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The future of flying: Explore more energy-efficient airplane wings

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Abstract. In recent years, there has been a substantial rise in the popularity of air travel, bringing with it a surge in the consumption of jet fuel, a nonrenewable resource responsible for 2.4% of global carbon emissions. As air travel continues to gain prevalence, the anticipation of a significant increase in carbon emissions and a subsequent surge in jet fuel costs looms large. Maintaining affordability in air travel while mitigating carbon emissions necessitates a focus on maximizing airfoil efficiency. This study investigates how airplane wing design affects the aerodynamic performance of aircraft, with a specific focus on the impact of wing angle of attack, wing length, and winglets. In this research, this study use Computational Fluid Dynamics software to simulate and analyze the aerodynamic forces acting upon an aircraft to deduce its drag and lift coefficients. Employing diverse fluid dynamics formulas, the research calculates the aerodynamic performance of various aircraft airfoil designs, aiming to identify the optimal design. The envisioned optimal configuration is likely to feature an elongated wing, a 20° angle of attack, and suitable winglets stalled, strategically incorporated to enhance overall efficiency in air travel.

Keywords: Aerodynamics, Force Analysis, Computational Fluid Dynamics, Aircraft Wing Design, Winglet

1. Introduction

1.1. Background

Airplanes stand out as the most efficient and also safest way of travel in the modern world. This is because of its remarkable speed which allows this study to cover extensive distances within a few hours. Accidents are also infrequent with only 5 fatal accidents among 32.2 million flights in 2022 [1]. Each aircraft has a pair of huge wings, which could generate enough lift to help the airplane overcome gravity. However, the large size of the wings also creates a large drag force, which greatly increases the consumption of fuel. So how to design airplane wings that could provide needed lift force but also have less drag force is an essential research topic. The airplane wing usually adopts the airfoil design, and the basic cross-section of an airfoil is shown in Figure 2. Hence, the airfoil wing's design is essential for an aircraft's performance. Increasing the lift and decreasing the drag can dramatically increase an aircraft's fuel efficiency, reducing carbon emissions and making air travel more affordable. This is important because most modern aircraft run on kerosene which is a non-renewable resource. Meanwhile, air travel makes up 2.4% of the global CO_2 emissions [2]. By increasing the efficiency, not only can the amount of CO2 emitted in the air be reduced, but this study can also make airplanes have better efficiency. As this study anticipate the proliferation of supersonic airplanes in the near future, capable of speeds exceeding 330 meters per second, the importance of efficiency becomes even more pronounced. Increased efficiency plays a vital role in mitigating resistance on the aircraft, especially at such high speeds. The broader impact of enhancing efficiency extends beyond mere travel convenience; it opens up air travel accessibility to a wider demographic, making it affordable for many individuals worldwide. Simultaneously, it contributes to maintaining a healthier environment for all life on Earth. Therefore, the pursuit of increased efficiency in air travel emerges as a key imperative for both social and environmental considerations.

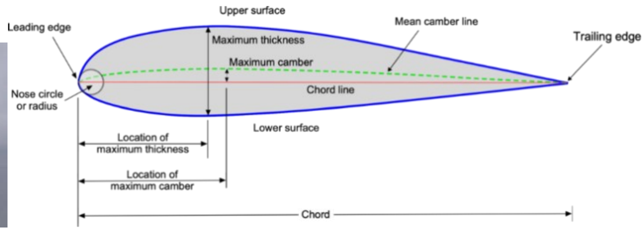

Figure 1. Boeing 747 Airplane [3]. **Figure 2.** Aircraft Airfoil Structure [4]

1.2. Literature Review

Many investigations on the aerodynamic performance of aircraft wings have been done. For example, in the paper "Proverse Yaw Characteristics of a Powered Blended Wing Body Aircraft of a Novel Design and Manufacture". The author used model aircraft and conducted flights to collect valuable data. The investigation involved testing various stabilizers and flaps to assess their impact on the aerodynamic behavior of the aircraft. In another paper titled "Development of a Rotor with Improved Aerodynamics to Propel a Quadcopter". the author delved into the influence of altering rotor shape on the aerodynamic performance of a quadcopter rotor. Utilizing 3D-printed rotors, the author conducted systematic tests on dedicated test stands to evaluate their performance. Additionally, this research scrutinized the effects of integrating winglets into the rotor design, providing insights into how such modifications can impact overall aerodynamics. In the study titled "Wing Design", the authors author explored the impact of altering the position, shape, and angle of attack of wings on aerodynamic performance. The paper delved into the effects of various wing configurations, including high-wing, mid-wing, low-wing, and parasol wings. Additionally, the author discussed crucial parameters such as aspect ratios and taper ratios, shedding light on their influence. In a parallel investigation, the paper titled "Aerodynamic Design Optimization Studies of a Blended-Wing-Body Aircraft"[9] focused on the effects of wing design for a blended wing-body aircraft. Utilizing Computational Fluid Dynamics (CFD), the study examined the implications of different wing designs and investigated the influence of changing speeds on these designs. The research contributes valuable insights into optimizing the aerodynamic performance of blended wing body aircraft through meticulous design considerations and CFD analysis.

1.3. This study

In this study, this study explores the impact of altering some key parameters—specifically, wing angle of attack, wing length, and the incorporation of winglets—on the drag and lift characteristics of a fixed-wing aircraft. The wing length is defined as the distance between the front and the back of the wing, while the angle of attack represents the angle formed by the airfoil and the direction of the freestream flow. Additionally, the study investigates the aerodynamic effects of winglets, small wings positioned at the wing's end, designed to enhance the aircraft's lift generation capabilities. My hypotheses are as follows: wing angle of attack, wing length, and winglet could have great effects on the aerodynamic performance of the airplane, and increasing the angle of attack will result in elevated levels of both lift and drag. Moreover, augmenting the wing length is anticipated to enhance lift with minimal impact on overall aerodynamic performance. Lastly, the addition of a winglet is hypothesized to marginally increase drag but significantly boost lift by mitigating turbulence along the wing's edge. This hypothesis is grounded in the expectation that the winglet will contribute to reducing turbulence, thereby positively influencing lift generation.

2. Methodology

In this section, this study introduces the governing equations that dictate fluid motions, providing insights into the underlying mechanisms governing the aerodynamic performance of aircraft. This discussion not only serves to elucidate the intricacies of aerodynamics but also offers a rationale for its utility in minimizing drag. The same set of equations is subsequently employed as a fundamental tool in the simulation phase to model and analyze the dynamic behavior of fluid motion. Consequently, it becomes imperative to illustrate the derivation and application of these equations within the simulation framework, highlighting their crucial role in understanding and predicting the aerodynamic characteristics of fixed-wing aircrafts.

2.1. General Approach to Research on Fluid Dynamics

The two most common research approaches to investigate the aerodynamic performance of an aircraft: Wind Tunnel Experiments and Computational Fluid Dynamics (CFD) Simulation. In CFD, computer software is used to calculate the performance of an aircraft model through simulation. In this study, Solidworks is used for the 3D modeling and CFD simulations of the model. Wind Tunnel Experiments, on the other hand, use a miniature model inside of a real wind tunnel which represents the real conditions of an actual flight. CFD is generally more accessible and cost- effective to conduct, however, it is quite limited and can only simulate phenomena to a certain extent. Wind Tunnel Experiments demand extensive preparation and involve the use of more costly equipment compared to CFD simulations. For this study, this study has chosen to employ CFD over Wind Tunnel Experiments due to its ease of setup, repeatability, and the absence of a need for advanced equipment.

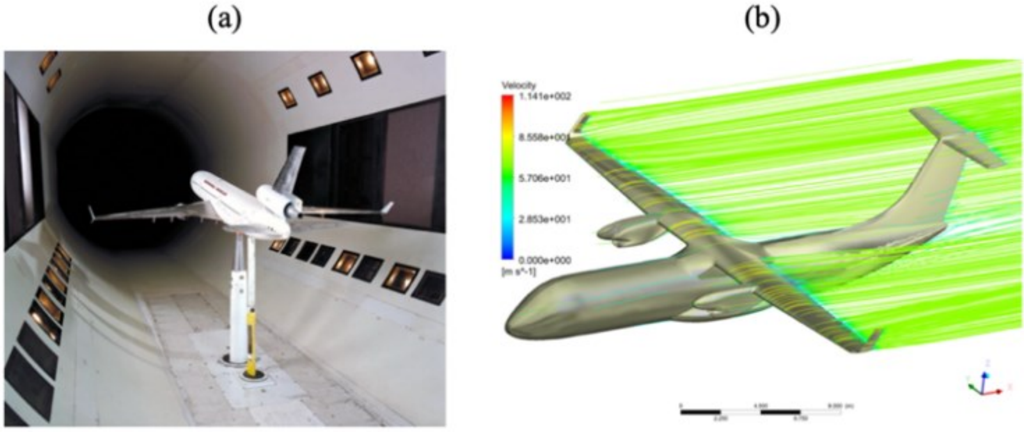

Figure 3. (a) NASA wind tunnel with the scale model of the MD-11 wide-body airliner [10], and (b) CFD simulation [11]

2.2. Principles of Fluid Dynamics

- **Mass conservations.**

The mass conservation states that for an arbitrary control volume, the net rate of mass increase within the volume is equal to the net mass flux into the volume. For example, in the infinitesimal control volume as shown in Figure 4, the rate of mass increase is $\frac{\partial(\rho dxdydz)}{\partial t}$. The net mass flux into the volume in the x-direction is calculated by subtracting the outflow rate from the inflow rate,

$$\rho v_x dydz - (\rho v_x dydz) + \frac{\partial(\rho v_x dydz)}{\partial x}dx = -\frac{\partial(\rho v_x)}{\partial x}dxdydz \tag{1}$$

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And similarly, the net mass flux into the volume in *y*- and *z*- directions are:

$$y \text{ direction: } -\frac{\partial(\rho v_y)}{\partial y}\mathrm{d}x\mathrm{d}y\mathrm{d}z \tag{2}$$

$$z \text{ direction: } -\frac{\partial(\rho v_z)}{\partial z}\mathrm{d}x\mathrm{d}y\mathrm{d}z \tag{3}$$

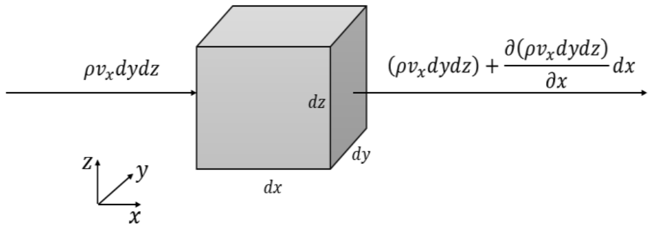

Figure 4. Taking *x* Direction as an Example Showing Mass Conservation in the Infinitesimal Control Volume

Summing the net mass fluxes into the volume in three directions (Equations 1-3) yields the total net mass fluxes, which equals to the rate of mass increase in the control volume,

$$-\frac{\partial(\rho v_x)}{\partial x}dxdydz - \frac{\partial(\rho v_y)}{\partial y}dxdydz - \frac{\partial(\rho v_z)}{\partial z}dxdydz = \frac{\partial \rho}{\partial t}dxdydz \tag{4}$$

By eliminating the term $dxdydz$, it simplifies to

$$-\left[\frac{\partial(\rho v_x)}{\partial x} + \frac{\partial(\rho v_y)}{\partial y} + \frac{\partial(\rho v_z)}{\partial z}\right] = \frac{\partial \rho}{\partial t} \tag{5}$$

For the general incompressible fluid flow, which is the case of my study, the fluid density is a constant value, i.e., $\rho = const$. Consequently, the rate of mass increase $\frac{\partial \rho}{\partial t} = 0$. This condition allows the expression of mass conservation as,

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0 \tag{6}$$

- **Momentum conservation**

The law of momentum conservation, an extension of Newton's 2nd Law, can be derived by expanding the equation of continuity in conjunction with the Newton's 2nd law. Given its vector nature, it can be decomposed into forces on each of the three dimensions. In general, the anticipated forces, including viscosity, pressure, and gravity, can be expressed in the following equations:

$$\mathrm{F} = \mathrm{ma} \tag{7}$$

$$x \text{ direction: } \rho\left(\frac{\partial v_x}{\partial t} + v_x\frac{\partial v_x}{\partial x} + v_y\frac{\partial v_x}{\partial y} + v_z\frac{\partial v_x}{\partial z}\right) = \mu\left[\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right] - \frac{\partial p}{\partial x} \tag{8}$$

$$y \text{ direction: } \rho\left(\frac{\partial v_y}{\partial t} + v_x\frac{\partial v_y}{\partial x} + v_y\frac{\partial v_y}{\partial y} + v_z\frac{\partial v_y}{\partial z}\right) = \mu\left[\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right] - \frac{\partial p}{\partial y} + \rho g_y \tag{9}$$

$$z \text{ direction: } \rho\left(\frac{\partial v_z}{\partial t} + v_x\frac{\partial v_z}{\partial x} + v_y\frac{\partial v_z}{\partial y} + v_z\frac{\partial v_z}{\partial z}\right) = \mu\left[\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2}\right] - \frac{\partial p}{\partial z} \tag{10}$$

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- **Bernoulli Principle**

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 \& = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \#(11)$$

Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. The principle is named after Daniel Bernoulli, a Swiss mathematician, who published it in 1738 in his book Hydrodynamics. This principle holds significant importance in the field of aircrafts. It serves as the foundational concept enabling aircraft to generate lift, a crucial factor in achieving flight.

2.3. Force Analysis

The primary forces that are acted upon an aircraft are drag, lift, gravity, and thrust. Drag is a force that pushes the aircraft in a direction opposing to the direction of motion. Drag poses a detrimental impact on the aerodynamic performance of an aircraft and should be minimized whenever possible. Trust pushes the aircraft forward and acts in the opposite direction of drag. Gravity is the force that attracts all objects with mass toward each other, pulling the aircraft toward the ground due to Earth’s gravitational attraction. Lift generated by the Bernoulli effect, acts in the upward direction, countering the force of gravity. Lift counters gravity and should be maximized for improving the aerodynamic performance.

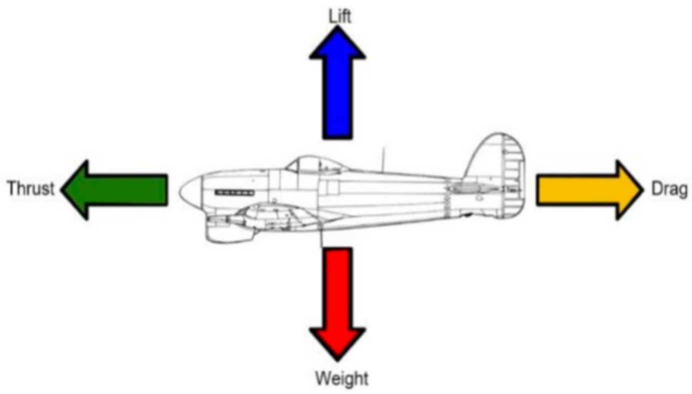

Figure 5. Forces Acted Upon an Aircraft.

The Drag and Lift coefficients are formulas that are used to quantify an object's capacity to generate drag and lift forces. The reason why drag coefficient and lift coefficient instead of drag and lift are used is because there are many factors affecting the amount of drag generated by an object. However, the significance of an object's capacity to generate drag or lift would be more important when considering its impact on aerodynamic performance.

The Drag Coefficient is defined as:

$$c_d = \frac{2F_d}{\rho u^2 A} \tag{12}$$

The lift coefficient is defined as:

$$c_l = \frac{2F_l}{\rho u^2 A} \tag{13}$$

Here C_d is the Drag coefficient, C_l is the lift coefficient. F_d is Drag(N). F_l is lift(N). u is speed(m/s). ρ is the the fluid density(kg/m^2). A is the reference area(m^2).

2.4. Utilized Software
SolidWorks is a 3D CAD design software developed by Dassault Systèmes. Widely employed for various design applications, it serves as a robust tool for individuals designing a range of objects and structures. SolidWorks enables this study to design model airplanes and simulate their performance in flight. The flow simulation tool allows this study to simulate an aircraft in the air and obtain information on the various forces acting upon it.

3. Results and Discussion
In this section, this study first elucidates the methodologies employed for aircraft model development, simulation procedures, and finally the presentation of investigation results.

3.1. Model Development:
To conduct the simulation and analysis, this study needs to create aircraft models. Firstly, this study creates a sketch of the aircraft body as shown in Figure 6. This study only makes half of a cross section because, the sketch can then be extended into a full body using the rotation tool.

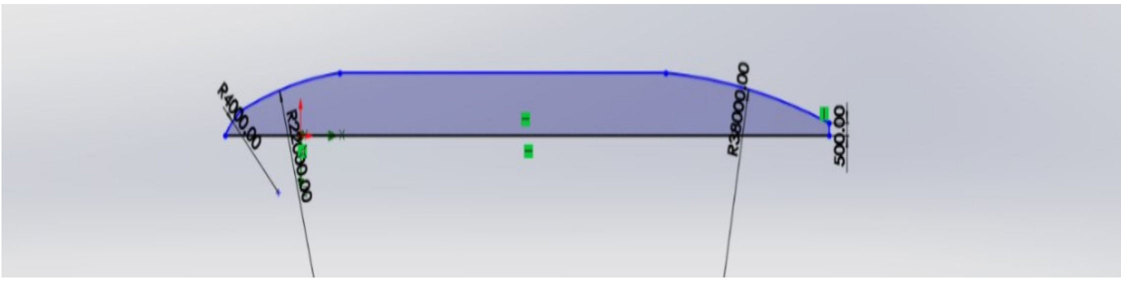

Figure 6. The Cross-section of an Airplane Body.

Next, this study initiates the airfoil design process by sketching the airfoil on the side of the aircraft body, as depicted in Figure 7. Utilizing the extrude tool, this study transforms the sketch into a three-dimensional object. Employing the symmetry tool, this study generates an identical copy of the airfoil on the opposite side of the aircraft body. Subsequently, this study replicates the procedure on the rear section of the plane, incorporating a smaller wing to craft rudders. The tail fin is then fashioned, featuring a single wing positioned above the rear of the aircraft, as illustrated in Figure 7.

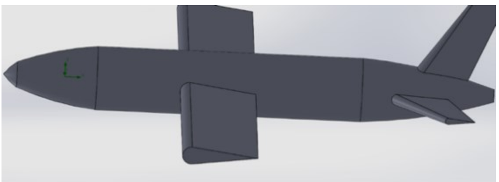

Figure 7. Aircraft Body with Wing.

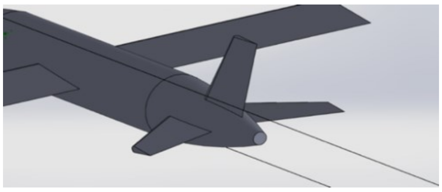

Figure 8. An Airplane Tail Fin

3.2. General Simulation Procedure
I first need to open the Solidworks flow simulation page to run simulations. Then this study uses the wizard tool and create a CFD flow simulation and apply custom settings. After that, the simulation page opens, this study can rename the simulation and give it a description as shown in Figure 9. This study then clicks “continue” and select the units. This study selects the SI units because it is the one this study am most familiar with and click “continue”.

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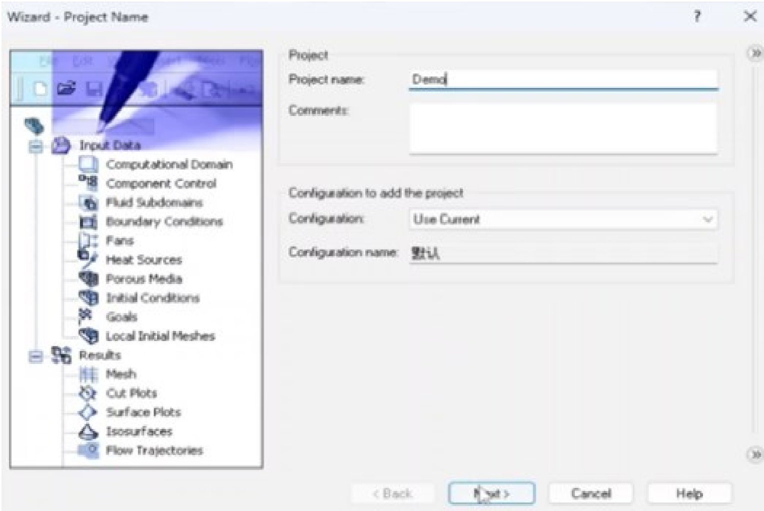

Figure 9. The Simulation Page

For the next step, this study chose the simulation type as external flow simulation mode as depicted in Figure 10 and proceed by selecting “continue”. In external flow simulation mode, the fluid is simulated to interact with the external surfaces of the object rather than within its internal spaces. In this research, this study employs the external flow simulation mode at default settings.

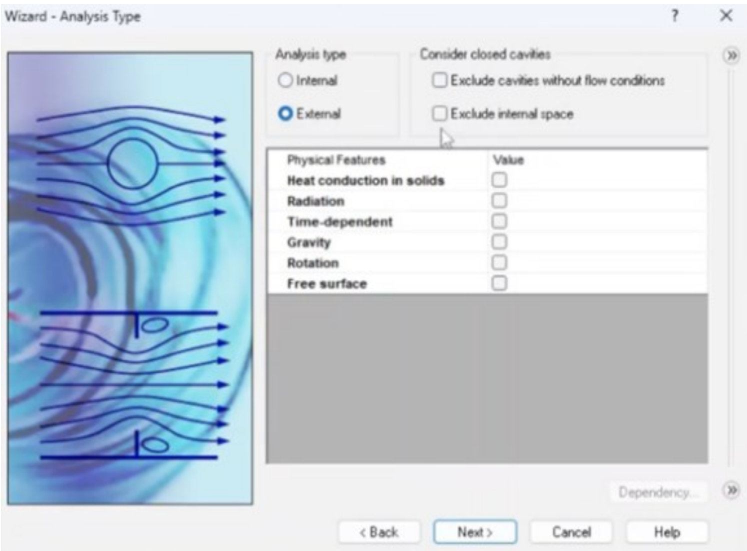

Figure 10. Picking the External Flow Simulation Mode

I proceed by clicking the plus sign next to “gases” and selecting air, as illustrated in figure 11. It's noteworthy that the default air setting in SolidWorks represents atmospheric pressure at sea level on Earth.

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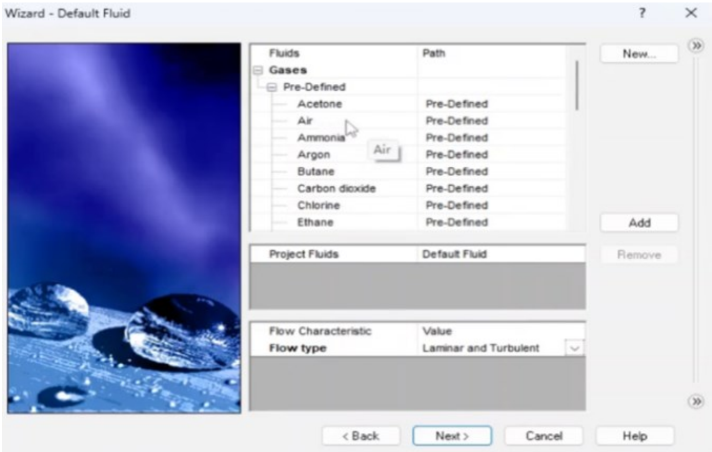

Figure 11. Picking Air as the Simulation Fluid.

On the initial environment conditions page, this study need to set the speed to 100 m/s which is my experimental velocity, as demonstrated in figure 12. Opting for a velocity of 100 m/s is a good speed is considered suitable for experimentation as it effectively simulates realistic flight conditions for an aircraft while maintaining a reasonable simulation time. This study then clicks complete, finalize the setup and prepare to commence the simulation.

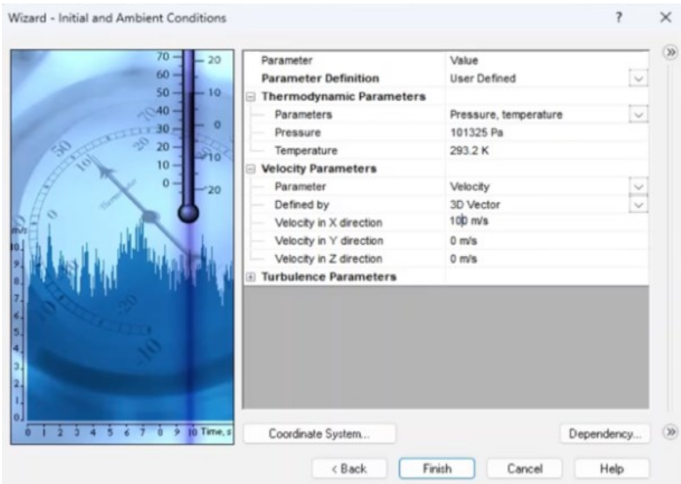

Figure 12. Setting the Speed

After that, this study defines the boundary conditions by selecting all the faces on the plane and switch the boundary type to “real wall” as shown in Figure 13 “Real wall” is a condition that simulates if the object was a solid object in real life with no microscopic bumps on its surface.

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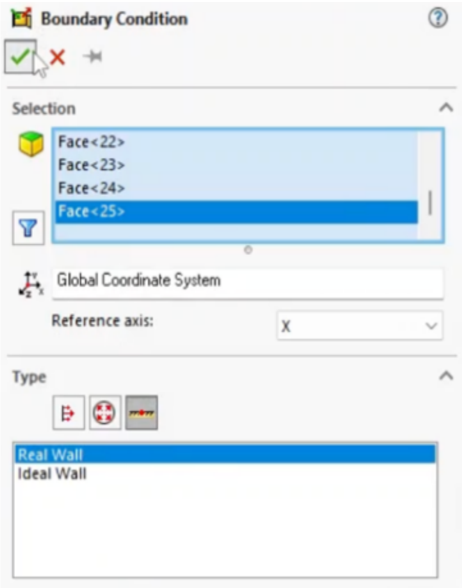

Figure 13. Defining Boundary Conditions

Figure 14. Computational Domain Settings

After that, this study set the computational domain. to the values 450 m, -150 m for X direction, 6 0m, -60 m for Y direction, and 40 m, -40 m for Z direction. This is a reasonable range for conducting simulations as this study want to analyze the flow around the airplane, so this study needs enough space for the flow to be fully developed.

Now this study inserts the simulation global goals. This study selects the drag and lift as shown in figure 15. This study needs to set these goals because this study needs to get these data in order to calculate drag coefficient and lift coefficient which are important in calculating aerodynamic efficiency.

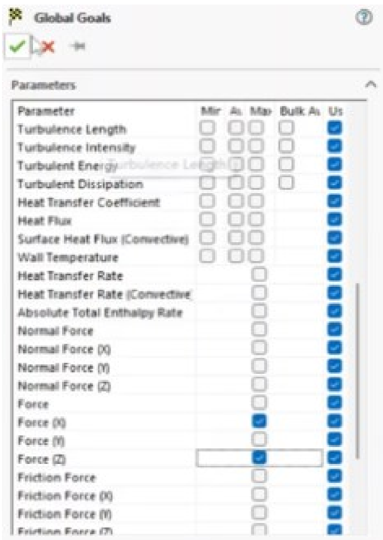

Figure 15. Picking the Global Goals

Aside from global goals, this study also needs to set the algebra goals. This study inserts the drag coefficient and lift coefficient goals as shown by figure 16.

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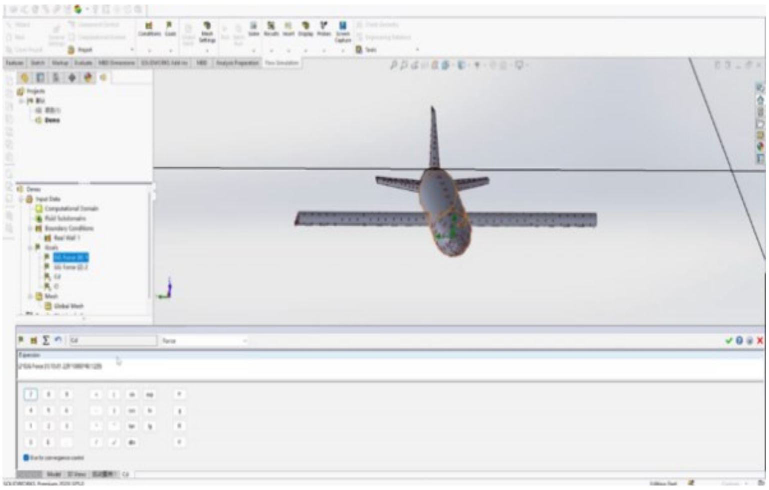

Figure 16. Inserting the Lift Coefficient Formula

To conclude the process, this study set the mesh as shown by Figure 17, the mesh is responsible for making the computer understand how precise the calculations need to be.

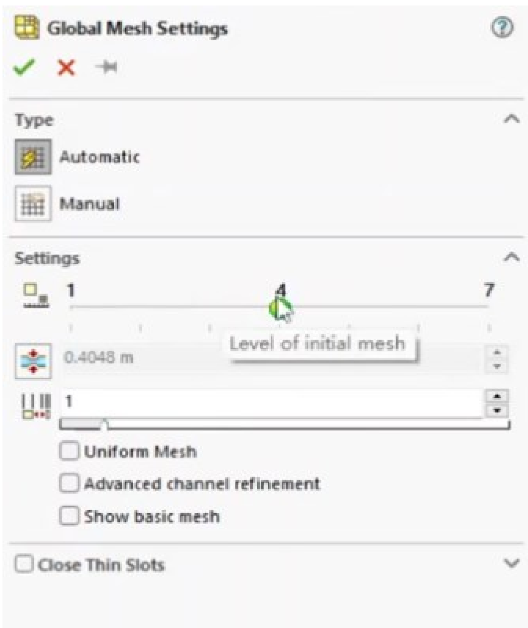

Figure 17. Changing the Global Mesh Settings

3.3. Effect of Modifying Aircraft Angle of Attack

Angle of attack is the angle between the chord line of the wing of a fixed-wing aircraft and the oncoming air for a fixed-wing aircraft. Modifying the angle of attack of an aircraft wing will have a significant impact on aerodynamic performance, making this parameter very crucial for aerodynamic performance. The aircraft with different wing angles are shown in Figure 18.

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Figure 18. Test Aircrafts with Different Angle of Attack, with the angle of attack from 0, 5, 10, 15, 20,25 degrees.

After conducting experiments, it can be concluded that by increasing the angle of attack, the drag coefficient and lift coefficient both increases as shown in figures 19 and 20. When the Angle of attack was 0, the drag coefficient was 0.92 and the lift coefficient was 0.04. After the angle of attack is increased to 25°, the drag coefficient was 1.83 and the lift coefficient is 2.49.

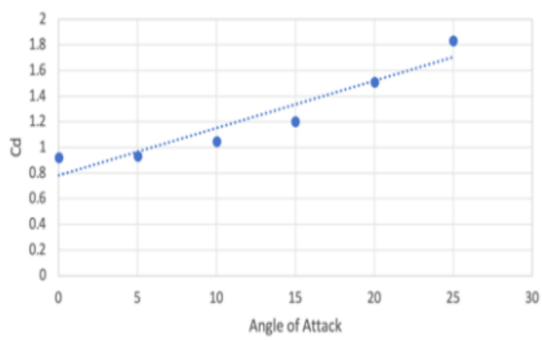

Figure 19. Drag Coefficient with Respect to Angle of Attack

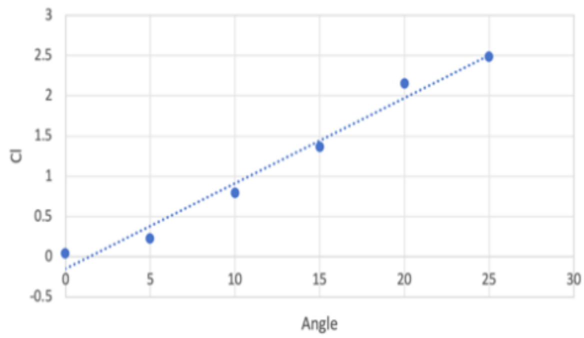

Figure 20. Lift Coefficient with Respect to Angle of Attack.

Using the pressure and velocity contours of the aircraft shown by Figures 21 and 22, this study can further understand how varying angles of attack influence aerodynamic performance. These contours offer a cross section of the aircraft to help this study understand what are the intensity of forces that occur inside of the aircraft. This unique perspective aids in comprehending the effects of different factors on aerodynamic efficiency and offers guidance on optimizing these factors for enhanced performance.

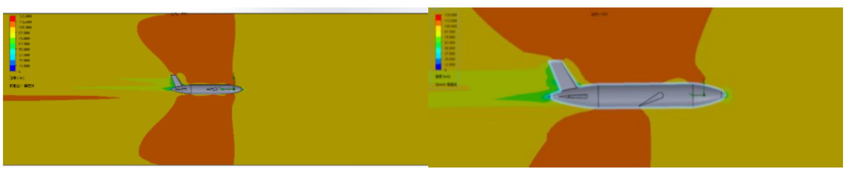

Figure 21. Velocity Contours for Angle of Attack

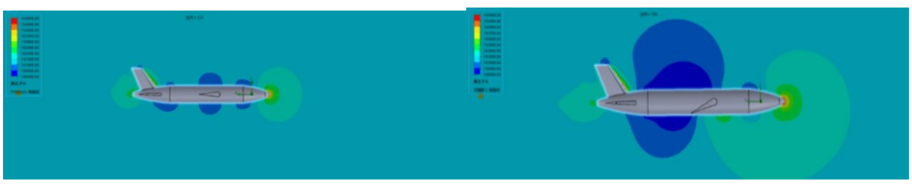

Figure 22. Pressure Contours for Angle of Attack

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In an ideal situation, there should be as little pressure on the top of the plane as possible and as much pressure on the bottom of the plane as possible. This will make the lift the strongest because the pressure on the bottom of the plane would push the aircraft up which generates lift. As shown in the figures above, the pressure on top of the aircraft decreased as the angle of attack increased. However, same trend applies to the bottom of the aircraft as well. There was a significant decrease in pressure on the bottom of the aircraft when the angle of attack was 25°. Thus, the aircraft with the best aerodynamic efficiency is the aircraft with 20° angle of attack. This shows that the optimum angle of attack for aerodynamic efficiency is 20°.

To balance out the drag and lift, the Cl/Cd ratio must be calculated. After calculating the ration, this study discovered that the Cl/Cd ratio is highest at a 20° angle as shown by figure 3.18. At, 0°, the Cl/Cd ratio is 0.04. After increasing the angle of attack, the Cl/Cd ratio peaked at 1.42 when the angle of attack was 20°. After that, the Cl/Cd ratio decreased to 1.36 when the angle of attack increased to 25°. This means that the aircraft will have the highest aerodynamic performance when the aircraft wing is at a 20° angle of attack since the drag is balanced with the lift.

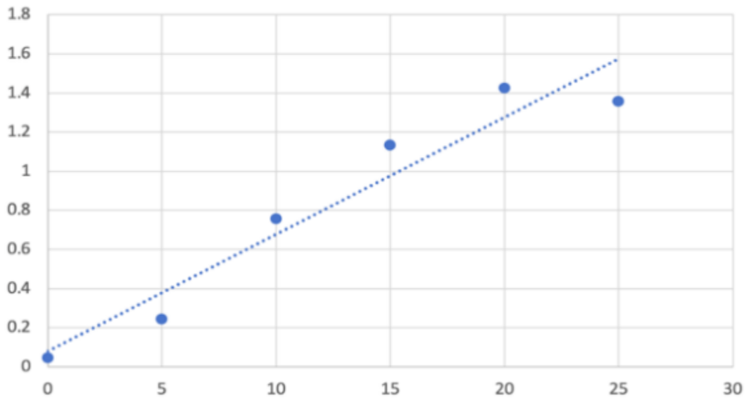

Figure 23. Cl/Cd Graph for Angle of Attack

3.4. Effect of Wing Length

The angle of attack of a wing is not the sole factor affecting wing performance. Another crucial factor is the wing length. In this context, wing length is defined as the distance between the front and back of an airfoil. Figure 24 shows my test aircrafts with different wing length. The pictures are arranged in an increasing order with the plane with the lowest wing length on the top and the highest on the bottom. The angle of attack is kept constant at 20° which had the highest aerodynamic performance as shown by the previous section.

Figure 24. Test Aircrafts with Different Wing Length.

After conducting experiments, this study has discovered that increasing wing length generally increases the lift while decreasing the drag. As shown in Figure 25, the Aerodynamic performance, which is the lift coefficient divided by the drag coefficient, has an increasing trend. The optimal aerodynamic performance was observed when the wing length reached its maximum, implying that the aircraft's aerodynamic efficiency is at its best when the wing length is longer.

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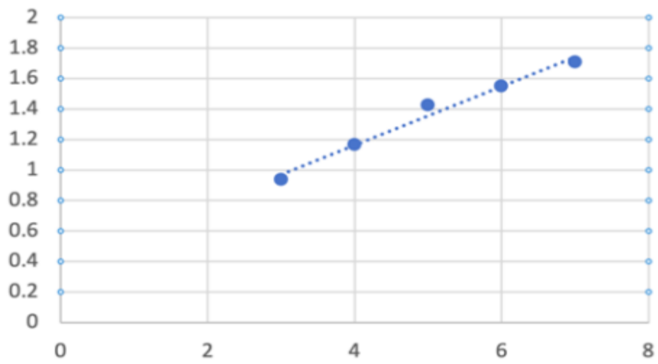

Figure 25. Cl/Cd Graph for Wing Length

As mentioned above, an aircraft more pressure below the aircraft and less above to increase aerodynamic efficiency. As shown by figure 26 and figure 27, the aircrafts all have a similar amount pressure on top of the plane. However, the plane with the highest pressure is the one with 7m wing length. This further reinforces that increasing wing length would increase lift.

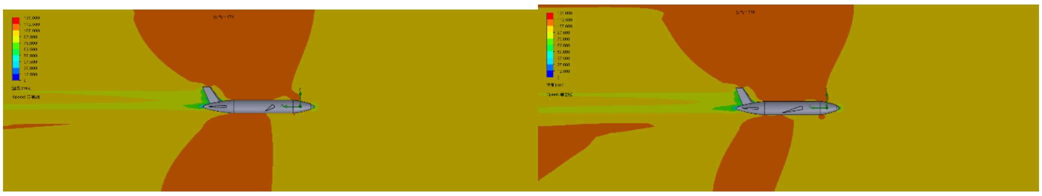

Figure 26. Aircrafts with Different Wing Length

Below are the pressure Contours for Wing Length:

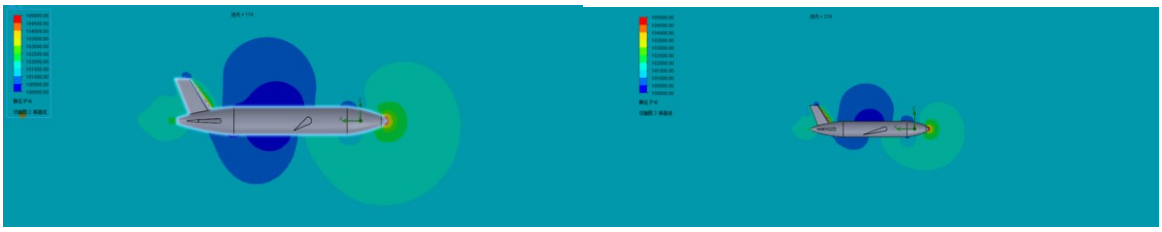

Figure 27. Pressure Contours for Wing Length

3.5. *Effect of Winglets*

Winglets are tiny wings that are added on the edge of a wing to increase lift. Winglets were inspired by nature when birds like eagles have tiny curves at the end of their wings. In the aerospace industry, many commercial aircraft companies incorporate winglets at the tips of wings to improve aerodynamic performance, a practice illustrated shown in figure 28.

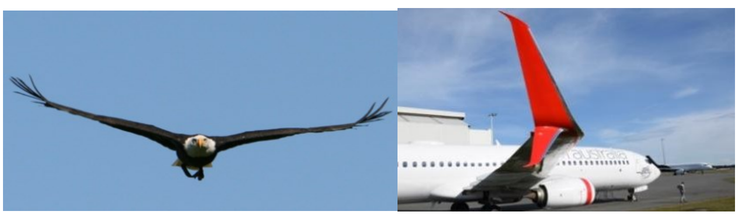

Figure 28. Eagle and Airplane Winglets

To understand the impacts of adding winglets to aircraft airfoils. This study then added winglets to my test aircraft in Solidworks and ran simulations. This study also conducted studies on changing the angle of the winglets to see the effects. After conducting experiments and calculations, this study discovered the lift-to-drag coefficient ratio was 1.13 before adding winglets and increased to 1.38 adding winglets. This shows that adding winglets does assist in improving aerodynamic performance. This study then wanted to conduct simulations on the effect on changing the winglet angle on the aerodynamic performance of an aircraft. This study took the same aircraft that this study used to get the previous results and changed the angle. As shown in figure 29, the first aircraft had a 40° winglet angle, the second had a 30° winglet angle, and the third had 20° winglet angle.

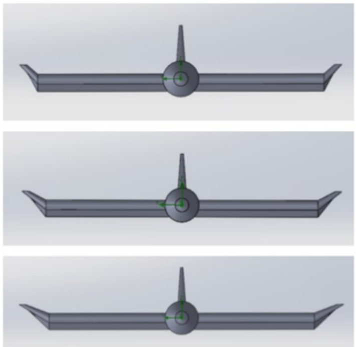

Figure 29. Test Aircrafts with Winglet.

After conducting experiments, the velocity and pressure contours of the different test aircrafts with winglets were once again obtained to give more insights on the effects of winglets on aerodynamic performance.

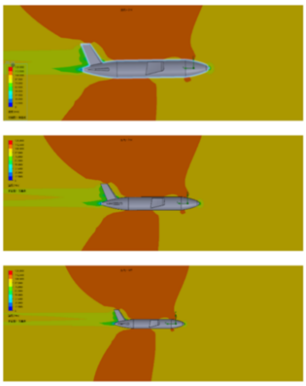

Figure 30. Velocity Contour for Airplanes with Different Winglet Angles

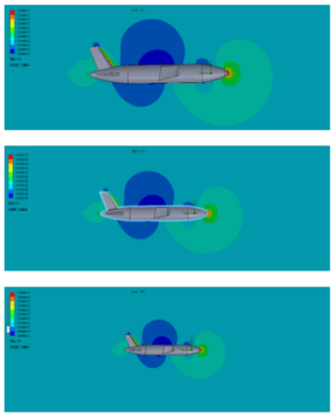

Figure 31. Pressure Contour for Airplanes with Different Winglet Angles

As depicted in figure 30 and figure 31, there is no significant difference between the velocity and pressure contours of the aircrafts with different winglet angles. This implies that winglet angle of aircraft can be modified in various ways without significantly impacting its efficiency.

This observation is further supported by the absence of a discernible trend in the Cl/Cd ratio. The negligible difference in the aerodynamic performance of these aircrafts suggests that any trend is too inconsequential to draw meaningful conclusions. As illustrated by figure 32, at 40° winglet angle which is the highest point, the aerodynamic performance was 0.722 while at 30° winglet angle which is the lowest point, the aerodynamic performance was 0.696. This difference is too insignificant to gain any value from and thus it can be concluded that modifying winglet angle has no significant impact on aerodynamic performance.

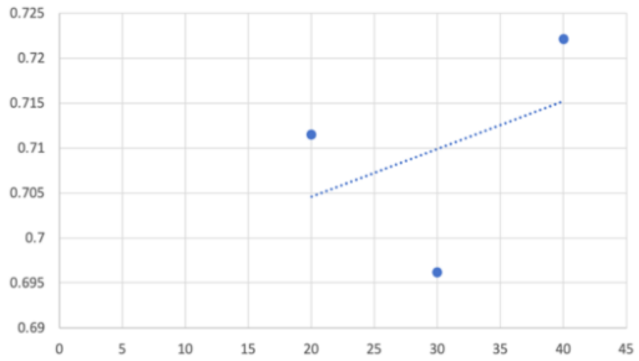

Figure 32. The ratio Cl/Cd with Respect to the Winglet Angle

4. Conclusion & Future Work

4.1. Conclusion

In this study, this study uses the CFD approach to investigate how the airplane wing design affects the aerodynamic performance of the airplane. Three parameters are investigated: the wing angle of attack, the wing length, and the winglets. The results indicate that, for the current airplane model, the optimal aerodynamic performance of an aircraft is achieved when the angle of attack is set at 20°. Furthermore, for the current airplane model, the experiment suggests that the most effective wing length for enhancing aerodynamic performance is 7m. Additionally, the study demonstrates that incorporating winglets contributes to improved aerodynamic performance, but the angle of the winglets has minimal impact on the overall efficiency. These findings hold significant implications for society, as aircraft designers can leverage this knowledge to maximize fuel efficiency and payload capacity.

4.2. Future work

I will persist in exploring factors that will affect aerodynamic performance like wing shape. Additionally, this study will create swept wings and delta wings to see their performance in the air. This study also wishes to test many models in different airspeeds to see what different airfoil designs might suit different scenarios. Moreover, my curiosity extends to understanding why high-speed aircraft, such as jets and space shuttles, seldom incorporate winglets. This inquiry stems from the hypothesis that fast-moving aircraft require exceedingly low drag for optimal flight, and the potential drag generated by winglets may influence their limited use in such applications.

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