MEAN CHARACTERISTICS OF FLOW IN JUNCTURES OF SWEPT WINGS AND BODIES

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Abstract

Flow in the juncture region of swept-wing bodies were analysed to study the development of the vortex system at Reynolds number of 95000. In the plane of symmetry of the wing the vortex system is observed to move closer to the wing leading edge with increase in sweep back angle of the wing. In the vertical direction the system moves closer to the body surface with increasing sweep back angles except for the 15^0 swept back configuration.. In the maximum thickness plane the system moves closer to the wing with increasing sweep back angle, but again with the exception of the 15^o swept back geometry. In this plane the system is located at almost similar vertical distance from the body except for the 15^0 case for which it is farther away from the body. In the plane at 80% of the chord, the vortex system for the straight wing-body geometry has lifted off the body surface the most. A system of multiple vortices can be inferred from the vertical velocity distributions in the plane of symmetry.

Introduction

Flow in the juncture formed by a wing-body exhibits complex fluid mechanics phenomena. This flow can be broadly divided into various regions (Fig. 1) These are a nominally two-dimensional approach boundary layer, a region where the boundary layer has three-dimensional characteristics due to thesecondary flows, separated flow and a vortex system and a region between the vortex system and the wing surface, the near-wake region and the far-wake region. Flow in Wing-body junctures is of interest due to a variety of reasons. These include increased skin friction drag, unsteadiness of the flow resulting in vibrations in the junctureregion as well aeroelastic influences of the juncture vortex system on aerodynamic surfaces downstream, and large heat transfers due to the massive mixing.

Considerable research activity is going on to understand and characterise wing-body juncture flow both theoretically as well as experimentally. It has looked at the mean characteristics of the juncture vortex system as well as its unsteady nature. Various experimental techniques have been used which include flow-visualization of the wing-body surfaces as well as the flow field and surface pressure measurements, flow field turbulence measurements using intrusive techniques ie hot-wire anemometry and non-intrusive methods like laser Doppler velocimetry. Reported work in literature show some interesting observations of this flow which at times are contradictory.

However all the reported works in the knowledge of the authors deal with straight wings/cylinders mounted on flat plates, though some experimental work does exist on wing fillets as well. A detailed review of literature can be found elsewhere (Ref. 1).

The present paper which is part of detailed work in the area therefore looks at the influence of wing sweep on juncture flow. The purpose of looking at this parameter is the non-availability of a systematic study which can be used for validations of computational codes as well as provide a baseline for studying juncture fillets.

Considering the sensitivity of the flow to intrusions a three-component laser Doppler velocimeter (LDV) has been used to measure the flow-field characteristics. In this paper the mean velocity characteristics in the juncture region will be presented showing the development of the vortex system as it progresses from the leading edge of the wing downstream.

Experimental Set-up

The tests were conducted in the 0.6x0.9m (2x3ft) low subsonic wind tunnel facility of the Texas A&M University. The juncture was simulated by a wing with a modified NACA 0020 airfoil having a 3:2 elliptic leading joined at the maximum thickness location. The wing was vertically mounted on the wind tunnel floor which simulated the body. The maximum thickness of the wing was 0.12m (4.8in) and the span was 0.89m (35in) resulting in an aspect ratio of 7.3 which was considered sufficient to preclude end effects. These end effects can significantly alter the vortex system characteristics as discussed in Ref. 2. Wings with zero sweep, and with sweep back angles of 15°, 30° and 45° were studied.

These tests were conducted at Reynolds number of 95,000 based on the maximum thickness of the wing. The flow was tripped at the entrance to the test section ensuring a turbulent boundary layer with a thickness () of 43mm, displacement thickness of 5.8mm and momentum thickness of 4.34mm .The Reynolds number based on momentum thickness of the boundary layer was ˜5000. The boundary layer characteristics plotted in the law of the wall co-ordinates (Fig. 2a) and the outer flow comparison with Coles' equilibrium turbulent boundary layer profile (Fig. 2b) confirmed the boundary layer to be turbulent.

The measurements were made using an Aerometrics Inc. three-component laser Doppler velocimetry system (LDV). The system was employed in the back scatter mode with on-axis measurement of the third component. Fog juice was used as seeding material. The particles produced were considered to be aerodynamically small enough to follow the flow-field. Measurements were made in the plane of symmetry upstream of the leading edge of the wing and in planes normal to the plane of the symmetry of the wing at the maximum thickness chord wise location and closer to the trailing edge at 80% of the chord length (0.80c). The measurements were made at points in the field ranging from 400 to 800 depending upon the sweep angle. The data points grid was such so as to resolve the vortex and was based on surface flow visualisation results. The number of samples taken at each data point were 2000. Complete details of the experimental set-up, test conditions and error analysis can be found in Ref. 1. Typical velocity vectors for the zero-sweep case are shown in Fig. 3.

Results and Discussion

The mean velocity measurements in the plane of symmetry of zero-sweep wing-body juncture (the baseline configuration) showed that the mean vortex location upstream of the wing leading edge was at X = -0.21 and Y = 0.047 where X and Y are the stream wise and vertical distances non-dimensionalised by the maximum thickness of the wing. The vertical influence of the juncture was more than one

. As the vortex system wrapped around the wing, the vortex mean centre in transverse plane at the maximum thickness location was observed to move to Z = -0.875 and Y =

0.042. At the 0.80c plane the vortex centre was at Z = -0.825 and Y = 0.125. Thus the system exhibited a tendency to move closer to the body surface as it wrapped around the wing and then lifting off as it progressed towards the trailing edge of the wing.

For the 15° swept back wing-body configuration, the vortex centre was estimated to be at X = -0.156 and Y = 0.052 in the plane of symmetry. The mean vortex signature at the maximum thickness plane is shown in Fig. 4b. The vortex centre was estimated to be at Z = -0.90 and Y = 0.042. At the trailing edge the vortex was observed to move to Z = -0.875 and Y = 0.115.

Mean velocities in the plane of symmetry for the 30° swept back wing-body configuration were observed to show the vortex centre is approximately located at X = -0.083 and Y = 0.036. In the maximum thickness plane, the vortex centre is estimated at Z = -0.85 and Y = 0.042 . At the trailing edge the vortex core is estimated at Z = -0.85 and Y = 0.084.

For the 45⁰ swept back wing-body geometry the vortex core mean location is estimated to be at X = -0.046 and Y = 0.036. The core moves to Z = -0.75 and Y = 0.052 in the maximum thickness plane . In the plane at 0.80c the vortex system's mean core is estimated at Z = -0.80 and Y = 0.073.

The vortex system is therefore observed to move closer in the plane of symmetry to the wing leading edge with increase in sweep back angle of the wing. This is expected as increasing sweep angles result in a reduced adverse pressure gradient delaying separation and ultimate transformation of the shear layer into the vortex system. The system is observed to move closer to the body surface with increasing sweep. However for the 15°-sweep configuration the mean vortex core moved away from the body surface. This is attributed to the additional strain rates because of the cross flow along the wing surface resulting in splitting of the vortex filament in 'three parts' ie a leading edge loop and the two legs, rather than splitting symmetrically in the middle as in case for the straight wing configuration. The leading edge loop then interacts with the next born vortex system causing the peculiar characteristics for this configuration. For the 15°-sweep configuration such a phenomenon was clearly observed in water tunnel flow visualisations (Ref. 1). This phenomenon was first reported by Thomas (Ref. 3) but not explained. In his experiment the split was being caused by the cross-flow due to low aspect ratio of the cylinder being used in the juncture geometry.

The system showed insensitivity to sweep angles in the maximum thickness plane in its distance from the body surface. However at higher sweep angle (ie 45°) the system was further away due to the influence of cross-flow along the wing finally overcoming the dynamics of the vortex system. In this plane, the trend was for the system to get closer to the plane of symmetry of the wing with increasing sweep except the 15° sweep configuration.

In the 0.80c plane the distance of vortex system from the body surface was more predictible with the mean core getting closer to the body surface with increasing sweep angles. The vortex system for the straight wing-body geometry has lifted of the body surface the most. With increasing sweep back angles of the wing the system is observed to move closer to the body surface.

The development of the vortex system is summarised in Figs. 4a and 4b

The vertical component of the velocity field in the plane of symmetry was used to gain further insight into the structure of the vortex system. Figure 5 is vertical velocity distribution in the plane of symmetry of the zero-sweep wing body juncture at a height of

Y = 0.042. The presence of a vortical structure closer to the wing leading edge can be easily inferred from the peak in the distribution. Similarly two other peaks further upstream signify the presence of other vortical structures in the flow. This is consistent with the flow visualization studies reported in Ref 1. Similar remarks can be made about the swept back wing-body configurations, distributions. However with increasing sweep these peaks are less and less discernible.

Conclusions

The juncture-vortex system showed strong influence of wing sweep. In general the vortex system moves closer to the wing leading edge and body surface in the plane of symmetry with increase in sweep back angle of the wing.

The vortex system wraps around the wing closer and closer with increasing sweep back angles.

With increasing the sweep angle the system lifts off lesser and lesser away from the body surface.

An anomaly was observed in the influence of wing sweep for the 15° swept back wing-body geometry.

The mean vortex signature shows a single structure with some counter-rotating activity closer to the body surface. However a system of multiple vortices can be inferred from the vertical velocity distributions in the plane of symmetry.

References

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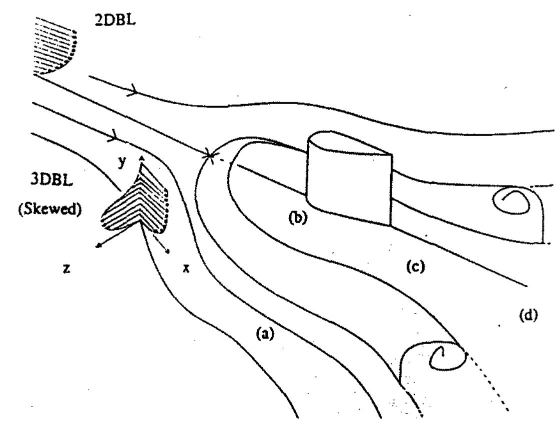

Fig. 1: Schematic of Juncture Flow

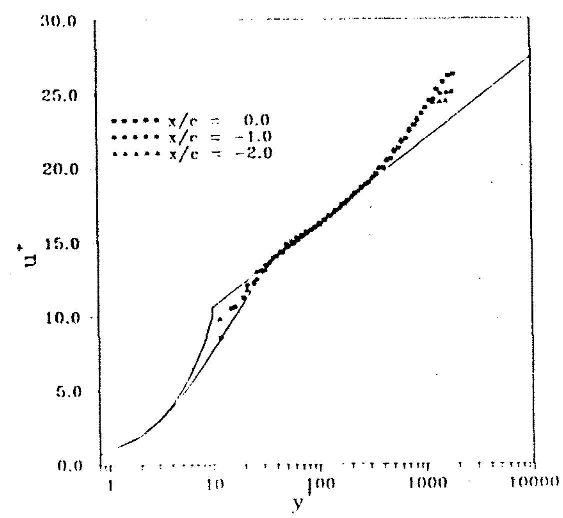

Fig. 2a: Boundary Layer Profile

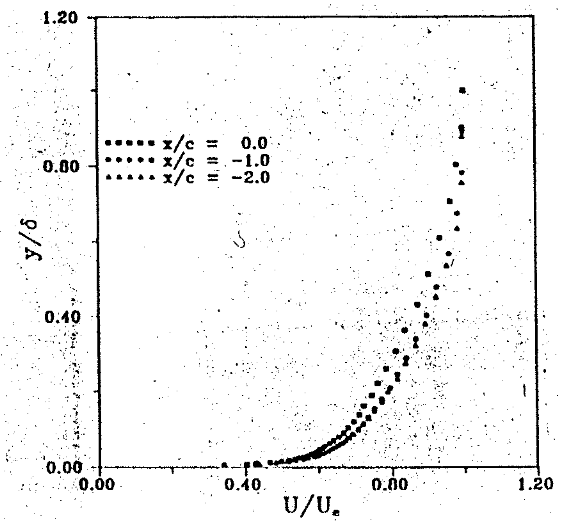

Fig. 2b: Comparison with Coles' Profile

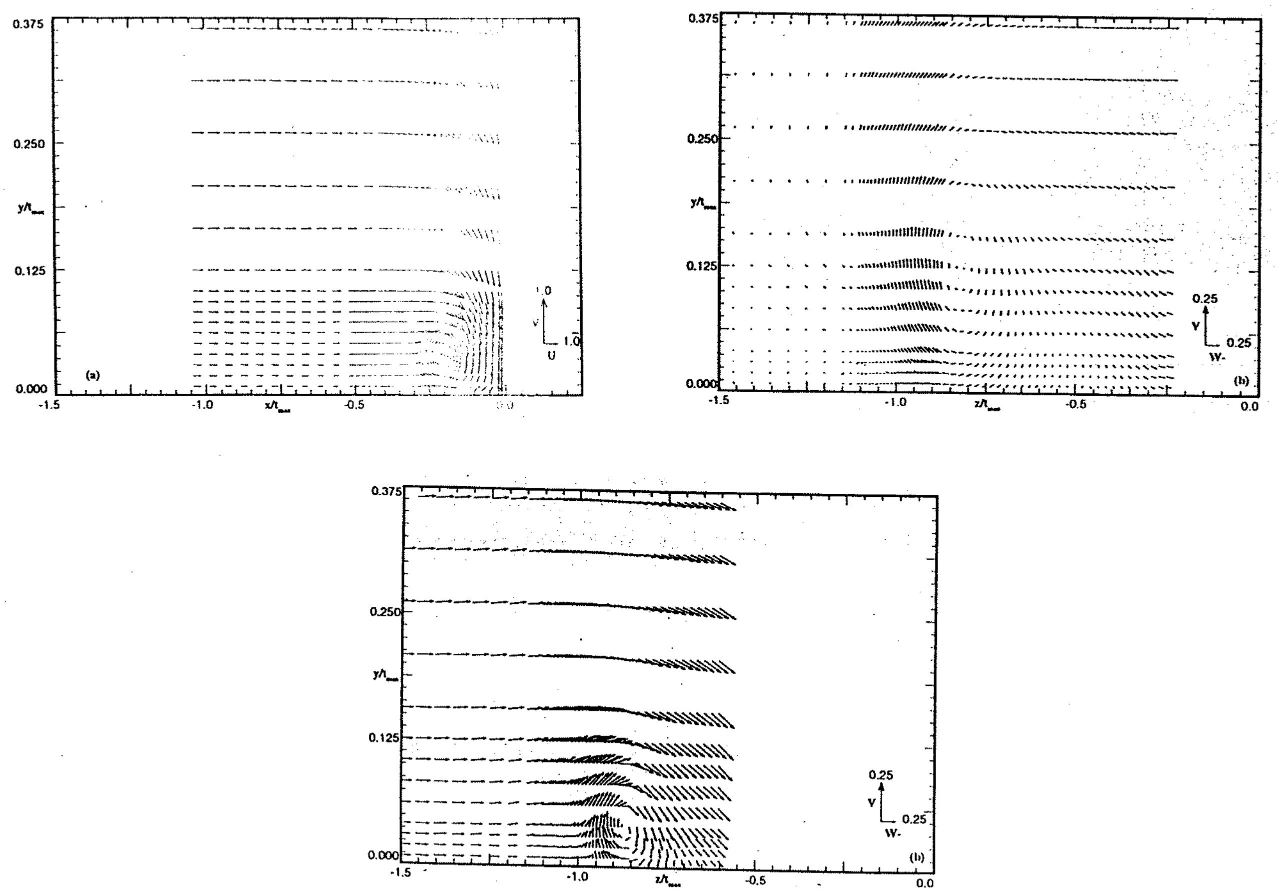

Fig. 3: Mean Velocity Vectors in Juncture of Zero-sweep Wing

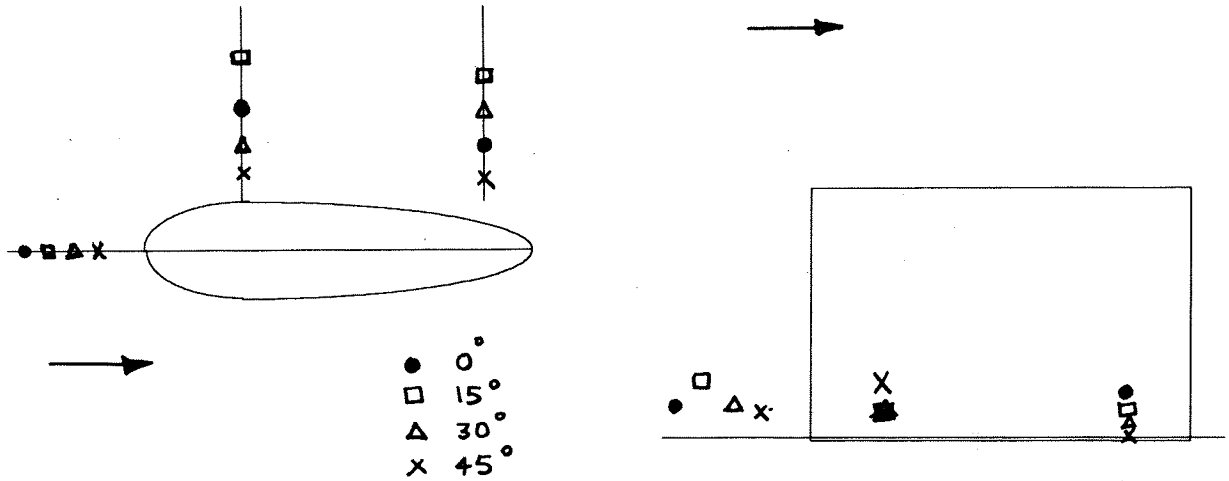

Fig. 4: Development of the Vortex System

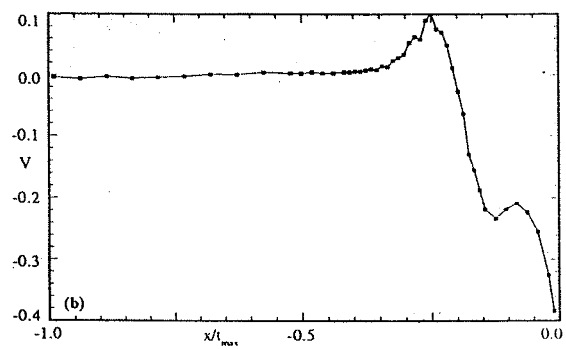

Fig. 5: Vertical Velocity Variation