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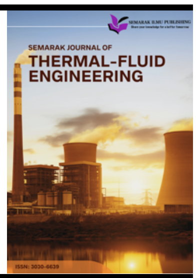

Analysis of Airflow Characteristics of Different Models of Unmanned Aerial Vehicles

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ABSTRACT

Unmanned aerial vehicles or drones have become popular in civil as well as military operations in recent years. Such developments call for new UAV designs that are able to perform a variety of missions. A UAV is an aircraft that operates independently or is operated remotely without occupant on board. This feature makes the system safer and cheaper than manned systems as indicated in the following sub-sections. In this paper, the authors pay attention to the assessment of aerodynamic characteristics of two different UAV models through CFD analysis. In the simulations, factors like the drag coefficient, lift, and velocity vectors were examined to enhance the UAV characteristics. In the flow pattern of Model 1, the airflow was strongly bounded to the UAV surface and hence high velocity zones and strong wing lift were observed. However, Model 2 had flow separation at the wing trailing edge; this increases drag and can lead to aerodynamic problems. The results of the simulation show that Model 1 had a higher lift and drag force of 15.162505 N and 16.392923 N respectively while Model 2 had almost no effect on the lift and drag forces. These differences can be explained by differences in the shape of the wings and the approach used in their design. Further, this research analyzed the effects of the wing loading on the UAV performance in the stall speed, climb rate, takeoff distance, and efficiency. These results indicate that CFD has a significant function in identifying the aerodynamics that offer understanding of UAVs with better performance. This research benefits the field of UAV and enhances the performance in both military and civil fields.

1. Introduction

Unmanned aerial vehicles (UAVs) or drones have attracted much attention for both civil and military purposes, and as a result, advanced UAVs have been designed to accomplish different tasks. A UAV is then described as an aircraft that is operated through remote control or can fly on its own without requiring a pilot on board; this helps the UAV perform important functions while at the same time protecting human life and is cheaper to operate than manned vehicles [1]. UAVs are applied in various civil and military operations, and they are used in reconnaissance operations. They can be

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fitted with one or more cameras, IMUs, LiDARs and GPS to capture and transmit data in real time [2, 3].

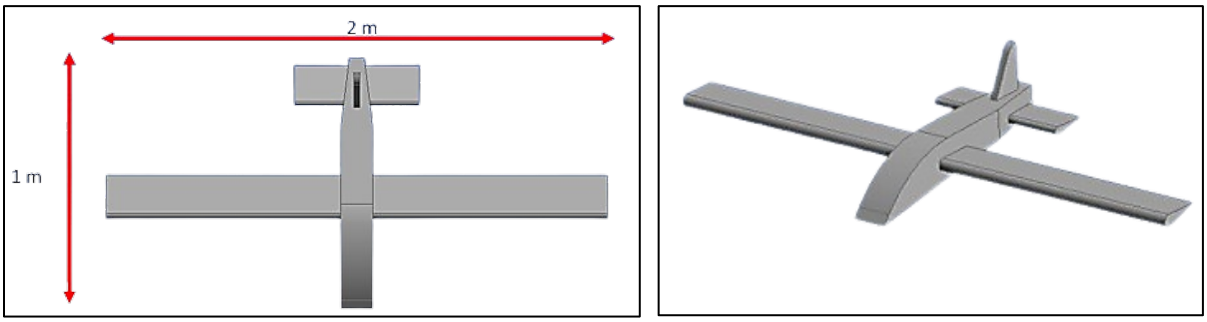
The growing use of UAVs in precision farming, search and rescue operations, wireless communication, and surveillance has created the need for several types of UAVs with different features in terms of size, weight, range, endurance, type of engine, and arrangement [4]. In the recent past, extensive research has been carried out to design and integrate UAVs for particular applications. The various UAV types with different performance features and the design and fabrication of UAV systems show the versatility of UAV systems and their functions. The analysis of UAV and parachute behavior is an interesting and complex area of research because there is a relatively small amount of information available from both theoretical and experimental points of view [5]. UAVs are classified by size, from similar in size to birds or large insects that can fly in and around buildings and other places inaccessible to people for surveillance [6,7]. Some of the constructed and analyzed small UAVs (with a weight of less than 10 kg) are the Flying Wing Golden Eagle, Cargo UAV, and SBXC Glider. The purpose of these computer simulations is to study the flow characteristics of these models and to improve the performance and stability of this aircraft [8-10].

This paper reviews past research efforts to assess the utility of UAVs in various applications. Originally developed for military use in operations deemed "dull, dirty, or dangerous" [11] by human personnel, UAVs have recently expanded into civilian domains. They are now employed in photography, product delivery, law enforcement surveillance, infrastructure inspections, and drone-racing events [12,13]. With ongoing interest from numerous companies, UAV technology is continuously being examined and improved.

2. Methodology

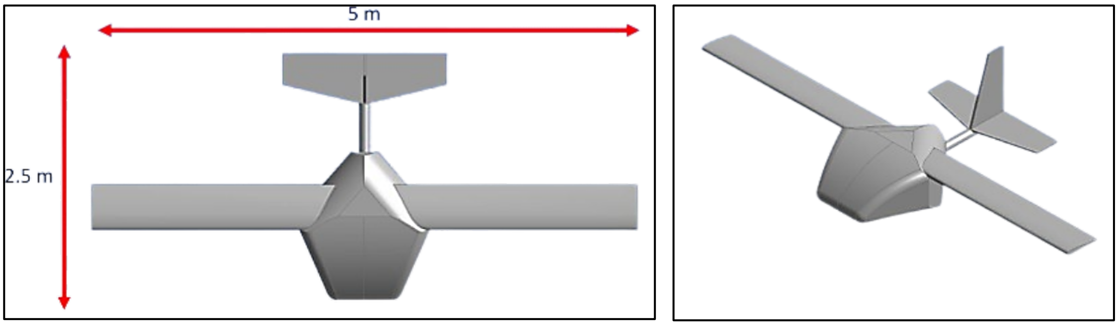
2.1 Description of UAV model

Two types of models were used for the simulation and while the models were of different size and shape under some conditions. The first model was 1 meter in length and 2 meters in width, while the second model was 2.5 meters in length and 5 meters in width. The simulation considers the outcome in relation to varying temperature settings for both models. In the following figures, UAV Models 1 and 2 are shown in top and isometric views as shown in Figures 1 and 2 respectively.



(a) (b)

Fig. 1. View of UAV model 1 (a) Top view (b) Isometric view



(a) (b)

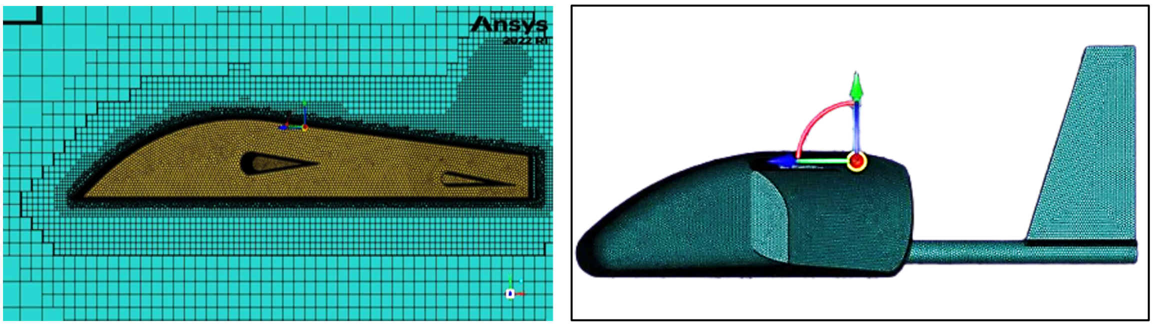
Fig. 2. View of UAV model 2 (a) Top view (b) Isometric view

2.2 Discretization Technique

There are several discretisation techniques available and the most popular ones are the finite difference, finite element, and finite volume techniques [14]. When it comes to CFD, the Finite Volume method is used because it naturally maintains mass, momentum, and energy [15]. In this case, the conservation laws are also satisfied for the entire domain when they are satisfied for each control volume [16]. As per ANSYS Fluent, the flow is discretized by a control volume based technique for discretizing the domain [17].

2.3 Meshing

Meshes were generated using the surface meshes applied to the UAV geometry as input. The meshes were refined mainly at the leading and trailing edges of the wings and stabilisers since large gradients or flow separations were expected. Greater gradients are anticipated at the sharp turns and other acute angles of the model. The generated surface mesh is shown in Figure 3.



(a) (b)

Fig. 3. Meshing of UAV models (a) Model 1 (b) Model 2

The skewness of the volume mesh was kept below 0.95 using the auto node move command to avoid any abrupt changes in the volumetric fluid region (Table 1). As with the surface mesh, the growth rate of the volume mesh elements was lowered to below 1.2. The low growth rate helped to achieve a good correspondence between the number of mesh elements and the geometry of the modeled object, which made it possible to maintain a proper transition between the volume mesh elements.

Table 1
Meshing nodes and faces

	UAV model 1	UAV model 2
Nodes	171338	308469
Edges	2247	2780
Faces	60321	106307
Cells	0	0
Skewness	0.73	0.88
Minimum Orthogonal	0.152	0.17
Boundary nodes	56789	103726
Boundary faces	108644	200846

2.4 Governing Equation

The Navier-Stokes equations govern the equations of computational fluid dynamics by describing how the velocity field of a fluid evolves over time, while accounting for various forces acting on it [18-20]. These equations are derived from the conservation laws of mass, momentum, and energy.

2.4.1 Conservation of mass (continuity equation)

The continuity equation ensures mass conservation in the fluid flow. For an incompressible fluid, these equations are expressed as:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho v) = 0 \tag{1}$$

$$\nabla.\mathrm{v} = 0 \tag{2}$$

where ρ denotes constant density and v is the velocity vector of the fluid.

2.4.2 Conservation of momentum (Navier-Stokes equation)

The momentum equation is derived from Newton's second law and includes terms for the viscous and pressure forces. For an incompressible Newtonian fluid, the Navier-Stokes equation in vector form is:

$$\rho\left(\frac{\partial v}{\partial t} + v.\nabla \mathrm{v}\right) = -\nabla \mathrm{p} + \mu \nabla^2 + f \tag{3}$$

where v denotes the velocity vector, p is the pressure, μ is the dynamic viscosity coefficient, and f represents body forces.

2.4.3 Conservation of energy

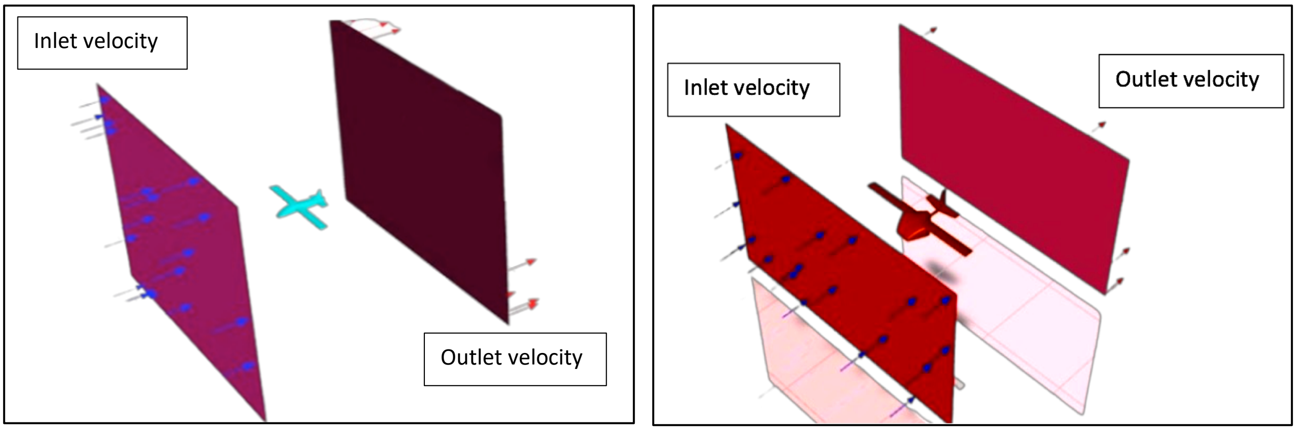
The energy equation accounts for changes in the internal energy within the fluid due to the work done by pressure forces, viscous dissipation, and heat conduction. The general form for energy conservation is:

$$\rho\left(\frac{\partial e}{\partial t} + v.\nabla \mathrm{e}\right) = -\nabla.q + \Phi + \mathrm{f}.\mathrm{v} \tag{4}$$

where e is the specific internal energy, q is the heat flux vector, and Φ represents the viscous dissipation function.

2.5 Boundary Conditions

For this analysis, the flow characteristics for each case were determined using an inlet velocity of 30 m/s for both geometries, model UAV 1 and model UAV 2, as shown in Figure 4.



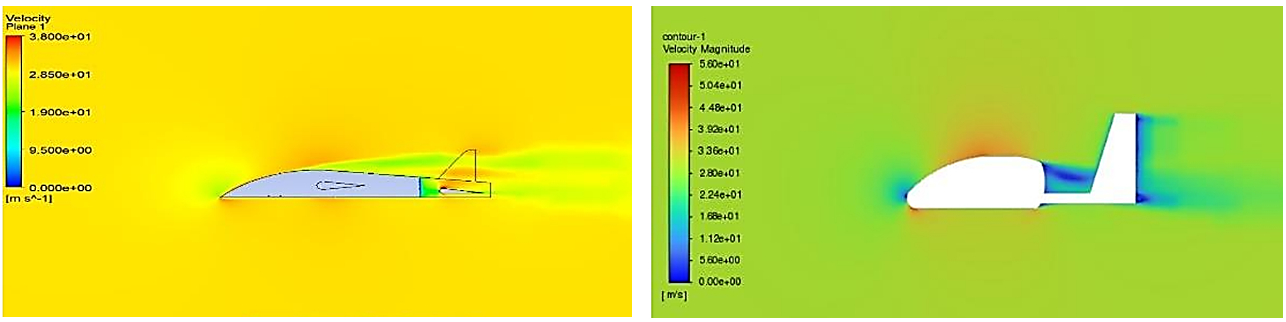
(a) (b)

Fig. 4. Inlet and outlet velocities for UAV models (a) Model 1 (b) Model 2

3. Results

3.1 Flow Characteristics of UAV Models

According to Figure 5, Model 1 indicates the flow pattern where the airflow is still closely bounded to the UAV skin and has high velocity areas and wing lift. There is little flow separation and drag visible around both the fuselage and wings, which attests to its aerodynamic effectiveness. While Model 2 demonstrates flow separation at the trailing edge of the wing, which means higher drag and possible aerodynamic drawbacks compared to Model 1. This variation in flow behaviour can be attributed to differences in the wing plan form and the general design philosophy of the two models.



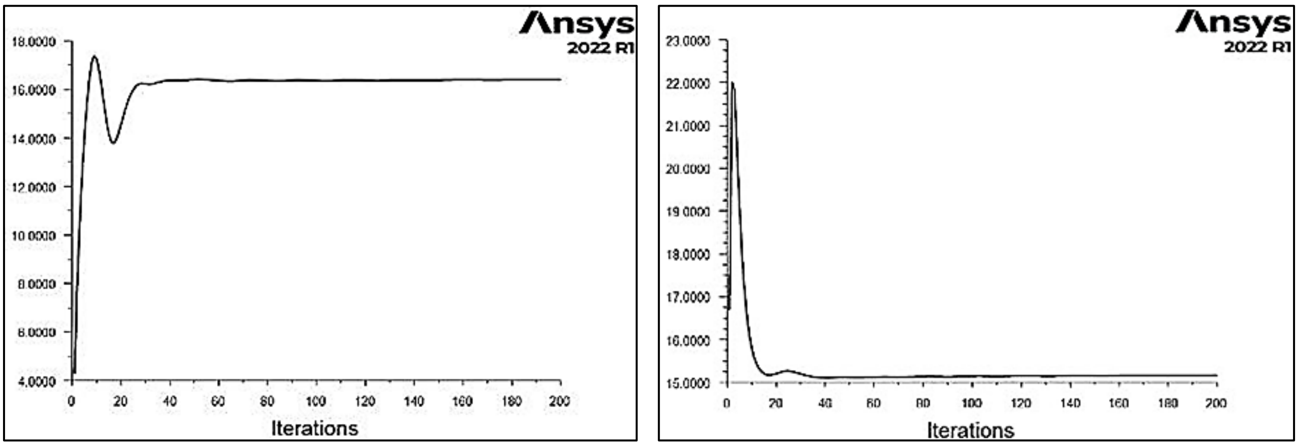
(a) (b)

Fig. 5. Velocity flow of UAV models (a) Model 1 (b) Model 2.

3.2 Aerodynamic Performance of the Models

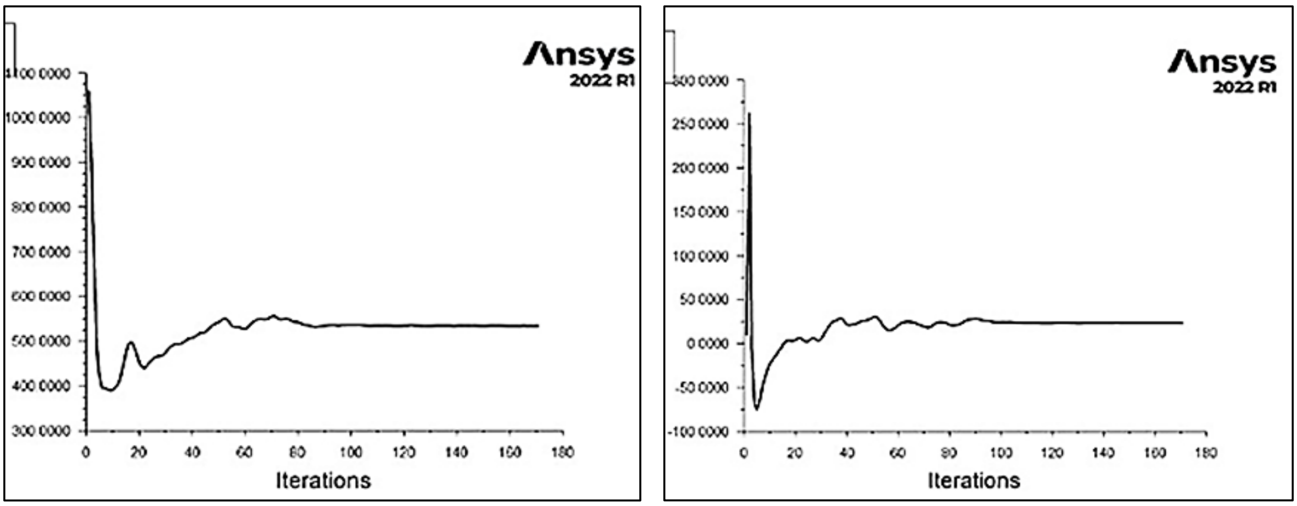
In the conceptual design phase, the first estimates were made about the aerodynamics, layout, dimensions, mass, and performance of the aircraft. The outline of each section is also presented in Figures 6 and 7 as well as the UAV conceptual design. Model 1 had a lift force of 15.162505 N and drag force of 16.392923 N (Figure 6). On the other hand, Model 2 had lower values as 1.1360126E-9 N of lift force and 1.1971296E-9 N of drag force as shown in figure 7. These results suggest that Model 1 produces significantly greater lift and drag forces than Model 2. This is because wing loading has a significant influence on the UAV weight; the larger the wings, the greater the drag of the UAV.

In addition, the stall speed, rate of climb, take-off distance and overall performance were directly influenced by the wing loading. By applying the criterion for the minimum lift necessary for level flight, it becomes possible to determine the velocity at which lift or drag is least and the efficiency ratio CL/CD most. The assessment made showed that a lift coefficient of 1.1971296E-9 N was at the level flight with the least drag. When the weight changes, the UAV can still achieve the optimal lift coefficient by adjusting either its velocity or altitude because this coefficient depends solely on aerodynamic characteristics such as air density.



(a) (b)

Fig. 6. The performance of UAV model 1 (a) Lift coefficient (N) (b) Drag coefficient (N)



(a) (b)

Fig. 7. Performance of UAV model 2 (a) Lift coefficient (N) (b) Drag coefficient (N)

4. Conclusions

This project aims to acquire the flow characteristics of two UAV models, including the drag coefficient, lift, and velocity vectors, by the end of the analysis. This study emphasises the significance of CFD in simulating UAV models to obtain essential results, such as the drag coefficient, lift, velocity, and streamlines, which are fundamental for creating an optimal UAV design with maximum performance. The first design of the UAV model showed that the lift and drag values were higher in Model 1 than in Model 2. Additionally, the scaled residuals and velocity vectors for both models were obtained.

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