A New Wind-Tunnel Technique for Providing Simulation of Flight Base Flow

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Nomenclature

D = diameter
k = thermal conductivity
M = Mach number
p' = dimensionless pressure
Pr = Prandtl number
Re = Reynolds number, $\rho_0 u_0 D/\mu_0$
T = Temperature
u = velocity
α = viscosity index
β = conductivity index
γ = specific heat ratio
θ = momentum thickness
μ = viscosity
ρ = density

Subscripts

B = base
∞ = freestream
L = laminar flow
m = mean value
0 = reference
T = turbulent flow

Introduction

THE base pressure prediction methods are limited to the simple case of two dimensional bodies. For three dimensional axisymmetric bodies, no available method exists for base pressure predictions. Consequently, an experimental determination of base pressure is the only means of providing information for vehicle design.

Reliable experimental data on base pressure are quite difficult to obtain in wind-tunnel tests because of the support interferences. The approach taken in resolving this problem was in providing a means of model support which did not create flow disturbances affecting the wake.

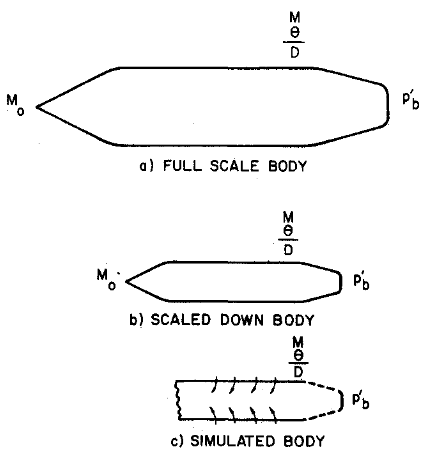

Fig. 1 Experimental techniques.

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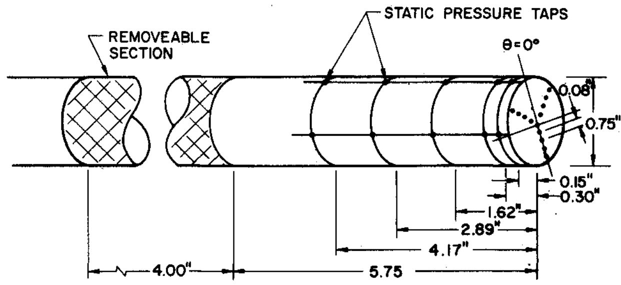

Fig. 2 Base pressure model.

Analysis

Governing parameters

If the governing differential equations and boundary conditions for flow over a body are made dimensionless, it can be shown that the pressure distribution can be written in the following functional form:

$$p' = f[\text{location}, Re, Pr, Mo, \alpha, \beta, \gamma, T_w/T_0, (\mu_T/\mu_{L0})_m, \times (k_T/k_{L0})_m] \quad (1)$$

At the base, the location is fixed. For subsonic and supersonic flows, the Prandtl number $P_r, \alpha, \beta, \gamma, T_w/T_0$ may be considered constant. In addition, if it is assumed that $(\mu_T/\mu_{L0})_m$ and $(K_T/k_{L0})_m$ are constant for turbulent flows (zero for laminar flows), for a fixed type of flow and vehicle geometry, the base pressure is a function of the Reynolds number and Mach number only, i.e.,

$$p_b' = f(Re, M_0) \quad (2)$$

This theoretical conclusion is consistent with all experimental data available in the literature. Since the dimensionless momentum thickness θ/D or dimensionless boundary-layer thickness δ/D is directly related to the Reynolds number, we can rewrite the expression as

$$p_b' = f(\theta/D, M_0) \quad (3)$$

It may be emphasized from Eq. (3) that the actual dimension of the body is not a parameter. Therefore, for two geometrically similar bodies in an environment having the same Mach number, dimensionless boundary-layer thickness, and the same type of flow (laminar or turbulent), the dimensionless base pressure is identically the same independent of vehicle size. As a result of this analytical conclusion, a scheme for obtaining reliable base pressure data free of support interferences was developed and demonstrated.

Experimental technique

Figure 1a shows a typical body shape for which the base pressure data are required. The size problem can be resolved by scaling up or scaling down since the actual size of the body is not a parameter (Fig. 1b). If the Mach number and the dimensionless boundary-layer thickness as well as the type of flow (laminar or turbulent) are the same, the dimensionless base pressure for the two bodies, Figs. 1a and 1b should be the same.

To solve the support problem, a long cylindrical body extended far upstream can be used so that there is no strut to interfere with the flow. Because of this extension, boundary layer would be thicker compared to the actual model. Boundary-layer thickness can be controlled by applying suction upstream of the base as shown in Fig. 1c. By controlling the flow and boundary-layer thickness so that the Mach number and the dimensionless momentum thickness as well as the type of flow (laminar or turbulent) upstream of the base are identical among Figs. 1a, 1b, and 1c, the dimensionless base pressure should be also identical.

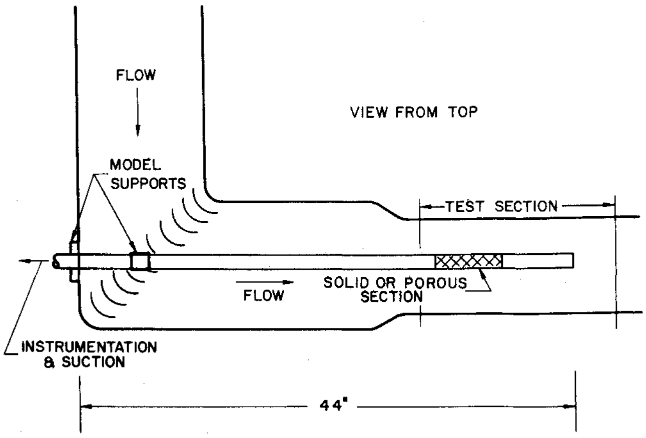

Fig. 3 Model installation.

Experimental study

Model design and installation: To demonstrate the technique, a cylindrical base pressure model (Fig. 2) was designed, fabricated, and tested in the Boeing Model Transonic Wind Tunnel and Boeing Model Supersonic Wind Tunnel. Pressure taps were installed on the cylinder surface as well as on the base. A porous section made of Rigimesh with 10% porosity was installed for boundary-layer control (Fig. 3). No flow perturbations were generated by the supporting structure affecting the base flow.

Results

Boundary-layer thickness

The boundary-layer thickness was measured by use of a Pitot probe. It was found that the boundary layer is essentially completely bled and its growth was reinitiated at the end of the porous section. The shape of the boundary-layer profile also indicated that the flow was turbulent.

Base pressure without suction

The base pressure as a function of Mach number is shown in Fig. 4. The results of free flight data as obtained by Hart[1] are also shown in the figure for comparison. There is reasonable agreement between the present wind-tunnel test and the free flight results.

Strut effects

For the model and Mach number range under consideration, it was found that the effects of the strut are to increase the base pressure slightly.

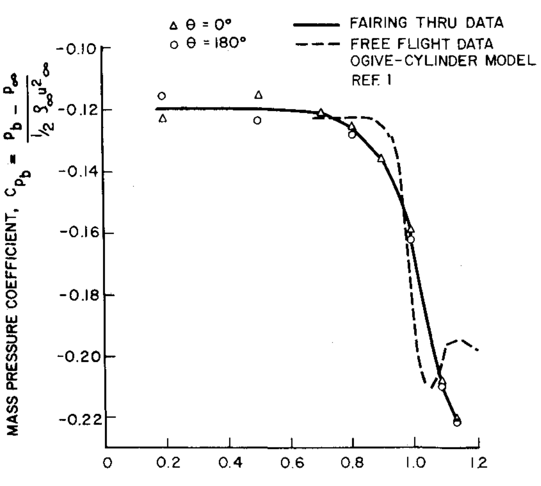

Fig. 4 Bluff cylinder base pressure.

Boundary-layer effects

The effect of boundary-layer thickness on the base pressure was found by measuring the base pressure with and without suction. In general, the base pressure is slightly higher with thicker boundary layer (without suction) than that with thinner boundary layer (with suction).

The base pressure as a function of momentum thickness at various Mach numbers was also determined. In general, the base pressure increases as the boundary-layer thickness increases. Also, there appears to be a critical boundary-layer thickness. Below this critical value, the base pressure is a strong function of the boundary-layer thickness. Above this critical value, the dependence of base pressure on the boundary-layer thickness is relatively insignificant.

Conclusions

The dimensionless base pressure in subsonic and supersonic flow is governed by two parameters: the Mach number and the dimensionless boundary layer thickness. This suggests the use of a long cylindrical body and boundary layer suction in place of the conventional mountings for base pressure models. The cylindrical body is extended and supported far upstream so that there is no strut to interfere with the flow. The boundary-layer thickness is controlled by use of suction ahead of the base pressure model. This scheme has been successfully demonstrated for the case of subsonic and transonic flows.

Reference

[1] Hart, R. G., "Effects of Stabilizing Fins and a Rear-Support Sting on the Base Pressures of a Body of Revolution in Free Flight at Mach Numbers from 0.7 to 1.3," RM L52E06, Sept. 1952, NACA.

Film-Cooling on the Anode of a Plasma Generator

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An investigation of the operating characteristics of an arc plasma generator whose anode is protected both by film- and water-cooling has been undertaken. Such a device allows the use of a refractory material for the anode without substantial ablation but does not yield the high conversion efficiency of electrical to thermal energy found previously with a purely film-cooling anode.[1] The apparatus[2] consists of a cathode section, a stack of four constrictor segments, and an anode assembly.

Argon is injected tangentially at the base of the constrictor stack, flows through the constrictor channel in contact with the electric arc, mixes with the film gas (also argon) at the upstream edge of the anode, and flows from the anode into a calorimeter. The film flow is injected radially and is turned so that it flows parallel to the anode surface by a slot formed by a boron-nitride nozzle and the graphite anode. The flow channel in the constrictor stack is of 9.54-

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