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EFFECT OF TURBULENCE ON AIR-FLOW MEASUREMENTS BEHIND ORIFICE PLATES

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

EFFECT OF TURBULENCE ON AIR-FLOW MEASUREMENTS BEHIND ORIFICE PLATES

By Jack N. Nielsen

SUMMARY

Determinations of air-flow quantity have been made in front of and behind three orifice plates to determine the errors introduced in the quantity measurements by the turbulence behind the orifice plates. For the orifice plates tested, the results showed that the measurements must be taken 40 to 60 hole diameters downstream from the plates to insure accuracy. A tendency for the indicated static pressure to rise during the decay of the turbulence was found. In all cases, the indicated total pressure dropped during the decay of turbulence.

INTRODUCTION

Orifice plates have come into general use for simulating radiators and other resistance elements in studies of air flow in cooling ducts. Although orifice plates have the advantage of much less scale effect than screens used for this purpose, the large-scale turbulence that they introduce interferes with the measurements of velocity and pressure loss when these measurements must be made close behind the plate. The purpose of the present investigation conducted at Langley Memorial Aeronautical Laboratory was to determine the variation of the magnitudes of the errors in the measurements of velocity and pressure loss with distance of the measuring tubes behind the orifice plate.

SYMBOLS

Q_o air-flow quantity measured in front of orifice plate

Q_i air-flow quantity measured behind orifice plate

q_o dynamic pressure at station upstream of orifice plate

p_o static pressure at station upstream of orifice plate

H_o total pressure at upstream face of orifice plate

p_i indicated static pressure at station behind orifice plate

H_i indicated total pressure at station behind orifice plate

APPARATUS AND METHODS

The duct system used in the tests is shown diagrammatically in figure 1. It consisted of a uniform rectangular test section of sheet metal, with a large wooden bell at the inlet and an expanding passage at the outlet leading to a variable-speed blower. The velocity of the entering air flow was measured by means of a network of static-pressure and total-pressure tubes placed in the throat of the bell (fig. 2). A similar network of tubes (fig. 3) was used for the downstream measurements, which were made at three different distances from the orifice plate: $9\frac{3}{4}$, $20\frac{3}{4}$, and $27\frac{3}{4}$ inches, as indicated in figure 1. The airspeed was about 67 feet per second for all tests. All pressures were recorded simultaneously by means of a 100-tube photographic manometer.

The three orifice plates tested, which are designated orifice plates 1, 2, and 3 (figs. 4, 5, and 6), were made of $\frac{3}{16}$-inch steel plate, with punched $\frac{3}{4}$-inch or $\frac{1}{2}$-inch holes. No effort was made to round off the edges formed by the punch. These edges faced upstream for orifice plates 1 and 2 and downstream for orifice plate 3. The direction in which the edges faced, however, produced no appreciable effect on the pressure-drop coefficient, according to reference 1. Orifice plate 3 had a design pressure-drop coefficient of 2.6 (reference 1). The other two plates had design pressure-drop coefficients of about 6.0 but differed in hole diameter. The characteristics of the three orifice plates are summarized in the following table:

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Orifice plate	Ratio of open area to frontal area	Hole diameter (in.)	Design pressure-drop coefficient (from fig. 7 of reference 1)	Measured pressure-drop coefficient
1	0.391	3/4	6.3	6.8
2	.402	1/2	6.0	5.9
3	.540	3/4	2.6	2.0

RESULTS AND DISCUSSION

In figure 7 the ratio of the air-flow quantity indicated by the measurements behind the orifice plate to the true air-flow quantity indicated by the measurements in front of the orifice plate Q_i/Q_o is plotted against distance behind the orifice plate. Simple arithmetic averages of the indicated velocities were used in computing these air-flow quantities. With orifice plate 1, which had the highest pressure drop, Q_i was 16 percent too high when measured $9\frac{3}{4}$ inches behind the plate and 5 percent too high at $27\frac{3}{4}$ inches behind the plate. With orifice plate 3, which had the lowest pressure drop, Q_i was too high by 7 percent and 2.5 percent, respectively, at these two stations. It is likely that at least part of the error at the downstream station is due to the absence of measuring tubes in the low-velocity boundary layer along the wall. This error did not exist in the measurement of Q_o because the boundary layer at the bell throat was very thin.

It appears, then, that for orifice plates of the type investigated, air-flow quantities measured behind the plate will be considerably too high unless the measuring tubes are between 40 and 60 hole diameters downstream from the plate. This length of duct will hardly be available, however, unless the orifices are smaller than those used in these tests. For example, if scale effect is negligible, $\frac{1}{4}$-inch orifices would be satisfactory in a full-scale simulated ethylene-glycol radiator duct. For this case, the orifice plate would be placed where the front face of the radiator would be and the measuring tubes would be placed 10 or 12 inches farther back, where the rear face would be.

In figures 8, 9, and 10 the pressure-drop coefficients, as determined from the readings of both the static-pressure

tubes and the total-pressure tubes, are plotted against distance behind the orifice plate. Behind orifice plates 1 and 2, the measured static pressure p_i tends to increase along the passage; the pressure drop determined from the static-pressure measurements correspondingly decreases. At least part of this static-pressure rise is due to a transformation of a portion of the random kinetic energy to static pressure during the decay of the turbulence.

The measured total pressure H_i decreases along the passage, and the pressure drop determined from the total-pressure measurements correspondingly increases. Here, again, part of the effect is due to the decay of the turbulence. The decrease in the measured total pressure is due to the following factors: First, the readings of a total-pressure tube in a turbulent flow are increased by a dynamic pressure based on the mean square of the turbulent velocities (reference 2); and, second, this dynamic pressure is not entirely recovered as total pressure during the decay of the turbulence. The two types of pressure-drop determination nearly agree where the error in the measurement of the air-flow quantity becomes small - that is, at 40 to 60 hole diameters downstream from the orifice plate.

It will be noted that the relative errors in the pressure-drop determination were, at least for orifice plates 1 and 2, less than the errors in the determination of the air-flow quantity. Thus, the maximum difference of the pressure-drop coefficients measured behind the orifice plate is only about 5 percent of their mean value in figures 8 and 9 and about 8 percent in figure 10.

CONCLUSIONS

1. Measured air-flow quantities may be 10 to 15 percent too high if the measuring tubes are 15 to 20 hole diameters behind an orifice plate. A distance of 40 to 60 hole diameters must be used for accuracy.

2. Pressure drops as determined from total-pressure-tube readings increase with distance of the tubes from the orifice plate; pressure drops as determined from static-pressure-tube readings tend to decrease with distance of the tubes from the orifice plate. For the orifice plates

tested, the two pressure drops become nearly equal at 40 to 60 hole diameters behind the plate, where the intensity of the turbulence in the air flow is greatly decreased.

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2. Goldstein, S.: A Note on the Measurement of Total Head and Static Pressure in a Turbulent Stream. Proc. Roy. Soc. (London), ser. A, vol. 155, no. 886, July 1, 1936, pp. 570-575.

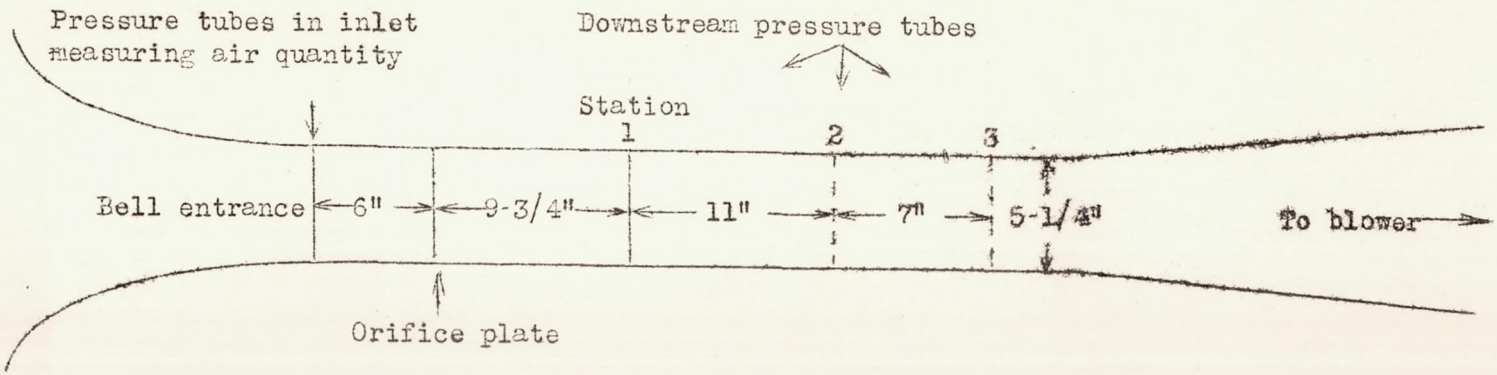

Figure 1.- Schematic diagram of test section.

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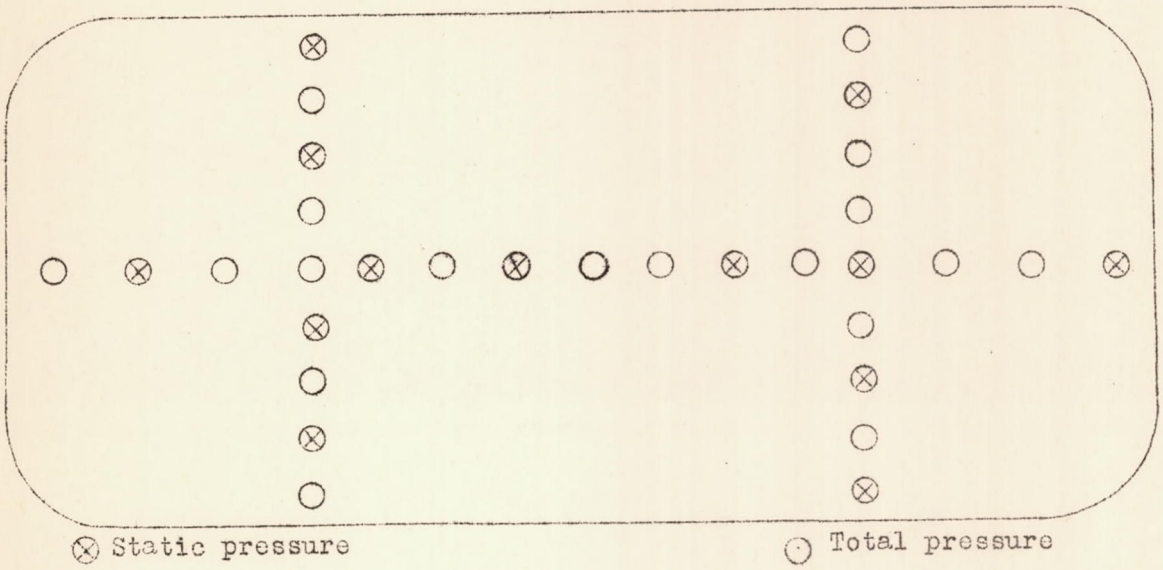

Figure 2.- Upstream network of static-pressure and total-pressure tubes.

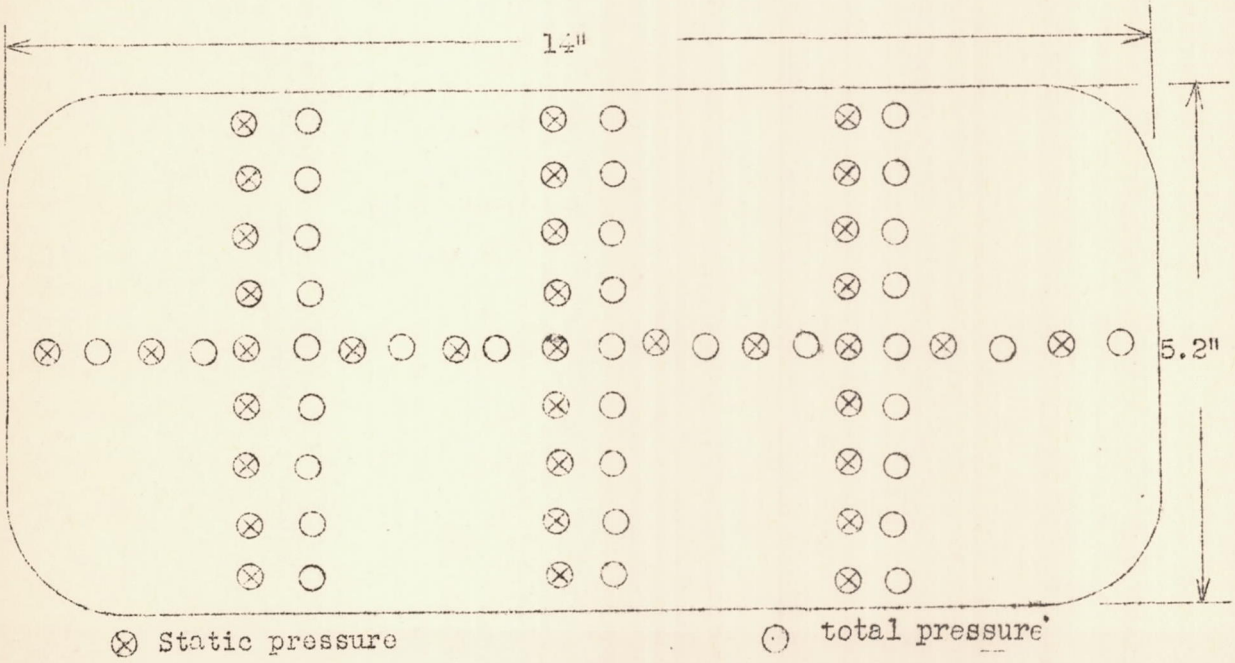

Figure 3.- Downstream network of static-pressure and total-pressure tubes.

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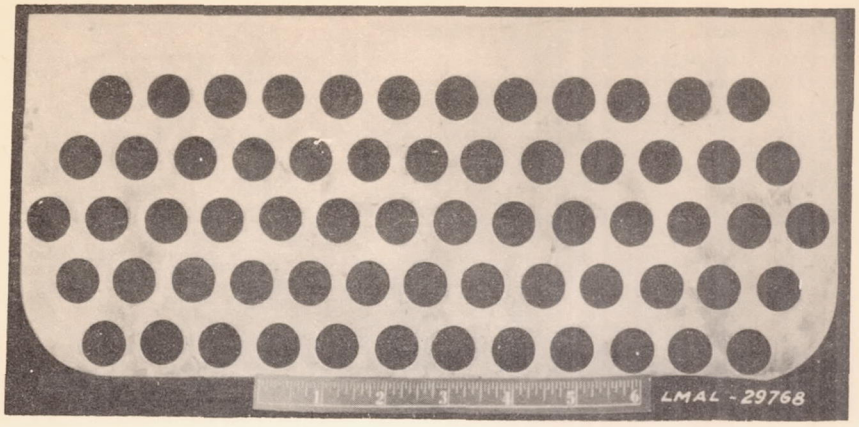

Figure 4.- Orifice plate 1.

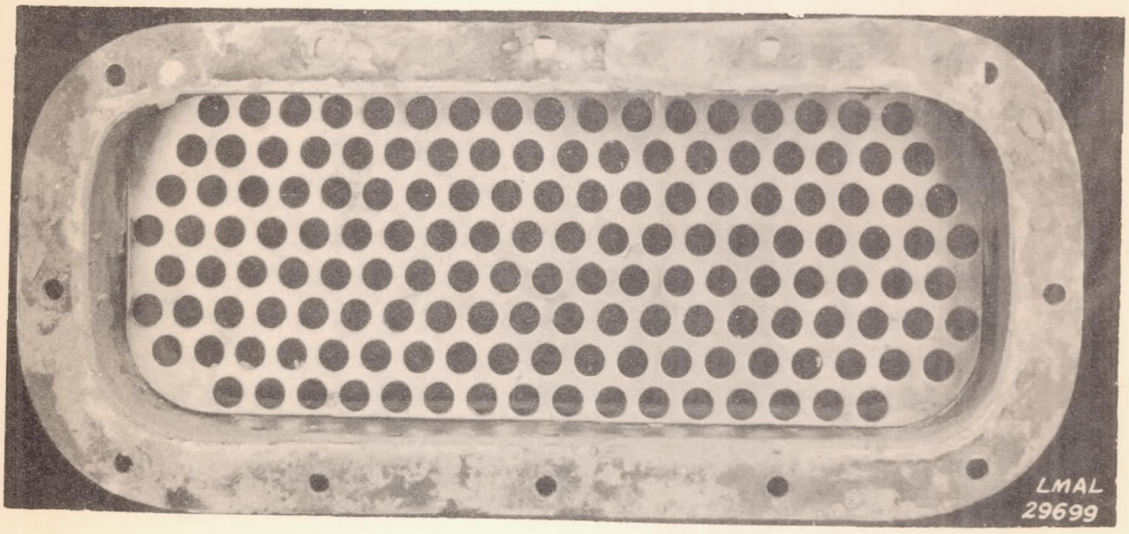

Figure 5.- Orifice plate 2.

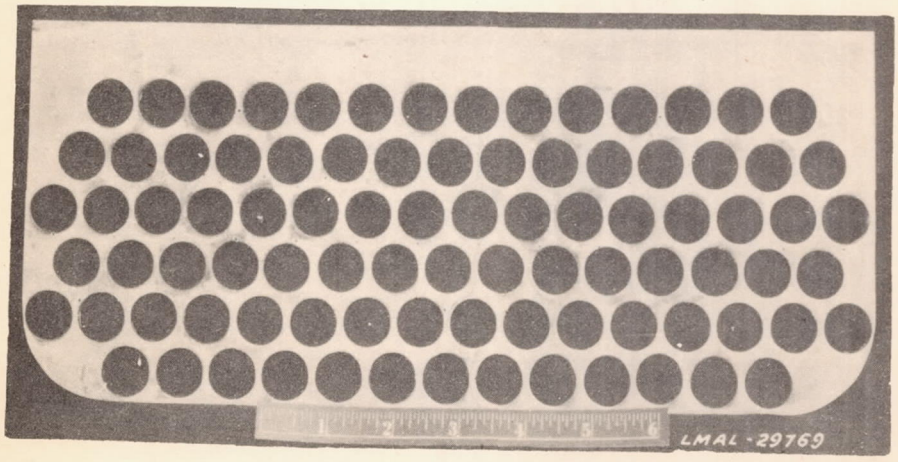

Figure 6.- Orifice plate 3.

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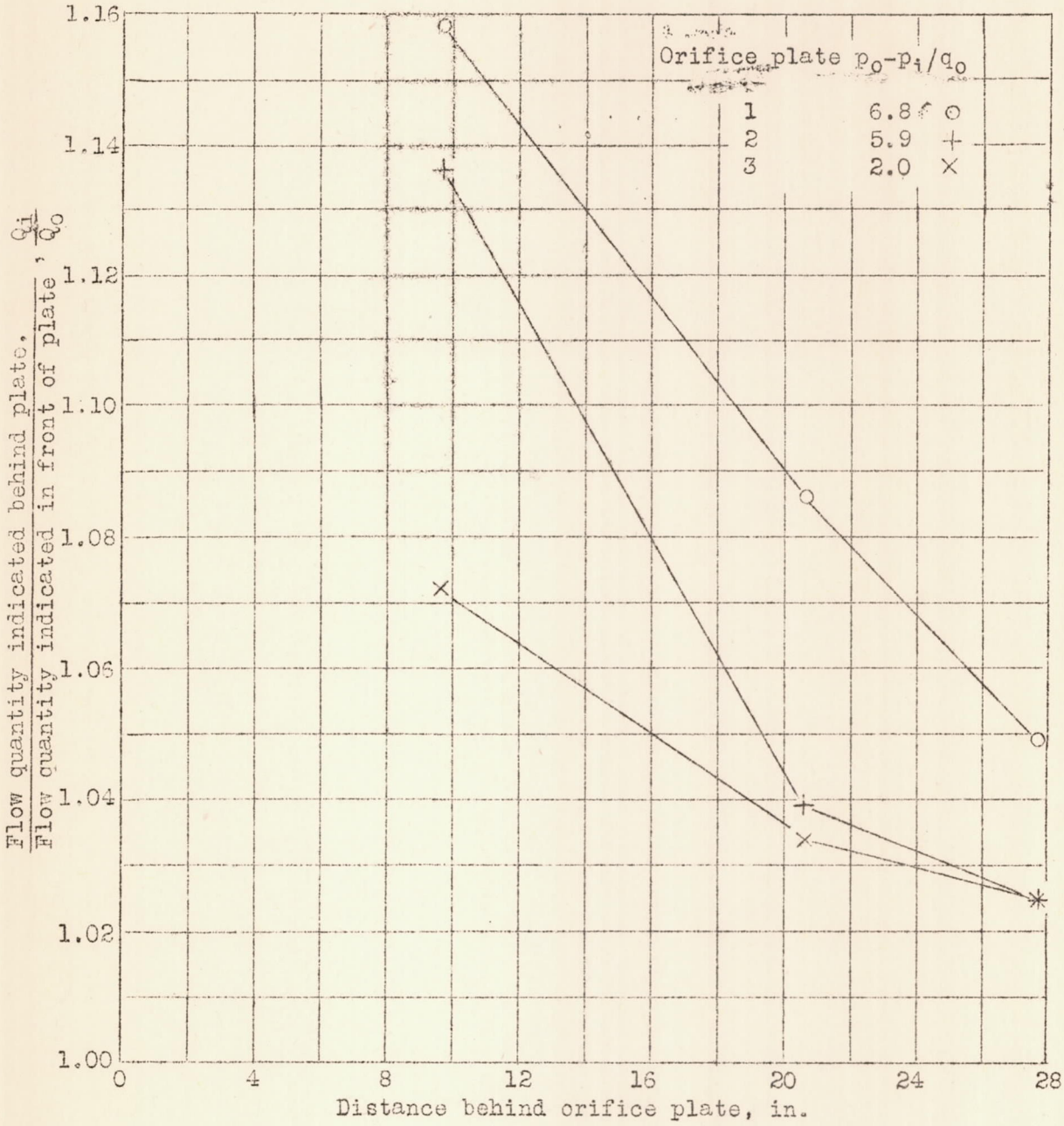

Figure 7.- Error in flow-quantity measurements downstream of orifice plate.

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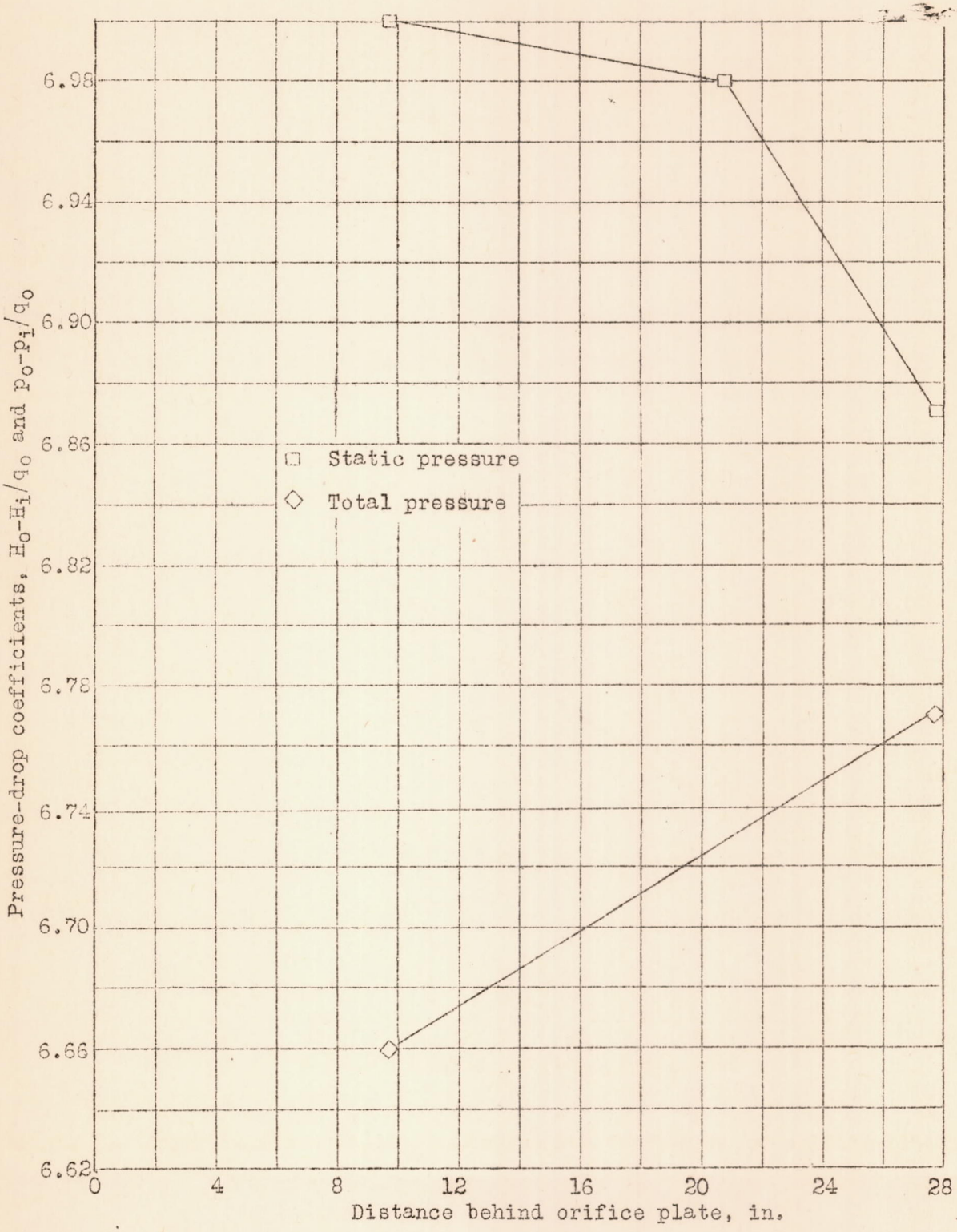

Figure 8.- Orifice-plate pressure-drop coefficients as measured by static-pressure and total-pressure tubes. Orifice plate 1.

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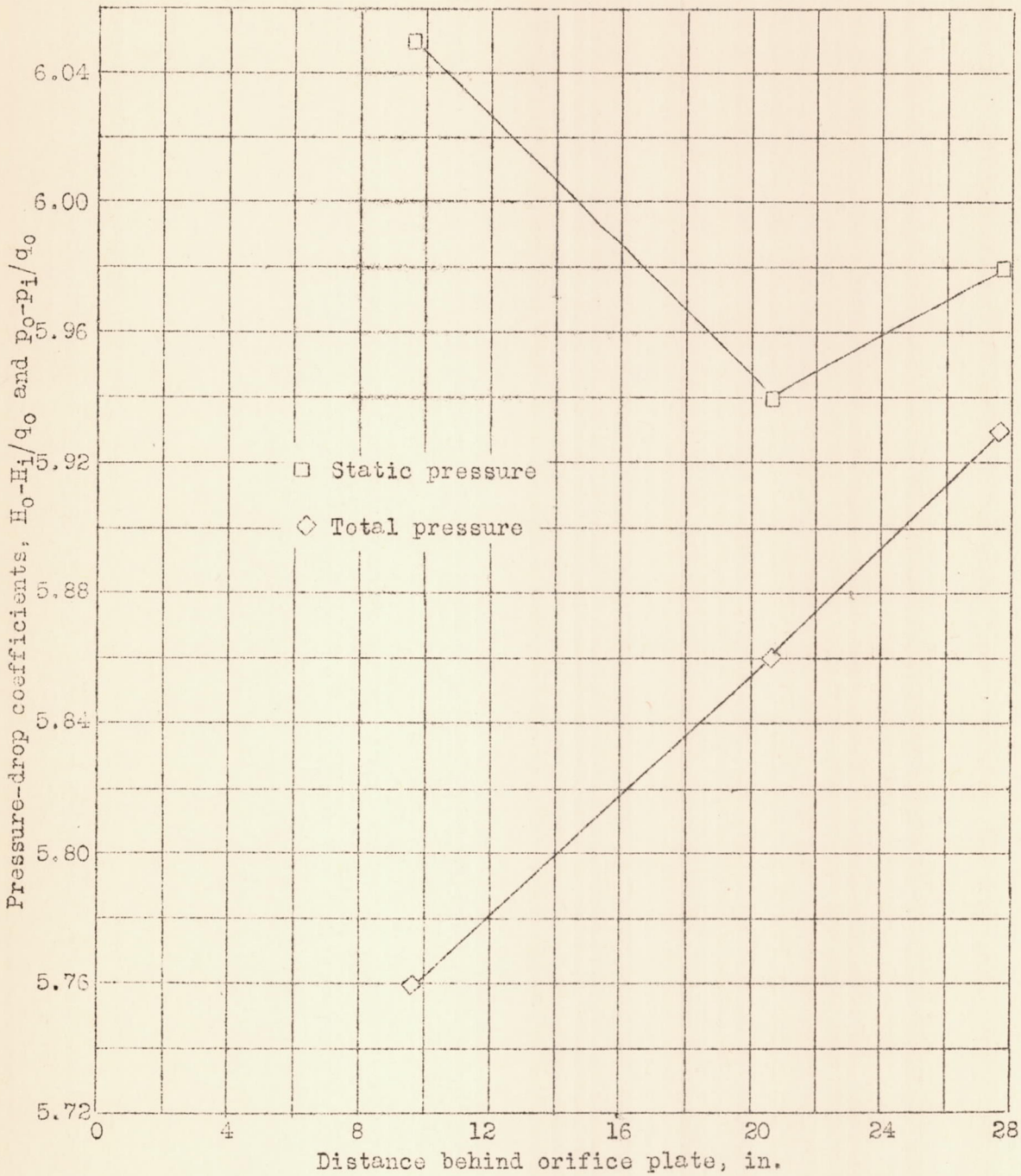

Figure 9.- Orifice-plate pressure-drop coefficients as measured by static-pressure and total-pressure tubes. Orifice plate 2.

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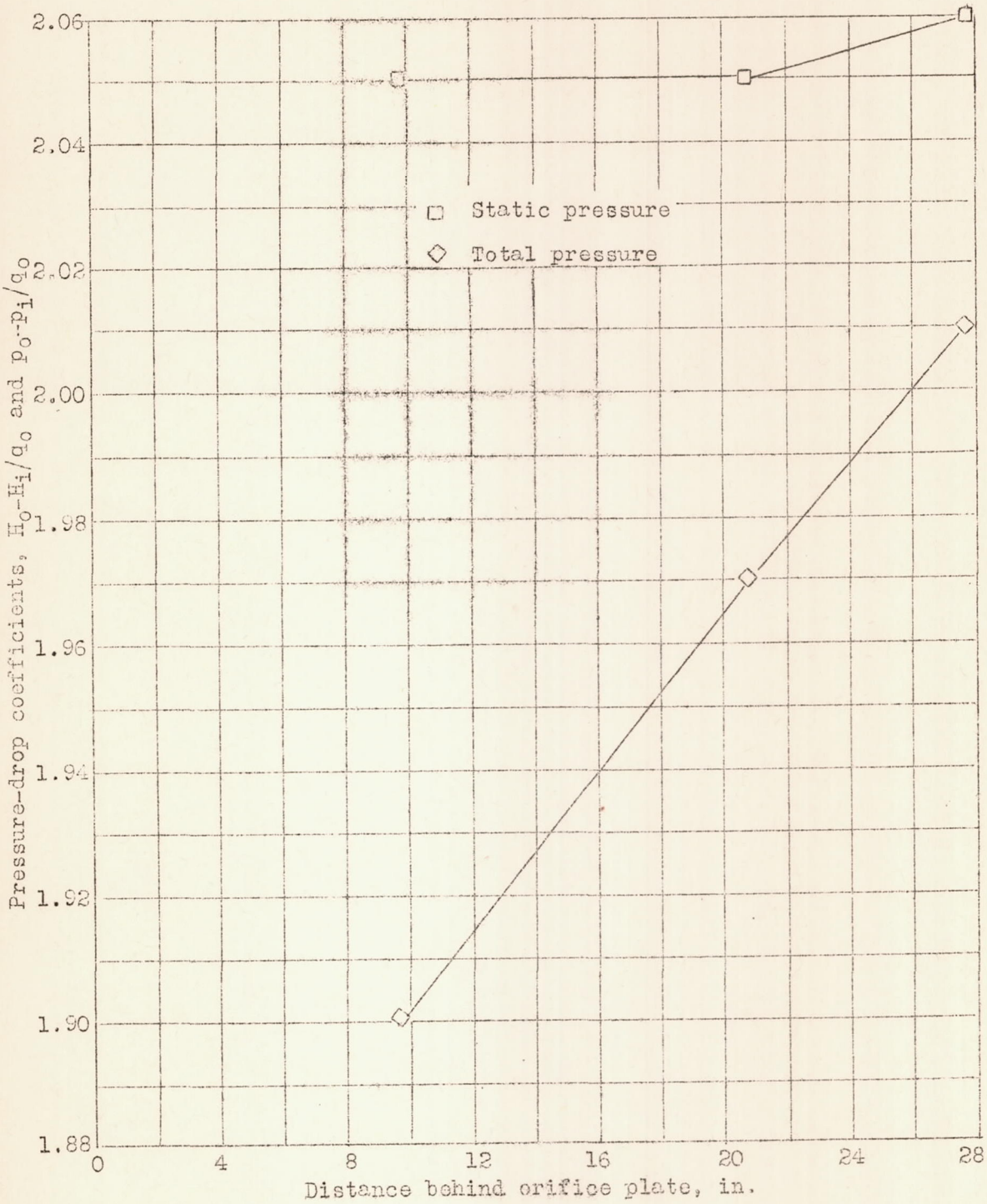

Figure 10.- Orifice-plate pressure-drop coefficients as measured by static-pressure and total-pressure tubes. Orifice plate 3.