THE ANALYSIS OF FLOW ON ROUND-EDGED DELTA WINGS

By

SHABUDIN BIN MAT

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ABSTRACT

The flow around three-dimensional aircraft wings, including delta-wings is very complicated. Much experimental and numerical work has been performed to discover its complexity. To date, all numerical calculations on delta wings have been carried out for either fully laminar or fully turbulent boundary layers. The transition status of the boundary layer is considered unknown despite several efforts to identify transition from laminar to turbulent flow. One such study, called the International Vortex Flow Experiment – 2 (VFE-2), has been carried out by an international group and mainly focuses on the boundary layers on delta wings. The data from the VFE-2 experimentals potentially provide the location of transition on the upper and lower surfaces of the wing to guide associated numerical studies. The effects of Reynolds number, Mach number, angle of attack and the leading edge bluntness are also investigated.

Almost all delta wing studies to date have involved tests on wings with sharp leading edges and these have led to the conclusion that the flows are relatively independent of Reynolds number. In fact, most real wings have finite leading edge radii. Hence, the flow separation is no longer fixed at the leading edge, thus making the flow dependent on Reynolds number. This particular aspect has been studied extensively by the VFE-2 team.

As part of the VFE-2 project, Glasgow University constructed a delta wing with four different sets of leading edges. Small-, medium- and large-radius edges and a pair of sharp leading edges were constructed in order to compare results from four delta wing configurations. In the current study experiments were carried out on these wings in the 2.65 metre by 2.04 metre, closed circuit, Argyll Wind tunnel of Glasgow University. The models were mounted on a specially designed sting support structure that allowed them to be pitched around a constant centre of rotation throughout the experiments. Tests were conducted at speeds of 20.63 m/s and 41.23 m/s representing Reynolds numbers of 1×10^6 & 2×10^6 respectively, based on the mean aerodynamic chords of the wings. The tests were conducted in three phases. In the first phase, steady and unsteady forces and moments on all wings were measured at an angle of attack that varied from $\alpha = 10^0$ to 25^0. The forces and moments were captured at two sampling rates; i.e., 100 Hz and 8000 Hz. The second test series captured flow visualization data on the four wings. In

these experiments, a mixture of Ondina oil and paraffin was combined with Dayglo powder and applied to the surfaces of the delta wings. The images of the flow topology on the wings were recorded. The final series of experiments involved Particle Image Velocimetry measurements. A stereo-PIV arrangement was applied in this experiment and two CCD-Cameras were positioned outside the test section for image capture.

The current study has identified interesting features of the interrelationship between the conventional leading edge primary vortex and the occurrence and development of the inner vortex on the round-edged delta wings. The inner vortex was first identified and verified by the VFE-2 team. The effects of Reynolds number, angle of attack and leading-edge radii on both vortices are discussed in detail. The steady balance data have shown that the normal force coefficients are sensitive to leading edge bluntness at moderate angles of attack but are less so at high angles of attack. In relation to this, the flow visualization images have also shown that the primary vortex origin is located further aft on the wing at higher leading edge bluntness. This impacts on the strength of the inner vortex which remains a significant flow feature until the primary vortex approaches the apex. The lateral extent of the inner vortex is very dependent on the primary vortex at the leading edge; i.e. the weakening of the primary vortex has positive effects on the inner vortex. Particle Image Velocimetry shows that the increase in leading edge bluntness significantly decreases the swirl magnitude of the primary vortex.

The results obtained from the current investigation provide considerable insight into the effects of Reynolds number, angle of attack and bluntness on the flow structures experienced by delta wings, with rounded leading edges. This work will, therefore, inform and guide future investigations of delta wing flows and has the potential to impact on future wing design.