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Performance Analysis of Asymmetrical airfoil for Subsonic flight using XFLR5 software

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Abstract: - Unmanned Aerial Vehicles (UAVs) are rapidly becoming more and more popular due to their ease of use, manoeuvrability and access due to otherwise inaccessible areas. Their performance and stability are dependent upon the airfoil used which is dependent upon the goal of the UAV. Thus, the selection of an airfoil is an important process involved in the design of an UAV. This paper provides a way to select an airfoil for an UAV by using computer simulation and modern technologies.

Key Words: — ***UAVs, Airfoils, Lift, Asymmetrical Airfoil, Payload, XFLR5, XFOIL, Subsonic.***

I. INTRODUCTION

Air transport has increased exponentially in the last few decades due to the rapid technological and economical advancements of today's world. This increase in production and manufacturing of aircraft also requires design engineers capable of designing an optimized aircraft for the required need. Wings are the building blocks of a good aircraft and airfoils are the core component required to craft a well-designed wing. UAVs (Unmanned Aerial Vehicles) require different wings than normal aircraft due to their smaller size and velocity. The design of wings for such aircraft has to be conducted with information from previous investigations on the behaviour of airfoils. An airfoil is the cross-sectional shape of an object that, when moved through a fluid such as air, creates an aerodynamic force. Aerofoils are employed on aircraft as wings to produce lift or as propeller blades to produce thrust. Both these forces are produced perpendicular to the air flow. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag [1]. The earliest serious work on the development of airfoil sections began in the late 1800's. H.F. Phillips patented a series of airfoil shapes in 1884. They were tested in one of the earliest wind tunnels in which "artificial currents of air were produced from induction by a steam jet in a wooden trunk or conduit." [2]. A wide range of airfoils was developed, and they were tested by National Advisory Committee for Aeronautics (NACA). Now, the modern aerofoil database is available in UIUC Aerofoil Coordinates database [3]. The designers have not yet settled for the best Aerofoil. The reasons for the modern airfoils look quite different from one another are that the flow conditions and the design goals change from one application to the next. Aerofoil designs for subsonic flight are different from supersonic flight. Subsonic flight airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with a symmetric curvature of upper and lower surfaces.

II. LITERATURE REVIEW

Performance analysis of an airfoil is conducted either experimentally or mathematically with the aid of computers. The estimation of an airfoil for design purposes is usually carried out using computers as it is far cheaper and easier than experimental techniques. Comparison of the mathematical results with the experimental results for the NACA 4416 airfoil were carried out by Jahangir Alam et al and explained about the fabrication of a UAV with a wing in the shape of a NACA 4416 airfoil [4]. Khanh Hieu Ngo and Thien Loc Huynh have conducted computational analyses on multiple symmetrical airfoils for unmanned aerial vehicles, verified their fidelity and have ranked the best suitable airfoils. They have used XFLR5 and JavaFoil to obtain their results [5]. Karaca et al investigated the the drag to lift ratio for airfoils through simulation-based approach for nonlinear dynamical modelling using case studies involving NACA 23012 airfoils. The flow around the airfoils was studied via numerical solutions of the 2D Navier–Stokes (NS) equations [6]. Presence of sharp or abrupt changes in the curvature of the airfoil could cause premature flow separation of the air from the airfoil, which results in much lower aerodynamic performance than expected. This is observed by an experimental investigation that Nazmul Haque conducted to explore better aerodynamic performance by incorporating curvature at the leading edge of a wing. A wooden model with straight leading and trailing edge i.e. rectangular planform and another model with curved leading edge and straight trailing edge were prepared with NACA 4412 airfoil in equal length (span) and surface area. Both the models were tested in a closed-circuit wind tunnel. It is found that the curved leading-edge wing planform is having higher lift coefficient and lower drag coefficient than the rectangular wing planform [7]. Arunvinthan and Nadaraja Pillai performed a series of wind tunnel tests to investigate the effect of turbulent inflows on the aerodynamic characteristics of the unsymmetrical airfoil at various turbulence intensities and Reynolds number. To assess the aerodynamic characteristics, surface pressure measurements were made over the unsymmetrical airfoil surface by using a simultaneous pressure scanner MPS4264 of Scanivalve make. It is found that the coefficient of lift increases with the increase in the turbulence intensity. The influence of turbulence on the aerodynamic hysteresis was also studied [8]. Shahid khan et al validated a newly designed low Reynolds number airfoil using direct design method in Xflr open source software. UIUC airfoil coordinates database is taken for the reference airfoil SS007 and, S1223 and E423. Using Xfoil parameters, panel code the airfoil parameters like thickness, camber, camber location is optimized at different Reynolds number ranging from 3.42*105 to 10.28*105 at different angle of attacks. The characteristics of new airfoil are analysed and validated from the reference airfoil SS007 which can produce a lift of 2.56 and high L/D ratio at stall angle [9].

Very few literatures are only available on the performance characteristics of high-lift, low-pitching moment asymmetrical Chuch Hollinger CH 10-48-13 airfoil for subsonic flight. In this study, the performance of asymmetrical Chuch Hollinger CH 10-48-13 airfoil for subsonic flight has been investigated using XFLR5 software.

III. Selection Of Airfoil

Airfoils are of two different types based on the mean camber and the chord line. An airfoil with no camber is known as a symmetrical airfoil and produces lift evenly on both sides and even when flying inverted. The airfoils present in stabilizers and rudders must be of symmetrical nature to avoid the aircraft from swaying too far to the right or the left without any manual input. The other type of airfoil is an asymmetrical airfoil which has a camber from the mean chord line. These types of airfoils produce uneven lift and are much better than symmetrical airfoils when used for conventional aircraft. They are commonly used in the wing section of the aircraft to produce more lift than symmetrical wings. Asymmetrical airfoils do not produce lift when the aircraft is inverted. Thus, only symmetrical airfoils are used for acrobatic aircraft. These factors influence the selection of the type of aircraft to be used greatly. Before the design and analysis process is started, preliminary calculations and estimations have to be made which are vital for the selection of an airfoil. The calculation of air density at higher altitudes and different temperatures can be calculated using the state equation.

The temperature of the atmosphere in which the aircraft must be flown is taken as the average of the temperature values in which the aircraft is estimated to be operated based on previously available meteorological data. For our purposes the pressure is 8.988 N/mm2. The universal gas constant is known to be a constant and then the density of the air can be calculated using the state equation. This equation gives the density of air in which the aircraft is to be flown. The flow characteristics of the aircraft is given by a non-dimensional number known as Reynold's number. This can be calculated using the equation:

$$Re = \frac{\rho v l}{\mu} \qquad (1)$$

Where,

ρ = Density of the fluid

v = Velocity of the fluid

l = length in contact with the fluid

μ = Dynamic viscosity of the fluid

The velocity of the flow is equal to the velocity of the object moving in a fluid and therefore, the velocity at which the aircraft moves is estimated manually. For demonstration purposes the flow velocity is taken as 25 ms−1. The dynamic viscosity of the atmosphere can also be determined from the atmospheric table. The length of the wing in contact is given by the chord width or chord length. The chord length is chosen with respect to an aspect ratio. The aspect ratio of an aircraft affects the performance and stability to a great extent. The aspect ratio chosen for demonstration is 6. This gives the flow field characteristics of the atmosphere in which the aircraft is to be flown. The airfoil must be analyzed and selected for optimum performance and stability for the required Reynold's number which is 513,760.

Based on the Reynold's number and from the literature the following airfoils were selected for analysis: NACA 0010, Selig/Donovan SD8020 and Chuch Hollinger CH 10-48-13.

IV. Method

The pressure drop across the airfoil is based on fundamental fluid mechanics phenomena such as Bernoulli's principle Newton's law of viscosity. The pressure gradient is explained by the difference in both static and dynamic pressures of the upper and lower airstreams due to the curved nature of the airfoil. This can be explained mathematically using the Bernoulli's equation:

$$\frac{P_1}{\rho} + \frac{v_1^2}{2} + gz_1 = \frac{P_2}{\rho} + \frac{v_2^2}{2} + gz_2 \qquad (2)$$

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The pressures P_1, P_2 are the static pressures of the airstreams above and below the airfoil respectively.

The second terms of the equation with half the velocity squared indicate the dynamic pressure of the respective airstreams.

The final terms indicate the pressure due to the gravitational head and it is affected by the difference in datum lines.

The total pressure of a fluid is known as the sum of its static pressure, dynamic pressure and the pressure due to the gravitational head.

$$P_{total} = P_{dynamic} + P_{static} + P_{gravitational} \quad (3)$$

This total pressure is constant across all airstreams in a closed system. Considering the area around the airfoil and the airstreams surrounding the airfoil as a closed system, the total pressure of the airstreams above and below can be estimated to be equal.

The velocities of the airstreams are known as the velocity of the airfoil determines the airstream velocity. Using this data, the static pressure of the airstream at a point can be calculated by the data obtained from the dynamic and gravitational components of pressure. The difference in this pressure is drawn in a graph and can be used to explain the lifting and drag characteristics of an airfoil.

For the selected airfoils, the freestream velocity, Reynold's number, density and aspect ratio were given as the input parameters to the XFLR5 software. For the given input, the coefficient of lift has been found out with respect to the angle of attack. The coefficient of lift is an essential parameter for the effective performance of the flight.

V. Results And Discussion

The analysis and design process are then performed using a free software called XFLR5 [3] with XFOIL [8] as the source code. The Reynold's number is entered and also the angle of attack at which the aircraft is estimated to be flown is also entered. Then the following important graphs are obtained.

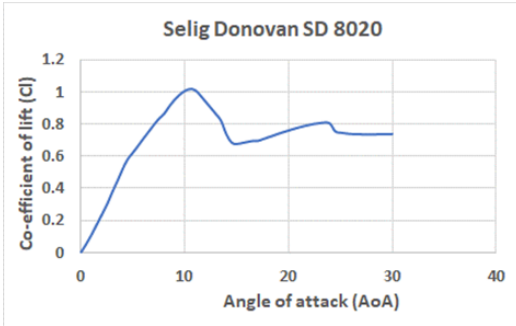

Fig.1. Cl vs Alpha (Selig/Donovan SD8020)

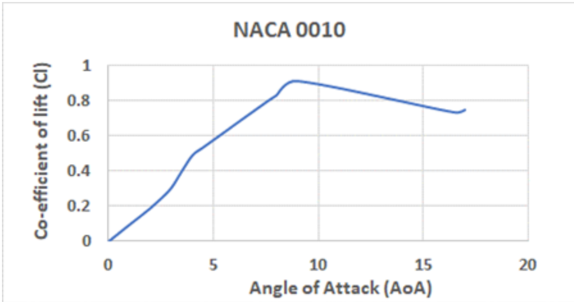

Fig.2. Cl vs Alpha (NACA 0010)

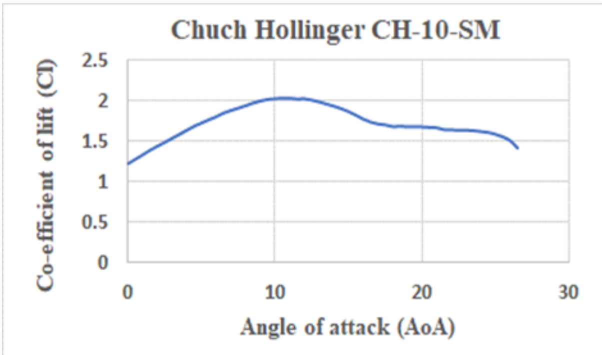

Fig.3. Cl vs Alpha (Chuch Hollinger CH 10-48-13)

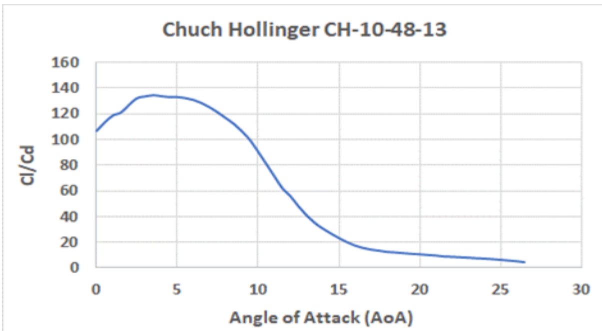

Fig.4. Cl/Cd vs Alpha (CH 10-48-13)

The coefficient of lift and drag are the two most commonly used parameters in the design of an aircraft. The ratio of the coefficient of lift to the coefficient of drag gives the aerodynamic efficiency. The greater the aerodynamic efficiency, the greater the performance of the aircraft. The maximum angle of attack the aircraft can reach safely without stalling is given by the Cl Vs Alpha curve. The drop in the curve of the Cl Vs Alpha curve denotes stalling. For asymmetrical airfoils stalling completely stunts further flight of the aircraft and causes failure of the aircraft. The maximum angle of attack at which the aircraft is to be flown is given by the Cl/Cd vs Alpha curve. The coefficient of drag can be calculated from the Cl Vs Cd graph shown for the given conditions. The stability of an aircraft can be partially determined from the shown graphs. The pitching moment coefficient has to be negative and be decreasing with increase in angle of attack. This cannot be completely determined as the airfoil is a two-dimensional object with no thickness and a wing has very different pitching moment characteristics than its airfoil based on the wingspan. The drag and lift forces exerted by the fluid medium on the object can be determined.

From the Cl vs alpha curve of the Selig/Donovan SD8020 airfoil the maximum coefficient of lift at the stalling angle of 10° is noted to be 1. The coefficient of lift of the NACA 0010 airfoil at the stalling angle of about 8° is 0.9. The coefficient of the lift of the Chuch Hollinger CH 10-48-13 is 2 at a stalling angle of about 10°. The coefficient of lift for the Chuch Hollinger CH 10-48-13 is the highest among the three airfoils with an almost 200% difference in the coefficient of lift. This gives the best lift performance for the specified input parameters.

The results were compared for different airfoils and the characteristics of the airfoil which matched the purpose of the UAV was selected. The design goal was to create an UAV that could carry a high payload at subsonic speeds at low angles of attack. The higher coefficient of lift at low angles of attack and low Reynold's number is required for an UAV which carries a heavy payload. The airfoil with the best aerodynamic performance (high Cl at different angles of attack) was selected among the simulated airfoils, which is the Chuch Hollinger CH 10-48-13.

VI. Conclusion

Three different airfoils, NACA 0010, Selig/Donovan SD8020 and Chuch Hollinger CH 10-48-13 were simulated for subsonic, low Reynold's number flight and their results were compared. For an UAV carrying heavy payloads, the Chuch Hollinger CH-10-48-13 has the desirable characteristics due to its higher coefficient of lift at low angles of attack. Thus, the Chuch Hollinger CH 10-48-13 is a very good choice for an airfoil to be used in a cargo carrying UAV.

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