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TESTS OF WESTINGHOUSE SONIC PYROMETERS

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FOREWORD

This report was prepared by the National Bureau of Standards, Washington, D. C., under USAF Contract No. (33-038)51-4063. The contract was initiated under the research and development project identified by Expenditure Order No. 540-20, Elements Non-Thermoelectric Temperature Sensing. It is administered under the direction of the Power Plant Laboratory of Wright Air Development Center. Mr. George Kuhlman and Mr. Charles Mayo are acting as project engineers.

ABSTRACT

This report presents the results of performance and calibration tests of two sonic-flow thermocouple pyrometers designed and constructed by the Westinghouse Electric Corporation.

PUBLICATION REVIEW

INTRODUCTION

This report presents the results obtained from studies with two sonic flow thermocouple pyrometers submitted by the Westinghouse Electric Corporation.

The sonic flow pyrometer is basically an aspirating or suction-type instrument in which the gas is made to flow over the sensing junction at sonic velocity, regardless of the flow conditions in the main gas stream. Under this condition, the maximum rate of heat transfer from the gas to the junction is maintained, thereby increasing the response rate and decreasing the effects of thermal radiation and conduction between the junction and the surroundings. Furthermore, it can be shown that, by means of a simple correction factor, the temperature indicated by the junction in the sonic flow region can be interpreted in terms of the total temperature of the main stream.

A detailed presentation of the basic principles of operation of the sonic flow pyrometer is given elsewhere and will not be repeated here.[1,2]

1. S. A. Allen and J. Hamm, A pyrometer for measuring total temperature in low density gas streams. Trans. Am. Soc. Mech. Engrs. 72, 851 (1950).

2. G. T. Lalos, A sonic-flow pyrometer for measuring gas temperatures. J. Research Nat. Bur. Standards 47, 179 (1951).

DESCRIPTION OF TEST UNIT

Figure 1 is a photograph of the Westinghouse sonic flow pyrometer. A sectional drawing giving constructional details is shown in figure 2. The outer sheath, nozzle and the tube containing the thermocouple are of Inconel. The gas, whose temperature is to be measured, is admitted through a 0.161" diameter hole near the end of the probe, and then passed through the nozzle. The thermocouple junction, formed by butt-welding the No. 20 gage Chromel and Alumel thermoelements, is supported by means of a ceramic insulator at a point about 5/16" downstream from the exit of the nozzle. The gas, after passing over the junction, is channeled to the probe head and is discharged to atmosphere or to a vacuum pump. A portion of the gas entering the probe passes over the outer surface of the nozzle and thence through the annular space between the outer sheath and the thermocouple sleeve to the discharge port in the head.

In order for the instrument to operate as a sonic pyrometer the pressure ratio across the nozzle section, in which the sensing junction is mounted, must be kept below 0.53. For applications in which the main stream is at or only slightly above ambient pressure, an aspirating system must be employed to maintain the required pressure ratio. In case the pressure of the gas at the inlet to the probe is sufficiently high, direct discharge to the atmosphere is adequate.

TEST PROCEDURE

The initial tests of the Westinghouse sonic pyrometers were made in an apparatus shown schematically in figure 3. The units were mounted singly in the test chamber with a reference thermocouple located immediately ahead of the inlet to the sonic pyrometer. For tests at high pressure, up to 90 lb/in^2 air at room temperature was supplied to the chamber by a compressor. The air which passed through the sonic pyrometer was discharged to the atmosphere. The emf of the thermocouple within the probe was compared directly with that of the reference thermocouple for a series of chamber pressures. As an aid in promoting temperature uniformity within the chamber, a small amount of air was bled off continuously.

Tests of the sonic pyrometer with normal atmospheric pressure at the probe inlet were carried out by removing the end of the chamber and connecting the probe discharge to a vacuum system. In addition, one of the Westinghouse probes was inserted into a stream of exhaust gas and its indication compared with that of a Ag-shielded Chromel-Alumel thermocouple. In this test installation, the static pressure of the exhaust gas was only a few inches of water above atmospheric and hence the probe had to be connected to a vacuum pump.

TEST RESULTS

The results obtained at room temperature with the two Westinghouse units are shown in figures 4 and 5. In each, the differences between the emf of the reference thermocouple and that of the probe are plotted against the pressure ratio, P_2/P_1. P_1 is the pressure at the probe inlet and P_2 the pressure at the probe discharge. It will be noted that this difference for pyrometer No. 1 attains a constant value at a pressure ratio of about 0.3, while the corresponding ratio for pyrometer No. 2 is about 0.2.

Following the procedures presented in references 1 and 2, the experimental value of the correction factor, α, required to convert the temperature, T_i, indicated by the sonic probe to the total temperature, T_t, of the main stream, (where temperatures are expressed in degrees absolute), the following results are obtained:

Probe No.	T_t (Degrees R)	T_i (Degrees R)	$\alpha = T_t/T_i$
1	530	521.6	1.016_1
2	530	521.0	1.017_3

During the tests of Westinghouse probe No. 2 in exhaust gas, a pressure ratio of about 0.15 was maintained across the probe. The gas flow rate of the main stream was 4 lbs/sec ft^2. Chromel-Alumel thermocouples peened into the pipe wall served to measure the wall temperatures. The indications of the Ag-shielded Chromel-Alumel junction in the gas stream were corrected for radiation losses and velocity effects to give the total temperature of the gas. The results together with calculated values of the correction factor, α, are given in the table.

Table 1. Calibration Data on Westinghouse Sonic Pyrometer No. 2

Temperatures			
T_{wall}	T_t	T_i	$\alpha = T_t/T_i$
Degrees R			
	530.0[1]	521.0[1]	1.017_3[1]
550	558.0	548.2	1.017_8
1160	1460.	1431	1.020_2
1235	1660.	1626	1.020_9
1340	1860.	1818	1.023_3
		Mean	1.020 ± .003

1. Data obtained in apparatus of figure 3

DISCUSSION OF RESULTS

The performance curves shown in figures 4 and 5 indicate that the pressure ratio P_2/P_1 required to attain constant values of ΔE for the two Westinghouse pyrometers are considerably below the theoretical value of 0.53 for a nozzle. The difference is due to pressure losses between the nozzle and the discharge. By reducing these losses through enlarging or improving the aerodynamic characteristics of the flow passages, the required pumping effort could be reduced.

The data in table 1 indicate a gradual increase in the value of the correction factor, α, with increasing gas temperature. In a former study of an experimental sonic pyrometer,[2] made under conditions in which radiation losses from probe to surroundings were eliminated, the values of α decreased from 1.021 at 100°F to 1.017 at 1300°F. The opposite trend in the α for the Westinghouse units is in a direction indicating that some heat is lost from the measuring junction by radiation and conduction. Comparison of the two sets of data indicates that the error in the Westinghouse units from this source should not exceed one percent of the absolute temperature under any of the present test conditions. This effect will increase with higher gas temperatures and with lower wall temperatures.

The results obtained on the tests of the Westinghouse probes are in good agreement with those presented in reference 1 on a similar instrument. It is believed that the Westinghouse sonic pyrometer should prove to be a reliable and practical instrument for temperature measurements in gas turbine testing and operation. A discussion of the rate of response of such instruments to sudden changes in temperature will be found in reference 2.

Washington, D. C.
January 17, 1952

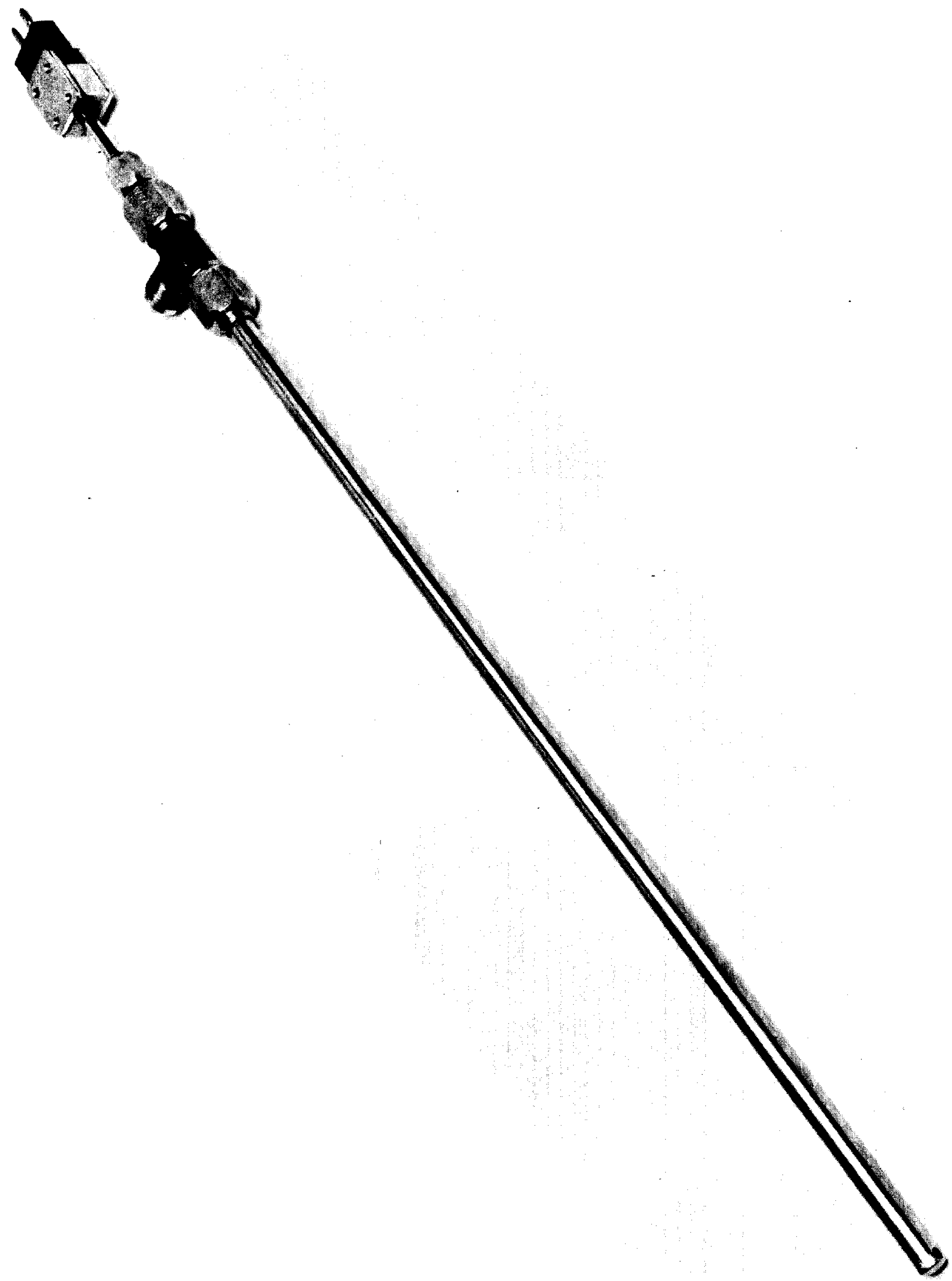

FIGURE 1 WESTINGHOUSE SONIC THERMOCOUPLE

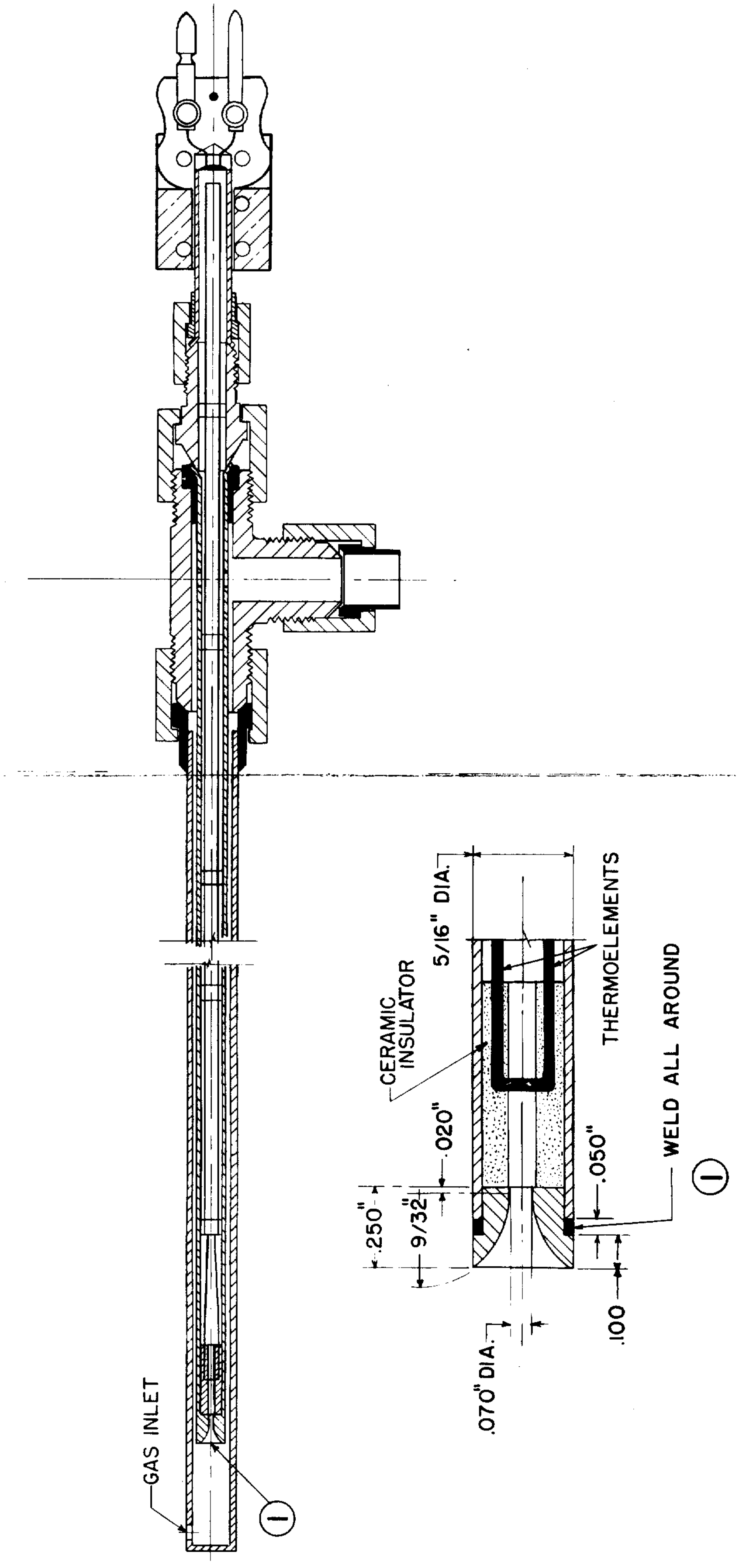

FIGURE 2 WESTINGHOUSE SONIC THERMOCOUPLE

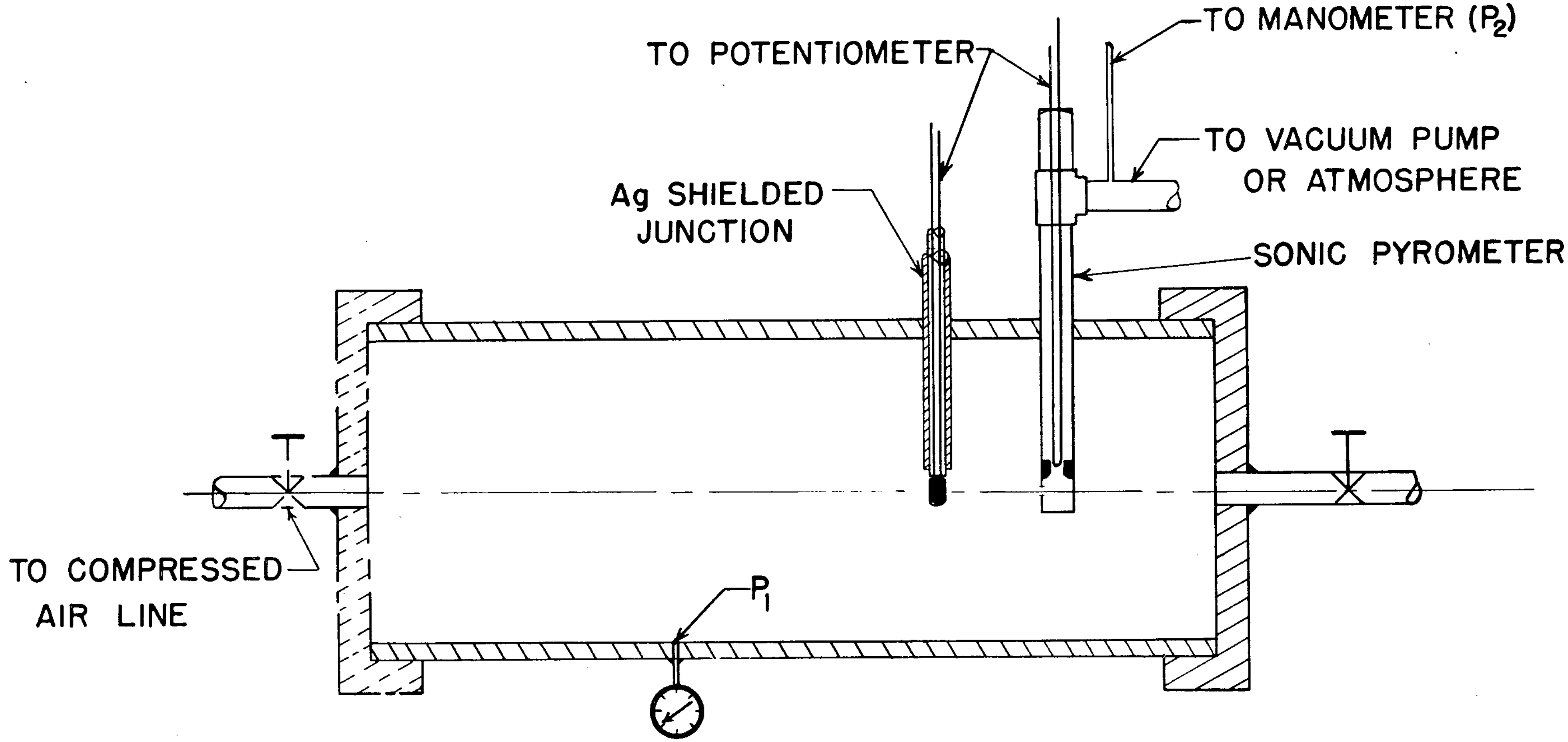

FIGURE 3 SCHEMATIC DIAGRAM OF TEST CHAMBER

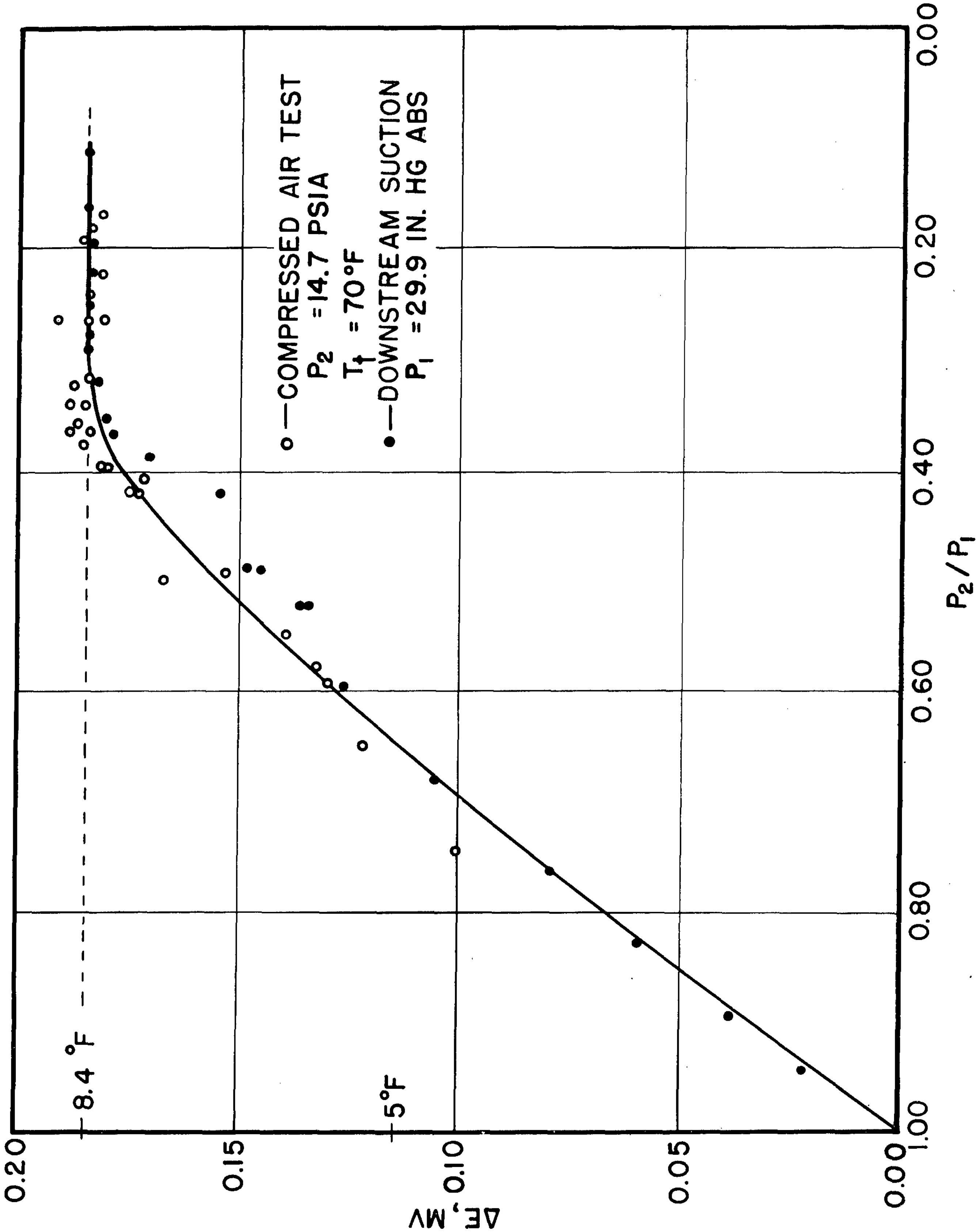

FIGURE 4 PERFORMANCE OF SONIC PYROMETER NO. 1

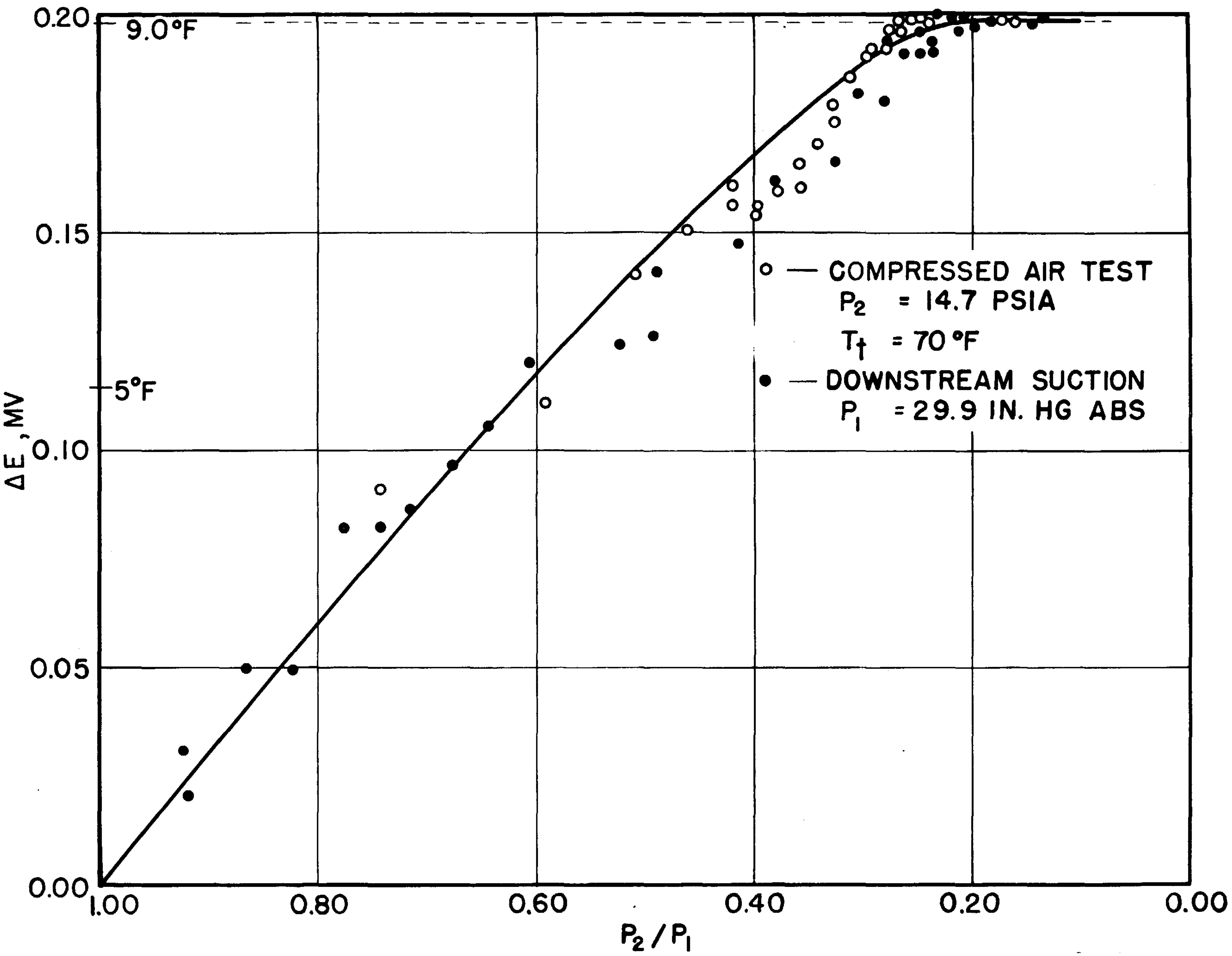

FIGURE 5 PERFORMANCE OF SONIC PYROMETER NO. 2