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Jet Effects on Near Wake of an Axisymmetric Bluff Body

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There have been a number of studies in recent years on subsonic axisymmetric base and near wake flow. This effort has been directed mainly toward base flow control with a view to reducing drag. Herein an experimental investigation of the base flow in the presence of a central jet has been presented. It was found that the presence of a jet significantly affects the near wake flow and the base drag.

Nomenclature

C_p = pressure coefficient = $(p-p_\infty)/\frac{1}{2}\rho U_\infty^2$
$\overline{C_p}$ = Calvert's parameter = $(C_p - C_{p\min})/(C_{p\max} - C_{p\min})$
D = diameter of base
R = radius of base
r = radial distance from center of base to pressure tap
U = velocity
X = axial distance from base
$\overline{X}$ = Calvert's parameter = $(X-X_{\min})/(X_s - X_{\min})$
Y = transverse axis
ρ = density
θ = angular position of pressure tap on base

Subscripts

b = on the base
CL = along wake axis
j = jet
min = minimum value
max = maximum value
S = stagnation point
∞ = freestream conditions

Introduction

BASE flow investigations have received considerable attention in recent years.[1-3] In most of the cases, however, attention has been focused on transonic and supersonic base flow phenomena behind two-dimensional and axisymmetric bodies. Some studies of jet effects on axisymmetric afterbodies in transonic and supersonic flow have also been carried out.[4,5] Compton[6] has studied effects of some base modifications on afterbody flow at subsonic and transonic speeds.

A study of three-dimensional base flows at low speeds reveals that there is still paucity of data in the near wake region, both theoretical and experimental. Low-speed investigations on axisymmetric blunt base bodies with particular reference to near wake region have been reported by several authors.[7-13] In regard to base flow control with a view to reduce base drag, the first experiments were due to Mair,[9] followed by the work of Goodyer.[10] More recently, Morel[12] has investigated the efficacy of base cavities as drag-reducing devices. Gai and Patil[13] investigated in detail the near wake region of an axisymmetric blunt based body in the presence of various base modifications. They also showed that Calvert's[7] similarity parameters are valid for a blunt base in the presence of base modifications.

While the above studies have emphasized the base flow and its control, they have not considered the effects on the near wake due to a central jet issuing from the base, both with and without base modifications. This problem is also of considerable practical significance. In the present study an attempt has been made to gain some understanding of this problem.

Experimental Details

The basic model used was the same as the one described in Ref. 13. To study the effects of base modifications, three configurations were investigated with the plain blunt base being used as a reference for comparison. The geometric details of these modifications are shown in Fig. 1.

To investigate the effects of a central jet, a nozzle with a settling chamber was incorporated into the base (Fig. 1e). The ratio of jet nozzle to base diameter was about 0.12. The injectant was air at approximately ambient temperature. The exit jet was incompressible and the jet to freestream velocity ratio was 1.2.

The experiments were conducted in an open circuit low-speed wind tunnel with a test section 610 mm × 610 mm at a freestream velocity of 25 m/s. The Reynolds number based on freestream conditions and the base diameter was 1.25×10^5.

Solid and wake blockage were estimated to be less than 2% and this was considered not serious enough to warrant any corrections for blockage effects.

Results and Discussion

Figure 2 shows the base pressure distribution on the blunt base with and without jet. With no jet, the base pressures are seen to be somewhat higher in the region 180 deg $\leq \theta \leq 360$ deg. This could not be due to the strut effect as the strut location corresponds to $\theta = 90$ deg. Such a nonuniformity in the pressure distribution has been attributed by Mair and Wilkin[14] to even the smallest of yaw angles (usually < 0.75 deg). The pressure distribution becomes almost uniform in the presence of a jet.

Results of base pressure distribution for the other three geometries showed similar trends. Table 1 shows the mean base pressure coefficient obtained for the various base geometries.

It is seen that first, with modifications to the base, the base pressure decreases, which implies an attendant increase in base drag. For the base with castellations and radial fins the base pressures are much lower. For the base with circumferential fins the decrease is not very significant. This increase in base drag in the presence of base modifications is unlike that observed in two-dimensional flows[15] and is consistent with earlier observations.[10,13]

Second, introducing a jet results in an increase in base pressure for all the geometries and that the increases are of the order of 15% to 20%. The base pressure recovery with jet is seen to be highest in the case of plain blunt base.

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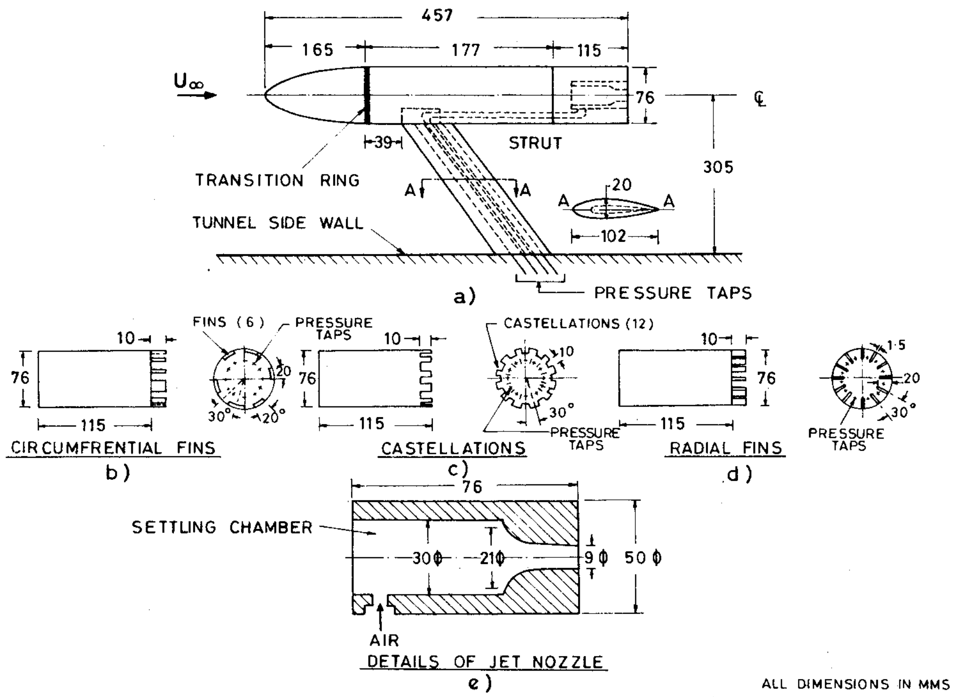

Fig. 1 Experimental arrangements and model details.

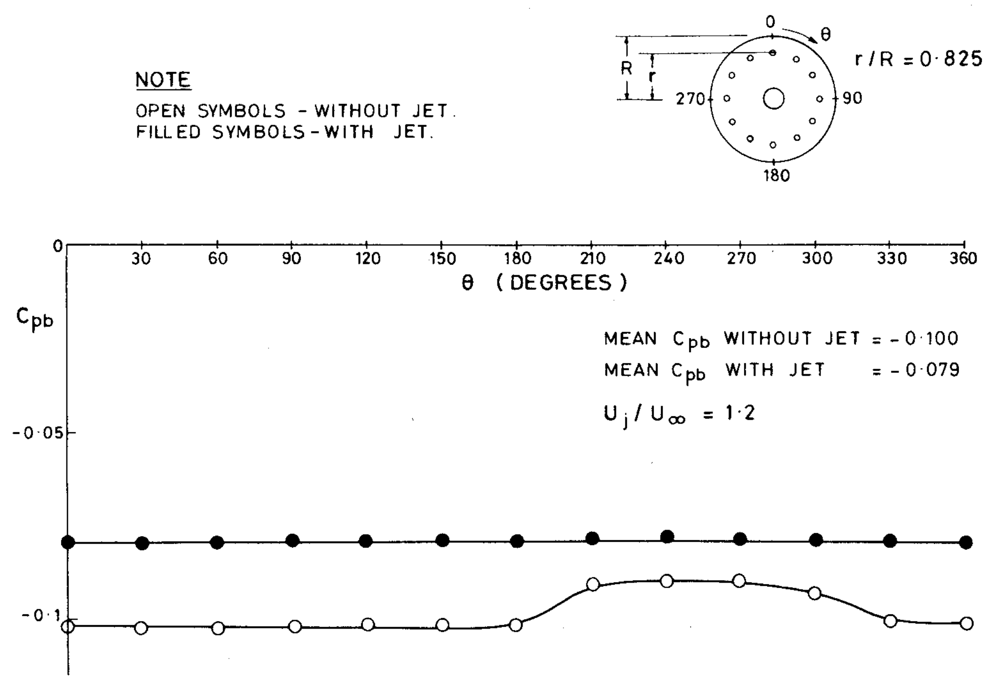

Fig. 2 Base pressures on blunt base with and without jet.

Table 1 Base pressure coefficients

Base geometry	Base pressure coefficient – C_{pb} (mean value) Without jet	With jet, %	Increase with jet, %
Blunt base	0.100	0.079	21
Circumferential fins	0.110	0.095	14
Castellations	0.148	0.120	19
Radial fins	0.143	0.113	20

Boundary layer velocity profiles measured near the base of the body showed them to be turbulent and close to the 1/7th power law profile. The profiles did not seem to be affected by the presence of the jet.

The detailed pressure distribution over the body showed that neither modifications to the base nor the issuing jet affected the pressure distribution. The "upstream influence" of the base itself was found to extend to about one base diameter. This is consistent with the results obtained in Ref. 13.

Figure 3 shows the variation of mean velocity along the wake axis without the jet. These results were obtained using the velocity head probe shown in the figure and described in

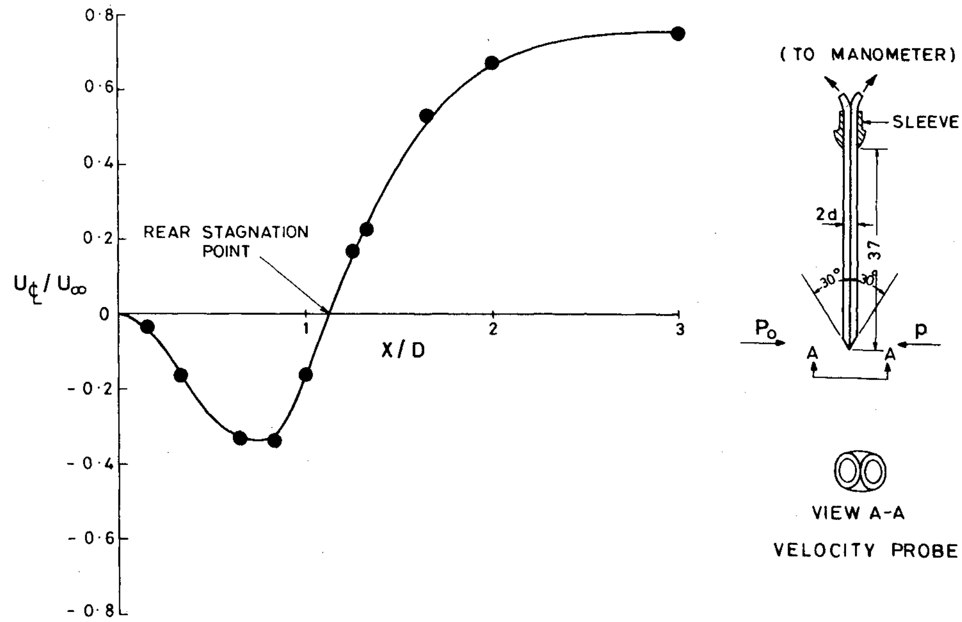

Fig. 3 Mean velocity variation along wake axis—no jet.

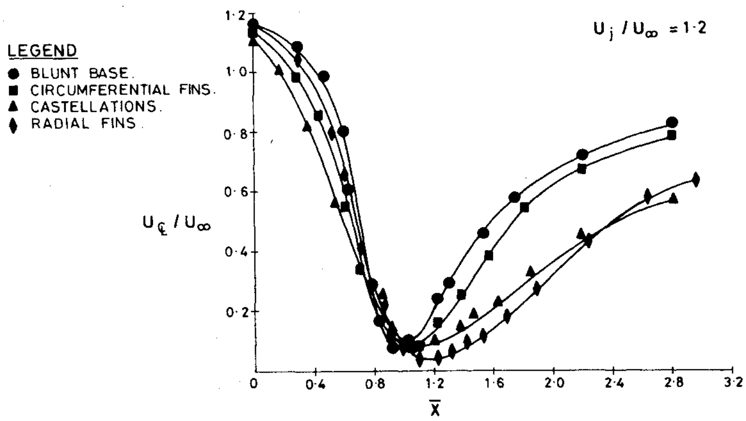

Fig. 4 Variation of velocity along wake axis—with jet.

Ref. 13. The rear stagnation point is seen to be located at about one base diameter.

Figure 4 shows the mean velocity variations on the wake axis with jet. In the presence of a jet, as expected, there is no negative velocity along the wake centerline. However, the velocity of the jet issuing from the base decreases rapidly up to $\bar{X} \simeq 1$. The minimum velocity for all the base geometries is less than 10% of the freestream velocity. Downstream of the velocity minimum the mean velocity once again starts increasing in a manner similar to that without jet.[13] This would indicate that the jet influence on the near wake is not strong beyond $\bar{X} = 1$.

In Ref. 13, it was shown that Calvert's similarity parameters for the near wake region correlate the data for different base geometries without a jet issuing from the base. Figure 5 shows the longitudinal wake similarity data in the presence of a jet in terms of Calvert's parameters. $\bar{X} = 0$ corresponds to the base in this case. The data seem to correlate reasonably well on the basis of these parameters. The peak value of $\bar{C}_p$ occurs at $\bar{X} \simeq 1.5$ and there is a distinct plateau between $\bar{X} = 0.1$ and 0.4 corresponding to $\bar{C}_p \simeq 0.2$. It would thus seem that these near wake correlation parameters are valid also for the case of an axisymmetric wake with a central jet emerging out of the base. Plotting the data in this manner shows that there is a continuous pressure recovery from the base downstream in the presence of a jet, showing the beneficial effect of jet on base drag.

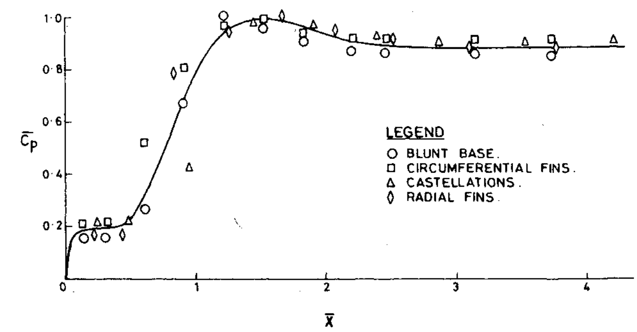

Fig. 5 Near wake similarity with jet.

Figure 6 shows wake profiles obtained at various distances downstream of the base for the four base geometries. First, in the near wake ($x/D \leq 1$) the velocities are positive near the axis, typical of a jet profile. However, the profiles show the existence of reversed velocities which would indicate that there is an annular recirculating region between the jet and the shear layer springing from the base. Second, the size of this annular region is affected by the base modifications, this being most noticeable for the castellated base.

The velocity profiles at a distance of $3D$ show that the influence of the jet is no longer felt. A schematic of the near wake flowfield with a jet is shown in Fig. 7.

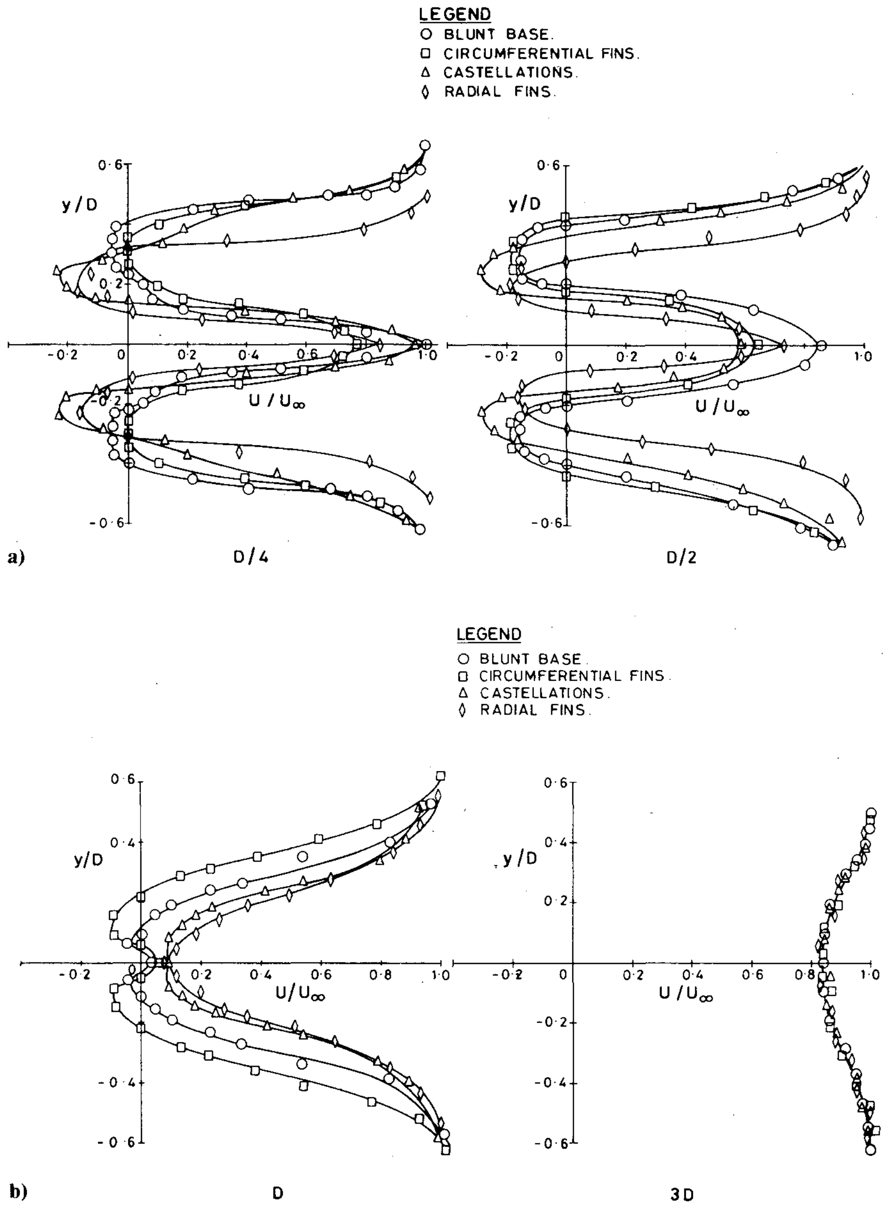

Fig. 6 Velocity profiles in the near wake.

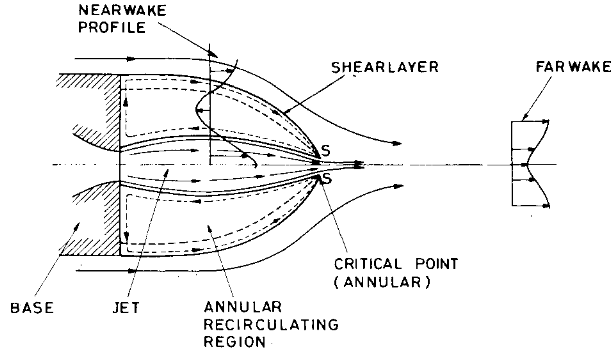

Fig. 7 Schematic of near wake flow with jet.

Conclusions

The present investigation has shown the following:

1) For the base geometries examined, in the presence of a jet, the base pressure recovery was generally of the order of 15% to 20%. The recovery was found to be highest in the case of a plain base.

2) With jet, the recirculating region was pushed radially outward so that an annular recirculating ring was found wedged between the emerging jet and the shear layer from the base. The jet and the shear layer start merging at approximately $X/D \simeq 1$.

3) For the value of U_j/U_∞ at which the present data was obtained, influence of the jet had disappeared completely at $X/D \simeq 3$ downstream of the base.

4) The near wake data, with jet, was found to correlate well in terms of Calvert's similarity parameters.

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