AIAA 81-0359R

An Experimental Study of Vortex Flow on a Slender Body at Large Incidence

Wladimiro Calarese*
Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio

Abstract

AN experimental investigation has been performed of the flow on the leeward side of a slender body of revolution at high angle of attack at Mach numbers of 0.6 and 0.7 and a unit Reynolds number of approximately 7×10^6/m. Hot film anemometers have been used to obtain the data. The asymmetry and steadiness of the vortex shedding pattern are ascertained. Representative mean velocity and turbulence intensity values are presented together with power spectral densities of the hot film output. Schlieren photography illustrates the flowfield.

Contents

Asymmetric vortex flow affects the performance of missiles and slender bodies of revolution flying at high angle of attack. For low freestream turbulence levels, steady asymmetric vortex shedding generally ensues at an angle of attack of 27 deg or more, up to about 50 deg, causing considerable side forces that affect the course and direction of a given missile. In a cross-flow plane, the vortices resemble a von Kármán vortex street past a two-dimensional cylinder (Fig. 1, Sec. A). At transonic speeds, the effects of vorticity can be more difficult to ascertain due to the vorticity dependence on the local Mach number, which might be subsonic or supersonic. Previous investigations have been performed on wake vortices,[1-5] but most of them deal with experiments at low freestream Mach numbers. In the present experiment, transonic data were obtained for the surface pressure coefficients, flowfield mean velocities, and turbulence intensities. Schlieren photography and high-speed movies were also taken.

The experiment was performed in the closed-circuit wind tunnel of the Trisonic Gasdynamic Facility of the Flight Dynamics Laboratory. The tests were conducted at Mach 0.6 and 0.7, at a tunnel stagnation temperature of 560°R, and unit Reynolds number of approximately 7×10^6/m. The tunnel freestream turbulence level was low, less than 1% of the freestream velocity. The tests were performed at an angle of attack of $\alpha = 45$ deg, and roll angles of $\phi = 0$ and 90 deg, on a 25.4 mm diam, sting-mounted model consisting of a sharp, tangent ogive nose of fineness ratio 3 followed by a cylindrical afterbody of fineness ratio 7.5. The model was equipped with four rows of pressure orifices.[5] Hot film anemometers mounted on a traverse mechanism (Fig. 1, Sec. C) were used to measure mean velocities and turbulence intensities in the model's wake. The disturbance produced by the probe was negligible, since its proximity to the model's surface did not alter appreciably the pre-existing surface pressure distribution. This distribution changed slightly when the model was rolled 90 deg from a vertical to a horizontal plane to obtain vertical velocity data. The change was less than 2% and, therefore, did not affect the data excessively, but it shows the sensitivity of the system to nose orientation. Test repeatability was checked and found to be satisfactory.

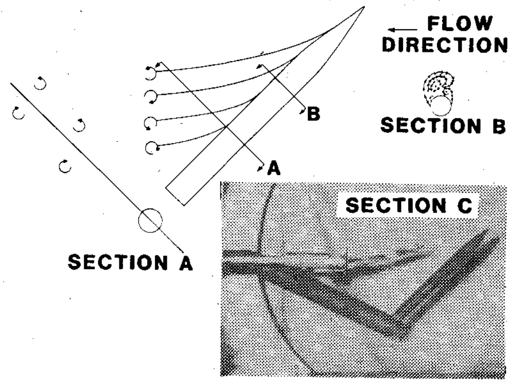

Fig. 1 Vortex pattern on ogive cylinder model and probe traverse mechanism.

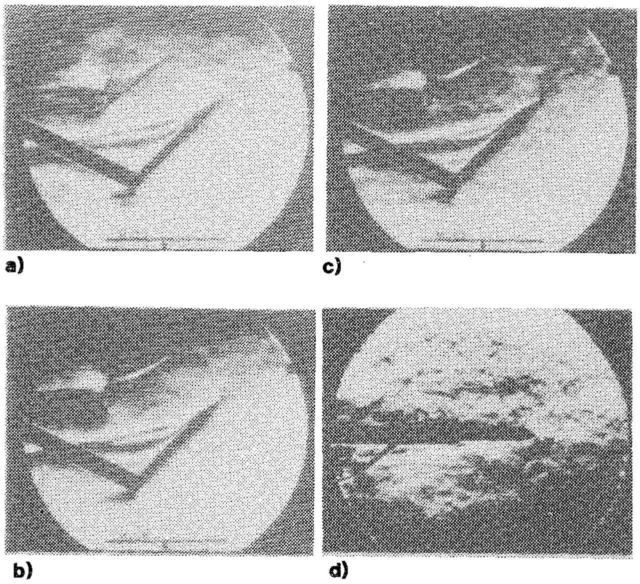

Fig. 2 Schlieren photographs of the flowfield at $\alpha = 45$ deg, different Mach numbers and roll angles. a) $M = 0.53$, $\phi = 0$ deg; b) $M = 0.58$, $\phi = 0$ deg; c) $M = 0.63$, $\phi = 0$ deg; d) $M = 0.6$, $\phi = 90$ deg.

Presented as Paper 81-0359 at the AIAA 19th Aerospace Sciences Meeting, St. Louis, Mo., Jan. 12-15, 1981; submitted March 10, 1981; synoptic received Aug. 31, 1981. This paper is declared a work of the U.S. Government and therefore is in the public domain. Full paper available from AIAA Library, 555 W. 57th St., New York, N.Y. 10019. Price: Microfiche, $3.00; hard copy, $7.00. **Remittance must accompany order.**

*Aerospace Engineer, AFWAL/FIMM. Member AIAA.

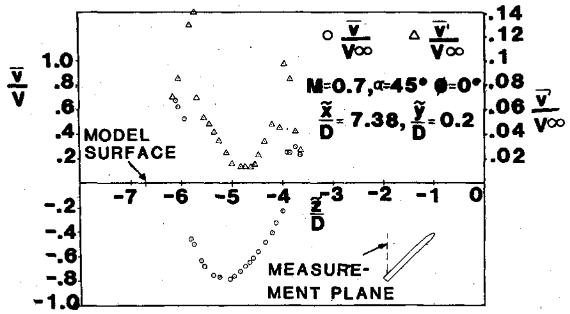

Fig. 3 Lateral mean velocity turbulence intensity, $M=0.7$, $\bar{x}/D=7.38$.

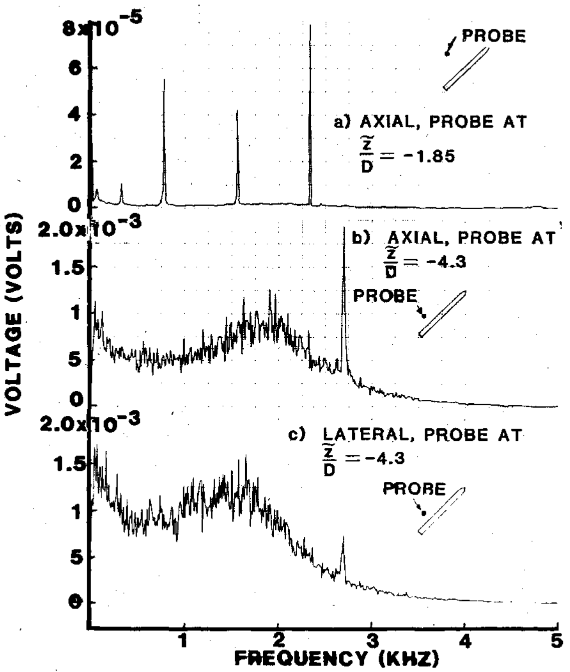

Fig. 4 Power spectral densities ($M=0.6$, $\alpha=45$ deg, $\phi=0$ deg, $\bar{x}/D=7.38$, $\bar{y}/D=0.2$).

The high-speed movies, capable of speeds up to 4000 frames/s, show that the vortex pattern is generally steady. The movies, surface pressure distributions, and photographs (Fig. 2) clearly show that the vortex pattern is asymmetric. By using liquid crystal paint on the model, it was ascertained experimentally that boundary-layer transition occurred asymmetrically.[5] Speculations that this asymmetric transition might occur were reported in Ref. 4.

Figure 2 shows schlieren photographs of the model flowfield at $\alpha=45$ deg, $\phi=0$ deg, and $\phi=90$ deg, and at different Mach numbers. The vortices behind the model can be easily seen. Regions of different light intensities can be detected. Low-intensity regions are adjacent to regions of high intensity. The vortex center lies along the boundary of the two regions.[3] The change in intensities is the consequence of the change in sign of the density gradient at the vortex center. The vortex starting position, i.e., the distance from the nose tip, clearly increases with Mach number. Also, the inclination of the trajectory of the first two vortices changes by a different amount with increasing Mach number. Consequently, the high-intensity region between the two vortices decreases. This might be considered as vortex meander, the amount of which is then not only dependent on the local turbulence but also on the freestream Mach number.

Figure 3 shows the hot film values of the lateral mean velocity and turbulence intensity of two counterrotating vortices at Mach 0.7. The corresponding configuration is sketched in Sec. B of Fig. 1. Similar data were obtained for the other velocity components at different axial locations. It was noted that the vertical distance between the vortices' centers increased downstream.

Power spectral densities (PSD) were obtained for the hot film voltage output, which corresponds to velocity fluctuations (Fig. 4). The data of Fig. 4a were taken in the inviscid flowfield adjacent to the vortex flow. The turbulence levels are very low, but a definite instability exists. Resonant peaks are observed at a fundamental frequency of about 800 Hz and its higher harmonics. When the probe was calibrated in the freestream, no disturbances or compressor noise of this kind were observed. Therefore, after some consultation,[6] it was concluded that the disturbance in the inviscid flow adjacent to the vortical flow should be classified as a Rayleigh instability. Necessary conditions for this instability to develop are that the velocity profile should contain a point of inflection and that the numerical value of the vorticity at the point of inflection must be a maximum,[7] which is exactly what happens, in the present case, in the adjacent vortex core. The data of Figs. 4b and 4c, taken inside the vortex flow (see Fig. 3), show high turbulence levels. The axial fluctuations are comparable to the lateral ones. Some disturbance is detected in the axial plots at a frequency of 2700 Hz. Since cross correlations could not be taken as only one probe was used in the experiment, it is impossible to know whether the disturbance was an acoustic disturbance due, for example, to tunnel noise, or coherent structure of turbulence, that is, a fluid dynamic disturbance propagating downstream.

References

[1] Owen, F. K. and Johnson, D. A., "Wake Vortex Measurements of Bodies at High Angle of Attack," AIAA Paper 78-23, Jan. 1978.

[2] Fidler, J. E., Schwind, R. G., and Nielsen, J. N., "An Investigation of Slender-Body Wake Vortices," NEAR TR-108, Feb. 1976.

[3] Thomson, K. D. and Morrison, D. F., "The Spacing, Position and Strength of Vortices in the Wake of Slender Cylindrical Bodies at Large Incidence," *Journal of Fluid Mechanics*, Vol. 50, Pt. 4, 1971, pp. 751-783.

[4] Reding, J. P. and Ericsson, L. E., "Maximum Side Forces and Associated Yawing Moments on Slender Bodies," *Journal of Spacecraft and Rockets*, Vol. 17, Nov.-Dec. 1980, pp. 515-521.

[5] Calarese, W., "An Experimental Study of Vortex Flow in the Wake of a Slender Body of Revolution at Large Incidence," AIAA Paper 81-0359, Jan. 1981.

[6] Hankey, W. L., private communication, AFWAL/FIMM, Wright Patterson Air Force Base, Ohio, 1980.

[7] Rosenhead, L., *Laminar Boundary Layers*, Oxford at the Clarendon Press, 1963, pp. 511-519.