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The Impacts of Reynolds Number on Stream Division of Naca Aerofoil

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Abstract— The reason for this examination is to explore the stream division above UTM 2D Aerofoil at three distinctive Reynolds numbers. The investigation was led in UTM-LST (Low Speed Passage). The weight circulation is done on three unique wingspans, which are 40%, half and 70%m of range and was estimated and plotted to watch the stream trademark at approach from 0° to 35° for each of the three diverse Reynolds numbers. The stream perception technique was done at 10m/s, 20m/s and 30m/s velocity from 0° to 18°. It is presumed that the Reynolds number of 1 × 106 isolates at 16°; Reynolds number of 1.5 × 106 isolates at 18° and Reynolds number of 2 × 106 isolates at 20°.

Keywords— UTM 2D Aerofoil, Wind Tunnel Experiments, Flow Visualization, Flow Separation

1.Introduction

Numerous specialists [1, 11, 12, 20] expressed that for typical instance of aerofoil, there will be a weight following up on the forward (driving edge) surface. For appended stream case, the weight on the toward the back surface (trailing edge) creates a net power to counter back the main edge power, so that there will be no weight drag. Yet, it is distinctive for isolated stream case, where the weight following up on the behind surface will be deficient to counter back the weight following up on the forward surface. Right now, net weight drag will be delivered toward the path towards the rearward surface thusly decreasing the speed.

ADVERSE PRESSURE GRADIENT

As per Basu [2], unfavourable weight angle is one of the significant terms that ought to be noted so as to research stream partition. Antagonistic weight inclination is where the weight increments in the stream bearing, where the district dP/dx (pressure angle) is sure. Unfriendly weight inclination happens when the static weight increments toward the stream. In limit layer condition, unfriendly weight inclination causes the speed of limit layer to decrease; subsequently, the motor vitality of the liquid particles is never again satisfactory to move the particles against the weight slope. This circumstance causes stream inversion for the layers closer to the divider or item surface. In any case, the layers further from the divider are continuous, which delivers more vitality. Stream inversion at the lower parts and further vigorous stream at the upper parts makes the liquid streams roll and separate from the divider, as clarified by Munson [14].

Types of Stalls

As per scarcely any specialists [2, 10, 13 and 18], it has been watched driving edge slow down happens in aerofoil attributes, for example, meagre aerofoil with the thickness proportion somewhere in the range of 10% and 16% of the harmony length. For all slow down cases, the stagnation point is moved descending at the main edge as the approach (AOA) increments. Be that as it may, for driving edge slow down, the stream partition begins at driving edge making the stream separate everywhere throughout the top surface of the aerofoil. As complexity to driving edge slow down, trailing edge slowdown is because of thicker sorts of aerofoil. For this kind of slow down, stream separate starts from the trailing edge. The division point moves towards the main edge as the AOA is expanded. It was noticed that the trailing edge slowdown is gentler than driving edge slow down however having lower greatest coefficient of lift esteem. Meagre aerofoil slowdown is for exceptionally slim aerofoil, which is characterized as level plate with thickness at 2% of aerofoil harmony length. This case is interesting in light of the fact that it envisions the two sorts of slow down which are driving edge and trailing edge slows down. From the start, stream starts to isolate at driving edge even at low AOA, yet because of outrageous thickness of aerofoil, the stream reattaches back further downstream which frames a detachment bubble. This detachment bubble marvel increases with the expansion of AOA because of the reattachment point moving further downstream. These three sorts of slows down depend on articulation from Anderson et al. [1] in his book of streamlined features. Right now, trial examination on streamlined features trademark about the stream partition over a 2-dimensional (2D) aerofoil has been performed, which researches the stream detachment above UTM 2D Wing at three diverse Reynolds Number - 1 × 106, 1.5 × 106 and 2 × 106.

Experimental Methods

Experimental method is used in order to identify how the flow separates and effect of different Reynolds Number to the flow separation. There are many flow visualization methods that have been perform such as oil method, smoke-wire method, particle image velocimetry and tuft thread method as in refs. [6,7,11,19 and 22], however according to John [4], tuft method is the best method for photographic evidence as it provides clear view, easy to apply and to analyse. As mentioned Tajuddin et al., [21], the flow separation and air flow formation around the blunt-edged delta wing can be easily observed. Shen et al., [19] stated that this technique can be used on both steady state flows as well as time varying flow fields, and complements a host of flow visualization techniques. In a steady flow field, each tuft is subjected to a constant wind force. As a result, the tuft can be observed to swing periodically. The direction of motion is the same as the flow field. The resulting tuft shows the changing orientation of the tuft as the vector field. In other words, the tufting method allows the invisible wind forces to be observed since its reactions are exerted onto the set of yarn, thread or even in the digital analysis virtual tuft.The method records the movement on the top surface of airfoil, and will be recorded by camera. Pressure distribution taps are used to monitor and the result will be used to support the data from flow visualization. Shahrul Sham Dol [5] stated that flow visualization is an important method in order to study the flow behaviour around objects including airfoil. In contrast of other methods, flow visualization is capable in delivering a qualitative macroscopic picture of the overall flow field instead of limitations from measuring flow conditions at discrete point within the flow field. Flow visualization is important to identify the flow pattern above the airfoil in various conditions which help to identify airfoil characteristic during the test. Basically, airfoil is tested in different angle of attack (AOA) until stalling effect occurs which is the critical value for the airfoil to obtain maximum coefficient of lift. The airfoil behaviour can be represented in coefficient of lift, CL vs. Angle of attack, α graph consists of the linear part and stalling part. But since the project is about flow separation, the flow visualization is more focused on the stalling part. There is also another parameter that is controlled in order to visualize the flow over an airfoil using the Reynolds number. Reynolds number is integrated with the free stream speed that will affect the type of flow acting to the aerofoil where this parameter need to be controlled in order to visualize the result that is being predicted.

2.Methodology

The model utilized is UTM 2D wing with even aerofoil to the determination of NACA 0012. Since the fundamental focal point of this undertaking is to explore the stream detachment, the venture was done by utilizing the strategies for pressure conveyance and stream representation. The unending wing model is mounted inside the test segment of UTM-LST, Low Speed Passage. Observe that the wing is tilted at a lot of approaches from 0° to 35° which covers the slow down approach. This is on the grounds that the slow down approach gives better stream division representation. Different parameters are included, for example, the breeze speed and Reynolds Number. The model is tried with three distinctive arrangement of Reynolds Number which are 1.0 x 106, 1.5 x 106 and 2.0 x 106 separately. These parameters help so as to see better about the impact of Reynolds Number to the stream separation. The pressure appropriation strategy was brought out through the weight taps on the aerofoil model surface. Weight dispersion technique gives neighbourhood pressure information to each point around the aerofoil so as to recognize the nearness of unfavourable weight inclination. Unfavourable weight event shows how much stream partition happens and in finding the division focuses on the top surface of the aerofoil. Weight inclination or dP/dx equivalent to zero shows that there is consistent weight on the locale where stream is isolated coming about to no weight contrast and can be seen by this technique concentrating on the level weight level district. In addition, purpose of partition could be watched either happening upstream or downstream the progress point, showing laminar or violent detachment. The information is recorded by the Lab View application on the air stream office with the assistance of compact electronic weight scanner. Using the tuft technique as the stream representation strategy is made utilizing the tuft technique as this technique is generally reasonable with the present offices accessible, where sets of strings are mounted on the top surface of the model. These arrangements of strings are mounted range insightful of the airfoil at every one of the model harmonies with the goal that the stream could be dissected as needs be. String tuft strategy is utilized so as to contemplate the stream bearing since the tuft respond on the powers delivered by the stream quality

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itself. Consequently, on account of stream division, there is no power following up on the tuft and turned around stream will make the tuft point to the opposite heading of the upstream test segment of the wind current. This technique is profitable since it gives visual information in which the stream conduct could be observed. The information is recorded by camera and watched physically to look at results as picked up by the weight circulation strategy. The test configurations for Pressure distribution method and Flow Visualization via Tuft method are shown in Table 1 and Table 2.

Table 1 Flow visualization Test Configuration

Span 1 (40% of model span)		Span 2 (50% of model span)		Span 3 (70% of model span)	
Airspeed	Angle	Airspeed	Angle	Airspeed	Angle
30.65 m/s,	0° to 35°	30.65 m/s,	0° to 35°	30.65 m/s,	0° to 35°
30.95 m/s	0° to 30°	30.95 m/s	0° to 30°	30.95 m/s	0° to 30°
60.25 m/s	0° to 24°	60.25 m/s	0° to 24°	60.25 m/s	0° to 24°

Table 2 Tuft Method: Wind-On Tuft testing configuration

Airspeed	Angle of attack
10.5 m/s	0° to 18°
20.5 m/s	0° to 18°
30.5 m/s	0° to 18°

UTM Half Model Specification

The model used in this project is the UTM 2D Wing Model which consists of symmetrical aero foil to the specification of NACA 0012. The span of the model is 1,476 mm, comfortably set in the wind tunnel test section with the height of 1.5 m as shown in Figure 1 and Figure 2. The model will be mounted and balanced in the middle of the test section that can be turned into different angles of attack by the turntable. The chord length of the wing is 500 m and consists of 96 pressure taps. Since this wing is a symmetrical wing, both upper and lower section will have the same amount of 16 pressure taps at the exact same location. The top and bottom surface for each span consist of 40%, 50% and 70% of wing span as shown in Table 4. Note that all the pressure taps are aligned at the same distance for each span as the wing model is mounted vertically across the flow field (Figure 1).

Fig. 1. UTM half model

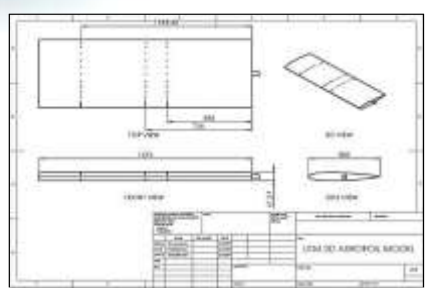

Fig. 2. The dWingspanof the UTM half model

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Table 3 Specifications of the UTM 2D Wing Model

UTM 2D WING MODEL SPECIFICATION	
Aero foil	NACA 0012
Wingspan	1477 mm
Chord Length	500 m
Max Thickness	12% at 30% chord (60 mm)
Number of Pressure Taps	97 (32 for each span and 16 on each span)
Location of Pressure Taps	40% span (588 mm), 50% span (738 mm) and 70% span (1,038 mm) from the tunnel floor

3.Results and Analysis

Pressure Distribution Method

The desired Reynolds Number can be controlled by manipulating the airspeed inside the wind tunnel section.

Table 4 UTM 2D Wing Model Pressure Tap Locations

Tap	X direction (chord wise)	Z direction (thickness)	Tap	X direction (chord wise)	Z direction (thickness)
1	12.5	13.1	16	475.0	-4.0
2	25.0	17.8	17	12.5	-13.1
3	37.5	21.0	18	25.0	-17.8
4	50.0	23.4	19	37.5	-21.0
5	75.0	26.7	20	50.0	-23.4
6	100.0	28.7	21	75.0	-26.7
7	125.0	29.7	22	100.0	-28.7
8	150.0	30.0	23	125.0	-29.7
9	175.0	29.7	24	150.0	-30.0
10	200.0	29.0	25	175.0	-29.7
11	250.0	26.5	26	200.0	-29.0
12	300.0	22.8	27	250.0	-26.5
13	350.0	18.3	28	300.0	-22.8
14	400.0	13.1	29	350.0	-18.3
15	450.0	7.2	30	400.0	-13.1

In the pressure distribution method, data obtained from this method is the local pressure at each point. Pressure coefficient is an important parameter since it shows relative pressure throughout the whole flow field and the way to analyze incompressible flow.

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Through this parameter it provides the general overview on the local static pressure difference to the ratio of dynamic pressure

Table 5 Wind tunnel airspeed calculated from the required Reynolds number

Reynolds Number	Airspeed Velocity (m/s)
1 000 000	30.60
1 500 000	45.90
2 000 000	61.20

At the angle of attack 16° as shown is the Figure -6, it is observed that there is the sudden drop of C_P value indicating to leading-edge stall. According to Anderson [1], thin airfoil with 10% to 16% of thickness ratio will have flow separation over the entire top surface where the origin of this separation occurs at leading-edge, and the lift curve is sharp-peaked shape due to rapid decrease in lift coefficient. The airfoil itself has 12% of thickness ratio so that leading-edge stall is predicted to occur. In the pressure distribution data, we can observe that there is existence of a region with constant pressure with no pressure differences (pressure plateau region). This starts to happen and it indicates that the flow begins to separate. In this situation, the pressure becomes constant due to the effect of adverse pressure gradient, in which the pressure increases rapidly and at this pressure plateau region shows that the increase of drag overrule the slight increase portion of lift in the leading-edge.

At this region constant pressure also causes the pressure gradient of dP/dx to be 0, therefore there is no pressure difference. Pressure difference plays a major role to ensure the flow attached to the surface. According to Munson [14], dP/dx = 0 marks the point where the flow starts to separate from the surface. This situation of no pressure difference occurs where there is no net force produced to hold or stick the flow down onto thesurface, which causes the flow to be separated.

Fig 3.Upper surface coefficient of lift distribution for 40% span at v = 30.60m/s, 45.90 m/s, 61.20m/s

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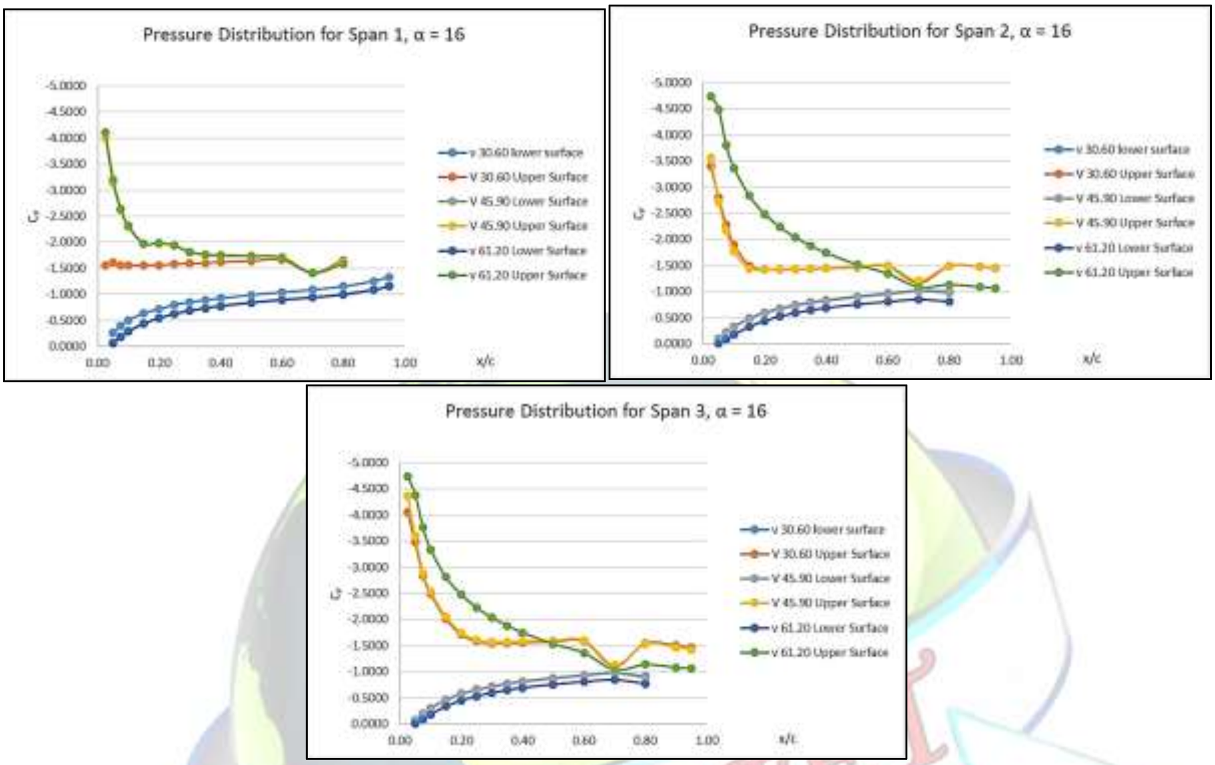

Fig. 7. V = 30.60 m/s starts flow separations for all span

FlowVisualization Method: Tuft Method

Figure 8 shows the photographic outcomes acquired from tuft testing for the stream perception. In Figure 8a, it very well may be seen that the stream condition is completely connected as shown by the straight direction of the string tuft following the free stream wind current heading. Right now, from the free stream of air are adequate to follow up on the tuft in order to shield the string from tumbling down. In both harmony positions, the string tuft stays in a straight development because of the stream being completely appended to the airfoil surface.

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a) Tuft Test at V = 10 m/s Angle of Attack 0°

b) Tuft Test at V = 10 m/s Angle of Attack 9°

4.Conclusions

A low speed air stream study is carried on the UTM 2D aerofoil model in the scope of 0° to 35° approach at Reynolds number 1.0 x 106, 1.5 x 106 and 2.0 x 106. It tends to be presumed that the Reynolds number of 1.0 x 106 isolates at 16°; and as the Reynolds number is expanded; the stream division could be postponed. Stream completely isolates for Reynolds number of 1.5 x 106 at 18° and Reynolds number of 2.0 x 106 at 20° in like manner. As the arrangement of laminar partition bubble with the stream division past progress point, it is discovered that the stream has laminar detachment for all Reynolds numbers. Weight coefficient circulation will in general be steady after high positive weight angle, adding to temperamental stream because of unfriendly weight inclination. Additionally, from the weight dispersion technique shows slow down states of the aerofoil occur during the event of stream division. What's more, by looking at the tuft perception technique and the weight dissemination information shows comparable information particularly during V = 30 m/s, where the stream division happens at $\alpha = 16°$ demonstrating the legitimacy of information from the two strategies. Moreover, the approach past stream partition made the stream be completely switched in the tuft stream representation.

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