NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4122

EXTERNAL INTERFERENCE EFFECTS OF FLOW THROUGH STATIC-PRESSURE ORIFICES OF AN NACA AIRSPEED HEAD AT A MACH NUMBER OF 3

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SUMMARY

Wind-tunnel tests have been made to determine the static-pressure error resulting from external interference effects of flow through the static-pressure orifices of an NACA airspeed head at a Mach number of 3 and 0° angle of attack.

The results indicated that the static-pressure error increased almost linearly with increase in mass flow through the orifices. At a mass-flow rate corresponding to that which would be obtained at high altitudes for an airplane in a 45° climb and for which the airspeed installation incorporates an airspeed indicator, a Mach meter, and an altimeter, the error in static pressure would be about 6 percent with a corresponding error in Mach number of 3 percent. In a vertical climb with this airspeed system the error would be 8 percent in static pressure and 4 percent in Mach number. The static-pressure error of the forward set of orifices was not influenced by varying flow rates through the rear orifices. However, varying flow rates through the forward orifices caused a small effect of 1 percent or less on the static-pressure error of the rear set of orifices.

INTRODUCTION

Airspeed installations on airplanes usually include a number of indicating instruments or recording instruments or both. Because of the volume of these instruments and the connecting tubing, air flows into or out of the airspeed system in a dive or climb, respectively. The flow through the tubing causes a pressure loss and hence the instruments are subjected to a pressure that is different from the pressure at the static- or total-pressure source. This pressure loss is, of course, the well-known pressure lag. (See ref. 1.) The volume of the airspeed system may be a source of another error. This error is associated with the interference of the flow through the static-pressure orifices on the external flow. If the interference is appreciable, the static pressure in the region of the orifices may be expected to be different from that with no flow through the system. For example, at supersonic speeds flow out of the static-pressure orifices may cause a shock wave and hence an increase in the static pressure. Flow into the orifices may cause an expansion wave or a decrease in static pressure.

In order to determine the magnitude of this interference effect, tests were made at a Mach number of 3 in the Langley 9- by 9-inch high Mach number jet on an NACA airspeed head at 0° angle of attack. This airspeed head has two separate sets of static-pressure orifices spaced axially on the tube. Measurements of static pressure in the chamber of each set of orifices were made with mass flow out of the orifices up to about 4.2×10^{-6} slugs per second and into the orifices up to about 0.6×10^{-6} slug per second. The measurements were made at two stagnation pressures in the tunnel for which the corresponding Reynolds numbers (based on tube diameter) were about 0.77×10^{6} and 1.2×10^{6}.

SYMBOLS

A	total area of static-pressure orifices leading to each chamber of airspeed head, 1.25×10^{-4} sq ft
h	altitude, ft
l	length of mass-flow measuring tube, 3.72 ft
p	pressure, lb/sq ft
p_c	pressure in chamber of airspeed head, lb/sq ft
$p_{c,0}$	pressure in chamber of airspeed head with zero flow through orifices, lb/sq ft
Δp	pressure drop in mass-flow measuring tube, lb/sq ft
R	gas constant for air, 53.3 ft/deg
r	internal radius of mass-flow measuring tube, 3.22×10^{-3} ft
T	temperature, $^{\circ}$R
t	time, sec
V_∞	free-stream velocity, ft/sec

v total volume of airplane airspeed installation, cu ft

w mass flow, $\frac{\pi r^4}{8\mu l}\Delta p \rho_2$, slugs/sec (positive values for flow out of airspeed-head orifices)

γ flight-path angle, deg

μ absolute viscosity of air in mass-flow measuring tube, slugs/ft-sec

ρ mass density of air, slugs/cu ft

Subscripts:

t stagnation conditions

∞ tunnel or free stream

1 refers to airplane airspeed installation

2 refers to mass-flow measuring tube

APPARATUS AND TESTS

The NACA airspeed head used in the tests had two sets of static-pressure orifices with each set vented to a separate chamber in the head (fig. 1). In the usual airspeed installation one of the chambers is connected to the recording instruments and the other, to the indicating instruments. For the tunnel tests, the chambers were modified by inserting an additional tube into each chamber as shown schematically (for one chamber) in figure 2. One tube provided the air flow through the orifices and the other permitted measurement of the static pressure in the chamber. Each chamber had its own independent flow system incorporating three pressure recording cells. Mass flow through each set of orifices was determined by means of a smooth tube 3.72 feet long and 0.00322 foot in inside diameter. This diameter was sufficiently small to ensure laminar flow in the tube for the mass flows covered in the tests. Mass flow was computed from the pressure drop Δp across the tube by using Poiseuille's relation $w = \frac{\pi r^4}{8\mu l}\rho_2\Delta p$.

The tests were conducted in the Langley 9- by 9-inch high Mach number jet at a Mach number of 3, with the airspeed head at 0° angle of attack. The tests were made by establishing various constant mass flows through the orifices of one chamber and taking records during steady-state conditions as the mass flow through the orifices of the other chamber was varied by discrete increments. This test procedure not only facilitated covering a range of test conditions but also simulated the probable condition of different rates of mass flow out of the two sets of orifices due to different system volumes as a result of various types and numbers of instruments with their connecting tubing. The range of mass flow covered in the tests varied from 0 up to a maximum of about 4.2×10^{-6} slugs per second; this maximum mass flow is of the order of that which would flow through the orifices of this type of airspeed head connected to the usual set of indicating instruments for the condition of the airplane changing altitude at a rate of 1,000 feet per second at sea level. Tests were made for mass-flow both into and out of the orifices; for each test, the flow was always in the same direction for both chambers. For flow out of the orifices, the mass-flow measuring tube was opened to atmospheric pressure through a valve with which the flow rate was controlled (fig. 2). The maximum mass flow for this direction was 4.2×10^{-6} slugs per second. For flow into the orifices, the mass-flow measuring tube was connected through the valve to a very low pressure tank; however, because of the low tunnel static pressure and hence the relatively low pressure differential for this flow direction, the maximum mass flow obtainable was about 0.6×10^{-6} slug per second. The Reynolds number of the flow out of the orifices, based on the diameter of the larger orifice (0.052 in.), was 400 for the mass-flow rate of 4.2×10^{-6} slugs per second.

Measurements were recorded by means of standard NACA differential-pressure cells. Data were obtained for differential pressures between: (1) tunnel static and chamber static pressures, (2) chamber static pressure and pressure at the end of the mass-flow tube, and (3) the pressure drop in the mass-flow tube (see fig. 2). Also recorded during the tests were tunnel stagnation temperatures and pressures and the temperature of the air flowing through the mass-flow measuring tube. Schleiren pictures of the flow passing the airspeed head were taken at right angles to the direction of air flow into or out of the orifices of the airspeed head. Measurements were made for two tunnel stagnation pressures, 75 and 115 lb/sq in., for which the corresponding Reynolds numbers (based on airspeed-head tube diameter) were about 0.77×10^6 and 1.2×10^6, respectively.

RESULTS AND DISCUSSION

The static-pressure error due to mass flow through the static-pressure orifices of the airspeed head was determined from measurements of the static pressure in the airspeed-head chambers relative to the static pressure at a tunnel-wall orifice about 1 foot upstream of the airspeed orifices (fig. 2). Because of the longitudinal pressure gradient in the tunnel, the measured pressure difference for zero mass flow through the orifices was not zero for either the forward or rear set of orifices. In order to indicate only the external interference effects of flow through the orifices, the measured static-pressure difference (as a fraction of the tunnel static pressure) as plotted against the mass-flow parameter $\frac{w}{\rho_\infty V_\infty A}$ was arbitrarily displaced to go through zero error at zero mass flow. These data are shown for the forward and rear sets of orifices in figures 3(a) and 3(b), respectively. Positive and negative values of $\frac{w}{\rho_\infty V_\infty A}$ represent flow out of and into the orifices, respectively. In the results for each set of orifices, the mass flow through the other set of orifices and the different tunnel stagnation pressures are indicated by different symbols.

For the forward orifices (fig. 3(a)), all the experimental test points fell on one curve, except for very small variations due to experimental error. This result indicates that there was no effect of the difference in Reynolds number due to the different tunnel stagnation pressures and also that there was no effect on the pressure at the forward orifices due to various flow rates for the rear orifices (a result which would be expected for supersonic flow). The static-pressure error increased almost linearly with increase in mass-flow parameter. For example, for flow out of the forward orifices, the error increased about 8.7 percent as the mass-flow parameter increased from 0 to 1.2×10^{-2}. For flow into the orifices, the error decreased about 2.1 percent as the mass-flow parameter increased from 0 to -0.27×10^{-2}.

For the rear orifices (fig. 3(b)), the variation of the static-pressure error with mass-flow parameter was about the same as that for the forward orifices. For a constant mass flow out of the rear orifices, the effect on the static-pressure error for the rear orifices due to increasing the mass flow out of the forward chamber was generally to make the error somewhat less. This is indicated in figure 3(b), where the square symbols are in general lower than the circles and the diamonds, in turn, are lower than the squares. The total spread in the static-pressure error for the rear orifice for the range of mass flow covered for the forward orifices was of the order of 1 percent.

Since the static-pressure errors of figure 3 were necessarily determined by measuring the static pressure in the chambers of the airspeed head, the errors include some effect of the static-pressure loss across the orifices at the higher mass flows. Estimates on the basis of a sudden expansion loss through the orifices with no external-flow effect indicate an error of about 0.9 percent for a mass-flow parameter of 1.3×10^{-2} and a tunnel stagnation pressure of 75 lb/sq in. This error is of the order of 1/10 of the error due to interference of the flow through the orifices with the external flow.

Schlieren photographs taken during the tests showed some shock waves due to flow out of the orifices for the higher rates of flow; however, inasmuch as the shock waves were weak, photographs are not presented.

The interpretation of the results of figure 3 for an airplane climbing or diving may be facilitated by converting the mass-flow parameter $\frac{w}{\rho_\infty V_\infty A}$ into related quantities involving flight conditions. For example, for an airplane having an airspeed installation of total volume v and a time rate of change of static pressure dp/dt, the mass of air entering or leaving the system through the orifices is

$$w = -\frac{\rho_1 v}{p_\infty}\frac{dp_\infty}{dt}$$

The mass-flow parameter is then

$$\frac{w}{\rho_\infty V_\infty A} = -\frac{\rho_1}{\rho_\infty}\frac{v}{V_\infty A}\frac{1}{p_\infty}\frac{dp_\infty}{dt} \tag{1}$$

For the atmosphere, the rate of change of static pressure with height may be expressed by the relation

$$\frac{dp_\infty}{dh} = -\frac{p_\infty}{RT_\infty} \tag{2}$$

When equation (2) is substituted into equation (1), the following equation results:

$$\frac{w}{\rho_\infty V_\infty A} = \frac{v}{AR}\frac{\rho_1}{\rho_\infty T_\infty}\frac{1}{V_\infty}\frac{dh}{dt}$$

and because

$$p_\infty = \rho_\infty RT_\infty = \rho_1 RT_1$$

then, the following form for the mass-flow parameter is obtained:

$$\frac{w}{\rho_\infty V_\infty A} = \frac{v}{ART_1}\frac{1}{V_\infty}\frac{dh}{dt} \quad (3)$$

Since $\frac{1}{V_\infty}\frac{dh}{dt} = \sin\gamma$, where γ is the flight-path angle, a final form of the mass-flow parameter is

$$\frac{w}{\rho_\infty V_\infty A} = \frac{v}{ART_1}\sin\gamma \quad (4)$$

With this expression for the mass-flow parameter, a quicker evaluation of the results of figure 3 may be made. For example, for an airplane in a 45° climb and for which the airspeed installation incorporates an airspeed indicator, a Mach meter, and an altimeter, the mass-flow parameter at high altitudes is of the order of 0.8×10^{-2}. For this value of mass-flow parameter the error in static pressure would be 6 percent and the corresponding error in Mach number would be 3 percent. For a vertical climb the mass-flow parameter would be about 1.1×10^{-2} and the error would be 8 percent in static pressure and 4 percent in Mach number.

CONCLUDING REMARKS

Results of tests to determine the static-pressure error resulting from external interference effects of flow through static-pressure orifices of an NACA airspeed head at a Mach number of 3 and 0° angle of attack have indicated that the static-pressure error increased almost linearly with increase in mass-flow parameter. At a mass-flow rate corresponding to that which would be obtained at high altitudes for an airplane in a 45° climb and for which the airspeed installation incorporates an airspeed indicator, a Mach meter, and an altimeter, the error in static pressure would be about 6 percent with a corresponding error in Mach number of 3 percent. In a vertical climb with this airspeed system the error would be 8 percent in static pressure and 4 percent in Mach number.

The static-pressure error of the forward set of orifices was not influenced by varying flow rates through the rear orifices. However, varying flow rates through the forward orifices caused a small effect of about 1 percent or less on the static-pressure error of the rear set of orifices.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 22, 1957.

REFERENCE

1. Lamb, J. P., Jr.: The Influence of Geometry Parameters Upon Lag Error in Airborne Pressure Measuring Systems. WADC Tech. Rep. 57-351, Wright Air. Dev. Center, U. S. Air Force, July 1957. (Available as ASTIA Doc. No. AD 130790.)

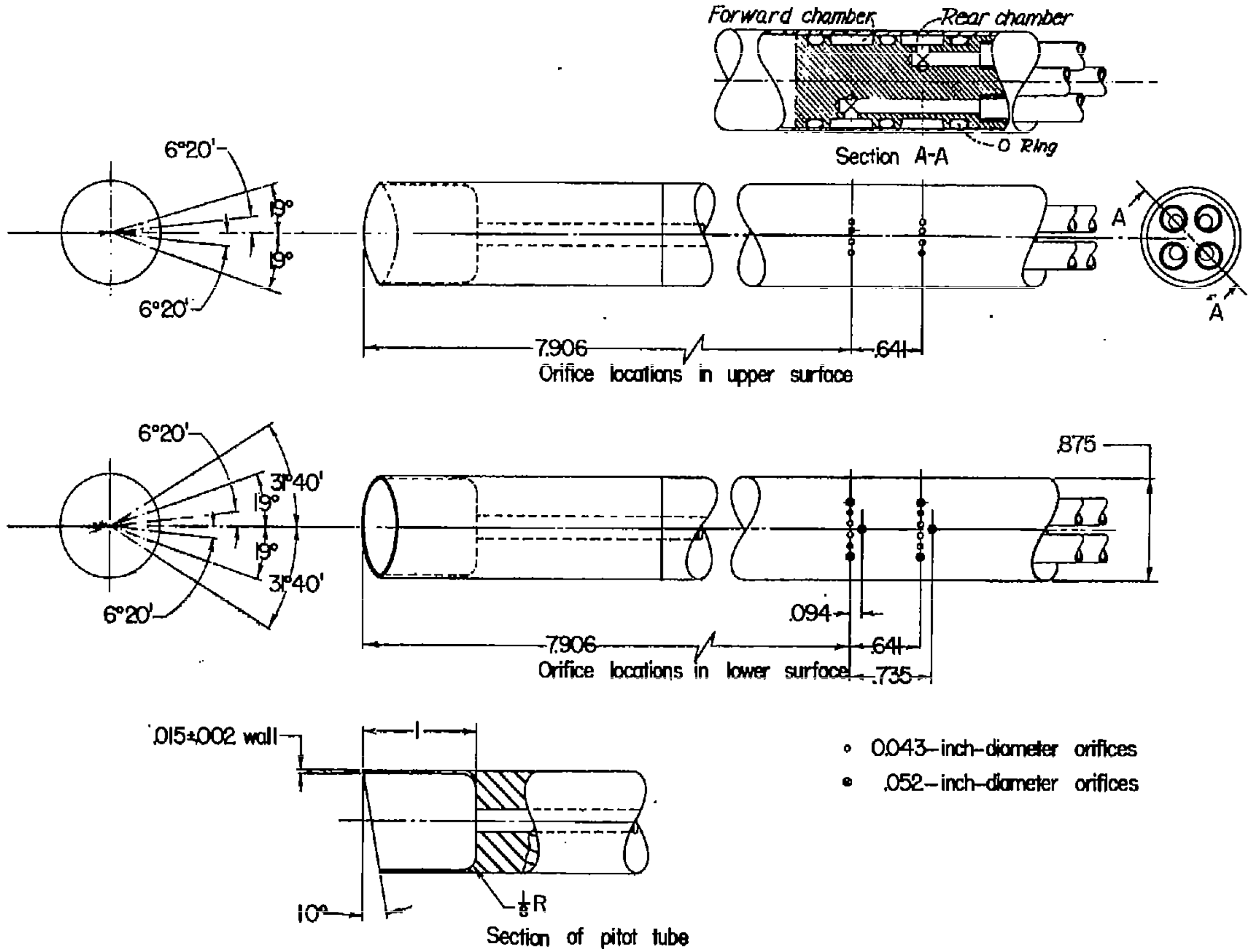


Figure 1.- Airspeed head as modified by insertion of an additional tube into each static-pressure chamber. Pitot tubing removed and pitot opening plugged. All linear dimensions are in inches.

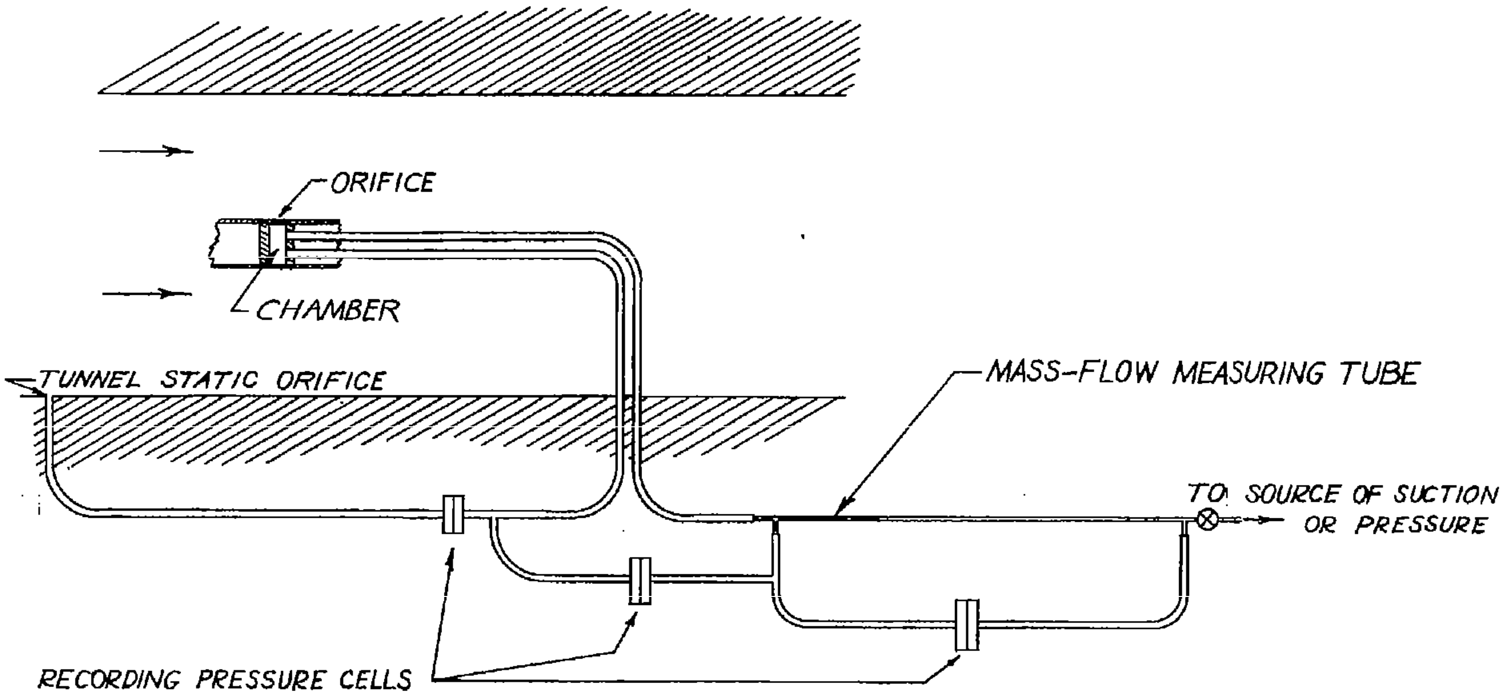
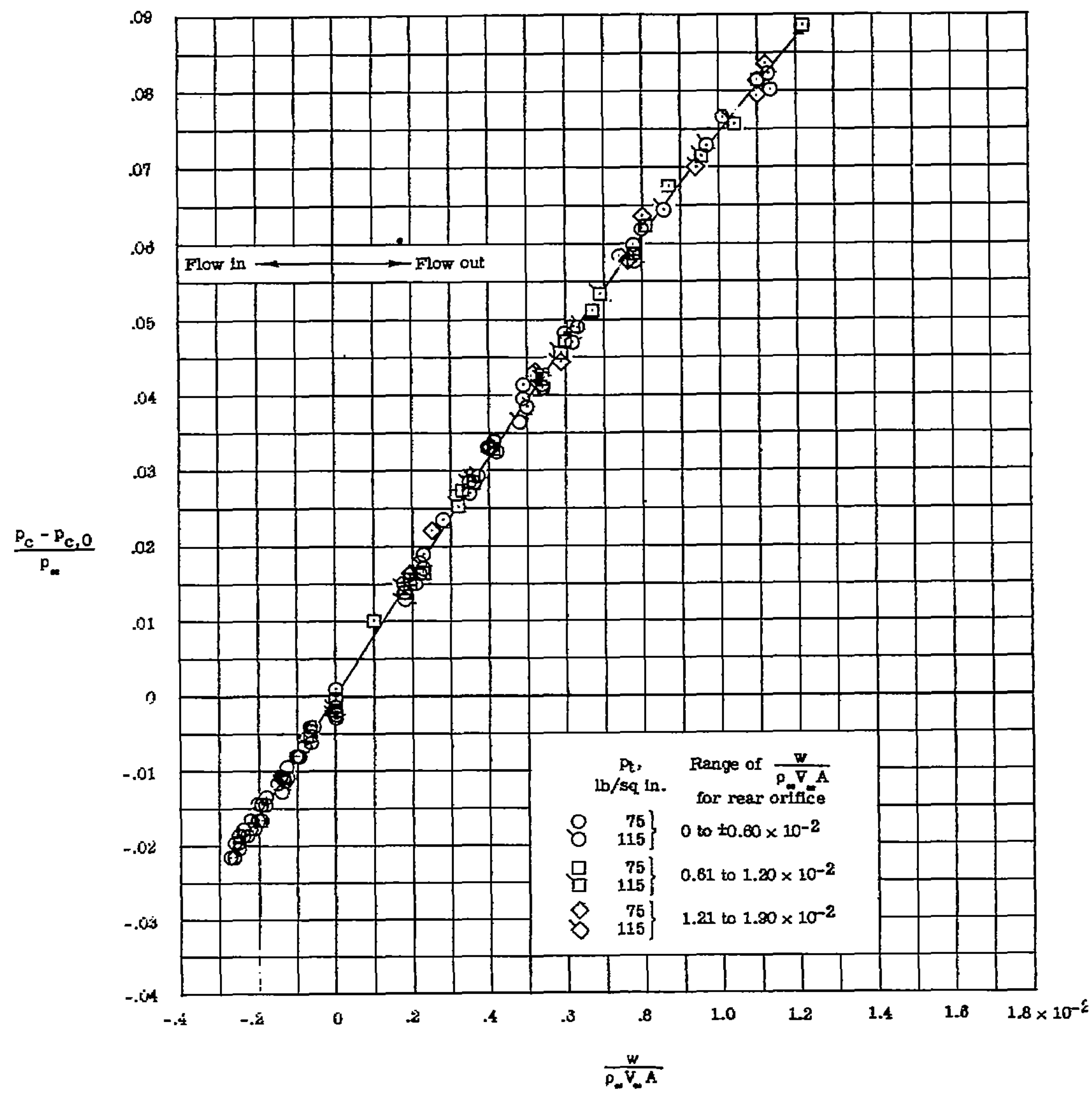
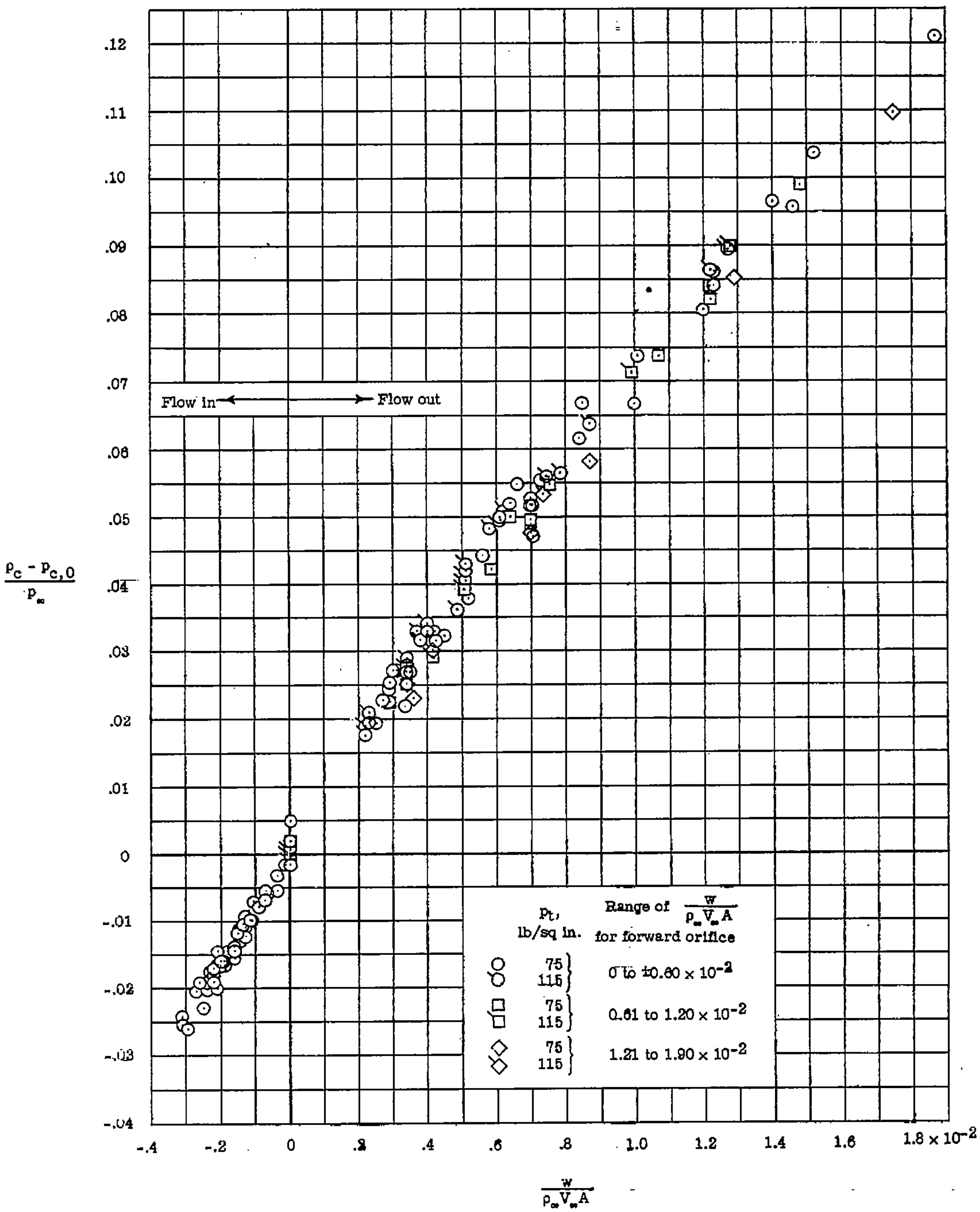


Figure 2.- Sketch showing mass-flow and pressure-measuring setup for one chamber of airspeed head.



(a) Forward orifice.

Figure 3.- Variation of static-pressure error of airspeed head with mass-flow parameter $\frac{w}{\rho_\infty V_\infty A}$ at Mach number 3.



(b) Rear orifice.

Figure 3.- Concluded.