Conclusions

The analysis proves that each isovel in the vicinity of the outer edge of the laminar boundary layer has an outward bulge on the plane of symmetry for any value of $\alpha(\pi>\alpha>0)$ without any special conditions.

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AIAA 82-4161

A Hot-Film Static-Pressure Probe

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Nomenclature

d = probe tube diameter, cm
ℓ = distance from probe tip to orifices, cm
p_{HF} = pressure measured by hot-film probe, mmHg
p_c = pressure measured by conventional probe, mmHg
$R_{c,I}$ = resistance of unheated sensor, Ω
R_{cold} = cold resistance of heated sensor, Ω
R_{hot} = resistance of heated sensor with 1.5 overheat ratio, Ω
N_{Re} = freestream unit Reynolds number, 1/cm
V_B = output of rear sensor, mV

Received Oct. 15, 1981; revision received Dec. 3, 1981. This paper is declared a work of the U.S. Government and therefore is in the public domain.

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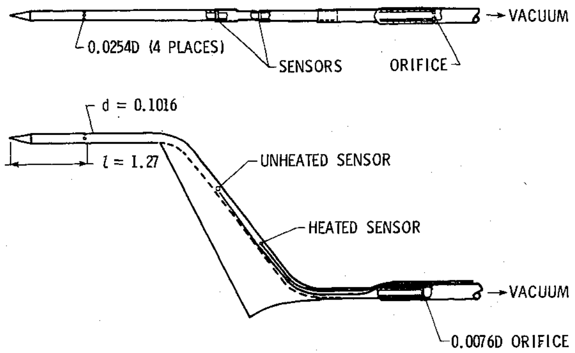

Fig. 1 Conventional probe configuration and the internal locations of the hot-film sensors and the sonic orifice (all dimensions in cm).

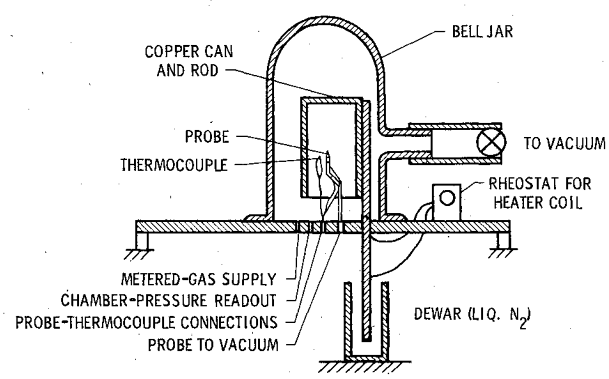

Fig. 2 Probe calibration apparatus.

Introduction

A CONICAL-NOSE, static-pressure probe with orifices located ten or more tube diameters downstream of the tip[1] can measure freestream pressure within 1-2% in supersonic flow. However, for blowdown tunnels, the pressure settling time in the connecting tubing and the readout equipment may be of the order of the tunnel run time. This makes static pressure surveys of the flowfield between a body and its shock impractical because of the large number of runs required to traverse the region.

To reduce response time, increase traverse speed, and obtain reasonably accurate values of static pressure, a probe has been developed which consists of a pair of hot-film sensors and a small orifice installed inside the probe downstream of the exterior orifices (Fig. 1). The rear sensor is operated at an overheat ratio (R_{hot}/R_{cold}) of 1.5 to 1.8. A constant-temperature anemometer keeps the sensor at the temperature set by the overheat ratio, and the bridge voltage will vary according to the velocity, pressure, and temperature of the fluid. By installing a sonic orifice downstream of the sensors and connecting the probe to a vacuum pump, the velocity of the fluid over the sensors will be constant and low subsonic. To account for the fluid temperature, a second sensor (front) is operated as a resistance thermometer (at a low-fixed current).

The procedure is to calibrate the probe in the gas of the interest over the range of temperatures and pressures anticipated in the wind-tunnel tests and then apply the calibration to reduce the data from those tests. Some other details of this study are contained in a paper[2] published previously.

The concept of using hot-film sensors and a sonic orifice is similar to that of Remenyik and Kovasznay,[3] who used a single hot wire in a wall orifice to measure the pressure fluctuations, and to that of Thermo-Systems Inc., who use a single sensor and a sonic orifice in their aspirating probes.[4]

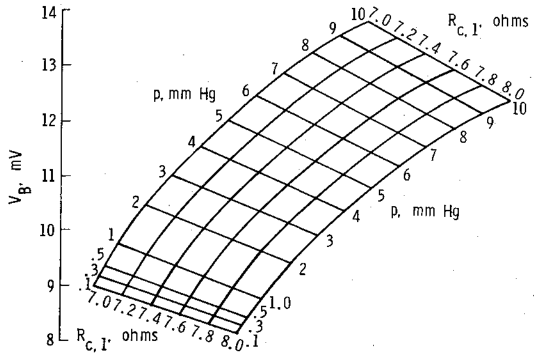

Fig. 3 Typical calibration of the hot-film static-pressure probe.

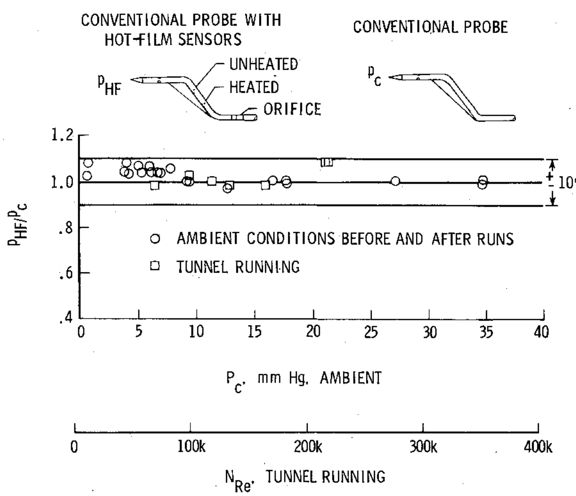

Fig. 4 Comparison of hot-film static-pressure probe readings with the conventional probe readings for a range of Reynolds numbers at Mach 20 in helium and at ambient conditions.

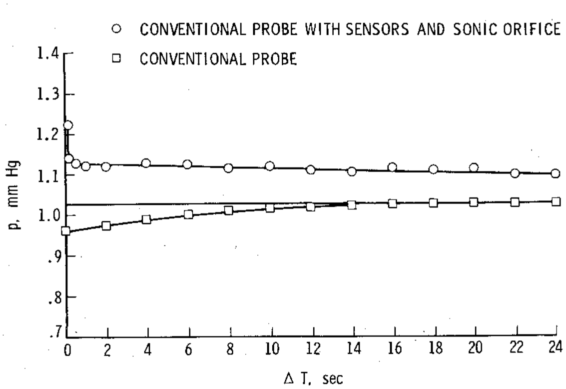

Fig. 5 Comparison of the relative settling time between the conventional probe and the conventional probe with the hot-film sensors and a sonic orifice.

Probe Calibration

The probe was calibrated in a bell jar, which was positioned on a metal plate and sealed with a rubber gasket (Fig. 2). The jar is evacuated through its side port and gas is metered into the jar through one of the four "o"-ring fittings in the plate under the mouth of the bell jar. The other three fittings are used to bring the probe and thermocouple wires out, to connect the probe to a vacuum source, and to connect the chamber to the pressure readout. A copper can encompassing the probe is heated or cooled to change the temperature of the gas passing through the probe. A typical probe calibration is shown in Fig. 3.

Wind-Tunnel Studies

Pressure readings from two probes, one having two hot-film sensors and an internal sonic orifice and the other connected to a conventional pressure gage, were recorded for several Reynolds numbers and compared (Fig. 4). Readings recorded prior to and immediately following each run are identified on the plot by the circles and the top abscissa scale. The readings taken during the run are plotted against Reynolds numbers (squares and bottom abscissa scale). The figure shows that direct application of the probe calibration will provide measurements within ±10%.

Although the time was recorded on the data tape, the exact time that the probe system started to settle was not identifiable. Nonetheless, the hot-film probe system (Fig. 5) settled almost immediately, whereas the conventional probe system required 16 s to settle, even when its system pressure was initially close to the expected value. The large difference in pressure level between the two probes (approximately 9%) is the largest for the tests and occurred at the highest Reynolds number. At the lower Reynolds numbers, the pressures agreed within ±3% (Fig. 4). The discrepancy at the highest Reynolds number is not understood, but it was the only run for which a complete time history was obtained.

In conclusion, the conventional static-pressure probe with a pair of hot-film sensors and an interior sonic orifice provides the means to survey flowfields in hypersonic flow at a rapid rate and with an accuracy of better than ±10%. The small loss in measuring accuracy is often more than a reasonable tradeoff for the improved survey capability. The basic configuration of the probe is still subject to the viscous and flow-angularity effects that must be properly assessed under the conditions of its use.

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