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CALIBRATION OF THREE TEMPERATURE PROBES AND A PRESSURE PROBE AT HIGH SPEEDS

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ADVANCE RESTRICTED REPORT

CALIBRATION OF THREE TEMPERATURE PROBES AND A PRESSURE PROBE AT HIGH SPEEDS

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SUMMARY

Three Franz-type temperature probes and a pitot-static tube for use in supercharger passages have been calibrated in the NACA 24-inch high-speed wind tunnel. These instruments were designed for use in supercharger investigations.

INTRODUCTION

At the suggestion of Pratt & Whitney Aircraft (Division of United Aircraft Corporation) and with the approval and recommendation of the NACA Special Subcommittee on Supercharger Compressors, three Franz-type temperature probes and a pitot-static tube for use in supercharger passages have been calibrated in the NACA 24-inch high-speed wind tunnel at the Langley Memorial Aeronautical Laboratory, Langley Field, Va. These instruments, supplied by Pratt & Whitney Aircraft, were designed for use in supercharger investigations.

METHODS AND APPARATUS

The 24-inch high-speed wind tunnel, in which these tests were conducted, is an induction-type wind tunnel without return passages, its induction nozzle being downstream from the test section (reference 1).

The impact or total pressure at the test section for all speeds is equal to the atmospheric pressure except for a small loss through screens. This loss, equal to approximately 0.13 percent of the dynamic pressure, has been determined by measurements of the loss through screens and by comparison of the impact pressure of several standard pitot tubes.

The static pressure at the test section was determined by calibrated static-pressure orifices in the tunnel wall upstream from the test section. Calibrations of the static-pressure orifices were made, in the usual manner, by comparing the pressures at the static-pressure orifices with the static pressure in the test section. For the calibrations, the static pressure at the test section was determined by measurements of the pressure acting on orifices at the test-section level in a long tube that extended from the region of practically zero velocity ahead of the entrance cone to a point well downstream of the test section. Tubes of two sizes were used in these calibrations, one tube being of 1/8-inch diameter and the other of 3/4-inch diameter. Identical results were obtained with either tube.

Temperature probes.- The three temperature probes, having thermocouples to indicate the temperature, were geometrically similar. The dimensions are given in figure 1 in terms of the diameter. The diameter of the larger probe was 5/16 inch and of each of the two smaller probes, 5/32 inch. The large probe and one small probe were made of fiber and were identical in construction. The other small probe was a modification of the first. The modification consisted of a steel sleeve extending along the cylindrical portion of the body of the probe. The sleeve, having a length of approximately 2.2 diameters, extended to a point 3 diameters back of the nose of the probe. The thickness of the sleeve was equal to the thickness of the fiber at the exit orifices. The orifices in the steel sleeve were drilled perpendicular to the axis of the sleeve.

The temperature probe was fastened rigidly at the tunnel wall and extended approximately 2 inches into the air stream. The thermocouple leads were connected to a potentiometer by copper wires. The junctures of the thermocouple leads and the copper wires were electrically insulated and were kept at a constant temperature in an ice-water bath, the temperature of which was checked with an accurate thermometer.

Pitot-static tube.- The pitot-static tube and the support are shown in figure 2. The tube, 0.049 inch in diameter, had four equally spaced 0.008-inch-diameter static-pressure orifices located 0.15 inch back of the impact opening. The impact opening was 0.019 inch in diameter. The distance from the end of the threaded part of the support to the head of the pitot-static tube could be varied from approximately 1/8 inch to 2 inches.

The pitot-static-tube support was fastened to the tunnel wall, the pitot-static tube being locked in its most forward position, which placed the head of the instrument approximately 2 inches from the tunnel wall. The angle between the head of the pitot-static tube and the air stream was held at 0°.

SYMBOLS

p_i	impact, or total pressure
p_s	static pressure
T_i	true adiabatic-compression temperature, degrees absolute
T_s	air-stream temperature, degrees absolute
M	Mach number
γ	ratio of specific heat at constant pressure to specific heat at constant volume

Values obtained from instrument readings are denoted by primed symbols.

RESULTS

The results of the calibrations are presented in figures 3 to 9. Figures 3, 4, and 5 show the calibration and temperature-recovery factors for the small original, the small modified, and the large temperature probe, respectively. A plot showing the relation between the pressure ratio and Mach number is given in figure 6. Figures 7 and 8 show the error in impact-pressure and in static-pressure readings, respectively, and figure 9 shows the calibration factor for the pitot-static tube. An estimate of the accidental error involved in the calibrations can be obtained from the scatter of the test points.

DISCUSSION

The temperature probes are actually designed to measure the adiabatic-compression temperature of an air stream. From this temperature and a knowledge of the total and static pressures in the air stream, the temperature of the air stream is determined. Normal interest thus centers on the so-called temperature-recovery factor, that is, the capability of the probe to measure the temperature rise resulting from the adiabatic compression of the air from the stream pressure to the pressure corresponding to zero velocity. Because these instruments, as noted before, actually are designed to measure the adiabatic-compression temperature, it is therefore interesting to examine the relation between the temperature measured and the true adiabatic-compression temperature, as well as the temperature-recovery factor.

The calibration factor, which is the ratio of the true to the indicated adiabatic-compression temperature, increases numerically for each of the temperature probes with increase in the compression ratio of the Mach number. The error in this factor, in percent of the true adiabatic-compression temperature in degrees absolute, at a Mach number of 0.9, is slightly greater than 1 percent for the small original probe (fig. 3) and is approximately 0.7 percent for the modified small probe and the large probe (figs. 4 and 5). Calculations based on the assumption that the flow did not separate from the divergent walls within the temperature probe indicated that the change in temperature resulting from the finite velocity at the thermocouple would be insignificant.

A comparison of the temperature-recovery factors for the two small probes (figs. 3 and 4) shows that the modified probe has a temperature-recovery factor which is approximately 5 percent higher than this factor for the original small all-fiber probe. A comparison of the factor for the modified small probe with the factor for the large all-fiber probe shows that the large probe is somewhat better. The difference in the factors decreases from approximately 3 percent at the lower values of the compression ratio to 1 percent at the higher values.

The temperature-recovery factor will be considered in more detail in order to show the reason for the large scatter of the test points at the low values of the compression ratio and to show the relation of the temperature-recovery factor to the calibration factor presented.

The relation between Mach number and compression ratio, as obtained from the relation between pressure, density, and velocity of sound, and Bernoulli's equation for a compressible fluid, is

$$M^2 = \frac{2}{\gamma - 1}\left[\left(\frac{p_i}{p_s}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]$$

This equation reduces to

$$M^2 = \frac{2}{\gamma - 1}\left(\frac{T_i}{T_s} - 1\right)$$

and

$$\frac{T_i}{T_s} = \frac{\gamma - 1}{2} M^2 + 1 = 0.2\ M^2 + 1$$

Thus, at low Mach numbers the differences between the stream temperature and the adiabatic-compression temperature become very small (approximately 5° F at a Mach number of 0.25). The experimental error involved in the determination of these temperatures, even though very small in actual degrees, becomes very important. At very low Mach numbers, the temperature-recovery factor may therefore have no practical significance because of the experimental error involved in its determination. For this reason, the curves showing the temperature-recovery factor were not extended to the lower values of Mach number. The temperature-recovery factor in terms of the calibration factor is

$$\frac{T_i{}' - T_s}{T_i - T_s} = \frac{T_i{}'}{T_i}\left(1 + \frac{5}{M^2}\right) - \frac{5}{M^2}$$

$$= \frac{T_i{}'}{T_i} - \frac{5}{M^2}\left(1 - \frac{T_i{}'}{T_i}\right)$$

This relation shows that the temperature-recovery factor is equal to the reciprocal of the instrument calibration factor less a term involving the Mach number and the instrument calibration factor.

The errors in the calibration of the pitot-static tube are separated into the errors in impact-pressure and in static-pressure readings. A comparison of the two errors, figures 7 and 8, respectively, indicates that the greater error occurs in the static-pressure reading at the highest values of the compression ratio, or speed. At the lowest compression ratios, the two errors are approximately equal and in the same direction and therefore tend to cancel each other.

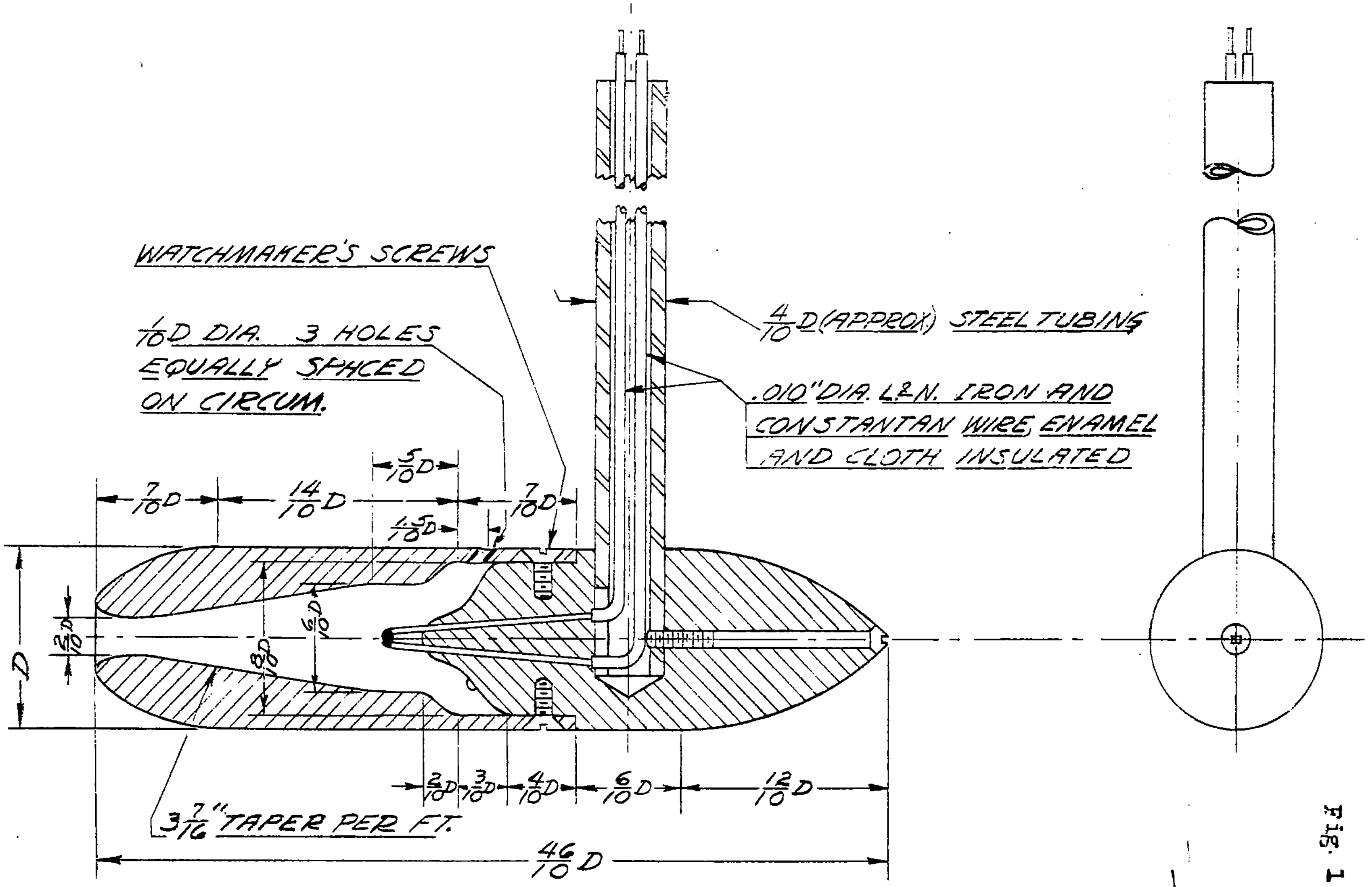
Considerable difficulty was encountered in obtaining the static-pressure reading because of the excessive damping in the pitot-static tube. This excessive damping resulted from any one of or a combination of the following factors: static-pressure orifices of small diameter, small number of static-pressure orifices, and restrictions in the static-pressure line within the tube itself resulting from the small free area of the static tube. A direct result of this extreme damping can be seen in the scatter of the test points in figure 8, of which the maximum value is ±2 percent.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Stack, John, Lindsey, W. F., and Littell, Robert E.: The Compressibility Burble and the Effect of Compressibility on Pressures and Forces Acting on an Airfoil. Rep. No. 646, NACA, 1938.

Figure 1.- PRATT & WHITNEY TEMPERATURE PROBE.



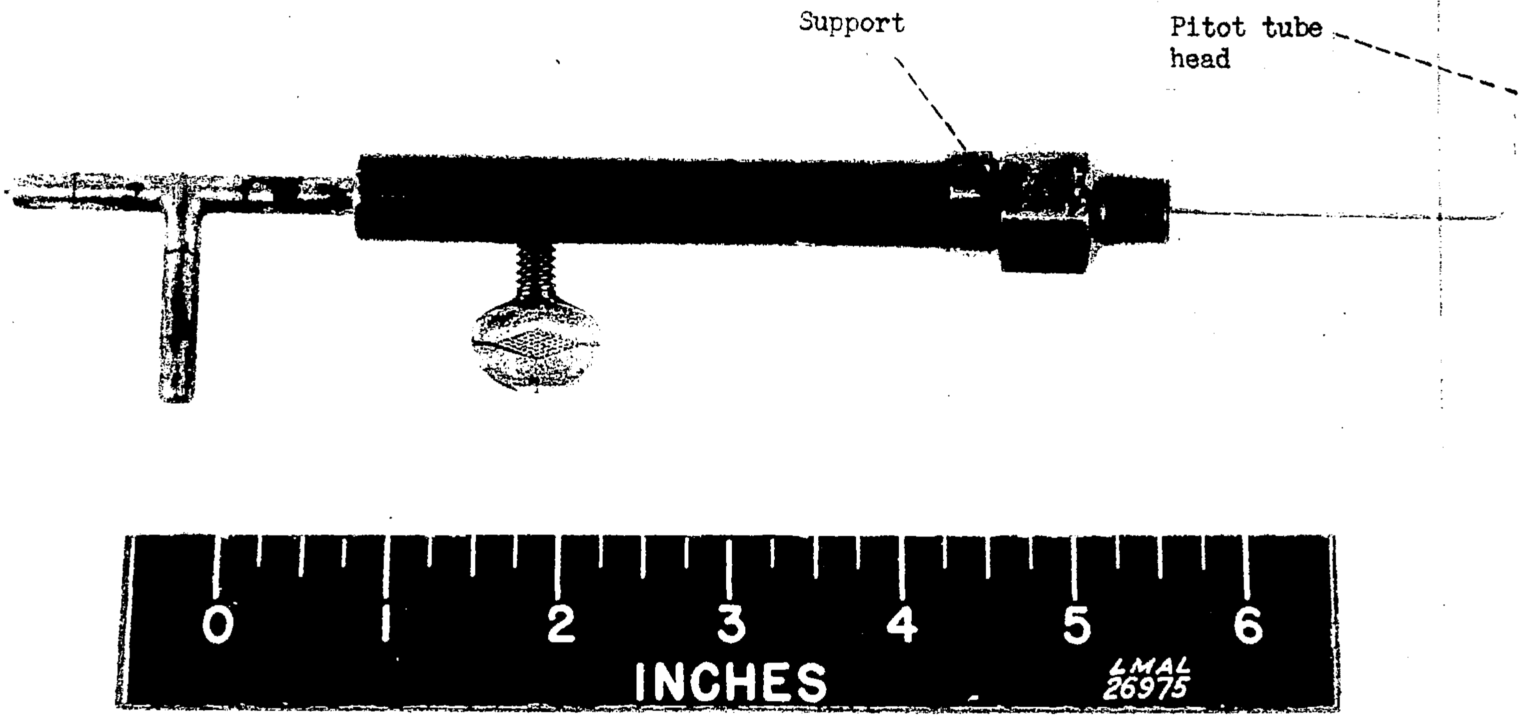


Figure 2.- Pratt and Whitney pitot-static tube.

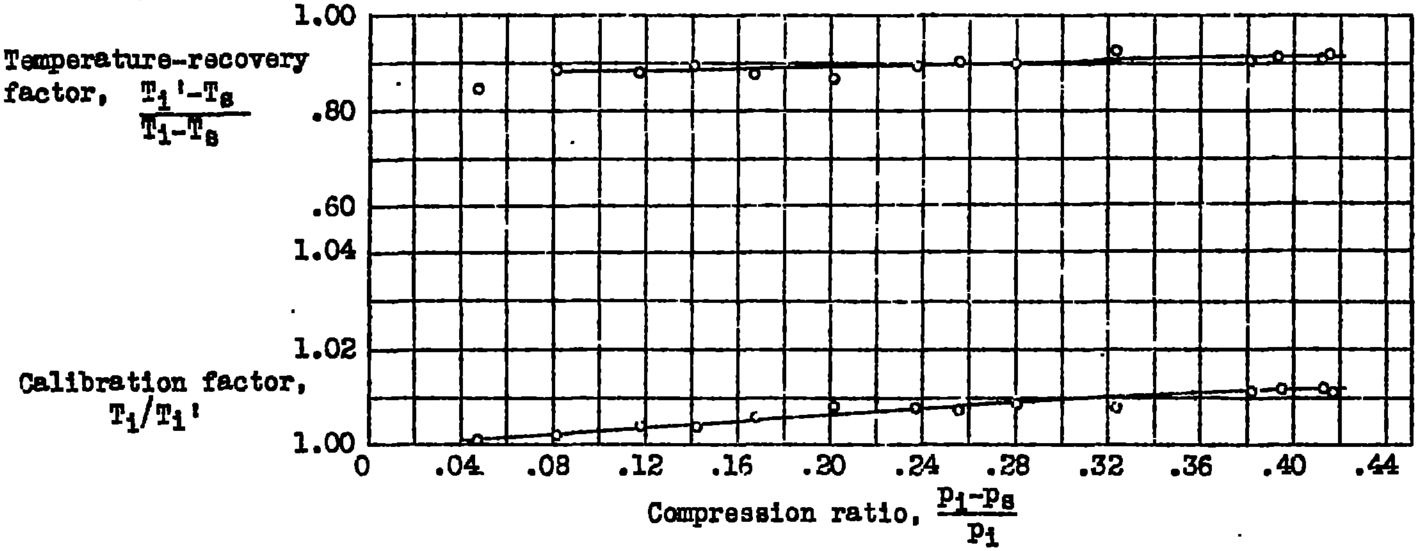


Figure 3.- Calibration of Pratt and Whitney temperature probe, 5/32 inch in diameter.

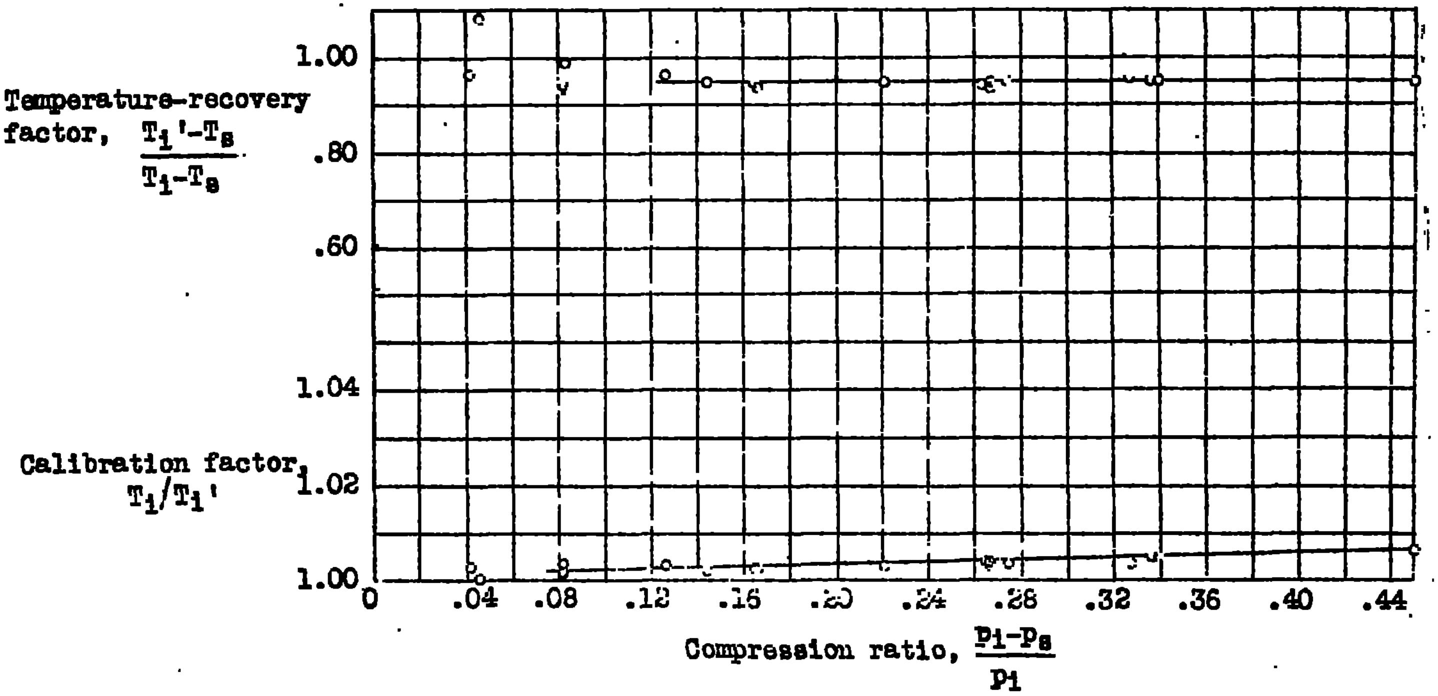


Figure 4.- Calibration of Pratt and Whitney temperature probe, 5/32 inch in diameter (modified).

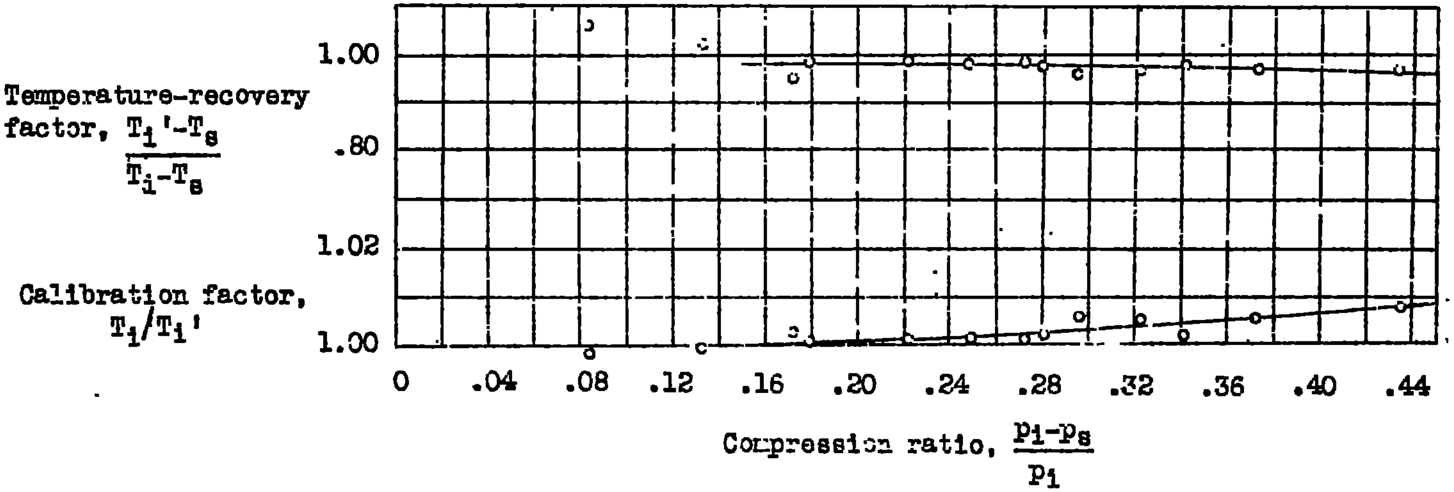


Figure 5.- Calibration of Pratt and Whitney temperature probe, 5/16 inch in diameter.

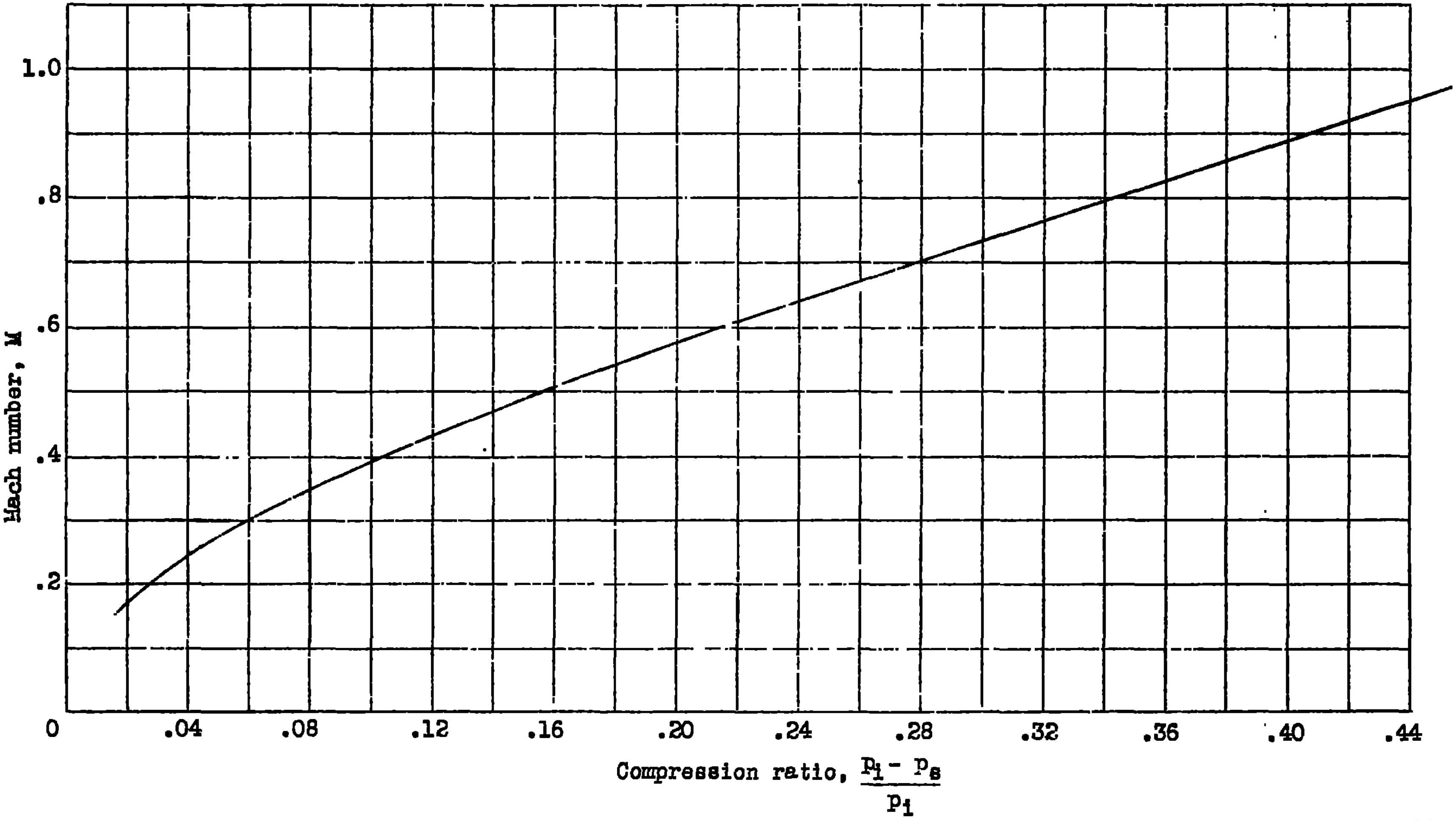


Figure 6.- Relation between Mach number and the compression ratio.

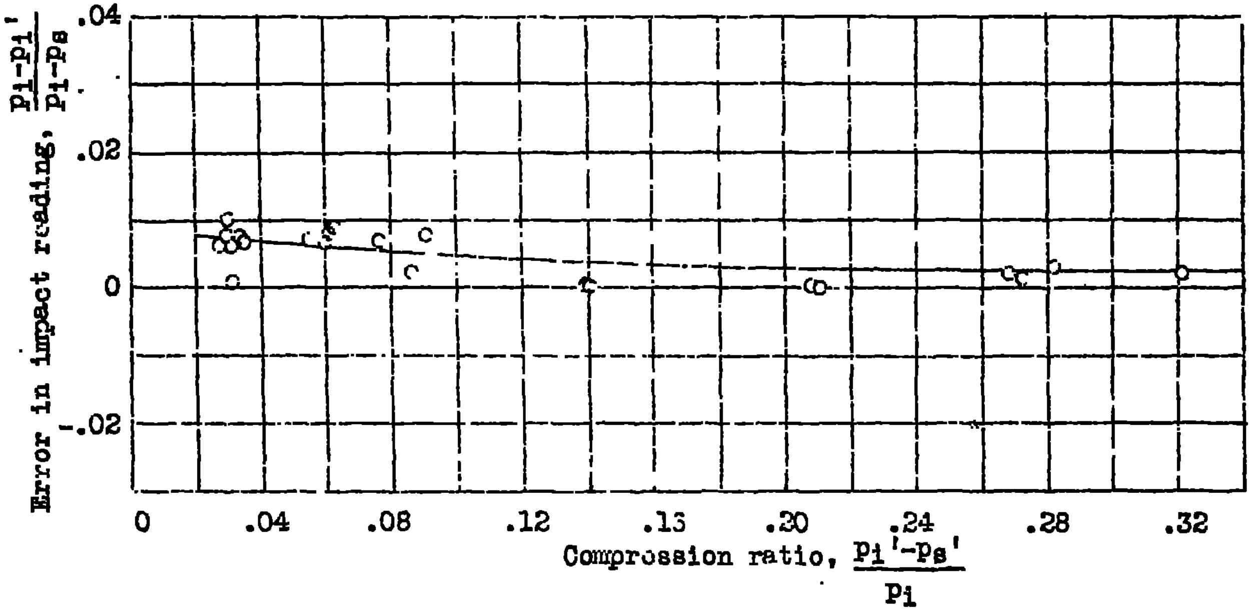


Figure 7.- Pratt and Whitney pitot-static tube error in impact-pressure reading.

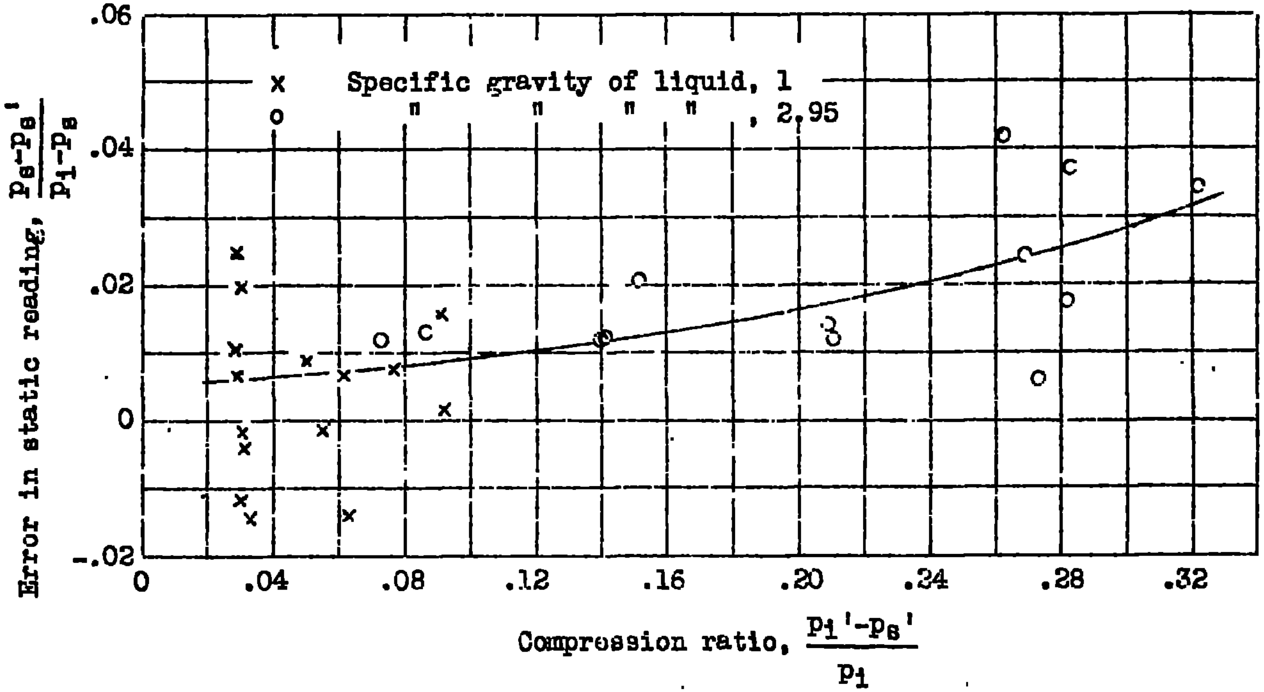


Figure 8.- Pratt and Whitney pitot-static tube error in static pressure reading.

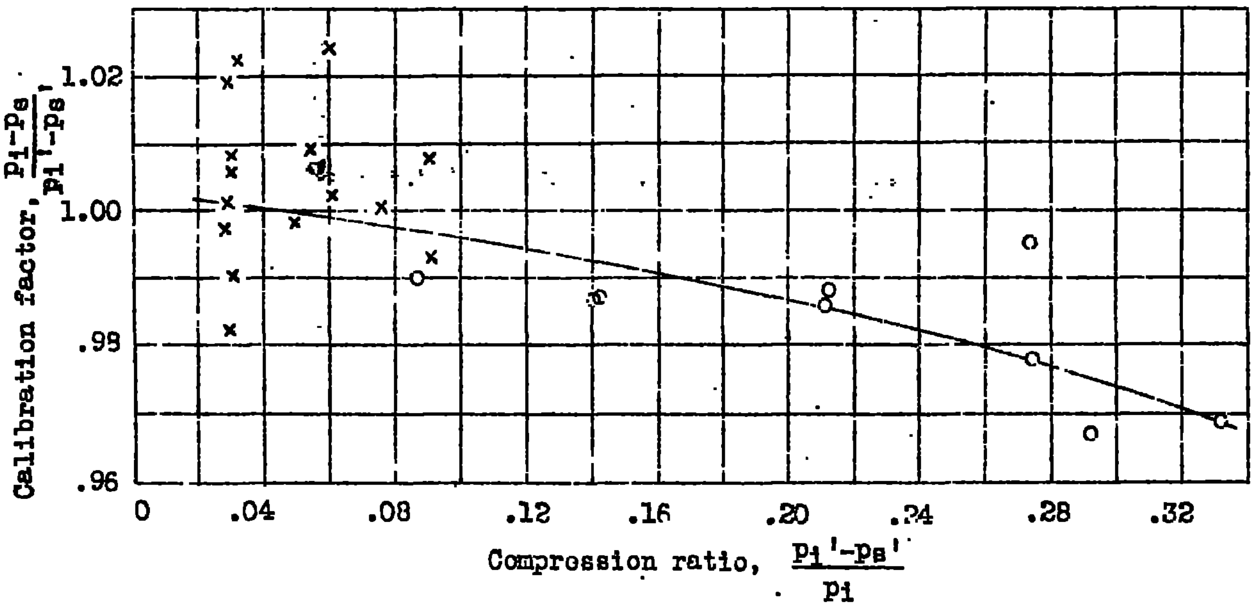


Figure 9.- Pratt and Whitney pitot-static tube calibration factor.

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