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Experimental Investigation to Study Flow & Heat Transfer Characteristics over A NACA0018 Aerofoil

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ABSTRACT: Experiments are carried out to study flow and heat transfer characteristics over NACA0018 Aerofoil when the body approaching the wall of a wind tunnel. Investigations have been done to study the effect of wall proximity due to flow separation around the body at Reynolds number 2.5×10^5, different height ratios and various angles of attack. Pressure coefficient values are decreases and then increases on the lower surface of the Aerofoil and decreases on the upper surface of the aerofoil at all angles of attack. The negative pressure coefficient and drag coefficient decreases as the body approaches the upper wall of wind tunnel . The local as well as average Nusselt number decreases as the height ratio decreases for all non-dimensional distance and angles of attack respectively.

Keywords: *Height-ratio, Angle of attack, Pressure Coefficient, Drag coefficient, Nusselt number.*

I. INTRODUCTION

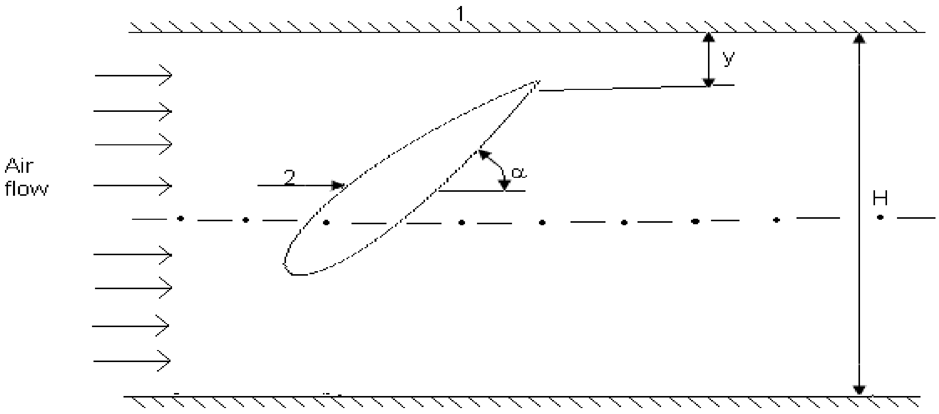
Many studies have been performed for flow and heat transfer characteristics over bluff bodies such as sphere, cylinder, square and rectangle prisms. The important characteristic of flow over a bluff bobby is the nature of boundary layer. As the stream lines pass over a bluff body, separation takes place due to excessive loss of momentum at adverse pressure gradient from a point, which is not far away from the leading edge. Forced convective heat transfer studies are carried out between the exterior surface of bluff bodies, which are important in number of fields such as heat exchangers, gas turbine blades, aircraft wings and cooling of electronic equipment. Brundage, A.L., et al., [1] conducted experiments to study trailing edge heat transfer and aerodynamic losses at realistic free stream mach numbers. Here a coolant was injected through a slot to know the thermal phenomena at trailing edge. Investigation on fluid flow and heat transfer characteristics for a square prism has been conducted by Chakrabarthy, D., Brahma, R., [2]. Here it was observed that the drag coefficient decreases with increase in angle of attack as the height ratio decreases. From the heat transfer experiments, it was revealed that Nusselt number decreases as the height ratio decreases for all non-dimensional distance and angles of attack respectively. The flow characteristics around an inclined elliptic cylinder were investigated by Choi, J.H., Lee, S.J., [3]. In this, they have found that at negative angles of attack, the boundary layer near the wall becomes disturbed more than for positive angles of attack. Dipes chakrabarty [4] has conducted experiments to study flow and heat transfer characteristics from a rectangular prism. In this, the variation of pressure coefficient has been shown with non dimensional distance for different height ratios and different angles of attack. The pressure distribution shows positive values on the front face and negative values on the rear face. From the heat transfer experiments, it was concluded that the local as well as average Nusselt number decreases as the height ratio decreases for all non-dimensional distance and angles of attack respectively. Experimental investigation of heat transfer coefficients for forced convection from a NACA-63421 airfoil was conducted by wang.X. et al. [5]. In this, new correlations for Nusselt number were developed to predict convective heat transfer from aero foils. The computational and experimental investigations were carried for low Reynolds number flows over SD 7003 aerofoil to predict transition by Yuan, et al., [6].

From the literature it appears that the experimental investigations on fluid flow and heat transfer characteristics over an airfoil surface by varying the distance from wall (i.e. considering wall effect) with different angles of attack have not been adequately covered. In the present work experimental investigations are carried out to determine pressure and drag coefficients over an airfoil surface from the measurement of pressure distribution and drag forces for different angles of incidence and for different height ratios. An attempt has also been made to determine heat transfer rates from the measurement of temperature distribution around the airfoil for the same conditions.

II. EXPERIMENTAL SET UP AND TECHNIQUE

Experiments are carried out in a wind tunnel and the details are as follows :

The wind tunnel is of suction type with an axial flow fan driven by a variable speed DC motor. It consists of an entrance section with a bell mouth inlet containing a flow straightener, screens and a straw honey comb. This section is followed by a 6.25:1 contraction section, the test section, a diffuser and the duct containing the axial flow fan. The whole unit is supported on steel frames. The complete wind tunnel except the test section is constructed of mild steel iron sheets for strength and rigidity. The test section is made of teak wood and has glass window for visual observation of flow phenomena. The control of the DC motor is by a rectifier controlled variable speed drive. Reynolds number up to 25, 00,000 can be achieved with this tunnel. The experiment has been carried out in subsonic wind tunnel with a test section 300 mm high 300mm wide and 800 mm long. The aerofoil has been fixed along the width of the test section. Position of the airfoil with respect to upper wall of wind tunnel has been shown in the fig.1.



1. Upper wall of the wind tunnel 2. Aerofoil

Fig.1: Schematic diagram showing the position of the airfoil in the test section

A clamp with holes has been made and fixed along the side wall of the test section for lifting the airfoil from centre towards upper wall of the wind tunnel to investigate the wall effect on fluid flow and heat transfer characteristics. Measurement of free stream velocity is performed using a Pitot tube and with a linkage mechanism transducer to determine drag force. A protractor is attached to the airfoil and is fitted in the side wall of the wind tunnel to measure the angle of rotation of the airfoil.

2.1 Aerofoil details

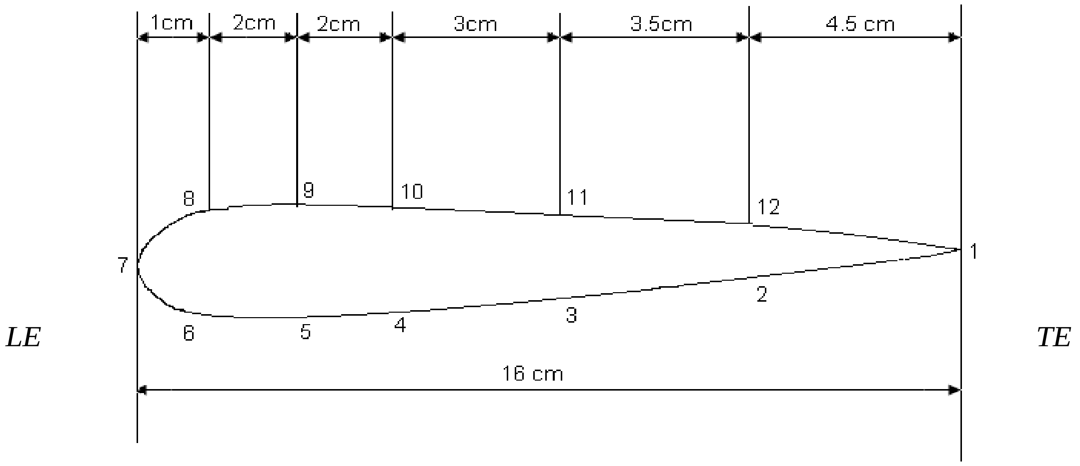


Fig.2: Aerofoil details

A test model of NACA0018 aerofoil has been selected for this study. The aerofoil is made of aluminum material with a chord of 16cm and a span of 25cm. The fig.2 shows the details of aerofoil. Holes of 12 number of each 1mm diameter are drilled on the upper and lower surfaces of the airfoil. Flexible tubes are fixed at these 12 locations and connected to multitube manometer for measurement of static pressure distribution. The measurements are taken for the following parameters.

(a)Angle of attack (α) = 0^0 - 40^0 for flow characteristics & 0^0 - 60^0 for heat transfer characteristics (b) Height ratios (y/H)) = 0.5, 0.33, 0.167and (c) Reynolds number = 2.5×10^5

Heat transfer experiment has been done under constant heat flux condition. Constant heat flux condition has been maintained by supplying electric power to the heating coil. The purpose of the present investigation is to measure the local temperature distribution on the surface of the aerofoil at steady state condition by 12 thermocouples at different points for calculation of local heat transfer coefficient and Nusselt number. Copper-iron thermo couples are soldered at different points on the surface of the airfoil. Thermo couple wires are brought out and connected to digital meters to note down the temperatures.

III. RESULTS AND DISCUSSIONS

3.1 Fluid flow characteristics

The flow characteristics around a NACA0018 airfoil have been studied by measuring the pressure distribution on the upper and lower surfaces. From the results it is observed that pressure distribution varies with the non dimensional distance as well as with the position of the airfoil with respect to upper wall.

The pressure coefficient, C_P values are determined using the following relation.

$$C_p = (P_a - P)/q \tag{1}$$

Where q = difference of manometer reading in cm.

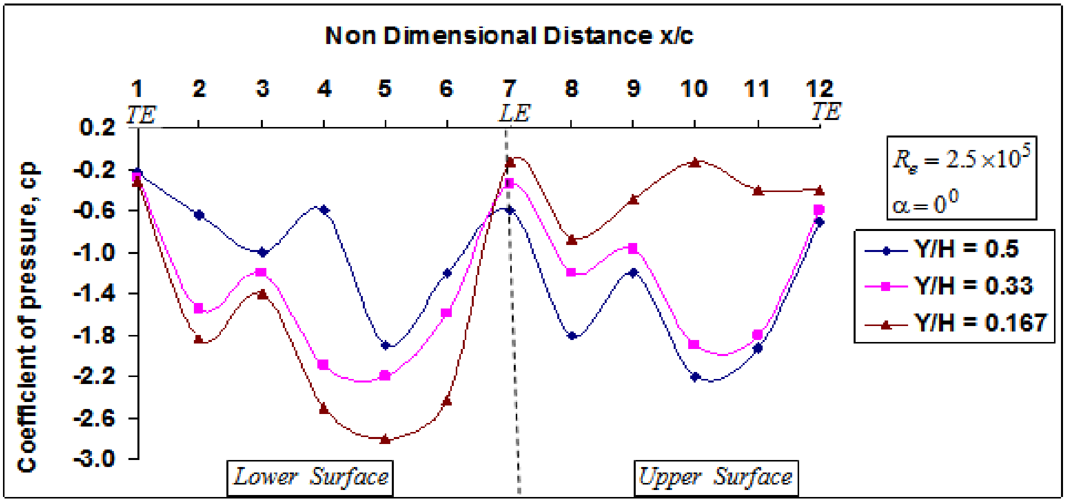


Fig.3: Variation of pressure coefficient with non dimensional distance at different height ratios (α=0°)

Fig.3 shows the variation of pressure coefficient with non-dimensional distance at different height ratios (i.e., y/H=0.5, 0.33, 0.167) for an angle of attack 0^0.It is observed that pressure coefficient decreases from leading edge to a non dimensional distance of 0.18 and then increases up to trailing edge on the lower surface of the airfoil. On the upper surface pressure coefficient decreases from leading edge to a non-dimensional distance of 0.31 and then increases up to trailing edge for a height ratio of y/H=0.5. The same behavior is observed for height ratio of y/H=0.33 and y/H=0.167 on the lower surface and a different behavior observed on the upper surface of the airfoil where pressure coefficient first increases and then decreases for height ratio of y/H=0.167.

Almost similar trend is observed for angles of attack 20^0 and 40^0 at different height ratios (i.e., y/H=0.5, 0.33, 0.167). By a careful examination we may find the following characteristics. (1)Pressure coefficient decreases and then increases on the lower surface of the aerofoil(2)On the most part of the upper surface pressure coefficient decreases due to flow separation and at very nearer to the TE slight increase in pressure coefficient observed due to flow re-attachment and pressure recovery(3) The pressure coefficient values are increased for almost all the points as the airfoil approaches towards the upper wall i.e. the value of y/H decreases on the upper surface, but the trend is reverse on the lower surface.

The drag coefficient values are determined using the following relations. The air flow velocity is determined from Pitot tube using the equation

$$v = 13\sqrt{q} \qquad (2)$$

The coefficient of drag, C_D is determined using the following relation for the air foil at different velocities v and angles of attack α.

$$C_D = \frac{2F_D}{\rho A V^2} \qquad (3)$$

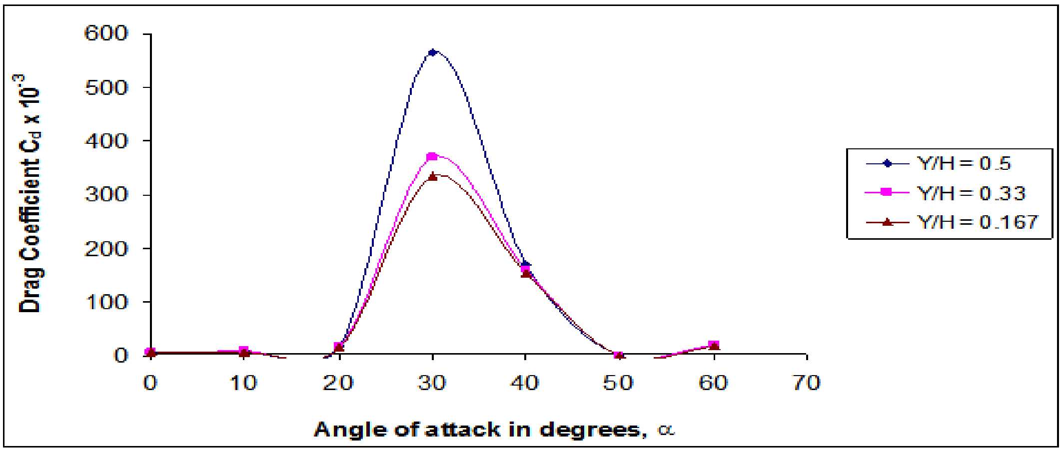


Fig.4: Variation of drag coefficient with angle of attack at different height ratios

Fig. 4 shows the variation of drag coefficient (C_D) with the angle of attack (α) for different height ratios (y/H) (i.e. y/H=0.5, 0.33, 0.167) at R_e=2.5 x 10^5. It is observed that as the value of y/H decreases the value of C_D also decreases for all angles of attack i.e. when the body has been approaching towards the upper wall, the value of drag coefficient decreases. The value of C_D is maximum at $\alpha = 30^o$.

From the plot between pressure coefficients versus non-dimensional distance, it is observed that as the body approaches towards the upper wall, the negative pressure coefficient and from the plot between drag coefficients versus angle of attack, the drag coefficient decreases. It is due to inter action with the boundary layer on the upper wall of the wind tunnel, the stream line patterns changes and the area under the separation zone at the upper surface of the airfoil decreases.

Also it is observed that the coefficient of drag (C_D) is maximum when the angle of attack is 30^0 from the graph between coefficient of drag (C_D) and angle of attack. This is due to fact that area of the bluff body (Aerofoil) is under maximum separation zone in that orientation.

3.2 Heat transfer characteristics

Heat transfer experiments have been carried out under constant heat flux condition. Heat flux has been calculated from the heat input divided by projected area of the aerofoil. The chord length of the airfoil has been taken as the characteristic length for the definition of the Nussult number. Temperatures on the surface of the foil are noted down using thermocouples at 12 points longitudinally along the chord.

Mean temperature can be calculated using the formula

$$T_m = \underset{n=i}{\overset{n=12}{\varepsilon}} Ti/n \qquad (4)$$

Neglecting radiating heat loss from the surface of the air foil, the local convective heat transfer coefficient is calculated using the formula

$$h_x = \frac{Q}{A\Delta T} \qquad (5)$$

Where Q = Heat Input, A is the projected area of the airfoil surface and ΔT is the temperature difference between the foil surface and the surrounding. Then local Nusselt number, Nu_x is calculated from the equation,

$$Nu_x = \frac{L_C h_x}{K} \qquad (6)$$

Local and average Nusselt numbers have been plotted for various angles of attack and height ratios for the aerofoil.

Figure 5 shows the variation of local Nusselt number (Nu_x) with the non dimensional distance (x/c) at α= 0^0.

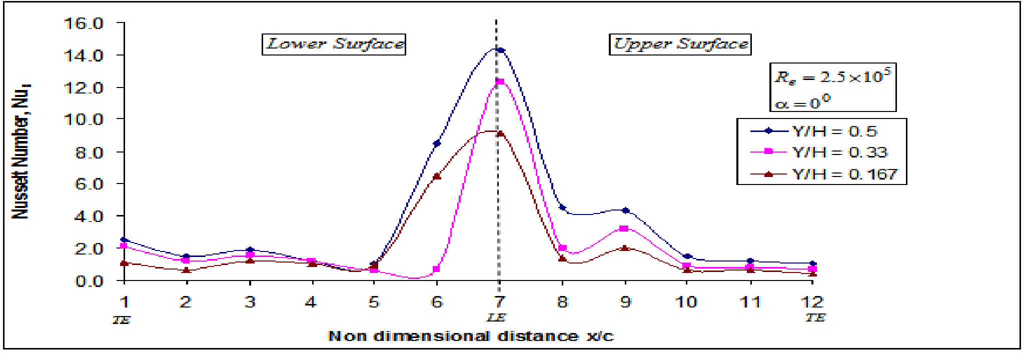


Fig.5: Variation of Nussselt number with non dimensional distance at different height ratios (α=0°)

In the fig. 5, for an angle of attack 0^0, the value of local Nusselt number ($Nu_{x)}$ decreases from the leading edge up to some point of thermo couples and then increases towards Trailing Edge on the lower surface of the aerofoil. And the local Nusselt number first decreases then increases up to certain value of x/c and then decreases on the upper surface of the aerofoil at a height ratio of y/H=0.5. Same nature is observed for y/H=0.33 and 0.167 and it is observed that the Nusselt number values are decreases as the bluff body approaches the upper wall of the wind tunnel. Almost all similar behavior is observed for the angles of attack 20^0 , 40^0 and 60°.

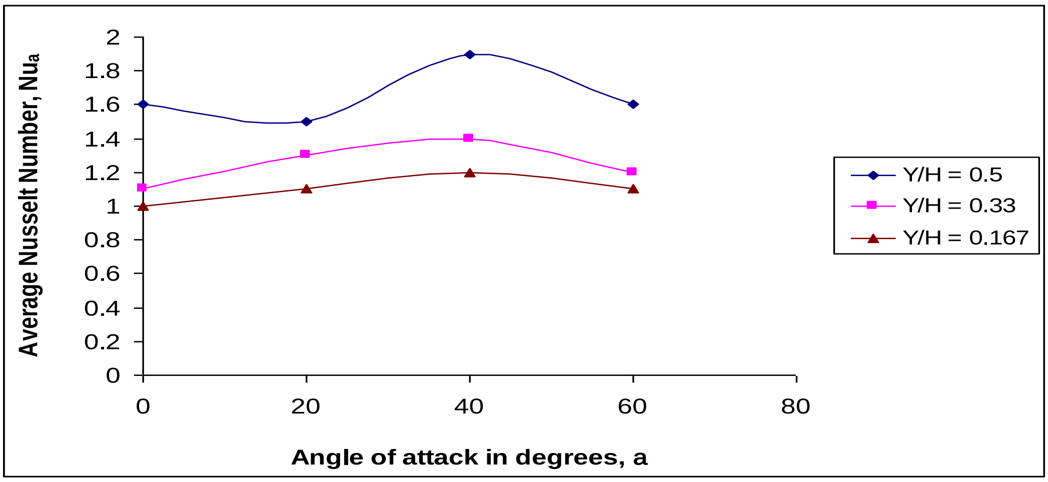


Fig.6: Variation of Average Nussselt number with angle of attack at different height ratios

Fig.6 shows the plot of average Nusselt number Nu_a with various angles of attack (α) at different height ratios (i.e. y/H=0.5, 0.33 and 0.167) for $R_e = 2.5\times10^5$. The maximum value of Nu_a has been observed at $\alpha = 40^o$. The average value of Nusselt number for all angles of attack decreases as the airfoil approaches towards the upper wall. Regarding the heat transfer experiment, the value of heat transfer coefficient decreases as the body approaches towards the upper wall of the wind tunnel as the area under separation zone decreases.

IV. CONCLUSIONS

The flow and heat transfer characteristics of NACA 0018 aerofoil were investigated experimentally by varying the distance from the wall (i.e. considering wall effect). The angle of attack was varied in the range of $0^0 \le \alpha \le 60^o$ for different height ratios (i.e. 0.5, 0.33, and 0.167) at Reynolds number 2.5×10^5. From the flow characteristics, it was concluded that pressure distribution varies with the non-dimensional distance as well as with the position of the Airfoil with respect to upper wall. It was observed that negative pressure coefficient values are decreases as the body approaches the upper wall of the wind tunnel and coefficient of drag decreases as the height ratio decreases. The value of C_D is maximum when α= 30^0. From the heat transfer characteristics, it was concluded that local and average Nusselt number decreases as the aerofoil approaches the upper wall of the wind tunnel for all the angles of attack. The maximum value of Nu_a has been observed at $\alpha = 40^o$.

Nomenclature

A	Projected area of Airfoil, m^2
C_D	drag coefficient
C_P	Pressure coefficient
F_D	drag force, N
h_x	local heat transfer coefficient, w/m^2k
h_a	average heat transfer coefficient, w/m^2k
H	height of the wind tunnel, mm
k	Thermal conductivity, W/mk
L_C	Characteristic length, mm
LE	Leading Edge
Nu_x	Local Nusselt number,
Nu_a	Average Nusselt number
n	No of thermo-couples
P	Static pressure, mm of water
P_a	ambient pressure, mm of water
q	Difference of manometer reading, cm
Q	Convective heat transfer rate, watts
R_e	Reynolds number based on velocity of air and characteristic length of aerofoil
TE	Trailing Edge
T_m	Mean airfoil surface temp, K
Ti	Thermo couple temperature, K
ΔT	Temperature difference between local wall temperature and the Surroundings, K
V	Velocity of air, m/s
Y	distance of the Aerofoil from the upper wall of the wind tunnel
Y/H	height ratio, a non-dimensional number
α	Angle of attack, degrees
ρ	Density of air, kg/m^3
μ	Dynamic viscosity of air, Ns/m^2

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