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Modeling and Simulation on Double Delta Wing

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Abstract

The surface flow pattern on the upper surface of a double delta wing has been studied experimentally using oil flow visualization technique at subsonic condition. Surface flow visualizations have been performed on a sharp edged single beveled 76°-40° double delta wing for 5°, 10° and 15° angle of attack (AoA) at a free stream Reynolds number of 2×10^5 based on the root chord length of the wing model. Subsequently CFD (computational fluid dynamics) analysis is carried out using CFD code Ansys Fluent. The computational domain is meshed with unstructured grids and Reynolds Averaged Navier Stokes (RANS) based steady state CFD simulations are carried out. The experimental and computational results are compared in the context of surface flow pattern.

Keywords

Double delta wing, Flow visualization, CFD Simulation, RANS

1. Introduction

Highly swept sharp edged double delta wing configurations are considered for its capability to provide stability to the vortices formed above the wing [1]. These configurations are employed in high speed fighter aircrafts for high maneuverability and to enhance the aerodynamic performances at supersonic speed [2], [3].

The subsonic aerodynamic characteristics of sharp edged double delta wings built for supersonic flights differ substantially due to the absence of shock wave formations [4]. Aerodynamic study of such wings in subsonic zone is relevant as these aircrafts fly at subsonic speed during landing, takeoff and reconnaissance mission.

The main flow separates at the sharp leading edge and two primary vortices known as strake and wing vortex are formed. The strake vortices are less prone to vortex breakdown for higher AoA and stabilize the wing vortices [5]. These vortices interact with each other at higher AoA causing lateral instabilities as described by Olsen and Nelson [6].

In 2009, Woodiga and Liu [7] measured the skin friction field on 76°-40° double delta wing using global oil film skin friction meter. Surface flow topology and vortex behaviours on 76°-40° double delta wing has been studied by Erickson and Gonzalez [2] at different AoA. Hsu et al. [8] computed the vortex interactions on a sharp edged 76°-60° double delta wing. A detailed computational study on the vortical flow structure on a 76°-40° double delta wing has been reported by Russel et al. [9].

The present study is focused on the identification of different surface flow patterns on the upper surface of a sharp edge 76°-40° double delta wing from flow visualization and computational studies. RANS (Reynolds Averaged Navier Stokes) based steady state computations are carried out with appropriate boundary conditions. SST k-ω turbulence model based second order upwind discretization schemes are adopted for the present CFD study. The experimental program and numerical methods are discussed in the following sections.

2. Experimental method

All the experiments in this program are carried out in the test section of a subsonic suction type open circuit wind tunnel available in the Fluid Mechanics and M/c Laboratory, Dept. of Power Engg. Jadavpur University. A schematic diagram of the wind tunnel is shown in Fig. 1. The test section of the wind tunnel having dimensions of 0.6 m×0.6 m×1.2 m is provided with transparent windows on top and side walls for flow visualization studies.
The entire set of experiment is carried out at a free-stream velocity of 15 m/s at Reynolds number of 2×10^5 based on the root chord length. The turbulence intensity at the free-stream location is 0.7%.

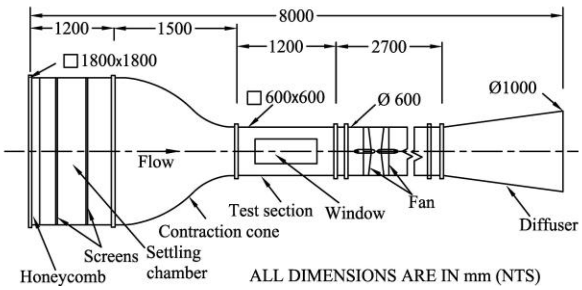

Figure 1: Experimental Setup

The wing model is a flat plate 76°-40° cropped double delta wing having sharp leading edges. The leading edge is single bevelled with 20° bevel angle. The trailing edge of the wing has a planed blunt edge. The root chord of the wing model is 191 mm and the wing span is 195 mm. Mean aerodynamic chord of the wing is 82.6 mm. The wing thickness is 6.5 mm. The aspect ratio of the wing model is 2.40. The schematic drawing of the double delta wing is shown in Fig. 2.

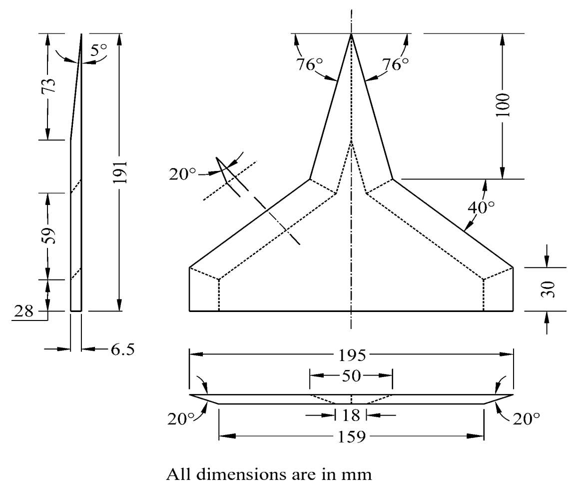

Figure 2: Geometry of double delta wing

Oil flow visualization studies have been performed on the upper surface of the 76°-40° double delta wing for 5°, 10° and 15° AoA without any sideslip. A proportionate mixture of lubricating oil, titanium dioxide and French chalk powder is painted uniformly as a thin layer on the upper flat surface of the wing models. The oil mixture is supposed to be aligned locally to the skin friction lines in the form of surface flow pattern during the run. The run is continued till the pattern stabilizes and the paint is dried out. The wing models are then dismantled from the traversing unit and brought outside form the wind tunnel test section. Afterwards snapshots are taken using a digital camera in a fluorescent light environment. All captured images are filtered for better visibility using Adobe Photoshop CS software.

3. Computation

RANS based steady state solution is considered for the present investigation within the flow domain over a sharp edged delta wing. Shear Stress Transport k-ω turbulence model (SST *k-ω*) can predict the flow separation process with higher accuracy and hence preferred for the present case of study [10]. Near wall mesh sizes are arranged appropriately to resolve the boundary layer velocity profile. Near wall characteristic coordinate *y+* is a very important parameter to resolve the feature of the boundary layer and found to be restricted within a maximum value of 1. Constant fluid properties (density and molecular viscosity) are assumed for the prevailing incompressible flow without any significant change in temperature. Second order upwind discretization scheme is applied for momentum, *k* and *ω*.

A convergence criterion of 10^{-4} is set for the residuals. Lift and drag convergence histories are monitored to ensure an unchanging value obtained during the last part of the solution process and the iterations are stopped after achieving this.

Unstructured hexahedral cells are generated except the triangular tip region of the double delta wing using pre-processor GAMBIT and shown in Fig. 3.

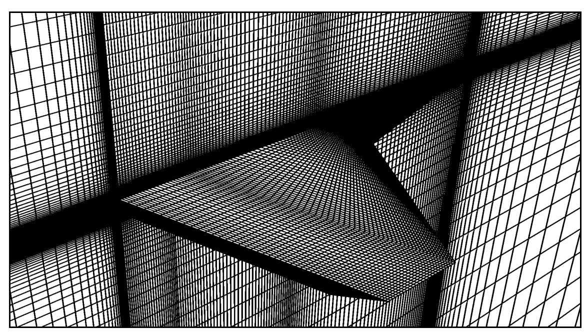

Figure 3: Grid structure over double delta wing

A symmetry boundary condition is applied to the central vertical symmetry plane for the symmetry solution. The inlet boundaries surrounding the model surfaces (except symmetry plane) are specified as velocity inlet with a free stream velocity magnitude of 15 m/s. No-slip wall conditions are applied to the model surfaces without any wall roughness. Free stream velocity directions are adjusted in accordance to the imposed angle of attack and sideslips for different simulation run. The outlet boundaries are specified as pressure outlet boundaries. The solution is initialized uniformly with the free stream condition throughout the domain.

4. Results and discussion

Subsonic surface flow pattern on the upper surface of a 76°-40° double delta wing has been investigated using oil-powder mixture and compared with the CFD results. The main flow separates at the leading edge and emerges as two distinct vortices as shown in Fig. 4(a).
The strake vortex secondary separation and reattachment lines are shown in Fig. 4(a). The wing vortex is originated from the strake end and the impression found inboard. The wing vortex secondary separation line is evident in Fig. 4(a). These two vortices are distinguishable up to the trailing edge at 5° AoA.

These vortices show an outboard movement and their interaction appeared as the AoA is increased. However the outboard curvature of the strake vortex is much more while the wing vortex remains almost straight at 10° AoA as shown in Fig. 5(a).

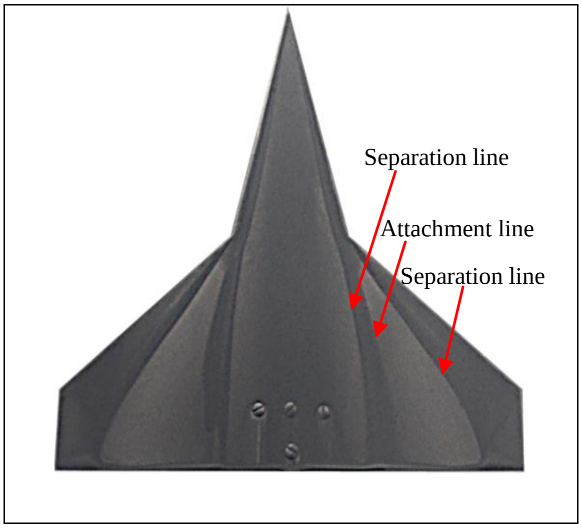

Figure 4(a): Surface flow pattern at 5° AoA (Expt.)

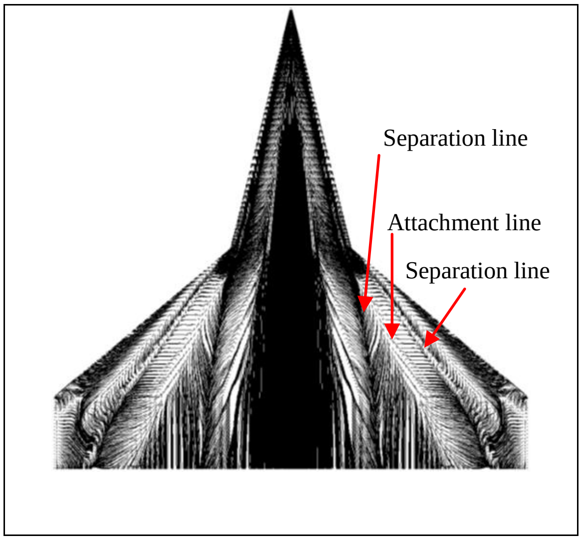

Figure 4(b): Surface flow pattern at 5° AoA (CFD)

The wing vortex gets distorted for further increase in AoA and shown in Fig. 6(a). The surface flow patterns obtained from the CFD analysis are shown in Fig. 4(b)-6(b). The computed flow pattern shows impression of the distinct vortex pairs at 5° AoA similar to the experiment. The attached flow region is extended on the central portion of the wing. The CFD result shows an inboard shifting of the wing vortex and outboard shifting of the strake vortex as the AoA is increased.
The computed flow topology shows good agreement with the experiment.

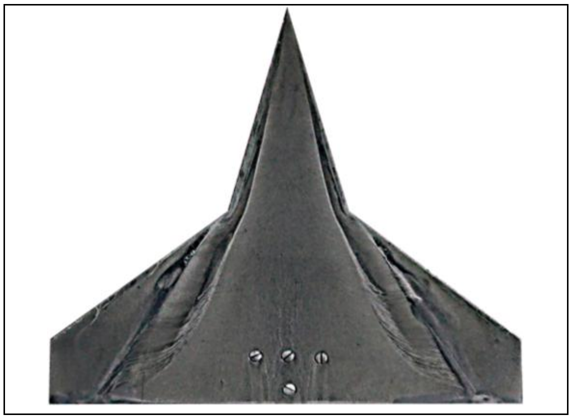

Figure 5(a): Surface flow pattern at 10° AoA (Expt.)

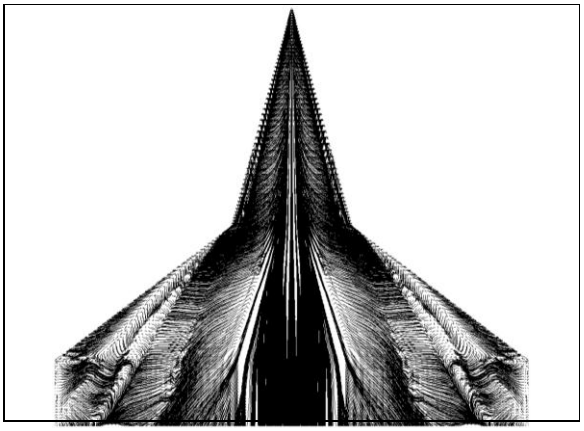

Figure 5(b): Surface flow pattern at 10° AoA (CFD)

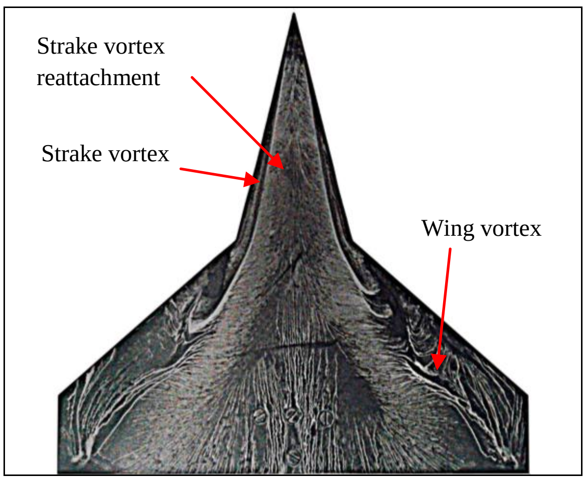

Figure 6(a): Surface flow pattern at 15° AoA (Expt.)

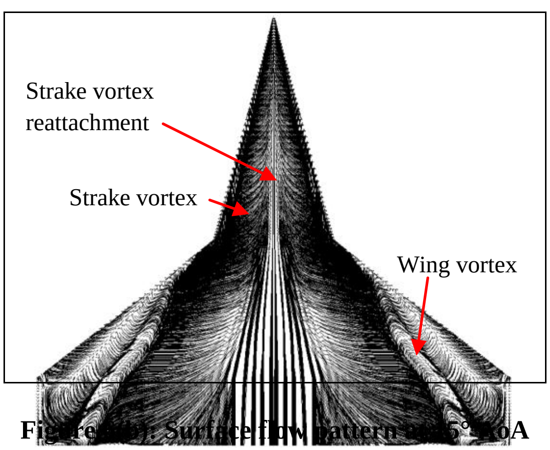

Figure 6(b): Surface flow pattern at 15° AoA (CFD)

5. Conclusion

The following conclusions have been made based on the present investigation.

- Oil flow visualization study on 76°-40° double delta wing shows the strake and wing vortex impressions distinctly.
- The attachment and separation lines are identified clearly. Surface flow topology shows distinct features like primary attachment, secondary attachment and separation lines.
- Experimental results are comparable with the validated data.
- CFD result shows good agreement with the experiment in the context of surface flow pattern.

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