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LOW-PRESSURE BOUNDARY-LAYER CONTROL IN DIFFUSERS AND BENDS

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ADVANCE RESTRICTED REPORT

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SUMMARY

Tests have been made to study the effectiveness of small pressure differences, such as exist between the inside of airplane ducts and the external airplane surfaces suitable for duct exits, in removing the duct boundary layer through slots in the duct wall and thereby reducing separation losses. Two-dimensional diffusers of 15° and 30° included angles and some 90° bends were tested. The 30° diffuser was tested with and without a resistance at the large end. Several different types of boundary layer were set up at the diffuser inlets.

All the diffuser tests indicated that the expansion losses could be reduced at least half by the removal of approximately 4 to 10 percent of the total air flow; and the pressure required to blow out the boundary layer was small relative to the pressures normally available in airplane ducts. The slots in the diffuser arrangements were generally formed merely by cutting narrow strips from the two diverging walls of the diffuser. Not more than one slot was used on each surface, and none were usually required on the two parallel walls of the diffuser. Effective boundary-layer control for the inner corners of the bends required a slot with a lip that projected into the duct in order to help "peel off" the boundary layer and also required somewhat higher internal pressures than were used with the diffusers.

INTRODUCTION

The efficiency of airplane ducts has generally been impaired by the limitations of the space available for duct installations. Rapid duct expansions and sharp or irregular bends have frequently resulted in flow separations so extensive that the resulting total-pressure losses noticeably impaired the airplane performance. Removal, by suction, of the boundary layer in a region where separation is imminent has been commonly recognized as a general remedy for flow separation (reference 1), although impractical for aircraft because of the complication of the necessary equipment. The pressure difference between the inside of an airplane duct and the free stream might be used to remove the boundary layer so that such additional equipment would be unnecessary.

The purpose of the present work was to investigate the possibility of attaining effective boundary-layer control by means of small pressure differences. Tests were made of diffusers and of 90° bends; measurements were made of the total-pressure losses and of the quantity of air lost through the boundary-layer-control slots. Because simplicity is desirable for any practical installation, the arrangements tested generally included not more than one slot on each of the two divergent walls of the diffusers and one slot on the inner wall of the 90° bends. Boundary layers of different thicknesses were used at the duct inlets in an effort to simulate different operating conditions. Since the outlet condition affects the flow and the total-pressure losses through a diffuser, three different outlet arrangements were tried: (1) an abrupt contraction to the final measurement section, (2) a long straight uniform section of ducting attached to the diffuser outlet, and (3) a resistance in the form of an intercooler at the diffuser outlet.

SYMBOLS

H total pressure, pounds per square foot

ΔH total-pressure loss in diffuser or bend

p static pressure, pounds per square foot

q dynamic pressure, pounds per square foot

V velocity, feet per second

Subscripts:

1 at inlet

0 atmospheric conditions

max maximum

APPARATUS, BLOWER, AND DUCT SYSTEM

The air flow was produced by a centrifugal blower driven by an automobile engine. In order to reduce the turbulence and improve the uniformity of the flow at the inlet of the test duct, an expanded passage with a straightener was inserted between the blower and the test duct (fig. 1). The straightener was an "egg-crate" arrangement with layers of screen across both the upstream and downstream ends. Behind the straightener, the passage contracted to a 5- by $12\frac{1}{2}$-inch rectangular section (fig. 1, section 1), which was the inlet for all the ducts tested.

The outlet arrangement, which was common to all test setups, consisted of a contracting passage (except for the bends), a 5- by $12\frac{1}{2}$-inch measurement section (section 2), and a flapped exit. The purpose of the flaps was to permit adjustment of the pressure in the system.

The diffusers were made with 15° and 30° included angles (figs. 1 and 2, respectively). For the tests without the resistance, the large end of the diffuser was 18 by $12\frac{1}{2}$ inches, which corresponds to a two-dimensional expansion of 3.6:1. A somewhat larger expansion was required for the tests with the resistance (fig. 3) since the duct had to be fitted to the 22- by 13-inch face of the Airesearch intercooler that served as the resistance. The bends (fig. 4) were made with inner radii of 1 and 2 inches and outer radii of 6 and 7 inches, respectively. The aspect ratio of both bends was 2.5. The duct system was of sheet iron except for the side walls near the critical sections, which were made of celluloid to facilitate tuft observations of the internal flow.

MEASUREMENTS

Total-pressure and static-pressure measurements at the inlet (section 1) and exit (section 2) permitted determination of the total-pressure losses within the system and of the quantity of air lost through the slots. Flow quantities at sections 1 and 2 were obtained in most cases from the arithmetic mean of the measured dynamic pressures. Tests without slots - that is, with no air loss - showed that the results from sections 1 and 2 agreed to about 1 percent; therefore, similar accuracy may be assumed for the slotted conditions. Similarly, for the determination of the total-pressure losses in the system, the arithmetic mean of the measured total pressures at sections 1 and 2 was used; however, when the flow was so irregular that an error of over 1 percent was indicated, the total pressures were weighted according to the local velocity.

Some uncertainty existed concerning the best way to determine the expansion losses in the diffuser-intercooler combinations. Losses measured at the exit included the large pressure drop through the intercooler, whereas losses measured at the face of the intercooler (section 5) would be considered inaccurate because of flow separation in the region of measurement. It was found, however, that the average of the total pressures at the face of the intercooler, obtained with shielded total-pressure tubes, always differed from the average total pressure at the exit by nearly the same amount - from 42 to 44 times the mean dynamic pressure at the intercooler, which presumably is the loss through the intercooler. Both methods therefore would have given about the same results. The results reported were determined from the averages at the face of the intercooler.

In addition to the measurements obtained with total-pressure and static-pressure tubes distributed across inlet and outlet areas at stations 1, 2, and 5, more detailed measurements were made, for several cases, of the boundary layers at the inlet and at several positions along the diffusers. These measurements were made near the midpoints of each of the walls at the sections designated 1, 3, and 4 in figures 2 and 3.

DESCRIPTION OF TESTS

Tuft Observations and Slot Arrangements

The location and arrangement of the slots were chosen largely from tuft observations of the flow in the diffuser. The main slot was usually placed slightly upstream of the point where the flow in the sealed duct separated. Such separation always occurred on the surface on which the incoming boundary layer was thickest; but, when there was no obstruction in the entrance cone so that the boundary layer was about equally thick on both upper and lower surfaces, the separation point would sometimes alternate between the two surfaces. In any case, when separation of the flow on the critical surface had been eliminated by the slot, separation generally occurred on the opposite surface at about the same section or perhaps slightly farther downstream. A slot on this surface therefore was also desirable. Although the use of only one slot on each of these two surfaces did not prevent eventual separation farther downstream, tufts showed that the velocities near these separated regions were very small so that only minor total-pressure losses were associated with this eventual separation.

In cases in which separation was observed to start in the corners or near the middle of a wall, partial-span slots were tried in these locations. These slots were found to be reasonably efficient, probably because the low pressure at the slot drew off part of the boundary layer of the adjacent flow in addition to the boundary layer of the air passing directly over the slot.

Slots on the side walls were not tried in most cases because separation from the side walls seldom occurred; apparently, boundary layers can withstand more pressure rise along the parallel walls than along the diverging walls.

In the bends, separation occurred just downstream of the corner on the inner wall. A slot formed by cutting a strip out of the wall, which served satisfactorily for the diffusers, did not suffice to remove the boundary layer in the bends - probably because of the low static pressure at the inner corner. Accordingly, the slots for the bends had to be designed to lead the boundary layer out of the duct. (See table VI.) Apparently, a boundary layer must be "peeled off" in this way if its total pressure, but not its static pressure, exceeds the external static pressure; a boundary layer will flow out of a simple flush slot only if its static pressure exceeds the external static pressure.

Inlet Boundary Layer

Since the total-pressure losses through a diffuser and the point of separation are affected by the inlet flow conditions, the boundary layer at the inlet was varied in thickness to simulate various operating conditions. With the entrance cone free of obstruction, the boundary layers were about 0.2 inch thick on the upper and lower surfaces of the inlet and slightly thicker on the sides. In some of the tests of the 30° diffuser, a 5- by $12\frac{1}{2}$-inch passage 20 inches long was inserted between the end of the entrance cone and the inlet of the diffuser. The boundary-layer thickness for these arrangements was about 0.5 inch. Thicker boundary layers were produced on the upper or lower surfaces by means of the obstructions indicated in figure 5. The wooden bar (case 1 for 15° diffuser) gave a very turbulent boundary layer about 2 inches thick. The 8-inch flat plate (case 2 for 15° diffuser) at the front of the entrance cone seemed to have almost no effect. The slightly inclined screen (case 3 for 15° diffuser) gave a uniform velocity variation from the top to the bottom of the inlet. The stepped layers of screen (cases 2 to 5 for 30° diffuser) were used in an effort to get thick boundary layers with less violent turbulence than that obtained with the wooden bar. Although the turbulence was reduced, the velocity distribution was distinctly stepped (fig. 6(b)). The velocity distributions for the 15° and 30° diffusers are shown in figure 6.

Outlet Flow Conditions

The total-pressure losses in an expanding duct are known to be affected by conditions at or beyond the end of the expansion region. When the duct contracts immediately downstream of the expansion, the separated region tends to be localized in the region of maximum cross section, and the resulting losses are less than when the maximum cross section of the duct extends for some distance downstream of the diffuser. The losses also tend to be reduced by a resistance at the end of the diffuser (reference 2). In order to check the usefulness of boundary-layer control in all three outlet conditions, the 30° diffuser was tested with and without a 60-inch passage beyond the end of the diffuser (fig. 2) and also with the intercooler at the end of the diffuser (fig. 3). Arrangements with the intercooler set at angles of 0°, 30°, and 45° to the diffuser axis were tried in order to compare the normal with the skew installations. The diffuser was the same basic diffuser in all cases except for adapting pieces to bring the angle of inclination from 45° to 30° and 0°. The intercooler tubes in these tests were across the flow and parallel to the straight sides of the duct. Two plates, perpendicular to the tubes, are built into the intercooler and divide the intercooler into three approximately equal parts.

RESULTS AND DISCUSSION

Tables I to VI show the total-pressure losses in terms of the dynamic pressure at the inlet $\Delta H/q_1$ for the various ducts and configurations. The indicated airflow loss through the slots was determined as the difference between the flow quantities measured at stations 1 and 2. The pressure differential $\frac{p_1 - p_0}{q_1}$ is shown to be negative in some cases. Because of the expansion between the inlet and the slot location, however, the pressure differential across the slots is positive so that flow out of the slots is possible. Several pressure differentials were used in some of the cases to produce different quantities of air flow through the slots and corresponding variations in total-pressure loss.

The 15° Diffuser

Table I shows the test results for the 15° diffuser with the inlet conditions given in figures 5(a) and 6(a). With the ducts sealed, the expansion losses were about $0.12q_1$ for case 2 and about $0.16q_1$ for cases 1 and 3, which had low-energy flow on the lower and upper surfaces, respectively. In all three cases, the losses could be reduced about half by bleeding 4 to 7 percent of the total flow. Increasing the quantity of air removed by increasing the internal pressure could not reduce the losses much further.

The 30° Diffuser without Intercooler

Table II shows the test results for the 30° diffuser with the inlet conditions given in figures 5(b) and 6(b). Without the 60-inch outlet section, the expansion losses for the sealed condition were $0.22q_1$ to $0.30q_1$, depending on the inlet conditions. Addition of the 60-inch section increased the losses by 30 to 40 percent. In every case, bleeding 7 percent or less of the air sufficed to reduce the losses by more than half if slots were provided on both upper and lower surfaces. Bleeding as much as 17 percent of the inlet-air quantity, as was done in case 4, did not appreciably decrease the total-pressure losses. A slot on only the upper surface, where the boundary layer was thickest, effected a smaller but nevertheless appreciable reduction in total-pressure losses. In such cases, bleeding more than the optimum quantity of air increases the losses, probably because it hastens separation on the opposite sealed surface.

The boundary-layer surveys shown in figures 7 and 8 for cases 4 and 5, respectively, help to illustrate the action of the slots. In both cases, without the slots, the low-energy air on the upper surface is on the verge of separating at section 3 and is definitely separated at section 4; whereas, with the slots installed, there is no indication of separation at section 4.

The 30° Diffuser with Intercooler

Results of tests with the intercooler set at angles of 0°, 30°, and 45° to the end of the diffuser are given in tables III, IV, and V, respectively. No inlet obstructions were used for these tests, although some of the tests were made with the 20-inch inlet passage between the entrance cone and the diffuser inlet.

Comparison of the results in tables III to V shows that inclining the intercooler to the diffuser axis generally did not increase the total-pressure losses. This result is of interest because such inclination has frequently been assumed to correspond essentially to an increased expansion and hence higher total-pressure losses.

For the tests without the 20-inch passage, the results showed, as before, that the losses could be reduced more than half by suitable slots on both the upper and lower surfaces. It was found necessary, however, to bleed about 12 percent of the air - a result that is probably related to the high internal pressures, which could not be reduced because of the high resistance of the intercooler. Efforts to use narrower slots to reduce the air loss seemed to give less effective boundary-layer control than was obtained for the 30° diffuser without an intercooler, which has broader slots and operates at smaller pressures.

Slots on only the upper and lower surfaces were found to be less satisfactory with than without the 20-inch entrance passage, probably because the boundary layer on the sides was thicker with the 20-inch entrance passage. A solution seemed to be to separate the flanges of the 20-inch section and the diffuser inlet so as to provide a $\frac{1}{4}$-inch slot completely around the inlet. A similar arrangement also gave a large reduction of the total-pressure losses for the cases without the 20-inch inlet section. The effectiveness of this slot around the inlet is remarkably high. The effect is doubtless related to that noted in reference 2 in which high duct efficiencies were observed when the boundary layer at the inlet was very thin. An obvious contributing factor is the loss of air at the slot itself, which causes the actual dynamic pressure just downstream of the slot to be only about 0.8 of the value on which the values of $\Delta H/q_1$ have been based. If the losses were calculated on the basis of this lower inlet dynamic pressure, this arrangement would, in most of the cases given, show about the same reduction in total-pressure losses as found with slots on only the upper and lower surfaces.

The distribution of total-pressure loss at the face of the intercooler is shown for a number of slotted and sealed conditions in figure 9. Large separated regions at the upper and lower surfaces are shown for the sealed conditions. The slots mostly eliminate these regions but sometimes develop a separated region on one of the sides. Velocity distributions across the horizontal and vertical center lines of the ducts at sections 1, 3, and 4 are shown in figure 10. This figure also shows how the slots prevent the early separation of the boundary layer.

Bends

The duct bends were tested without obstructions in the entrance cone and without the 20-inch inlet section. As has already been noted, the inner corners of the bends required some redesign in order to provide a slot that peeled off the boundary layer. The slotted conditions accordingly cannot be compared with corresponding sealed conditions, as was done with the diffusers, in order to evaluate the reduction in total-pressure losses. Table VI, which shows the results for the bends, therefore does not give values for the reduction in $\Delta H/q_1$. The effectiveness of the slots is indicated by comparison of the given values of $\Delta H/q_1$ with the values for the three sealed conditions shown, especially the arrangements with the 2-inch inner radius for which the losses were 14 and 18 percent. All indicated total-pressure losses have been corrected for the friction loss between the inlet and exit measurement sections.

The total-pressure losses for the most efficient of the slotted conditions are of the order of 6 to 10 percent with about 5 to 10 percent loss of air. Most of the designs shown in table VI have a fairly large inner radius, with the slot not very far beyond the end of the bend. The value of $\frac{p_1 - p_0}{q_1}$ must be of the order of 0.85 in order that the pressure suffice to blow out the required amount of air.

Figure 11, which shows the distribution of dynamic pressures at the exit of the bend for slotted and sealed conditions, indicates an increased uniformity of flow for the slotted condition.

APPLICATION

Pressures Required

As can be seen in tables I and II, adequate boundary-layer control in the diffusers was obtained with small values of $\frac{p_1 - p_0}{q_1}$. The adaptation of this principle to duct installations on actual airplanes should be feasible since the average airplane diffuser inlet shows static pressures greater than that of the free stream; that is, there is generally more than enough pressure to blow out the boundary layer into the free stream. In a practical design, however, the boundary layer would probably be blown out, not directly into the free stream but into some duct especially provided for the purpose or into some space within the wing or fuselage from which an outlet would be provided. The pressure here would probably be higher than that of the free stream; however, the ease with which boundary-layer control was obtained even with small pressure differentials makes it unlikely that essential difficulties would be encountered in a practical design.

In the case of the sharp bends, the required values of $\frac{p_1 - p_0}{q_1}$ were of the order of 0.85, corresponding to an inlet-velocity ratio of about 0.73, which is not very much higher than usual design values. Boundary-layer control for sharp bends will probably be inadequate if the space into which the slot delivers has a pressure that exceeds the free-stream static pressure by several tenths of the flight dynamic pressure.

Leakage Losses

All the total pressure of the boundary layer that is blown out need not be considered lost before the boundary layer finally leaves the airplane. As has just been mentioned, the boundary layer will probably be blown out into a space where the static pressure (hence the total pressure) will be appreciably higher than the free-stream static pressure. It would be relatively easy, furthermore, to provide a smoother slot than was used in the present tests, together with a small diffuser, so that the dynamic pressure of the air blown out of the slot would be partly recovered. Even in cases in which leakage losses corresponding to such boundary-layer control are large, the method may still help to provide necessary pressure in an otherwise unacceptable duct.

CONCLUSIONS

The results of tests of diffusers having 15° and 30° included angles and of 90° bends with various arrangements of slots for boundary-layer control indicated the following conclusions:

1. A small pressure differential, such as could be obtained between a typical airplane diffuser inlet and a duct exit, was sufficient for effective boundary-layer control in the flow through a diffuser.

2. The pressure differentials required for effective boundary-layer control are of higher magnitude (0.85 of the bend-inlet dynamic pressures) for duct bends than for diffusers; however, pressure differentials of this magnitude are generally obtainable in airplane duct bend installations.

3. For the diffusers and bends tested, total-pressure losses due to separation could generally be reduced at least half by boundary-layer control.

4. Removal of approximately 4 to 10 percent of the air generally sufficed for optimum improvement of the flow. Removing excess air through the same slots did not further improve the flow.

5. Very simple slot designs with not more than one slot per surface - generally slots on only the two diverging walls of the diffuser - were adequate for satisfactory boundary-layer control.

6. In a rectangular diffuser, in which one pair of opposite walls diverge while the other pair remain parallel, separation tended to occur only on the diverging walls if the initial boundary layer was small, and boundary-layer control on these walls alone seemed to improve the flow. When the entering boundary layer was relatively thick, however, it was necessary to provide slots on the parallel walls, also.

7. Effective boundary-layer control for the inner corners of the bends required a slot with a lip that projected into the duct in order to help "peel off" the boundary layer.

8. The energy losses associated with the removal of the boundary layer need not be excessive for a correctly designed boundary-layer bleed duct.

9. Inclination of an intercooler to the diffuser axis, up to angles of 45°, generally did not increase the diffuser total-pressure losses.

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REFERENCES

1. Prandtl, L. and Tietjens, O. G.: Applied Hydro- and Aeromechanics. McGraw-Hill Book Co., Inc., 1934, p. 294.

2. McLellan, Charles H., and Nichols, Mark R.: An Investigation of Diffuser-Resistance Combinations in Duct Systems. NACA ARR, Feb. 1942.

TABLE I.- RESULTS OF TESTS OF 15° DIFFUSER WITHOUT INTERCOOLER

[Top and bottom slots are same distance from diffuser entrance]

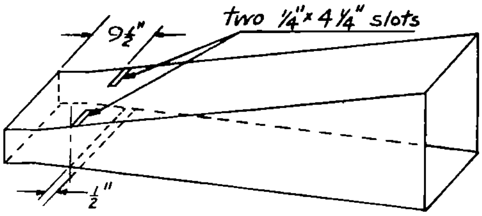
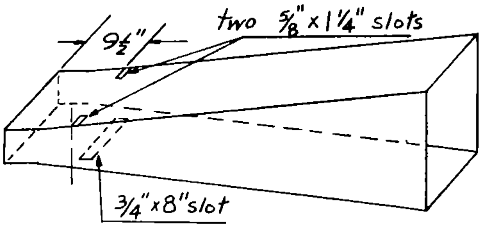
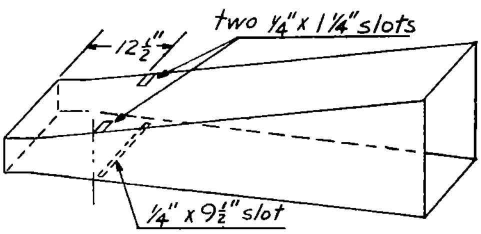
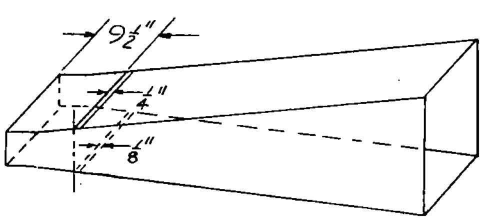
Arrangement of diffuser slots	Case	$\frac{p_1-p_0}{q_1}$	Air lost through slots (percent)	$\Delta H/q_1$ Slotted	$\Delta H/q_1$ Sealed	Reduction in $\Delta H/q_1$ (percent)
	1	-0.42	5	0.10	0.16	38
		-.34	7	.08	.16	50
		-.25	9	.07	.16	56
	2	-0.21	4.5	0.06	0.12	50
		-.31	4	.09	.12	25
		-.40	3	.10	.12	17
	2	-0.40	1	0.10	0.12	17
		-.30	3	.10	.12	17
		-.17	4	.09	.12	25
	3	-0.31	4	0.09	0.17	47
		-.21	7	.09	.17	47

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TABLE II.- RESULTS OF TESTS OF 30° DIFFUSER WITHOUT INTERCOOLER

[Top and bottom slots are same distance from diffuser entrance]

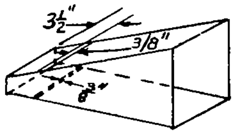
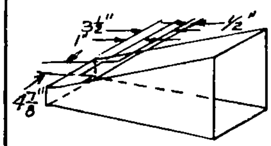
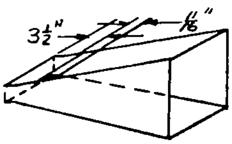
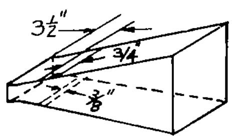
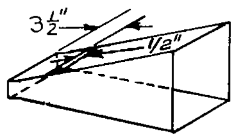
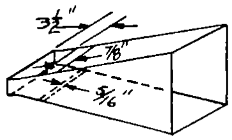
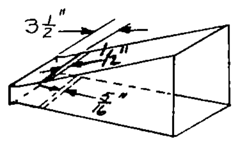
Arrangement of diffuser slots	Case	60-inch straight section	$\frac{p_1 - p_0}{q_1}$	Air lost through slots (percent)	$\Delta H/q_1$		Reduction in $\Delta H/q_1$ (percent)
					Slotted	Sealed	
	1	Off	-0.19	8	0.10	0.22	55
		On	-0.18	6	0.13	0.32	59
	2	Off	-0.19	6	0.12	0.27	56
		On	-0.16	7	0.18	0.37	51
	3	Off	-0.13 -.11	6.5 7	0.18 .22	0.30	40 27
		On	-0.06 -.04	6.5 7	0.25 .28	0.40	37 30
	4	Off	-0.19 .19 -.17	6 17 5	0.09 .08 .09	0.24	63 67 63
		On	-0.16 -.15	6 7	0.13 .14	0.37	65 62
	5	On	-0.22	2	0.29	0.35	17
		On	-0.04	5	0.30		14
	5	On	-0.13	6	0.14	0.35	60
		Off	-0.14	5	0.11	0.23	52
	5	On	-0.08	4	0.15	0.35	57

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TABLE III.- RESULTS OF TESTS OF 30° DIFFUSER WITH INTERCOOLER AT 0° TO DIFFUSER

[Top and bottom slots are same distance from diffuser entrance]

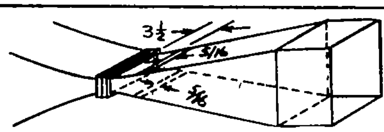
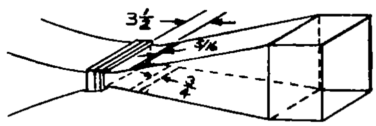
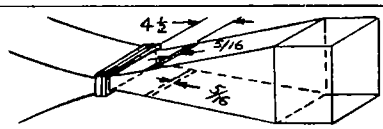
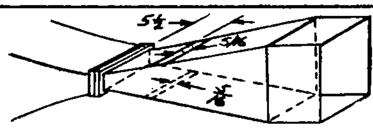
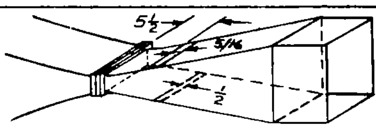
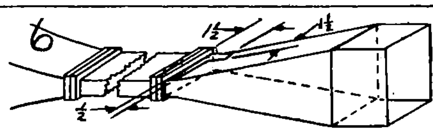
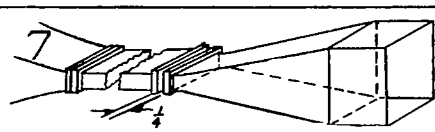
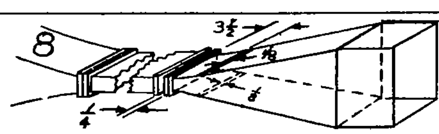
Arrangement of diffuser inlet and slots (Dimensions in in.)	$\frac{p_1 - p_0}{q_1}$	Air lost through slots (percent)	$\Delta H/q_1$		Reduction in $\Delta H/q_1$ (percent)
			Slotted	Sealed	
1 	1.10	12	0.16	0.38	58
2 	0.89	14	0.14	0.38	63
3 	1.01	12	0.14	0.38	63
4 	1.10	12	0.23	0.38	40
5 	0.93	13	0.12	0.38	68
6 	0.97	15	0.24	0.40	40
7 	1.06	11	0.18	0.40	55
8 	0.98	14	0.23	0.40	43

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TABLE IV.- RESULTS OF TESTS OF 30° DIFFUSER WITH INTERCOOLER AT 30° TO DIFFUSER

[Top and bottom slots are same distance from diffuser entrance]

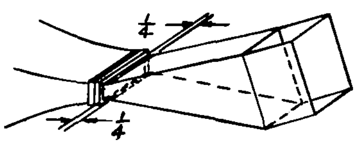
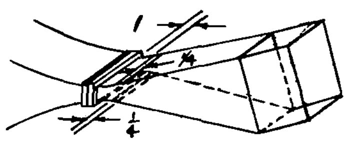
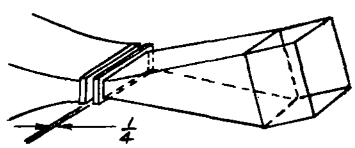
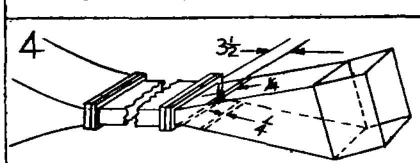
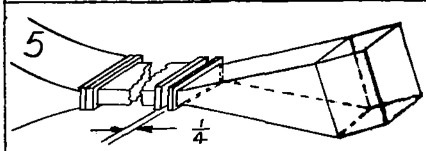
Arrangement of diffuser inlet and slots (Dimensions in in.)	$\frac{p_1 - p_0}{q_1}$	Air lost through slots (percent)	$\Delta H/q_1$		Reduction in $\Delta H/q_1$ (percent)
			Slotted	Sealed	
1 	1.16	11	0.17	0.30	43
2 	1.40	8	0.17	0.30	43
3 	1.20	9	0.08	0.30	73
4 	1.47	12	0.30	0.36	17
5 	1.34	11	0.22	0.36	39

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TABLE V.- RESULTS OF TESTS OF 30° DIFFUSER WITH INTERCOOLER AT 45° TO DIFFUSER

[Top and bottom slots are same distance from diffuser entrance]

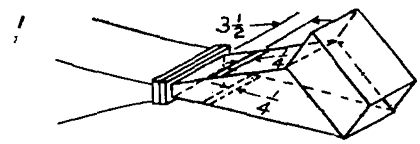
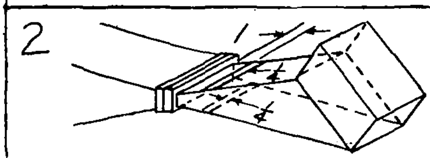
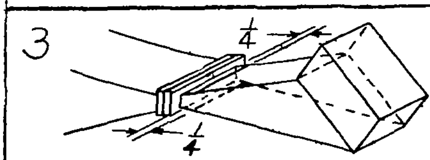
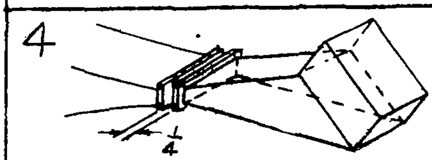
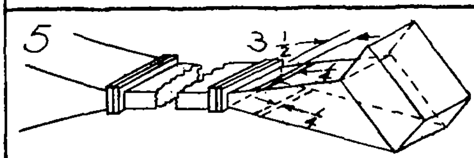
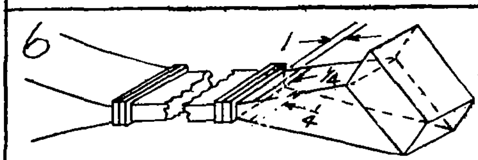
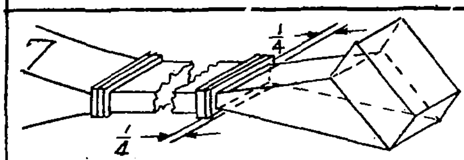
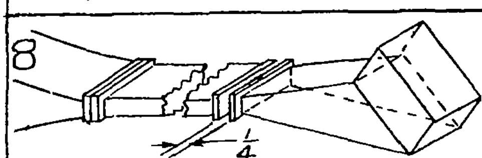
Arrangement of diffuser inlet and slots (Dimensions in in.)	$\frac{p_1 - p_0}{q_1}$	Air lost through slots (percent)	$\Delta H/q_1$		Reduction in $\Delta H/q_1$ (percent)
			Slotted	Sealed	
1 	1.31	9	0.15	0.29	48
2 	1.47	7	0.16	0.29	45
3 	1.34	9	0.16	0.29	45
4 	1.18	12	0.13	0.29	55
5 	1.60	9	0.33	0.41	20
6 	1.45	10	0.29	0.41	30
7 	1.37	11	0.26	0.41	35
8 	1.25	13	0.17	0.41	59

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TABLE VI. RESULTS OF TESTS OF 90° BEND

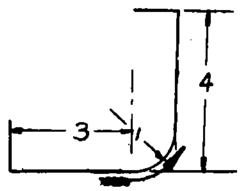
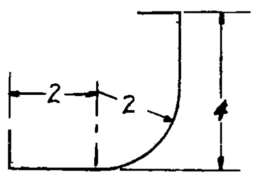
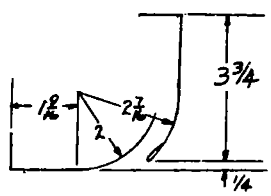
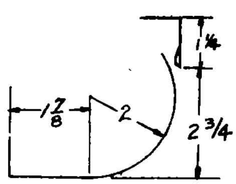
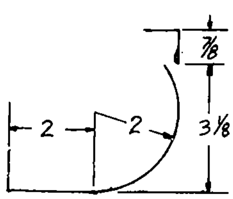
Arrangement of inner wall of bend (Dimensions in in.)	Outside radius of bend (in.)	$\frac{p_1 - p_0}{q_1}$	Air lost through slots (percent)	$\Delta H/q_1$
1 	6	---	0	0.31
2 	6	---	0	0.18
3 	6	0.66 1.12	2 5	0.18 .11
4 	6	0.63	14	0.05
5 	6	0.50 .58	7 10	0.13 .11

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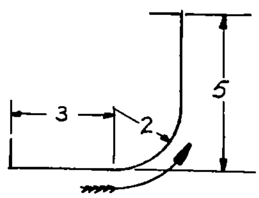
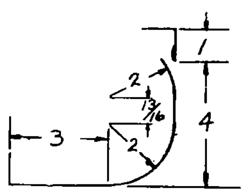
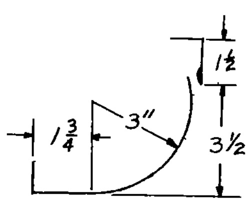
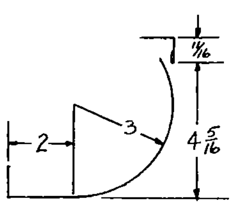
TABLE VI.- RESULTS OF TESTS OF 90° BEND - Concluded

Arrangement of inner wall of bend (Dimensions in in.)	Outside radius of bend (in.)	$\frac{p_1 - p_0}{q_1}$	Air lost through slots (percent)	$\Delta H/q_1$
6 	7	-----	0	0.14
7 	7	0.86	5	0.07
8 	7	0.85 .61	8 3	0.06 .14
9 	7	0.50 .84	2 6	0.12 .06

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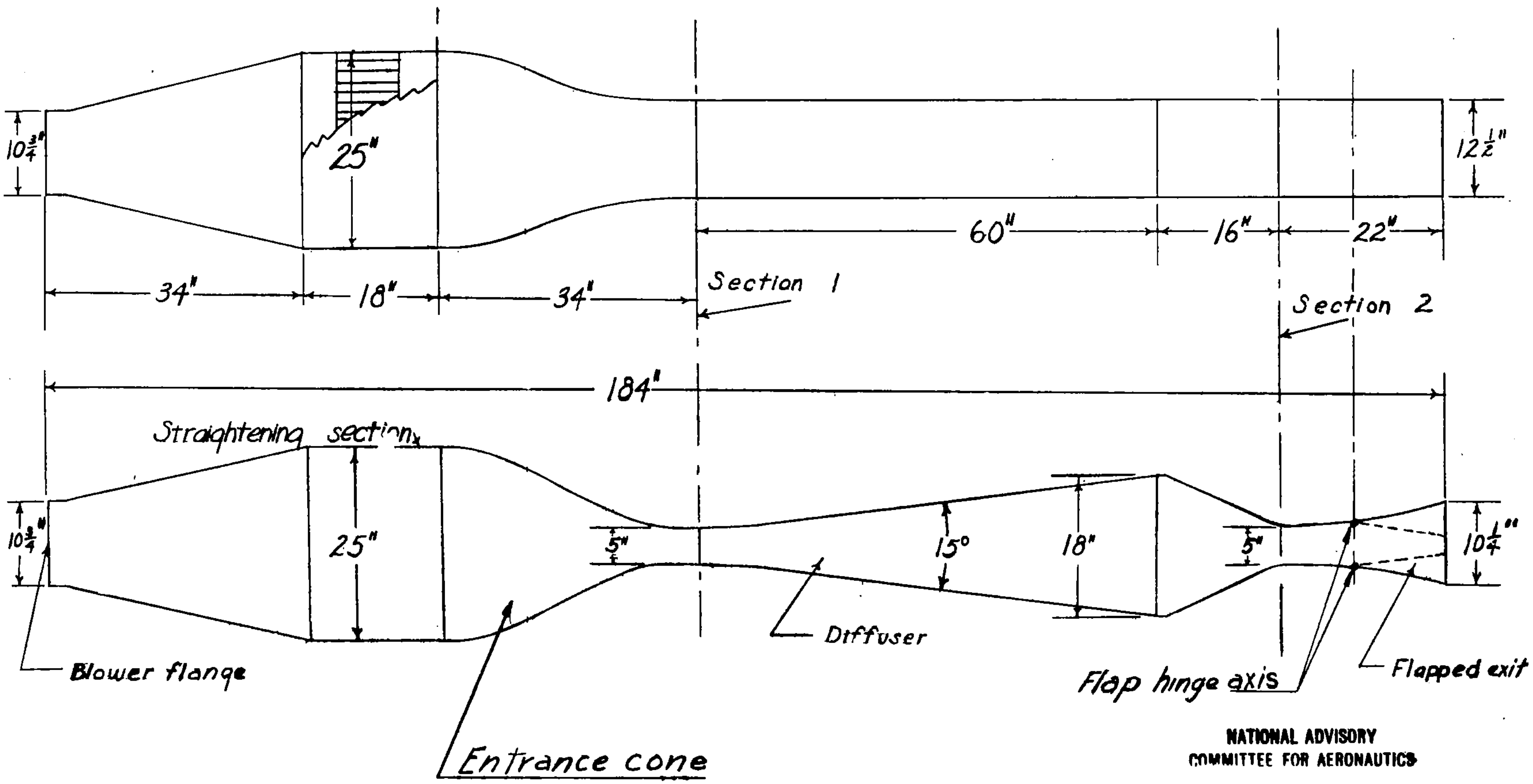

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Figure 1.- Setup for tests of 15° diffuser. Measurements made at sections 1 and 2.

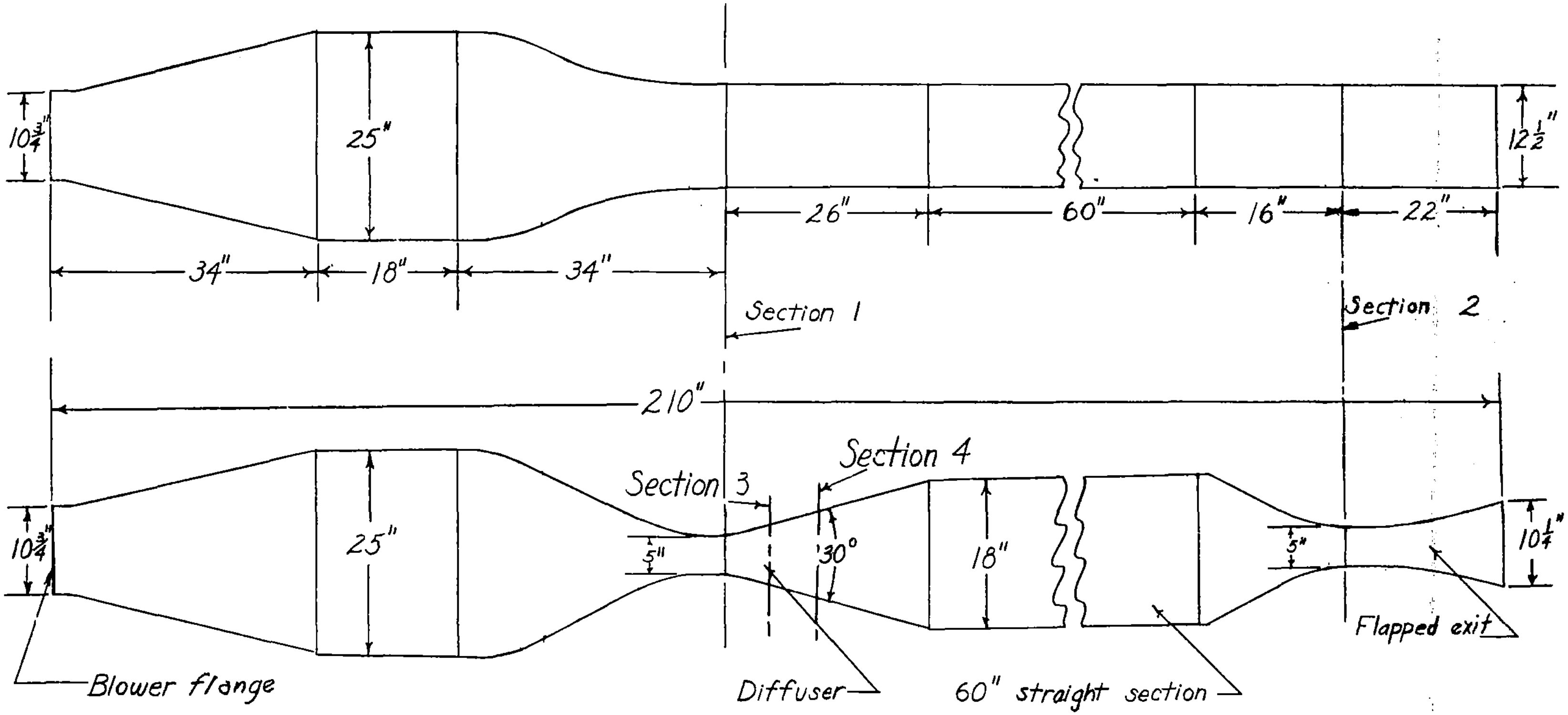

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Figure 2.- Setup for tests of 30° diffuser. Measurements made at sections 1 to 4.

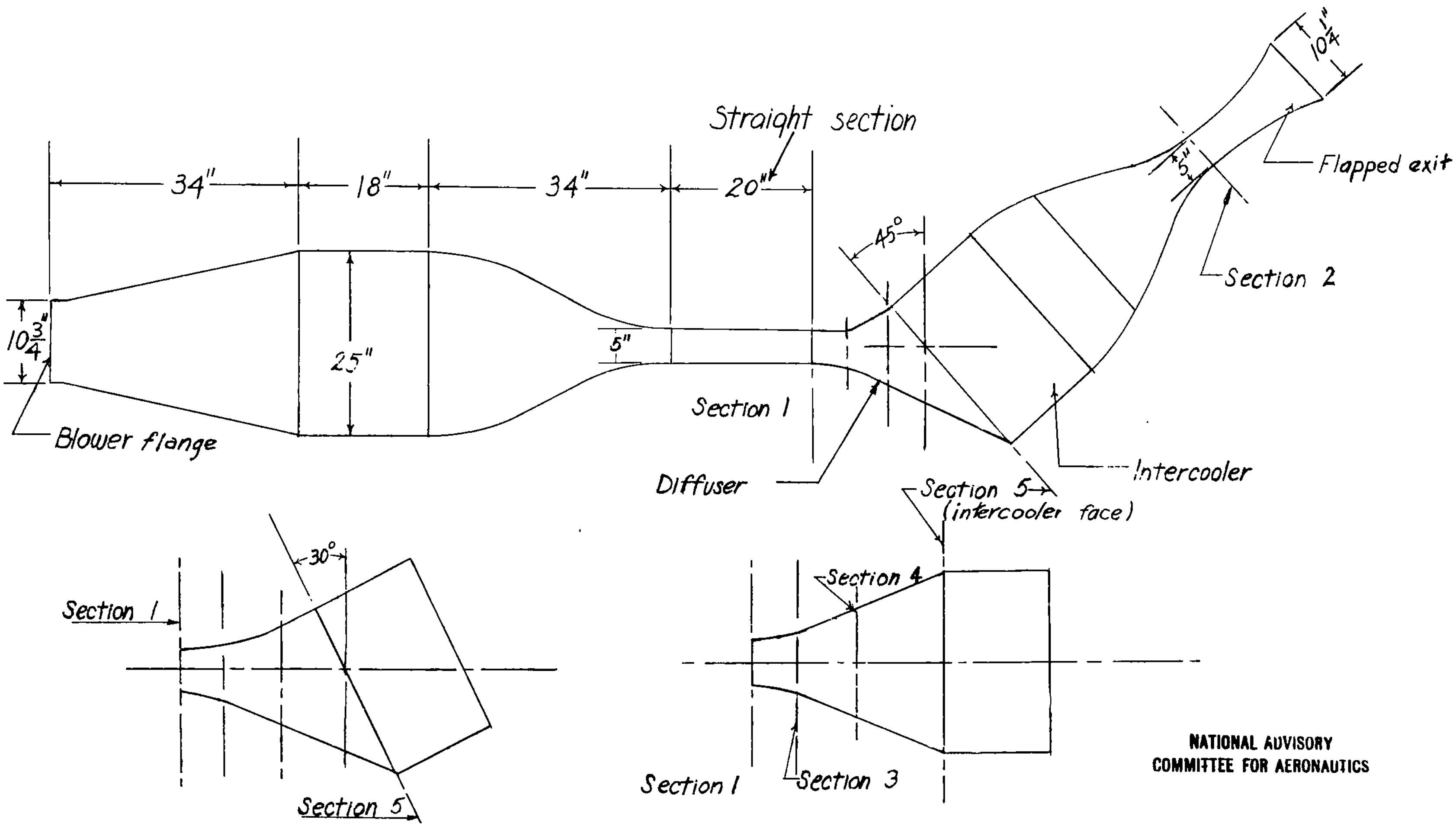

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Figure 3.- Setup for tests of 30° diffuser with intercooler at 0°, 30°, and 45° to diffuser axis. Measurements made at sections 1 to 5.

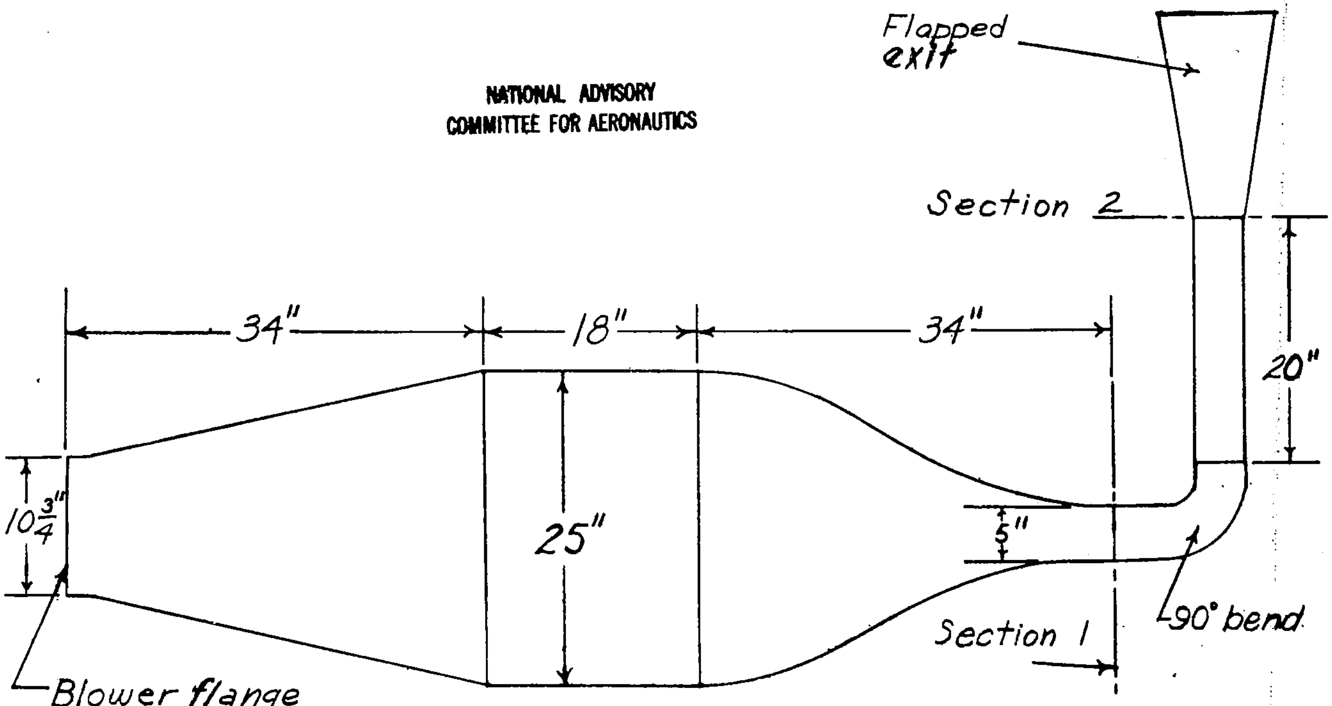
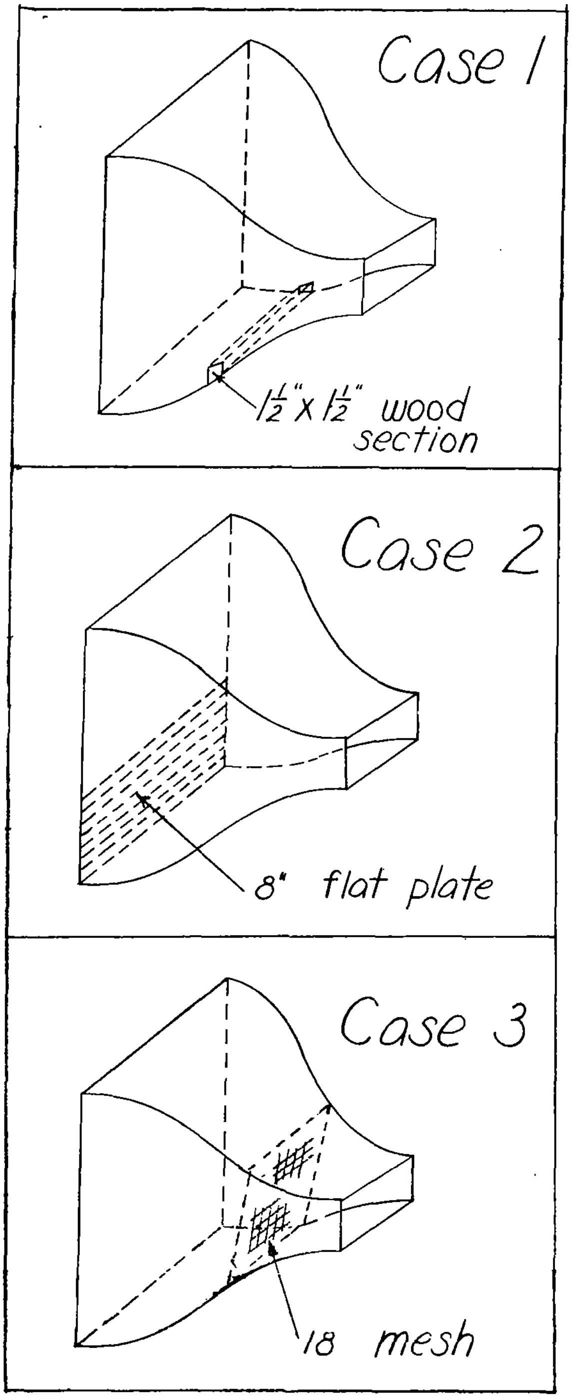
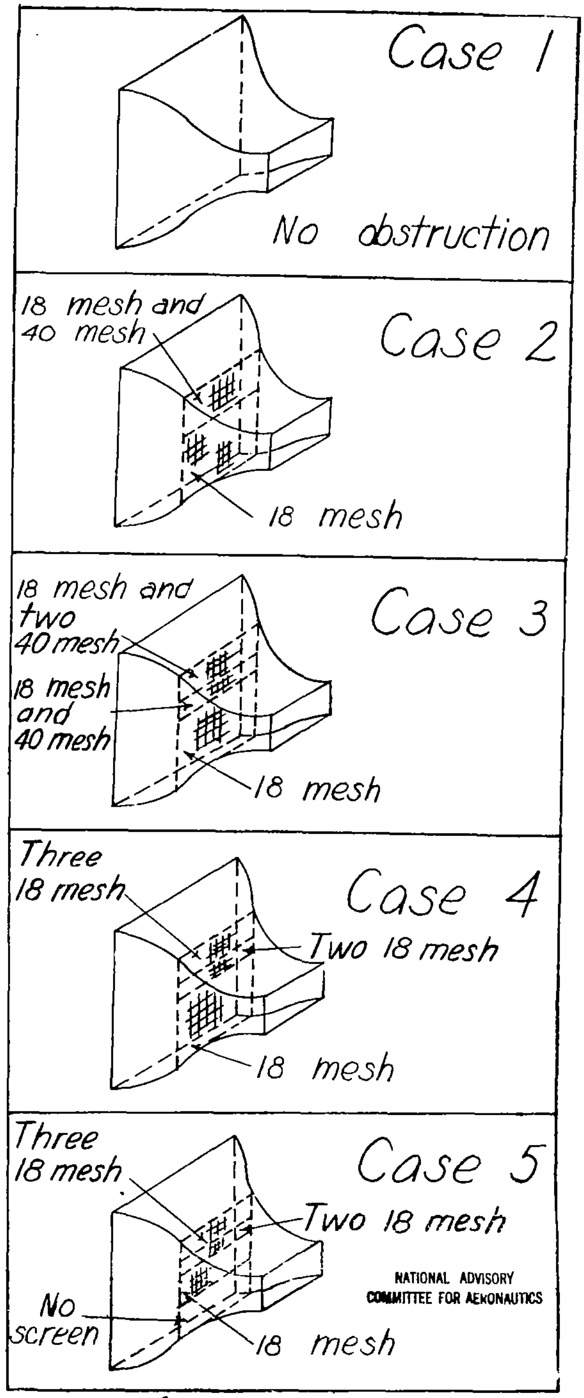


Figure 4.- Setup for tests of 90° bends with inner radii of 1 and 2 inches and outer radii of 6 and 7 inches, respectively. Measurements made at sections 1 and 2.

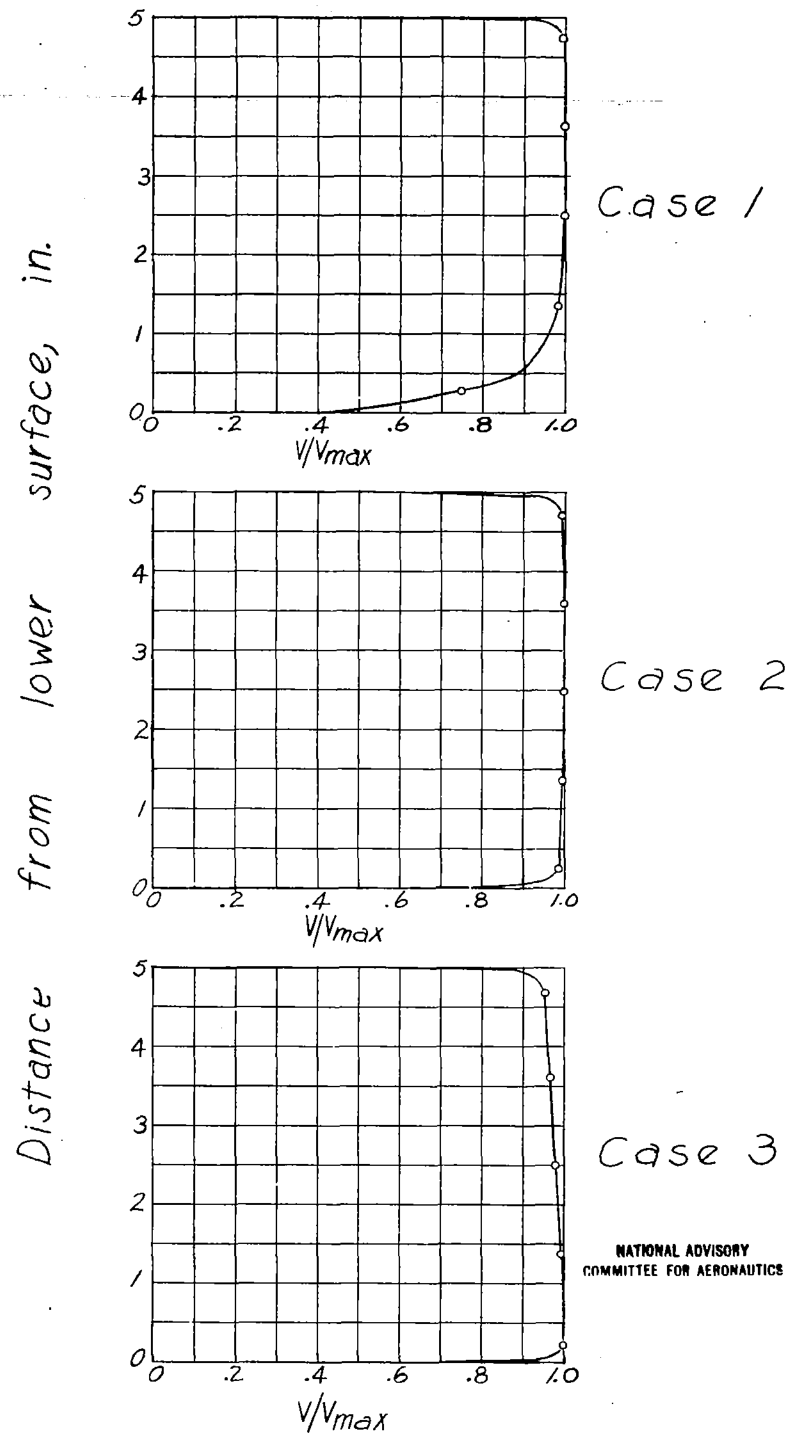


(a) 15° diffuser.



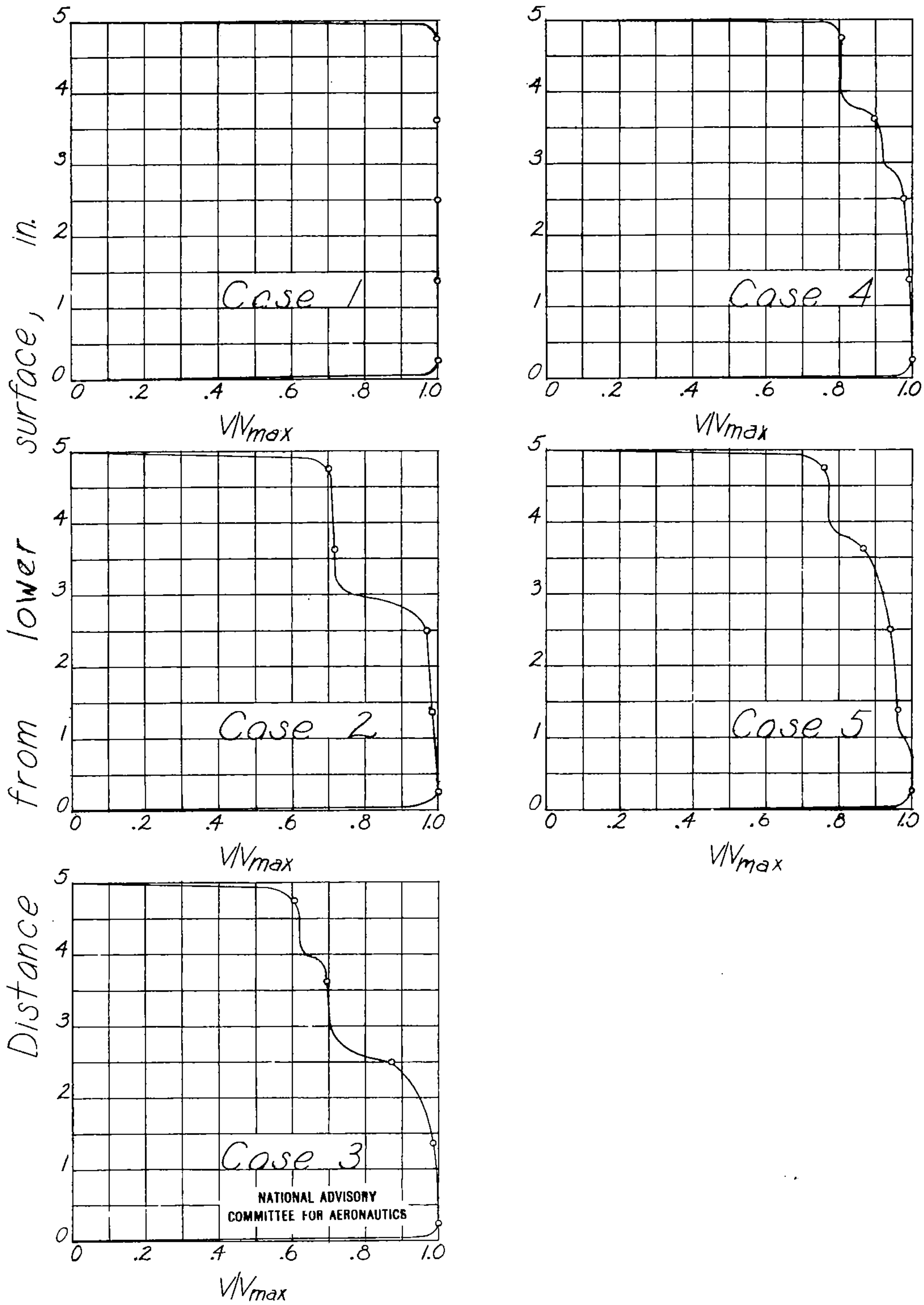
(b) 30° diffuser.

Figure 5.- Arrangement of obstructions ahead of diffuser inlet.



(a) 15° diffuser.

Figure 6.- Velocity distributions at entrance of diffuser.



(b) 30° diffuser.

Figure 6.- Concluded.

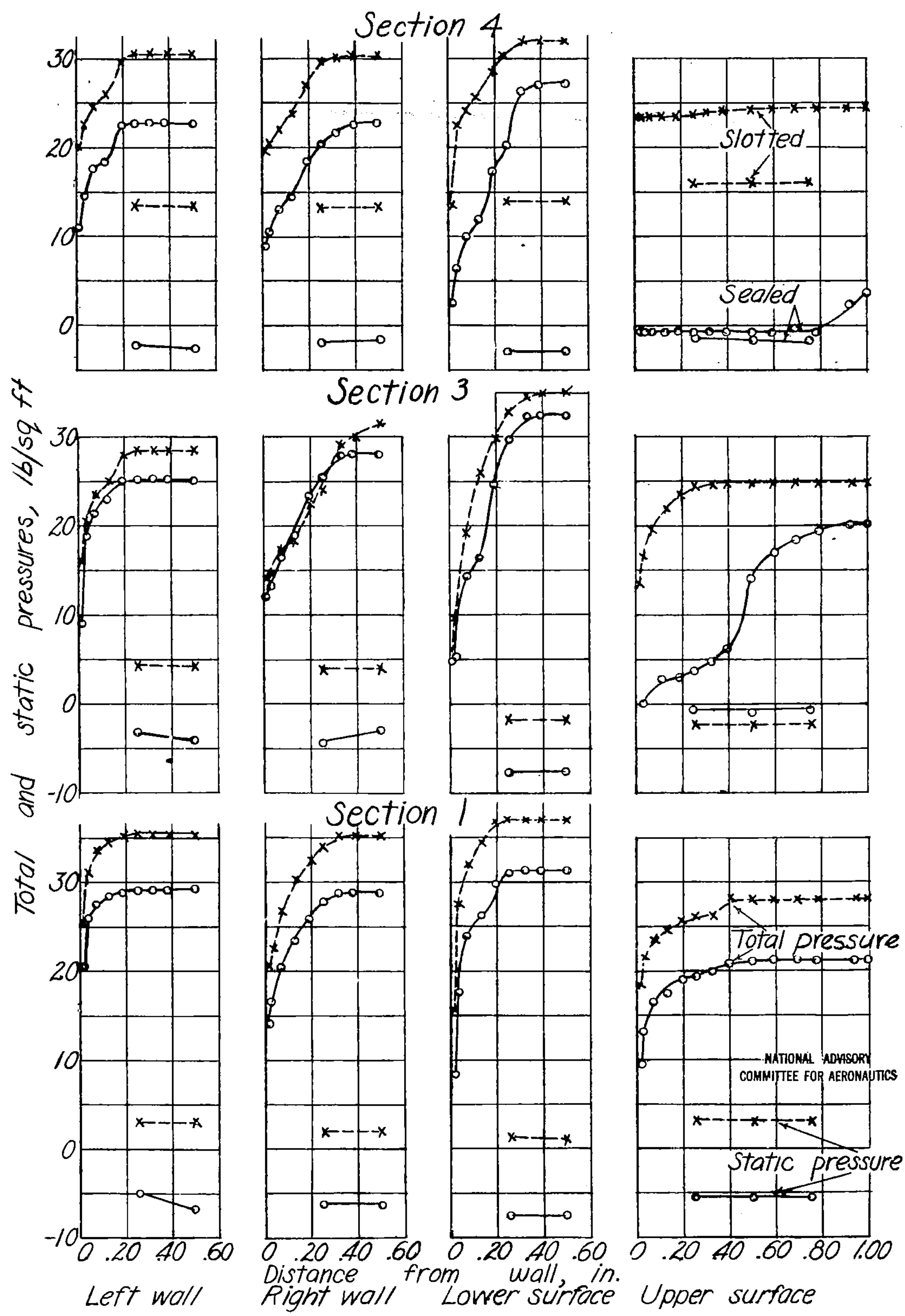


Figure 7.- Total-pressure and static-pressure distributions in boundary layer of 30° diffuser. Case 4, table II; $\frac{p-p_1}{q_1} = -0.17$.

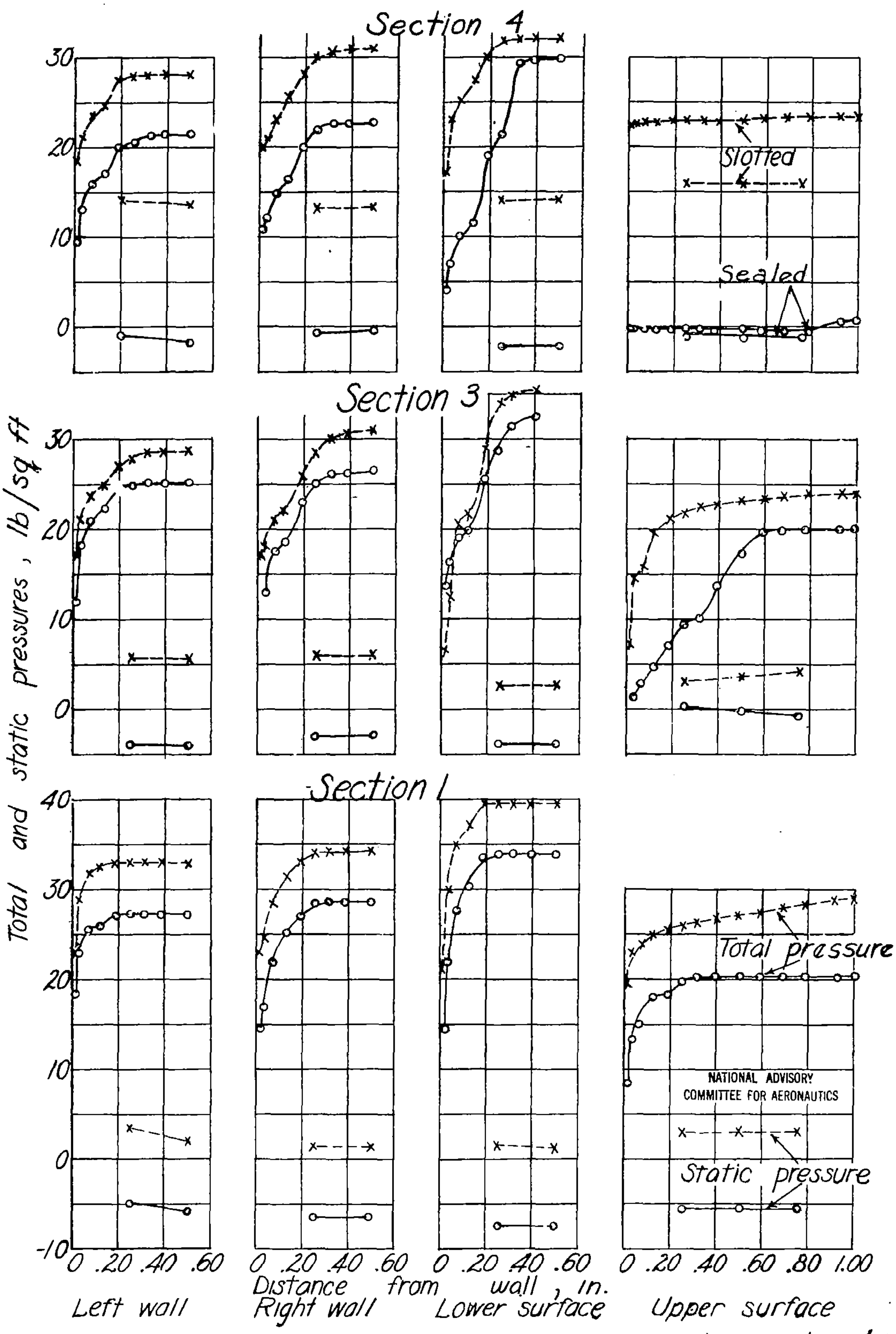
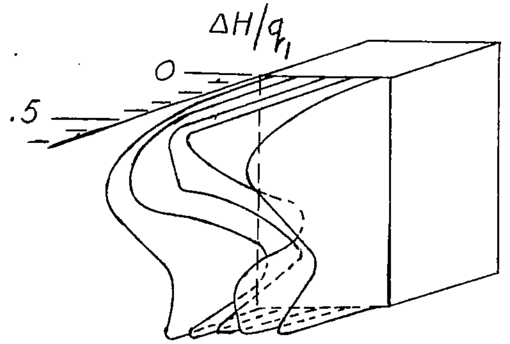
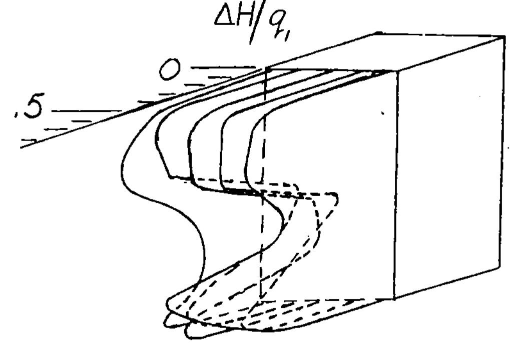


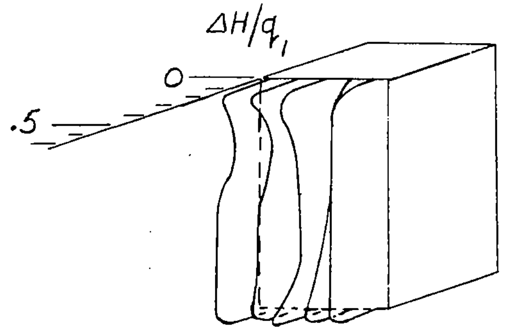
Figure 8.- Total-pressure and static-pressure distributions in boundary layer of 30° diffuser. Case 5, table II; $\frac{p_1 - p_0}{q_1} = -0.14$.



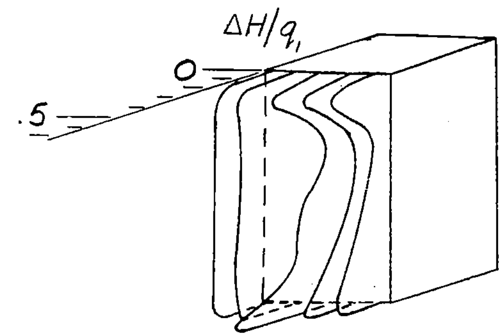
Sealed condition



Sealed condition; 20-in. section in front of diffuser



Slot arrangement 5, table III



Slot arrangement 7, table III; 20-in. section in front of diffuser

(a) Intercooler at 0° to diffuser.

Figure 9.- Loss of total pressure between inlet and face of intercooler given as fraction of inlet dynamic pressure.

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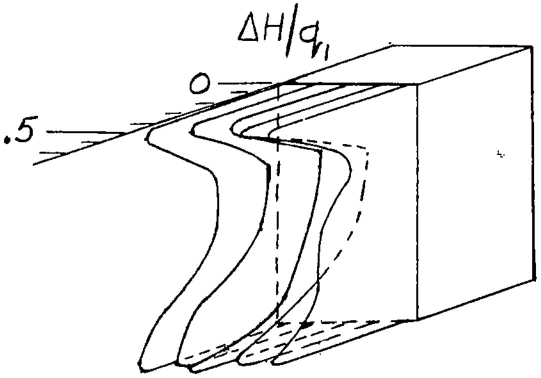
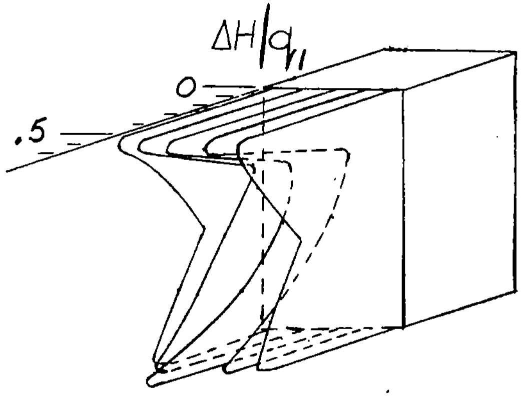
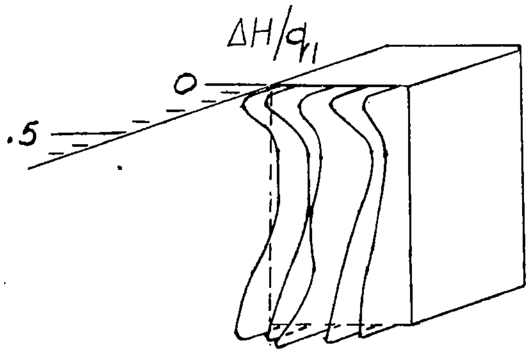


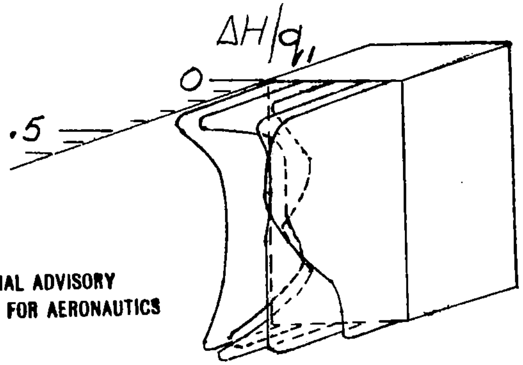
Sealed condition



Sealed condition; 20-in. section in front of diffuser



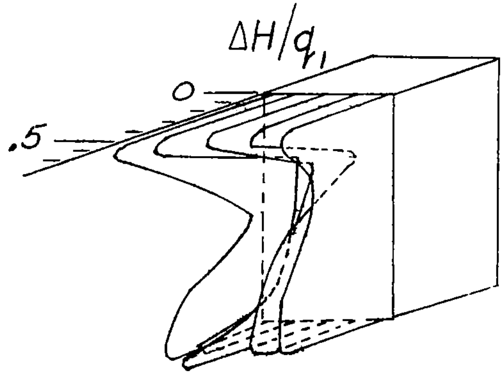
Slot arrangement 3, table IV



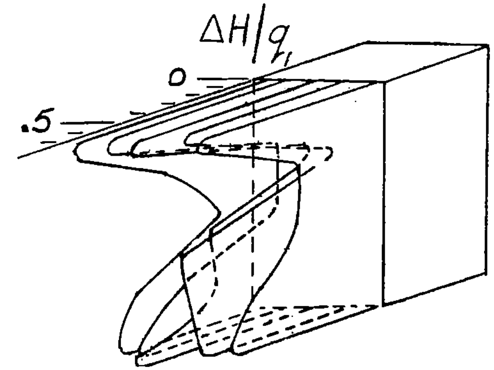
Slot arrangement 5, table IV; 20-in. section in front of diffuser

(b) Intercooler at 30° to diffuser.

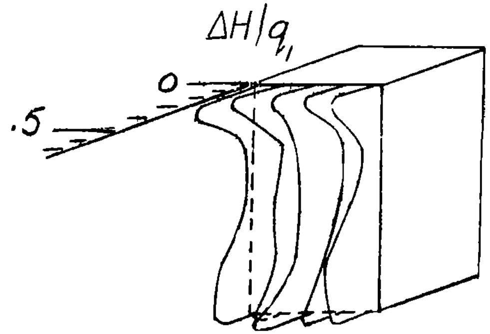
Figure 9.- Continued.



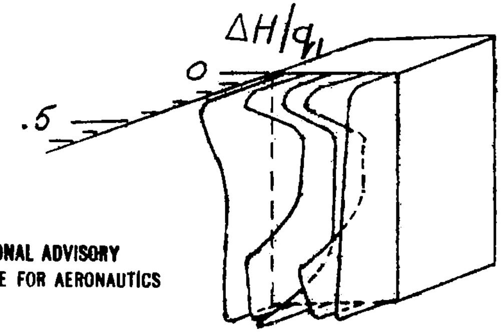
Sealed condition



Sealed condition; 20-in. section in front of diffuser



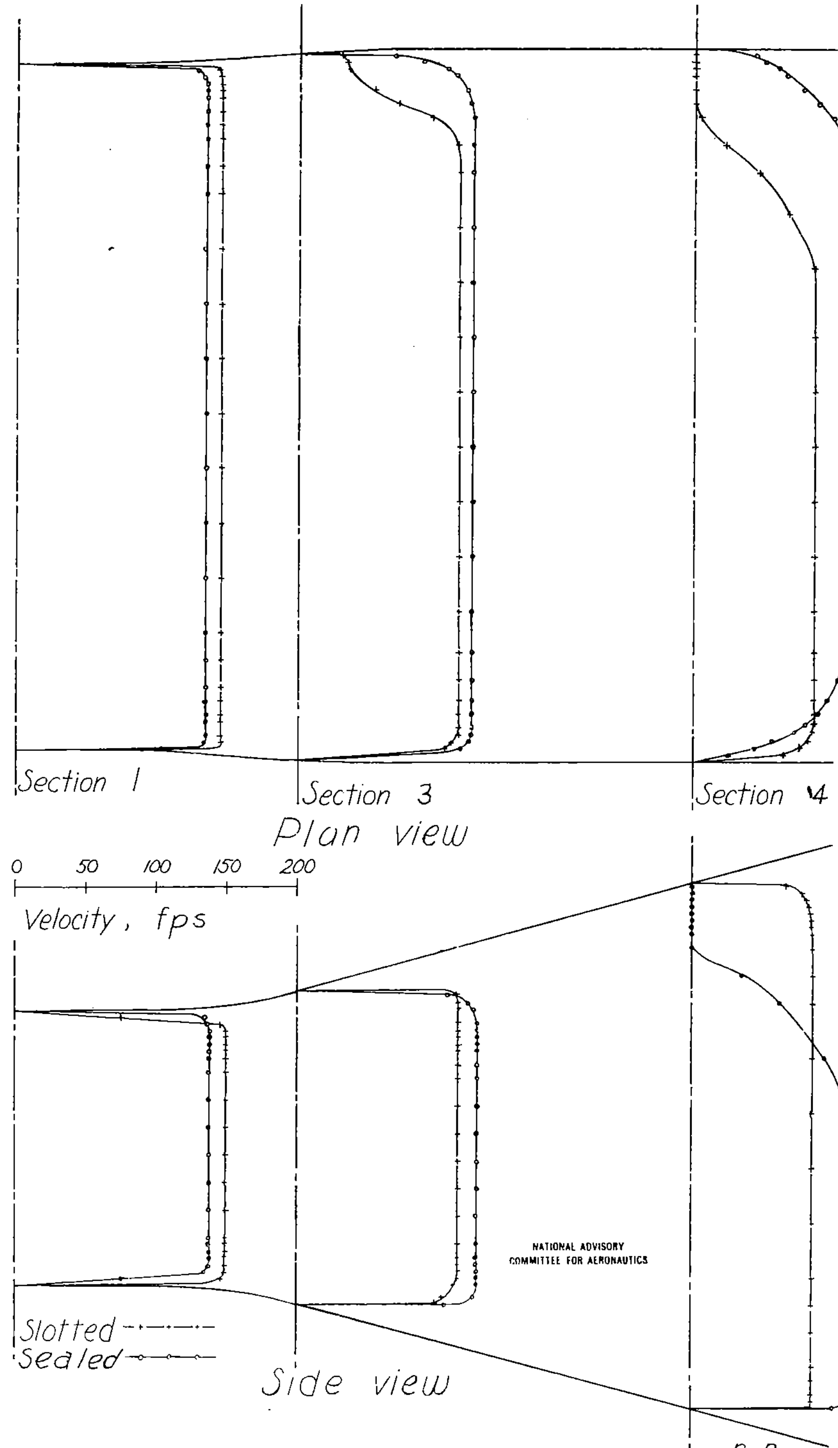
Slot arrangement 4, table V



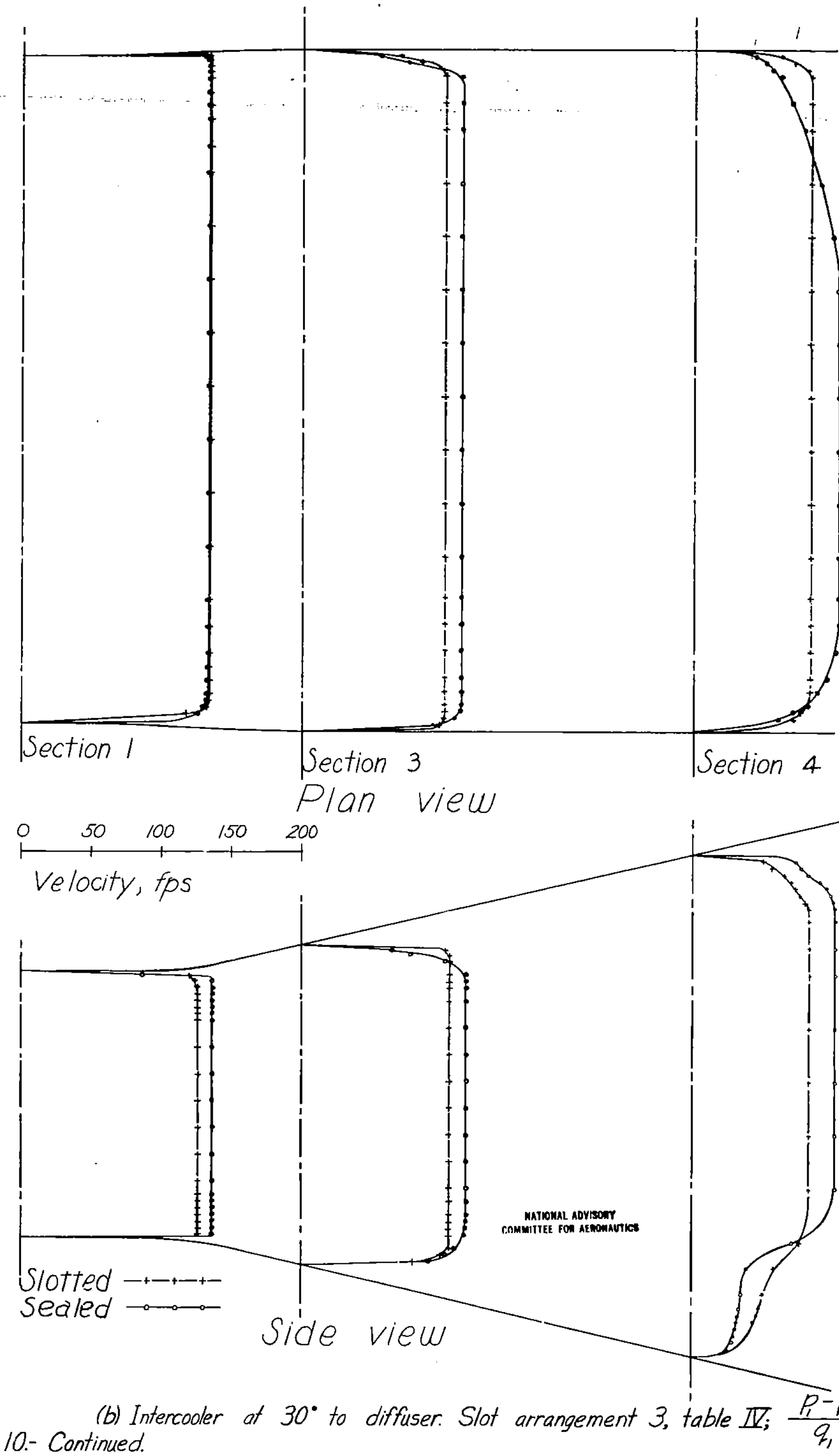
Slot arrangement 8, table V; 20-in. section in front of diffuser

(c) Intercooler at 45° to diffuser.

Figure 9.- Concluded.

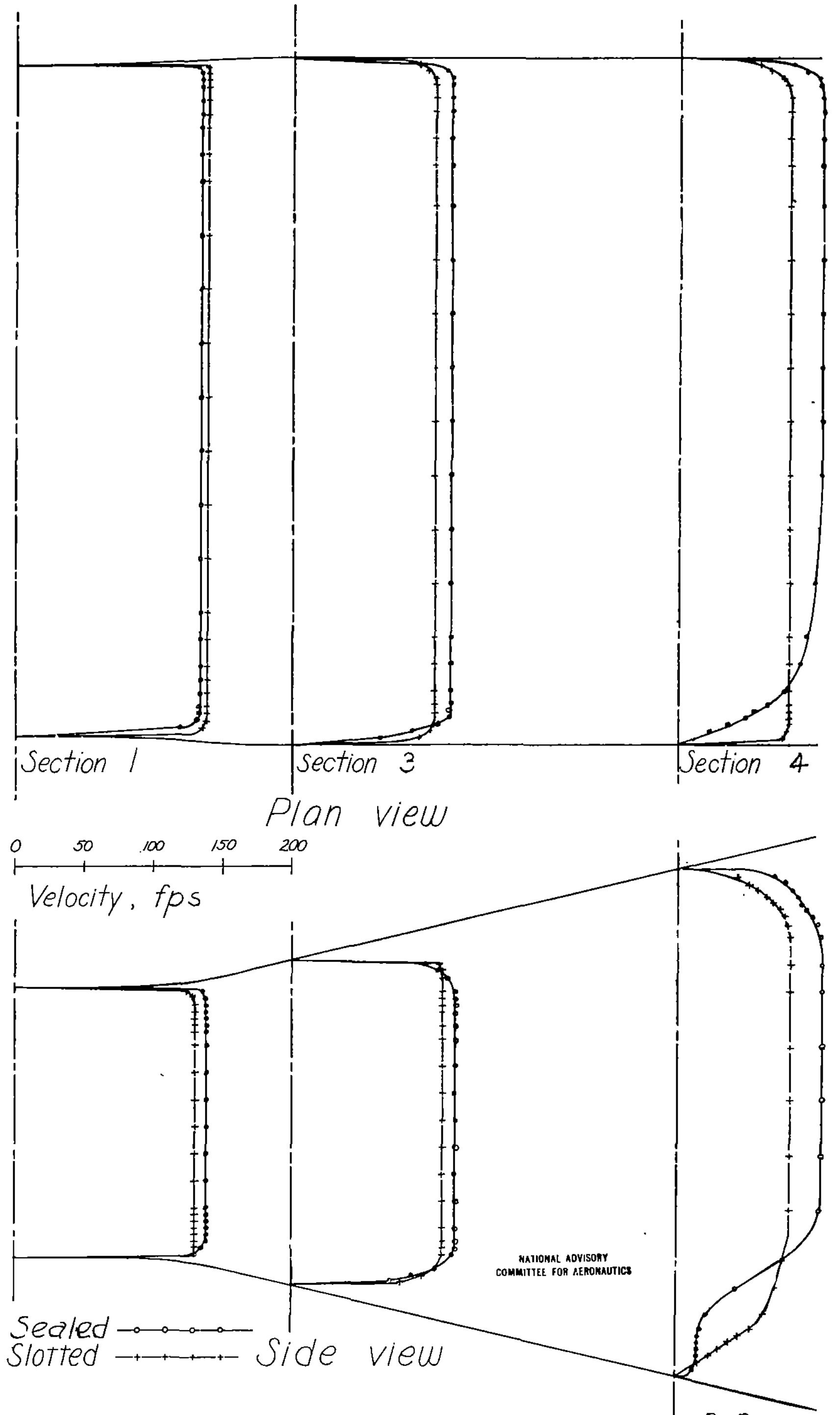


(a) Intercooler at 0° to diffuser. Slot arrangement 2, table III; $\frac{p_1 - p_2}{q_1} = 0.89$.
Figure 10.- Velocity distributions of 30° diffuser with intercooler.

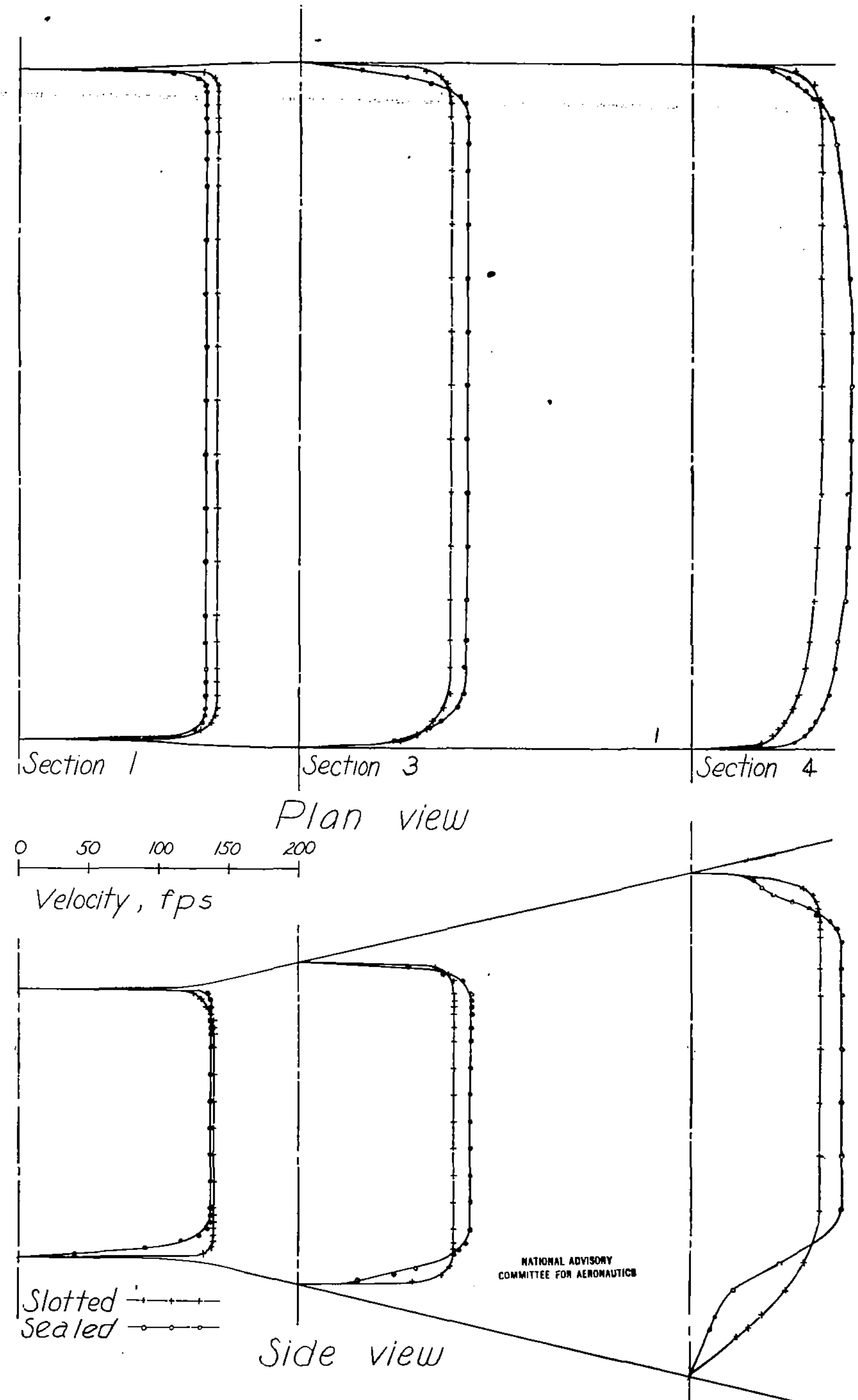


(b) Intercooler at 30° to diffuser. Slot arrangement 3, table IV; $\frac{P_1 - p_0}{q_1} = 1.20$.

Figure 10.- Continued.

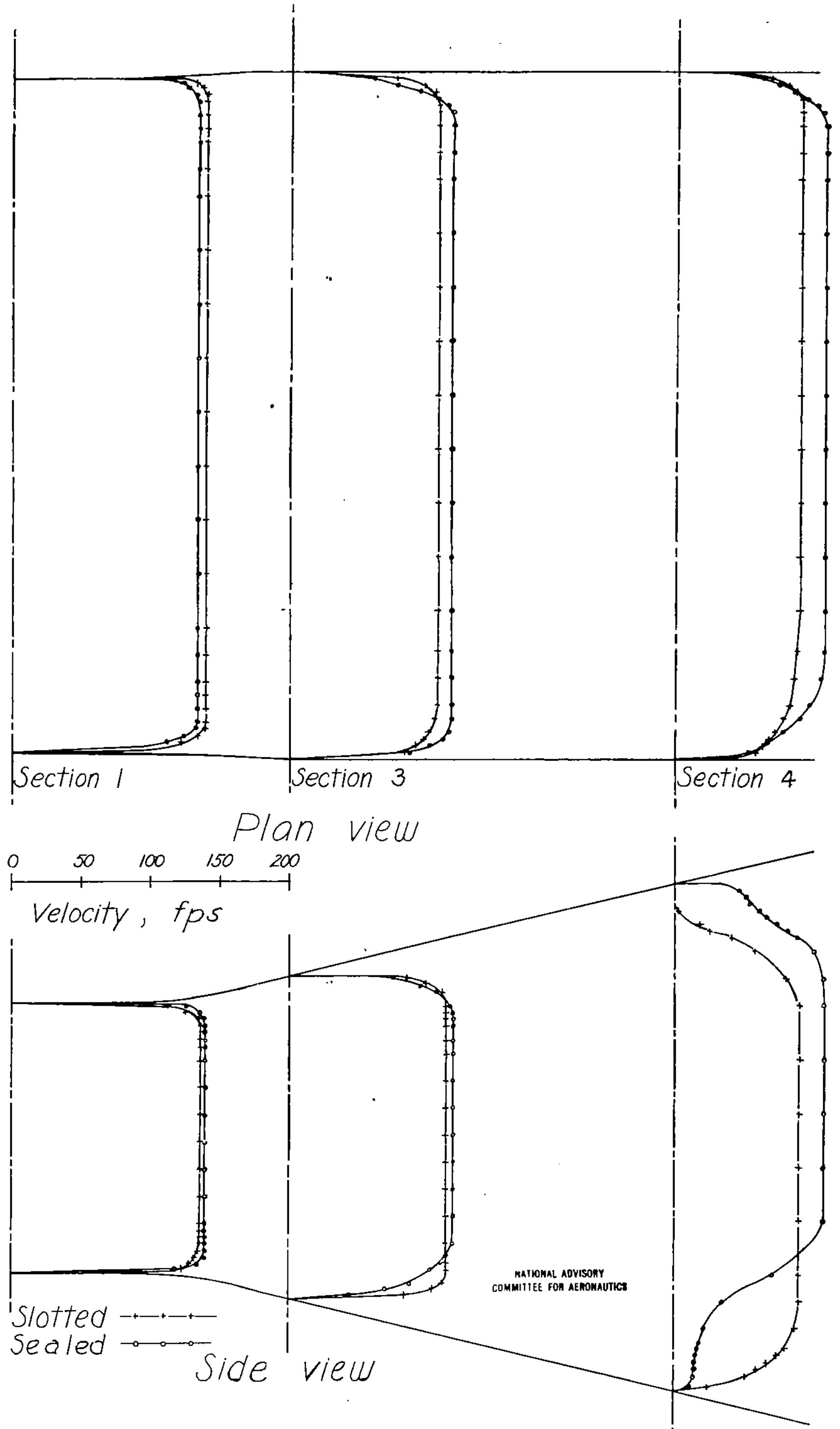


(c) Intercooler at 45° to diffuser. Slot arrangement 4, table V; $\frac{P_1 - P_0}{q_1} = 1.18$.
Figure 10.- Continued.



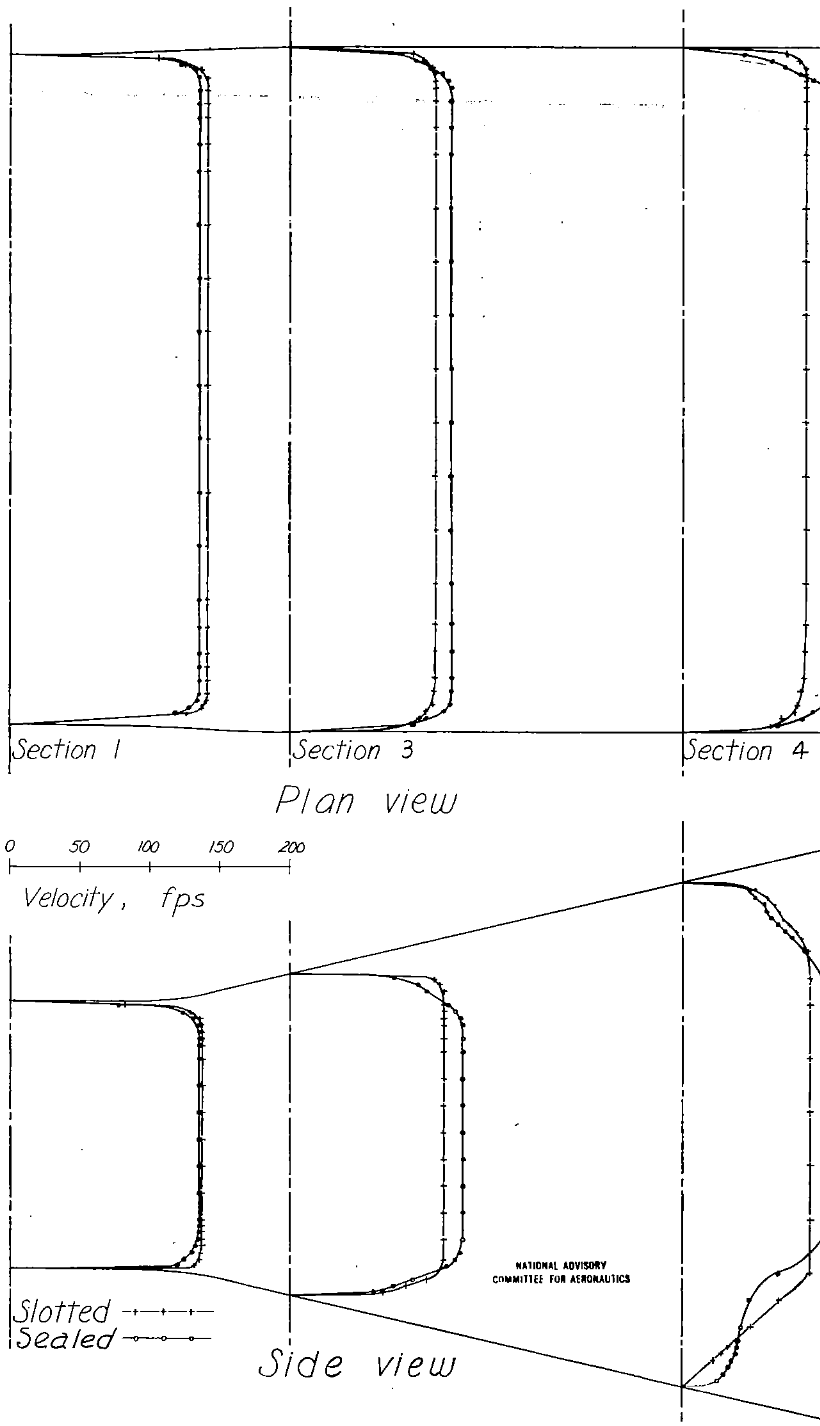
(d) Intercooler at 0° to diffuser; 20-inch straight section in front of diffuser. Slot arrangement 7, table III; $\frac{p_1-p_0}{q_1} = 1.06$.

Figure 10.- Continued.



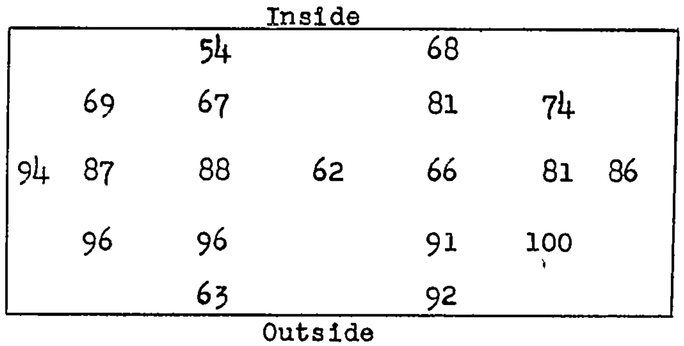
(e) Intercooler at 30° to diffuser; 20-inch straight section in front of diffuser. Slot arrangement 5, table IV; $\frac{P_1 - P_2}{q_1} = 1.34$.

Figure 10.- Continued.

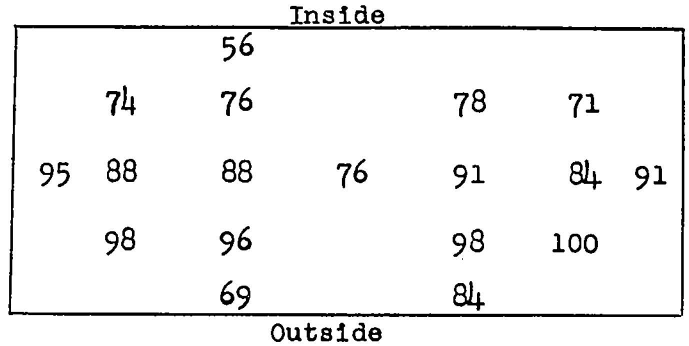


(f) Intercooler 45° to diffuser; 20-inch straight section in front of diffuser. Slot arrangement 8, table V; $\frac{p_1 - p_2}{q_1} = 1.25$.

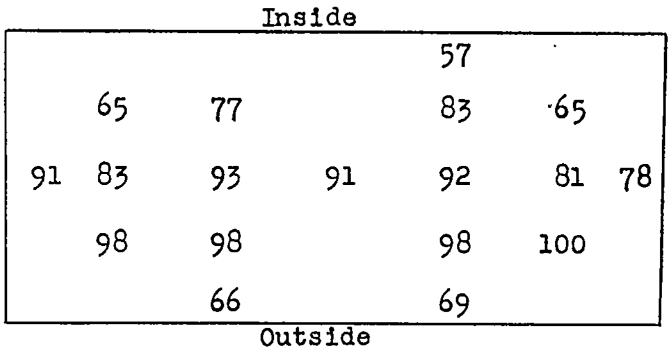
Figure 10.- Concluded.



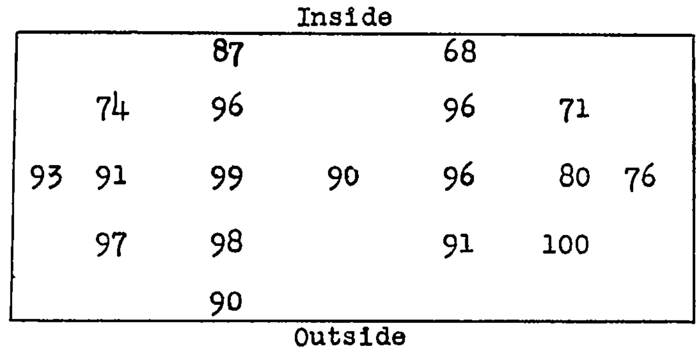
(a) Sealed condition; 6-inch outside radius; substitute 2-inch inside radius.



(b) Slot arrangement 4, table VI; $\frac{p_1 - p_0}{q_1} = 0.63$; 6-inch outside radius.



(c) Sealed condition; 7-inch outside radius; 2-inch inside radius.



(d) Slot arrangement 7, table VI; $\frac{p_1 - p_0}{q_1} = 0.86$; 7-inch outside radius.

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Figure 11.- Dynamic-pressure distribution at section 2 of 90° bends given as percent of maximum dynamic pressure.