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Experimental Study of Streamline Generation over an Aerofoil in a Free Wind Stream in Wind Tunnel

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Abstract—*Study of aerofoil has been of profound impact in the field of aerodynamics especially new aerofoil sections as its use leads to the enhancement of aerodynamic properties of various vehicles and instruments. The aerodynamic properties of any aerofoil section however depend on the velocity and pressure distribution around the same. The generation of streamline around the aerofoil section in turn determines the velocity and pressure distribution making it necessary to study the streamline pattern. The present paper concentrate on determination of streamline pattern along the surface of a non-standard aerofoil at three different angles of attack (AoAs) for two different free stream velocities.*

1. INTRODUCTION

Aerodynamics is all about moving effectively through the air. One such structure carrying out this function properly is aerofoil and is also on which the present study is focused [1, 2]. The focus being on non-standard aerofoils more than the standard ones in recent times is the motivation behind using a NACA3119 for the present study [3, 4].

Now, the aerodynamic characteristics of concern for an aerofoil are mainly affected by the velocity and pressure distributions surrounding the aerofoil [5, 6]. Moreover, the region surrounding the aerofoil where the velocity changes from zero to maximum namely, the boundary layer can be segregated into two zones based on the type of flow, Laminar and Turbulent [7]. Laminar region indicates the zone where the fluid flows efficiently, gently increasing in speed along the boundary layer. Turbulent zone is characterized by chaotic mixing instead of movement in smooth layers. Hence, the laminar zone is sometimes said to be streamline flow with the movement being parallel to the streamlines.

A streamline denotes the line tangential to the instantaneous velocity direction. The streamline pattern around an object over which a fluid flows is the reason behind the various distributions obtained around it. Specifically, the curvature of a streamline is related to the pressure gradient acting perpendicular to the same [8]. Further, air resistance, i.e., drag follows the distinction between laminar and turbulent flow. Moreover, to reduce drag streamlining or contouring of an object is done. Hence, the study of streamline pattern generated around an aerodynamic structure is of paramount importance to determine its performance [9, 10, 11].

This leads us to the current study where the streamline pattern generated along the surface of a non-standard NACA3119 aerofoil has been experimentally observed for three angles of attacks for two free stream velocities.

2. EXPERIMENTAL SET-UP AND PROCEDURE:

The experiments were conducted in a subsonic closed-circuit wind tunnel **(Fig. 1)** whose lower test section is of dimensions 4m x 1m x 1m (Length x Height x Width) and the upper test section has dimensions 3m x 4m x 4m (Length x Height x Width).

Fig. 1: Model of Wind Tunnel

An axial flow fan, operated by a Siemens make Variable speed motor creates the flow of wind inside the tunnel. An ABB make variable frequency drive having the drive range of 0 – 50Hz; is used to alter the speed of motor to achieve different free stream velocities inside the tunnel. Velocity variation can be achieved in the range 0-32 ms^{-1}. A pitot tube (make: spectrum) has been used to measure the free stream pressure difference using a digital differential manometer (make: Kimo, Model no. : CP300-HP). The manometer is capable of measuring 0/+10Pa to -10000/+10000Pa.

In the lower test section, a wooden asymmetric aerofoil **(Fig. 2)** has been placed whose dimensions are: Chord length = 21.9cm, leading edge radius = 2.1 cm, maximum thickness = 4.2cm, maximum camber = 0.7cm at 10% of chord length. As per the NACA 4 digit nomenclature the camber aerofoil used is designated as NACA3119. This aerofoil is not a standard one because the maximum camber which this aerofoil has is 3% which is considerably higher than the cambered aerofoils analyzed experimentally till date.

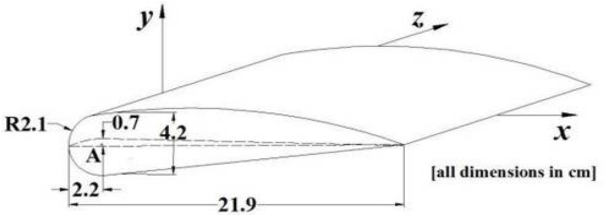

Fig. 2: Aerofoil Section

The aerofoil is firmly held in its longitudinal position by means of two wooden cylindrical beams.

As a preliminary analysis, the work is focused on determination of the streamline pattern around the aerofoil. The coordinate system assumes x axis along the chord axis along the span and y axis along the height of the aerofoil surface.

The aerofoil surface has been divided into grid points to facilitate the collection of the experimental data. The lower surface has 3 grid points in the z direction and 9 grid points in the x direction. The thickness of the aerofoil is considered negligible in order to avoid the small difference in y direction for the two surfaces. The pressure difference over the aerofoil has been measured for 3 different angles of attacks of -10°, 0° and +10° corresponding to 2 different free stream velocities, 12 ms^{-1} and 13.5 ms^{-1}. Different angles of attack have been achieved by rotating the cylindrical beams at angles corresponding to multiples of 10 °.

The free air stream is started over the aerofoil after placing it longitudinally in the test section. The pitot tube is placed over different grid points and the pressure difference is noted. The maximum pressure difference and the pressure difference along the horizontal are noted in order to get the direction of the velocity vector. The velocity at every point is computed using Bernoulli's equation and is given by

$$v = \sqrt{\frac{2g\Delta P}{\rho}}$$

where, v represents velocity, g is the gravitational acceleration, ΔP is the pressure difference and ρ is the density of air; incompressibility of air has been assumed in the calculations and the direction of the velocity vector can be determined by :

$$\alpha = \cos^{-1}(v_H/v_S)$$

where, v_H is the horizontal velocity and v_S is the velocity along the surface, α being the angle between the horizontal component and the velocity along the surface.

3. RESULTS AND DISCUSSIONS:

In **Figs. 3(a)-(f)** the streamline pattern of the flow, corresponding to 12m/s and 13.6m/s free stream velocity at 0º, 10º and -10º angles of attack of the airfoil for each velocity have been shown.

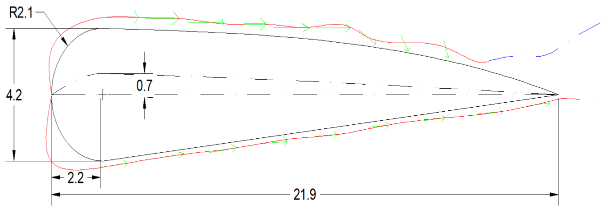

Fig. 3(a).Streamline pattern for 0º AoA in 12m/s free stream velocity

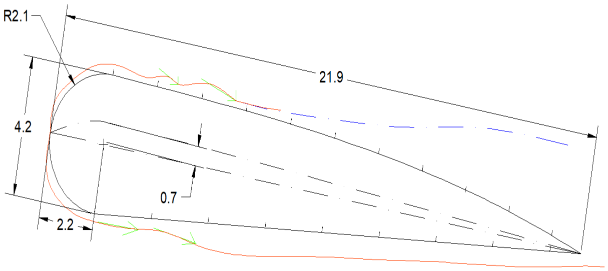

Fig. 3(b).Streamline pattern for 10º AoA in 12m/s free stream velocity

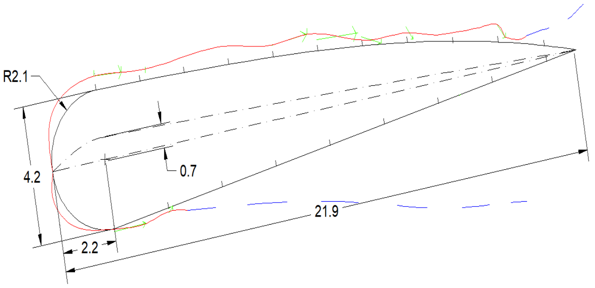

Fig. 3(c).Streamline pattern for -10º AoA in 12m/s free stream velocity

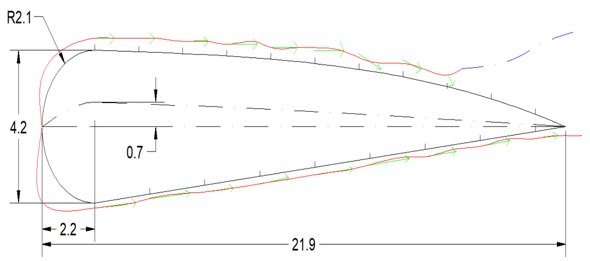

Fig. 3(d).Streamline pattern for 0°AoA in 13.6m/s free stream velocity

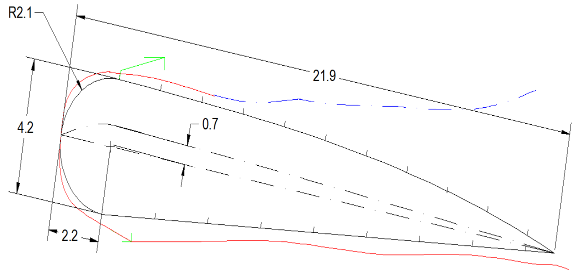

Fig. 3(e).Streamline pattern for 10°AoA in 13.6m/s free stream velocity

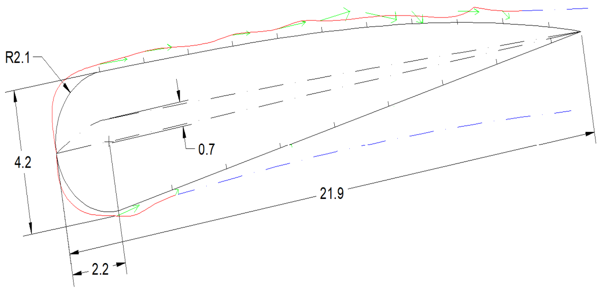

Fig. 3(f).Streamline pattern for -10°AoA in 13.6m/s free stream velocity

In every figure, arrows are used to represent the experimental data for the velocity vector and solid line is used to represent the streamline pattern of the flow by interpolation of this data. The dotted line represents the predicted flow pattern after the flow separation.

As seen from the pattern, the boundary layer separation of the upper surface occurs closer to the leading edge in case of 10° angle of attack compared to 0° angle of attack. The boundary layer separation can be attributed to turbulence generation in the flow regime. This earlier flow separation signifies higher lift force on increasing the angle of attack. The boundary layer separation of the lower surface occurs closer to the trailing edge in case of -10° angle of attack compared to 0° angle of attack, thus generating higher lift in the downward direction.

For higher free stream velocity, the separation occurs farther away from the trailing edge which can be attributed to the fact that turbulence increases on increasing the velocity and hence generating higher upward lift force on increasing the velocity.

Since the airfoil is an asymmetric one, even in case of 0° angle of attack, there is a flow separation towards the trailing edge resulting in a lift force.

4. CONCLUSION AND FUTURE SCOPE:

The streamline pattern generated over the surface of a non-standard aerofoil section has been experimentally determined in a wind tunnel for various angles of attacks and free stream velocities. The pattern generated conforms to general theories in terms of lift generation. Further determination of the aerodynamic co-efficients of the aerofoil used is really on the cards as a future scope.

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