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Surface Flow Visualization Tests on Swept Back Wing Configuration Subjected to Subsonic Flow

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ABSTRACT

For this investigation swept-back configuration of the wing has been studied experimentally utilizing the surface flow visualization method. Swept-back wings have been widely implemented to achieve high aerodynamic efficiency under high-speed operation. To understand flow structure over wing the pattern formed by surface flow visualization techniques over wing leeward surface has been well implemented in aerodynamic literature. However, it is desirable to investigate the flow structure formed over swept-back wing under low-speed operation. In this study, an experimental study was conducted using surface flow visualization technique upon swept-back, tapered wing configuration. The wing has aspect ratio of 4 and designed using RAE2822 airfoil configuration. Changes in flow pattern with change in angle of attack have mainly been studied. Oil flow visualization studies showed increase in heavy span-wise flow with an increase in angle of incidence. At low-speed operation, the formation of separation bubble over the airfoil and induced span-wise flow from the presence of sweep and taper create three-dimensional vortex flow structure over the wing.

Keywords: Supercritical airfoil, Surface flow Visualization, Swept back tapered wing, Three-dimensional flow structure.

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INTRODUCTION

Swept back tapered wing design was first invented during world-war II in 1950s. Among recently declassified reports of NASA it was found that pioneer of swept-wing design Jones[1] did a study on effect of sweep back on boundary layer and separation in 1947. Swept tapered wing designs were extensively implemented in aircraft design for safe, cheap, and high-speed travel.

Haines and Rhodes[2] in 1954 performed an experimental study on swept-back wings in between mach no. 0.50 to 0.95. They found that at high incidence, a part span vortex sheet originates from near the lead edge at the inboard end of separation and trails back across the wing.

Haines[3] in 1954 further performed surface flow investigation at high incidence and low mach no. and concluded that wings suffer from leading-edge separation.

In 1970s Whitcomb[4] at NASA pioneered the design of supercritical airfoil to improve wing performance in high speed operation. Poll[5] implemented oil-flow visualization to on RAE 101 airfoil profile wing at several different swept angle configuration within Reynolds number range of 1.1×10^6 to 2.7×10^6. Poll observed the formation of spiral vortex structure indicated in oil flow pattern for swept back angle (Λ) exceeding 15°. He analyzed that formation of spiral vortex structure consists of flow separation near the leading edge and reattachment of flow near trailing edge after separation bubble. To further illustrate, a schematic of 3D flow structure over the tapered swept-back wing is shown in Figure 1.

Carmichael B.H. (1982)[6] in his outstanding report named 'Low Reynolds Number Airfoil Survey' for the first time arranged together the most exhaustive list of references available of known experimental and theoretical results regarding low Reynolds number analysis.

Swept-back wing configuration is still widely adopted design for commercial as well as military aircrafts. In modern days, technological improvements lead to a small scale flying machine known as MAV (Micro Air Vehicle) or UAV (Unmanned Air Vehicle), which mostly implements swept-back wing. MAVs have several different used case scenarios e.g., fire detection, monitoring and controlling traffic and military

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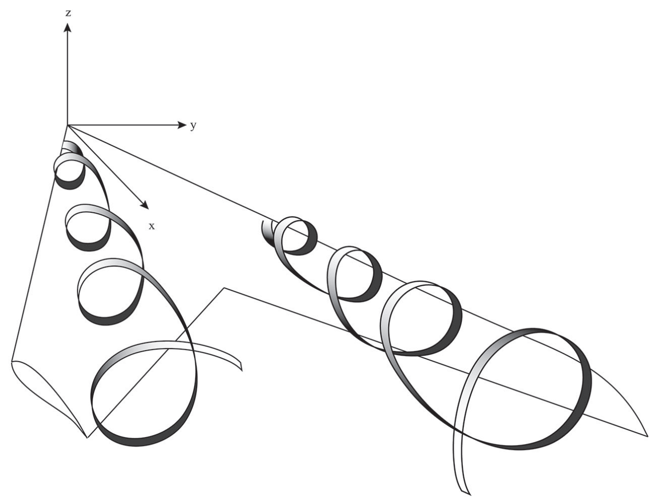


Figure 1: Schematic of swept-back, tapered wing vortex flow

reconnaissance etc.[7] These MAVs and military aircrafts frequently operate within very low Reynolds number region while landing, take-off or mid-air maneuvering conditions etc.

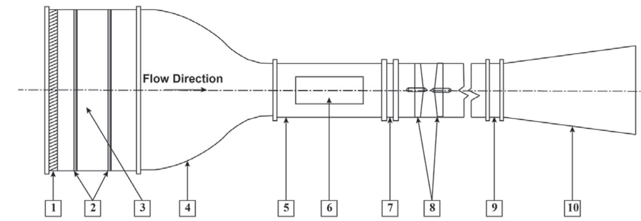
However, the basic natures of most of the experimental investigations are of confidential nature and especially the practical investigation related results and data. Despite an understanding of flow structure and boundary layer formed over wing during low-speed operation is still a topic of interest.[8-16] Besides the applications of micro UAVs and aircrafts present investigation also aims to contribute toward the design or understanding of other applications of wing, e.g., wind turbine generators, fluid mixing machines, blades of rotary equipments, swirling fans in burner etc.

Therefore, due to the interesting wider application and scarcity in the availability of experimental data in open literature of tapered swept wing configuration, in an effort to extend the understanding of change in boundary layer flow features with change in incidence a surface flow visualization study was conducted on a tapered swept-back wing designed using supercritical (RAE2822) airfoil operating under low Reynolds number.

Experimental Arrangements

The experiment is carried out at a free- stream velocity (u_∞) of 12m/s at Reynolds number of 1.5×10^5 based on the mean aerodynamic chord. The current investigation was carried out in an open-loop, suction-type subsonic wind tunnel located at Jadavpur University, India, Power Engineering, Fluid Mechanics, and M/C Laboratory. Wind tunnel has a test section of 0.6m×0.6m covered in transparent plexiglas windows on top and side walls to facilitate flow visualization studies. A schematic diagram of the wind tunnel is shown in Figure 2.

For the present experiment, a wing model designed as 30° swept-back, tapered and tail-less design utilizing RAE



[1] Honeycomb, [2] Screens, [3] Settling chamber, [4] Contraction Cone (9:1), [5] Test Section (SQ 600X600mm), [6] Transparent Panel, [7] Transition Piece, [8] Fan, [9] Damper, [10] Diffuser

Figure 2: Schematics of wind tunnel.

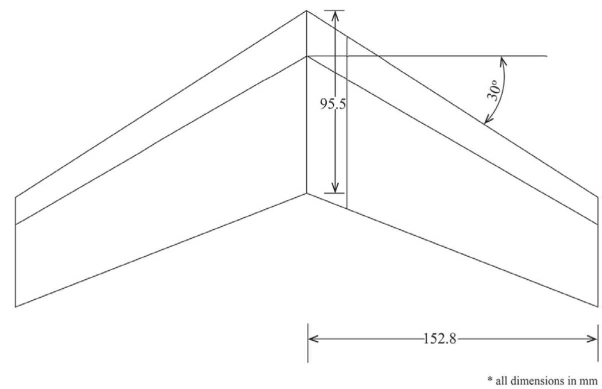


Figure 3: Geometry of Wing Model

2822[17] airfoil profile. Top surface of the composite structure wing model was fabricated using a polished aluminum alloy plate, the planform of which is shown in Figure 3.

The entire set of experiments is carried out at a free-stream velocity (u_∞) of 12m/s. For the oil flow visualization experiment, ratio of the amount of oil, pigment and additive in oil-flow mixture and also the density of mixture was decided by several trial and errors. The experiment was carried out at several different angles of incidence. After applying the oil-pigment mixture over wing surface, model is kept under experimental flow conditions for a certain amount of time. Then the model was taken out and picture was taken and inverted for qualitative analysis.

Results and Discussion

Experiments were conducted over swept-back tapered wing configuration between α of 0° and 30° and at Re_{MAC} of 5.95×104. Figure 4 illustrates surface flow pattern formed on leeward surface of wing model from oil flow visualization experiments. Along with the experimental images black dotted line with an arrow are drawn schematically over the experimental images to delineate probable flow patterns in allusion with the surface flow pattern observed from experiments. Figure 4 gives a hint towards the formation of several different flow conditions e.g., attached flow, laminar separation, separation bubble, and three-dimensional flow etc.[18] Schematic sketch of two-dimensional imaginary flows over the airfoil according to oil flow patterns is also added at the bottom for each angle of incidence.

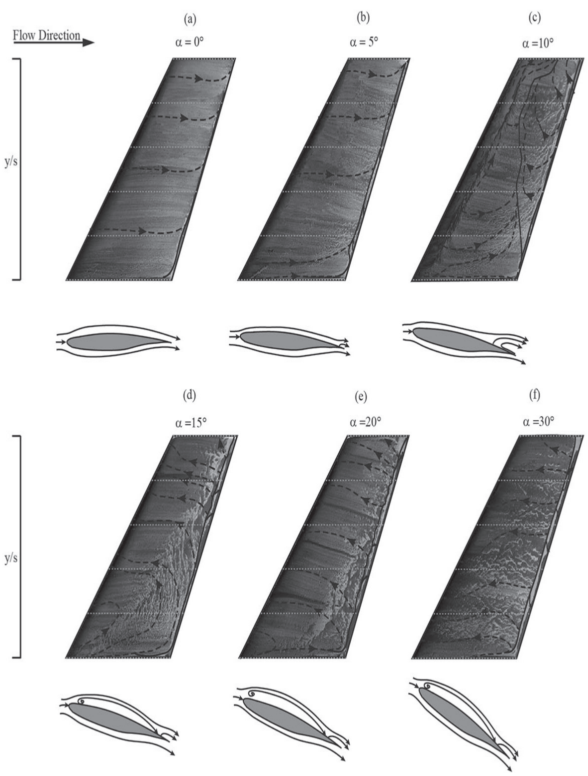


Figure 4: Surface Flow Visualization Pattern With Schematic Sketches Over Leeward Surface of Swept-Back, Tapered Wing Model

Form Figure 4 (a). it can be observed that at $\alpha = 0°$ boundary layer remains attached throughout the wing leeward surface as a result pattern seems to indicate movement along mainstream direction staring from leading edge to trailing edge of the wing model. It appears the airflow through the wing surface smoothly without producing any trace of separation or vortical structure. Figure 4(b) illustrates that at $\alpha = 5°$ compared to 0° span-wise flow gets increased. Flow patterns indicate distortion of flow lines near mid and outboard portion or near tip of the wing model. Distortion of flow near the wing tip may have been caused by end effects as discussed by Bertin and Smith.[19] Near the inboard section, a considerable portion of flow seems to have remained two-dimensional. Along the trailing edge of the wing formation of a flow separation line can also be observed. Figure 4(c) indicates flow pattern formation at $\alpha = 10°$. It can be observed that flow lines gets pushed more toward the outboard portion of wing under heavy influence of span-wise flow. Compared to $\alpha = 5°$ separation line appears to be moved upstream near mid and outboard portion of wing surface.

At $\alpha = 15°$ flow patterns indicate the formation of separation bubble over the wing leeward surface as depicted in Figure 4(d). Separation bubble appeared to be formed near leading edge and leaves an impression of separation structure near the trailing edge. An increase in span-wise flow components can also be observed as the flow lines originating from the inboard get pushed towards the wing model's outboard section. Figures 4 (e) and 4(f) represent flow pattern formation at 20° and 30°, respectively. The three-dimensional structure appears to be present for both angles of attack. It can be observed that flow patterns originating from a near inboard portion of wing make more tight turn in comparison to $\alpha = 15°$ seems to indicate the formation of 3D flow. It can be deducted that defected flow from the leading-edge help to form a 3D vortex structure over the wing.

It can be deduced that as flow gets deflected from the leading edge forms a three-dimensional vortex over the wing. With an increase in angle of attack the three-dimensional bubble over the wing gets pushed forward.

Conclusion

In the present note, surface flow visualization is utilized to study flow structure over swept-back, tapered wing of RAE2822 airfoil while operating under low Reynolds number.

Flow visualization results at $\alpha = 0°, 5°, 10°, 15°, 20°$, and 30° were discussed. The results indicate increase in span-wise flow component over suction surface of wing with increment in α. Careful scrutiny of figures indicates different flow features like attached flow, laminar separation, separation bubble, three-dimensional flow etc. From $\alpha = 15°$ or higher formation of three-dimensional vortex structure can be estimated over wing suction surface.

Nomenclature

English Symbols

AoA	Angle of attack
$AR = b^2/S$	Aspect Ratio
MAC	Mean Aerodynamic Chord
Re_{MAC}	Reynolds number based on Mean Aerodynamic Chord
u_∞	Free-stream velocity

Greek Symbols

α	Angle of Attack
Λ	Swept Angle

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