Unsteady Flow behind a Blunt Based Pod Model

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Abstract. The present experimental work aims to investigate the flow behind a blunt based cylindrical body, mounted on a short strut under a flat plate. This configuration represents a generic model of a pod that is retrofitted with a pylon on to the undersurface of aircraft for the purpose of carrying surveillance, navigation and targeting systems. Measurements and flow visualization in the near wake region showed the presence of oscillations with regular periodicity which scaled with the flow velocity. The influence of close proximity of the plate was found to force the mean wake flow axis to deviate away from the plate. The separated flow, initially laden with azimuthal vorticity in the base region, appeared to be dominated by a pair of contra-rotating streamwise vortices in the developing wake.

Key words: unsteady wake, pressure fluctuations, vortex, base flow, pod.

1. Introduction

Pods carry special mission surveillance and LANTIRN systems which, when retrofitted on to a fighter aircraft, significantly enhance their navigating and targeting capabilities in night and hostile weather. Due to practical constraints, these avionics pods cannot be always of the best aerodynamic shapes and hence usually possess blunt base. The pods are externally mounted on to short pylons beneath aircraft leaving a small gap from the undersurface. Such configuration renders considerable complexities, due to interaction of separated base flow behind the pod with pylon wake and the undersurface boundary layer, and produces highly unsteady wake with significant fluctuations in dynamic pressure. The resultant oscillations in the wake flow grow with the speed and can cause sonic fatigue at high speeds leading to failure of downstream structures. Severe damage to the ventral fin of F-16 has been cited by Maines et al. [1], Smith et al. [2] and Shaw et al. [3] as a motivating factor to initiate the research work on development of control methods to suppress the acoustic loads along with their frequencies suitably altered in the wake of the LANTIRN pod.

The present work stems from the realization that characteristics of wake flow of a pod assembly are different from that of an axisymmetric slender bluff body and therefore, our current understanding of such flows must be furthered for any evolvement of an effective control mechanism.

2. Experimental Methods

The test model was made similar to the one used in earlier studies [1, 2, 3] - a cylindrical body with hemispherical head and blunt base (pod), mounted on a low aspect ratio strut (pylon) under a flat plate (aircraft undersurface) as depicted in Figure 1. The length and the diameter of the pod were 430 mm and 110 mm, respectively. The pylon cross section was NACA 0015 airfoil with 333 mm chord. The pylon maintained a gap of 47 mm between the pod and the plate which extended downstream of the pod up to 4 diameter from its base.

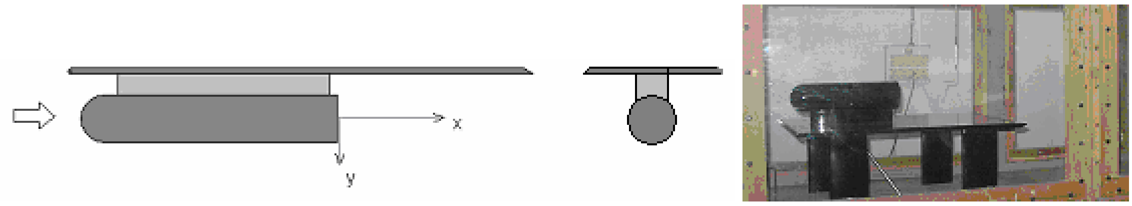


Figure 1. Schematic of test model and picture of its mounting arrangement in the wind tunnel.

Experiments were conducted in a 915 mm x 915 mm wind tunnel having provision for the traverse of measuring probes through a slit in the ceiling. Therefore, the model was fitted in inverted position (pod above the plate) on the floor of the test section by means of streamlined struts as shown in the picture in Figure 1. Ultra low differential pressure transducers of type RS 395-237 were used to measure the time dependant pressures at desired points through taps and various types of tubes [4]. A PC based data acquisition system, comprising of NI card PCI 6025E Series and LabVIEW software version 7.1, was used to acquire and process the data. A Dantec SPT smoke generator and a 5 watt Argon-ion laser were used for laser sheet flow visualization technique. A vortex meter (rotor with straight vanes at zero incidence) was also used to physically verify existence of streamwise vortices and to locate their position.

3. Results and Discussion

The test Reynolds number based on the free-stream velocity of 9.8 m/s and the pod model diameter was about 6.9×10^4. In fact, the Reynolds number value was subcritical when calculated on the basis of the pod length. Therefore, it was believed that the boundary layer at the pod trailing edge was laminar for the velocity profile tends to become *fuller* just before separation. The measured boundary layer thickness at the trailing edge diametrically opposite to the pylon was found to be about 10% of the pod diameter. Pressure over the pod base area was found to vary by a slight margin about the mean base pressure coefficient value of about -0.26. The base pressure tended to decrease towards the pylon under combined influence of pylon wake and the plate boundary layer.

Figure 2 shows velocity profiles in the central vertical plane at two axial locations – before and after the closure point (free stagnation point). At x/D=1, close to the axis, the velocity could not be measured for the pitot probe was in reverse flow within the recirculation region. However, at x/D=3.5, the minimum velocity attains about 80% of the edge velocity and the profile spreads out suggesting a rapid recovery in the wake deficit due to entrainment and mixing. As growth of the pod wake is restricted in the direction of the plate, the wake axis is seen to deviate in the opposite direction, the phenomenon referred to as downwash [1]. The velocity profiles clearly exhibit mingling of the pylon wake and the plate boundary layer.

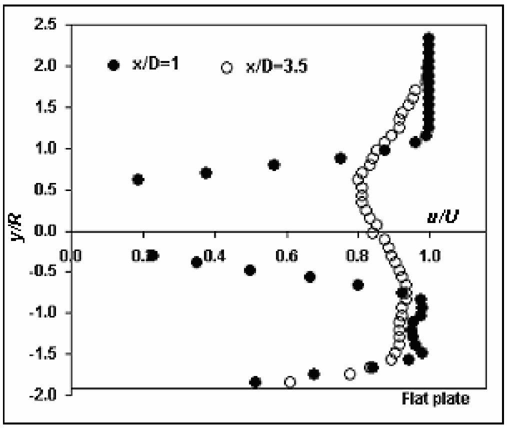


Figure 2. Velocity profiles in vertical (xy) plane at z/R=0.

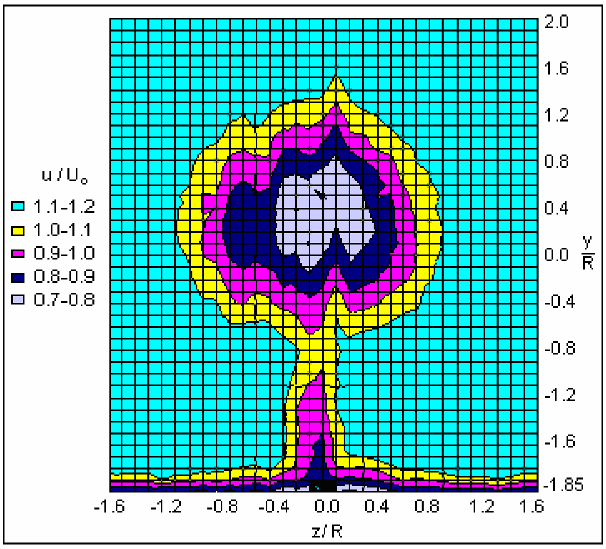


Figure 3. Velocity distribution in transverse (yz) plane at x/D=2.

Figure 3 shows contours of velocity in relation to the free-stream velocity in transverse plane at x/D=2. There exist regions of velocity that is higher than the free-stream due to solid and wake blockages. The plot is nearly symmetric about the vertical plane and features of the downwash, pylon wake and the plate boundary layer are seemingly consistent with those noted in Figure 2.

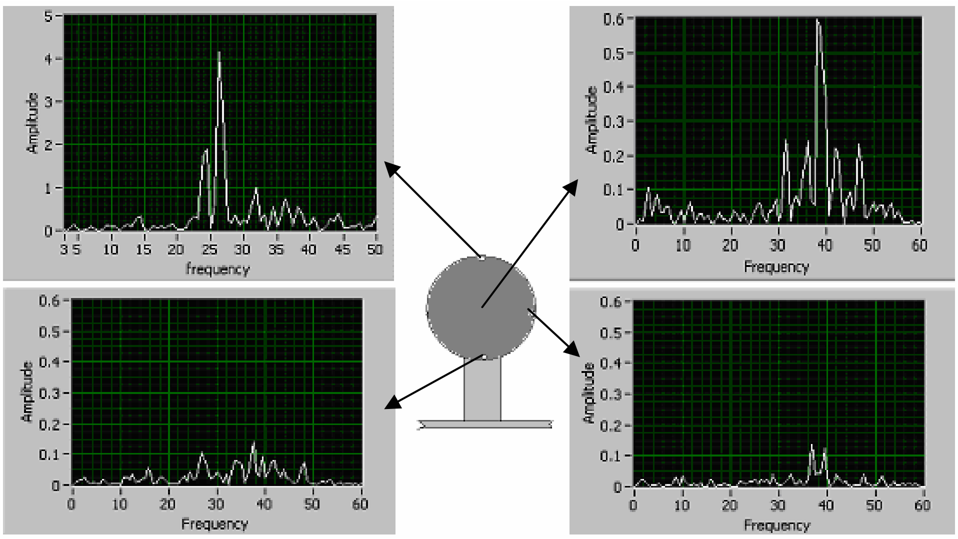


Figure 4. Frequency spectra of unsteady pitot pressures at various locations in the transverse yz plane at x/D=2.

Frequency spectra of pitot pressure fluctuations registered at the centre and various circumferential locations at 2 diameter from the pod base are depicted in Figure 4. The spectral peaks represent the primary frequency and intensity of oscillations in the wake. The oscillations appear to be localized – on the sides and towards the pylon they are almost non-existent but in the center and opposite to the pylon a discernible periodicity is observed. The frequency is seen to change from 39 Hz in the centre to 26 Hz at the edge along with the amplitude growing about 7 times.

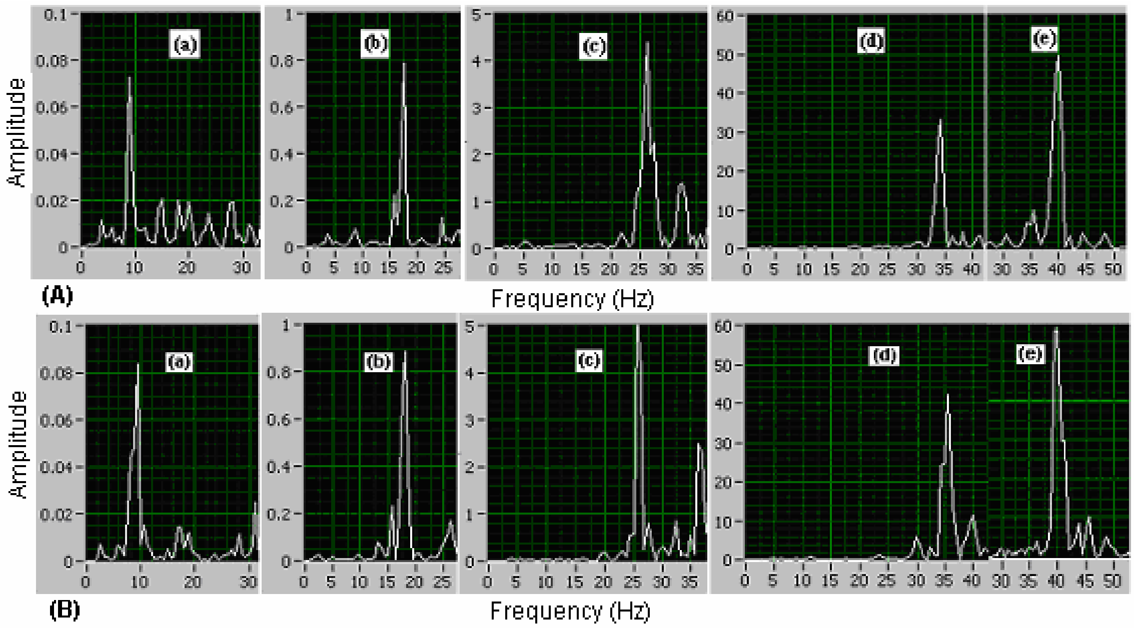


Figure 5. Frequency spectra in the first quadrant (A) y/R=0.5, z/R=0.5 and the second quadrant (B) y/R=0.5, z/R=-0.5 of the wake at x/D=2 for different flow velocities. (a) U=4 m/s, (b) U=7 m/s, (c) U=10 m/s, (d) U=13 m/s and (e) U=15 m/s.

Figure 5 shows that the wake oscillations more or less matched in frequency and in strength on either side of the plane of symmetry. However, it could not be ascertained whether they were in phase or out of phase. The peak frequency is seen to scale with the flow velocity but the rise in the amplitude is increasingly steep. The Strouhal number estimated from the peak frequency is plotted against the Reynolds number in Figure 6. It appears to suggest that the Strouhal number for such configuration would eventually reach S_t=0.29.

Figure 7 shows velocity vectors obtained in the first and the fourth quadrants in the cross plane at x/D=1, assuming the flow to be symmetric about y-axis. It clearly indicates that the flow field, though expected to be dominated by large scale azimuthal vortical structures, contains a streamwise vortex with clockwise rotation in the fourth quadrant. Traverse of the vortex meter confirmed existence of a pair of contra-rotating streamwise vortices slightly away from the pod axis toward the plate; the location of one of them is shown as marked in the figure. It is indeed surprising that the maximum flow instabilities occur on opposite side.

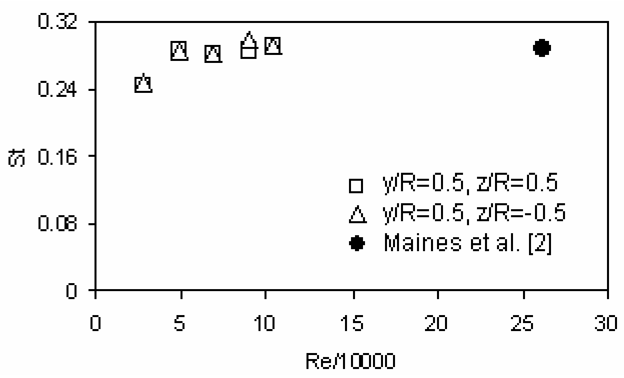


Figure 6. Wake Strouhal number obtained at x/D=2.

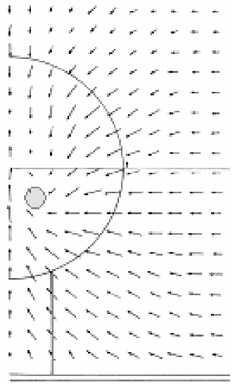
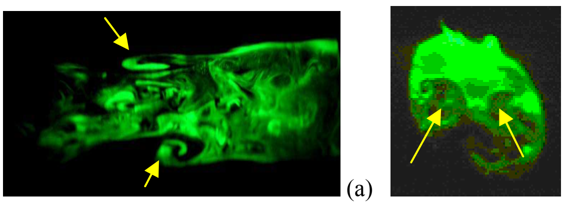


Figure 7. Velocity vectors in half yz plane at x/D=1.

Photographs of laser sheet flow visualization are shown in Figure 8. Existence of azimuthal vortices shrouding the wake and a pair of streamwise vortices inside the wake, marked by arrows, is evident in Figures 8(a) and 8(b), respectively.



(a) (b)

Figure 8. Wake flow visualization using smoke and laser sheet technique: (a) cut view in horizontal xz plane at y/R=0, (b) cut view in transverse yz plane at x/D=2.

4. Concluding Remarks

Formation of a pair of contra-rotating streamwise vortices amidst shroud of azimuthal vortices in the base region and the downwash due to the presence of the plate appear to be peculiar features of a pod wake. The maximum of unsteadiness in the pod wake is found to be position dependent. Attribution of the oscillations in the pod wake to the pair of streamwise vortices needs confirmation through further investigation as positions of their occurrence are seen to be in opposite direction away from each other.

References

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