Underexpanded Jet-Freestream Interactions on an Axisymmetric Afterbody Configuration

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Experimental investigations are carried out in the 0.3 m trisonic wind tunnel at NAL to study exhaust jet-freestream interactions on an axisymmetric afterbody configuration. The model chosen for these studies is an equivalent body of revolution of a representative combat aircraft configuration. The effects of jet pressure ratio and freestream Mach number on boattail, base, and afterbody pressure drag are studied along with color Schlieren flow visualization of the afterbody flowfield. Experiments are carried out in the freestream Mach number range of 0.6 to 1.1 at Reynolds number from 20×10^6/m to 35×10^6/m keeping model at zero degree of incidence. Jet pressure ratio is varied from 1 to 6 during this investigation. The jet at nozzle exit is sonic throughout these tests. Experimental results show that the underexpanded jet plume affects predominantly the afterbody pressure distribution and hence the afterbody pressure drag. Upstream influence of the jet extends even up to the boattail shoulder and is predominant in the region of freestream shock location over the afterbody at transonic speeds. The movement of shock location determined from color Schlieren flow visualization studies agree well with the theoretical predictions made on the basis of transonic small perturbation calculations.

Nomenclature

Am	= maximum cross-sectional area ($\pi Dm^2/4$), m^2
Cp	= pressure coefficient; $Cp = (p - p_\infty)/q_\infty$
$C_{D\beta}$	= base drag coefficient
C_{DI}	= boattail drag coefficient
C_{DP}	= pressure drag coefficient, $C_{DP} = D_P/(q_\infty \cdot Am)$ also $C_{DP} = C_{DB} + C_{D\alpha}$
D_p	= pressure drag, N
Dm	= maximum diameter of the model, mm
L	= length of the afterbody, mm
ℓ	= length of the model, mm
M	= Mach number
P_O	= stagnation pressure, N/m^2
P_{OJ}/p_∞	= ratio of jet stagnation to freestream static pressure (jet pressure ratio)
q	= dynamic pressure, N/m^2
x	= axial coordinate, mm

Subscripts

A	= afterbody
B,b	= base
J	= jet
∞	= freestream
S	= shock, separation
β	= boattail

I. Introduction

FLOW interactions taking place near the aft end of an aerospace vehicle in presence of jets can have important repercussions on its performance. In particular, afterbody drag characteristic is greatly influenced by jet plume blockage and entrainment, which depends largely on velocity and temperature gradients existing between the jet and external flow.[1-3] For example, afterbody/nozzle drag in a typical figher aircraft may be as large as 20% of the total aircraft drag at transonic speeds.[4] In the case of a missile, the base drag may be as large as 70% of the total drag at transonic speeds.[5] Systematic and extensive wind-tunnel testing is required to study these aft end interactions, which are generally quite complex.[6-8]

Several experimental studies on jet effects have been reported in the literature. For example, experimental investigations of Reubush et al.[9] at NASA, Zonars et al.[10] at AFFDL, Dissen et al.[11] at DFVLR, and others are generally limited to the determination of pressure distribution and drag characteristics of the afterbodies. Also, the base drag of the annular base region of the afterbody is often neglected in most of these investigations, and its behavior in presence of a jet is not generally studied. Moreover, most of these studies are not supplemented by flow visualization studies, which prevents understanding of the behavior of flow over the boattailed afterbody as well as nozzle-exit region, particularly at transonic speeds. The present investigation was undertaken to study the effects of underexpanded sonic jet-freestream interactions on an axisymmetric boattailed afterbody configuration, systematically varying freestream Mach number and jet pressure ratio. Color Schlieren flow-visualization studies were also carried out to facilitate understanding of the behavior of the flow (particularly the shocks and their movement over the afterbody) with and without an underexpanded sonic jet.

II. Model and Test Conditions

The model (Fig. 1), 0.372 m long, is an equivalent body of revolution of a representative combat aircraft configuration. The model afterbody was designed to have a convergent nozzle with exit diameter of 0.0145 m. The model was mounted on the side wall of the wind tunnel with the help of a hollow strut.[12]

Experiments were conducted in the freestream Mach number range of 0.6 to 1.1 at Reynolds number from 20×10^6/m to 35×10^6/m. The jet pressure ratio was varied from 1 (jet-off) to about 6, keeping the model at zero degree of incidence during this investigation.

III. Afterbody Test Rig

A test rig (Fig. 2) was designed and fabricated especially for conducting afterbody/base flow studies for configurations of various aerospace vehicles in presence of jets in the 0.3 m trisonic wind tunnel. Special design features of the rig are a) interchangeability for axisymmetric configurations and nonaxisymmetric shapes of realistic aircraft configurations and b) easier changing of various afterbody/nozzle geometries. The

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