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INVESTIGATION OF AERODYNAMIC PERFORMANCE OF AIRBUS A380 AIRCRAFT USING WIND TUNNEL

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ABSTRACT

Airbus A380, propelled by four turbofan engines, is the world's largest passenger airliner by capacity manufactured by Airbus. It has made its first flight on 27th April 2005 and entered into service on 25th October 2007 with Singapore airlines. Being a double decker, it can accommodate 525 passengers in a three class configuration or up to 853 passengers in economy class configuration. Since its prototype till November 2018, Airbus has successfully delivered 232 aircrafts to their customers and had also received 331 firm orders for further manufacturing. It has a range of 15,700 km and a cruising speed of Mach 0.85. The airplane is a good combination of high strength and low weight, which is ensured by aluminium alloys and composite materials used in its construction. The aerodynamics associated with such a wide body, double deck, aircraft is of interest and needs attention in order to design its successor, which is still awaited and the aeronautical engineers are currently working for. In this paper, an attempt is made to experimentally investigate the aerodynamic performance of scaled down balsa wood model of A380 aircraft using low speed subsonic wind tunnel. The efficiency of the design is estimated in terms of lift coefficient measured at various angles of attack (0^0, 5^0, 10^0, 15^o and 18^o). The flow visualization is done using tufts and smoke on the surface of the model with and without winglets to understand the nature of free-stream flow over the complete body, effectiveness of the wing planform and significance of winglets.

Keywords: *Airbus A380, aerodynamics, lift coefficient, angle of attack, wind tunnel, winglets, flow visualization*

I. INTRODUCTION

The world's largest passenger airliner, A380 from Airbus made its first flight on 27^{th} April 2005 and started its commercial service with Singapore Airlines on 25^{th} October 2007. This double deck and a wide body design was a challenge to Boeing's monopoly in the large aircraft market on the basis of capacity to accommodate maximum passengers. The A380 is equipped with four turbofan engines-Rolls Royce Trent 900 or the Engine Alliance GP7000 are the available power plant configurations. The upper deck of the fuselage, which extends to about 70.4 m, is narrower as compared to the lower deck but still remains comparable in dimensions with other airliners. The wing is designed for a maximum takeoff weight of over 650 tonnes, installed with fences (winglets) at the wingtip to reduce induced drag which in turn enhances fuel efficiency. The wingspan of the aircraft is 79.75 m with an aspect ratio of 7.8 [1].

Despite of its wide shape, it has a good combination of better aerodynamics and lower airframe weight, which is ensured by the use of aluminium alloys and composite materials like carbon-fibre reinforced plastic, glass fibre reinforced plastic and quartz-fibre reinforced plastic in its construction. It is also the first airliner having central wing made up of carbon fibre reinforced plastic [2]. Each turbofan engine produces around 70,000 pounds of thrust. Maximum range is about 15000 km with a cruising speed and cruising altitude of about 0.85 and 13 km respectively [3].

To design such an airliner (Fig. 1) was a challenge to the aircraft designers since very sharp skills were required to avoid a compromise between an aircraft body that requires to be spaciously designed and the aerodynamic performance associated with it. The present study deals with the analysis of A380's aerodynamic performance for a given free stream flight conditions using the scaled down model in low speed subsonic wind tunnel and visualizing the flow over the same using tufts and smoke to understand the effectiveness of the winglets. The author believes that this experimental work can motivate the students, academicians and enthusiasts having interest in the aerospace field to study and take the work ahead to contribute the aerospace community for the development of more sophisticated designs.

Fig. 1. Airbus A380 [4]

II. THEORY

Aerodynamic, propulsive and the self weight are the forces which act on an aircraft during its flight. Lift is the component of aerodynamic force that pulls the aircraft in upward direction against the gravitational force. Wing is the main lifting surface and is composed of several airfoil cross-sections distributed along its span. When the air flows over these airfoils, lift is generated because of the higher air pressure existing below the wing and lower above the wing. The pressure distribution on the surface is governed by Bernoulli's theorem, which states that an increase in velocity leads to decrease in pressure. The various components of the resultant aerodynamic force acting on the airfoil at an angle of attack (α), is shown in the Fig. 2.

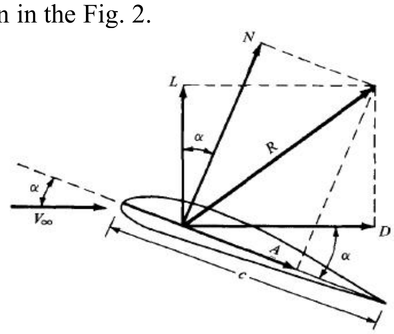

Fig. 2. Components of the aerodynamic force [5]

Fig. 3.

Lift can be seen to be acting perpendicular to the direction of the oncoming air (freestream) and is given by equation 1, while drag opposes the forward motion of an aircraft and acts parallel to the direction of freestream.

$$L = Ncos\alpha - Asin\alpha \qquad (1)$$

$$D = Nsin\alpha + Acos\alpha \qquad (2)$$

To achieve the higher lifting force, engineers carefully design the airfoil or select the profile from NACA airfoil series as per the requirement of their aircraft. The efficiency of the airfoil depends on its lift coefficient value at different angles of attack. Airfoil with higher lift coefficient (or L/D) not only promises better aerodynamic performance but also improves other static and dynamic performance parameters [6] of the aircraft such as minimum thrust and power required, minimum stalling velocity etc. The maximum value of lift coefficient is limited by a stalling angle of attack, beyond which the flow separates away from the surface and no more lift exist on the wing. However, lift coefficient may be increased by using high lift devices at the time of takeoff and landing.

Parasite drag, induced drag and the wave drag are also required to be taken care of and should be kept at minimum in order to get higher lift to drag ratio. The drag reduces both the lift generated and thrust available from the engine. Now the days, aircraft's wing incorporates winglets at the wingtip to reduce the intensity of the wake vortices [7]. This helps in minimizing the induced drag and improves the lift distribution throughout the wing span.

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III. EXPERIMENTAL

The low speed subsonic wind tunnel (Fig. 3) of Aerodynamics Lab, Amity University Lucknow Campus was used for conducting the aerodynamic analysis. It is driven by 3 phase induction motor of 7.5 HP. The dimensions of the cross-sectional area of the test section are 0.30 m X 0.30 m and length is 1.0 m.

Fig. 4. Wind Tunnel setup with multi-tube manometer

The scaled down model of A380 aircraft having a wing span of 0.225 m, made up of balsa wood, can be seen in Fig. 4. It was fabricated using the dimensions available in the literature [1]. For various angle of attack and constant free stream velocity, the lift generated is measured using the force sensors, the setup can be seen in Fig. 5. To measure lift, two sensors are mounted at the tip of the wings and one at the rear tail.

Fig. 5. scaled down model of A380 having wingspan of 0.225 m

Fig. 6.

Velocity of the air inside the test section was calculated using equation (3) [8] by measuring the pressure difference (total and static) of the freestream air with the help of pitot static tube and U tube manometer. The U tube manometer is inclined at an angle of 15^0 from the horizontal plane.

Fig. 7. Model with force sensors inside the test section

$$V = \sqrt{2g\Delta h sin\theta \frac{\rho_{water}}{\rho_{air}}} \quad (3)$$

Where,
$\rho_{air} = 1.207\ Kg/m^3, \rho_{water} = 1000\ Kg/m^3$, $\theta(angle\ of\ inclination\ of\ manometer) = 15^o$ and $\Delta h = difference\ in\ the\ columns\ of\ manometer$ (in m)
Lift acting on the aircraft is given by the following relation [5],

$$L = \frac{1}{2}\rho V_\infty{}^2 S C_L \quad (4)$$

Equation 4 can be rewritten in terms of Lift coefficient as follows

$$C_L = \frac{L}{\frac{1}{2}\rho V_\infty{}^2 S} \quad (5)$$

Where ρ = *density of the freestream in* Kg/m^3, V_∞ = *velocity of the freestream in m/s, L=lift in Newton,* C_L = *lift coefficient, S= wing area in* m^2

The wing area of the aircraft model having a trapezoidal planform is calculated using Equation (6) [9] given below,

$$S = \frac{b}{2}(C_t + C_r) \quad (6)$$

Where $b(wing\ span) = 0.225\ m, C_r(root\ chord\ length) = 0.052\ m\ and\ C_t(tail\ chord\ length) = 0.013\ m$
Airbus A380's wing is given a geometric and aerodynamic twist as the airfoil used at the root and tip of the aircraft are different and was approximated as NASA SC (2)-0610 and NASA SC (2)-0606 [10]. Such twisting can delays the flow separation and helps in maintaining the stable flight.

Flow visualization, also being part of the present study, is done specifically over wing of the model with and without winglets. Although several methods for visualizing the flow past the body exists but in the present work, only two methods [11], tufts (at the trailing edge of the wing) and smoke have been introduced over the model to understand the nature of the flow at 0^o and 18^o angle of attack, region of wing tip wake vortices, separated flows and contribution of winglets.

IV. RESULTS AND DISCUSSION

The lift measured for five different angles of attack (0^o, 5^o, 10^o, 15^o and 18^o) at constant free stream velocity of 27.82 m/s is shown in Table I. Lift coefficient is calculated using equation (5). Manometer readings which were used along with equation (3) to estimate the velocity of the flow field can be seen in Table II. It was observed during velocity measurement that location of the pitot tube inside the test section plays an important role and must be placed at the centre of the flow away from the tunnel wall.

Fig. 6 shows a plot between lift coefficient and angle of attack. It can be inferred from the trend line of C_L Vs α plot that lift coefficient first increases linearly with the angle of attack, reaches a maximum value of 1.59 around 12° (known as stalling angle or critical angle of attack), and then decreases due to flow separation over the wings. Also, it can be noted that the lift coefficient at an alpha of zero degree is 0.4450, a non-zero value, as it was expected from the aircraft having a wing of cambered airfoil cross-section.

TABLE I. EXPERIMENTAL DATA

Angle of Attack, α (Degree)	Lift (Newton)	Lift Coefficient, C_L
0^0	1.520	0.4450
5^0	4.659	1.3640
10^0	5.199	1.5221
15^0	4.610	1.3497
18^0	4.169	1.2206

TABLE II. MANOMETER READING

h_1 (m)	h_2(m)	Δh(m)
0.287	0.103	0.184

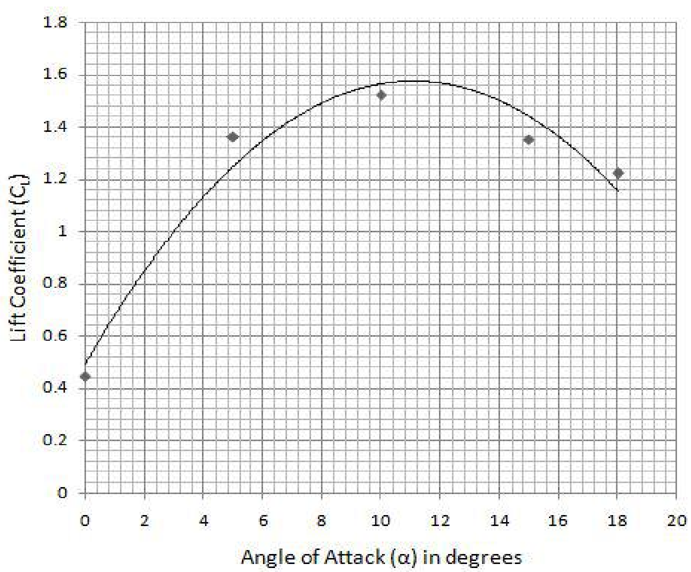
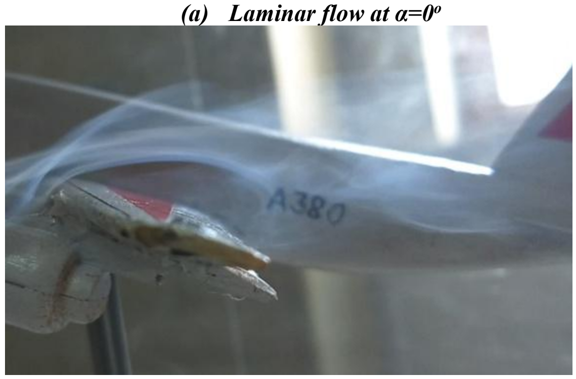


Fig. 8. Lift Coefficient Vs Angle of Attack

Fig. 9.

In order to visualize the flow, smoke was introduced near the wing. The nature of the flow over an aircraft at an angle of attack 0° and 18° can be seen in Fig. 7 (a) and (b) respectively. At α=0°, flow being laminar, is following the shape of the wing while at α=18°, flow separation has caused the flow to reverse into the flow field as wakes and resulted into the loss of lift.

(a) Laminar flow at α=0º

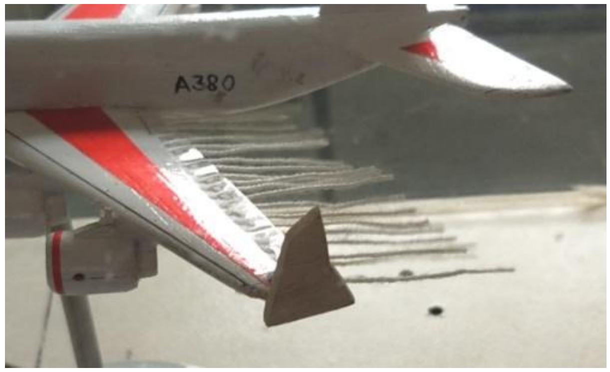


(b) Reverse flow zone at α=18º

Fig. 7. ***Flow Visualization using smoke***

To understand the contribution of winglets, tufts at the trailing edge of the wing was used. It is observed during the experiment that the strength of the wing tip trailing vortices can be reduced or may completely be avoided by using winglets. Fig. 8 (a) and (b) gives a clear understanding of the flow near the wingtip (with and without winglets). The tufts at the wingtip is continuously in disturbed state due to the trailing vortices originating from the wing with no winglets installed while rest at its mean position after the winglets was installed.

(a) No Winglet



(b) With Winglet

Fig. 8. Flow visualization using tufts

V. CONCLUSIONS

The lift coefficient for various angles of attack has been estimated and is tabulated in Table I. The value of C_L at zero degree angle of attack is found to be 0.4450 while it reaches its maximum value of 1.59 at a critical angle of attack around 12^o. The flow visualization methods used in the present study have been successful in giving clear picture of the behavior of the flow and have helped in understanding the significance of the winglets.

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