Detached-eddy simulations and analyses on new vortical flows over a 76/40 double delta wing

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The double delta wing is a simplified configuration used for studying aircraft aerodynamics. It is composed of a highly-swept delta wing connected in front of the main delta wing with a smaller sweep, reflecting the combination of a leading edge extension and the swept main wing. The aerodynamic performance of such wings, which includes the behavior of the leeside vortical flows at moderate and high angles of attack (AoA) at low speed, is of research interest.

The prominent aerodynamic feature of the delta wing is the dominant leading edge vortex pair on the lee side, particularly over wings with sharp leading edges. For the single delta wing, research techniques can well describe the main vortices in the absence of vortex breakdown, including good prediction of the surface pressure distribution. Because of the appearance of a geometric discontinuity in the double delta wing connecting the strake and the wing, a wing vortex is generated at the discontinuity inducing a nonlinear interaction with the strake vortex. This nonlinear interaction makes it difficult to obtain an accurate prediction of the aerodynamic performance of such a double delta wing. Fujii considered that it would be difficult to obtain reasonable agreement with experimental results even with a large increase in the computational grid.

Based on current work, the understanding of flows past a double delta wing with sharp leading edges is as follows: 1) vortices are the dominant flow feature; 2) the basic vortical system consists of the strake and wing vortices, with secondary or even tertiary vortices; 3) vortex breakdown will occur when the AoA increases beyond a certain angle. The breakdown of the wing vortex occurs prior to that of the strake vortex. Other than the dominant vortices, small-scale structures initially appear at the wing tip at certain AoA, and massively-separated flows emerge. With an increase in the AoA, the region of separation gradually enlarges, and finally the whole upper wing is immersed in the massively separated flow. It is widely accepted that traditional Reynolds averaged Navier-Stokes (RANS) is not appropriate for simulation when massive separation occurs. Direct numerical simulation (DNS) and large eddy simulation (LES) can be used but at high cost. Detached-eddy simulation (DES) or a RANS/LES hybrid method combines the advantages of DNS and LES fitting the needs of engineering development while providing the useful details needed for fundamental research, and are thus considered suitable tools for studying such flow regimes. The applications using this method have been conducted on various aspects of fluid mechanics.

Because of the importance of the vortical flows of the double delta wing, every pattern of vortices needs to be carefully studied by computational and experimental analysis. As mentioned above, DES or RANS/LES serve as efficient ways to study the vortical flow when massively separated flow appears. The 76/40° double delta wing is thought to be important for investigations in which the topology of the vortex-dominated flow field is advantageous for atmospheric flight using vortical flows in air combat for takeoff and landing. In the present work, we use SA-DES to compute the massively separated flows of the 76/40° double delta wing previously studied by Verhaagen. Through computation, we found a new type of cross-flow vortex, which occurs at an AoA starting from 15. The vortex differs from the strake and wing vortex or other vortices in massively separated flows.

By means of physical analysis based on the numerical simulation, we conclude that the vortices are caused by cross-flow instability. Because of the specific features of the double delta wing, the cross-flow is primarily caused by the induction of the leading edge vortices, which differs from the cause of the cross flow over the swept blunt wing.

Using a velocity transformation, we provide the cross-section topology of the cross-flow vortices and information about the singular points on the section. The analysis shows that the speed of movement of the vortex reaches that of free stream. The wave length of the vortex array and the characteristic frequency are also obtained, providing useful information for further experimental investigation.

It is also shown by analysis that the cross-flow vortex can cause a 10-20% deviation of the pressure distribution to the averaged counterpart. It should be noted that the deviation is local and unsteady, which should be considered in the evaluation of the influence of vortices on aerodynamic performance.

Finally we propose a new type of cross-flow vortex that differs from the vortical substructure.

More information: phys.scichina.com:8083/Jwk_sci … abstract507764.shtml

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