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OBSERVATIONS ON TURBULENT BOUNDARY LAYER AND THE NEAR WAKE OF AN AFTERBODY

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ABSTRACT

Measurements of mean velocity and velocity fluctuations have been carried out in the incompressible turbulent boundary layer and the near wake of a circular arc boat-tailed afterbody. Results show significant departure of the boundary layer mean velocity profiles in the adverse pressure gradient region from the universal characteristics. The mean velocity profiles and the centre line velocity variation in the near wake show similarity. A mear velocity in the near wake is deduced from these observations.

INTRODUCTION:

Flow region near an afterbody of an airborne vehicle has technological as well as scientific interest on account of its contribution to aerodynamic drag. The turbulent boundary layer approaching the base is subjected to large pressure gradient and to longitudinal and transverse curvature. It convects vorticity into the recirculating region near the base. On the other hand, the latter has an upstream influence on the boundary layer. This interaction is weak in supersonic case and is relatively well understood, but the problem is more serious in subsonic case.

Several measurements have been made in the boundary layer and wake of an axisymmetric streamlined body (e.g. Patel et.al (1979)) and the wake of a blunt body without boat-tail (e.g. Merz et.al (1978)). They essentially highlight special features of thick axisymmetric turbulent boundary layers and axisymmetric wakes.

The present investigation deals with the turbulent boundary layer and the wake of an axisymmetric blunt based body having a maximum diameter (D) of 80mm and a circular arc boat-tail. The boat-tail region is preceeded by 7.2D long cylindrical part giving a standard initial condition. The length-to-diameter ratio is 0.8 giving the chord angle of 14° or the boat-tail angle of 27° at the base. This configuration models relatively short and steep afterbodies on which the boundary layer is more susceptible to separate.

EXPERIMENTAL SET-UP

Figure 1 gives the geometry of the model. Experiments were conducted in 0.91 m diameter wind tunnel at freestream velocities (U_1) upto 28 m/s and without jet. The freestream turbulence is less than 0.3%. Measurements were carried out by using Pitot probe, disc probe and a single hot wire probe. Probes were traversed perpendicular to the surface, along the model axis and perpendicular to it to study the boundary layer and the wake respectively. Near wake measurements show that the departure from axisymmetry of the mean velocity field due to the model support is rather small.

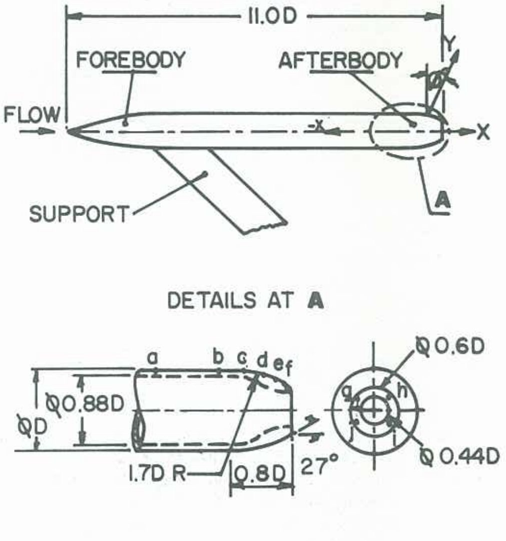

Figure 1. Afterbody model. D=80mm. Wall taps a to f are at distances (X) = -1.81D, -0.94D, -0.62D, -0.38D, -0.19D and -0.06D from the base, g to j are base pressure taps.

RESULTS AND CONCLUSIONS

The Afterbody Boundary Layer

The wall pressure distribution (Figure 2) has an initial region, (stations a to c) with favourable pressure gradient (FPG), and the subsequent region (stations d to f) having an adverse pressure gradient (APG).

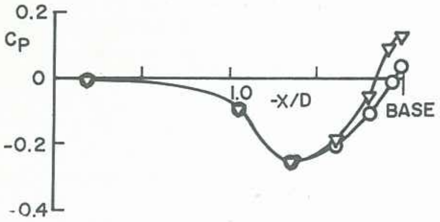

Figure 2. Pressure distribution on the afterbody at U_1(m/s) = 15.7(○) and 25.0(▽).

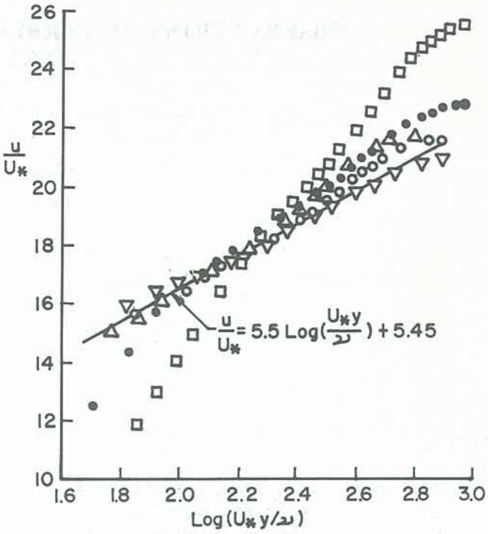

Figure 3. Boundary layer mean velocity profiles at a(△), b(○), c(▽), d(●) and e(□). U_1=25m/s.

The overall development of the boundary layer on the afterbody at U_1 = 25 m/s is indicated below.

Station	a	f
δ/D	0.13	0.21
H	1.27	1.73
Cf x 10^3	4.1	2.5

Skin friction was determined using Clauser's method. Mean velocity profiles in wall law coordinates (two-dimensional) are shown in Figure 3. While the logarithmic region has universal coefficients in the FPG (stations a to c), there are marked departures in the APG (stations d to e). Also, the wake component tends to decrease in FPG, while it increases rapidly in APG as may be expected. Similar characteristics of mean velocity profiles in APG regions have been observed by other investigators (e.g. Dengel et.al (1982)).

The longitudinal rms velocity fluctuation (σ_t) profiles, Figure 4 show a trend towards similarity. Close to the surface, σ_t decreases in FPG region and increases in APG region as the flow proceeds on the afterbody.

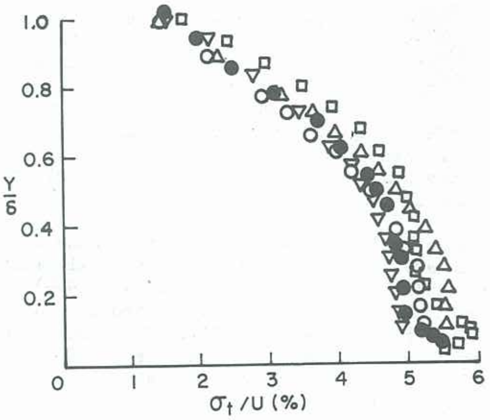

Figure 4. Longitudinal rms velocity fluctuation profiles at a(△), b(○), c(▽), d(●) and e(□). U_1 = 25m/s.

The Near Wake

The mean velocity profiles in the near wake (X/D = 0.5 to 5.5) are similar to a first approximation, Figure 5. (The recirculating region, based on mean velocity field ends at about X/D = 0.4). The correlation given by Ostowari et. al (1989) seems to provide a fair approximation, although there are small systematic departures.

An interesting conclusion of the present study is the similarity of the centre line velocity in the range (X/D) of 0.5 to 5.5 and R_D of 0.6 to 1.3 x 10^5, Figure 6. It may be noted that the axial length scale involves Reynolds number.

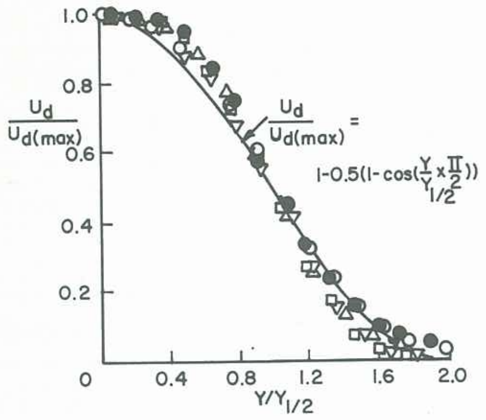

Figure 5. Mean velocity profiles in the near wake at X/D = 0.5(○), 1.0(●), 1.5(▽), 2.0 (□) and 5.5(△). U_1 = 25m/s.

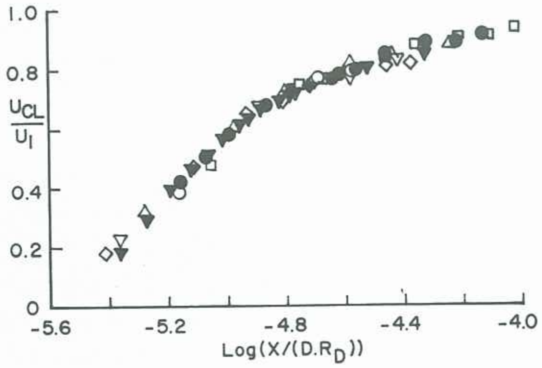

Figure 6. Mean velocity variation on the wake centre line at U_1 = 12.2(□), 15.7(●), 20.5 (△), 25.0(▼) and 27.7(◇). X/D = 0.5 to 5.5, R_D = 0.6 x 10^5 to 1.3 x 10^5.

One can deduce from the above two observations that the mean velocity can be described in terms of

$$\frac{u}{U_1} = g\left(\frac{U}{U_1} - f\right) + f \qquad (1)$$

where

$$\frac{u-U_{CL}}{U-U_{CL}} = g\left(\frac{Y}{Y_{1/2}}\right) \qquad (2)$$

$$\frac{U_{CL}}{U_1} = f\left(\frac{X}{D.R_D}\right) \qquad (3)$$

If $U=U_1$

$$\frac{u}{U_1} = g\left(1-f\right) + f \qquad (4)$$

ACKNOWLEDGEMENT

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NOMENCLATURE

C_f	Skin friction coefficient
C_p	Wall static pressure coefficient (wall pressure at 'a' is the reference)
D	Maximum model diameter
f,g	Functions, see Figures 5&6
H	Shape factor
R_D	Reynolds number ($U_1 D/\nu$)
u	Local velocity
U	Velocity outside the boundary layer or wake edge
U_1	Freestream velocity
U_{CL}	Wake centre line velocity
U_d	Velocity defect ($u-U_{CL}$)
$U_{d(max)}$	$U-U_{CL}$
U_*	Friction velocity
X	Distance along model axis
Y	Distance normal to model surface or axis
$Y_{1/2}$	Y at U_d=0.5 $U_{d(max)}$ in wake
δ	Boundary layer thickness
ν	Kinematic viscosity

REFERENCES

DENGEL, P., FERNHOLZ, H.H., VAGT, J.D. (1982) Turbulent and mean flow measurements in an incompressible axisymmetric boundary layer with incipient separation. In Turbulent Shear Flows 3, pp 225-236, Springer Verlag : Berlin

MERZ, R.A., PAGE, R.H., PRZIREMBEL, C.E.G. (1978) Subsonic axisymmetric near wake studies. AIAA J 16 No. 7 pp 656-662.

OSTOWARI, C., PAGE, R.H. (1989) Velocity defect of axisymmetric wakes. Experiments in Fluids 7 pp 284-285.

PATEL, V.C., LEE, Y.T., GUVEN, O. (1979) Measurements in the thick axisymmetric turbulent boundary layer and the near wake of a low drag body of revolution. In Turbulent Shear Flows 1, pp 137-153. Springer Verlag : Berlin.