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Performance of Square-Edged Orifices and Orifice-Target Combinations as Air Mixers

T. K. Faison, Jr., J. C. Davis and P. R. Achenbach

Building Research Division
Institute for Applied Technology
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Contents

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A study was made at the National Bureau of Standards to determine the effectiveness of the square-edged orifice, or the orifice in combination with a target (circular baffle), for mixing an air stream which was initially nonuniform with respect to temperature. By achieving uniformity of temperature at all points within the cross section of an air stream, instrumentation for measurement might be simplified and a more representative temperature value obtained. Orifices having throat diameters of 8, 12, and 16 in were evaluated in a 24-in circular test duct to determine mixing effectiveness under selected test conditions of temperature distribution and flow rate. Targets of 8, 12, and 16 in in diameter in combination with a 12-in orifice were also investigated under similar conditions.

Graphic material is presented which illustrates how the orifice and orifice-target combinations perform as mixing devices under selected conditions. Results indicate that the 8-in (0.33 diam ratio) orifice effectively diminished the nonuniformity of temperature but only at a high pressure drop across the orifice and that a distance of 4.5 duct diameters was required for mixing.

Key Words: Diameter ratio, mixing effectiveness, square-edged orifice, temperature measurement, temperature pattern.

1. Introduction

The National Bureau of Standards has undertaken a study to determine methods or processes by which nonuniformity of temperature in an air stream in a duct can be corrected by forced mixing. Since the enthalpy of an air water-vapor mixture is related to its temperature and moisture content, the flow of energy represented by the moving air stream can best be determined if the measured values of dry-bulb temperature and dewpoint or wet-bulb temperature are truly representative of the entire air stream. Under conditions where nonuniformity of velocity, temperature, and humidity exist, realistic averages of temperature and humidity are very difficult to obtain. During laboratory tests where moving air is involved, the measurement difficulties due to poor mixing can sometimes be compensated for by taking many temperature measurements throughout the cross section of the air stream. But even when a large number of measurements are taken, the observed values must be evaluated and weighted, with respect to both temperature and velocity. For nonuniform distributions of temperature and velocity, a method of weighting should be used for proper representation of the average temperature of the total mass of air that is passing a measuring station or stations.

A much better method of determining the average air temperature is to produce a high degree of uniformity of the air temperature through use of a mixing device. Determination of the average temperature could then be accomplished by making only a few measurements. If the mixing is good enough, one observation will suffice.

A number of mixing devices are under investigation in this study. This paper, the second in a series of three on the apparatus and mixing devices, presents performance data for the square-edged orifice, and the combination of orifice and target (circular baffle), two methods of mixing which have been in use in laboratories for a number of years.

These methods mix the air principally by a jet action. There has been considerable work done on jet mixing, but most other investigators [1, 2, 3, 4] [1] have studied the mixing of the jet with the surrounding air under unbounded conditions whereas this study is concerned with mixing in a duct. Theoretical and experimental work has been done with both heated and unheated jets. In previous investigations, the jets have been axially symmetrical, whereas the present work deals with an unbalanced distribution of temperature within the air stream.

[1] Figures in brackets indicate the literature references at the end of this paper.

2. Test Apparatus and Procedure

2.1. Temperature Measurements

A test apparatus [5] was designed and built for producing controlled temperature and humidity conditions in an air stream to facilitate measurement of the effectiveness of air mixing devices. A schematic layout of the apparatus is shown in figure 1. A stream of air, maintained at a constant and substantially uniform temperature, was drawn into the apparatus with an inlet blower. The air stream was conditioned to a desired pattern of nonuniformity of temperature in that portion of the apparatus shown in figure 1 as Section A–A. The air stream was not conditioned with respect to humidity for the tests covered in this paper. Temperature measurements were made in a 24-in diam duct at stations upstream and downstream from a mixing device. These measurements provided information about the temperature pattern upstream from the mixer and the resulting distribution downstream. Conditions of nonuniformity at the upstream measuring station were controlled and reproduced from test to test. A mixing device, in this case an orifice, was placed just downstream from the location shown in figure 1 as Section B–B and the air stream of nonuniform temperature was forced through the mixer.

At selected distances downstream from the mixer, measurements were made to determine the temperature distribution as an indicator of the effectiveness of the mixing device in producing uniformity of temperature. By observing the temperature distribution in the duct at each of several stations downstream from the mixer, the progress of the mixing process could be evaluated and the station of optimum mixing could be determined.

A statistical analysis was made of the upstream and downstream temperature values to determine the standard deviations at the respective stations. For each of five sets of temperature determinations recorded in a test, standard deviation values were computed from which mixing effectiveness was calculated. The five effectiveness values were averaged to obtain the effectiveness for a particular test. A value of effectiveness for a mixing device was calculated by subtracting from unity the ratio of downstream to upstream standard deviation. The functions, standard deviation and effectiveness, are shown below:

$$\text{S.D.}=\left[\frac{1}{n-1}\sum(x_i-\bar{x})^2\right]^{1/2}$$

$$\text{Effectiveness}_{(\text{S.D.})}=\left(1-\frac{\text{S.D.}_{\text{DS}}}{\text{S.D.}_{\text{US}}}\right)\times 100\%$$

where:

x_i=individual measurements
$\bar{x}$=arithmetic mean
n=number of measurements
S.D._{DS}=standard deviation downstream
S.D._{US}=standard deviation upstream.

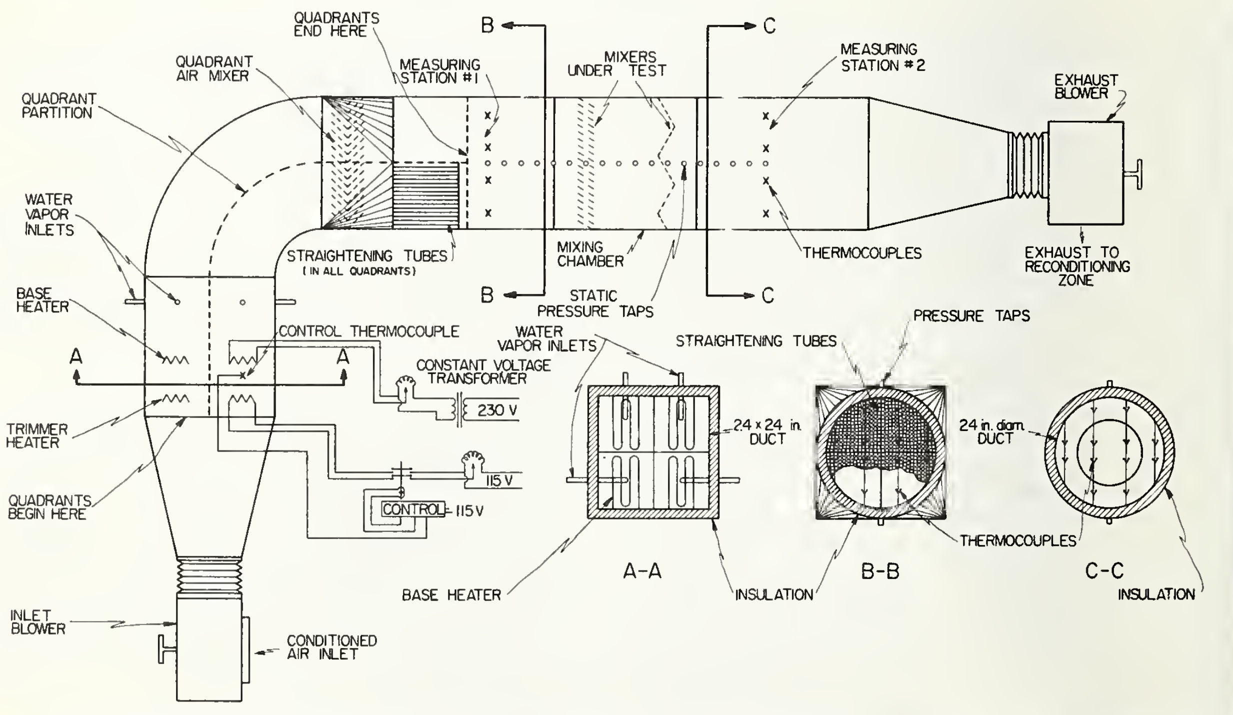

FIGURE 1. *Schematic of the mixing apparatus which produces the test condition and houses the mixing devices to be evaluated.*

The range of values was also found for the sets of upstream and downstream temperatures. An alternate method for determining effectiveness, based on the range, was figured by subtracting from unity the ratio of downstream to upstream ranges. This relationship is shown below:

$$\text{Effectiveness}_{(\text{Range})}=\left(1-\frac{\text{Range}_{\text{DS}}}{\text{Range}_{\text{US}}}\right)\times 100\%$$

$$\text{Range}_{\text{DS}}=(x_{\max}-x_{\min})\ \text{downstream}$$

$$\text{Range}_{\text{US}}=(x_{\max}-x_{\min})\ \text{upstream}$$

This latter method based on the range is simpler to use but the results can be much more affected by variation of a single observation.

Tests were performed under varied physical arrangements such as different orifice sizes and different longitudinal positions of the plane of measurement downstream of the orifice. Tests were also performed under the following varied stream conditions: different temperature patterns, flow rates, and magnitudes of temperature difference. Steady state conditions were maintained throughout the system, a necessary condition for the above formulas to give a valid indication of effectiveness.

The conditioning section of the 24-in square duct upstream of the mixing device was divided into four quadrants for producing distinct and reproducible temperature distributions. The temperature patterns were obtained by means of different electrical energy inputs into the air streams in the quadrants. Most of the tests were performed with a temperature difference between warm and cool quadrants of approximately 3 deg F, with three of the quadrants kept at the higher temperature and the fourth at the lower temperature.

The temperature distribution in the cross-sectional area of the air stream at each station was measured with 24 calibrated copper-constantan thermocouples, fixed in similar patterns at each station. Each thermocouple was soldered to a small washer which, because of its mass, provided damping of small temperature fluctuations. Location of the thermocouples at the upstream measuring station is shown in figure 2. The tubes which served to aline the air stream as it issued from the quadrants toward the upstream measuring station can be seen in the background of figure 2. The enlargement shows a typical assembly of the thermocouple and its holder.

The measuring station upstream from the mixing device was always located at the same place in the test duct and was used to determine the temperature distribution of the air as it left the four quadrants of the duct. The downstream measuring station was movable from test to test; thus, temperature distributions within the cross section of the air stream could be taken at different distances downstream from the mixing device.

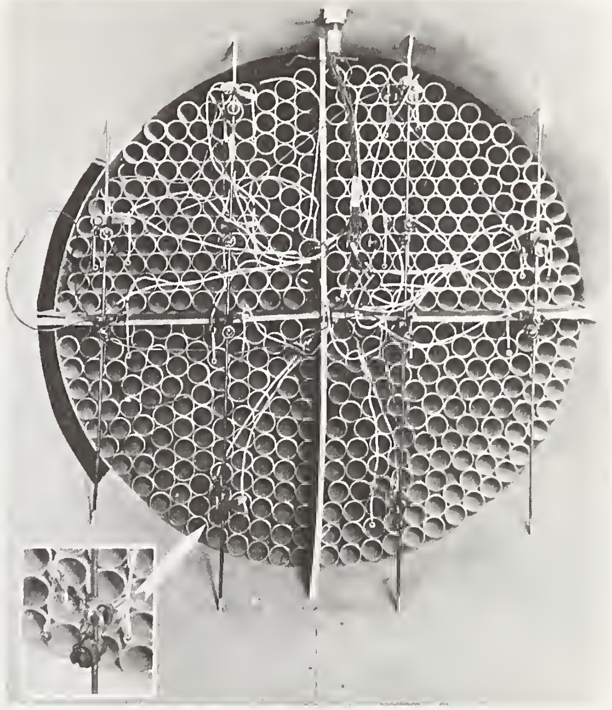

FIGURE 2. *View of the upstream measuring station and detail of the thermocouples and holders.*

Periodically the thermocouples at each measuring station were checked to determine the magnitude of deviation between any two thermocouples at a station. For this purpose the thermocouples were immersed in a container of water under isothermal conditions and the greatest deviation between any 2 of the 24 thermocouples at either station was determined. These differences never exceeded 0.7 μV (equivalent to about 0.03 °F) and are considered adequate for this work. The indicating instrument was a precision manual potentiometer, providing resolution for comparison or difference readings to the nearest 0.1 μV.

2.2. Static Pressure Measurements

Static pressure measurements were taken at 4-in intervals along the length of the duct to determine the variation in pressure from the upstream measuring station to the most remote location of the downstream measuring station. Figure 3 shows a characteristic static pressure profile for a square-edged orifice which illustrates the static pressure regain and the location that has proved to be the approximate location of optimum mixing.

It was found in this study that no appreciable increase in mixing effectiveness was observed beyond the station where maximum regain occurred. Static pressure regain for the orifice has been studied and described in other publications [6] and the data gathered in this study were in good agreement with previous work.

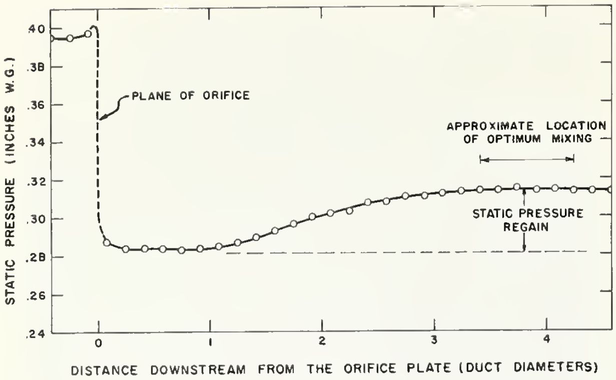

FIGURE 3. *Static pressure profile for the 0.50 diam ratio orifice.*

2.3. Flow Visualization

To gain knowledge of the pattern of flow as the air passed through and on downstream from the mixing device, a method of flow visualization was devised, using a smaller apparatus and dimensionally scaled orifices or orifices with targets, to demonstrate the process of mixing. Smoke was used to simulate conditions of nonuniformity which were present in the large apparatus. By proper lighting, the mixing process was clearly visible through an 8-in diam plastic duct making it possible to study the stream qualitatively as it issued through the orifice in the form of a jet, and to observe the entraining of the air around the jet. In the case of the orifice, movement of the smoke in the area surrounding the jet could be followed in the low pressure region near the downstream face of the orifice plate. In the case of the orifice-target combination, the movement of the air in the wake of the target was observed. From these observations a qualitative determination of the effectiveness of the mixers was gained.

Less definitive techniques of flow visualization were also used, such as observation of thread flutter, which served to give a general profile of intensity and direction of flow at a number of cross sections along the length of the apparatus. Shown in figure 4 are sketches of the apparent flow pattern in the duct when using these techniques with the

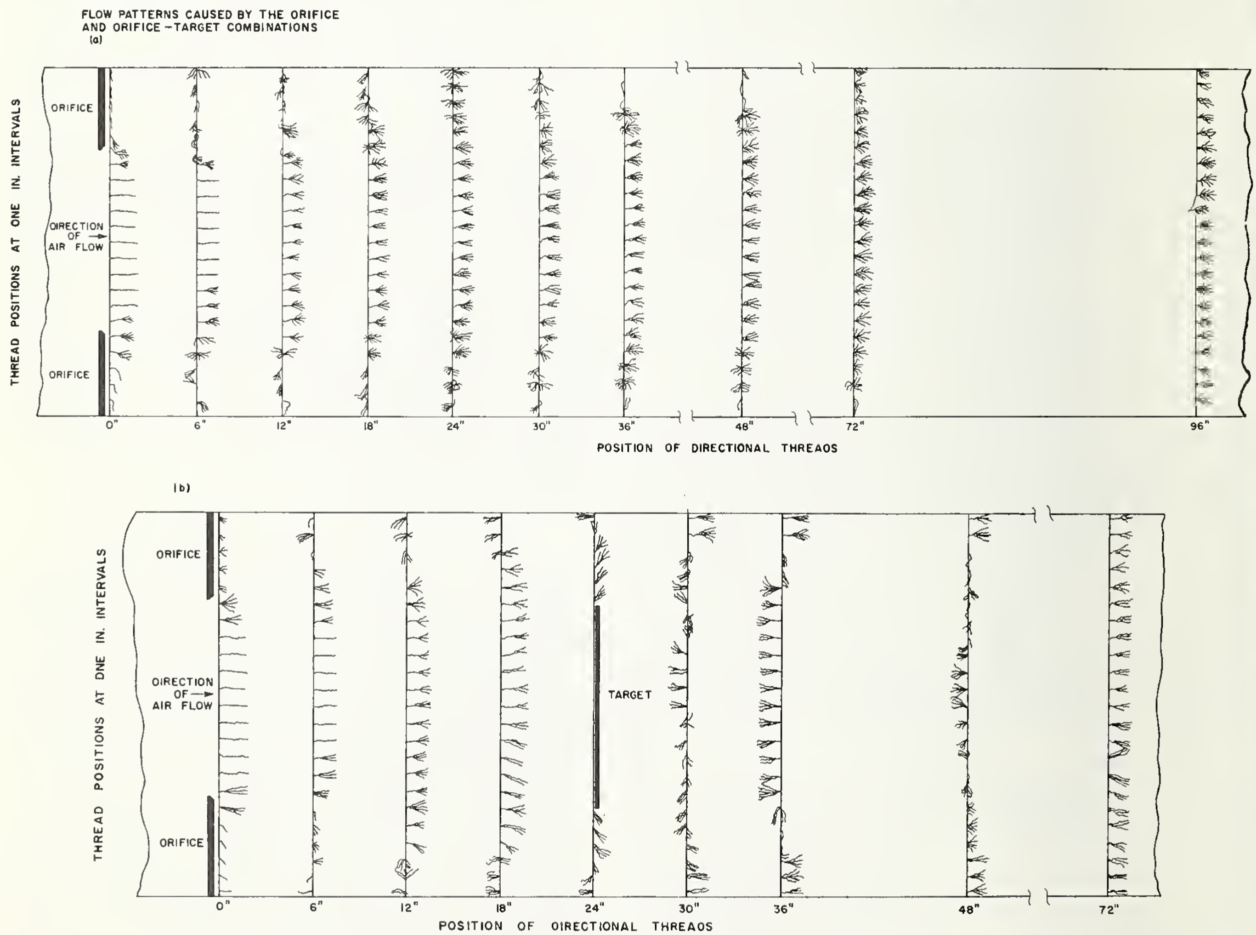

FIGURE 4. *Flow patterns caused by the orifice and orifice-target combinations.*

(a) 12-in orifice
(b) 12-in orifice in combination with a 12-in target

orifice and orifice-target combination. The flutter and change in direction of the air flow is indicated by multiple positions of the single thread used at each point in the cross section of the duct. These patterns were consistent with those obtained through flow visualization with smoke, but were not as dramatic nor definitive in presentation of detail and sharpness of outline.

3. Description of Mixers

The orifices used in these tests conform to the specifications set forth for the "German Standard Orifice 1939" [7]. This type of orifice has been the subject of extensive research both in Germany and the United States. Studies of the square-edged orifice were made at the National Bureau of Standards [8] to determine the flow characteristics, such as compressibility, discharge coefficients, and pressure distribution. Figure 5 shows the recommended dimensions of the square-edged orifice plate.

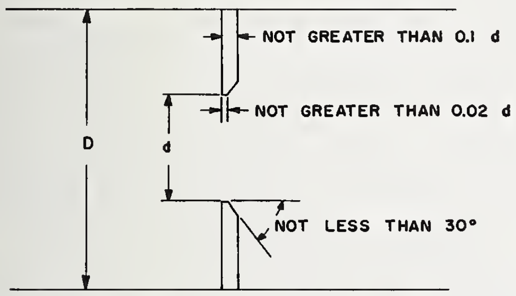

FIGURE 5. *Dimensions for "German Standard Orifice 1939" (Pressure taps ommitted).*

The orifices were made of 3/8-in thick aluminum plate. The diameter ratios of the orifice plates were 0.33, 0.50, and 0.67, with their throat diameters being 8, 12, and 16 in, respectively. The throats were machined so that the leading edge of each orifice was sharp and square. The downstream edge of each throat was beveled at a 45° angle to give a throat thickness of 1/16 in. Each of the orifices could be fitted into a housing which was securely attached to the duct wall, making them readily interchangeable, and assuring that the orifice throat was concentric with the duct.

The targets were also 8, 12, and 16 in in diameter and were made of 1/16-in steel plate. They were supported from the duct wall by four struts providing a concentric placement within the duct. The target could be easily relocated at various positions downstream from the orifice simply by adjusting the compression of the struts against the duct wall. Figure 6 shows the position of a target in combination with the orifice.

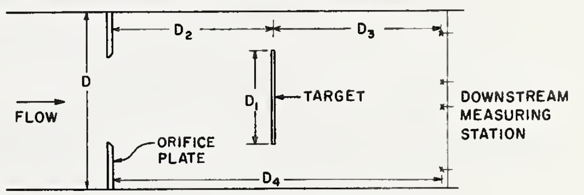

FIGURE 6. *Typical assembly of the orifice-target combinations.*

4. Test Conditions

For determining the effectiveness of mixing devices as related to the temperature differences in an air stream, tests were performed using the initial temperature patterns shown in figure 7. After establishing steady operating conditions, the test for mixer effectiveness for a given set of conditions was conducted over a one-hour period with temperature readings taken on the quarter-hour. An analysis of the five sets of readings gave standard deviations as described earlier. Preliminary tests [5] with no mixing device in the duct showed that mixing caused by the inherent turbulence and duct configuration was less than 7 percent when calculated by the range method of figuring effectiveness. When calculated by the standard deviation method, a higher value of 17 percent was obtained for this natural mixing because this method takes into account all of the observed values. Some mixing which is not indicated by the range method does occur at the interface between the streams of different temperature air.

The static pressure profiles along the duct and air flow rates were measured for each test, except in the cases where only the measuring station was moved to provide variation in distance between stations. Air flow rates were determined by means of pitot-static probe traverses in a rectangular duct located upstream from the inlet blower. The relative humidity corresponded to ambient laboratory conditions at all times.

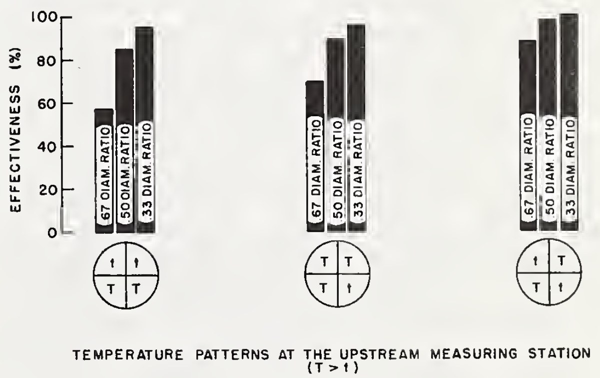

FIGURE 7. *Mixing effectiveness of the three orifices as related to temperature pattern and orifice-duct diameter ratio d/D.*

During the evaluation of the orifice mixers, the following items were varied, one at a time:

(1) Temperature pattern—as shown in figure 7.
(2) Distance from orifice to downstream measuring station.
(3) Magniture of temperature difference upstream of the mixer.
(4) Air flow rate.

When the orifice-target combinations were studied the following parameters were varied in addition to those listed above for the orifices alone:

(1) Distance from the orifice to the target.
(2) Target size in combination with a particular orifice.

5. Performance of Mixers

5.1. Orifices

All values of mixing effectiveness presented are based on the standard deviation determination, except for the summary tables where results of both methods are listed. The effectiveness of the orifices for the three temperature patterns is shown graphically in figure 7. A study of the bar graphs in figure 7 indicates that the mixing effectiveness increased as the diameter ratio of the orifices decreased; it increased as the interface area between the cold and warm elements of the air stream increased; and it increased as the mass or size of the colder elements of the air stream decreased. The data in figure 7 suggests that the orifice-duct diameter ratio may be the most significant of these three parameters, and the interface area between the cold and warm elements of next importance. Most of the tests were performed with the temperature pattern illustrated in the center of figure 7.

Through flow visualization, in the smaller scaled apparatus, a qualitative observation of the spreading and mixing of the jet with the surrounding fluid was made. It was discernible in this apparatus using smoke as an indicator, that the smaller orifices with diameter ratios of 0.33 and 0.50 provided better mixing than the orifice with a diameter ratio of 0.67. Measurements were then taken in the large apparatus to indicate the temperature distribution at selected distances downstream from the mixer to determine in a quantitative manner the extent of mixing at various points after the air had passed through the orifice.

Figure 8 illustrates the effect of varying the magnitude of air temperature difference over the range of 0.5 to 20.0 deg F at the mixer inlet as related to mixing effectiveness. It is evident from the findings that the effectiveness was not materially affected by the variation in magnitude of the temperature difference. As a consequence the 3 deg F difference was chosen for use in most tests because it presented a measurable difference before and after mixing, and the condition was easily controlled. This difference in temperature was sufficiently large compared with the magnitude of the errors of the instrumentation to give reliable effectiveness values. The anomalous point on figure 8 for the 8-in orifice at 0.5 deg F temperature difference between the quadrants was probably caused by the greater ratio of measurement error to temperature difference for this test condition. No such anomalies appear in the curves for any of the orifices at temperature differences larger than 1.5 deg F.

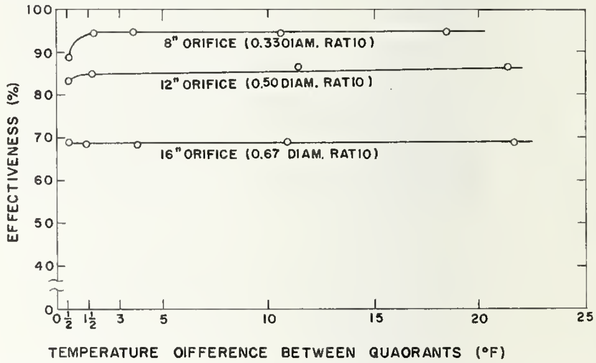

Figure 8. *Effect of air temperature difference at mixer inlet upon the performance of the orifices.*

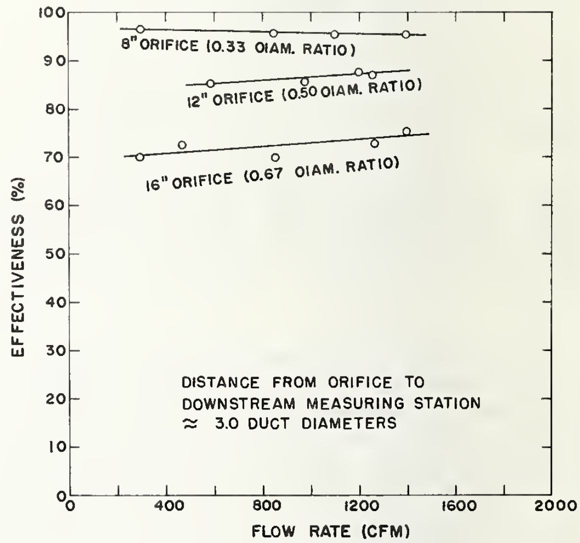

Figure 9. *Performance of the orifices over a selected range of flow rates.*

Air flow rates were adjusted from 300 to 1400 cfm during the investigation. It is shown by figure 9 that there was less than 5 percent change in effectiveness for the 0.67 and 0.50 diam ratio orifices and much less change for the 0.33 diam ratio orifice as the flow rate was varied over this range. The Reynolds number in the throat of the orifices varied between 3×10^4 and 3×10^5 for the range of flows used. Plots of the effectiveness as a function of Reynolds number give essentially the same relationship as shown in figure 9 for effectiveness versus flow rate.

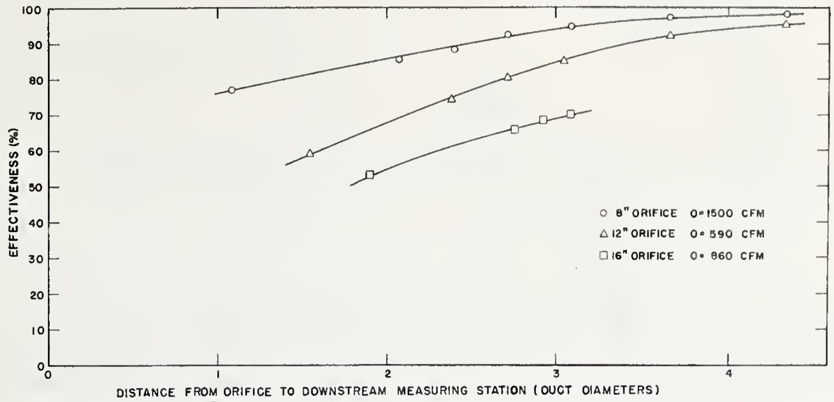

Figure 10. *Mixer effectiveness as the distance from the orifice to the measuring station is varied.*

Figure 10 shows the mixing effectiveness of the three orifices in relation to the distance from the plane of the orifice. These curves show that most of the mixing was accomplished in the first three duct diameters following the mixer. However, to achieve best mixing with an orifice, an orifice with a diameter ratio of 0.50 or less should be used and it should be placed at least 4 duct diameters ahead of the point where uniformity is required.

It should be noted in figure 10 that the air flow rates used for the three orifices were different and that the flow rates were not proportional to orifice area. However, considering the small effect of air flow rate on mixer effectiveness revealed in figure 9, the comparison made of the three orifices in figure 10 for different air flow rates is reasonably valid. That is, the relative positions of the three curves would be altered only slightly if all of the data had been taken at the same air flow rate.

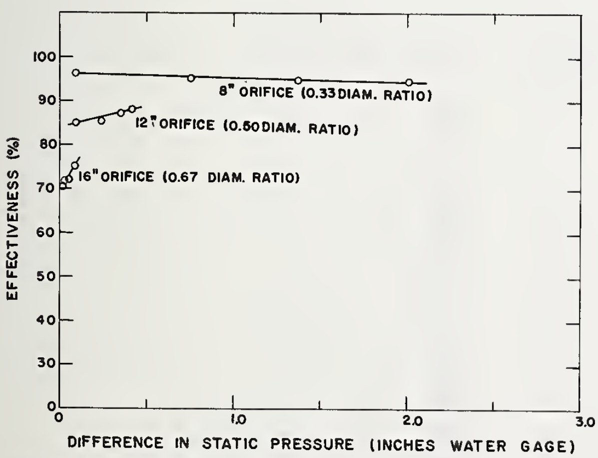

Figure 11. *Performance of the orifices as a function of pressure drop across the orifice.*

Usually when using any type of mixing device, in addition to the length required for mixing, an important factor is the pressure drop across the device. Figure 11 shows the effectiveness as related to pressure drop for the three orifices. As shown in figures 9 and 11, there was very little change in performance of the 0.33 diam ratio orifice over the range of flow and pressure drop for these tests. The 0.50 and 0.67 diam ratio orifices did exhibit small increases in effectiveness for increases in flow rate and pressure drop. Thus, these figures show, in the range of these tests, effectiveness depends largely on the diameter ratio rather than the flow rate or pressure drop. Further, there appears to be a practical limit to the increase in effectiveness that could be gained at the expense of increased pressure losses by utilizing orifices of smaller than 0.33 diam ratio.

Figures 12 and 13 illustrate the performance of the 0.50 and 0.33 diam ratio orifices, respectively, at several stations downstream from the mixer location. Shown in these figures to the left of the plane of the orifice are the temperature pattern and the temperature distribution upstream from the mixing device showing an approximate temperature difference of 3 deg F. To the right of the mixer are distributions which show progressive improvement in uniformity of temperature as the air passes down the duct. These illustrations are consistent with the curves of figure 10 which show mixing effectiveness as a function of distance from the orifice to the downstream measuring station. The "temperature profiles" shown in figures 12 and 13 for the various stations of observation should not be regarded as the temperature distribution along any diameter of the test duct, but rather a combined linear presentation of the temperatures observed in the four quadrants of the test duct. Tables 1(a), 1(b), and 1(c) are tabulations of the conditions under which each test was run and the performance of each device under these conditions.

5.2. Orifice-Target Combinations

The study of the orifice-target combinations was carried out using the 0.50 diam ratio orifice in combination with the different targets. Figure 14

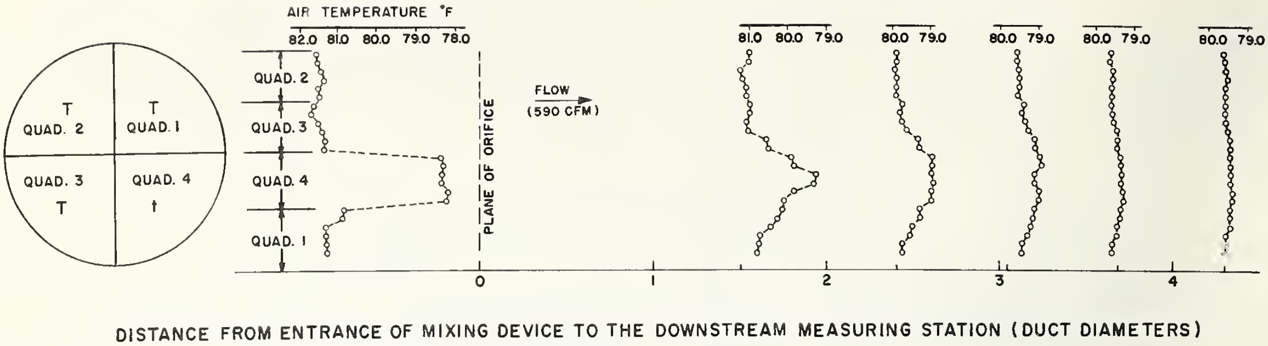

Figure 12. *Temperature distribution of air stream at points upstream and downstream from the 0.50 diam ratio orifice.*

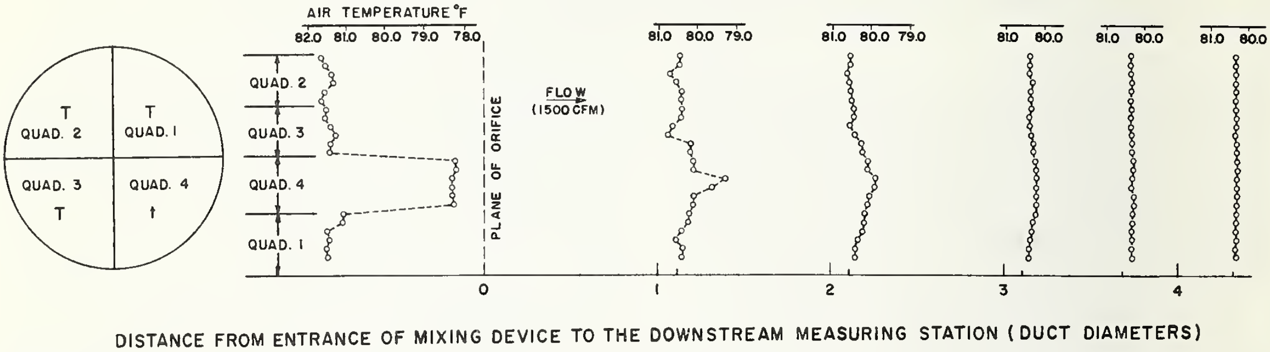

Figure 13. *Temperature distribution of air stream at points upstream and downstream from the 0.33 diam ratio orifice.*

Table 1. SUMMARY OF TEST CONDITIONS AND PERFORMANCE OF THE SQUARE-EDGED ORIFICE

1(a) 0.67 diameter ratio orifice (16-inch orifice)

Test No.	Temperature Difference (°F)	Flow Rate (cfm)	Pressure Drop Across Mixer (in. W.G.)	Distance from Orifice to Measuring Station (in.)	(Duct Diam.)	Temp. Pattern*	% Effectiveness Range	Std.Dev.
1	3.9	1700	.14	62	2.6		65.4	69.4
2	3.9	1700	.14	62	2.6		44.8	56.9
3	3.6	1700	.14	62	2.6		80.1	87.0
4	.6	860	.04	70	2.9		64.7	69.2
5	1.4	860	.04	70	2.9		63.6	68.8
6	10.9	860	.04	70	2.9		61.1	69.0
7	21.6	860	.04	70	2.9		58.3	68.7
8	3.8	860	.04	74	3.1		63.7	69.9
9	3.2	860	.04	66	2.7		60.7	65.9
10	3.8	860	.04	70	2.9		61.9	68.6
11	3.8	860	.04	46	1.9		48.4	53.5
12	3.8	1270	.06	74	3.1		66.7	72.3
13	3.7	1400	.09	74	3.1		71.9	75.1
14	3.5	470	.01	74	3.1		66.3	72.2
15	3.3	300	-	74	3.1		60.3	69.8

* Shaded area indicates a different temperature from unshaded area.

1(b) 0.50 diameter ratio orifice (12-inch orifice)

Test No.	Temperature Difference (°F)	Flow Rate (cfm)	Pressure Drop Across Mixer (in. W.G.)	Distance from Orifice to Measuring Station (in.)	(Duct Diam.)	Temp. Pattern*	% Effectiveness Range	Std.Dev.
1	3.5	1260	.42	73	3.0		86.7	88.4
2	3.7	1260	.42	73	3.0		95.4	97.2
3	3.7	1260	.42	73	3.0		76.0	84.8
4	.6	590	.10	73	3.0		81.8	83.5
5	1.7	590	.10	73	3.0		83.7	85.4
6	11.4	590	.10	73	3.0		83.9	86.8
7	21.3	590	.10	73	3.0		83.0	86.6
8	3.6	590	.10	65	2.7		77.9	80.4
9	3.6	590	.10	57	2.4		72.1	74.3
10	3.9	590	.10	37	1.5		48.4	59.3
11	3.8	590	.10	73	3.0		82.0	85.1
12	3.4	980	.25	73	3.0		83.6	85.5
13	3.5	1200	.36	73	3.0		86.2	87.4
14	3.5	590	.10	88	3.7		90.1	92.0
15	3.6	590	.10	104	4.3		93.7	95.2

* Shaded area indicates a different temperature from unshaded area.

1(c) 0.33 diameter ratio orifice (8-inch orifice)

Test No.	Temperature Difference (°F)	Flow Rate (cfm)	Pressure Drop Across Mixer (in. W.G.)	Distance from Orifice to Measuring Station (in.)	(Duct Diam.)	Temp. Pattern*	% Effectiveness Range	Std.Dev.
1	3.7	1100	1.37	74	3.1		94.2	95.0
2	3.4	1100	1.37	74	3.1		97.9	98.7
3	3.7	1100	1.37	74	3.1		91.1	94.6
4	3.9	850	.76	74	3.1		93.8	95.1
5	3.6	1500	2.01	74	3.1		93.7	94.9
6	.6	1500	2.01	74	3.1		85.5	89.1
7	1.8	1500	2.01	74	3.1		93.3	94.8
8	10.6	1500	2.01	74	3.1		93.5	94.6
9	18.4	1500	2.01	74	3.1		93.6	94.7
10	3.6	1500	2.01	66	2.7		90.9	92.5
11	3.6	1500	2.01	58	2.4		85.3	88.6
12	3.6	1500	2.01	50	2.1		79.9	85.5
13	3.5	1500	2.01	26	1.1		57.6	77.1
14	3.4	300	.10	74	3.1		95.5	96.3
15	3.6	1500	2.01	104	4.3		97.8	98.2
16	3.4	1500	2.01	88	3.7		96.2	97.1

*Shaded area indicates a different temperature from unshaded area.

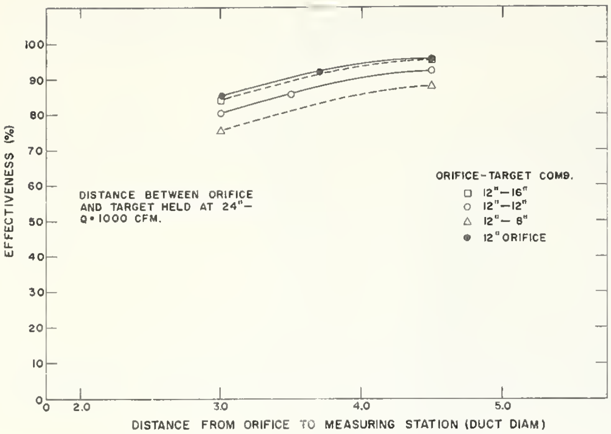

FIGURE 14. *Performance of the combination orifice-target mixer at selected points downstream and of the same orifice alone.*

shows the performance of three combinations under similar conditions. Tests were made to determine the performance of the orifice-target combinations when the distance between the orifice and target was varied. Two series of tests were performed, one in which the overall distance from the orifice to the downstream measuring station was held constant and the other in which the distance from the target to the downstream measuring station was constant. The results showed that location of the target one duct diameter from the orifice was a reasonable choice. Over the range of distances used for the tests there was no improvement over the plain orifice for any of the combinations of the 0.50 diam ratio orifice with each of the three targets. Figure 15 illustrates the magnitude of the pressure drop across the 0.50 diam ratio orifice and the same orifice plus combinations of the 8-, 12-, and 16-in targets. This shows that there was a penalty of greater pressure drop without any accompanying increase in effectiveness.

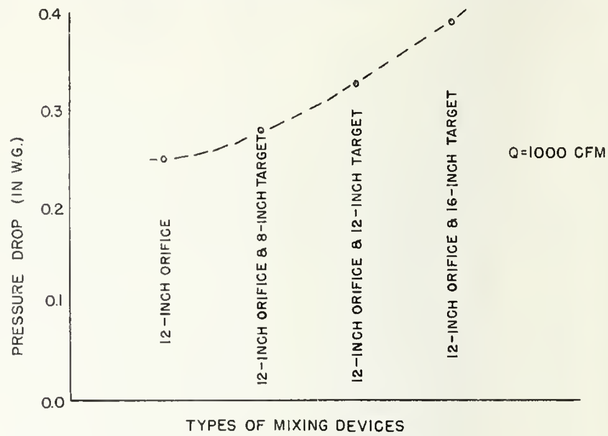

FIGURE 15. *Pressure drop across the orifice and orifice-target combinations for a flow rate of 1000 cfm.*

Figure 16 illustrates the performance of the orifice-target combinations in terms of temperature patterns just as figures 12 and 13 did for the orifices without the target. Since these initial investigations showed little or no improvement of the orifice-target combinations over the plain orifice, this phase of the study was curtailed. Table 2 is a summary tabulation of the conditions under which the orifice-target combinations were tested and the performance observed at each test condition.

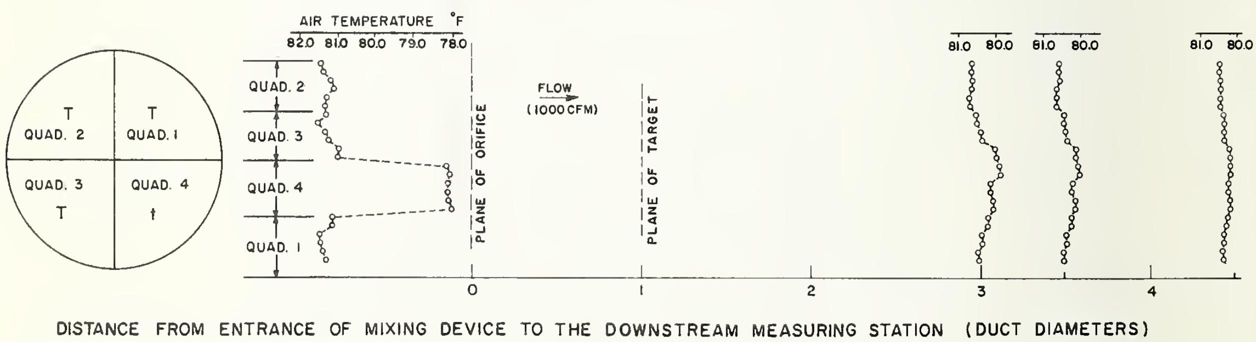

FIGURE 16. *Temperature distribution of air stream at points upstream and downstream from the mixing device (0.50 diam ratio orifice and 12-in target combination).*

TABLE 2 SUMMARY OF TEST CONDITIONS AND PERFORMANCE OF THE ORIFICE-TARGET COMBINATIONS

Orifice-Target Combinations

Test No.	Temperature Difference (°F)	Flow Rate (cfm)	D_1 Target Diameter (in.)	D_1 Target Diameter (D_1/D)*	D_2 Dist. from Orifice to Target (in.)	D_2 Dist. from Orifice to Target (Duct Diam.)	D_3 Dist. from Target to Meas. Stat. (in.)	D_3 Dist. from Target to Meas. Stat. (Duct Diam.)	D_4 Overall Distance (in.)	D_4 Overall Distance (Duct Diam.)	Temp. Pattern**	% Effectiveness Range	% Effectiveness Std. Dev.
1	3.3	1000	16	.67	24	1.0	48	2.0	72	3.0		79.2	84.0
2	3.6	1000	16	.67	24	1.0	84	3.5	108	4.5		94.1	95.6
3	3.5	1000	8	.33	24	1.0	84	3.5	108	4.5		84.4	87.9
4	3.5	1000	8	.33	24	1.0	48	2.0	72	3.0		69.6	75.1
5	3.3	1000	12	.50	24	1.0	48	2.0	72	3.0		74.5	80.2
6	3.5	1000	12	.50	12	.5	48	2.0	60	2.5		77.3	82.1
7	3.6	1000	12	.50	36	1.5	48	2.0	84	3.5		78.5	82.3
8	3.6	1000	12	.50	48	2.0	48	2.0	96	4.0		82.3	85.4
9	3.5	1300	12	.50	24	1.0	60	2.5	84	3.5		83.0	85.7
10	3.6	1000	12	.50	24	1.0	60	2.5	84	3.5		82.6	86.3
11	3.4	1000	12	.50	24	1.0	84	3.5	108	4.5		90.4	92.3
12	3.5	1000	12	.50	36	1.5	72	3.0	108	4.5		87.5	89.7

* D = diameter of duct; D_1 = diameter of target.

** Shaded area indicates a temperature different from the unshaded area.

6. Conclusion

The results of this investigation showed that an orifice having a diameter ratio of approximately 0.33 was consistently more effective over the distance tested in reducing the thermal differences in an unmixed air stream. However, the mixing process was accompanied by a high pressure drop across the mixer. If the pressure drop can be tolerated, temperature nonuniformity could be reduced to 3 or 4 percent of its original value, at a distance of approximately 4.5 duct diameters downstream from the orifice. The study indicated that diameter ratio was the most important parameter affecting the mixing effectiveness but that the interface area between cold and warm elements of the air stream and the size of the nonisothermal elements also had a bearing on the mixing process. The performance of the orifice-target combinations showed no improvement over the plain orifice even when using a target as large as two-thirds of the duct diameter.

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