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# DUCT VELOCITY PROFILES AND THE PLACEMENT OF AIR CONTROL SENSORS

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## ABSTRACT

*Pitot tubes were used to determine air velocities downstream of 69 sheet metal duct fittings, including elbows, conical contractions, conical diffusers, round-to-round junctions, and rectangular-toround junctions. For target mass-average velocities of 1000 and 2500 fpm, centerline velocities were measured at distances of 1, 2, 4, 6, and 10 diameters downstream of the fittings. Vertical and horizontal velocity profiles were obtained at the same stations for a target mass-average velocity of 1750 fpm. For junctions, measurements were made over a range of main-to-branch flow rate ratios. For one elbow and two tees, profiles were also obtained at downstream distances larger than 10 diameters.*

*Results are expressed as the ratio of measured velocity to average velocity. Flow is not fully developed for any case. Flow rate calculations using profile data for 20 cases yield large errors at 1 diameter downstream of any fitting; however, the error is significantly lower at the 10-diameter station. Typical vertical and horizontal profiles at each measuring station are shown graphically. Measured centerline velocities are tabulated.*

*The identification of the velocity profiles leaving these fittings is of particular importance in locating VAV terminal units within a duct system. The control accuracies of these terminals cannot be expected to be any greater than the accuracy of measurement of the parameter they are controlling, in this case velocity or velocity pressure. The data obtained in this study offer valuable information regarding the optimal location of these measuring and controlling devices, as well as the expected accuracies of measurement and, thus, control.*

## INTRODUCTION

The primary objective of the work reported in this paper was to measure centerline velocity at distances of 1, 2, 4, 6, and 10 diameters ($D$) downstream of 69 HVAC sheet metal duct fittings including elbows, conical contractions, conical diffusers, roundto-round junctions, and rectangular-to-round junctions. Only centerline velocities were measured for target mass-average velocities of 1000 and 2500 fpm, while velocity profiles were obtained via traverses for a target mass-average velocity of 1750 fpm. Detailed descriptions of the work, a complete listing of all data, and plots of vertical and horizontal profiles are given in Griggs et al. (1987).

A secondary objective of this study was to apply the data obtained through the testing phase to predict optimal location of singlepoint flow-measuring devices and to estimate the relative accuracy that might be expected under optimal and less than optimal, but more realistic, conditions. Although most pneumatically controlled terminal units currently utilize some type of flow-averaging sensor with multiple pick-up points, many electronically controlled units still offer only a single-point pick-up. This collection of data, obtained at various distances downstream from the fittings and at various main/branch duct velocities, enables certain conclusions to be formed regarding the selection of optimal sensor locations and identifies limitations of the single-point sensor accuracy when subjected to certain take-off and operational conditions. The data do not cover velocity patterns from disturbances such as dampers and flexible duct.

## EXPERIMENTAL SYSTEM

Air flow through the duct system was provided by a centrifugal fan driven by a 30-hp motor. Flow rates were determined from measurements of pressure drop across a set of spun aluminum, longradius, ASME-type nozzles mounted within a plenum. Figure 1 is a schematic of the system, configured for tests with branch-type fittings. A sheet metal transition connected the fan outlet to the plenum inlet. Air was dumped from ports on both sides of the transition between the fan and plenum to control flow rate. A 24 to 14/10-in.-diameter transition was used between the plenum and an entrance length of 14- or 10-in.-diameter duct. A second transition was used between the entrance section and the test system duct. A flow straightener, fabricated in accordance with ASHRAE Standard 51-1985 (ASHRAE 1985a), was placed in one section of the upstream 14- or 10-in.-diameter duct. A sufficient length of test system duct was placed upstream of the fitting to provide fully developed flow at the fitting entrance. The length was greater in all cases than that calculated by

$$L_e/D \cong 4.4\,Re_D^{1/6} \qquad (1)$$

Equation 1 is given by White (1986) to estimate the length required for turbulent flow to develop.

Nozzles having nominal diameters of 4, 6, and 8 inches were used in determining the supply flow rate. An orifice plate, calibrated against the nozzles, was used to

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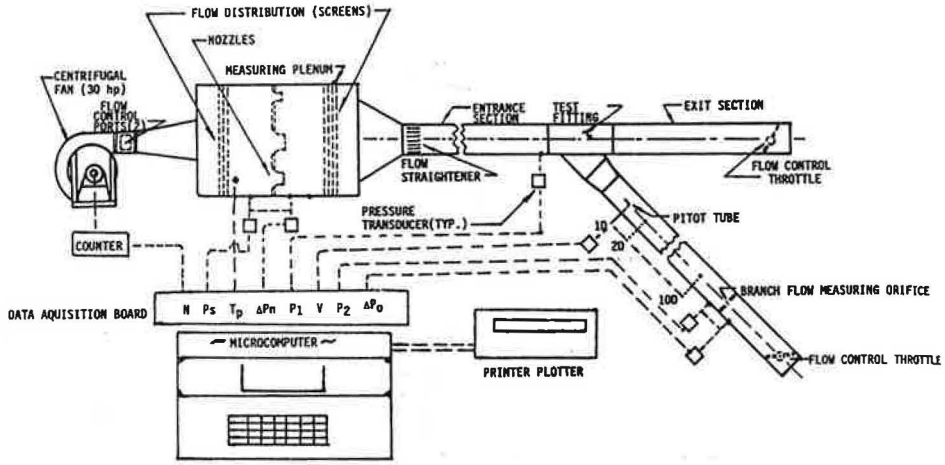



Dimensions for FIG. 1 are: 42 wide by 20.0 deep.

***Figure 1*** *Schematic of experimental system, configured for tests with a branch-type fitting*

determine flow rate in the branch. During testing, a particular nozzle or combination of nozzles was used in establishing a desired flow rate. Unused nozzles were plugged with smooth vinyl balls.

An apparatus was built to facilitate systematic positioning of pitot tubes. The apparatus consisted principally of a structural base, a movable traversing fixture, and items to aid in automated measurements. The base was supported on casters that allowed it to be positioned in proper alignment with the duct and test fitting. Extended braces and straps permitted a 16-ft section of duct to be properly aligned and firmly attached to the base. The traversing fixture supported two pitot tubes and was designed to move one along a horizontal line of travel and the other along a vertical line of travel. Computer-controlled stepping motors were used to move the pitot tubes across the duct. The traversing fixture was mounted on guide rods running along the top of the apparatus. A computer-controlled chain drive was used to position the fixture longitudinally.

Ambient dry- and wet-bulb temperatures and barometric pressures were measured to determine ambient air density, which was corrected for other stations within the test system using local pressure and temperature measurements. Pressure drop across the ASME nozzle bank and upstream static pressure were measured to determine supply flow rate. When branch ducts were involved, the pressure drop across the orifice and upstream static pressure were measured to determine branch flow rate. Pressure differentials were obtained using micromanometers having a scale readability of 0.001 in. $H_2O$.

The pressure differential output of each pitot tube was routed to a capacitance-type pressure transducer, which, in turn, produced an output voltage that was routed directly to the data acquisition system. The data acquisition system was calibrated and checked routinely against a reference micromanometer. Pitot tube outputs were processed automatically. The fitting and upstream duct were leak checked prior to making velocity measurements.

## SCOPE OF TESTS

Each fitting is coded first by a letter or set of letters designating the fitting. This was followed by a sequential number assigned to the fitting in its category. The next digit was always the letter D followed by a number indicating target average test velocities. For elbows, contractions, and diffusers, D1, D2, and D3 represent, respectively, target velocities of 1000, 1750, and 2500 fpm. For wyes and tees, a two-digit number after D indicates a particular combination of main and branch target velocities, with 1, 2, and 3 associated, respectively, with 1000, 1750, and 2500 fpm. Two examples follow.

E2D2 . . . . . E 2 D2

- D2 . . . . Target Velocity After Fitting = 1750 fpm
- 2 . . . . . Elbow Number 2
- E . . . . . Designates Elbow

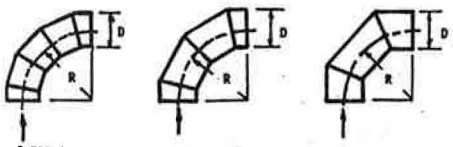
DY1D12 . . . DY 1 D12

- D12 . . . . Target Velocities After Fitting 1000 fpm (main) 1750 fpm (branch)
- 1 . . . . . Wye Number 1 for DY group
- DY . . . . . Wyes of particular type

**TABLE 1**
**Identification of Elbows Tested**

| Code | Dia. (inches) | R/D | Number of Pieces | Turning Angle (degrees) | Average Velocity (sfpm) Case D1 | Case D2 | Case D3 |
|---|---|---|---|---|---|---|---|
| E1 | 6 | 1.0 | 3 | 90 | 994 | 1629* | 2277 |
| E2 | 6 | 1.0 | 4 | 90 | 991 | 1612* | 2238 |
| E3 | 6 | 1.0 | 5 | 90 | 1020 | 1656* | 2278 |
| E4 | 6 | 1.5 | 3 | 90 | 960 | 1611* | 2213 |
| E5 | 6 | 1.5 | 4 | 90 | 946 | 1609* | 2311 |
| E6 | 6 | 1.5 | 5 | 90 | 951 | 1618* | 2284 |
| E7 | 10 | 1.0 | 3 | 90 | 993 | 1634* | 2340 |
| E8 | 10 | 1.0 | 4 | 90 | 988 | 1675* | 2368 |
| E9 | 10 | 1.0 | 5 | 90 | 988 | 1684* | 2369 |
| E10 | 10 | 1.5 | 3 | 90 | 981 | 1632* | 2362 |
| E11 | 10 | 1.5 | 4 | 90 | 961 | 1651* | 2340 |
| E12 | 10 | 1.5 | 5 | 90 | 965 | 1641* | 2350 |
| E13 | 16 | 1.0 | 3 | 90 | 940 | 1630* | 2354 |
| E14 | 16 | 1.0 | 4 | 90 | 980 | 1644* | 2344 |
| E15 | 16 | 1.0 | 5 | 90 | 932 | 1653* | 2354 |
| E16 | 16 | 1.5 | 3 | 90 | 978 | 1644* | 2370 |
| E17 | 16 | 1.5 | 4 | 90 | 979 | 1648* | 2348 |
| E18 | 16 | 1.5 | 5 | 90 | 978 | 1639* | 2347 |
| E19 | 6 | 1.0 | 3 | 45 | 959 | 1647* | 2301 |
| E20 | 6 | 1.0 | 4 | 45 | 951 | 1671* | 2299 |
| E21 | 6 | 1.0 | 5 | 45 | 947 | 1660* | 2295 |
| E22 | 6 | 1.5 | 3 | 45 | 945 | 1679* | 2333 |
| E23 | 6 | 1.5 | 4 | 45 | 946 | 1672* | 2345 |
| E24 | 6 | 1.5 | 5 | 45 | 947 | 1676* | 2333 |
| E25 | 10 | 1.0 | 3 | 45 | 938 | 1650* | 2362 |
| E26 | 10 | 1.0 | 4 | 45 | 973 | 1626* | 2358 |
| E27 | 10 | 1.0 | 5 | 45 | 981 | 1641* | 2356 |
| E28 | 10 | 1.5 | 3 | 45 | 974 | 1640* | 2358 |
| E29 | 10 | 1.5 | 4 | 45 | 904 | 1636* | 2342 |
| E30 | 10 | 1.5 | 5 | 45 | 986 | 1637* | 2373 |
| E31 | 16 | 1.0 | 3 | 45 | 924 | 1647* | 2345 |
| E32 | 16 | 1.0 | 4 | 45 | 911 | 1635* | 2334 |
| E33 | 16 | 1.0 | 5 | 45 | 928 | 1636* | 2363 |
| E34 | 16 | 1.5 | 3 | 45 | 920 | 1642* | 2375 |
| E35 | 16 | 1.5 | 4 | 45 | 926 | 1641* | 2346 |
| E36 | 16 | 1.5 | 5 | 45 | 930 | 1637* | 2344 |

*Designates cases for which complete profiles were obtained.




ELBOWS: CODE E
REFERENCE FITTING 3-2, p. 33.33, 1985 ASHRAE FUNDAMENTALS

Tables 1 through 5 identify the 69 fittings. Average velocities for the tests are given in sfpm. Since air density within the duct was typically less than standard density, velocities in sfpm are smaller than actual target velocities of 1000, 1750, and 2500 fpm. Cases denoted by an asterisk (*) in Tables 1 through 5 are those for which vertical and horizontal traverses were made. Only centerline velocities were measured for the other cases.

## RESULTS

The final report (Griggs et al. 1987) documents the extensive results. Illustrative centerline velocity data plots, velocity profiles, and summaries are included in this paper.

Centerline velocity data for all elbows are given in Table 6. Results for all elbows are similar, with the most apparent distinction being between those for 45° and 90° elbows. Centerline velocities for contractions and diffusers are given in Tables 7 and 8. Marked distinction was found in the profiles downstream of these fittings when operating as a diffuser and when operating as a contraction. Centerline velocities for round-to-round diverging junctions are given in Table 9. Table 10 contains centerline data for round diverging wyes having a 45° elbow tap connection. Centerline data for junctions with a rectangular main and a 6-in.diameter branch are listed in Table 11.

The centerline velocity data were examined while considering the physical distinction between fittings within a category to see if variation in data could be correlated with particular factors. The most discernible influence was angle for elbows, wyes, and tees.

Groupings of data were plotted to portray the spread in centerline velocities at each longitudinal measuring station. The solid line in each plot connects the average values at each position. Elbow data are shown in Figure 2. Conical contraction and conical diffuser data are plotted in Figure 3. All data for contractions are plotted together, while those for diffusers have been grouped for each of the three diffusion angles. Note the scale difference between plots for contractions and diffusers when comparing results. Figure 4 is for round-to-round junctions, while Figure 5 is for rectangular-to-round junctions.

The spread in centerline data was large immediately after the fitting in all cases. The most consistent consolidation of data at the 10-diameter station was noted for the elbows. The dispersion of data at all stations was more pronounced for the wyes and tees. Data spread in general suggests situational dependence, but attempts to identify such through examination of data sorted by distinctive elements within a category were unfruitful. Consequently, it is recommended that tabulated data be used without attempting to rely on a single number within a category.

The distinction between vertical and horizontal profiles and downstream profile evolution is shown for representative tests in Figures 6 through 13. The broken line in each case shows where $V/\bar{V}$ is unity. The scale permits qualitative evaluation at best, but all data represented here and all other profile data can be examined more quantitatively by referring to expanded plots given in the project report (Griggs et al. 1987). A few additional tests were included where measurements were made farther from the fitting than the upper value of 10 diameters included in the original work, with the intent being to explore the continuing effect of flow development, which did not occur at the 10-diameter location in all cases. Figures 12 and 13 show profiles for these additional tests.

Velocity profiles exhibited some interesting patterns. The vertical profiles following elbows exhibited considerable symmetry, while asymmetry was evident in the horizontal ones near the fitting (Figures 6 and 12). For contractions, the velocity profiles were similar and nearly symmetrical for both the vertical and horizontal traverses. The similarity and symmetry also occurred for diffusers, but the patterns and local velocity magnitudes were quite distinct for the two different fittings. Example cases for wyes and tees are shown in Figures 9, 10, 11, and 13. Vertical profiles for wyes and tees were also more consistently symmetrical than were horizontal profiles. Within the range of conditions

examined for each fitting type, larger variations in patterns occurred for junctions than for the undivided fittings (elbows, contractions, and diffusers). The absence of symmetry and the fact that larger velocity gradients were present close to the fitting undoubtedly contributed to the spread in measured centerline velocities noted earlier.

## MEASUREMENT UNCERTAINTIES

Uncertainty in the results, reported as $V/\bar{V}$, is due to uncertainties in local velocity, flow rate, and cross-sectional area determinations. Pressure differentials from the pitot tubes were routed to a capacitance-type transducer, whose output was, in turn, routed to a computer-aided data acquisition system. The complete system was routinely calibrated against a micromanometer having a scale readability of 0.001 in. $H_2O$. Routine experience with these units indicates that this accuracy is difficult to ascertain through extensive production-type testing. An uncertainty in pressure differential measurement of ±0.001 in. $H_2O$ would correspond to a possible error ranging from ±0.26% to ±1.6% for the range of velocities encountered in this work. With a more realistic uncertainty of ±0.003 in. $H_2O$, the resultant range would be ±0.8% to ±4.8%. The larger percentages are for velocities of about 1000 fpm.

A detailed error analysis, made for the flow-measuring system used in this work, was previously reported to ASHRAE (Henderson et al. 1986). Error estimates included therein depended on flow conditions, but they indicated that flow rate should be within ±2% when care is exercised throughout. Swim (1986) has also discussed practical problems associated with flow rate measurement and use of pitot tubes. For $V/\bar{V}$ values near 1.0, an error of ±3% indicates a band on the ratio of about ±0.03. Some of the data resulted in a smaller spread than this, but accuracy better than ±3% would be most difficult to claim.

## FLOW RATE ESTIMATION

Determining flow rate from velocity measurement probably ranges in practice from making a single measurement (e.g., centerline) to detailed traversing. Estimating flow rate from centerline velocity is rooted in the validity of this approach for symmetrical, fully developed flow. When fully developed flow in a circular passage can be represented by the power law expression,

$$V = V_c [1 - (2r/D)]^{1/n} \quad (2)$$

the relationship between average and centerline velocities is

$$\bar{V}/V_c = \frac{2n^2}{(n + 1)(2n + 1)}. \quad (3)$$

The power law exponent varies with Reynolds number (Sissom and Pitts 1972). When flows prevail where velocities are not governed by known mathematical relationships, the use of only the single centerline velocity could lead to considerable error unless its relationship to the average velocity is known from experimental work. The extensive tabulations of centerline velocity provided by this study should be useful for the range of conditions covered and should provide insight for other cases as well.

HVAC testing and balancing practitioners most likely make multiple velocity measurements when determining flow rate. Detailed specifications for making traverses are specified in a SMACNA manual (SMACNA 1983) and in Chapter 13 of the 1985 *ASHRAE Fundamentals* (ASHRAE 1985b). Selected sets of data from this work were used to estimate flow rate by interpolating data to obtain velocities at radii specified in ASHRAE (1985b).

The scheme used in averaging velocities for flow rate estimation was based on the traverse pattern specified in Chapter 13 of ASHRAE (1985b). The specification requires measurement of 20 velocities at prescribed radii. Ten are made on one diameter and the other ten on a second diameter 90° from the first. Flow rate calculations were made via this technique for 20 sets of data, encompassing data from fittings of each category included in this work. Estimated flow rates, expressed as an average of $V/\bar{V}$, are tabulated in Tables 12 through 15. A value of 1.0 would indicate exact prediction. For each case, results are given for the horizontal and vertical traverse data at each of the five longitudinal measuring stations. The ratio corresponding to the prescribed 20-point averaging scheme is given by the average of two tabular entries. The reason that separate numbers are shown for vertical and horizontal is to indicate what is obtained if only one traverse is made in the respective plane. The ratios shown for each direction are what is obtained if only 10 values, based on a single traverse, are used assuming symmetry in the other plane. When averaging the ratios for both directions, consistent with the two-diameter traverse, the error is less than the maximum error based on a single traverse in all cases. In several cases where large error occurs if only one plane is used, the two-plane error is small because the error for the two single-plane traverses counteracts. Individual data spread for each case examined is best obtained from Tables 12 through 15. An abridged summary follows.

For each fitting category, two numbers are shown. One is the maximum error calculated for the selected cases using only a single traverse. The other, in parentheses, is the maximum error for each category for the cases examined if two traverses are used. These are listed to provide an overview. Since variations occurred for different fittings within a category, more specific case-by-case details should be obtained from Tables 12 through 15. The largest errors occurred for data obtained nearest the fitting.

More consistent results for all cases are obtained when flow rate determinations are based on measurements 10 diameters downstream of the fitting. When measurements must be made closer to a fitting, careful scrutiny should be given to interpretation. The data obtained in this work and included here should provide both qualitative and quantitative insight to those who make field velocity measurements downstream of HVAC sheet metal fittings.

## APPLICATION TO THE LOCATION OF VELOCITY/VELOCITY PRESSURE SENSORS

The data gathered in this study are intended to be of practical use in the determination of the optimal location of velocity/velocity pressure sensors. Tables 6 through 11 present a ratio of centerline velocity to average duct veloc-

| | 1D | | 2D | | 4D | | 6D | | 10D | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Elbows | 16.4 | (5.2) | 10.0 | (6.8) | 6.8 | (6.2) | 6.2 | (5:7) | 4.9 | (3.9) |
| 2. Contractions | 2.9 | (2.1) | 2.9 | (2.2) | 3.6 | (3.0) | 4.6 | (3.8) | 4.2 | (3.1) |
| 3. Diffusers | 40.6 | (35.3) | 27.7 | (24.7) | 11.5 | (11.8) | 5.3 | (4.8) | 1.2 | (1.1) |
| 4. Y's(*) | 44.7 | (16.8) | 22.6 | (5.8) | 12 | (5.9) | 10.5 | (6.2) | 7.1 | (5.4) |
| 5. DY's(*) | 18.7 | (8.4) | 15.4 | (9.1) | 11.7 | (8.3) | 10.4 | (8.1) | 8.1 | (6.5) |
| 6. T's(*) | 25.8 | (10.5) | 20.5 | (4.0) | 6.4 | (4.0) | 5.1 | (2.7) | 2.9 | (2.6) |

*See Nomenclature

ity for various fitting types, traverse locations, and main/branch velocities. These data can be used to:

1. determine the distance between the fitting and the sensor that is required to obtain a centerline velocity representative of average duct velocity,
2. determine the distance between a fitting and velocity sensor required to obtain a repeatable ratio of centerline velocity to average duct velocity over a range of average duct velocities that would be similar to the range of velocities experienced in a VAV system,
3. develop a recommendation of certain fittings that should be avoided in designing VAV systems due to their inherent tendency to disrupt the flow leading into a VAV control unit.

The remainder of this section evaluates the tested fittings with these objectives in mind.

Table 6 presents the ratios of centerline to average duct velocity for varying sizes of 90° elbows of 3-, 4-, and 5-piece construction at various average duct velocities. For almost all elbows tested, a distance of 6 diameters of straight duct between the elbow and the sensor is required to obtain a centerline velocity representative of the average duct velocity. However, the repeatability of the ratio of the centerline to average velocity at various duct velocities is evident at two diameters of distance. Placement of a velocity sensor at this location should yield repeatable measurements that all have the same ratio to average duct velocity. Utilization of the sensor in such a location would simply involve a correction to the sensor calibration curve based on the ratio of centerline to average duct velocity for the installed sensor.

Tables 7 and 8 present similar data for round-to-round contraction and diffusion fittings. Measurements taken as far as 10 diameters from the fittings failed to identify a location where the centerline velocity was representative of the average duct velocity. However, when the fittings were subjected to various duct velocities, these ratios were basically repeatable at distances as little as one diameter between the fitting and the measurement location.

Table 9 presents data for round diverging junctions. Fittings Y1, Y2, and Y3 represent junctions where the branch tap exits at 90° from the main duct. These fittings demonstrated a centerline velocity that was relatively representative of average duct velocity at a measurement location four diameters from the fitting. For all locations less than four diameters, neither a representative nor repeatable measurement was indicated. Fittings Y4, Y5, and Y6 represent fittings whose branch tap exits at 30° from the main duct. These fittings exhibited no measurement location less than 10 diameters downstream where either the centerline velocity was representative of the average duct velocity or the ratio of the two velocities was consistent. As a result, these fittings should be avoided when designing VAV systems.

Table 10 contains similar data for round diverging wyes with a 45° elbow tap connection. Again, no location within 10 diameters of the fitting was determined where either the centerline velocity was indicative of the average duct velocity or their ratios were repeatable over the prescribed range of velocities. These fittings should also be avoided when designing VAV duct systems.

Table 11 represents data for diverging junctions with a rectangular main duct feeding a round tap. Fittings T1, T2, and T3 are fittings with the branch tap exiting at a 30° angle from the main duct. The centerline velocity was not representative of the average duct velocity at any measurement location within 10 diameters of the fitting. The ratio of the centerline to average velocity was fairly repeatable at distances 6 to 10 diameters from the fitting. These distances are not, however, very practical in actual installations. Fittings T4, T5, and T6 are fittings where the branch tap exits at 90° from the main duct. Again, no measurement location was identified within 10 diameters of the fitting where the centerline velocity was indicative of the average velocity. Fairly consistent ratios of centerline to average velocity were obtained at distances of four diameters and greater from the fitting. Fittings T7, T8, and T9 are identical to T1, T2, and T3 except that they have a conical branch connection to the main duct. This difference in construction makes no significant improvement in performance. Fittings T10, T11, and T12 are identical to T4, T5, and T6 except that they also contain a conical branch tap. Again, no significant improvement in performance was noted.

## SUMMARY OF GUIDELINES FOR SENSOR LOCATION

Centerline velocity measurements taken downstream of elbows can be expected to yield reasonable accuracy provided the measurement location is separated from the fitting by at least 6 diameters of straight, rigid duct downstream of the elbow. Similar measurements taken in a round, rigid branch duct exiting at a right angle from a rectangular main and a round, diverging junction with the branch exiting at 90° from the main duct can be expected to yield accurate results provided the sensor location is separated by at least 4 diameters of straight, rigid duct from the main duct. Other fittings tested did not exhibit any location within 10 diameters of the fitting where the centerline velocity was indicative of the average duct velocity.

Measurements made following rigid 90° elbows and round-to-round contracting and diffusing fittings indicated that a consistent ratio of centerline to average velocity ($V_c/\bar{V}$) is obtainable with as little as 2 diameters of rigid duct between the fitting and measurement location. Consistency of this ratio is also obtainable when 4 diameters of straight duct separate the sensor and a round diverging junction with a branch exit angle of 90°. Diverging junctions with rectangular mains and a round branch exiting at 30° require 6 to 10 diameters separation for a consistent ratio of $V_c/\bar{V}$ to exist, and 4 diameters when the branch exits at a right angle rather than 30°.

In actual field application, the lengths of straight, rigid duct noted above are seldom available upstream of desired sensor locations. All of these facts lead to one simple conclusion—once installed, the velocity sensor should be calibrated by means of determining the branch air flow by traverse or outlet readings and establishing a sensor calibration curve that relates to the installed device. Care should be taken to provide as much straight duct immediately preceding the sensor as possible. Fittings identified as poor for use preceding such sensors should be avoided. Field measurement—and thus control—accuracies should not be expected to exceed or even equal those obtained in the laboratory setup of this study. Data are not applicable to flexible duct connections from the duct main to a terminal box.

## CONCLUSIONS

Within the scope of tests made in this project, the following conclusions are offered.

1. At 10 diameters after fittings, flow is not completely symmetrical or fully developed. Lack of development appears more prevalent for divided fittings than undivided ones. Data obtained for three additional tests at larger distances show near development at approximately 25 diameters, but even for such extended lengths, exact coincidence of vertical and horizontal profiles is not observed.
2. $V_c/\bar{V}$ for elbows is not markedly influenced by flow rate, diameter, number of segments, or *R/D*. Turning angle appears to have the most distinctive influence on results. Vertical profiles exhibit near symmetry, but horizontal ones are asymmetric.
3. Most symmetry occurs for conical contractions. Profiles are flat immediately after the fitting; they appear almost developed at 10 diameters downstream. Magnitudes of $V_c/\bar{V}$ varied with contraction angle.
4. Pronounced jetting occurs immediately after conical diffusers with separation occurring near the wall. Velocity profiles are markedly different from those after conical contractions. Magnitudes of $V_c/\bar{V}$ depended strongly on diffusion angle.
5. For round-to-round and rectangular-to-round junctions, the main-to-branch angle and the ratio of main-to-branch flow rate appears to influence velocity magnitudes and profile patterns. For these divided flow fittings, downstream vertical profiles exhibit near symmetry, as is the case with elbows, but horizontal profiles are characterized by marked asymmetry.
6. Use of single-plane traverses immediately after fittings (e.g., up to 4 diameters) for flow rate determination can lead to large error. More reliable determinations (e.g., on the order of ±5%) can be made if the proper traverses are made at distances greater than 10 diameters.
7. Placement of a single-point velocity sensor at least two diameters downstream of elbows will provide repeatable measurements; it would be necessary to calibrate the sensor using data for the ratios of measured centerline to average velocities.


## ACKNOWLEDGMENTS

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## NOMENCLATURE

| | |
|---|---|
| $D$ | = duct diameter (in.) |
| fpm | = feet per minute |
| $Le$ | = entrance length |
| $n$ | = exponent in power law equation (Equation 2) |
| $r$ | = variable radius within flow (Equation 2) |
| $R$ | = centerline radius of elbows or radius of round duct (in.) |
| $Re_D$ | = Reynolds number (dimensionless) |
| sfpm | = standard feet per minute |
| $V$ | = local velocity (fpm) |
| $V_c$ | = centerline velocity (fpm) |
| $\bar{V}$ | = mass-average velocity (fpm or sfpm) |

### Fitting Code Prefixes

| | |
|---|---|
| C | = prefix used in coding contractions |
| DC | = prefix used in coding diffusers |
| DY | = prefix used in coding round-to-round wyes with a 45° elbow connecting main to branch |
| E | = prefix used in coding elbows |
| T | = prefix used in coding rectangular-to-round junctions |
| Y | = prefix used in coding round-to-round junctions |

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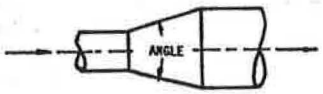
## TABLE 2
### Identification of Round-to-Round Diverging (Diffusers) and Converging (Contractions) Fittings Tested

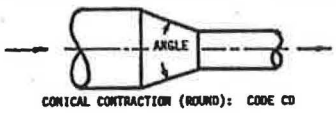
| Inlet Dia. to Outlet Dia. (in.) | Divergence Angle (deg.) | Average Velocity (sfpm) D1 | D2 | D3 | D4 |
|---|---|---|---|---|---|
| 6 to 10 | 20 | 964 | 1584* | 2448 | 590* |
| 6 to 10 | 45 | 956 | 1659* | 2260 | 600* |
| 6 to 10 | 90 | 971 | 1672* | 2228 | 602* |
| 6 to 12 | 20 | 904 | 1598* | 2369 | 403* |
| 6 to 12 | 45 | 927 | 1597* | 2166 | 396* |
| 6 to 12 | 90 | 930 | 1602* | 2117 | 399* |
| 10 to 6 | 20 | 996* | 1573* | 2337 | 4394* |
| 10 to 6 | 45 | 1028 | 1587* | 2368 | 4460* |
| 10 to 6 | 90 | 1011 | 1563* | 2339 | 4405* |
| 12 to 6 | 20 | 994* | 1650* | 2415 | 6402* |
| 12 to 6 | 45 | 898 | 1500* | 2436 | 6256* |
| 12 to 6 | 90 | 924 | 1587* | 2303 | 6351* |

*Designates cases for which complete profiles were obtained.




CONICAL DIFFUSER (ROUND): CODE DCD

REFERENCE FITTING 4-1, p. 33.37, 1985 ASHRAE FUNDAMENTALS



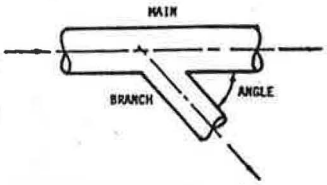

CONICAL CONTRACTION (ROUND): CODE CD

REFERENCE FITTING 5-1, p. 33.39, 1985 ASHRAE FUNDAMENTALS

## TABLE 3
### Identification of Round-to-Round Wyes Tested

| Code No. | Diameter of Main (inches) | Diameter of Branch (inches) | Divergence Angle (degrees) | V Branch / V Main Test D11 | D12 | D13 | D21 | D22 | D23 | D31 | D32 | D33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Y1 | 10 | 6 | 90 | 982 / 926 | 952 / 1648 | 927 / 2281 | 1611 / 935 | 1604* / 1614 | 1590 / 2270 | 2281 / 935 | 2305 / 1623 | 2280 / 2285 |
| Y2 | 12 | 6 | 90 | 933 / 933 | 933 / 1631 | 922 / 2268 | 1618* / 936 | 1610* / 1617 | 1580* / 2281 | 2257 / 932 | 2278 / 1658 | 2295 / 2271 |
| Y3 | 16 | 6 | 90 | 909 / 936 | 882 / 1623 | 946 / 2265 | 1592 / 934 | 1591* / 1612 | 1572 / 2267 | 2267 / 935 | 2284 / 1620 | 2308 / 2252 |
| Y4 | 10 | 6 | 30 | 908 / 928 | 924 / 1658 | 900 / 2259 | 1621 / 946 | 1610* / 1641 | 1631 / 2285 | 2323 / 935 | 2293 / 1632 | 2298 / 2264 |
| Y5 | 12 | 6 | 30 | 913 / 935 | 912 / 1610 | 928 / 2255 | 1604* / 939 | 1620* / 1623 | 1621* / 2273 | 2285 / 928 | 2278 / 1618 | 2297 / 2266 |
| Y6 | 16 | 6 | 30 | 957 / 937 | 942 / 1619 | 905 / 2258 | 1612 / 927 | 1629* / 1610 | 1605 / 2263 | 2329 / 931 | 2280 / 1622 | 2305 / 2269 |

*Designates cases for which complete profiles were obtained.



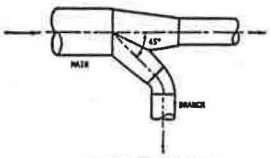

DIVERGING WYE (ROUND): CODE Y

REFERENCE FITTING 6-8, p. 33.37, 1981 ASHRAE FUNDAMENTALS

## TABLE 4
### Identification of Tested Wyes with 45° Elbow-to-Branch Connection

| Code No. | Inlet Diameter (inches) | Inline Outlet Diameter (inches) | Branch Diameter (degrees) | V Branch / V Main Test D11 | D12 | D13 | D21 | D22 | D23 | D31 | D32 | D33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DY1 | 10 | 6 | 6 | 945 / 938 | 981 / 1635 | 931 / 2264 | 1619 / 942 | 1589* / 1620 | 1586 / 2263 | 2290 / 924 | 2261 / 1636 | 2270 / 2250 |
| DY2 | 12 | 6 | 6 | 921 / 935 | 920 / 1637 | 947 / 2267 | 1610* / 933 | 1617* / 1634 | 1629* / 2271 | 2310 / 932 | 2304 / 1631 | 2300 / 2270 |
| DY3 | 16 | 6 | 6 | 906 / 938 | 891 / 1622 | 924 / 2268 | 1622 / 939 | 1659* / 1631 | 1623 / 2263 | 1646 / 924 | 1728 / 1623 | 1811 / 2266 |

* Designates cases for which complete profiles were obtained.

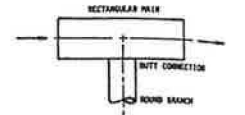



DIVERGING 45° WYE, CONICAL MAIN AND BRANCH, WITH 45° ELBOW, BRANCH 90° TO MAIN: CODE BY REFERENCE FITTING 6-17, p. 33.43, 1985 ASHRAE FUNDAMENTALS

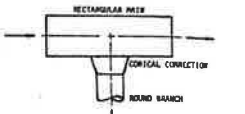
## TABLE 5
## Identification of Tested Tees with a Rectangular Main and a 6-Inch Diameter Branch

| Code No. | Main Width by Height (inches) | Branch Angle (degrees) | Tap Type [a] | $\frac{V\ Branch}{V\ Main}$ Test D11 | D12 | D13 | D21 | D22 | D23 | D31 | D32 | D33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 8 x 7 | 30 | 1 | 923/931 | 913/1642 | | 1618/924 | 1638*/1617 | 1602/2268 | 2272/935 | 2270/1619 | 2280/2262 |
| T2 | 12 x 10 | 30 | 1 | 904/935 | 898/1615 | 899/2254 | 1605*/931 | 1600*/1613 | 1592*/2277 | 2262/935 | 2263/1630 | 2253/2265 |
| T3 | 18 x 10 | 30 | 1 | 939/935 | 923/1600 | 908/2245 | 1596/933 | 1598*/1619 | 1592/2260 | 2284/929 | 2288/1622 | 2277/2256 |
| T4 | 8 x 7 | 90 | 1 | 912/933 | 910/1602 | | 1630/931 | 1596*/1629 | 1608/2270 | 2286/933 | 2279/1634 | 2299/2268 |
| T5 | 12 x 10 | 90 | 1 | 934/933 | 931/1632 | 921/2264 | 1591*/928 | 1577*/1621 | 1572*/2266 | 2252/932 | 2253/1631 | 2244/2268 |
| T6 | 18 x 10 | 90 | 1 | 954/937 | 953/1602 | 957/2264 | 1623/935 | 1584*/1594 | 1612/2265 | 2281/934 | 2277/1595 | 2281/2262 |
| T7 | 8 x 7 | 30 | 2 | 910/937 | 929/1661 | | 1596/935 | 1602*/1614 | 1650/2266 | 2269/935 | 2281/1628 | 2285/2269 |
| T8 | 12 x 10 | 30 | 2 | 942/933 | 934/1620 | 914/2270 | 1590*/928 | 1584*/1603 | 1588*/2265 | 2269/931 | 2265/1622 | 2259/2265 |
| T9 | 18 x 10 | 30 | 2 | 917/935 | 925/1595 | 935/2266 | 1588/942 | 1584*/1602 | 1590/2262 | 2303/935 | 2296/1600 | 2295/2271 |
| T10 | 8 x 7 | 90 | 2 | 910/933 | 934/1659 | | 1610/935 | 1600*/1621 | 1651/2261 | 2303/931 | 2311/1628 | 2279/2254 |
| T11 | 12 x 10 | 90 | 2 | 904/935 | 906/1635 | 904/2267 | 1579*/935 | 1583*/1628 | 1591*/2269 | 2223/939 | 2214/1640 | 2188/2263 |
| T12 | 18 x 10 | 90 | 2 | 899/934 | 899/1601 | 912/2269 | 1608/923 | 1599*/1598 | 1605/2261 | 2286/939 | 2278/1591 | 2278/2264 |

*Designates causes for which complete profiles were obtained.
[a] (1) Butt (Round) Connection; (2) Conical Connection



DIVERGING TEE, RECTANGULAR MAIN TO ROUND BUTT TAP (90° CASE SHOWN): CODE T
REFERENCE FITTING 6-26, p. 33.45, 1985 ASHRAE FUNDAMENTALS



DIVERGING TEE, RECTANGULAR MAIN TO ROUND CONICAL TAP (90° CASE SHOWN): CODE T
REFERENCE FITTING 6-27, p. 33.45, 1985 ASHRAE FUNDAMENTALS

## TABLE 6
## Centerline Velocity Data for Elbows

| Code | Dia.(in.) | No. Pcs. | R/D | Angle (Deg.) | Velocity Ratio, Vc / Vavg. 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|---|
| E1D1 | 6 | 3 | 1 | 90 | 0.72 | 0.77 | 0.92 | 1.03 | 1.11 |
| E1D2 | 6 | 3 | 1 | 90 | 0.73 | 0.77 | 0.92 | 1.02 | 1.08 |
| E1D3 | 6 | 3 | 1 | 90 | 0.75 | 0.79 | 0.94 | 1.03 | 1.10 |
| E2D1 | 6 | 4 | 1 | 90 | 0.76 | 0.78 | 0.94 | 1.04 | 1.11 |
| E2D2 | 6 | 4 | 1 | 90 | 0.81 | 0.80 | 0.94 | 1.03 | 1.10 |
| E2D3 | 6 | 4 | 1 | 90 | 0.83 | 0.81 | 0.94 | 1.04 | 1.11 |
| E3D1 | 6 | 5 | 1 | 90 | 0.71 | 0.79 | 0.96 | 1.06 | 1.11 |
| E3D2 | 6 | 5 | 1 | 90 | 0.75 | 0.81 | 0.98 | 1.07 | 1.12 |
| E3D3 | 6 | 5 | 1 | 90 | 0.76 | 0.81 | 0.96 | 1.06 | 1.11 |
| E4D1 | 6 | 3 | 1.5 | 90 | 0.73 | 0.75 | 0.92 | 1.01 | 1.08 |
| E4D2 | 6 | 3 | 1.5 | 90 | 0.74 | 0.76 | 0.94 | 1.02 | 1.08 |
| E4D3 | 6 | 3 | 1.5 | 90 | 0.79 | 0.77 | 0.94 | 1.02 | 1.08 |
| E5D1 | 6 | 4 | 1.5 | 90 | 0.77 | 0.79 | 0.95 | 1.03 | 1.07 |
| E5D2 | 6 | 4 | 1.5 | 90 | 0.76 | 0.79 | 0.96 | 1.03 | 1.08 |
| E5D3 | 6 | 4 | 1.5 | 90 | 0.77 | 0.79 | 0.95 | 1.03 | 1.08 |
| E6D1 | 6 | 5 | 1.5 | 90 | 0.69 | 0.79 | 0.96 | 1.03 | 1.08 |
| E6D2 | 6 | 5 | 1.5 | 90 | 0.68 | 0.80 | 0.98 | 1.05 | 1.09 |
| E6D3 | 6 | 5 | 1.5 | 90 | 0.72 | 0.80 | 0.98 | 1.05 | 1.09 |
| E7D1 | 10 | 3 | 1 | 90 | 0.79 | 0.77 | 0.92 | 1.01 | 1.08 |
| E7D2 | 10 | 3 | 1 | 90 | 0.83 | 0.77 | 0.92 | 1.02 | 1.09 |
| E7D3 | 10 | 3 | 1 | 90 | 0.88 | 0.79 | 0.91 | 1.01 | 1.08 |
| E8D1 | 10 | 4 | 1 | 90 | 0.79 | 0.78 | 0.95 | 1.05 | 1.11 |
| E8D2 | 10 | 4 | 1 | 90 | 0.84 | 0.81 | 0.95 | 1.04 | 1.10 |
| E8D3 | 10 | 4 | 1 | 90 | 0.83 | 0.80 | 0.95 | 1.04 | 1.10 |
| E9D1 | 10 | 5 | 1 | 90 | 0.86 | 0.79 | 0.95 | 1.04 | 1.12 |
| E9D2 | 10 | 5 | 1 | 90 | 0.87 | 0.81 | 0.95 | 1.05 | 1.11 |
| E9D3 | 10 | 5 | 1 | 90 | 0.90 | 0.82 | 0.96 | 1.04 | 1.10 |
| E10D1 | 10 | 3 | 1.5 | 90 | 0.76 | 0.76 | 0.93 | 1.01 | 1.06 |
| E10D2 | 10 | 3 | 1.5 | 90 | 0.77 | 0.77 | 0.94 | 1.01 | 1.07 |
| E10D3 | 10 | 3 | 1.5 | 90 | 0.82 | 0.77 | 0.93 | 1.00 | 1.07 |
| E11D1 | 10 | 4 | 1.5 | 90 | 0.64 | 0.83 | 0.99 | 1.04 | 1.08 |
| E11D2 | 10 | 4 | 1.5 | 90 | 0.69 | 0.81 | 0.98 | 1.04 | 1.08 |
| E11D3 | 10 | 4 | 1.5 | 90 | 0.70 | 0.83 | 0.99 | 1.05 | 1.09 |
| E12D1 | 10 | 5 | 1.5 | 90 | 0.72 | 0.82 | 0.99 | 1.05 | 1.09 |
| E12D2 | 10 | 5 | 1.5 | 90 | 0.74 | 0.82 | 0.98 | 1.05 | 1.08 |
| E12D3 | 10 | 5 | 1.5 | 90 | 0.79 | 0.84 | 1.00 | 1.06 | 1.09 |
| E13D1 | 16 | 3 | 1 | 90 | 0.81 | 0.77 | 0.94 | 0.96 | 1.09 |
| E13D2 | 16 | 3 | 1 | 90 | 0.84 | 0.79 | 0.94 | 1.03 | 1.09 |
| E13D3 | 16 | 3 | 1 | 90 | 0.85 | 0.79 | 0.95 | 1.03 | 1.09 |
| E14D1 | 16 | 4 | 1 | 90 | 0.85 | 0.80 | 0.95 | 1.03 | 1.09 |
| E14D2 | 16 | 4 | 1 | 90 | 0.90 | 0.80 | 0.95 | 1.01 | 1.09 |
| E14D3 | 16 | 4 | 1 | 90 | 0.93 | 0.81 | 0.95 | 1.03 | 1.09 |
| E15D1 | 16 | 5 | 1 | 90 | 0.82 | 0.83 | 0.98 | 1.05 | 1.10 |
| E15D2 | 16 | 5 | 1 | 90 | 0.88 | 0.84 | 0.96 | 1.04 | 1.10 |
| E15D3 | 16 | 5 | 1 | 90 | 0.87 | 0.82 | 0.97 | 1.04 | 1.10 |

## TABLE 6
### Centerline Velocity Data for Elbows (*Continued*)

| Code | Dia. (in.) | No. Pcs. | R/D | Angle (Deg.) | Velocity Ratio, Vc / Vavg. 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|---|
| E16D1 | 16 | 3 | 1.5 | 90 | 0.87 | 0.81 | 0.92 | 1.00 | 1.07 |
| E16D2 | 16 | 3 | 1.5 | 90 | 0.91 | 0.80 | 0.92 | 1.00 | 1.07 |
| E16D3 | 16 | 3 | 1.5 | 90 | 0.91 | 0.80 | 0.91 | 0.99 | 1.06 |
| E17D1 | 16 | 4 | 1.5 | 90 | 0.80 | 0.83 | 0.97 | 1.03 | 1.07 |
| E17D2 | 16 | 4 | 1.5 | 90 | 0.80 | 0.83 | 0.97 | 1.03 | 1.08 |
| E17D3 | 16 | 4 | 1.5 | 90 | 0.81 | 0.82 | 0.96 | 1.02 | 1.08 |
| E18D1 | 16 | 5 | 1.5 | 90 | 0.76 | 0.85 | 1.00 | 1.04 | 1.09 |
| E18D2 | 16 | 5 | 1.5 | 90 | 0.82 | 0.85 | 0.99 | 1.06 | 1.09 |
| E18D3 | 16 | 5 | 1.5 | 90 | 0.84 | 0.85 | 1.00 | 1.05 | 1.09 |
| E19D1 | 6 | 3 | 1 | 45 | 1.23 | 0.93 | 0.93 | 0.98 | 1.06 |
| E19D2 | 6 | 3 | 1 | 45 | 1.21 | 0.89 | 0.93 | 0.98 | 1.06 |
| E19D3 | 6 | 3 | 1 | 45 | 1.25 | 0.96 | 0.94 | 1.00 | 1.07 |
| E20D1 | 6 | 4 | 1 | 45 | 1.20 | 0.83 | 0.87 | 0.95 | 1.03 |
| E20D2 | 6 | 4 | 1 | 45 | 1.22 | 0.86 | 0.89 | 0.97 | 1.05 |
| E20D3 | 6 | 4 | 1 | 45 | 1.24 | 0.90 | 0.90 | 0.97 | 1.05 |
| E21D1 | 6 | 5 | 1 | 45 | 1.19 | 0.86 | 0.89 | 0.98 | 1.05 |
| E21D2 | 6 | 5 | 1 | 45 | 1.18 | 0.88 | 0.92 | 0.98 | 1.06 |
| E21D3 | 6 | 5 | 1 | 45 | 1.23 | 0.90 | 0.92 | 0.98 | 1.05 |
| E22D1 | 6 | 3 | 1.5 | 45 | 1.17 | 0.88 | 0.88 | 0.97 | 1.06 |
| E22D2 | 6 | 3 | 1.5 | 45 | 1.17 | 0.89 | 0.91 | 0.99 | 1.06 |
| E22D3 | 6 | 3 | 1.5 | 45 | 1.20 | 0.92 | 0.91 | 0.98 | 1.06 |
| E23D1 | 6 | 4 | 1.5 | 45 | 1.21 | 0.83 | 0.89 | 0.97 | 1.07 |
| E23D2 | 6 | 4 | 1.5 | 45 | 1.21 | 0.85 | 0.91 | 0.99 | 1.06 |
| E23D3 | 6 | 4 | 1.5 | 45 | 1.22 | 0.88 | 0.89 | 0.97 | 1.05 |
| E24D1 | 6 | 5 | 1.5 | 45 | 1.21 | 0.86 | 0.90 | 0.98 | 1.06 |
| E24D2 | 6 | 5 | 1.5 | 45 | 1.22 | 0.87 | 0.92 | 1.00 | 1.07 |
| E24D3 | 6 | 5 | 1.5 | 45 | 1.23 | 0.92 | 0.92 | 0.99 | 1.06 |
| E25D1 | 10 | 3 | 1 | 45 | 1.19 | 0.84 | 0.86 | 0.95 | 1.03 |
| E25D2 | 10 | 3 | 1 | 45 | 1.21 | 0.87 | 0.89 | 0.96 | 1.04 |
| E25D3 | 10 | 3 | 1 | 45 | 1.24 | 0.92 | 0.90 | 0.97 | 1.05 |
| E26D1 | 10 | 4 | 1 | 45 | 1.22 | 0.88 | 0.87 | 0.96 | 1.05 |
| E26D2 | 10 | 4 | 1 | 45 | 1.24 | 0.91 | 0.89 | 0.96 | 1.05 |
| E26D3 | 10 | 4 | 1 | 45 | 1.25 | 0.95 | 0.91 | 0.98 | 1.05 |
| E27D1 | 10 | 5 | 1 | 45 | 1.20 | 0.84 | 0.86 | 0.95 | 1.03 |
| E27D2 | 10 | 5 | 1 | 45 | 1.22 | 0.87 | 0.87 | 0.97 | 1.05 |
| E27D3 | 10 | 5 | 1 | 45 | 1.24 | 0.90 | 0.90 | 0.97 | 1.05 |
| E28D1 | 10 | 3 | 1.5 | 45 | 1.20 | 0.90 | 0.87 | 0.96 | 1.05 |
| E28D2 | 10 | 3 | 1.5 | 45 | 1.21 | 0.93 | 0.87 | 0.97 | 1.05 |
| E28D3 | 10 | 3 | 1.5 | 45 | 1.22 | 0.95 | 0.89 | 0.97 | 1.06 |
| E29D1 | 10 | 4 | 1.5 | 45 | 1.19 | 0.88 | 0.85 | 0.97 | 1.06 |
| E29D2 | 10 | 4 | 1.5 | 45 | 1.21 | 0.92 | 0.88 | 0.98 | 1.05 |
| E29D3 | 10 | 4 | 1.5 | 45 | 1.22 | 0.95 | 0.90 | 0.99 | 1.06 |
| E30D1 | 10 | 5 | 1.5 | 45 | 1.19 | 0.87 | 0.87 | 0.97 | 1.06 |
| E30D2 | 10 | 5 | 1.5 | 45 | 1.19 | 0.91 | 0.87 | 0.97 | 1.05 |
| E30D3 | 10 | 5 | 1.5 | 45 | 1.21 | 0.93 | 0.86 | 0.96 | 1.03 |



## TABLE 6
### Centerline Velocity Data for Elbows (*Concluded*)

| Code | Dia. (in.) | No. Pcs. | R/D | Angle (Deg.) | Velocity Ratio, Vc / Vavg. 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|---|
| E31D1 | 16 | 3 | 1 | 45 | 1.22 | 0.97 | 0.89 | 0.96 | 1.04 |
| E31D2 | 16 | 3 | 1 | 45 | 1.22 | 0.98 | 0.91 | 0.97 | 1.04 |
| E31D3 | 16 | 3 | 1 | 45 | 1.23 | 1.00 | 0.90 | 0.95 | 1.04 |
| E32D1 | 16 | 4 | 1 | 45 | 1.24 | 0.95 | 0.90 | 0.96 | 1.05 |
| E32D2 | 16 | 4 | 1 | 45 | 1.24 | 1.00 | 0.91 | 0.97 | 1.04 |
| E32D3 | 16 | 4 | 1 | 45 | 1.25 | 1.02 | 0.93 | 0.97 | 1.05 |
| E33D1 | 16 | 5 | 1 | 45 | 1.22 | 0.96 | 0.90 | 0.96 | 1.06 |
| E33D2 | 16 | 5 | 1 | 45 | 1.24 | 0.98 | 0.90 | 0.96 | 1.04 |
| E33D3 | 16 | 5 | 1 | 45 | 1.25 | 1.01 | 0.93 | 0.98 | 1.05 |
| E34D1 | 16 | 3 | 1.5 | 45 | 1.21 | 1.01 | 0.88 | 0.96 | 1.05 |
| E34D2 | 16 | 3 | 1.5 | 45 | 1.20 | 1.05 | 0.88 | 0.95 | 1.06 |
| E34D3 | 16 | 3 | 1.5 | 45 | 1.20 | 1.05 | 0.88 | 0.95 | 1.03 |
| E35D1 | 16 | 4 | 1.5 | 45 | 1.20 | 0.99 | 0.87 | 0.98 | 1.06 |
| E35D2 | 16 | 4 | 1.5 | 45 | 1.20 | 1.04 | 0.88 | 0.96 | 1.05 |
| E35D3 | 16 | 4 | 1.5 | 45 | 1.20 | 1.05 | 0.88 | 0.97 | 1.05 |
| E36D1 | 16 | 5 | 1.5 | 45 | 1.19 | 1.00 | 0.87 | 0.96 | 1.05 |
| E36D2 | 16 | 5 | 1.5 | 45 | 1.20 | 1.04 | 0.88 | 0.96 | 1.05 |
| E36D3 | 16 | 5 | 1.5 | 45 | 1.20 | 1.07 | 0.88 | 0.96 | 1.05 |

## TABLE 7
## Centerline Velocity Data for Round-to-Round Contractions

| Code | Inlet Dia. to Outlet Di (in.) | Angle (Deg.) | Velocity Ratio, Vc / Vavg 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|
| CD1D1 | 10 TO 6 | 20 | 1.08 | 1.09 | 1.10 | 1.13 | 1.15 |
| CD1D2 | 10 TO 6 | 20 | 1.10 | 1.10 | 1.12 | 1.14 | 1.17 |
| CD1D3 | 10 TO 6 | 20 | 1.10 | 1.11 | 1.12 | 1.14 | 1.17 |
| CD1D4 | 10 TO 6 | 20 | 1.13 | 1.14 | 1.16 | 1.18 | 1.20 |
| CD2D1 | 10 TO 6 | 45 | 1.12 | 1.13 | 1.14 | 1.16 | 1.21 |
| CD2D2 | 10 TO 6 | 45 | 1.12 | 1.12 | 1.14 | 1.16 | 1.18 |
| CD2D3 | 10 TO 6 | 45 | 1.12 | 1.13 | 1.14 | 1.16 | 1.19 |
| CD2D4 | 10 TO 6 | 45 | 1.14 | 1.14 | 1.16 | 1.17 | 1.19 |
| CD3D1 | 10 TO 6 | 90 | 1.17 | 1.16 | 1.18 | 1.20 | 1.21 |
| CD3D2 | 10 TO 6 | 90 | 1.16 | 1.16 | 1.17 | 1.18 | 1.20 |
| CD3D3 | 10 TO 6 | 90 | 1.17 | 1.17 | 1.18 | 1.20 | 1.21 |
| CD3D4 | 10 TO 6 | 90 | 1.20 | 1.20 | 1.21 | 1.22 | 1.23 |
| CD4D1 | 12 TO 6 | 20 | 1.06 | 1.08 | 1.08 | 1.11 | 1.15 |
| CD4D2 | 12 TO 6 | 20 | 1.07 | 1.08 | 1.11 | 1.13 | 1.16 |
| CD4D3 | 12 TO 6 | 20 | 1.07 | 1.08 | 1.10 | 1.12 | 1.14 |
| CD4D4 | 12 TO 6 | 20 | 1.08 | 1.09 | 1.11 | 1.12 | 1.15 |
| CD5D1 | 12 TO 6 | 45 | 1.11 | 1.11 | 1.13 | 1.15 | 1.19 |
| CD5D2 | 12 TO 6 | 45 | 1.09 | 1.10 | 1.12 | 1.15 | 1.17 |
| CD5D3 | 12 TO 6 | 45 | 1.09 | 1.10 | 1.12 | 1.14 | 1.16 |
| CD5D4 | 12 TO 6 | 45 | 1.10 | 1.10 | 1.11 | 1.13 | 1.15 |
| CD6D1 | 12 TO 6 | 90 | 1.15 | 1.15 | 1.17 | 1.2 | 1.2 |
| CD6D2 | 12 TO 6 | 90 | 1.16 | 1.15 | 1.17 | 1.19 | 1.21 |
| CD6D3 | 12 TO 6 | 90 | 1.16 | 1.16 | 1.17 | 1.19 | 1.20 |
| CD6D4 | 12 TO 6 | 90 | 1.17 | 1.16 | 1.17 | 1.19 | 1.19 |

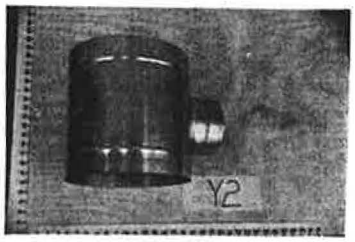


## TABLE 8
## Centerline Velocity Data for Round-to-Round Diffusers

| Code | Inlet Dia. to Outlet Di (in.) | Angle (Deg.) | Velocity Ratio, Vc / Vavg 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|
| DCD1D1 | 6 TO 10 | 20 | 2.27 | 1.86 | 1.32 | 1.19 | 1.15 |
| DCD1D2 | 6 TO 10 | 20 | 2.26 | 1.86 | 1.26 | 1.13 | 1.12 |
| DCD1D3 | 6 TO 10 | 20 | 2.36 | 1.80 | 1.28 | 1.14 | 1.11 |
| DCD1D4 | 6 TO 10 | 20 | 2.40 | 1.83 | 1.28 | 1.17 | 1.13 |
| DCD2D1 | 6 TO 10 | 45 | 2.59 | 1.65 | 1.09 | 1.05 | 1.07 |
| DCD2D2 | 6 TO 10 | 45 | 2.59 | 1.65 | 1.11 | 1.08 | 1.09 |
| DCD2D3 | 6 TO 10 | 45 | 2.55 | 1.63 | 1.11 | 1.08 | 1.09 |
| DCD2D4 | 6 TO 10 | 45 | 2.81 | 1.74 | 1.19 | 1.11 | 1.14 |
| DCD3D1 | 6 TO 10 | 90 | 3.46 | 2.82 | 1.43 | 1.13 | 1.12 |
| DCD3D2 | 6 TO 10 | 90 | 3.42 | 2.75 | 1.43 | 1.13 | 1.09 |
| DCD3D3 | 6 TO 10 | 90 | 3.35 | 2.76 | 1.39 | 1.11 | 1.09 |
| DCD3D4 | 6 TO 10 | 90 | 3.46 | 2.87 | 1.42 | 1.15 | 1.11 |
| DCD4D1 | 6 TO 12 | 20 | 2.79 | 1.91 | 1.19 | 1.08 | 1.08 |
| DCD4D2 | 6 TO 12 | 20 | 2.86 | 1.96 | 1.20 | 1.07 | 1.06 |
| DCD4D3 | 6 TO 12 | 20 | 2.81 | 2.00 | 1.21 | 1.08 | 1.09 |
| DCD4D4 | 6 TO 12 | 20 | 2.83 | 2.00 | 1.13 | 0.96 | 1.00 |
| DCD5D1 | 6 TO 12 | 45 | 2.36 | 1.56 | 1.07 | 1.09 | 1.08 |
| DCD5D2 | 6 TO 12 | 45 | 2.25 | 1.52 | 1.14 | 1.09 | 1.09 |
| DCD5D3 | 6 TO 12 | 45 | 2.41 | 1.54 | 1.15 | 1.11 | 1.10 |
| DCD5D4 | 6 TO 12 | 45 | 2.53 | 1.63 | 1.02 | 1.02 | 1.02 |
| DCD6D1 | 6 TO 12 | 90 | 4.87 | 3.28 | 1.26 | 1.02 | 1.00 |
| DCD6D2 | 6 TO 12 | 90 | 4.81 | 3.29 | 1.33 | 1.10 | 1.08 |
| DCD6D3 | 6 TO 12 | 90 | 4.05 | 3.23 | 1.33 | 1.09 | 1.09 |
| DCD6D4 | 6 TO 12 | 90 | 4.93 | 3.41 | 1.29 | 0.97 | 1.01 |


## TABLE 9
## Centerline Velocity Data for Round Diverging Junctions

| Code | Dia. of Main (in.) | Dia. of Branch (in.) | Branch Angle (Deg.) | Velocity Ratio, Vc / Vavg 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|
| Y3D11 | 10 | 6 | 90 | 0.35 | 0.66 | 1.04 | 1.12 | 1.12 |
| Y3D12 | 10 | 6 | 90 | 0.78 | 0.78 | 1.03 | 1.11 | 1.12 |
| Y3D13 | 10 | 6 | 90 | 0.91 | 0.85 | 1.04 | 1.10 | 1.12 |
| Y3D21 | 10 | 6 | 90 | 0.26 | 0.54 | 1.08 | 1.12 | 1.08 |
| Y3D22 | 10 | 6 | 90 | 0.60 | 0.67 | 1.01 | 1.07 | 1.06 |
| Y3D23 | 10 | 6 | 90 | 0.91 | 0.78 | 1.06 | 1.11 | 1.09 |
| Y3D31 | 10 | 6 | 90 | 0.22 | 0.55 | 1.16 | 1.17 | 1.08 |
| Y3D32 | 10 | 6 | 90 | 0.28 | 0.66 | 1.08 | 1.17 | 1.15 |
| Y3D33 | 10 | 6 | 90 | 0.48 | 0.70 | 1.05 | 1.13 | 1.12 |
| Y3D11 | 12 | 6 | 90 | 0.26 | 0.58 | 1.01 | 1.09 | 1.08 |
| Y3D12 | 12 | 6 | 90 | 0.80 | 0.74 | 1.00 | 1.07 | 1.09 |
| Y3D13 | 12 | 6 | 90 | 1.02 | 0.82 | 1.01 | 1.08 | 1.11 |
| Y3D21 | 12 | 6 | 90 | 0.18 | 0.35 | 1.07 | 1.10 | 1.07 |
| Y3D22 | 12 | 6 | 90 | 0.32 | 0.61 | 1.03 | 1.11 | 1.10 |
| Y3D23 | 12 | 6 | 90 | 0.63 | 0.69 | 1.01 | 1.10 | 1.11 |
| Y3D31 | 12 | 6 | 90 | 0.18 | 0.32 | 1.02 | 1.09 | 1.02 |
| Y3D32 | 12 | 6 | 90 | 0.22 | 0.64 | 1.06 | 1.16 | 1.14 |
| Y3D33 | 12 | 6 | 90 | 0.38 | 0.65 | 1.00 | 1.10 | 1.10 |
| Y3D11 | 16 | 6 | 90 | 0.63 | 0.62 | 1.08 | 1.18 | 1.18 |
| Y3D12 | 16 | 6 | 90 | 1.01 | 0.73 | 0.98 | 1.08 | 1.10 |
| Y3D13 | 16 | 6 | 90 | 1.17 | 0.74 | 0.96 | 1.04 | 1.08 |
| Y3D21 | 16 | 6 | 90 | 0.18 | 0.47 | 1.11 | 1.18 | 1.18 |
| Y3D22 | 16 | 6 | 90 | 0.43 | 0.59 | 1.00 | 1.11 | 1.09 |
| Y3D23 | 16 | 6 | 90 | 1.10 | 0.65 | 0.98 | 1.07 | 1.08 |
| Y3D31 | 16 | 6 | 90 | 0.18 | 0.32 | 1.10 | 1.24 | 1.14 |
| Y3D32 | 16 | 6 | 90 | 0.13 | 0.52 | 1.02 | 1.12 | 1.08 |
| Y3D33 | 16 | 6 | 90 | 0.56 | 0.63 | 1.02 | 1.10 | 1.07 |
| Y4D11 | 10 | 6 | 30 | 1.26 | 1.23 | 1.15 | 1.12 | 1.10 |
| Y4D12 | 10 | 6 | 30 | 1.22 | 1.11 | 1.13 | 1.13 | 1.12 |
| Y4D13 | 10 | 6 | 30 | 1.02 | 1.04 | 1.10 | 1.13 | 1.12 |
| Y4D21 | 10 | 6 | 30 | 1.23 | 1.22 | 1.28 | 1.24 | 1.13 |
| Y4D22 | 10 | 6 | 30 | 1.21 | 1.18 | 1.09 | 1.05 | 1.05 |
| Y4D23 | 10 | 6 | 30 | 1.22 | 1.15 | 1.09 | 1.05 | 1.05 |
| Y4D31 | 10 | 6 | 30 | 1.21 | 1.39 | 1.42 | 1.23 | 1.08 |
| Y4D32 | 10 | 6 | 30 | 1.13 | 1.13 | 1.13 | 1.13 | 1.15 |
| Y4D33 | 10 | 6 | 30 | 1.21 | 1.18 | 1.08 | 1.06 | 1.04 |
| Y5D11 | 12 | 6 | 30 | 1.24 | 1.19 | 1.12 | 1.11 | 1.12 |
| Y5D12 | 12 | 6 | 30 | 1.09 | 1.02 | 1.08 | 1.11 | 1.10 |
| Y5D13 | 12 | 6 | 30 | 0.94 | 0.98 | 1.08 | 1.11 | 1.11 |
| Y5D21 | 12 | 6 | 30 | 1.31 | 1.29 | 1.31 | 1.27 | 1.13 |
| Y5D22 | 12 | 6 | 30 | 1.18 | 1.14 | 1.08 | 1.06 | 1.07 |
| Y5D23 | 12 | 6 | 30 | 1.22 | 1.13 | 1.10 | 1.10 | 1.11 |
| Y5D31 | 12 | 6 | 30 | 1.52 | 1.52 | 1.44 | 1.20 | 1.08 |
| Y5D32 | 12 | 6 | 30 | 1.21 | 1.23 | 1.22 | 1.22 | 1.17 |
| Y5D33 | 12 | 6 | 30 | 1.21 | 1.18 | 1.12 | 1.11 | 1.11 |
| Y6D11 | 16 | 6 | 30 | 1.27 | 1.22 | 1.18 | 1.20 | 1.20 |
| Y6D12 | 16 | 6 | 30 | 0.95 | 0.99 | 1.05 | 1.12 | 1.13 |
| Y6D13 | 16 | 6 | 30 | 0.83 | 0.90 | 1.06 | 1.11 | 1.12 |
| Y6D21 | 16 | 6 | 30 | 1.45 | 1.41 | 1.39 | 1.33 | 1.23 |
| Y6D22 | 16 | 6 | 30 | 1.25 | 1.20 | 1.17 | 1.17 | 1.14 |
| Y6D23 | 16 | 6 | 30 | 1.08 | 1.02 | 1.08 | 1.12 | 1.13 |
| Y6D31 | 16 | 6 | 30 | 1.52 | 1.61 | 1.51 | 1.26 | 1.15 |
| Y6D32 | 16 | 6 | 30 | 1.29 | 1.27 | 1.20 | 1.20 | 1.18 |
| Y6D33 | 16 | 6 | 30 | 1.21 | 1.18 | 1.14 | 1.12 | 1.10 |



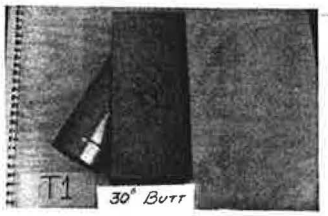


## TABLE 10
## Centerline Velocity Data for Round Diverging Wyes Having a 45° Elbow Tap Connection

| Code | Dia. of Main (in.) | Dia. of Branch (in.) | Dia. Inline Outlet (in.) | Velocity Ratio, Vc / Vavg 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|
| DY1D11 | 10 | 6 | 6 | 1.12 | 1.10 | 1.05 | 1.04 | 1.06 |
| DY1D12 | 10 | 6 | 6 | 1.16 | 1.13 | 1.04 | 1.04 | 1.08 |
| DY1D13 | 10 | 6 | 6 | 1.16 | 1.11 | 1.04 | 1.06 | 1.09 |
| DY1D21 | 10 | 6 | 6 | 1.22 | 1.17 | 1.11 | 1.17 | 1.20 |
| DY1D22 | 10 | 6 | 6 | 1.12 | 1.09 | 1.04 | 1.02 | 1.05 |
| DY1D23 | 10 | 6 | 6 | 1.09 | 1.08 | 0.99 | 0.98 | 1.01 |
| DY1D31 | 10 | 6 | 6 | 1.14 | 1.08 | 1.19 | 1.29 | 1.13 |
| DY1D32 | 10 | 6 | 6 | 1.18 | 1.14 | 1.06 | 1.10 | 1.15 |
| DY1D33 | 10 | 6 | 6 | 1.17 | 1.14 | 1.10 | 1.08 | 1.11 |
| DY2D11 | 12 | 6 | 6 | 1.17 | 1.10 | 1.03 | 1.00 | 1.06 |
| DY2D12 | 12 | 6 | 6 | 1.18 | 1.15 | 1.04 | 1.04 | 1.07 |
| DY2D13 | 12 | 6 | 6 | 1.20 | 1.16 | 1.04 | 1.02 | 1.07 |
| DY2D21 | 12 | 6 | 6 | 1.16 | 1.04 | 1.07 | 1.24 | 1.14 |
| DY2D22 | 12 | 6 | 6 | 1.14 | 1.08 | 1.02 | 1.02 | 1.07 |
| DY2D23 | 12 | 6 | 6 | 1.11 | 1.08 | 1.01 | 1.00 | 1.02 |
| DY2D31 | 12 | 6 | 6 | 0.81 | 0.88 | 1.13 | 1.19 | 1.11 |
| DY2D32 | 12 | 6 | 6 | 1.15 | 1.14 | 1.13 | 1.17 | 1.14 |
| DY2D33 | 12 | 6 | 6 | 0.18 | 1.13 | 1.06 | 1.05 | 1.11 |
| DY3D11 | 16 | 6 | 6 | 1.19 | 1.13 | 1.07 | 1.05 | 1.09 |
| DY3D12 | 16 | 6 | 6 | 1.16 | 1.11 | 1.01 | 1.00 | 1.03 |
| DY3D13 | 16 | 6 | 6 | 1.17 | 1.10 | 0.98 | 0.98 | 1.02 |
| DY3D21 | 16 | 6 | 6 | 1.20 | 1.11 | 1.08 | 1.20 | 1.28 |
| DY3D22 | 16 | 6 | 6 | 1.14 | 1.10 | 1.03 | 1.03 | 1.09 |
| DY3D23 | 16 | 6 | 6 | 1.15 | 1.08 | 1.00 | 1.02 | 1.05 |
| DY3D31 | 16 | 6 | 6 | 1.19 | 1.08 | 1.16 | 1.25 | 1.25 |
| DY3D32 | 16 | 6 | 6 | 1.16 | 1.09 | 1.01 | 1.03 | 1.10 |
| DY3D33 | 16 | 6 | 6 | 1.15 | 1.09 | 1.02 | 1.02 | 1.05 |


## TABLE 11
### Centerline Velocity Data for Diverging Junctions with Rectangular Main and Round Branches

| Code | Rect. Main W x H (in.) | Branch Takeoff angle (Deg.) | Tap Conn. Type | Velocity Ratio, Vc / Vavg 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|
| T1D11 | 8 X 7 | 30 | STR | 1.10 | 1.14 | 1.01 | 0.95 | 0.98 |
| T1D12 | 8 X 7 | 30 | STR | 1.29 | 1.16 | 1.09 | 1.05 | 1.03 |
| T1D21 | 8 X 7 | 30 | STR | 1.15 | 1.10 | 1.16 | 1.17 | 1.14 |
| T1D22 | 8 X 7 | 30 | STR | 1.21 | 1.15 | 1.03 | 0.96 | 0.99 |
| T1D23 | 8 X 7 | 30 | STR | 1.26 | 1.17 | 1.10 | 1.05 | 1.03 |
| T1D31 | 8 X 7 | 30 | STR | 0.96 | 1.05 | 1.31 | 1.32 | 1.16 |
| T1D32 | 8 X 7 | 30 | STR | 1.10 | 1.07 | 1.00 | 1.02 | 1.06 |
| T1D33 | 8 X 7 | 30 | STR | 1.21 | 1.16 | 1.03 | 0.98 | 0.98 |
| T2D11 | 12 X 10 | 30 | STR | 1.22 | 1.21 | 1.17 | 1.15 | 1.15 |
| T2D12 | 12 X 10 | 30 | STR | 1.31 | 1.12 | 1.11 | 1.14 | 1.12 |
| T2D13 | 12 X 10 | 30 | STR | 1.28 | 1.07 | 1.09 | 1.14 | 1.12 |
| T2D21 | 12 X 10 | 30 | STR | 1.51 | 1.41 | 1.31 | 1.21 | 1.09 |
| T2D22 | 12 X 10 | 30 | STR | 1.21 | 1.21 | 1.16 | 1.15 | 1.13 |
| T2D23 | 12 X 10 | 30 | STR | 1.28 | 1.17 | 1.11 | 1.13 | 1.15 |
| T2D31 | 12 X 10 | 30 | STR | 1.69 | 1.75 | 1.38 | 1.14 | 1.08 |
| T2D32 | 12 X 10 | 30 | STR | 1.34 | 1.31 | 1.26 | 1.19 | 1.13 |
| T2D33 | 12 X 10 | 30 | STR | 1.21 | 1.20 | 1.17 | 1.14 | 1.12 |
| T3D11 | 18 X 10 | 30 | STR | 1.17 | 1.17 | 1.14 | 1.14 | 1.11 |
| T3D12 | 18 X 10 | 30 | STR | 1.26 | 1.08 | 1.07 | 1.11 | 1.12 |
| T3D13 | 18 X 10 | 30 | STR | 1.26 | 1.04 | 1.08 | 1.12 | 1.10 |
| T3D21 | 18 X 10 | 30 | STR | 1.40 | 1.36 | 1.31 | 1.23 | 1.11 |
| T3D22 | 18 X 10 | 30 | STR | 1.17 | 1.17 | 1.17 | 1.15 | 1.13 |
| T3D23 | 18 X 10 | 30 | STR | 1.21 | 1.14 | 1.09 | 1.11 | 1.12 |
| T3D31 | 18 X 10 | 30 | STR | 1.48 | 1.53 | 1.32 | 1.15 | 1.05 |
| T3D32 | 18 X 10 | 30 | STR | 1.30 | 1.28 | 1.24 | 1.22 | 1.13 |
| T3D33 | 18 X 10 | 30 | STR | 1.16 | 1.16 | 1.16 | 1.15 | 1.12 |




## TABLE 11
### Centerline Velocity Data for Diverging Junctions with Rectangular Main and Round Branches (*Continued*)

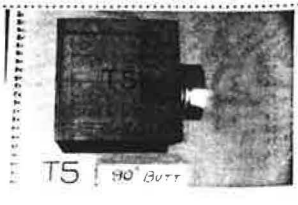
| Code | Rect. Main W x H (in.) | Branch Takeoff angle (Deg.) | Tap Conn. Type | Velocity Ratio, Vc / Vavg 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|
| T10D11 | 8 X 7 | 90 | CON | 0.57 | 0.70 | 0.96 | 1.03 | 1.07 |
| T10D12 | 8 X 7 | 90 | CON | 0.75 | 0.84 | 0.97 | 1.04 | 1.06 |
| T10D21 | 8 X 7 | 90 | CON | 0.26 | 0.54 | 0.99 | 1.09 | 1.08 |
| T10D22 | 8 X 7 | 90 | CON | 0.58 | 0.72 | 0.96 | 1.05 | 1.08 |
| T10D23 | 8 X 7 | 90 | CON | 0.70 | 0.77 | 0.96 | 1.03 | 1.07 |
| T10D31 | 8 X 7 | 90 | CON | 0.19 | 0.39 | 0.97 | 1.11 | 1.08 |
| T10D32 | 8 X 7 | 90 | CON | 0.39 | 0.63 | 0.97 | 1.07 | 1.08 |
| T10D33 | 8 X 7 | 90 | CON | 0.58 | 0.74 | 0.98 | 1.06 | 1.09 |
| T11D11 | 12 X 10 | 90 | CON | 0.69 | 0.73 | 0.93 | 1.00 | 1.06 |
| T11D12 | 12 X 10 | 90 | CON | 0.83 | 0.80 | 0.92 | 0.99 | 1.03 |
| T11D13 | 12 X 10 | 90 | CON | 0.95 | 0.85 | 0.96 | 1.01 | 1.05 |
| T11D21 | 12 X 10 | 90 | CON | 0.48 | 0.70 | 0.98 | 1.09 | 1.08 |
| T11D22 | 12 X 10 | 90 | CON | 0.74 | 0.76 | 0.93 | 1.01 | 1.06 |
| T11D23 | 12 X 10 | 90 | CON | 0.81 | 0.77 | 0.91 | 0.98 | 1.04 |
| T11D31 | 12 X 10 | 90 | CON | 0.22 | 0.67 | 1.06 | 1.12 | 1.07 |
| T11D32 | 12 X 10 | 90 | CON | 0.61 | 0.72 | 0.97 | 1.07 | 1.08 |
| T11D33 | 12 X 10 | 90 | CON | 0.74 | 0.75 | 0.93 | 1.02 | 1.07 |
| T12D11 | 18 X 10 | 90 | CON | 0.94 | 0.86 | 0.93 | 1.02 | 1.07 |
| T12D12 | 18 X 10 | 90 | CON | 0.99 | 0.87 | 0.91 | 0.98 | 1.05 |
| T12D13 | 18 X 10 | 90 | CON | 1.05 | 0.89 | 0.93 | 1.00 | 1.05 |
| T12D21 | 18 X 10 | 90 | CON | 1.13 | 1.12 | 1.10 | 1.16 | 1.10 |
| T12D22 | 18 X 10 | 90 | CON | 0.94 | 0.85 | 0.91 | 1.01 | 1.06 |
| T12D23 | 18 X 10 | 90 | CON | 0.96 | 0.86 | 0.92 | 0.98 | 1.04 |
| T12D31 | 18 X 10 | 90 | CON | 1.56 | 1.38 | 1.35 | 1.21 | 1.07 |
| T12D32 | 18 X 10 | 90 | CON | 1.07 | 1.00 | 1.04 | 1.09 | 1.09 |
| T12D33 | 18 X 10 | 90 | CON | 0.96 | 0.90 | 0.95 | 1.04 | 1.06 |


## TABLE 11
### Centerline Velocity Data for Diverging Junctions with Rectangular Main and Round Branches (*Continued*)

| Code | Rect. Main W x H (in.) | Branch Takeoff angle (Deg.) | Tap Conn. Type | Velocity Ratio, Vc / Vavg 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|
| T7D11 | 8 X 7 | 30 | CON | 1.00 | 0.95 | 0.92 | 0.95 | 1.02 |
| T7D12 | 8 X 7 | 30 | CON | 1.11 | 1.06 | 0.96 | 1.01 | 1.06 |
| T7D21 | 8 X 7 | 30 | CON | 0.88 | 0.91 | 1.01 | 1.11 | 1.10 |
| T7D22 | 8 X 7 | 30 | CON | 1.01 | 0.95 | 0.93 | 0.98 | 1.03 |
| T7D23 | 8 X 7 | 30 | CON | 1.09 | 1.01 | 0.95 | 0.99 | 1.05 |
| T7D31 | 8 X 7 | 30 | CON | 0.94 | 0.97 | 1.21 | 1.20 | 1.09 |
| T7D32 | 8 X 7 | 30 | CON | 0.95 | 0.92 | 0.98 | 1.04 | 1.09 |
| T7D33 | 8 X 7 | 30 | CON | 1.02 | 0.96 | 0.94 | 0.99 | 1.04 |
| T8D11 | 12 X 10 | 30 | CON | 1.11 | 1.09 | 1.07 | 1.10 | 1.11 |
| T8D12 | 12 X 10 | 30 | CON | 1.10 | 1.10 | 1.09 | 1.08 | 1.05 |
| T8D13 | 12 X 10 | 30 | CON | 1.12 | 1.09 | 1.09 | 1.10 | 1.06 |
| T8D21 | 12 X 10 | 30 | CON | 1.25 | 1.24 | 1.26 | 1.23 | 1.13 |
| T8D22 | 12 X 10 | 30 | CON | 1.12 | 1.10 | 1.07 | 1.08 | 1.09 |
| T8D23 | 12 X 10 | 30 | CON | 1.09 | 1.09 | 1.08 | 1.08 | 1.04 |
| T8D31 | 12 X 10 | 30 | CON | 1.40 | 1.44 | 1.31 | 1.16 | 1.06 |
| T8D32 | 12 X 10 | 30 | CON | 1.15 | 1.13 | 1.14 | 1.17 | 1.15 |
| T8D33 | 12 X 10 | 30 | CON | 1.11 | 1.08 | 1.07 | 1.07 | 1.08 |
| T9D11 | 18 X 10 | 30 | CON | 1.08 | 1.05 | 1.03 | 1.03 | 1.07 |
| T9D12 | 18 X 10 | 30 | CON | 1.09 | 1.09 | 1.09 | 1.09 | 1.05 |
| T9D13 | 18 X 10 | 30 | CON | 1.11 | 1.11 | 1.11 | 1.11 | 1.07 |
| T9D21 | 18 X 10 | 30 | CON | 1.15 | 1.11 | 1.15 | 1.18 | 1.13 |
| T9D22 | 18 X 10 | 30 | CON | 1.09 | 1.05 | 1.04 | 1.05 | 1.08 |
| T9D23 | 18 X 10 | 30 | CON | 1.09 | 1.09 | 1.08 | 1.07 | 1.05 |
| T9D31 | 18 X 10 | 30 | CON | 1.32 | 1.35 | 1.31 | 1.15 | 1.05 |
| T9D32 | 18 X 10 | 30 | CON | 1.08 | 1.07 | 1.09 | 1.12 | 1.12 |
| T9D33 | 18 X 10 | 30 | CON | 1.07 | 1.02 | 1.02 | 1.03 | 1.06 |

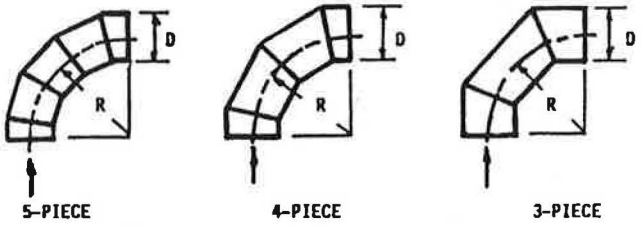

## TABLE 11
### Centerline Velocity Data for Diverging Junctions with Rectangular Main and Round Branches (*Concluded*)

| Code | Rect. Main W x H (in.) | Branch Takeoff angle (Deg.) | Tap Conn. Type | Velocity Ratio, Vc / Vavg 1D | 2D | 4D | 6D | 10D |
|---|---|---|---|---|---|---|---|---|
| T4D11 | 8 X 7 | 90 | STR | 0.45 | 0.47 | 0.94 | 1.06 | 1.06 |
| T4D12 | 8 X 7 | 90 | STR | 1.09 | 0.63 | 0.94 | 1.05 | 1.08 |
| T4D21 | 8 X 7 | 90 | STR | 0.18 | 0.23 | 0.88 | 1.07 | 1.08 |
| T4D22 | 8 X 7 | 90 | STR | 0.19 | 0.35 | 0.91 | 1.02 | 1.04 |
| T4D23 | 8 X 7 | 90 | STR | 0.81 | 0.57 | 0.97 | 1.08 | 1.09 |
| T4D31 | 8 X 7 | 90 | STR | 0.18 | 0.26 | 0.83 | 1.05 | 1.07 |
| T4D32 | 8 X 7 | 90 | STR | 0.11 | 0.29 | 0.93 | 1.05 | 1.07 |
| T4D33 | 8 X 7 | 90 | STR | 0.34 | 0.36 | 0.94 | 1.05 | 1.06 |
| T5D11 | 12 X 10 | 90 | STR | 0.43 | 0.32 | 0.90 | 1.05 | 1.04 |
| T5D12 | 12 X 10 | 90 | STR | 1.02 | 0.56 | 0.90 | 1.02 | 1.07 |
| T5D13 | 12 X 10 | 90 | STR | 1.13 | 0.71 | 0.89 | 1.02 | 1.07 |
| T5D21 | 12 X 10 | 90 | STR | 0.18 | 0.24 | 0.98 | 1.09 | 1.03 |
| T5D22 | 12 X 10 | 90 | STR | 0.59 | 0.44 | 0.91 | 1.07 | 1.07 |
| T5D23 | 12 X 10 | 90 | STR | 0.96 | 0.61 | 0.92 | 1.06 | 1.09 |
| T5D31 | 12 X 10 | 90 | STR | 0.18 | 0.18 | 0.94 | 1.11 | 1.03 |
| T5D32 | 12 X 10 | 90 | STR | 0.25 | 0.27 | 0.91 | 1.10 | 1.06 |
| T5D33 | 12 X 10 | 90 | STR | 0.60 | 0.45 | 0.93 | 1.06 | 1.09 |
| T6D11 | 18 X 10 | 90 | STR | 0.71 | 0.43 | 0.97 | 1.12 | 1.10 |
| T6D12 | 18 X 10 | 90 | STR | 1.19 | 0.64 | 0.94 | 1.08 | 1.08 |
| T6D13 | 18 X 10 | 90 | STR | 1.31 | 0.73 | 0.89 | 1.02 | 1.08 |
| T6D21 | 18 X 10 | 90 | STR | 0.18 | 0.26 | 1.06 | 1.13 | 1.07 |
| T6D22 | 18 X 10 | 90 | STR | 0.61 | 0.38 | 0.97 | 1.07 | 1.06 |
| T6D23 | 18 X 10 | 90 | STR | 1.18 | 0.66 | 0.99 | 1.11 | 1.11 |
| T6D31 | 18 X 10 | 90 | STR | 0.18 | 0.23 | 1.10 | 1.13 | 1.08 |
| T6D32 | 18 X 10 | 90 | STR | 0.17 | 0.33 | 1.04 | 1.11 | 1.08 |
| T6D33 | 18 X 10 | 90 | STR | 0.75 | 0.43 | 0.98 | 1.09 | 1.09 |



## TABLE 12
### Ratio of Average Velocity from Pitot Traverse to Average Velocity from Independently Measured Flow Rate (Selected Elbow Cases)

| Traverse Position | Traverse Plane | Fitting Test Code Number | | | |
|---|---|---|---|---|---|
| | | E1D2 | E13D2 | E19D2 | E31D2 |
| 1D | V | 1.118 | 1.158 | 1.164 | 1.102 |
| | H | 0.964 | 0.929 | 0.845 | 0.849 |
| 2D | V | 1.082 | 1.086 | 1.100 | 1.085 |
| | H | 1.017 | 1.006 | 0.970 | 0.944 |
| 4D | V | 1.065 | 1.063 | 1.068 | 1.045 |
| | H | 1.043 | 1.021 | 1.013 | 0.988 |
| 6D | V | 1.057 | 1.062 | 1.061 | 1.040 |
| | H | 1.043 | 1.009 | 1.026 | 0.974 |
| 10D | V | 1.048 | 0.971 | 1.049 | 1.015 |
| | H | 1.033 | 1.026 | 1.021 | 1.001 |



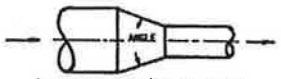

5-PIECE 4-PIECE 3-PIECE

ELBOWS: CODE E

REFERENCE FITTING 3-2, p. 33.33, 1985 ASHRAE FUNDAMENTALS

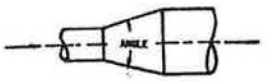
## TABLE 13
### Ratio of Average Velocity from Pitot Traverse to Average Velocity from Independently Measured Flow Rate (Selected Contraction and Diffuser Cases)

| Traverse Position | Traverse Plane | Fitting Test Code Number | | | |
|---|---|---|---|---|---|
| | | Diffusers | | Contractions | |
| | | DCD4D2 | DCD6D2 | CD4D2 | CD6D2 |
| 1D | V | 1.232 | 1.300 | 1.029 | 1.011 |
| | H | 1.158 | 1.406 | 1.013 | 1.021 |
| 2D | V | 1.184 | 1.217 | 1.029 | 1.022 |
| | H | 1.146 | 1.277 | 1.015 | 1.018 |
| 4D | V | 1.052 | 1.102 | 1.033 | 1.036 |
| | H | 1.079 | 1.115 | 1.021 | 1.024 |
| 6D | V | 1.021 | 1.043 | 1.038 | 1.046 |
| | H | 1.029 | 1.053 | 1.020 | 1.029 |
| 10D | V | 1.003 | 1.012 | 1.034 | 1.042 |
| | H | 1.005 | 1.009 | 1.009 | 1.019 |




CONICAL CONTRACTION (ROUND): CODE CD

REFERENCE FITTING 5-1, p. 33.39, 1985 ASHRAE FUNDAMENTALS

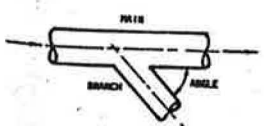



CONICAL DIFFUSER (ROUND): CODE DCD

REFERENCE FITTING 6-1, p. 33.37, 1985 ASHRAE FUNDAMENTALS

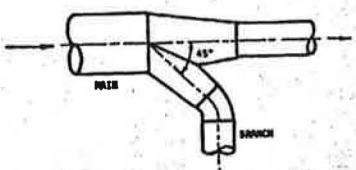
## TABLE 14
### Ratio of Average Velocity from Pitot Traverse to Average Velocity from Independently Measured Flow Rate (Selected Y and DY Cases)

| Traverse Position | Traverse Plane | Fitting Test Code Number | | | |
|---|---|---|---|---|---|
| | | Y's | | DY's | |
| | | Y1D22 (90 Deg.) | Y4D22 (30 Deg.) | DY1D22 | DY3D22 |
| 1D | V | 1.447 | 1.137 | 1.126 | 1.187 |
| | H | 0.888 | 0.929 | 0.946 | 0.980 |
| 2D | V | 1.226 | 1.130 | 1.075 | 1.154 |
| | H | 0.890 | 0.970 | 0.937 | 1.028 |
| 4D | V | 1.075 | 1.120 | 1.043 | 1.117 |
| | H | 1.003 | 0.997 | 0.989 | 1.048 |
| 6D | V | 1.023 | 1.105 | 1.036 | 1.104 |
| | H | 1.002 | 1.018 | 1.003 | 1.058 |
| 10D | V | 0.979 | 1.071 | 1.029 | 1.081 |
| | H | 0.979 | 1.036 | 0.998 | 1.049 |




DIVERGING WYE (ROUND): CODE Y

REFERENCE FITTING 6-8, p. 33.37, 1985 ASHRAE FUNDAMENTALS

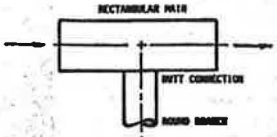



DIVERGING 45° WYE, CONICAL MAIN AND BRANCH, WITH 45° ELBOW, BRANCH 90° TO MAIN: CODE DY

REFERENCE FITTING 6-17, p. 33.43, 1985 ASHRAE FUNDAMENTALS

## TABLE 15
### Average Velocity Ratios on the Basis of Equal Area (Selected Tee Cases)

| Traverse Postion | Traverse Plane | Fitting Test Code Number | | | |
|---|---|---|---|---|---|
| | | Straight Tap | | | |
| | | T1D22 | T3D22 | T4D22 | T6D22 |
| 1D | V | 1.088 | 1.062 | 1.149 | 1.258 |
| | H | 0.902 | 0.928 | 0.877 | 0.951 |
| 2D | V | 1.077 | 1.068 | 1.126 | 1.204 |
| | H | 0.921 | 0.934 | 0.853 | 0.847 |
| 4D | V | 1.056 | 1.064 | 1.045 | 1.025 |
| | H | 0.939 | 0.978 | 0.993 | 1.055 |
| 6D | V | 1.037 | 1.051 | 1.003 | 0.986 |
| | H | 0.953 | 1.002 | 0.990 | 1.039 |
| 10D | V | 1.015 | 1.004 | 0.972 | 0.971 |
| | H | 0.971 | 1.015 | 0.976 | 0.982 |




DIVERGING TEE, RECTANGULAR MAIN TO ROUND BUTT TAP (90° CASE SHOWN): CODE T

REFERENCE FITTING 6-26, p. 33.45, 1985 ASHRAE FUNDAMENTALS

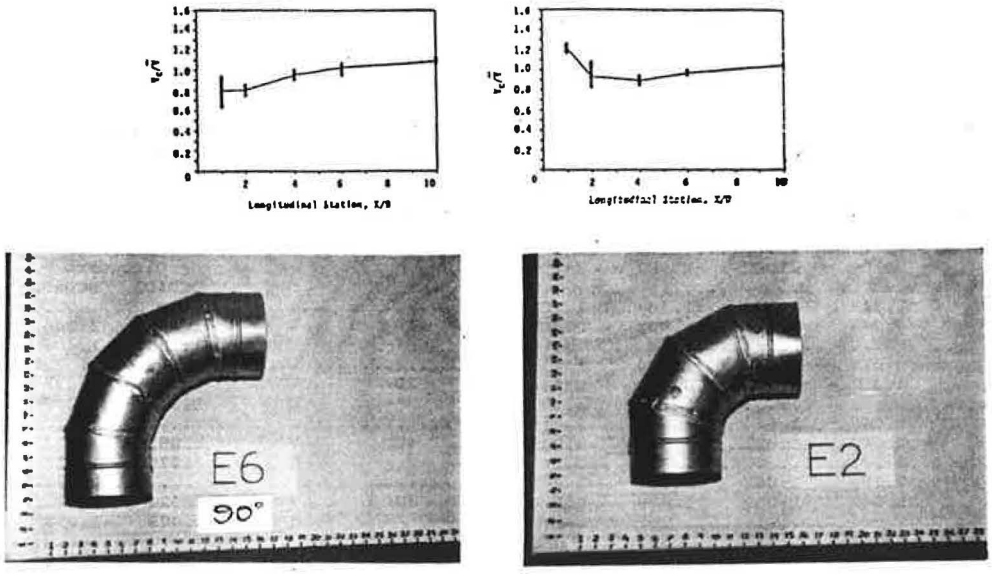



**Figure 2** *Centerline velocity data for elbows (a) 90°; (b) 45°*

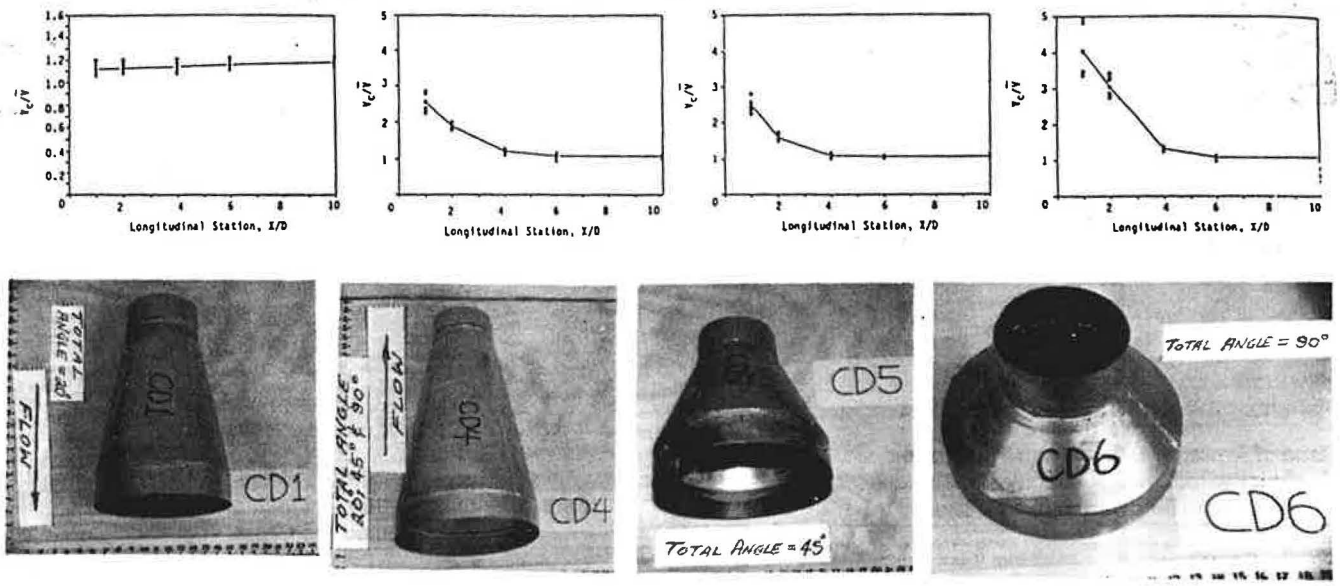



**Figure 3** *Centerline velocity data for contractions and and diffusers*
*(a) all contractions (CDs); (b) 20° diffuser (DCD1 and DCD4);*
*(c) 45° diffuser (DCD2 and DCD5); (d) 90° diffuser (DCD3 and DCD6)*

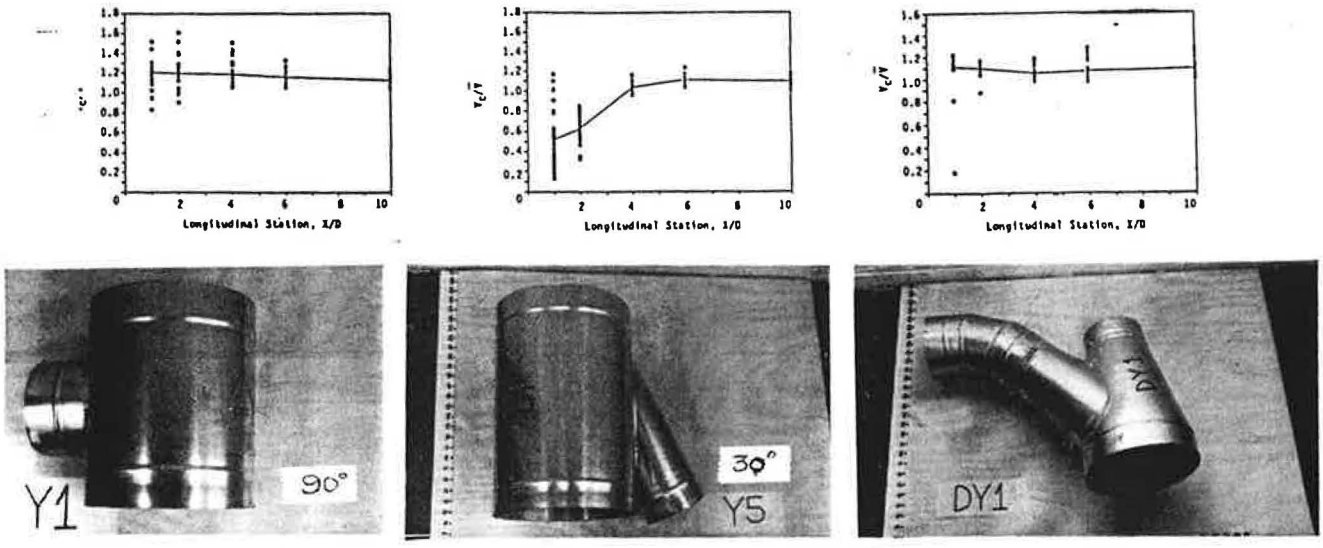



**Figure 4** *Centerline velocity data for round-to-round junctions (a) 90°; (b) 30°; (c) all DY's*

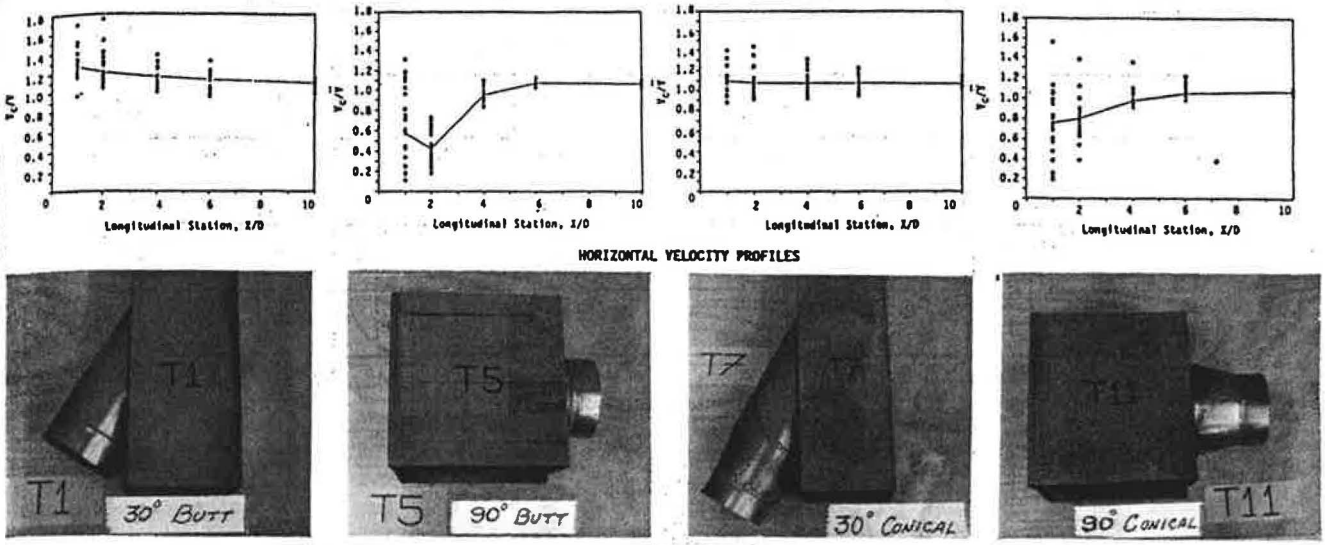



**Figure 5** *Centerline velocity data for rectangular-to-round junctions (a) 30° butt tap; (b) 90° butt tap; (c) 30° conical tap; (d) 90° conical tap*

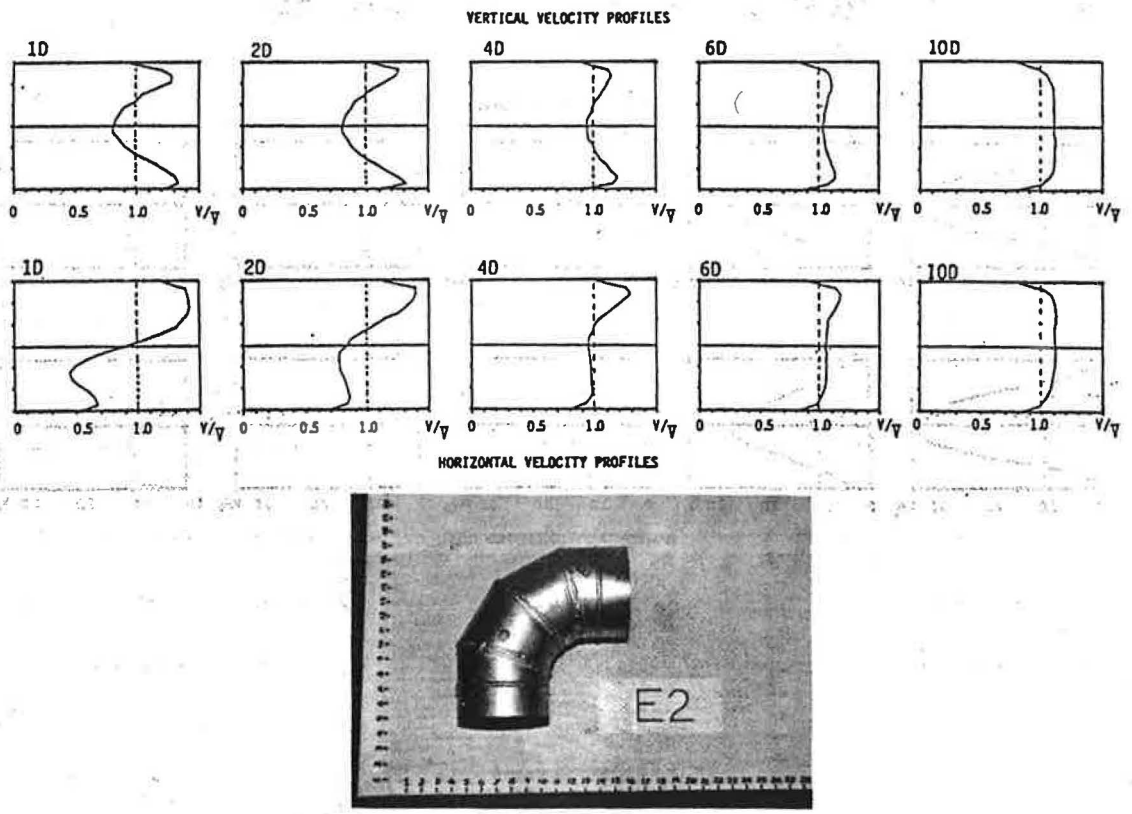



**Figure 6** *Depiction of profile evolution for test case E2D2*

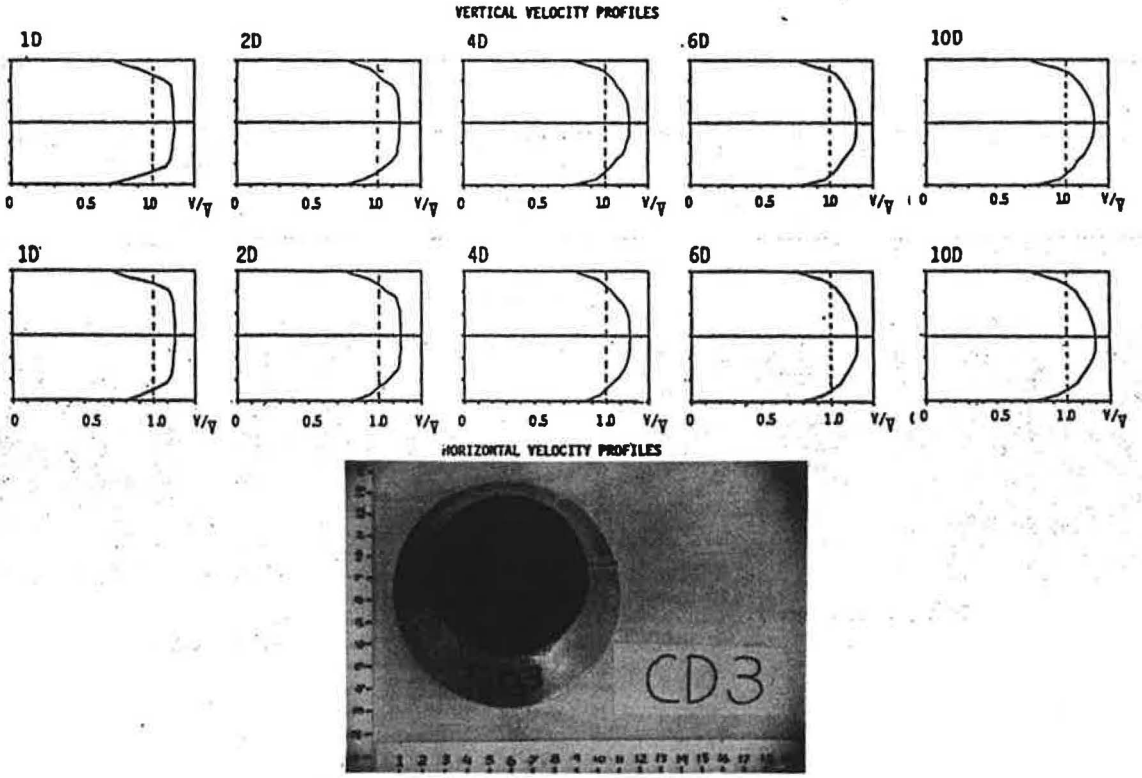



***Figure 7*** *Depiction of profile evolution for test case CD3D2*

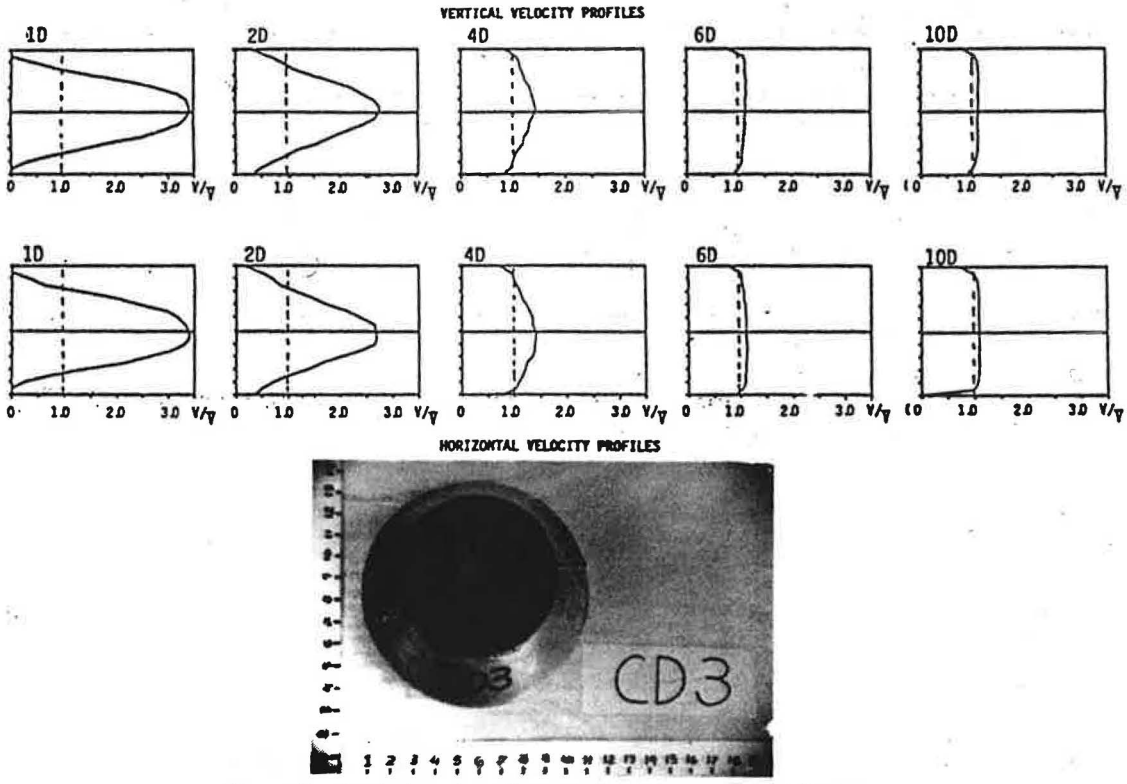



***Figure 8*** *Depiction of profile evolution for test case DCD3D2*

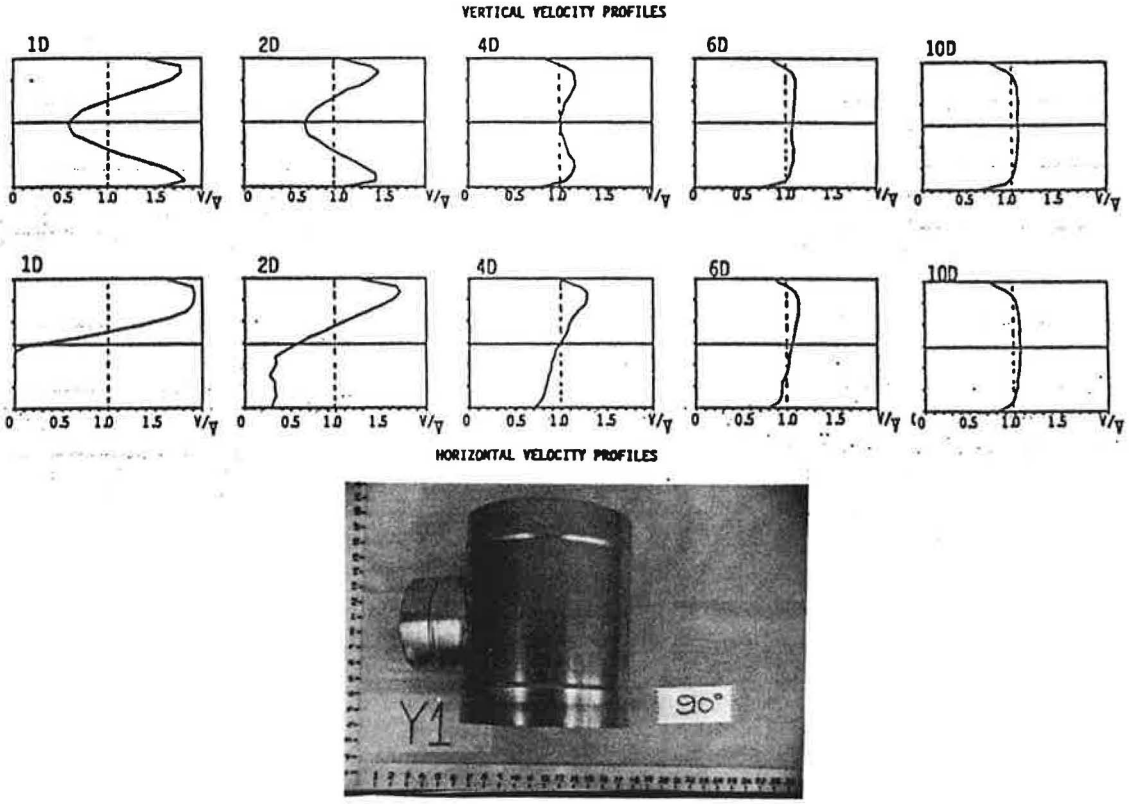



**Figure 9** *Depiction of profile evolution for test case Y1D22*

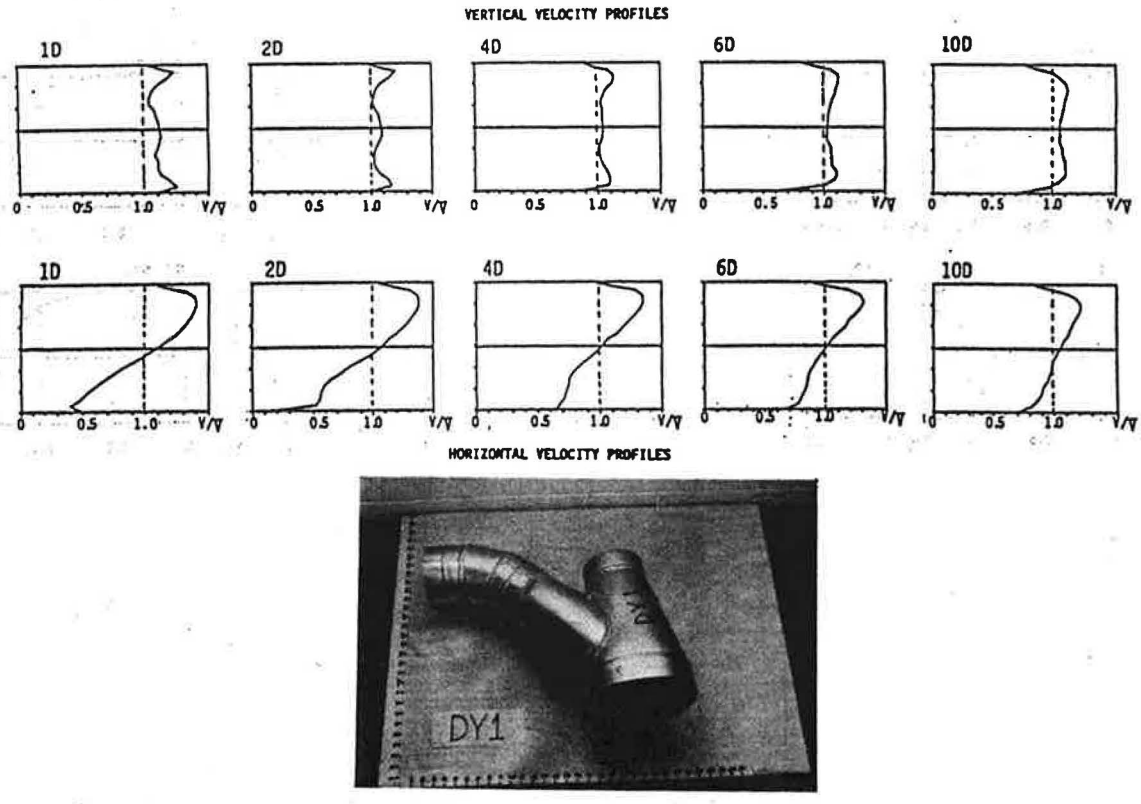



**Figure 10** *Depiction of profile evolution for test case DY1D22*

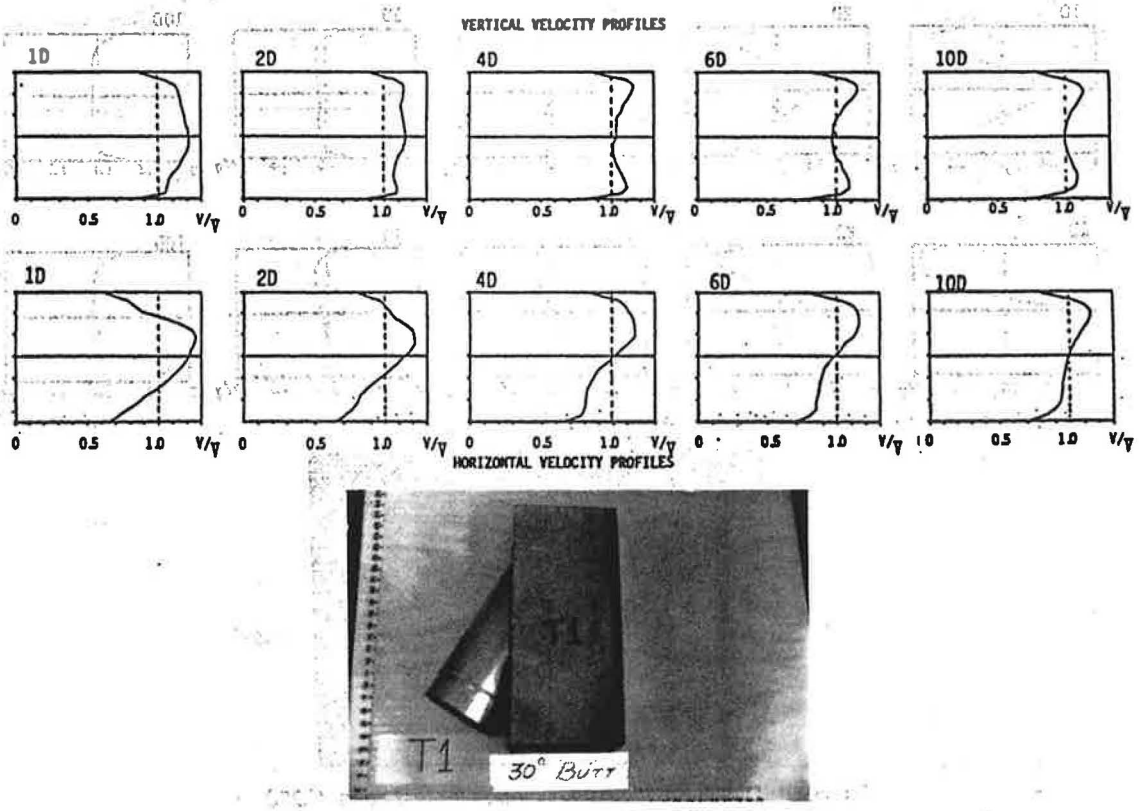



***Figure 11*** *Depiction of profile evolution for test case T1D22*

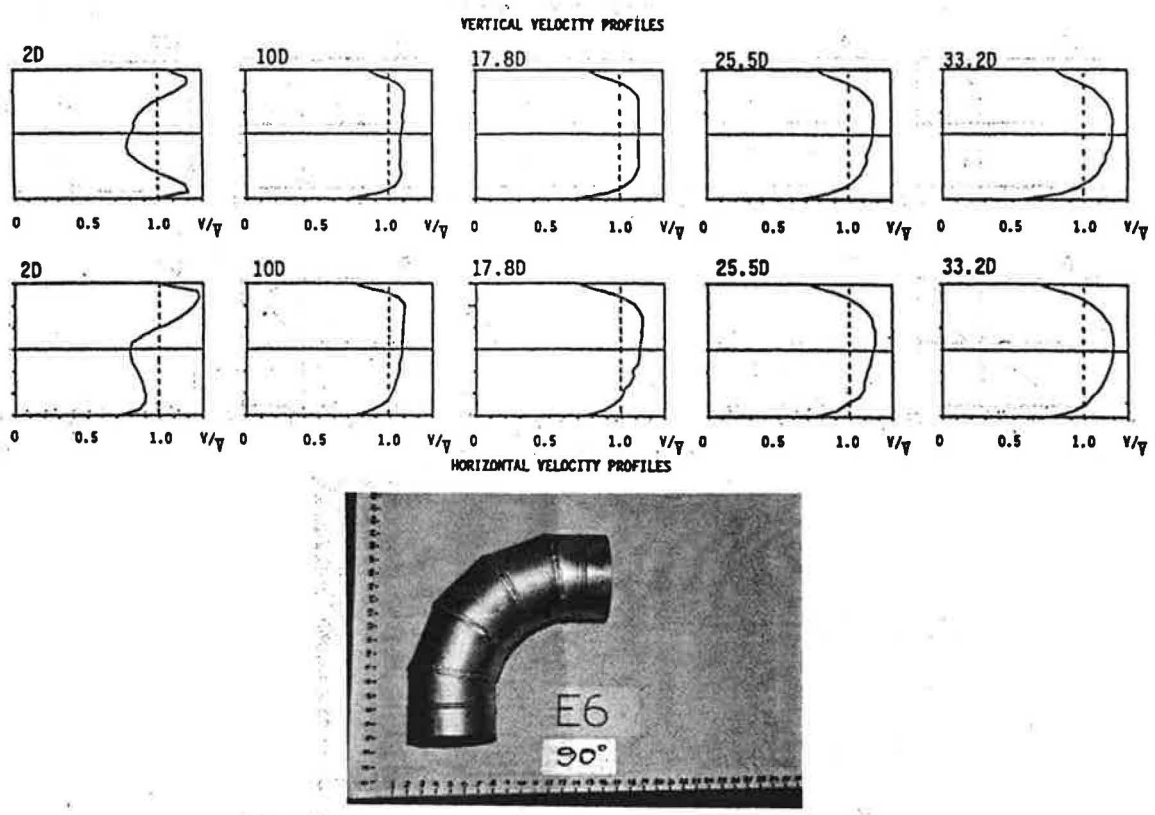



***Figure 12*** *Depiction of profile evolution for test case E6D22 with extended downstream measuring stations*

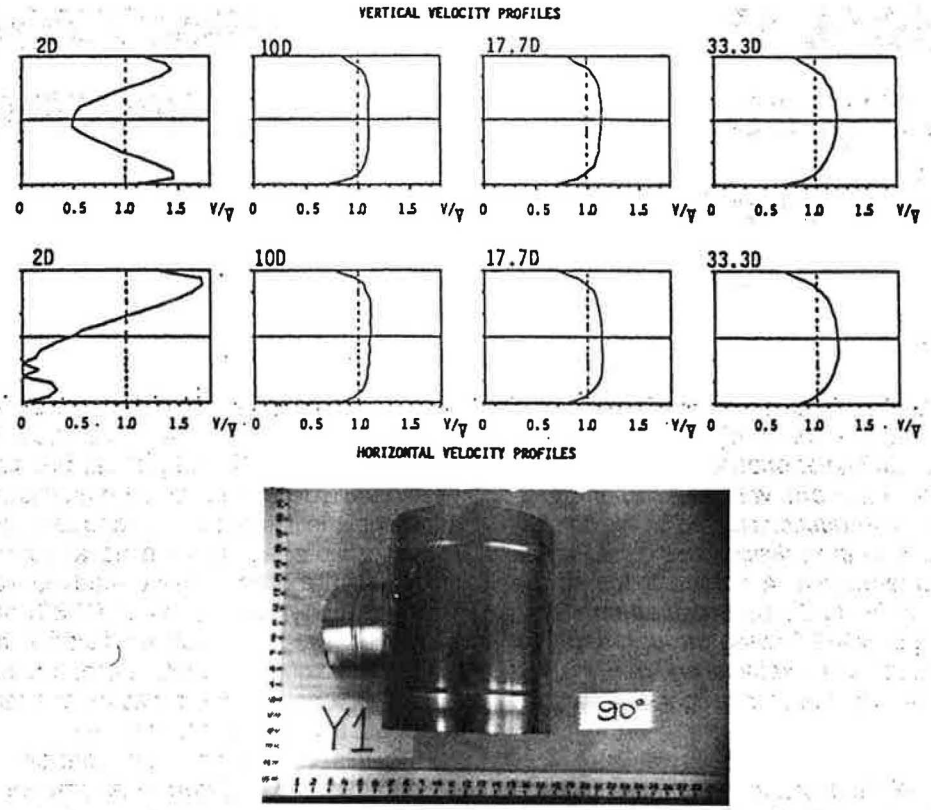






***Figure 13*** *Depiction of profile evolution for test case Y1D22 with extended downstream measuring stations*