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PRELIMINARY TESTS WITH MASS FLUX PROBE IN SUPERSONIC STREAM

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by Lloyd N. Krause and George E. Glawe

Lewis Research Center

Cleveland, Ohio

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SUMMARY

This investigation was undertaken to determine experimentally the accuracy of a mass flux probe system using two inlet designs. One inlet design was sharp-lipped and had both the internal and external lip surfaces bevelled at 15° (symmetrical). A second inlet, which had only an external 15° bevel (unsymmetrical), was initially sharp and then was progressively blunted to various degrees during the test program. The purpose of using the two shapes was to compare the ideal, sharp inlet lip with the blunt lip inlets that are considered necessary to achieve adequate cooling in streams developing high stagnation-point heat-transfer rates.

The Mach number of the tests ranged from 2.0 to 2.6, and the total temperature ranged from 530° to 700° R (290° to 390° K) with a tunnel inlet Reynolds number of the order of 2.5×10^{6} per foot (8.2×10^{6} m^{-1}).

The symmetrical sharp-lipped inlet yielded excellent results, while the unsymmetrical wedge inlet with both sharp and blunt lips had an effective capture area up to 4 percent greater than the geometric capture area.

INTRODUCTION

Experimental work in fluid mechanics usually involves measurements of total pressure, static pressure, total or static temperature, and flow direction. Many techniques and devices are available to make these measurements in low-temperature, low-velocity streams. However, for more severe environments, such as high-temperature supersonic flows, investigators are continuously searching for new methods of measuring these parameters and others that would help to describe the flow field more thoroughly.

One such device, in which there has been a renewed interest, is a probe that measures the mass flow rate per unit area ρV of various streams. Such a mass flux probe can be applied to stream profile surveys of arc tunnels and to combustion studies in advanced turbojet and ramjet engines. Some of the advantages of such a device are the following:

(1) It has small real-gas effects.

(2) It can be used in mass-weighting a temperature profile to obtain enthalpy distribution.

(3) It can be used alternately as, or in conjunction with, a total pressure probe to obtain the separate quantities, stream density ρ and stream velocity V. The stream momentum ρV^2 is obtained by the indicated total pressure measurement $p_{t_{ind}}$, as shown in figure 1. This ρV^2 indication along with the ρV measurement of the mass flux probe is then used to calculate the values for ρ and V.

References 1 to 6 considered applications of this probe in streams at near-ambient as well as at high temperatures. In the high-temperature applications, the probe system was applied without first experimentally establishing its accuracy in a more ideal flow.

The present investigation was undertaken (1) to establish the accuracy of a mass flux probe system that uses a sharp-edged inlet in a supersonic stream with a well-defined mass flow rate per unit area ρV and (2) to examine the ability of blunted inlets to capture the ρV stream tube. The purpose of using the two shapes was to compare the ideal, sharp inlet lip with the blunt lip inlets that are considered necessary to achieve adequate cooling in streams developing high-stagnation-point heat-transfer rates.

An example of the heat load for a proposed future application is presented in figure 2, which shows the approximate lip-stagnation heating rate as a function of lip radius. It seems quite unlikely that adequate cooling can be achieved without departing to some degree from a sharp-lipped inlet.

DESCRIPTION OF TESTS

Inlet Geometries

Two supersonic probe inlet designs were tested: one had a sharp symmetrical lip, and the other had an unsymmetrical lip that was blunted (by rounding) to various degrees as the test proceeded. Figure 3 shows the two basic inlet geometries. Inlet A has a sharp lip with a 15° half-angle symmetrical wedge shape, tapering internally to a straight throat section and then diverging at a 9° half-angle. The geometric capture area A_g for this circular inlet is based on a diameter D_g measured at the center of curvature of the rounded lip section.

A supersonic inlet with a converging duct such as that of inlet A has the disadvantage of a low limiting Mach number below which it cannot pass the shock and swallow the total stream tube approaching the inlet geometric capture area. This lower limit is related to a contraction ratio A_g/A_{th}, where A_{th} is the minimum throat area. For this test, the contraction ratio of inlet A was sized to pass the flow above a Mach number of 2.

Inlet B had an unsymmetrical wedge inlet with an external 15° bevel and an internal 0° straight run through the throat with a 9° half-angle divergent passage downstream. The inlet initially had a thin lip (0.000_8-inch or 0.002_0-cm rad), but on successive runs the lip was blunted to radii of 0.002_5, 0.005_5, 0.011_0, and 0.022_2 inch (0.006_3, 0.014_0, 0.027_9, and 0.056_4 cm). The geometric capture area A_g for circular inlet B is defined as previously for inlet A; that is, it is based on the diameter of the circle of contact of a lip with a tangent plane normal to the centerline.

A cross section of inlet A is presented in figure 4, and a cross section of inlet B with the 0.022_2-inch (0.056_4-cm) lip radius is shown in figure 5.

Tunnel Installation

The tests were conducted in the 10- by 10-foot (3- by 3-m) supersonic tunnel of the NASA Lewis Research Center. The probe was incorporated in a single diamond-airfoil strut with other sensors and run in conjunction with a major program involving a full-scale engine inlet. The installation is shown in figure 6. Other sensors on the strut, along with the mass flux probe inlet, were used to measure the tunnel ρV in the vicinity of the inlet. These other sensors included a 20° total-angle static-pressure cone, a shielded, high-recovery thermocouple probe, and a total-pressure tube. The mass flow rate through the probe was measured with an orifice according to recommended ASME practices. An error analysis of the flow measuring system indicated an inaccuracy of 1/2 percent. Several runs were made with each configuration of both inlets.

The Mach number of the tests ranged from 2.0 to 2.6, and the total temperatures ranged between 530° and 700° R (290° and 390° K) with a tunnel unit Reynolds number of the order of 2.5×10^6 Reynolds number per foot (8.2×10^6 Re/m). The Reynolds number for the probe, based on the inlet diameter, was 6.5×10^4, and the mass flow rate through the probe was of the order of 1×10^{-2} pound per second (0.5×10^{-2} kg/sec).

RESULTS AND DISCUSSION

The results of the tests are given in table I, where the data are presented as the ratio of the effective capture area A_e to the geometric capture area A_g. The geometric capture area A_g is as previously defined by physical measurement, and the effective capture area A_e is calculated by

$$A_e = \frac{\dot{m}}{\rho V} \tag{1}$$

where $\dot{m}$ is the mass flow rate measured through the probe, and ρV is the mass flow rate per unit area of the tunnel obtained from the pressure and temperature sensors on the strut. A capture area ratio A_e/A_g greater than 1 indicates that the probe is passing more flow than that based on the geometric capture area. The symmetrical sharp-lipped inlet A shows excellent agreement with the measured tunnel ρV. The unsymmetrical inlet B, yielded values of the capture area ratio A_e/A_g ranging from 1.01 to 1.04 for successive lip radii of 0.000_8 to 0.011_0 inch (0.002_0 to 0.027_9 cm). If it is assumed that the stagnation ring is stable and that the flow divides smoothly at the ring, then the stagnation ring diameter for this inlet design lies outside the diameter defined by the geometric capture area. Relating this argument to the value of $A_e/A_g = 1.04$ for the 0.005_5-inch- (0.014_0-cm-) lip-radius configuration indicates that the stagnation ring is displaced outward on the lip a distance of approximately 0.003 inch (0.008 cm) from the geometric capture area ring. This displacement amounts to a "shift" of about one-third of the lip thickness.

The data for the 0.022_2-inch- (0.056_4-cm-) radius inlet lip show that the capture area ratio A_e/A_g dropped to 0.93 for a Mach number of 2.6 and to 0.84 for a Mach number of 2. The contraction ratio A_g/A_{th} for this largest radius inlet lip, however, reached the point where it was greater than the theoretical maximum allowed for the probe to swallow the total stream tube below a Mach number of 2.8. The largest thick-lipped configuration thus shows the decrease in the ability of the probe to pass the stream flow tube approaching the geometric capture area at these lower Mach numbers. This inability to swallow the shock would also be expected even for a sharp-lipped inlet design having the same contraction ratio A_g/A_{th} as the blunted lip with the largest radius.

In reference 6 the author discusses mass flux probe inlet design considerations similar to the two basic types reported herein. He contends that a sharp-lipped, double-bevel inlet such as inlet A should have an effective capture area that is well defined by the geometric capture area, but that the unsymmetrical inlet, such as type B with the external bevel only, is likely to have an effective capture area greater than the geometric capture area for even the sharp-lipped configuration. This present experiment showed that for the unsymmetrical lip the effective capture area was in fact greater than the geometric capture area. An attempt to analyze the flow in the vicinity of the lip to explain the result is considered beyond the scope of this report.

CONCLUDING REMARKS

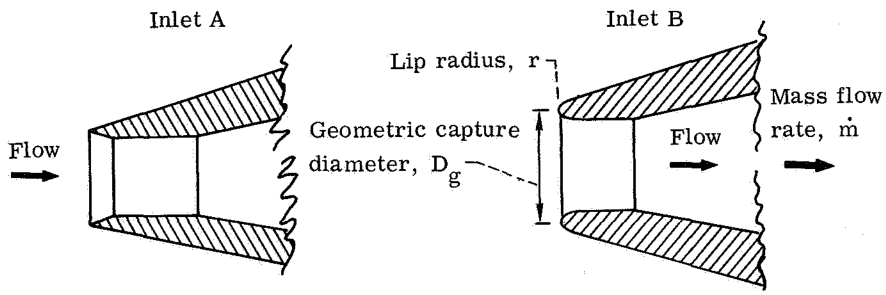
Experimental tests conducted on two basic inlet designs demonstrated the potential accuracy of a mass flux probe system in a supersonic stream. Preliminary tests were made in a well-defined flow stream and indicate that an effective capture area for the designs is sufficiently close to the geometric capture area to provide predictability of calibration to within a few percent. These results provide encouragement for further investigation of the probe in more severe environments.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 15, 1967,
126-15-02-07-22.

REFERENCES

1. Coles, Donald: Measurements in the Boundary Layer on a Smooth Flat Plate in Supersonic Flow. II. Instrumentation and Experimental Techniques at the Jet Propulsion Laboratory. Rep. No. 20-70, Jet Propulsion Lab., California Inst. Tech., June 1, 1953.
2. Liccini, L. L.: N. O. L. Hypersonic Tunnel No. 4 Results VIII: Development and Calibration of Mass Flow Probes in Hypersonic Flow. NAVORD Rep. 4078, Naval Ordnance Lab., Nov. 1, 1955.
3. Stalker, R. J : A Mass Flow Probe for Use in Short Duration Hypersonic Flows. The High Temperature Aspects of Hypersonic Flow. W. C. Nelson, ed., AGARDograph-68., Macmillan Co., 1964, pp. 271-280.
4. Van Camp, W. M.; Esker, D. W.; Checkley, R. J.; Duke, W. G.; and Kroutil, J. C.: Study of Arc-Jet Propulsion Devices. Rep. No. E368 (NASA CR-54691), McDonnell Aircraft Corp., Mar. 1966.
5. Kroutil, Joseph C.: Mass Flux and Impact Pressure Probes for Use in Arcjet Exhausts. AIAA J., vol. 5, no. 8, Aug. 1967, pp. 1503-1504.
6. Huber, Franz J. A.: Probes for Measuring Mass Flux, Stagnation Point Heating, and Total Enthalpy of High Temperature Hypersonic Gas Flows. Paper No. 66-750, AIAA, Sept. 1966.

TABLE I. - TEST RESULTS



(a) Inlet A

Lip radius, r		Capture area ratio, A_e/A_g	
		Mach number	
in.	cm	2.3	2.5
0.000_6	0.001_5	1.00	1.00

(b) Inlet B

Lip radius, r		Capture area ratio, A_e/A_g		
		Mach number		
in.	cm	2.0	2.5	2.6
0.000_8	0.002_0	-----	1.02	-----
$.002_5$	$.006_3$	-----	1.04	-----
$.005_5$	$.014_0$	-----	1.04	-----
$.011_0$	$.027_9$	-----	1.01	-----
$.022_2$	$.056_4$	[a]0.84	----	[a]0.93

[a]Nose shock not swallowed because of contraction ratio limit.

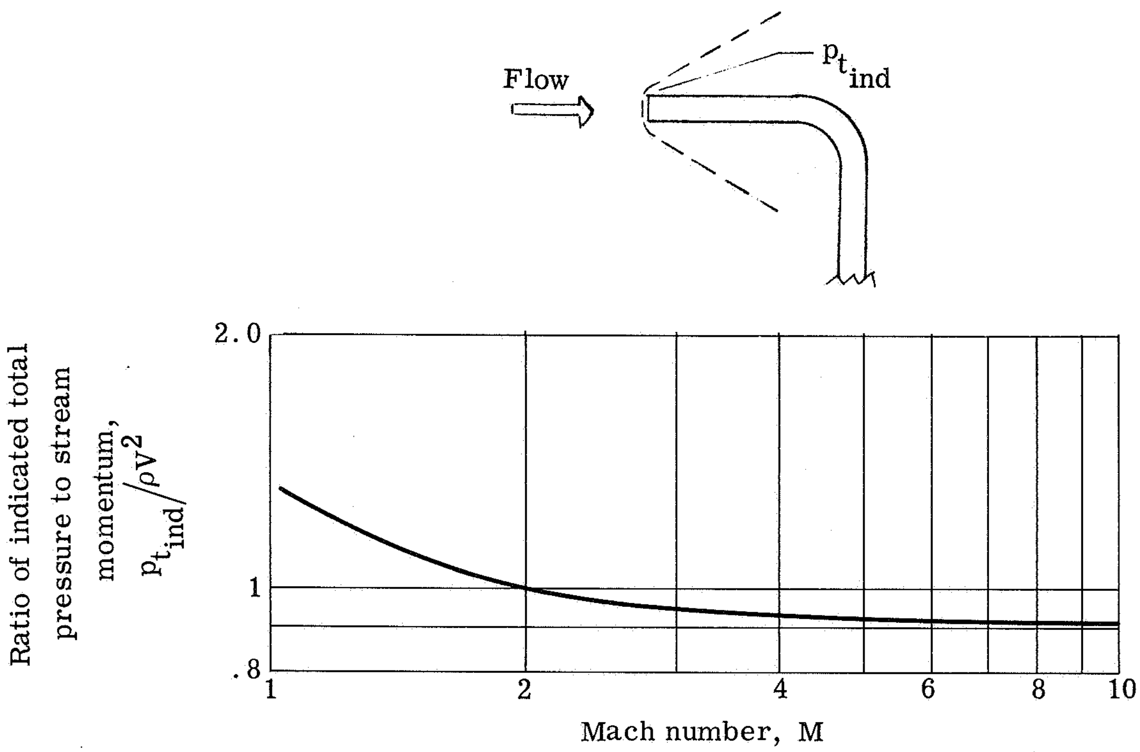


Figure 1. - Pressure indication of total head tube for ratio of specific heats of 1.4.

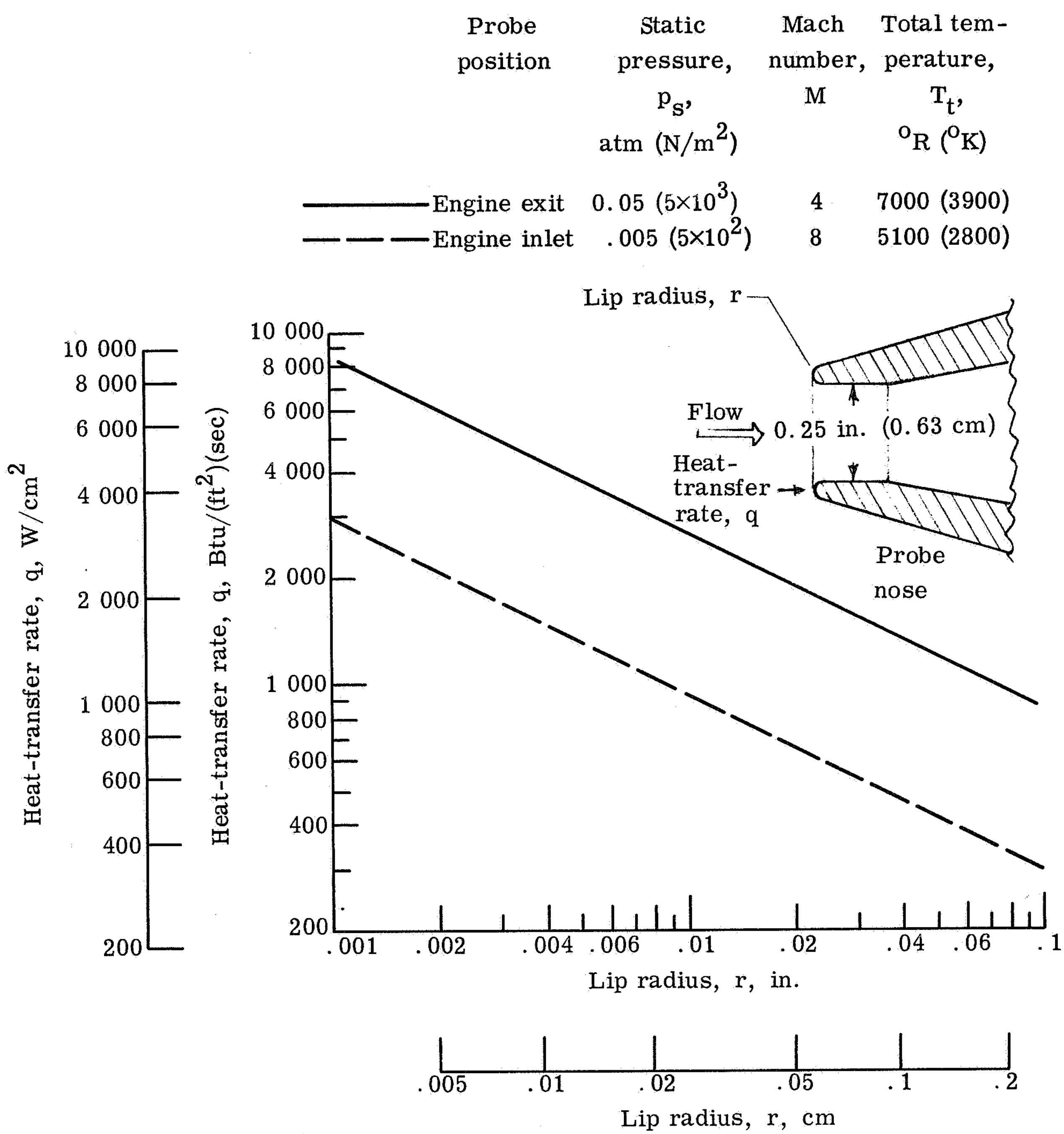
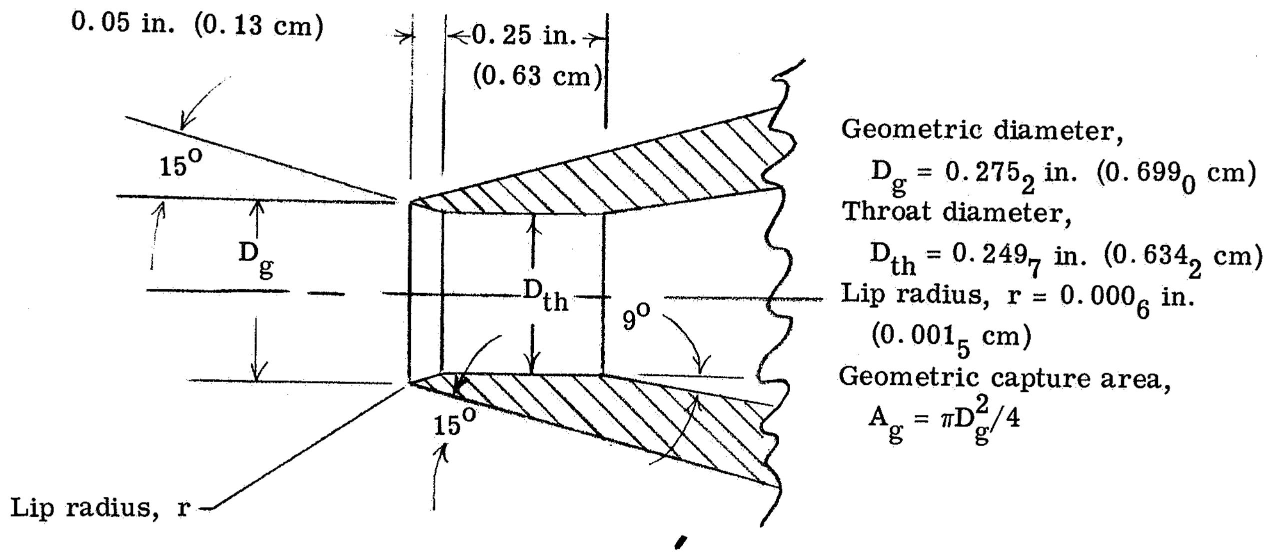
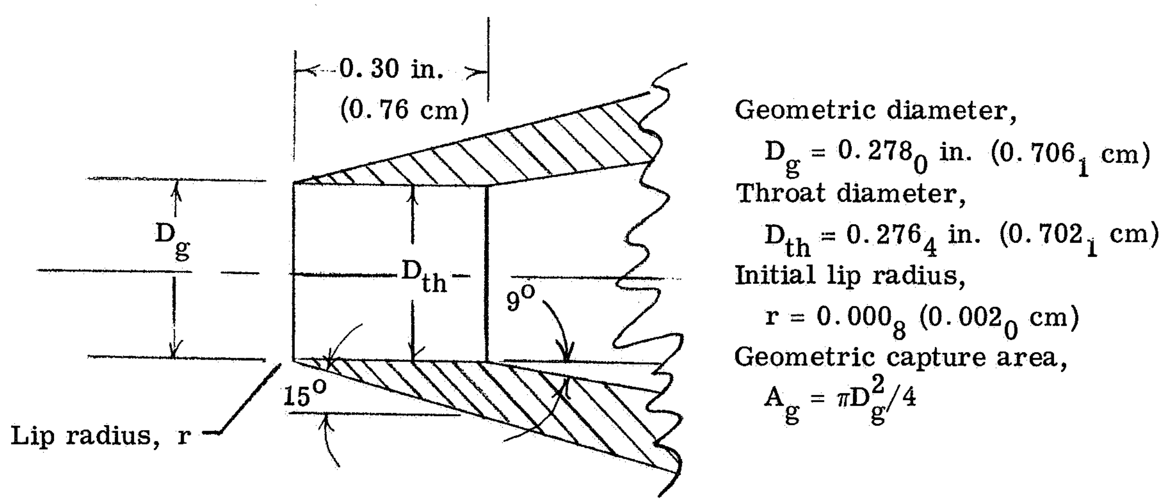


Figure 2. - Probe stagnation-ring heat-transfer rate for hypersonic research engine example. Flight Mach number, 8; altitude, 120 000 feet (36 600 m).



(a) Inlet A.



(b) Inlet B.

Figure 3. - Details of probe inlets.

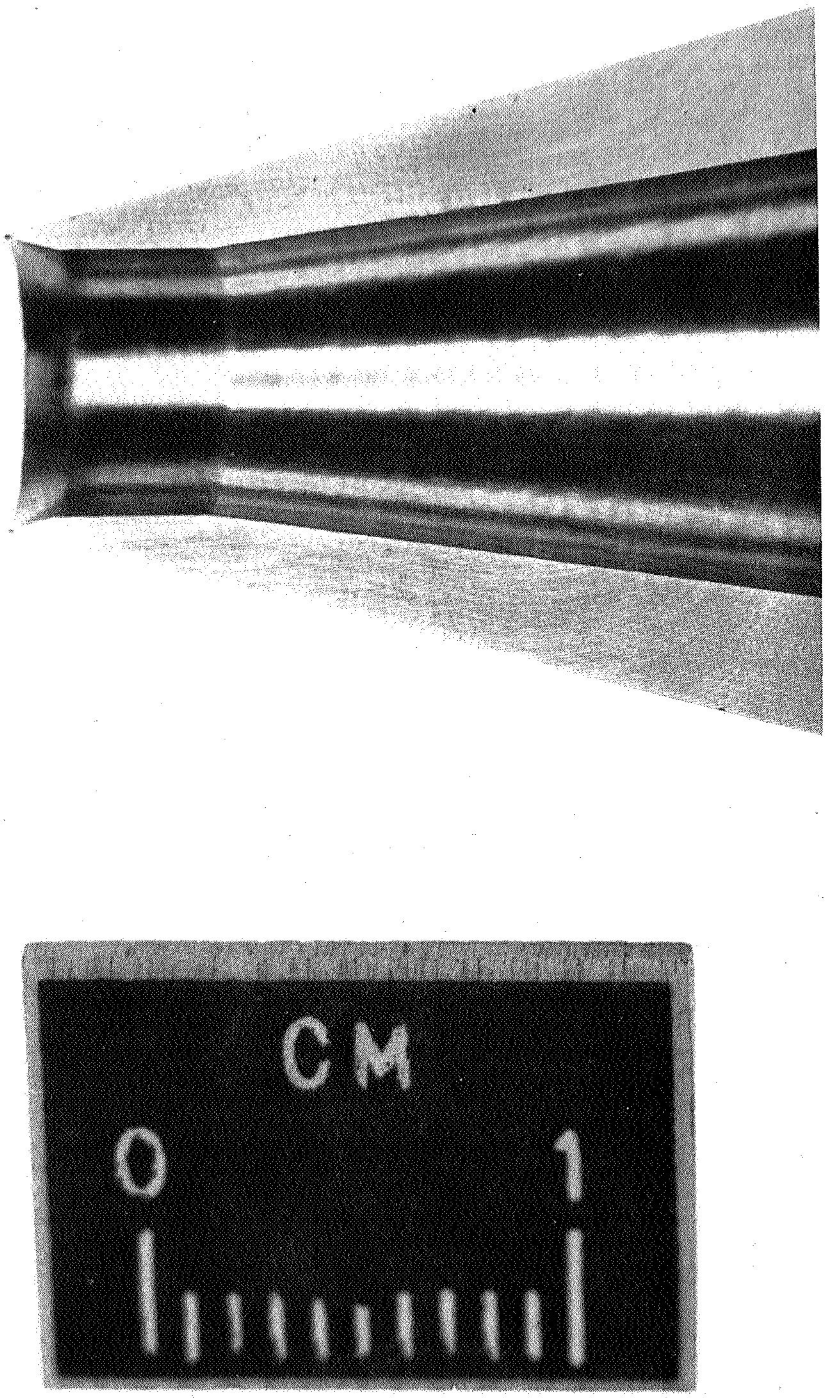


Figure 4. - Cross section of inlet A.

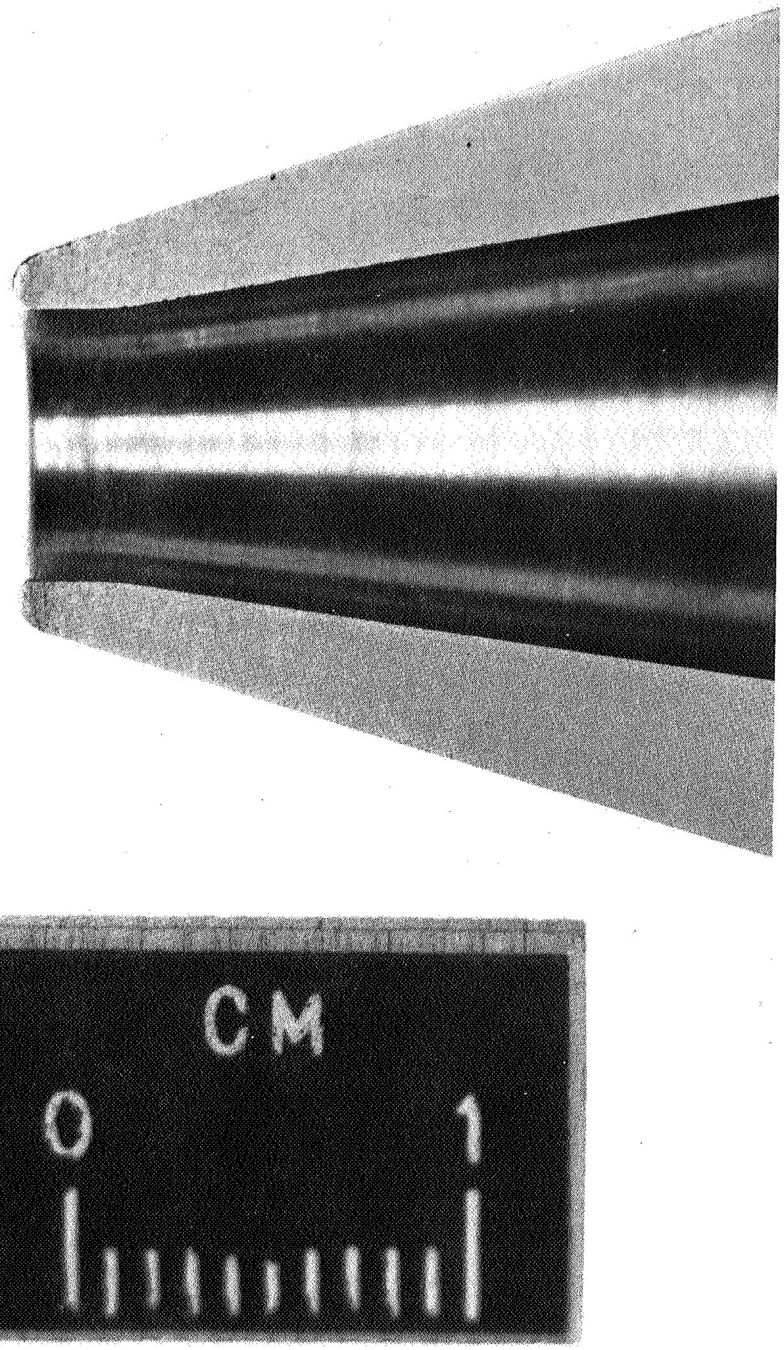


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Figure 5. - Cross section of inlet B with 0.022_2-inch- (0.056_4-cm-) radius lip.

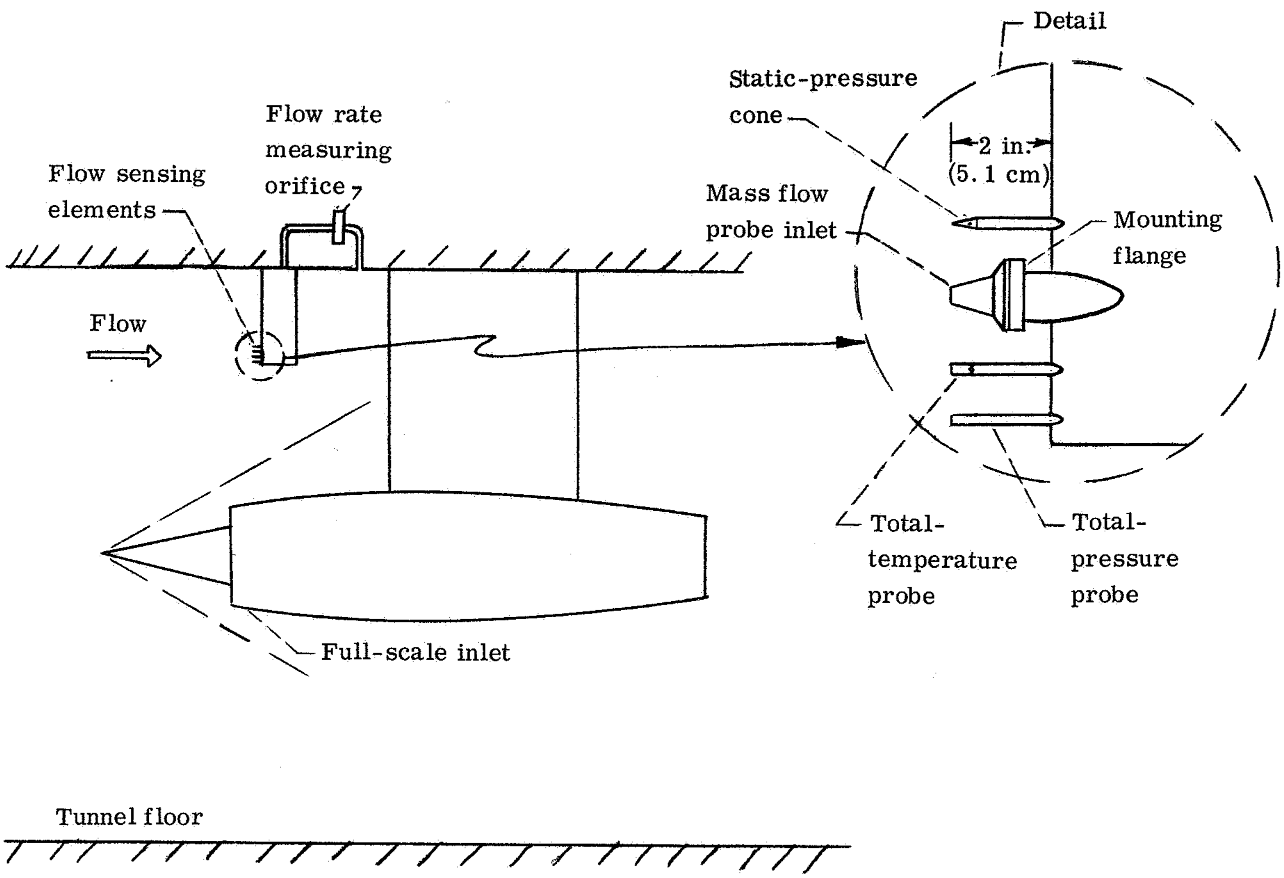

Figure 6. - Tunnel installation.

NASA-Langley, 1968 —— 14 E-4193