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INVESTIGATION OF FLOW THROUGH AN INTERCOOLER SET AT VARIOUS ANGLES TO THE SUPPLY DUCT

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INVESTIGATION OF FLOW THROUGH AN INTERCOOLER SET AT VARIOUS ANGLES TO THE SUPPLY DUCT

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SUMMARY

An investigation was made to determine the flow losses that occur as a result of locating the axis of an intercooler at various angles with respect to the supply-duct axis and also to determine the flow pattern through the intercooler. The flow losses were found to be small for angles of inclination up to about 70°. The distribution of flow through the intercooler also appeared to be fairly uniform up to about this angle. The shape of the entrance to the intercooler-flow-passage cells appeared to affect the losses of the duct-intercooler combination.

INTRODUCTION

In the design of duct systems for aircraft the problem invariably arises of diffusing the air prior to its entry into a heat exchanger. Inasmuch as the air is again speeded up as it enters the heat exchanger, it appears that the diffuser might be partly or wholly dispensed with if a means could be found for distributing the air uniformly over the face of the heat exchanger. Such a means is the setting of the flow-path axis of the heat exchanger at an angle with the axis of the duct in such a way that the projected area of the face of the heat exchanger is approximately equal to that of the duct. In addition to helping diffuse the air, mounting the heat exchanger at an angle to the duct axis also affords a convenient means of turning the air, a condition that is often necessary, especially for intercooler installations.

The purpose of this investigation was to determine the losses that would result from locating the axis of an intercooler at various angles to a duct axis and also to determine the flow pattern through the intercooler. This investigation was limited to a combination of a rectangular duct and a Harrison intercooler. The duct area automatically decreased as the angle with the intercooler axis increased and provided thereby a range of face-duct area ratios.

APPARATUS AND METHODS

The test apparatus is shown in figure 1. An axial fan located at the downstream end of the test duct drew air successively through an entrance bell, an entrance duct, the intercooler, a transition box, a damping chamber, and a venturi for measuring the quantity of flow. The flow conditions at the front of the intercooler for a given quantity of flow were determined solely by the entrance duct.

The entrance bell and the entrance duct were adjustable; the center line of the entrance duct could consequently be set at several angles to the axis of the intercooler. As the sides of the entrance duct were kept parallel to its center line, the ratio of the area of the face of the intercooler to the area of the duct varied as the secant of the angle of bend. The tests were made at 10° intervals from 0° to 80°, measured between the duct and the intercooler axis.

A Harrison intercooler with a $13\frac{1}{4}$- by $20\frac{9}{16}$-inch face and a core depth of $9\frac{1}{2}$ inches was used. A sketch of a portion of the face of the intercooler is shown in figure 2. The cooling air flows into the passages shown in the main view of the sketch and the charge air being cooled flows endwise through the intercooler in the charge-flow layers that alternate with the cooling-air layers.

Two arrangements of the duct-intercooler combination were tested and are described in terms of the height-width ratio of the face of the intercooler:

(1) When the bend was in the plane of the longer side of the intercooler face as shown in figure 1, the height-width ratio was 0.644.

(2) When the bend was in the plane of the shorter side of the face, the height-width ratio of the intercooler was 1.55.

It should be noted from figure 3 that the flow passages through the intercooler were different for the two height-width ratios. In one case, $h/w = 0.644$, the air was met by a cascade of closely spaced strips which caused an abrupt change in direction of flow at the intercooler face (fig. 3(a)). As the corrugated strips were not continuous through the intercooler, the flow could filter sidewise if pressure differences happened to exist. In the other case, $h/w = 1.55$, the air was allowed to turn more gradually as it entered the intercooler, but sidewise filtration was impossible (fig. 3(b)).

Measurements of total and static pressures were made by means of survey rakes and tubes located at the center of the duct parallel to the plane of the bend at sections 1, 2, 3, and 4. (See fig. 1.)

The velocity distributions at the face of the intercooler could not be obtained by pressure measurements at sections 1 and 2 because radial flow prevented the measurement of static pressures at the face of the intercooler. When the intercooler height-width ratio was 0.644, the velocity distribution could not be determined from pressure measurements at section 3 because the cooling-air passages were not continuous through the intercooler and allowed cross flow to take place. When the height-width ratio of the intercooler was 1.55, an indication of the velocity at the intercooler face was obtained from examination of the maximum local velocity behind each cooling-air layer across section 3. Tuft surveys were used to examine the flow at the face of the intercooler in all cases.

The low capacity of the blower prevented the attainment of velocities at the face of the intercooler corresponding to those encountered in flight at high speed. The tests were conducted over a range of velocities at the face of the intercooler from 7.6 feet per second to 23.2 feet per second.

SYMBOLS

The following symbols and units are used:

K conductivity of intercooler $Q/A_2\sqrt{2\Delta p_c/\rho} = \sqrt{\bar{q}_2/\Delta p_c}$

h/w height-width ratio of intercooler

Q volume rate of flow, cubic feet per second

H total pressure loss, pounds per square foot

p static pressure, pounds per square foot

Δp pressure drop across specified system, pounds per square foot

q dynamic pressure, pounds per square foot

A area of section, square feet

h height of intercooler face perpendicular to plane of bend, feet

w width of intercooler face in plane of bend, feet

θ angle of bend, measured between axis of entrance duct and axis of intercooler, degrees

x distance from inner duct wall, feet

V velocity of air, feet per second

ρ mass density of air, slugs per cubic foot

Subscripts:

c duct-cooler combination in which $\theta = 0^\circ$

s duct-cooler combination in which θ is any specified angle

1,2,3,4 sections as numbered in figure 1

A bar above a symbol denotes an average value. All velocities are based on projected areas.

RESULTS AND DISCUSSION

The calibration of the intercooler is shown in figure 4. The two curves represent the same data in different forms.

Effect of duct-cooler angle.- The effects of changes in the bend angle θ on the pressure-drop ratio of the system $\Delta p_s/\Delta p_c$ for the range of face velocities tested are shown in figure 5 for the system with the intercooler height-width ratio of 0.644 and in figure 6 for the system with the intercooler height-width ratio of 1.55. The face-duct area ratios that correspond to the values of θ are also shown on these figures. The increase in pressure drop was found to be small for both intercooler height-width ratios for values of θ up to 70° (face-duct area ratio of 2.923) for face velocities up to 22 feet per second. For bend angles greater than 70°, $\Delta p_s/\Delta p_c$ increased rapidly and should approach infinity at 90°, at which angle the duct area is zero. The system with the higher intercooler height-width ratio was found to have the lower pressure drops for all values of θ. This effect probably has nothing to do with the height-width ratio of the intercooler but is attributed to the condition at the cell entrances. It may be noted from figure 2 that the air can enter the cells for the condition of $h/w = 1.55$ much more gradually than for the condition of $h/w = 0.644$, and lower energy losses are incurred.

Figure 7 is a plot of $\Delta p_s/\Delta p_c$ against the average velocity at the face of the intercooler for several values of θ. Extrapolations of these curves indicate that the value of $\Delta p_s/\Delta p_c$ for $\theta = 60°$ for a face velocity of 60 feet per second, a representative full-scale value, would probably have been 1.12 or less.

Analysis of flow through system.- Velocity distributions at the face of the intercooler could not be obtained by pressure measurements for the reasons previously discussed. Tuft surveys, however, indicated that the flow was entering all portions of the intercooler fairly evenly for values of θ up to 70°. At $\theta = 80°$ the tuft surveys indicated that the velocity distribution was irregular, as apparently little flow was entering that portion of the intercooler next to the inside wall of the bend. This condition was probably partly due to the extreme abruptness of the inside corner of the bend, as shown in figure 1.

Separation and turbulence were noticed at the outer wall about 3 inches upstream from the bend for values of θ of 50° and greater. The flow was apparently entering the outer portions of the intercooler face satisfactorily, however, and when the abrupt corner was faired out by a piece of sheet metal (see fig. 1), this turbulence was nearly eliminated.

Figure 8 provides a further indication of the velocity distribution at the intercooler face for the system with the intercooler height-width ratio of 1.55. This figure is a plot of the maximum local velocities measured at section 3 behind the individual cooling-air layers for a range of values of θ. As the cross-sectional area of the cooling layers constituted about half the intercooler-face area, the velocity measured immediately behind each layer was about twice the velocity based on the face area. Inasmuch as the cooling-air layers did not allow sidewise flow, this figure indicates that the velocity distribution for this case was fairly uniform up to $\theta = 70^{\circ}$ and that little flow was passing through that portion of the intercooler next to the inner wall at $\theta = 80^{\circ}$, as was shown by the tuft surveys.

Figure 9 provides a still further indication of the velocity distribution at the intercooler face for the intercooler height-width ratio of 0.644. In this figure are shown a series of plots of the total-pressure distributions $(H/\Delta p_c)$ measured at sections 1, 2, 3, and 4 for a range of angles of θ. For bend angles greater than 60° or 70° the total pressure losses at section 2 were very irregular. At $\theta = 80^{\circ}$ these losses became a large part of the total losses and their magnitude at the inner wall indicates that very little air was flowing through this section of the intercooler.

It is interesting to note in figure 9 that, even for the high values of θ at which the total-pressure losses at section 2 were very irregular, the total-pressure distribution at section 3 was fairly uniform. This condition may have been caused by cross flow within the intercooler from regions of high static pressure to regions of low static pressure. This cross flow tended to produce a uniform velocity distribution behind the intercooler and to cause a minimum pressure drop across the intercooler.

It is also interesting to note the difference between the $H_3/\Delta p_c$ and the $\Delta p_s/\Delta p_c$ curves in figure 9. The loss indicated by this difference between sections 3 and 4 was probably caused by the rapid expansion of the air at the rear of the intercooler because of the relatively blunt downstream end of the alternately blanked-off layers and is directly chargeable to the intercooler.

CONCLUDING REMARKS

1. The flow losses of a duct-intercooler combination were found to increase only slightly with a tilting of the intercooler flow axis with respect to the entrance duct for angles up to about 70°.

2. The distribution of flow through the intercooler appeared to be fairly uniform for angles of inclination up to about 70°.

3. The shape of the entrance to the intercooler-flow-passage cells appeared to affect the losses of the duct-intercooler combination.

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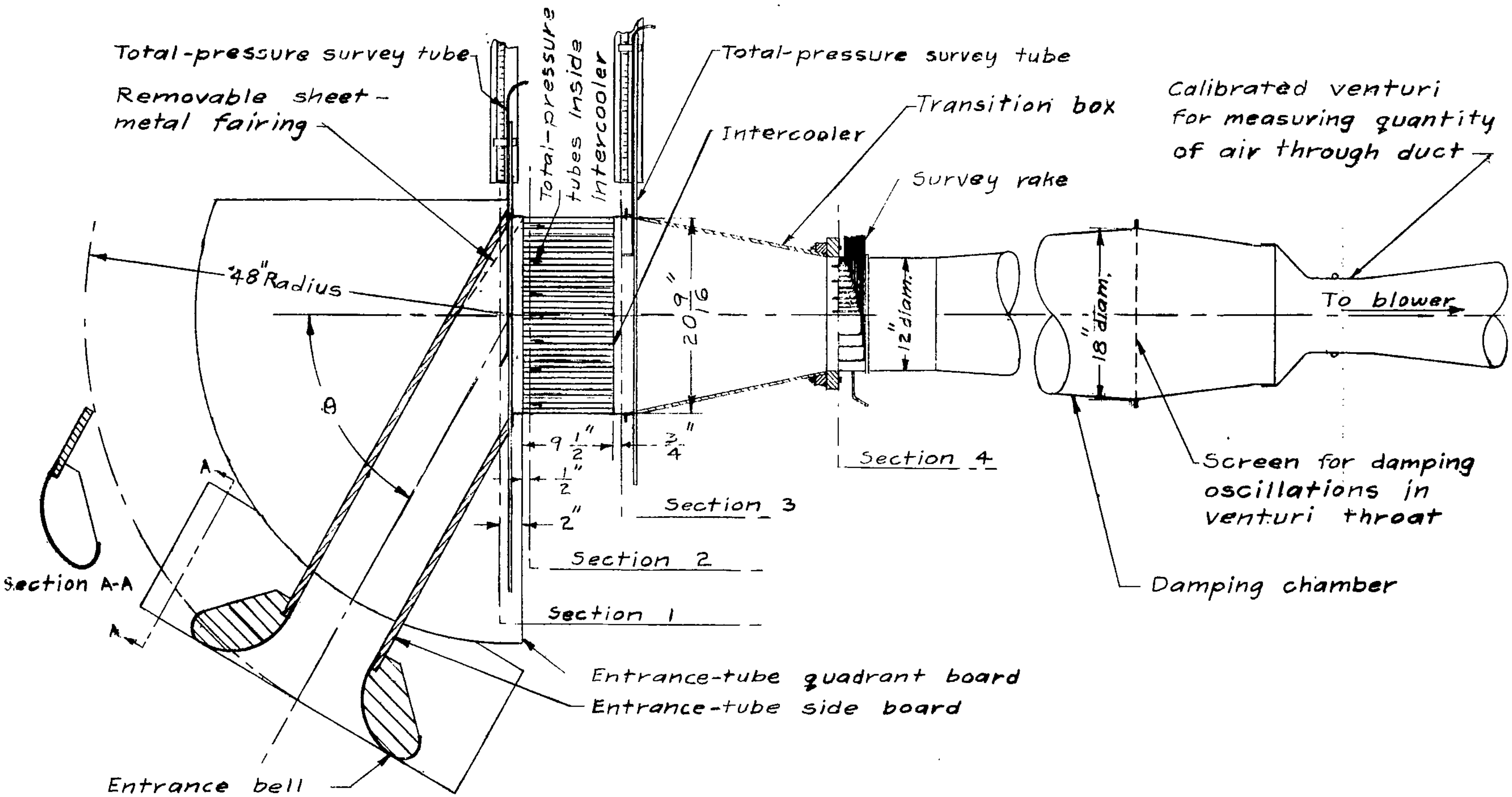


Figure 1 .- Plan view of bend-diffuser-resistance test equipment.

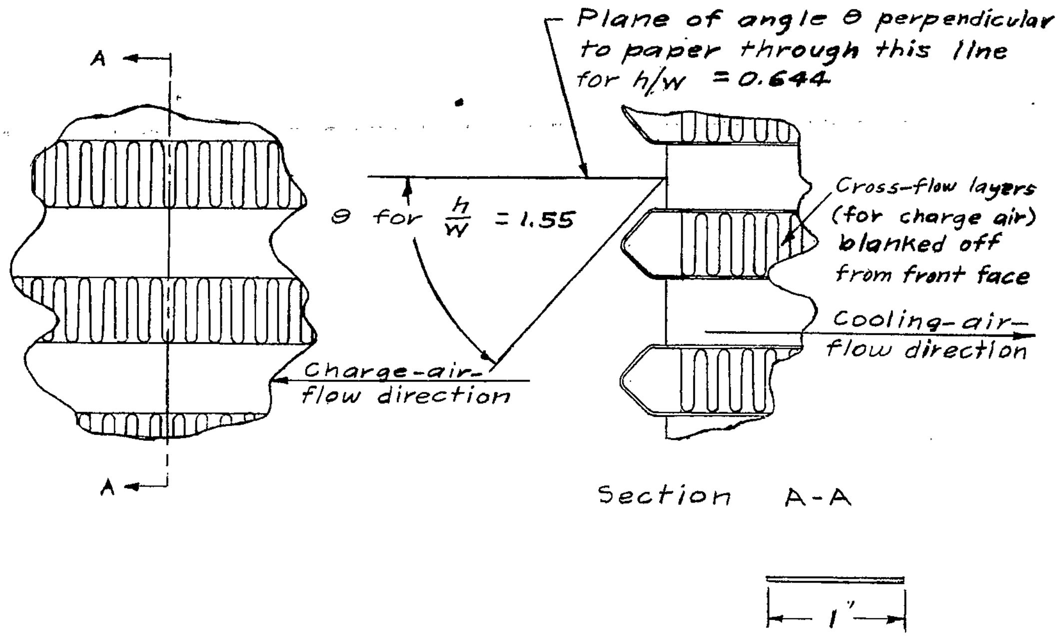
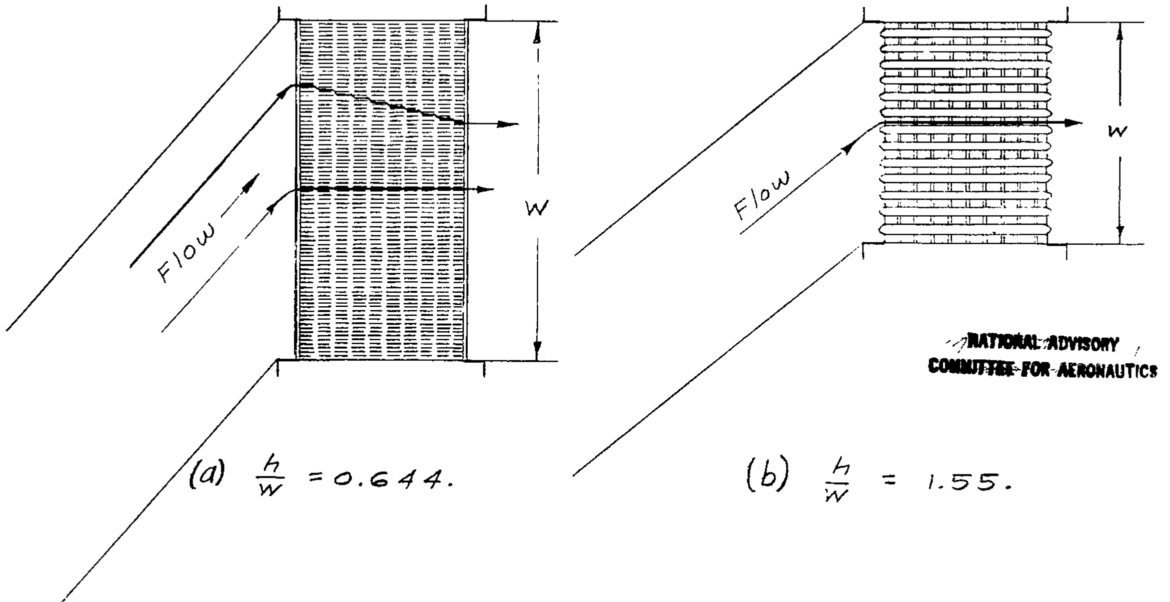


Figure 2 – Portion of front face of intercooler.



(a) $\frac{h}{w} = 0.644$. (b) $\frac{h}{w} = 1.55$.

Figure 3.– Flow passages of intercooler.
Short lengths of corrugated strips allow air to filter sidewise in one direction through the intercooler.

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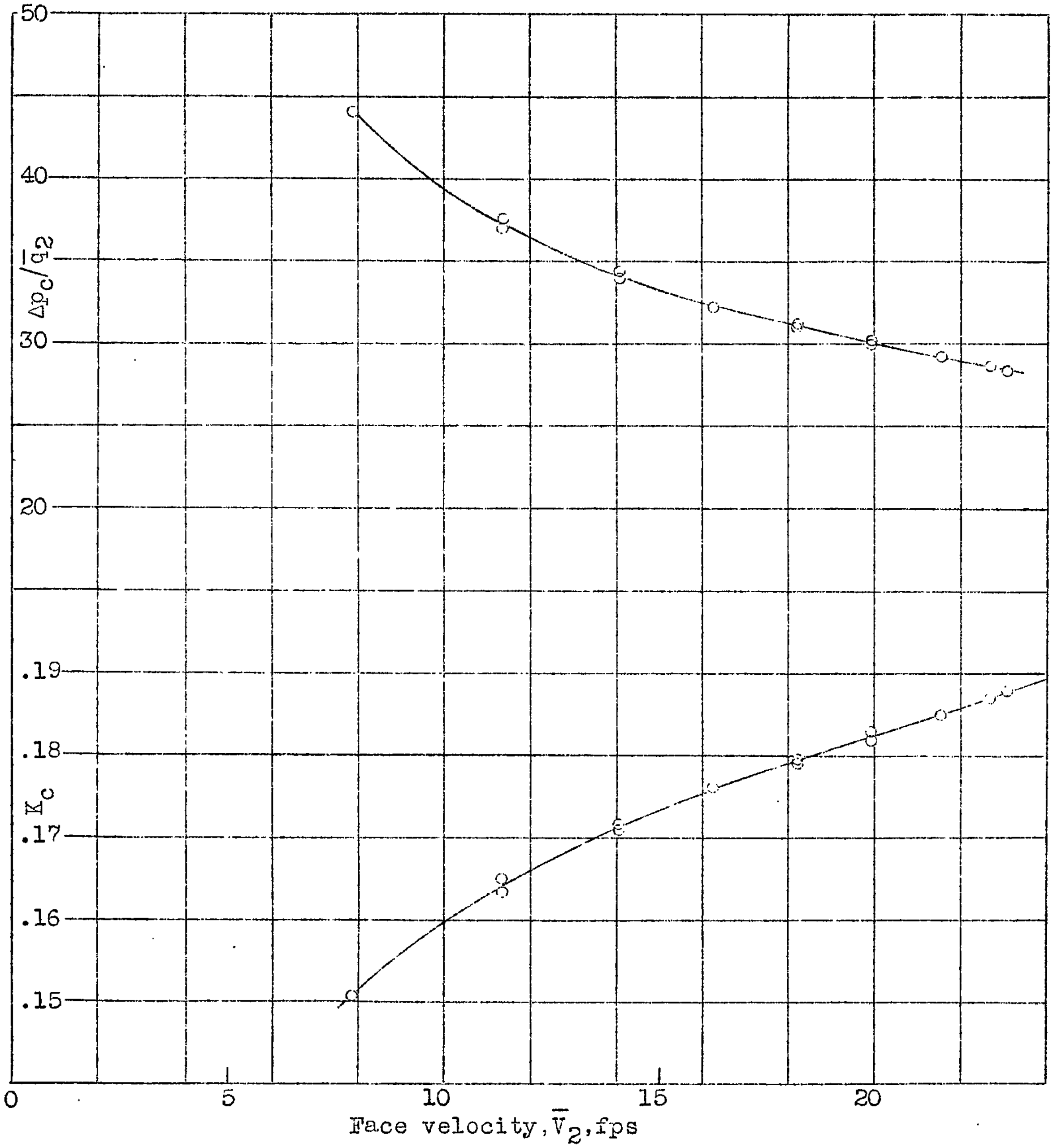

Figure 4.- Variation of K_c and $\Delta p_c/\bar{q}_2$ with the average velocity at the face of the intercooler. Standard air.

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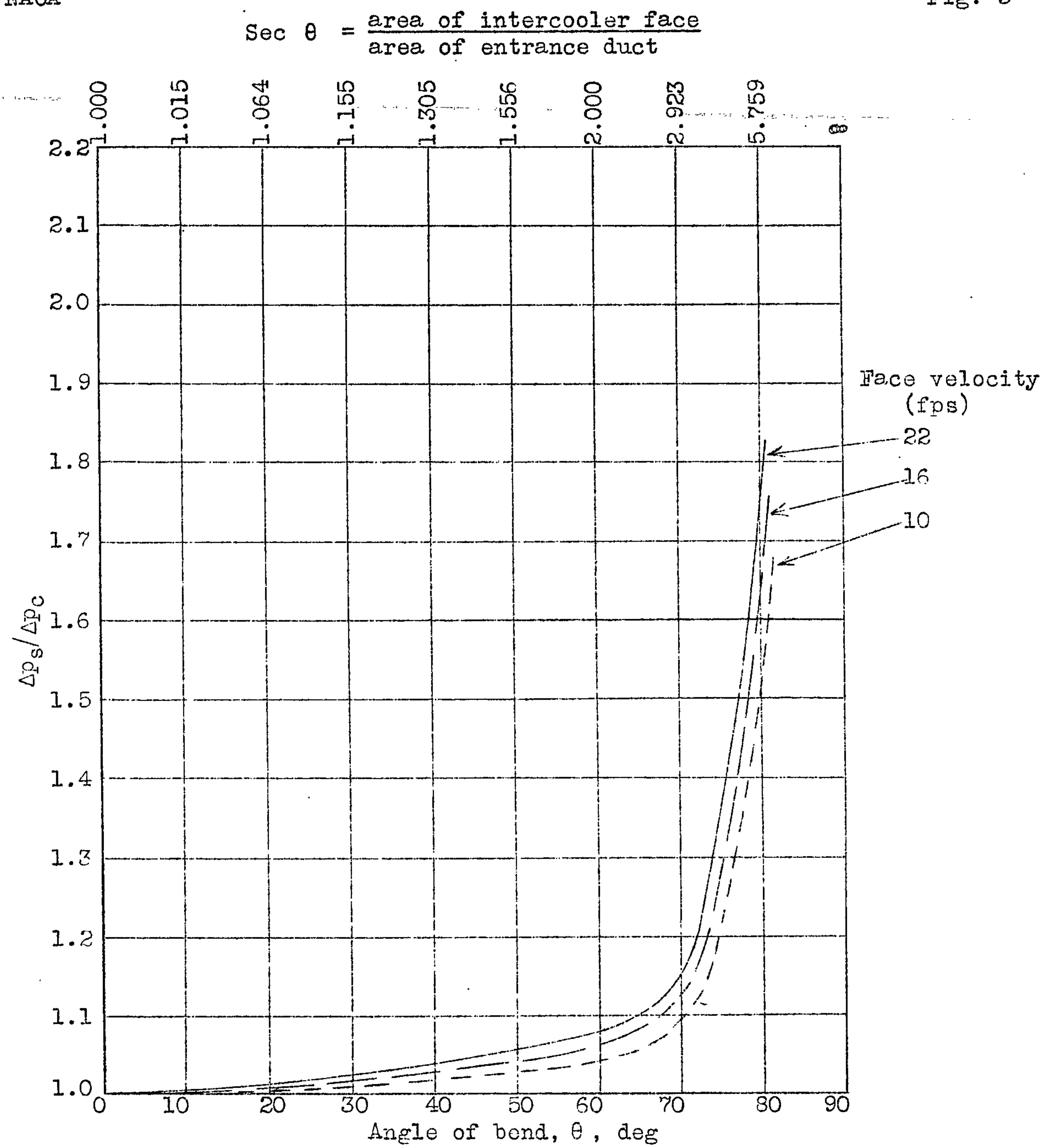

Figure 5.- Variation of the pressure-drop ratio of the system with the angle of bend of the approach duct. Intercooler height-width ratio, 0.644; standard air.

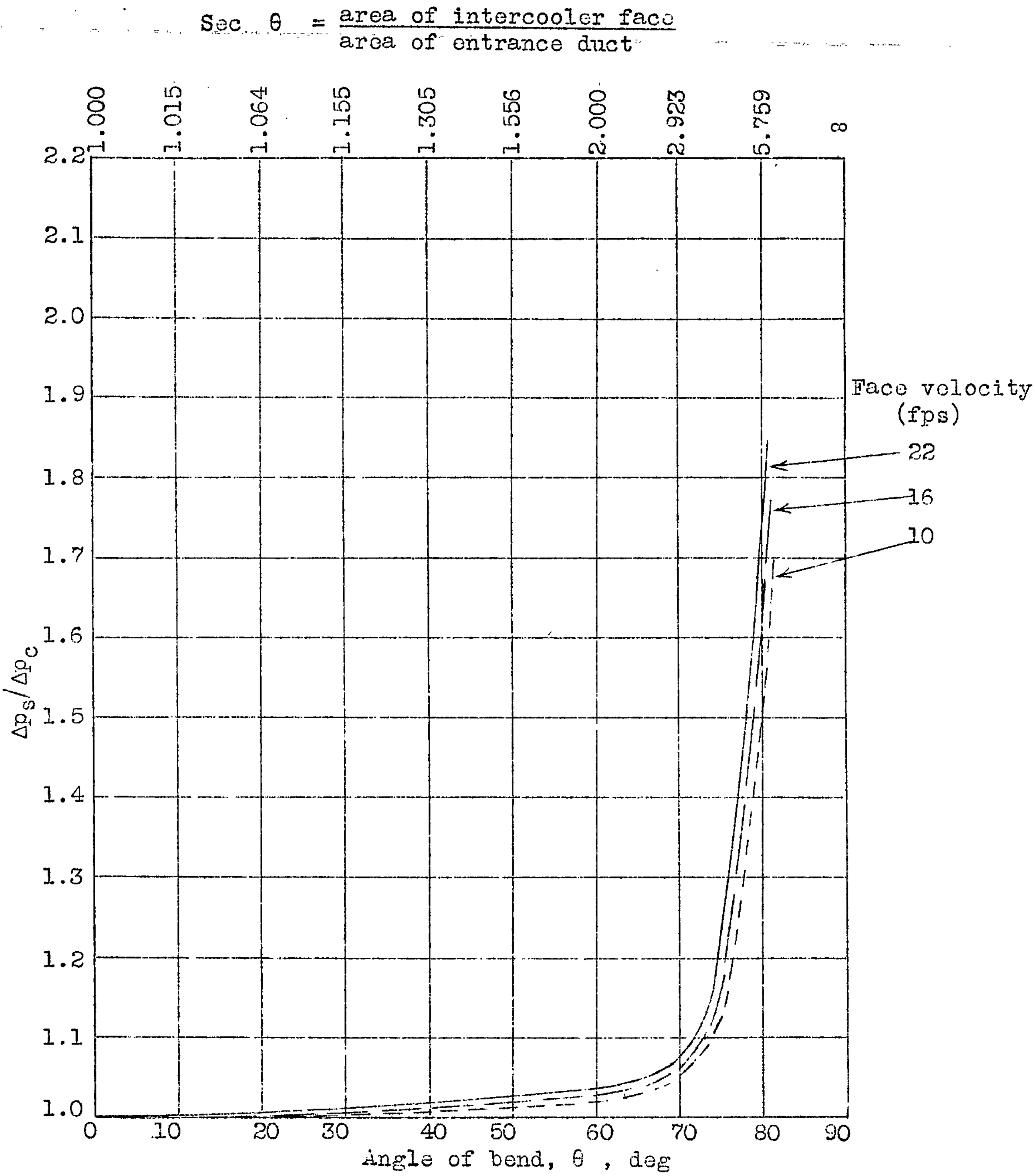

Figure 6.- Variation of the pressure-drop ratio of the system with the angle of bend of the approach duct. Intercooler height-width ratio, 1.55; standard air.

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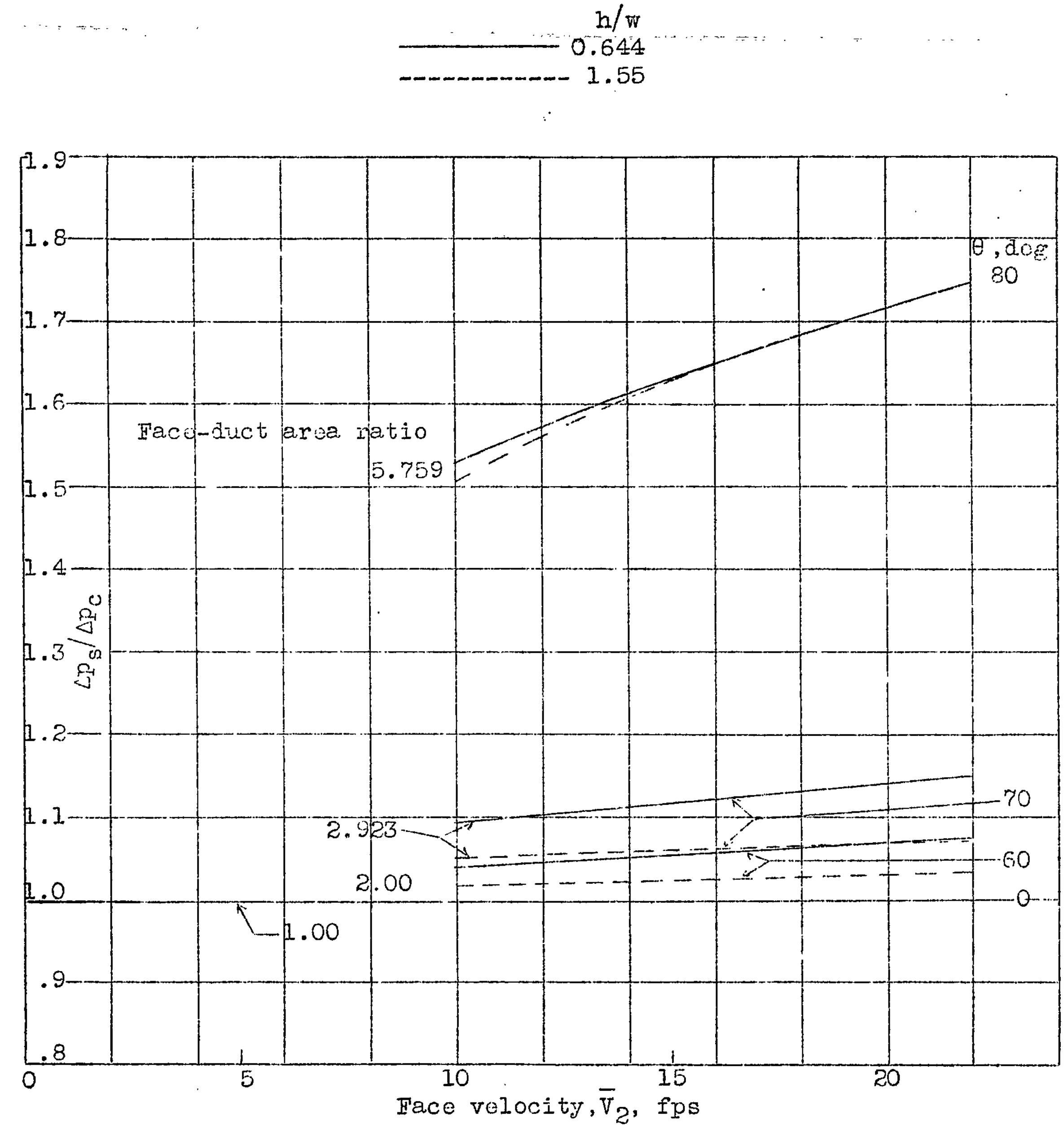

Figure 7.- Variation of the pressure-drop ratio of the system with the average velocity at the face of the intercooler for various values of θ . Standard air.

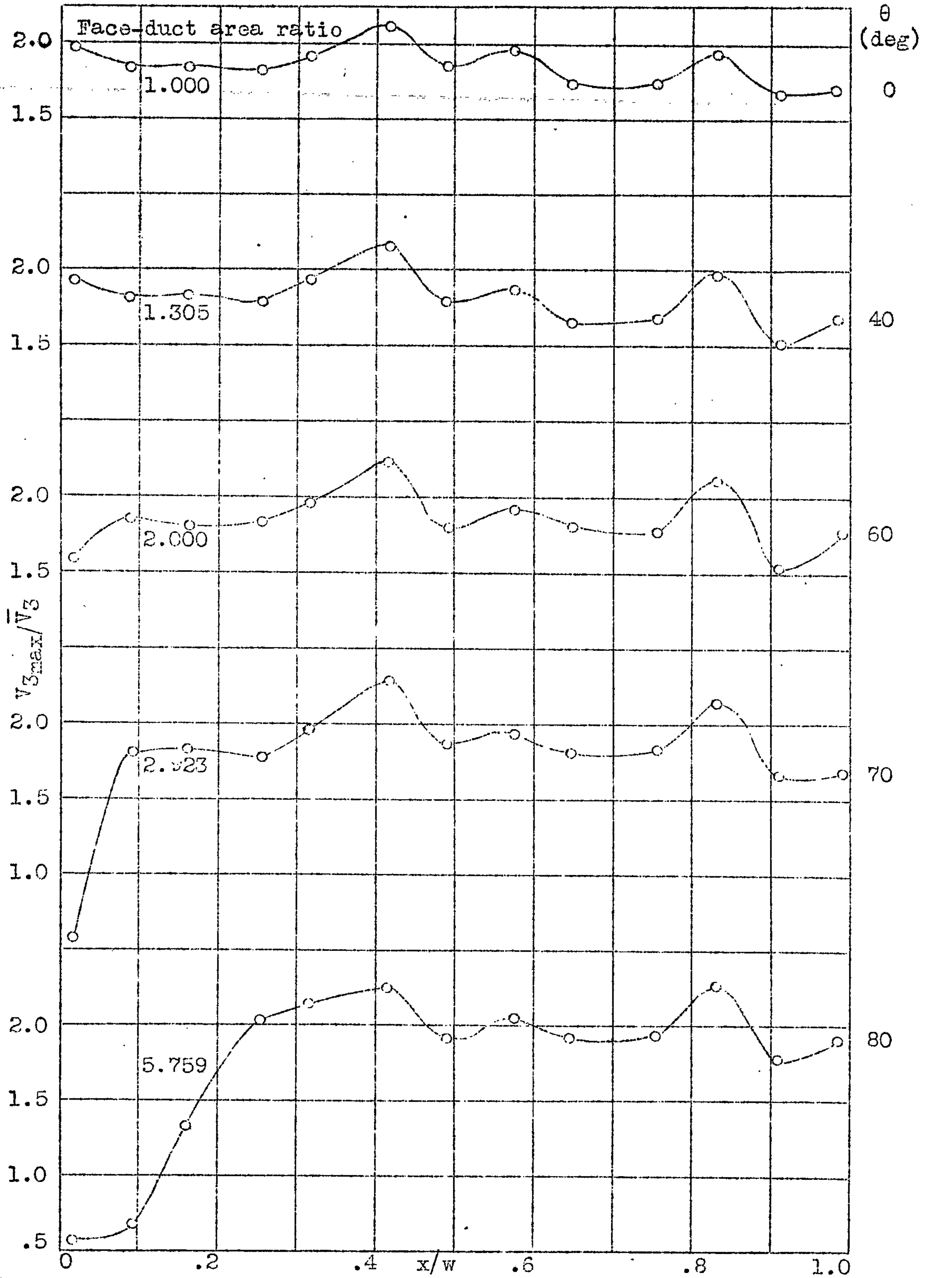

Figure 8.- Velocity distributions at horizontal center line at rear of intercooler. h/w, 1.55; $V_{3_{max}}$ is the local peak velocity immediately behind the cooling air layer; $\overline{V}_3$ is the average face velocity.

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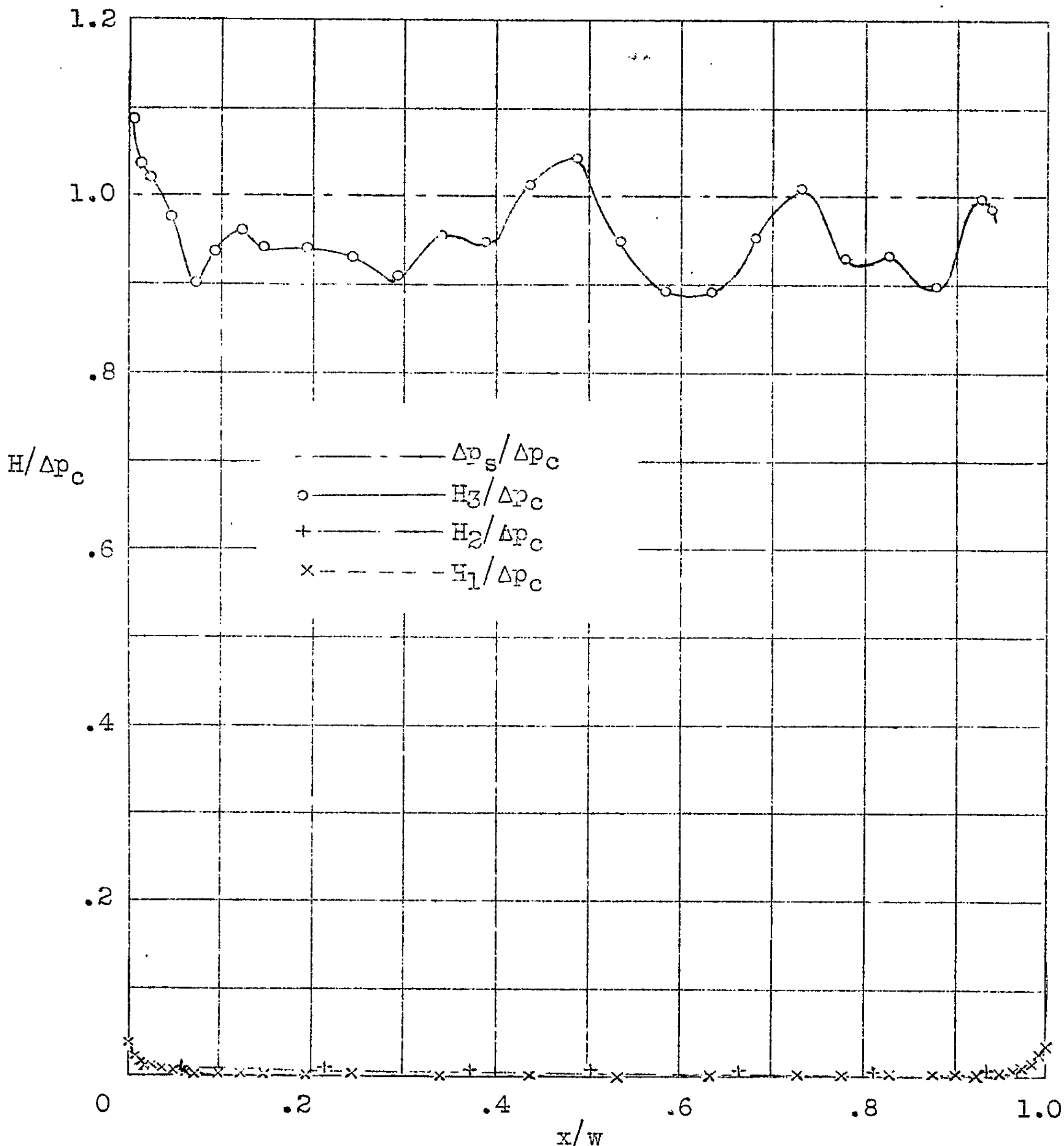

(a) θ, 0°; face-duct area ratio, 1; face velocity, 23.1 fps.

Figure 9(a to e).- Total-pressure-loss distributions at the horizontal center line of the intercooler. Intercooler height-width ratio = 0.644.

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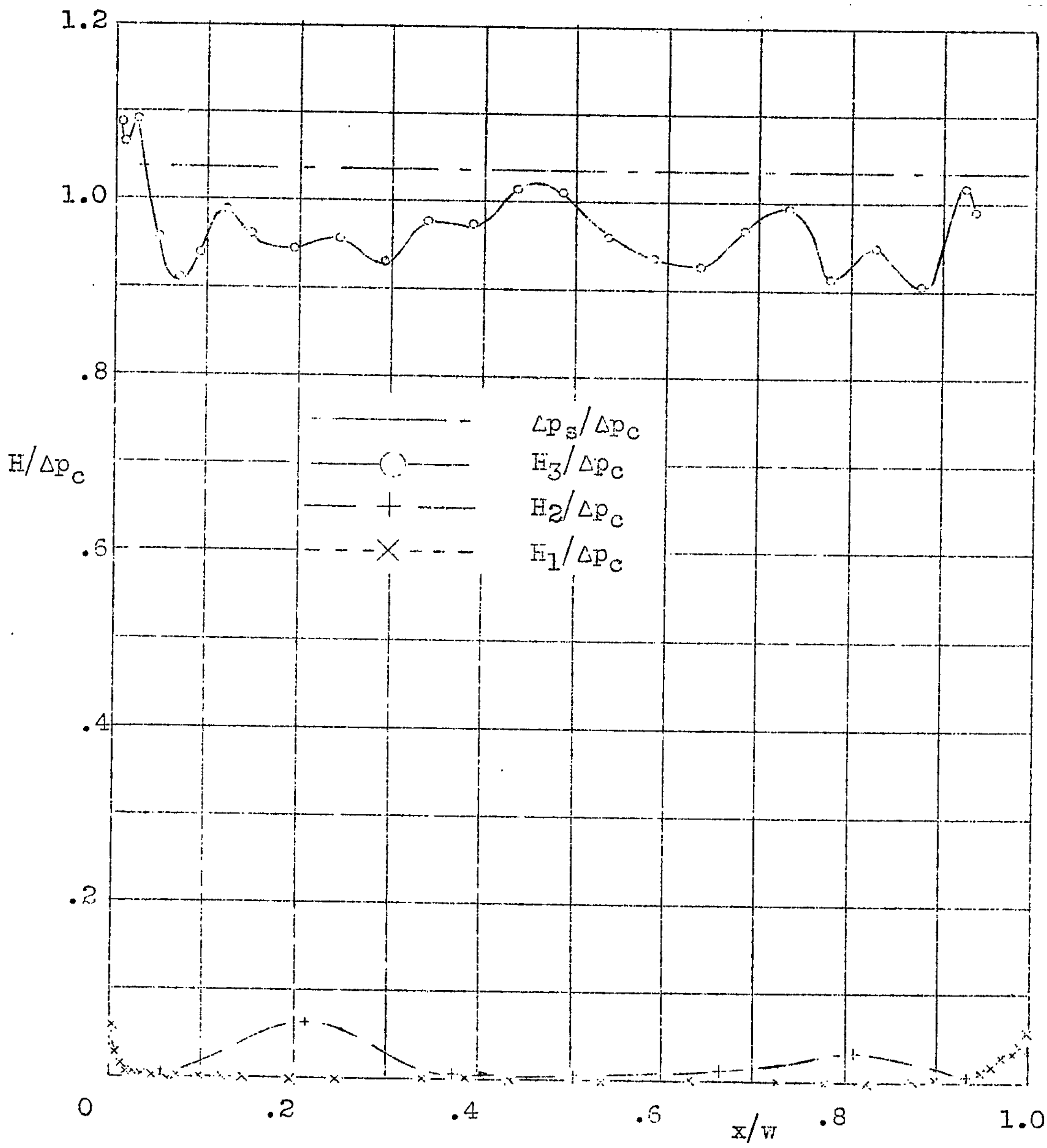
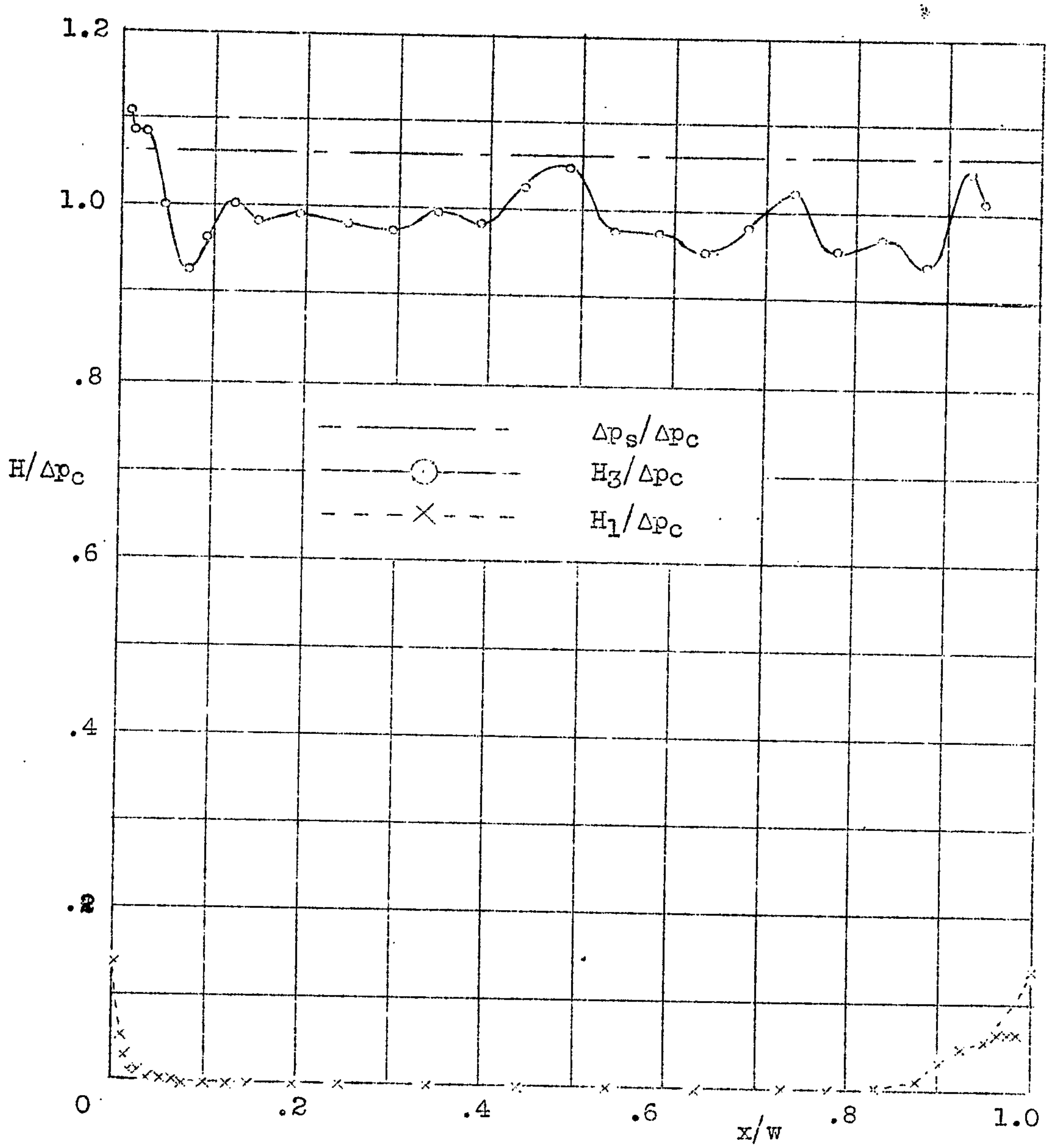


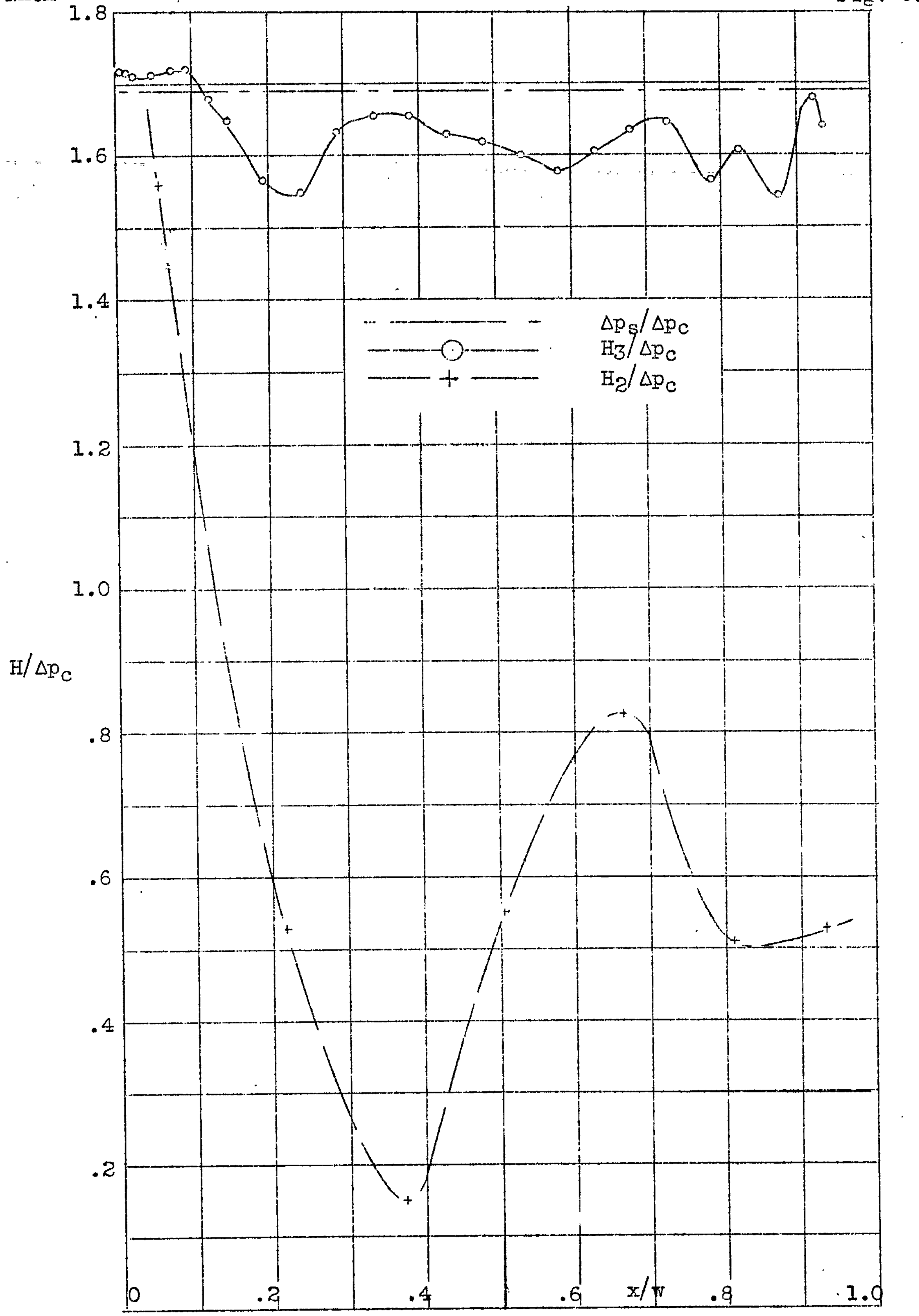
(b) θ, 40°; face-duct area ratio, 1.305; face velocity, 22.1 fps.

Figure 9.- Continued



(c) θ, 60°; face-duct area ratio, 2.00; face velocity, 21.7 fps.

Figure 9.- Continued



(e) θ, 80°; face-duct area ratio, 5.759; face velocity, 19.1 fps.

Figure 9.- Concluded

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ABSTRACT

Flow losses which occur as a result of locating the axis of an intercooler at various angles with respect to supply-duct axis were determined. Flow patterns through intercooler were analyzed. Investigation was limited to a combination of rectangular duct and Harrison intercooler. Flow losses were small for angles of inclination up to 70%. Entrance shape to intercooler-flow-passage cells appeared to affect losses of duct-intercooler combination.

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