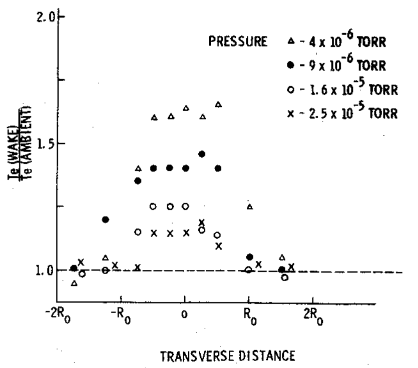


**Fig. 4 Transverse electron temperature profiles (normalized to the ambient $T_e$) taken at 1.3 $R_0$ downstream from the sphere center (radius $= R_0 = 4$ cm) at several system pressures and for flow conditions $E_i \sim 4.5$ eV, $T_e \sim 800$K, $n \sim 5 \times 10^4/\text{cm}^3$, and $\phi_s \sim +0.3$V.**

the sphere in the pressure range $4 \times 10^{-6} \leq P \leq 2.5 \times 10^{-5}$ Torr. The conditions are identical to those of Fig. 2 except for $\phi_s$ which is now equal to $+0.3$ V. We have chosen to examine the influence of the slow ions on the electron temperature at the closest vicinity to the sphere downstream, since it is in this region that the effect of $T_e$ (wake)$>T_e$ (ambient) is pronounced.[12-14]

As is seen from Fig. 4, $T_e$ (wake) is larger than $T_e$(ambient) for pressures smaller than about $1.6 \times 10^{-5}$ Torr. For the higher pressures, the enhancement in $T_e$(wake) with respect to $T_e$(ambient) is close to the experimental error in the electron temperature determination. The trend seems, however, to be clear. Namely, as the pressure increases the influence of the slow ions on the electron temperature observations is more significant, which is similar to the influence of the slow ions on the electron current profiles (see Fig. 3).

In summary, the findings of this study indicate that the effect of slow ions, when $\alpha \leq 0.3$, is not significant for measurements of ion current variations in the wake zone. However, this is not the case when studies are aimed at the quantitative examination of electron current and temperature variations in the near wake zone. In these instances, the measurements of electron properties in the wake should be done at very low systems pressures or over a range of system pressures in order to ascertain the effect of slow ions.

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# Aft-Body Drag Reduction by Combined Boat-Tailing and Base Blowing at $M = 3$

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## Introduction

THE major source of drag of a blunt-based slender body at moderate supersonic speeds is the aft-body. The primary factor accounting for high aft-body drag is the low base pressure. Two potentially effective means of increasing base pressure are boat-tailing and small rates of gas injection at the base. A recent review of the base flow problem including injection[1] presents several semiempirical methods of calculating base pressure but points out that the greatest uncertainities in the flow are associated with the base corner region and development of the mixing layer, to which the axisymmetric geometry adds further complication.

The effect of boat-tailing is well covered in an earlier review[2] which presents evidence that conical boat-tails are superior to other shapes (ogival, concave) and that appreciable reduction in base drag can be obtained with boat tails of moderate angles and lengths up to about 1 or 1.5 calibers. An early study of base bleed to reduce supersonic aft-body drag[3] showed that small rates of injection caused the base pressure to rise, but increased rates led to a reversal attributed to entrainment of the base flow by the bleed air due to its increasing velocity. At very low injection rates, of course, the opposite is true—the flow entrains the low momentum gas. Factors which influence the effectiveness of base injection, extensively studied by Bowman and Clayden,[4-7] include: the gas injection geometry, the temperature of the injected gas, its molecular weight, and the boundary-layer thickness.

The present study is concerned with the combined use of boat-tailing and base blowing to minimize the aft-body drag of a projectile configuration at Mach 3 and high Reynolds numbers. A more extensive description of the study and discussion of the flowfield is given in Ref. 8.

## Test Apparatus

The ogive-cylinder projectile model of 30mm (1.181 in.) diameter with rifling ring and interchangeable aft-bodies shown in Fig. 1 was tested in the Air Force Flight Dynamics Laboratory 8 x 8 in. Mach 3 high Reynolds number wind tunnel. Air and helium were the two gases injected through

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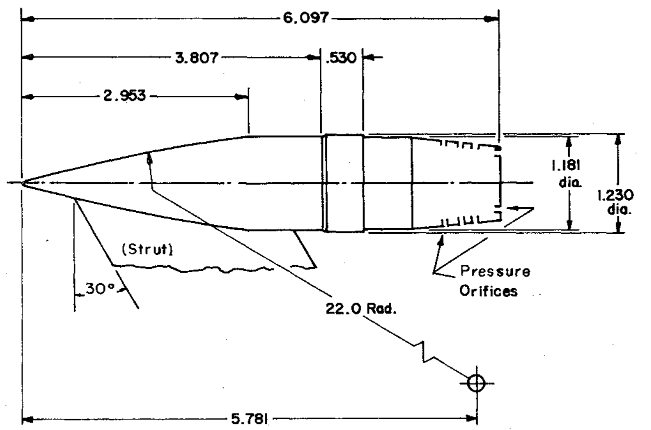


Fig. 1 Model dimensions in inches.

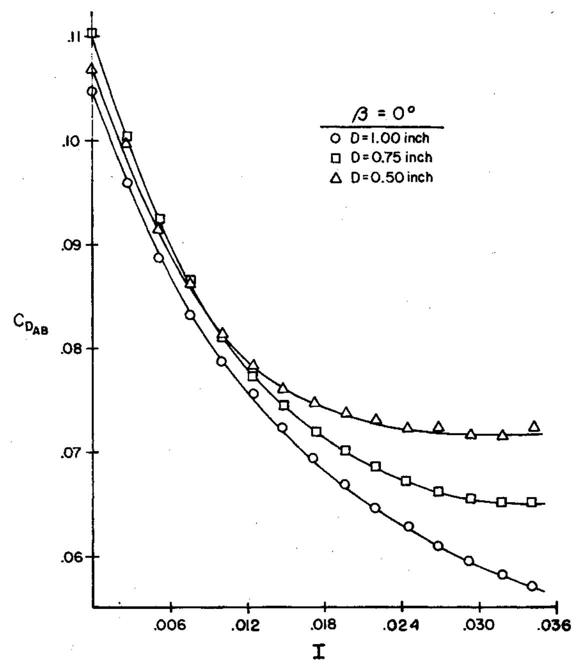


Fig. 2 Effect of air injection on aft-body drag coefficient for cylindrical after-body and various orifice diameter.

porous plugs in the base of the aft-bodies. The flow was metered from a high pressure gas supply through a choked orifice. Three aft-bodies were cylindrical with injection orifice (porous plug) diameters $D = ½, ¾$, and 1 in., respectively.

Four aft-bodies had boat-tails of ½ caliber length (15mm) with angles $\beta = 3°, 6°, 9°$, and 12°, respectively, and injection orifice diameters of 0.625 in. The remaining two aft-bodies had 6° boat-tails of lengths ¾ and 1 caliber, respectively, and injection orifice diameters of 0.625 in. Eight pressure orifices were located in the base region and distributed in the streamwise direction on top and bottom (to assess strut interference) of each aft-body. The pressure measurements served to calculate aft-body drag. Strut interference on the base flowfield was deemed to be negligible based on the measured aft-body pressures and experience with similar designs.[9]

The tests were conducted at a freestream Mach number of 2.93 and stagnation pressure of 75 psia for which the Reynolds number based on model length was 8 million. Boundary-layer thickness is not a significant parameter for layers that are turbulent and thin relative to the base diameter.[5]

## Discussion of Results

Results are presented in terms of the nondimensional base injection parameter $I = \dot{m}/(\rho_\infty u_\infty A)$ which is the ratio of the mass flow of gas injected to the mass flow of a freestream

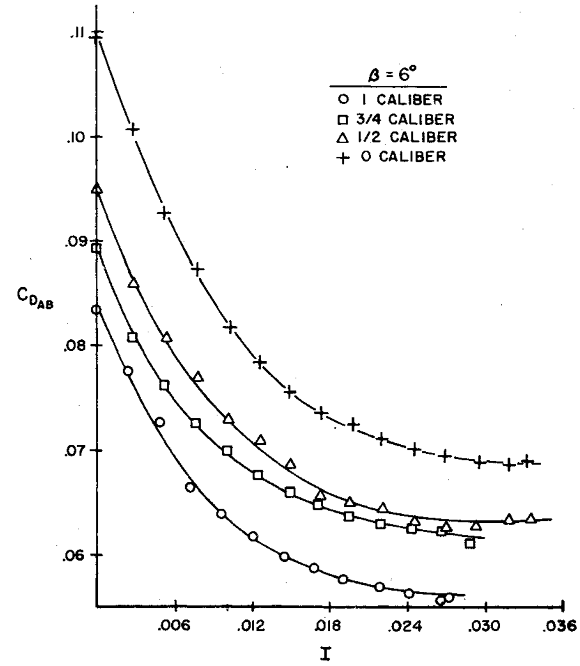


Fig. 3 Effect of air injection on aft-body drag coefficient for 6° boat-tail angle and various boat-tail lengths.

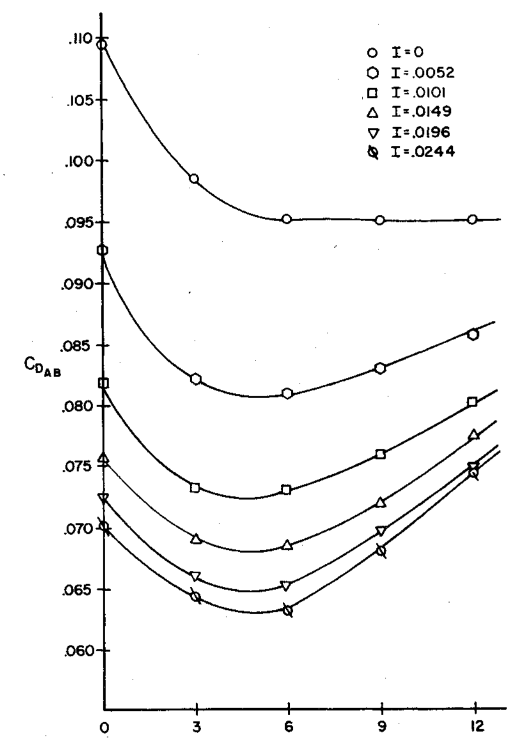


Fig. 4 Effect of boat-tail angle on aft-body drag coefficient for various rates of air injection.

tube of cross section $A$ equal to that of the projectile. Most of the results given are for air as those for helium show basically the same qualitative trends.

The effect of air injection on the aft-body drag coefficient, $C_{D_{AB}}$, of the cylindrical models for three different injection orifice diameters is shown in Fig. 2. There is virtually no difference in the curves for injection rates up to about $I = 0.014$ (the slight shift in the curves is within experimental accuracy); but beyond this value, the smallest injection orifice rapidly approaches a minimum drag whereas the largest orifice continues to exhibit a significant drag reduction. This indicates

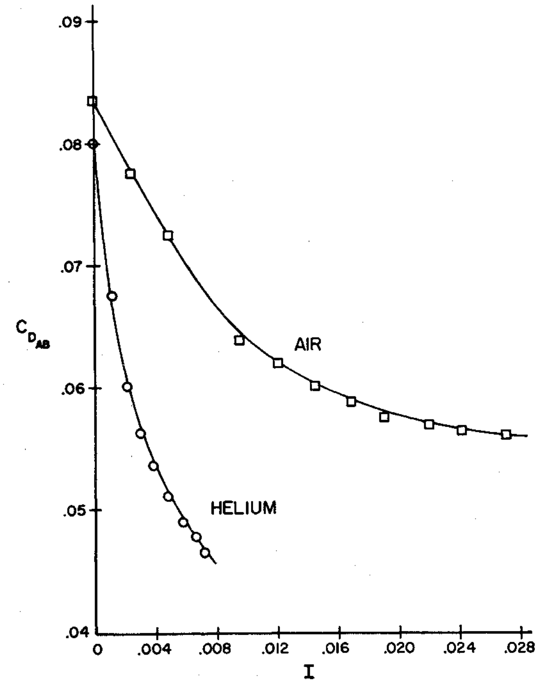


**Fig. 5 Comparison of the effects of air and helium injection on aft-body drag coefficient for a 1 caliber 6° boat-tail.**

that the velocity of the injected flow for the smallest orifice is becoming significant at the higher injection rates shown. This result is in agreement with earlier studies.[4] Figure 2 clearly shows the significant decrease in drag resulting from small base blowing rates. For the largest injection orifice diameter, the base drag coefficient is almost halved at injection rates of $I=0.03$.

The effect of air injection on aft-body drag coefficient for three 6°boat-tail aft-bodies of lengths 1, ¾, and ½ calibers, and a configuration without boat-tailing is shown in Fig. 3. For the latter configuration, the midpoints between the curves for $D=0.75$ in. and $0.50$ in. of Fig. 2 were taken to conform with the orifice diameter of $D=0.625$ inches for all the boat-tail configurations.

The advantage of a long boat-tail is evident from the consistently lower drag coefficient obtained with each increase in length. Physically, this is explained by the fact that the pressure rises along the boat-tail length so that the longer the boat-tail, the higher the pressure at its trailing edge, which in turn, results in a higher base pressure and, therefore, lower drag. The rate of decrease in drag can be expected to drop off with much further increase in boat-tail length.[2]

The effect of boat-tail angle on aft-body drag coefficient for various rates of injection is shown in Fig. 4. Note that, without injection, boat-tails of 6°,9° and 12°result in aboutan equal reduction in aft-body drag. However, with base injection, minimum drag occurs for a boat-tail angle in the neighborhood of 6°.

The results for base injection of helium show similar qualitative trends to those for air, e.g., steady decrease in drag with increasing boat-tail length, minimum drag configuration with injection for a boat-tail angle in the neighborhood of 6°.However, quantitatively, with helium injection, the mass flow rates are considerably smaller than those for air for a given base pressure rise and the base pressure continues to rise well above the peaks obtained with air injection. Thus, lower drag values are obtained with helium.

Figure 5 gives a sample comparison of results for air and helium injection for a 6° boat-tail, 1 caliber long, clearly illustrating the lower injection rates and lower drag obtainable with a light gas. The helium results are expected to be somewhat closer than those of air to the high temperature, low density products of combustion of fumers used in practical projectile applications.[10]

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# Wake Effects in Finite Amplitude Nonsteady Motion of Slender Profiles

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## Introduction

NONSTEADY motion of thin wings is always accompanied by shedding of the boundary layer from the separation point in the form of a thin sheet deforming into vortices. It is possible to obtain a reasonably accurate description of this phenomenon from the study of ideal fluid motion, using Kutta condition for determining circulation, provided the medium in which the wing moves has small viscosity, and the angle of incidence is small. Karman and Sears,[1] Kuessner,[2] and Theodorsen[3] developed unsteady aerofoil theory. Their results, based on the additional assumption that the trailing edge of the profile traverses rectilinear path, found extensive applications in aerodynamics as well as ship-hydrodynamics. This theory has significant applications in animal locomotion. Lighthill[4] studied the lunate-tail hydrodynamics using Prandtl's acceleration potential method which earlier had found brilliant applications in Possio's[5]

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