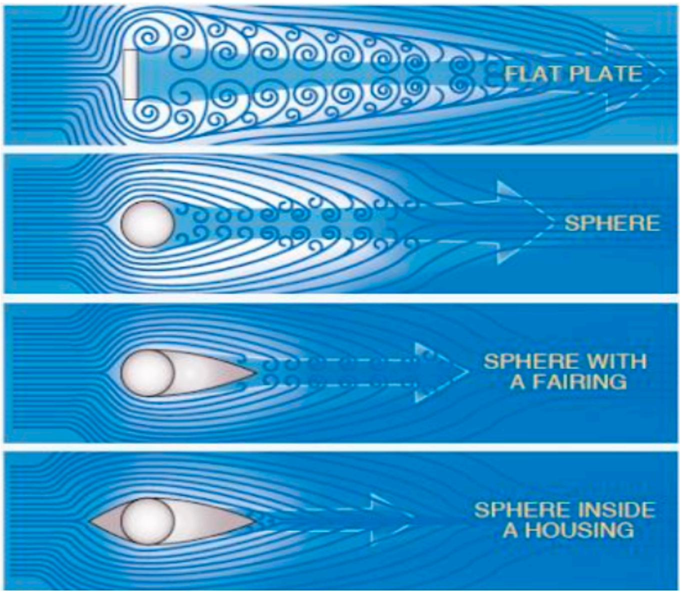

Fig. 2. Form drag [5]

Drag is both an inevitable outcome of flight and a major factor in performance efficiency. It is governed by parameters such as flight speed, wing area, air density, and aircraft configuration. Because each UAV has a unique configuration, performance assessments must account for the combined effect of these variables. The aerodynamic efficiency is often quantified using the drag coefficient (C_D), which is influenced by the reference area and geometry of the aircraft [7,8].

The total drag coefficient is composed of two primary components. The first is the zero-lift drag coefficient (C_{DO}), which accounts for all drag not related to lift production, including form drag, skin friction, and interference drag. The second is induced drag, which arises as a result of lift generation and is more significant at lower speeds and higher angles of attack.

The total drag coefficient (C_D) is expressed by the following formula:

$$C_D = \frac{D}{0.5\,\rho V^2 A} \qquad (1)$$

where:
C_D = Total drag coefficient
D = Total drag force (including induced and parasite components)
ρ = Air density
V= Flight velocity
A= Reference area (typically wing area)

This formula calculates the overall drag acting on the aircraft during flight, combining both induced and parasitic drag effects. As shown in Figure 3, the shape of an object significantly influences its drag characteristics. More streamlined shapes yield lower drag coefficients, indicating improved aerodynamic efficiency.

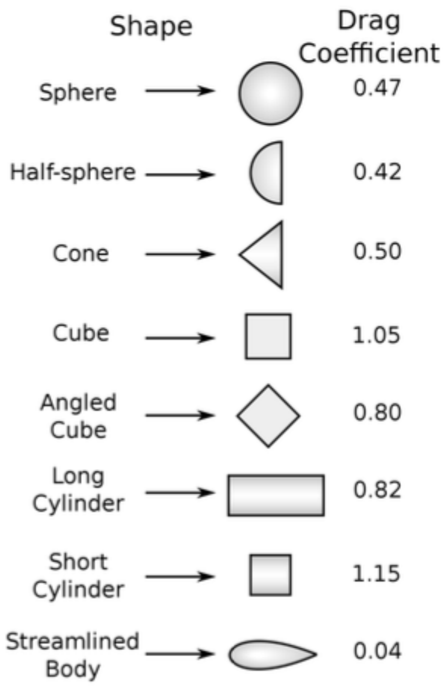

Fig. 3. Coefficient of drag based on shape of objects

2.3 Computational Fuselage

To begin designing a new VTOL UAV, the main wing, tailplane, VTOL motor boom and body, which is the fuselage, will all be designed first. The design was fully created using SolidWorks Software. After designing all the major parts, the assembly of the parts will also be done in SolidWorks. The design of the three fuselages will be created in SolidWorks. Figure 4 illustrates the complete design of a fuselage and other parts in figures 5 – 7. The fuselage was sketched then lofted. Configurations of the fuselage can also be edited.

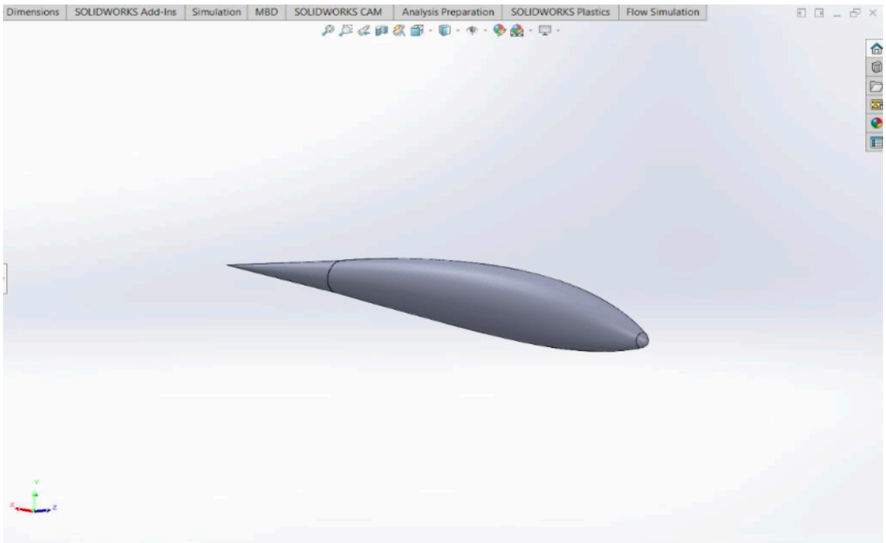

Fig. 4. Design of fuselage

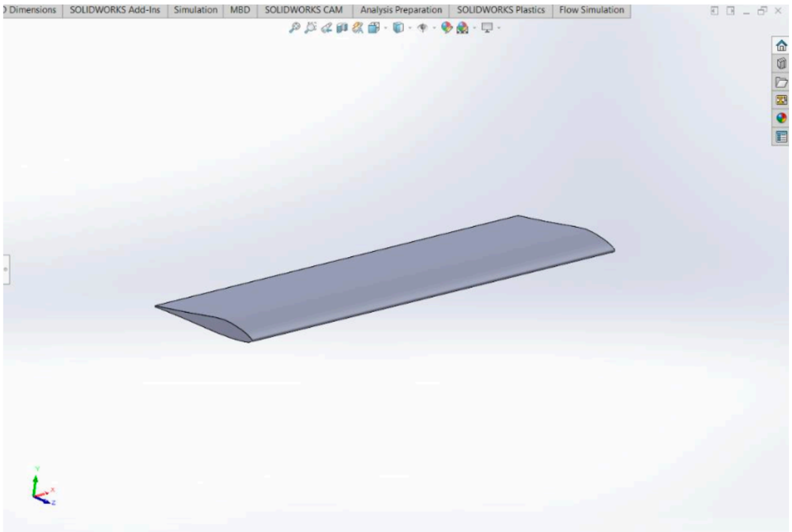

Fig. 5. Design of main wing

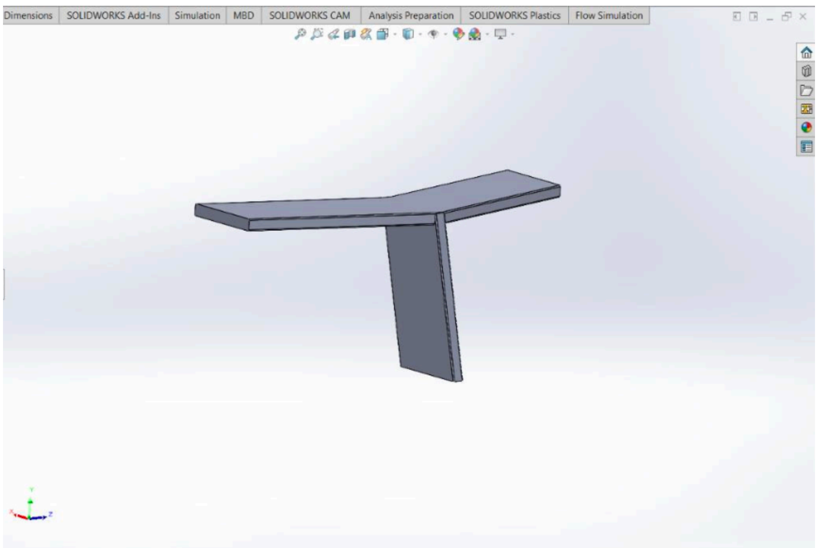

Fig. 6. Design of tailplane

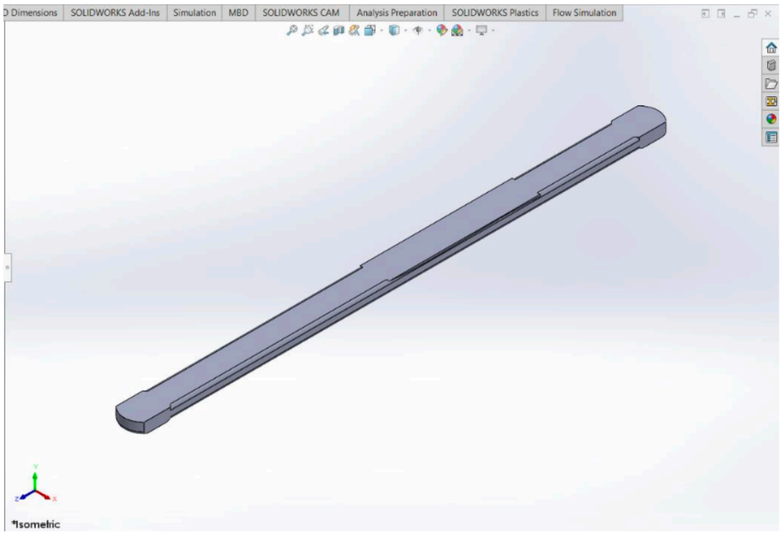

Fig. 7. Design of VTOL motor boom

Then, all parts will be assembled as shown in Figure 8. Hence, a VTOL UAV have been created. Afterwards, the fuselage will be replaced with two other different fuselage designs. The main wing, tailplane and VTOL motor boom will not be replaced. This is to create three new VTOL UAV with different fuselage designs. By this, the objectives can be achieved because the computational analysis will differ only due to the different fuselage designs.

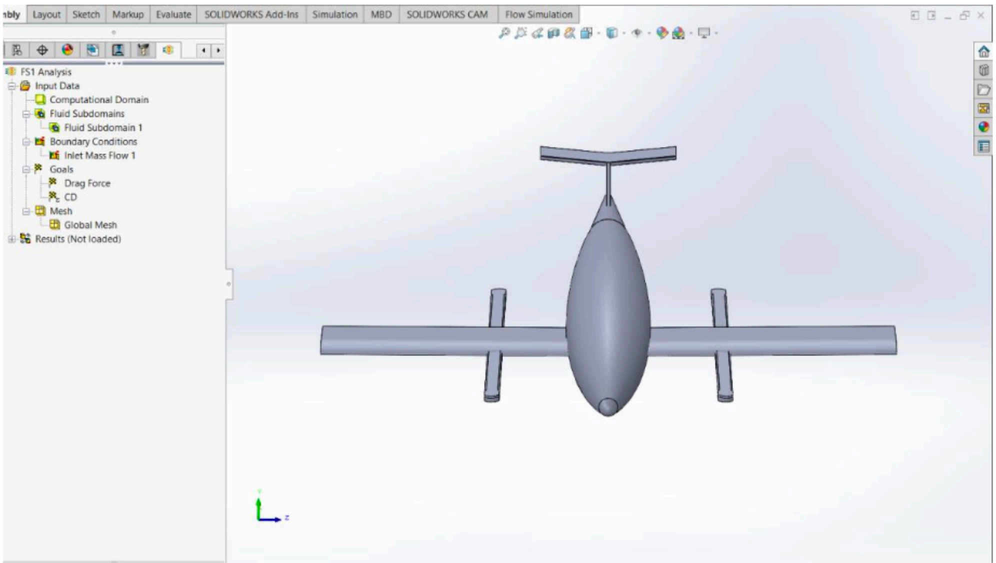

Fig. 8. Assembly of designed parts

3. Results and Discussion

3.1 Configurational Layout

Four major parts of a typical VTOL UAV model are wing, fuselage, tailplane and VTOL motor boom. Mid wing type model has been chosen. Total mass of this model is 960.00g. The left and right wings have been designed same for all models. Features which have been used during designing the wings of this model are as follows:

- Aero foil type: Cambered aero foil
- Root Chord: 15.00cm
- Tip Chord: 15.00cm
- Tip to tip length of both wing: 58.00cm
- Wingspan: 116.00cm
- Area: 0.174$m2$
- Root to Tip Sweep: 0

The tailplane consist horizontal and vertical stabilizer. Total length of horizontal stabilizer is 34.00cm and the root chord is 16cm. Meanwhile total length of the vertical stabilizer is 13.00cm. The tailplane have been designed same for all models and have been placed in a suitable position at the rear side of the fuselage.

The shape of the first designed fuselage is streamlined body. Its nose-to-tail length is 102cm. The isometric of the first VTOL UAV fuselage model is shown in Figure 9.

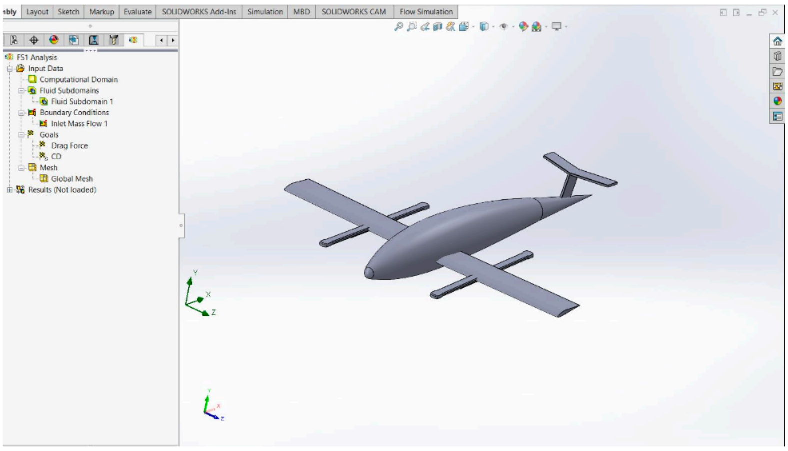

Fig. 9. Isometric view of the first fuselage

The shape of the second designed fuselage is modified from the first fuselage. The rear side of the fuselage is curved downward. Its nose to tail length is 102cm. The isometric of the second UAV fuselage model is shown in Figure 10.

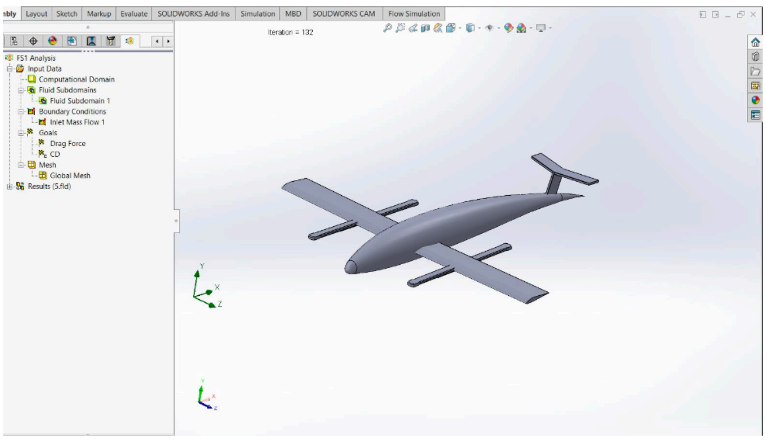

Fig. 10. Isometric view of the second fuselage

The shape of the third designed fuselage is modified from the first fuselage. The rear side of the fuselage is curved upward. Its nose to tail length is 102cm. The isometric of the third UAV fuselage model is shown in figure 11.

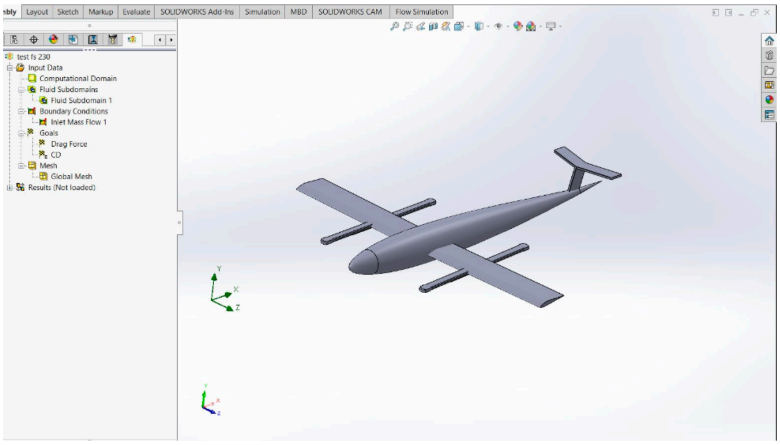

Fig. 11. Isometric view of the third fuselage

3.2 Drag Performance at Different Velocities

To support quantitative comparison between the aerodynamic performance of different fuselage designs, the percentage difference in drag coefficient (C_D) was calculated using Equation (2). This metric enables an objective assessment of how much drag is reduced or increased between any two models at a given angle of attack. The formula is expressed as:

$$C_D\ Percentage\ Difference = \frac{V1-V2}{V1} \times 100 \qquad (2)$$

where V1 and V2 represent the drag coefficients of the baseline and comparison models, respectively. By applying this formula across different velocities and angles of attack, it is possible to quantify aerodynamic improvements resulting from fuselage design modifications. This approach strengthens the interpretation of graphical trends and helps identify the most aerodynamically efficient configuration.

3.2.1 Comparison of drag coefficient of different models at 10m/s

Figure 12 shows the variation of drag coefficient C_D with angle of attack (AOA) for three UAV fuselage models at 10 m/s. Across all models, a parabolic trend is observed, where C_D increases with AOA, typical of aerodynamic behaviour due to increased flow separation and pressure drag at higher angles. Among the designs, Model 2, with a downward-curved rear fuselage, consistently records the highest drag, likely due to early flow separation and greater wake turbulence. Model 1, featuring a straight fuselage, performs moderately. In contrast, Model 3, with an upward-curved rear, shows the lowest drag throughout the AOA range.

The superior performance of Model 3 suggests that the upward curvature helps streamline airflow, delay separation, and reduce wake formation, resulting in improved aerodynamic efficiency. At AOA = 8°, Model 3 reduces drag by approximately 21% compared to Model 2. This highlights the significant impact of fuselage aft-end shaping on drag characteristics and supports the selection of Model 3 as the optimal design for low-speed UAV operations where minimizing drag is essential for enhancing flight performance and endurance.

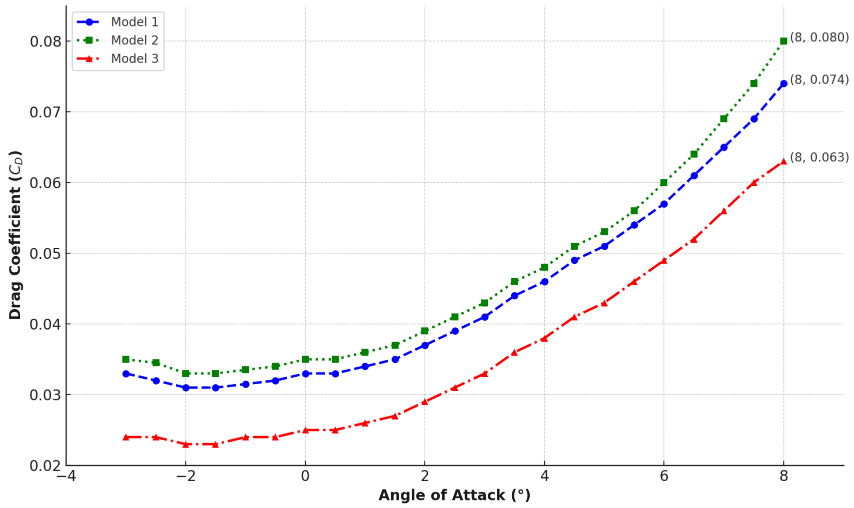

Fig. 12. Comparison of drag coefficient with AOA of different models at 10 m/s

3.2.2 Comparison of drag coefficient of different models at 20m/s

Figure 13 presents the variation of drag coefficient C_D with angle of attack (AOA) for three UAV fuselage models at a flight velocity of 20 m/s. Across all models, a parabolic trend is observed where C_D increases progressively with AOA, consistent with aerodynamic theory due to the growing influence of flow separation and pressure drag at higher angles. Among the three configurations, Model 2 (downward-curved rear) exhibits the highest drag coefficients throughout, indicating increased wake turbulence and adverse pressure gradient effects. Model 1 (straight fuselage) shows intermediate performance, while Model 3 (upward-curved rear) consistently demonstrates the lowest drag, reflecting more streamlined flow behaviour and delayed separation at the aft end.

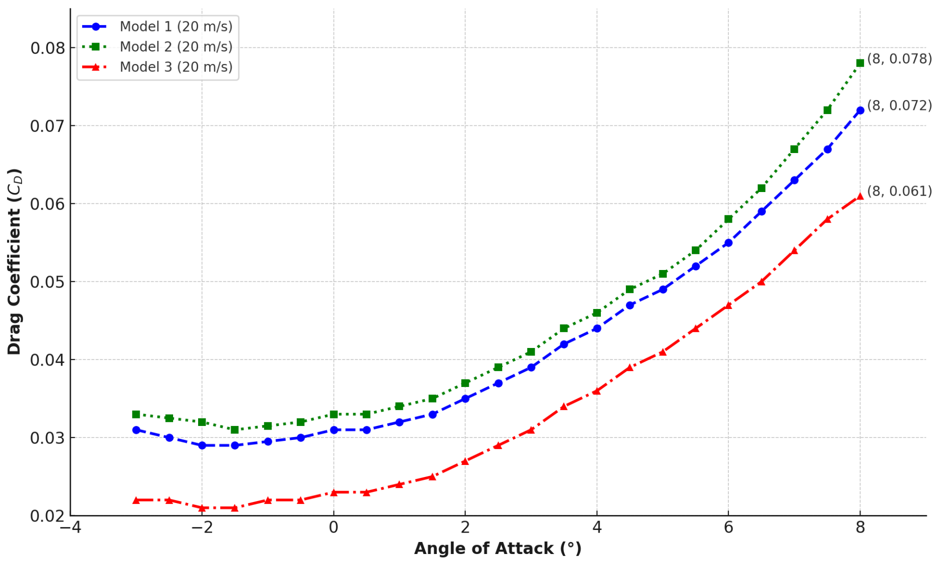

Fig. 13. Comparison of drag coefficient with AOA of different models at 20m/s

At AOA = 8°, the drag coefficients for Model 2, Model 1, and Model 3 are 0.078, 0.072, and 0.061, respectively. This confirms a notable drag reduction of approximately 22% in Model 3 compared to Model 2 at this condition. The results underscore the significant impact of fuselage geometry on aerodynamic performance. Specifically, the upward-curved rear design of Model 3 promotes smoother airflow detachment and reduces overall drag, making it the most efficient design for operations at higher velocities where minimizing drag is critical to enhancing endurance and power efficiency.

Figure 14 presents the drag coefficient C_D variation with angle of attack (AOA) for Model 3, evaluated at two different flight speeds: 10 m/s and 20 m/s. Model 3 was selected for this focused comparison because earlier analyses showed it consistently produced the lowest drag coefficient among the three fuselage designs, indicating superior aerodynamic efficiency. The upward-curved rear section of this model likely promotes smoother airflow detachment, resulting in reduced pressure drag and wake turbulence.

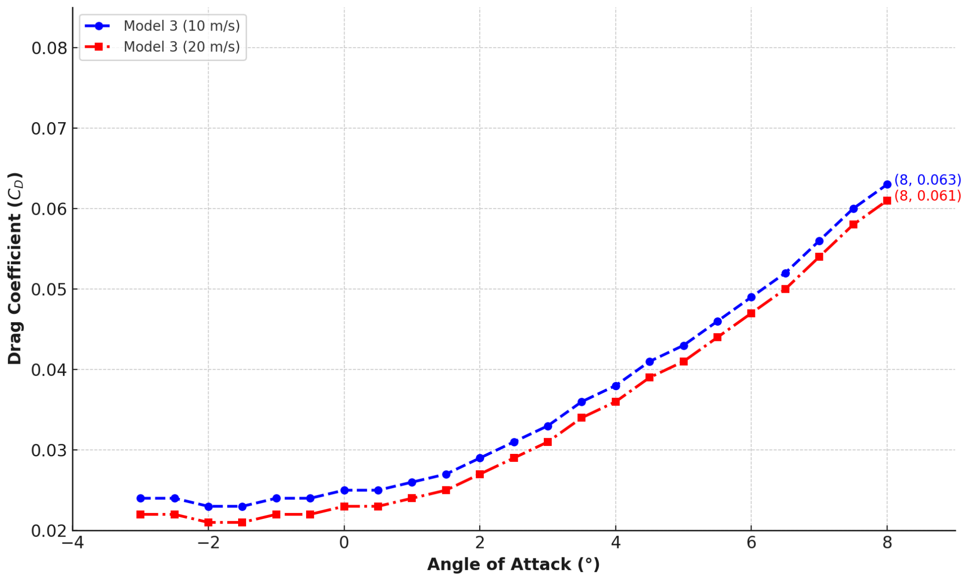

Fig. 14. Comparison of drag coefficient vs. angle of attack for model 3 at 10 m/s and 20 m/s

The graph shows that across all AOAs, the C_D values at 20 m/s are slightly lower than those at 10 m/s. For example, at 8°, the drag coefficient drops from 0.063 at 10 m/s to 0.061 at 20 m/s. This trend reflects the typical reduction in induced drag with increasing velocity. Although the reduction is modest, it reinforces the benefit of higher speed in reducing aerodynamic resistance, even without changing the geometry. These findings confirm that Model 3 not only performs best structurally but also scales well with speed, making it a strong candidate for efficient UAV operations across varying flight conditions.

4. Conclusions

To improve the aerodynamic efficiency of small UAVs, minimizing drag is essential, especially given their requirement for higher lift at lower operating speeds. This study focused on the role of fuselage design in reducing drag, with the objective of developing a more streamlined configuration. Three fuselage designs were created using SolidWorks, each with similar overall geometry but differing in rear-end shaping: one with a straight tail, another curved downward, and the third curved upward.

Computational analysis was conducted to evaluate the drag coefficients of the three designs at flight speeds of 10 m/s and 20 m/s. The results showed that the third fuselage model, featuring an upward-curved rear, consistently produced the lowest drag coefficient across all angles of attack and speeds. Model 2, with the downward-curved tail, exhibited the highest drag. Further comparison of Model 3 at two speeds demonstrated that the drag coefficient decreases slightly as speed increases, consistent with the reduction in induced drag. These findings confirm that both geometrical shaping and flight speed contribute significantly to aerodynamic performance. Model 3 is therefore recommended for VTOL UAV applications due to its superior drag performance and adaptability to varying flight conditions.

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