Appendix C

Heat Pipe Flow Modeling Study

“Heat Pipe And Flue System Physical Gas Flow Model Study,” Final Report prepared by Fluid Systems Engineering, Inc. for NYSEG, Belco Project No. 92J030, New York State Electric & Gas Corporation, Binghamton, New York, December 1993.

FINAL REPORT

HEAT PIPE AND FLUE SYSTEM

PHYSICAL GAS FLOW MODEL STUDY

for

New York State Electric & Gas Corp.
Milliken Station, Unit No. 2
Lansing, New York

Commissioned by:

Belco Technologies Corporation
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Belco Project No. 92J030

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1.0 INTRODUCTION

This report presents the results of a physical gas flow model study of the new heat pipe ("Q-Pipe") and associated flue system for New York State Electric & Gas Corp., Milliken Station, Unit 2.

Each heat pipe contains two isolated chambers: a gas side and an air side. Within each chamber is a series of sealed finned tubes which contain a heat transfer fluid which transfers energy from the hot boiler exhaust gases to the ambient combustion air. The tubes, and chambers, are angled at 5° downward toward the gas side to allow the cooled heat transfer fluid to condense and roll down the tubes toward the gas side.

The gas side flue system starts at the exit of the economizer. The gas enters the heat pipe and is directed downward past the tubes. The heat pipe is divided into a large "secondary" section and a smaller "primary" section. To facilitate some ash capture, two pyramidal hoppers are located at the bottom of the heat pipe. The gas exits the heat pipe and is directed upward and over the heat pipe through a wide "crossover" duct which connects to the Unit 2 ESP. The mass flow rate for the gas side is 1,500,000 lbm/hr (750,000 lbm/hr for each north and south heat pipe).

The air side flue system starts at the F.D. fan discharge flange. The air enters the heat pipe through a wide-angle pyramidal diffuser and is directed upward. A bypass duct is located on one side of the heat pipe chamber to adjust heat transfer rates. The heated air exits the heat pipe and is directed towards the boiler. The mass flow rate for the air side is 1,125,000 lbm/hr (562,500 lbm/hr for each north and south heat pipe).

A 1/12 scale model was used for flow simulation. The model for the gas side extended from the exit of the economizer duct to the riser duct leading to the ESP. The air side model extended from the exit of the F.D. fan to the boiler inlet duct. Because of the unit's symmetry, only one side (the south side) of the system was modeled.

Testing was carried out at $(1/12)^2$ design flow, corresponding to the design gas velocity, using ambient air as the test gas. A diagram of the gas and air side models are shown in Figures 1 and 2, respectively (Appendix A). Details of the test stations are shown in Figures 3 and 4.

1.1 Objectives of the Study

The following items were accomplished in the study:

- Distribute gas flow evenly within the air and gas side ductwork.
- Minimize dust drop-out in ductwork.
- Minimize pressure drop.
- Provide a velocity profile leading to the ESP that is similar to profiles measured in a previous model study of the Unit 1 ESP.
- Maintain 70 ft/sec along the floor of the crossover duct.

2.0 DISCUSSION AND SUMMARY OF RESULTS

The following is a summary of the model test results. Specific information about each test is shown in Section 5.0.

2.1 Gas Side System

Inlet Duct

Shown in Appendix D (p. D.2, D.3) are final velocity distribution results at TS-1 which is located at the entrance to the heat pipe inlet hood. Early tests showed that the four (4) turning vanes at the economizer outlet duct 90° turn were necessary to provide a good distribution to the heat pipe entrance (see Sketch 1, Appendix B). Without these vanes, the flow was higher along the inlet duct floor which caused the flow distribution to be biased to the east side of the heat pipe.

Shown in Appendix C (p. C.2 - C.4) is the velocity distribution at the center of the heat pipe. As shown, the distribution is very good (RMS=7.63%) with a good east-to-west distribution which indicates that the ladder vanes are effective in turning the gas as enters the inlet hood. Earlier tests with an alternate ladder vane design were found to direct more gas toward the east side of the heat pipe (towards the primary duct). The problem was found to be the stiffened leading edge portion of the ladder vanes which was located on the gas-separated side of the vanes. This stiffener caused the gas to be redirected back towards the primary side. The final ladder vane design (see Sketch 1, Appendix B) has a 0-2" horizontal leading edge located on the *upstream* side of the vane which provides structural stiffness and helps to effectively turn the gas.

<u>Heat Pipe Hopper Region</u>

Shown in Sketch 2, Appendix B are a series of baffle plates that were added above the hoppers. These baffles provide a "false floor" above the hoppers which reduces the amount of gas entering and exiting the hoppers. Without these baffles, strong flow vectors were found to enter and exit the hoppers. The baffles greatly reduced this activity by reducing the scale of these flow vectors, thereby reducing the scouring potential.

Also shown in Sketch 2 are turning vanes located in the outlet duct. The vane at the entrance to the outlet duct has a long leading edge in order to keep the flow attached to the upper duct surface where it would surely separate if there were no vane present. The outside corner of the duct has a 1'-9" radius to reduce ash buildup and minimize pressure drop. The four splitter vanes help to spread the gas evenly as it enters the asymmetrical riser duct.

<u>Crossover Duct</u>

Shown in Appendix D (p. D.14) is a velocity profile measured in the crossover duct between the trusses (see Appendix A, Figure 1). As shown, the profile is biased high towards the floor with a velocity above 70 ft/sec near the floor. Previous tests with only a 1'-0 high baffle showed that a maximum velocity of only 55 ft/sec was obtained near the floor. Increasing the baffle height to 1'-6" significantly increased the velocity near the floor, which in turn will reduce ash drop-out potential.

Also shown in Appendix D (p. D.4 - D.5) is the velocity distribution at TS-3 which is located at the 474'-0 elevation (see Figure 1, Appendix A). Shown in Appendix E (p. E.2 - E.5) are test results at the equivalent location from the ESP flow model study (Dynagen, 1992). The results from the ESP model study have been incorporated into the format used in this report for comparison. As shown, the results at TS-3 (present study) have a similar velocity profile shape to the ESP model study results (left and right side). The RMS results for the left and right side ESP ducts are 10.92% and 11.59%, respectively. The RMS for the present study is 9.72%. In order to achieve this good distribution, the vanes located in the 90° elbow at the exit of the crossover duct were relocated (see Sketch 3, Appendix B). Because roof baffles were added, the velocity profile approaching the elbow was very distorted. Relocating the leading edges of the vanes was necessary to distribute the gas evenly as it makes the 90° turn *and* expansion. Earlier tests were run with the elbow vanes in their original position and deflector "kicker" vanes at the exit of the elbow, but these vanes were not effective in providing a good distribution at TS-3.

Gas Side Flue System Pressure Drop

Shown in Table 1 (p. 7) are field (prototype) pressure drop estimates for the gas side ductwork. As shown, the gas inlet duct pressure drop is 0.62 in. w.g. and the outlet duct pressure drop is 1.88 in. w.g. for a total pressure drop of 2.50 in. w.g. for the gas side ductwork system. A significant portion of this pressure drop is due to the crossover duct. This is primarily due to the addition of the roof baffles and the blockage due to the trusses and turning vane stiffeners.

Another significant contribution to the overall pressure drop is the heat pipe outlet. This area reduction is approximately 9:1, which adds a considerable amount of pressure drop.

The above pressure drop estimates *do not* include the heat pipe pressure losses. Pressure drop calculations are shown in Appendix F (p. F.2).

2.2 Air Side System

<u>Inlet Duct</u>

Shown in Appendix D (p. D.15) is a velocity profile taken at TS-1 showing the simulated F.D. fan discharge profile. This profile was created by installing a deflector baffle at the model inlet (see Figure 2, Appendix A). Also shown in Appendix D (p. D.16) is a depiction of a typical velocity profile at the exit of a centrifugal fan (AMCA, 1990). As shown, the simulated velocity profile contains a reverse (zero) flow region which would correspond to the cutoff region of the fan discharge. In general, the simulated velocity profile resembles the figure, and provides a reasonable approximation to the effect of this non-uniformity.

Shown in Appendix C (p. C.5 - C.13) are velocity distributions at the center of the heat pipe with the bypass damper closed, half-open and full-open. As shown, the RMS for the closed bypass damper test is 25.24%, which is satisfactory. The maldistribution is partly due to the residual effect of the non-uniform fan discharge velocity profile. Tests with and without the fan simulation deflector baffle showed that this does cause a distribution decay. The perforated plate shown in Sketch 4, Appendix B was found to reduce some of the maldistribution effects and should be incorporated since the actual velocity profile may differ from what was modeled. Results could have been improved with the addition of perforated plates in the inlet (a common practice in ESP pyramidal inlet diffusers), but the amount of structural members needed to support that plates would diminish their effectiveness. Instead, a series of splitter vanes were incorporated in the inlet to spread the gas outward in the expansion.

Results for the half-open and full-open bypass damper tests (p. C.8 - C.13) show that the velocity along the north wall increased. This was somewhat unexpected since the bypass duct opening is located away from this area. This could be due to the fan discharge maldistribution in combination with the bypass duct opening causing a very low pressure zone at the entrance to the heat pipe. The distributions, however, are similar to the closed bypass damper tests.

Outlet Duct

Shown in Appendix D (p. D.6 - D.9) are velocity distributions at TS-3 for the inlet and outlet flow tests. As shown, the RMS at this location is about 28% which can be considered only fair. This less than ideal distribution is due to the unusual geometry of the outlet hood. Tests were run to improve the distribution with turning vanes in the ductwork, but it was clearly determined that the problem originates at the outlet hood. The three (3) turning vanes in the hood (see Sketch 5, Appendix B) helped to keep the flow from separating off the floor of the duct as it enters the outlet duct, and reduced the RMS by about 10%. The side-to-side distribution, however, could not be fully corrected without adding a series of complicated vanes within the heat pipe hood. The vertical turning vanes at the exit of the hood (see Sketch 5, Appendix B) help to keep the gas attached to the south wall. The other vanes in the outlet duct were incorporated to minimize pressure drop and produce the best possible flow distribution.

Air Side Flue System Pressure Drop

Shown in Table 1 (p. 7) are estimated field (prototype) pressure drops for the inlet and outlet flue system. As shown the inlet and outlet pressure drops are both 1.25 in. w.g. for a total of 2.50 in. w.g. for the air side ductwork system. The inlet pressure drop is primarily due to the large area increase in combination with the high inlet velocity. The perforated plate (63% open area) is contributing only about 0.25 in. w.g to this total.

Similarly, the outlet duct loss is primarily due to the outlet hood area reduction. Calculations show that the hood will contribute over 1.00 in. w.g. to the total pressure drop. The asymmetric geometry and high exit velocity (> 80 ft/sec) also add substantial pressure drop. The turning vanes incorporated in the outlet duct helped to minimize this pressure drop.

The above pressure drop estimates *do not* include the heat pipe pressure losses. Pressure drop calculations are shown in Appendix F (p. F.3).

TABLE 1 - FINAL HEAT PIPE FLUE SYSTEM FIELD PRESSURE DROP ESTIMATES

GAS SIDE INLET (367,647 ACFM @ 680°F)

100% DESIGN FLOW

FROM	TO	AVG. ΔP (in. w.g.)
ECONOMIZER OUTLET DUCT	INLET HOOD ENTRANCE (TS-1)	0.17
INLET HOOD ENTRANCE (TS-1)	HEAT PIPE INLET	0.45

TOTAL = 0.62

GAS SIDE OUTLET (227,272 ACFM @ 253°F)

100% DESIGN FLOW

FROM	TO	AVG. ΔP (in. w.g.)
HEAT PIPE OUTLET	OUTLET DUCT RISER	0.72
OUTLET DUCT RISER	ESP INLET DUCT (TS-3)	1.16

TOTAL = 1.88

AIR SIDE INLET (130,208 ACFM @ 80°F)

100% DESIGN FLOW

FROM	TO	AVG. ΔP (in. w.g.)
F.D. FAN DISCHARGE (TS-1)	HEAT PIPE INLET	1.25

AIR SIDE OUTLET (260,417 ACFM @ 616°F)

100% DESIGN FLOW

FROM	TO	AVG. ΔP (in. w.g.)
HEAT PIPE OUTLET	BOILER INLET DUCT (TS-3)	1.25

2.3 Dust Drop-Out

The gas side system was evaluated for dust drop-out and two specific areas were tested with the procedure detailed in Section 4.6: the duct between the economizer outlet and the heat pipe inlet, and the crossover duct. Since an objective was to obtain 70 ft/sec along the floor of the crossover duct, dust drop-out testing was done with the final configuration of 1'-6" high baffles. Testing indicated that all of the dust in this area was swept clear at 50% design flow conditions.

Testing in the economizer outlet duct showed that all dust was swept way at approximately 50% design flow. A description of the dust tests is presented in Section 4.6.

3.0 MODEL DESCRIPTION

The model was constructed to 1/12 scale out of 1/4 in. thick clear plexiglas. The gas side model extended from the economizer outlet duct to the exit of the crossover duct (see Figure 1, Appendix A). The air side model extended from the F.D. fan discharge flange to the boiler inlet duct (see Figure 2, Appendix A). Because of symmetry, only the south heat pipe system was modeled.

Turning vanes were constructed out of 24 gauge galvanized sheet steel. Perforated plates were made of 22 gauge, die-punched sheet steel, with 1/8" or 3/16" round holes on staggered centers. Rows of holes were masked with tape in order to achieve the desired open area.

The gas side model was connected to the laboratory fan via a wooden hook-up box. The crossover duct was extended vertically and horizontally over the model inlet to connect to the hook-up box. The air side model outlet duct was extended horizontally to the hook-up box.

Figures 1 and 2 in Appendix A show the model ESP arrangements and the locations of the test stations. Details of the test stations are shown in Figures 3 and 4.

4.0 TEST PROCEDURES AND INSTRUMENTATION

4.1 Modeling Procedures

Due to the reduced scale and different gas properties of the model system and prototype system, Reynolds numbers will be lower in the model than in the actual system. If exact dynamic similitude were to be achieved with a model, very high flow rates, a very large model or other fluids such as water would need to be used. These options are impractical for a study of this nature and are not really necessary. The Reynolds numbers in this modeled system are well within the fully turbulent flow regime. Experience has shown that there are only minor Reynolds number effects between the model and the prototype when the flow is turbulent, so velocity distribution and pressure loss effects remain similar.

It is very important to achieve exact geometric similarity in the model in order to accurately represent all flow boundaries and internal structures (where critical). Using a prototype-to-model gas velocity ratio of 1:1 will ensure that the flow is fully turbulent and careful attention to geometric similarity will enable the model to be used effectively for flow evaluation and correction.

Heat Pipe Pressure Drop

In order to simulate the pressure loss effects due to the heat transfer tubes, four (4) perforated plates were added in the gas and air side models to simulate the heat pipe's resistance. In the actual system, the heavy resistance of the tubes (2.90 in. w.g. for gas side and 3.85 in. w.g. for air side) will help to distribute the gas more evenly. It is very important to account for this in the model. Without this heavy resistance in the model, flow distribution will appear to be poorer than it actually is.

To account for the difference in gas density between the model and prototype, a very large pressure drop would have to be simulated in the model to achieve the pressure drops noted above. Approximately 5 in. w.g for the gas side and 6 in. w.g. for the air side would need to be simulated in the model. Due to structural limitations of the model, this could not be achieved. Instead, approximately 1.3 in. w.g. and 3.8 in. w.g were simulated in the gas and air sides, respectively, as based on *inlet* flow rates. Since these values are substantially less than the required values, flow distribution results can be considered conservative (i.e. actual distribution should be better).

Table 2 shows a comparison of the prototype and model parameters for both the air and gas side systems. Typical ductwork Reynolds numbers in the system, based on the corresponding duct hydraulic diameter, are also shown.

TABLE 2 - PROTOTYPE TO MODEL PARAMETRIC COMPARISON

Gas Side Inlet

	PROTOTYPE	MODEL
DIMENSIONAL SCALE:	FULL	1/12
100% INLET GAS FLOW RATE (ACFM):	367,647	2553
VELOCITY SCALE:	1:1	1:1
GAS TEMPERATURE (°F):	680	60-80
GAS DENSITY (lbm/ft^3):	.034	.074-.076
GAS KINEMATIC VISCOSITY (ft^2/sec):	5.8×10^{-4}	1.6×10^{-4}
REYNOLDS NUMBER, 14' x 6.5' DUCT, Re_D	1.0×10^{6}	3.1×10^{5}

Gas Side Outlet

	PROTOTYPE	MODEL
DIMENSIONAL SCALE:	FULL	1/12
100% INLET GAS FLOW RATE (ACFM):	227,272	1578
VELOCITY SCALE:	1:1	1:1
GAS TEMPERATURE (°F):	253	60-80
GAS DENSITY (lbm/ft^3):	.055	.074-.076
GAS KINEMATIC VISCOSITY (ft^2/sec):	2.5×10^{-4}	1.6×10^{-4}
REYNOLDS NUMBER, 34' x 3.5' DUCT, Re_D	8.1×10^{5}	1.0×10^{5}

TABLE 2 (con't) PROTOTYPE TO MODEL PARAMETRIC COMPARISON

Air Side Inlet

	PROTOTYPE	MODEL
DIMENSIONAL SCALE:	FULL	1/12
100% INLET GAS FLOW RATE (ACFM):	130,208	904
VELOCITY SCALE:	1:1	1:1
GAS TEMPERATURE (°F):	80	60-80
GAS DENSITY (lbm/ft^3):	.072	.074-.076
GAS KINEMATIC VISCOSITY (ft^2/sec):	1.6×10^{-4}	1.6×10^{-4}
REYNOLDS NUMBER, 4' x 5.66' DUCT, Re_D	2.8×10^6	2.3×10^5

Air Side Outlet

	PROTOTYPE	MODEL
DIMENSIONAL SCALE:	FULL	1/12
100% INLET GAS FLOW RATE (ACFM):	260,417	1808
VELOCITY SCALE:	1:1	1:1
GAS TEMPERATURE (°F):	616	60-80
GAS DENSITY (lbm/ft^3):	.036	.074-.076
GAS KINEMATIC VISCOSITY (ft^2/sec):	5.6×10^{-4}	1.6×10^{-4}
REYNOLDS NUMBER, 9' x 9' DUCT, Re_D	8.6×10^5	2.5×10^5

4.2 Test Procedures

Air was supplied under negative pressure to the 1/12th scale model by a centrifugal blower. The flow rate was adjusted with the use of guillotine dampers at the blower inlet. Air flow rates were monitored throughout the test program by pitot tube measurements in the gas side model at TS-1 or TS-3. Flow rates in the air side model were monitored at TS-3.

4.3 Heat Pipe Velocity Measurements

A TSI Model 8450 hot-wire anemometer was used to measure the gas velocity in the heat pipe chambers. The velocity range for this NIST traceable meter is 0-2000 ft/min, it is accurate to +/- 0.5% of the full-scale rating, and has a response time of approximately 0.2 sec. A copy of the meter calibration certificate is presented in Appendix G. The transducer of the meter has a linearized 0-5 Volt output signal which is fed to a portable computer. The computer was equipped with an internal analog-to-digital A/D converter board which converts the output voltage signal to a digital signal which could then be converted to velocity (ft/min). Customized software was then used to acquire and reduce the data.

The sensing element of the anemometer was mounted on the end of a long stainless steel probe which entered the heat pipe through the side normal to the outside wall, therefore the probe was angled at 5° from horizontal. The probe was driven by a stationary gearmotor, on a ball screw/linear bearing assembly which rides on steel shafts. At each measurement point, ten velocity readings were taken and an average of the ten readings was stored in memory; this represented the average velocity at that point.

As shown in Figure 4, Appendix A, there were 48 points measured in the air side chamber and 54 points measured in the gas side chamber. The gas side tests included 6 points in the primary duct.

The following criteria was used to evaluate the statistical test results:

The percent <u>Root Mean Square Index (% RMS)</u> is a statistical measure of variance used to depict the amount of deviation in quantity and magnitude within a set of numbers. The

%RMS is calculated by the following method. First, the variance is defined by:

$$Variance = \frac{n\sum_{i=1}^{n} u_i^2 - \left(\sum_{i=1}^{n} u_i\right)^2}{n(n-1)}$$

or

$$Variance = \frac{\sum_{i=1}^{n} u_i^2 - n\bar{u}^2}{(n-1)}$$

where

n	=	total number of velocity points evaluated
u_i	=	value of each data point
$\bar{u}$	=	arithmetic mean

and the Standard Deviation, σ, is found from:

$$\sigma = \sqrt{Variance}$$

and the % RMS is found from:

$$\%RMS = 100 \times \frac{\sigma}{\bar{u}}$$

The above relationships can be rewritten as:

$$\%RMS = 100 \times \sqrt{\frac{n}{(n-1)}\left[\frac{n\sum_{i=1}^{n} u_i^2}{\left(\sum_{i=1}^{n} u_i\right)^2} - 1\right]}$$

4.4 Pressure Measurements

A United Sensor pitot-static tube was used to measure velocities at various locations in the model as shown in Figures 1 and 2 in Appendix A. The dynamic pressure output from the probe was measured on a Dwyer inclined manometer. The dynamic pressures were converted to velocities and then a statistical analysis was done on these velocities (see Appendix D).

As shown in Appendix D, average, maximum, minimum, standard deviation and RMS were calculated for each test station. Static pressures were read from taps in the duct walls. Total pressures were calculated from the sum of the measured static and dynamic pressures.

These total pressures were then reduced to prototype design flow conditions taking into account the difference in gas densities due to gas temperature, and design vs. measured flow rates. The equation used for this calculation is:

$$\Delta P_p = \Delta P_m \left(\frac{\%Q_d}{\%Q_a}\right)^2 \left(\frac{\rho_p}{\rho_m}\right)$$

where

ΔP_p = expected total pressure loss in the prototype (actual system) (in. w.g.)

ΔP_m = measured total pressure loss in the model (in. w.g.)

$\%Q_d$ = design gas flow rate (%)

$\%Q_a$ = actual gas flow rate measured in model (%)

ρ_p = estimated gas density in the prototype (actual system) (lbm/ft^3)

ρ_m = estimated air density in the model system (lbm/ft^3)

4.5 Streamer and Smoke Observations

The flow direction and degree of turbulence at various points in the system was evaluated by using a streamer consisting of a long thin steel rod with a 4" long section of cotton string attached to the end. Smoke visualization was used when examining flow behavior in the model. A high volume fogger, emitting white smoke, was used to visualize the flow through the entire system.

4.6 Dust Fall-Out Observations

Model dust fallout observations were conducted at gas flow rates simulating 25%, 50%, 75%, 100% and 125% design flow conditions.

Reasonable dynamic similarity was established by using a fine silica test particulate and adjusting the gas velocity to account for the difference in gas density between the model and the prototype. The silica had a mean particle size of 230 microns and a specific gravity of 2.6. This material was considered as a worse case representation of the most coarse fraction of the actual flyash. The model gas velocity scale was reduced from 1:1 to .85:1. This velocity correction is discussed in further detail below.

The silica was layered on the horizontal surfaces of the model ductwork to an average height of about 1/4". The model flow rate was started at 25%, and gradually increased to 125% in 25% increments.

Particle Dynamic Similitude Methodology

The main concern in dust fallout evaluations is the coarse fraction of the particulate. The large particles are far more susceptible to fallout than the fine particles. This can be illustrated by considering the two major forces acting on each particle, namely the aerodynamic drag (F_D) and gravity (F_g) as expressed in the following equations.

Drag Force:

$$F_D = \frac{C_D \rho A V^2}{2 g}$$

where

F_D = Drag force (lbs)
C_D = Drag Coefficient of particle (dimensionless)
A = Projected area of particle (ft^2)
V = Velocity of flue gas (ft/sec)
ρ = Density of flue gas (lbm/ft^3)
g = Acceleration due to gravity (ft/sec^2)

Gravitation Force:

$$F_g = S.G.(P_V)(62.4)$$

where

F_g = Gravitational force (lbs)
S.G. = Specific gravity of particle (dimensionless)
P_v = Particle volume (ft^3)
62.4 = Density of water (lbs/ft^3)

Aerodynamic drag force provides the mechanism for transport. The gravitational force provides the impetus for fallout. Particle drag is directly influenced by the projected area of the particle which is a square function of the particle size. The gravitational force is influenced by the volume of the particle which is a cubic function of particle size.

In the model, the air had a gas density of 0.076 lbm/ft^3. In the prototype system, the gas density is expected to be 0.055 lbm/ft^3 in the crossover duct. Since the induced drag force on the particle is proportional to gas density, the higher gas density in the model would induce a greater drag force than the actual flue gas, at a given velocity.

To compensate for the drag force difference, the model air flow (V_m) was reduced proportionately by the square root of the ratio of field to model gas densities, as shown below:

$$V_m = V_p \sqrt{\frac{\rho_p}{\rho_m}} = V_p \sqrt{\frac{.055}{.076}} = 0.85 V_p$$

where

ρ_p = Field Gas Density
V_p = Field Flow Rate
ρ_m = Model Gas Density
V_m = Model Flow Rate

This correction method does not account for the *exact* particle size in the model and the prototype since the drag coefficient for any particle is dependent on the Reynolds number (based on the particle diameter). However, since this method only accounts for the largest particles in the system, it provides a general indication of where any problem areas may exist.

5.0 DESCRIPTION OF THE TESTS

The following is a brief description of the tests performed on the model during flow correction to determine the gas velocity distributions and pressures. There were a total of 5 tests run for the gas side and 15 tests for the air side.

Gas Side

Test 1 — Baseline test. 1'-0 high roof baffles and existing vanes in outlet elbow in crossover duct. No vanes in economizer outlet duct. Results showed poor distribution at TS-3. High velocity along floor in TS-1.

<u>Test 2</u> Kicker vanes were added at outlet elbow of crossover duct. Results showed improved distribution, but still poor.

<u>Test 3</u> Vanes added to economizer outlet duct. Results showed an improved distribution at TS-1. Also tested velocity distribution in crossover duct: max. velocity near floor was 55 ft/sec.

<u>Test 4</u> Replaced 1'-0 baffles with 1'-6" baffles and varied spacing of outlet elbow vanes. Results showed velocity along floor > 70 ft/sec; RMS @ TS-3 < 10%.

<u>Test 5</u> Modified inlet hood ladder vanes to reduce reverse flow observed with smoke. Distribution in heat pipe was acceptable.

<u>Air Side</u>

<u>Tests 1-8</u> A series of tests were run utilizing perforated plates in the inlet diffuser. Measurements were made upstream of the resistance plates which produced very erratic readings because of 3-dimensional effects. Perforated plates in the inlet were abandoned because of structural support problems in field.

<u>Tests 9-11</u> Experimented with different pressure drop values across heat pipe. Results indicated that the higher the pressure drop, the better the distribution.

<u>Tests 12-15</u> Added and optimized splitter vanes in inlet diffuser. Distribution without splitters produced RMS values > 50%. Final results produced RMS values between 25 and 30%.

6.0 CONCLUSIONS AND RECOMMENDATIONS

On the basis of the preceding test results and observations, the following changes are to be implemented in the system for maximum flow control benefit. These changes, detailed in Appendix B, are as follows:

In the gas side ductwork, incorporate the following:

1) four (4) turning vanes at the economizer outlet duct as shown in Sketch 1.
2) 17 ladder vanes in the inlet hood as shown in Sketch 1.
3) two (2) angled vanes in inlet hood as shown in Sketch 1.
4) baffles in hopper region as shown in Sketch 2.
5) turning vanes near hopper outlet as shown in Sketch 2
6) turning vanes, roof baffles, and relocation of existing vanes as shown in Sketch 3.

In the air side ductwork, incorporate the following

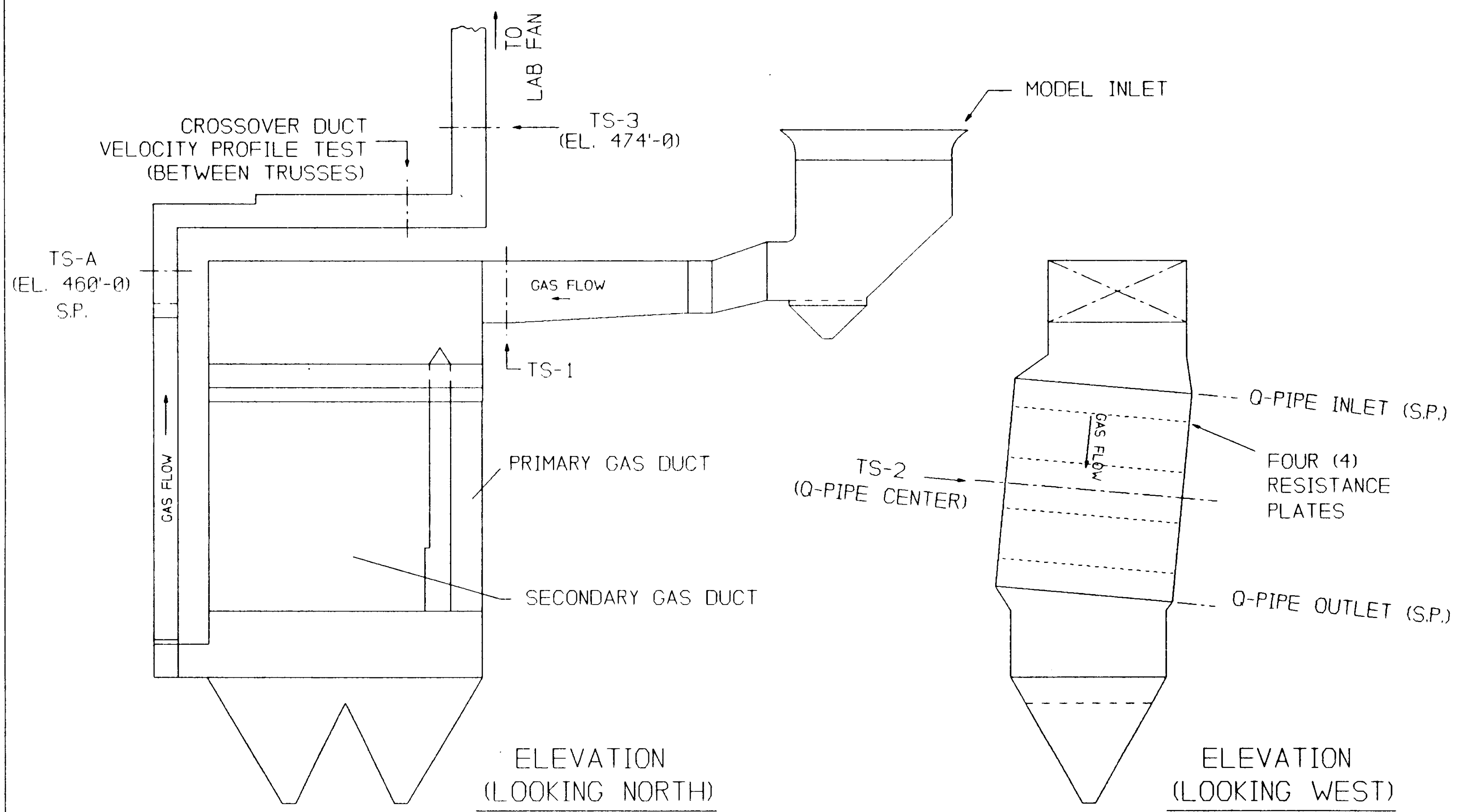
1) inlet diffuser splitter vanes as shown in Sketch 4.
2) perforated plate (63% open area) in inlet diffuser as shown in Sketch 4.
3) outlet hood turning vanes and ductwork turning vanes as shown in Sketch 5.

7.0 LIST OF REFERENCES

1. Experimental Model Study on the Electrostatic Precipitator and Duct System for the Milliken Station Unit 1, Dynagen, Inc., October 8, 1992.

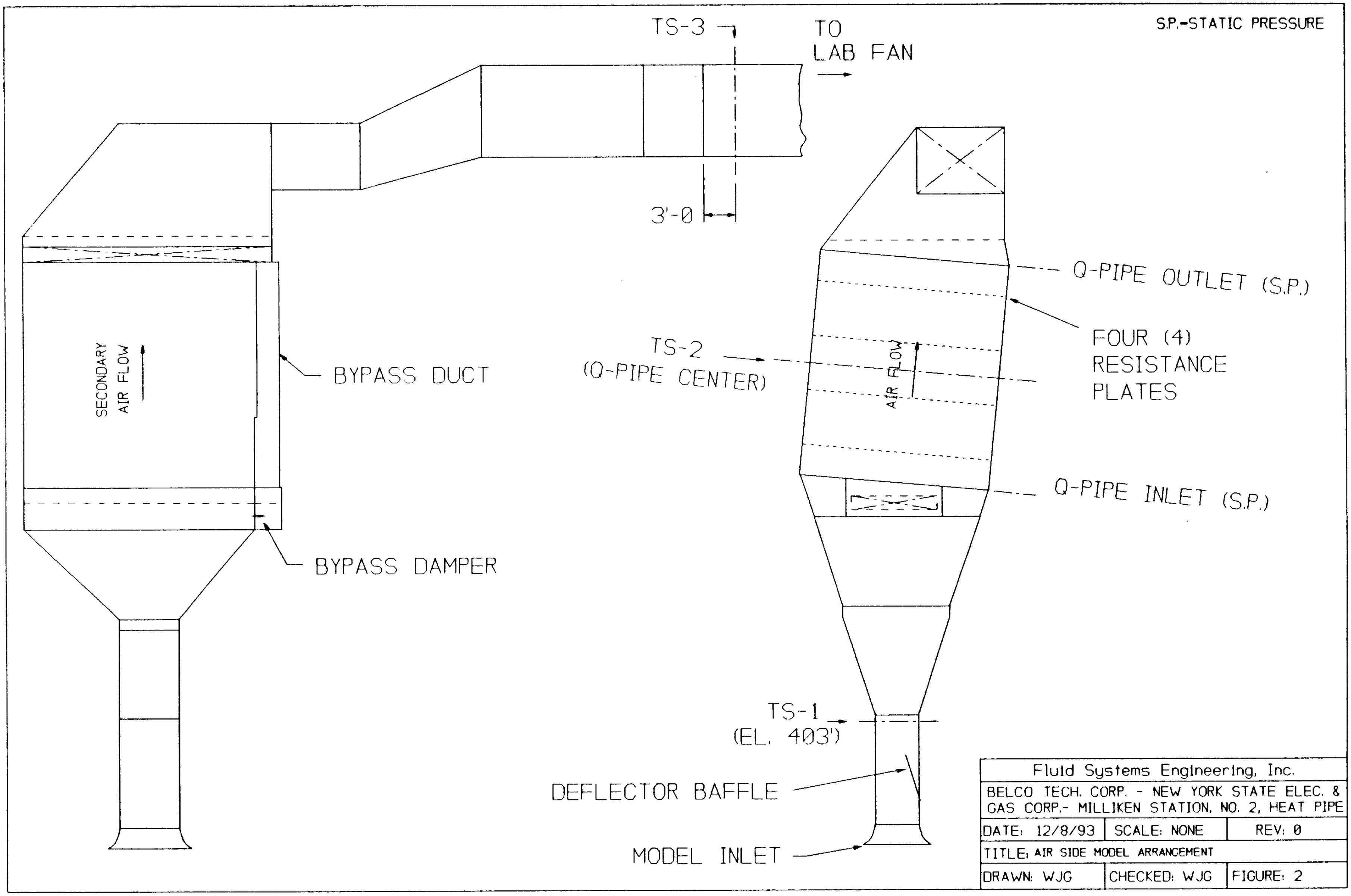
2. Fans and Systems, Publication 201-90, Air Movement and Control Association, 1990.

APPENDIX A - MODEL FIGURES

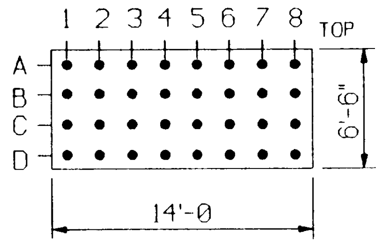


S.P.=STATIC PRESSURE

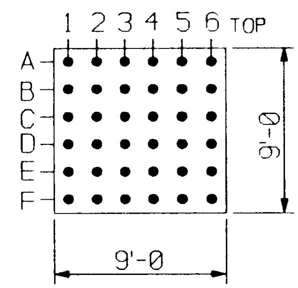
Fluid Systems Engineering, Inc.		
BELCO TECH. CORP. - NEW YORK STATE ELEC. & GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE		
DATE: 12/8/93	SCALE: NONE	REV: 0
TITLE: GAS SIDE MODEL ARRANGEMENT		
DRAWN: WJG	CHECKED: WJG	FIGURE: 1



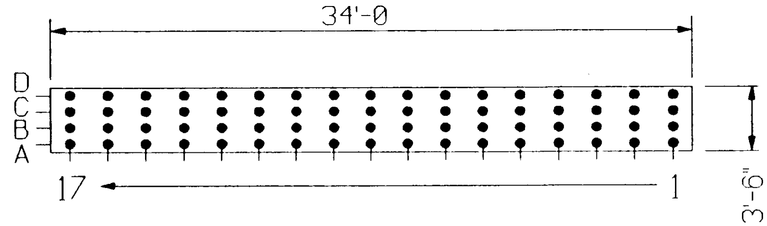
Fluid Systems Engineering, Inc.		
BELCO TECH. CORP. - NEW YORK STATE ELEC. & GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE		
DATE: 12/8/93	SCALE: NONE	REV: 0
TITLE: AIR SIDE MODEL ARRANGEMENT		
DRAWN: WJG	CHECKED: WJG	FIGURE: 2



TS-1 (GAS SIDE)
(GAS FLOW INTO PAGE)



TS-3 (AIR SIDE)
(GAS FLOW INTO PAGE)



← N

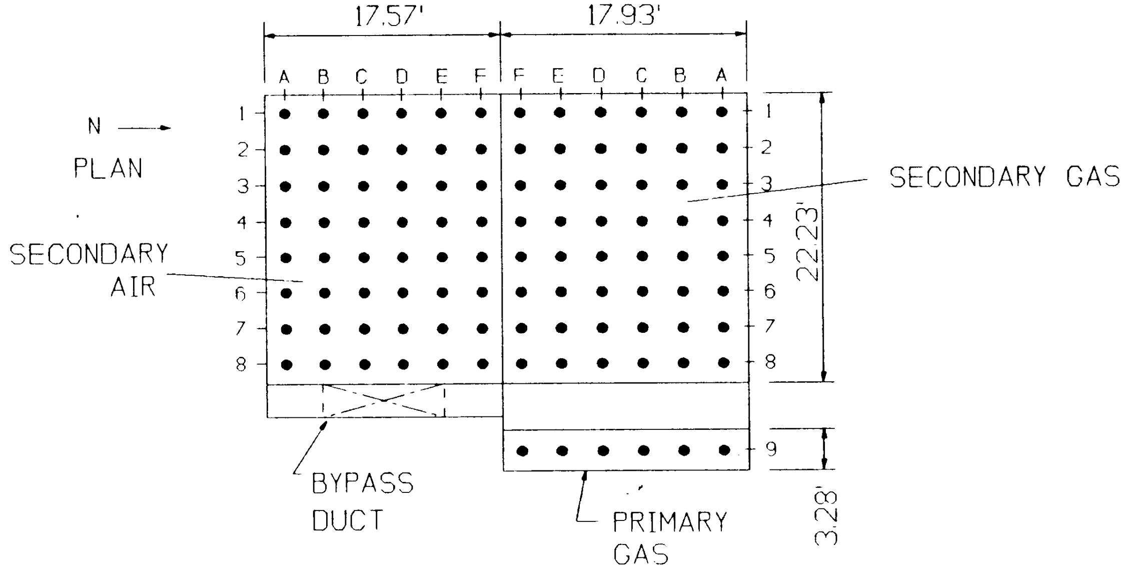
TS-3 (GAS SIDE
(GAS FLOW OUT OF PAGE)

NOTES

1. ALL POINTS EQUALLY SPACED
(DISTANCE FROM WALL = 1/2 SPACING)

Fluid Systems Engineering, Inc.		
BELCO TECH. CORP. - NEW YORK STATE ELEC. & GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE		
DATE: 12/8/93	SCALE: NONE	REV: 0
TITLE: MODEL PITOT TUBE TEST STATION DETAILS		
DRAWN: WJG	CHECKED: WJG	FIGURE: 3

A.5



TS-2 (GAS & AIR SIDES)

NOTES

1. ALL POINTS EQUALLY SPACED
(DISTANCE FROM WALL = 1/2 SPACING)

Fluid Systems Engineering, Inc.		
BELCO TECH. CORP. - NEW YORK STATE ELEC. & GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE		
DATE: 12/8/93	SCALE: NONE	REV: 0
TITLE: MODEL ANEMOMETER TEST STATION DETAILS		
DRAWN: WJG	CHECKED: WJG	FIGURE: 4

APPENDIX B - FINAL RECOMMENDED FLOW CONTROL DEVICE SKETCHES

SKETCH 1 - INLET GAS DUCT FLOW CONTROL DEVICES, REV. 1

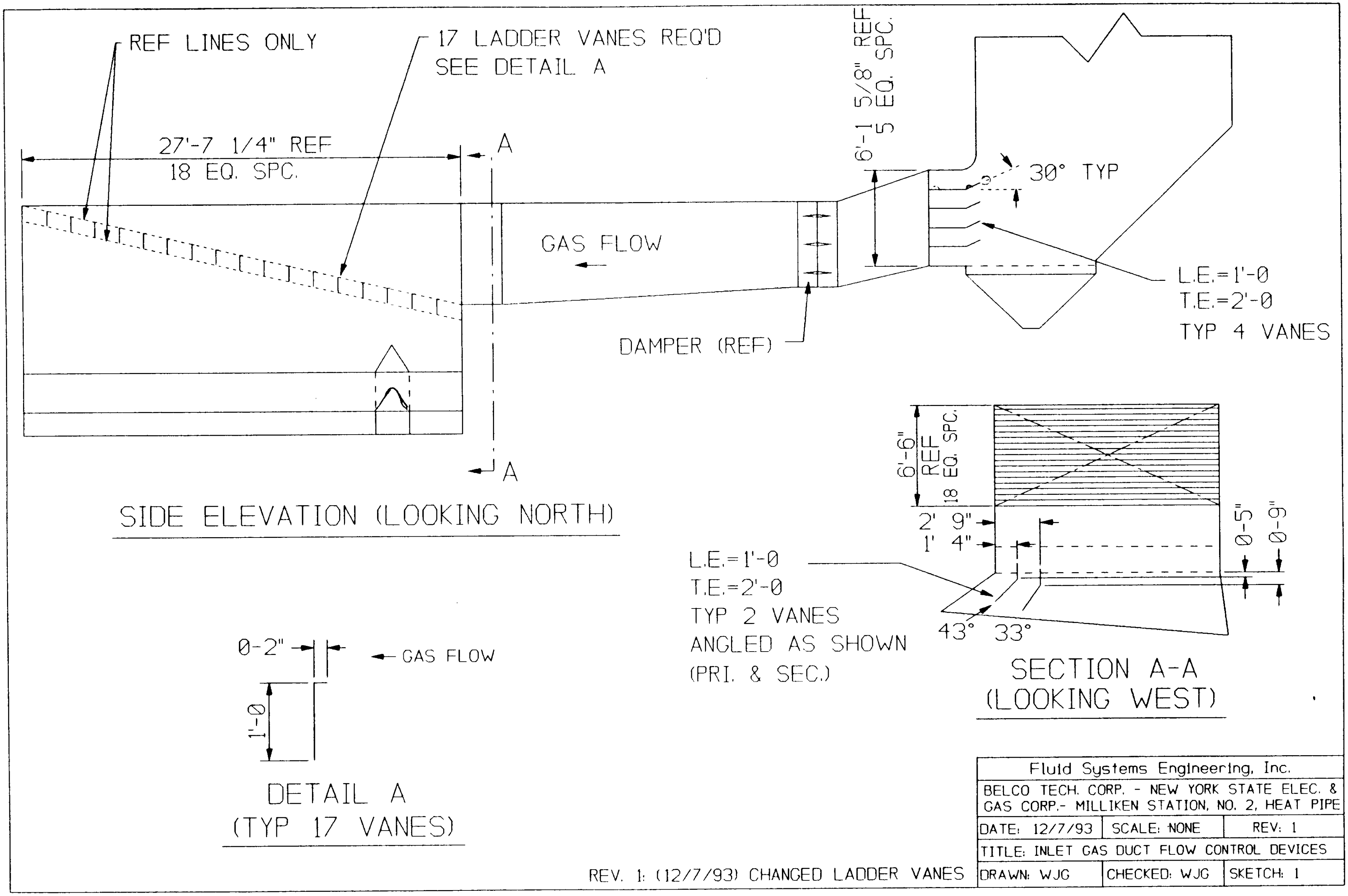
SKETCH 2 - OUTLET GAS DUCT FLOW CONTROL DEVICES, REV. 0

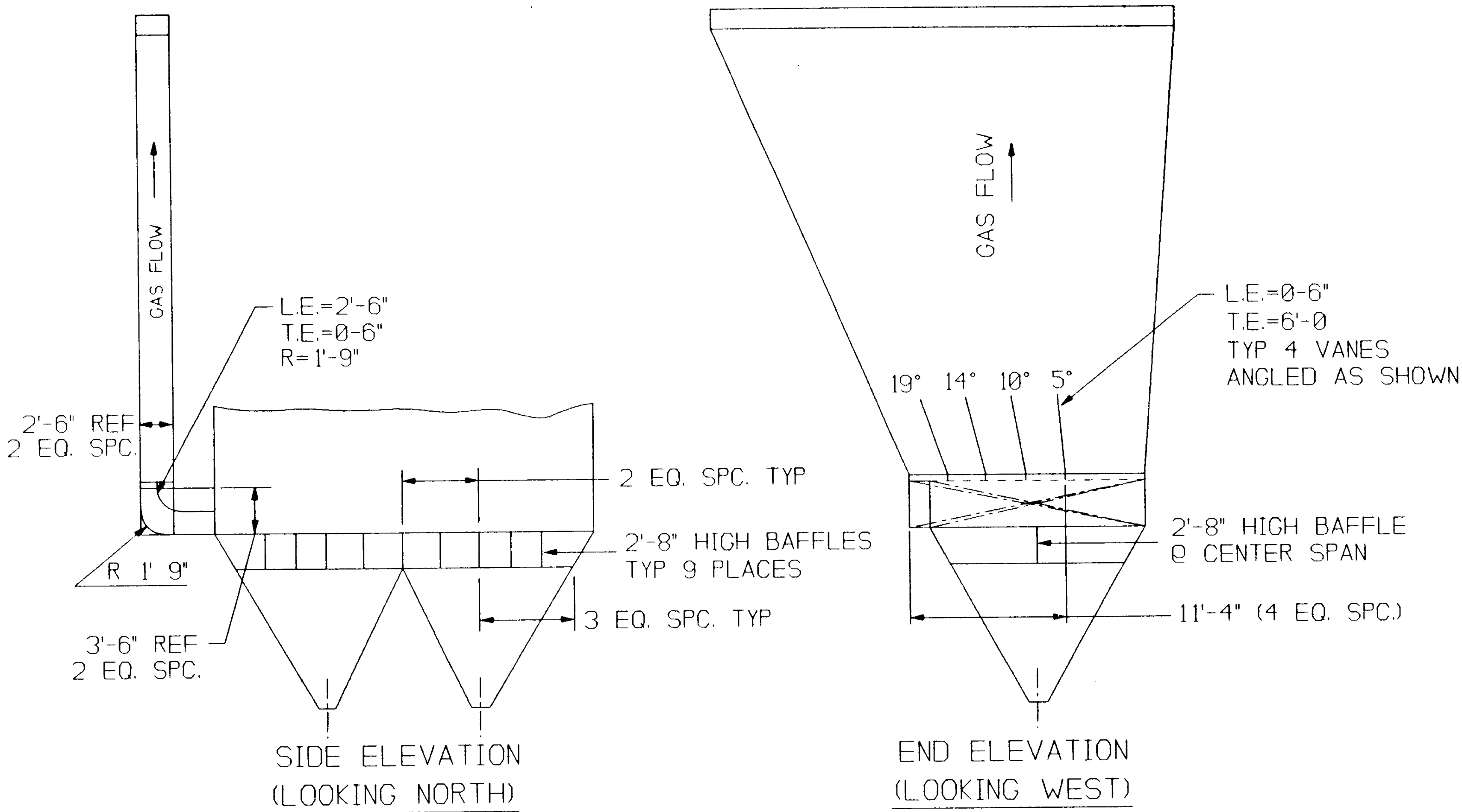
SKETCH 3 - GAS CROSSOVER DUCT FLOW CONTROL DEVICES, REV. 0

SKETCH 4 - INLET AIR DUCT FLOW CONTROL DEVICES, REV. 0

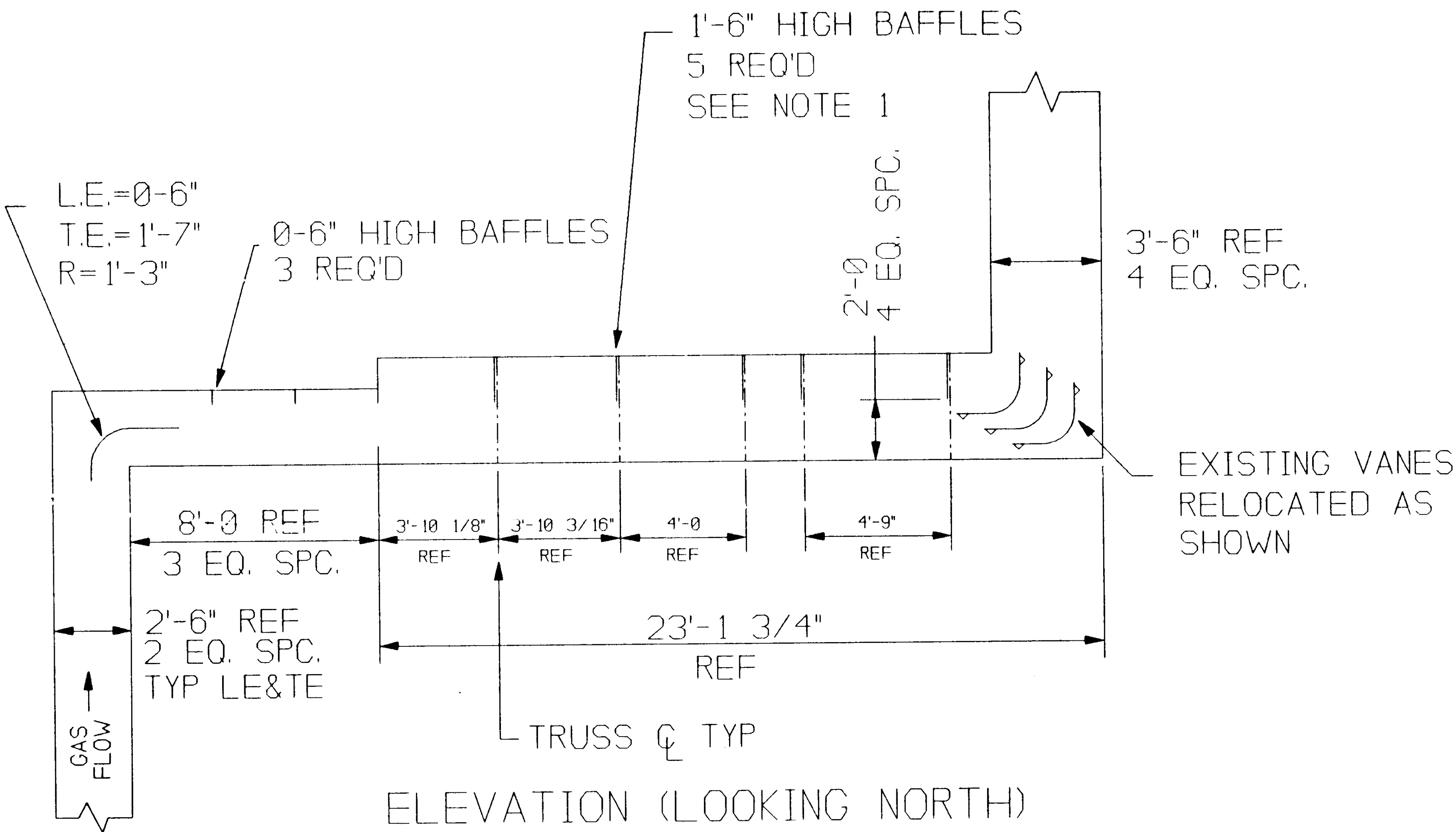
SKETCH 5 - OUTLET AIR DUCT FLOW CONTROL DEVICES, REV. 0

R2


REF LINES ONLY
17 LADDER VANES REQ'D
SEE DETAIL A
27'-7 1/4" REF
18 EQ. SPC.
A
6'-1 5/8" REF
5 EQ. SPC.
30° TYP
GAS FLOW
L.E.=1'-0
T.E.=2'-0
TYP 4 VANES
DAMPER (REF)
A
SIDE ELEVATION (LOOKING NORTH)
6'-6" REF
18 EQ. SPC.
2' 9"
1' 4"
0-5"
0-9"
L.E.=1'-0
T.E.=2'-0
TYP 2 VANES
ANGLED AS SHOWN
(PRI. & SEC.)
43°
33°
SECTION A-A
(LOOKING WEST)
0-2"
GAS FLOW
1'-0
DETAIL A
(TYP 17 VANES)
REV. 1: (12/7/93) CHANGED LADDER VANES
Fluid Systems Engineering, Inc.
BELCO TECH. CORP. - NEW YORK STATE ELEC. &
GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE
DATE: 12/7/93
SCALE: NONE
REV: 1
TITLE: INLET GAS DUCT FLOW CONTROL DEVICES
DRAWN: WJG
CHECKED: WJG
SKETCH: 1



Fluid Systems Engineering, Inc.		
BELCO TECH. CORP. - NEW YORK STATE ELEC. & GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE		
DATE: 12/2/93	SCALE: NONE	REV: 0
TITLE: OUTLET GAS DUCT FLOW CONTROL DEVICES		
DRAWN: WJG	CHECKED: WJG	SKETCH: 2

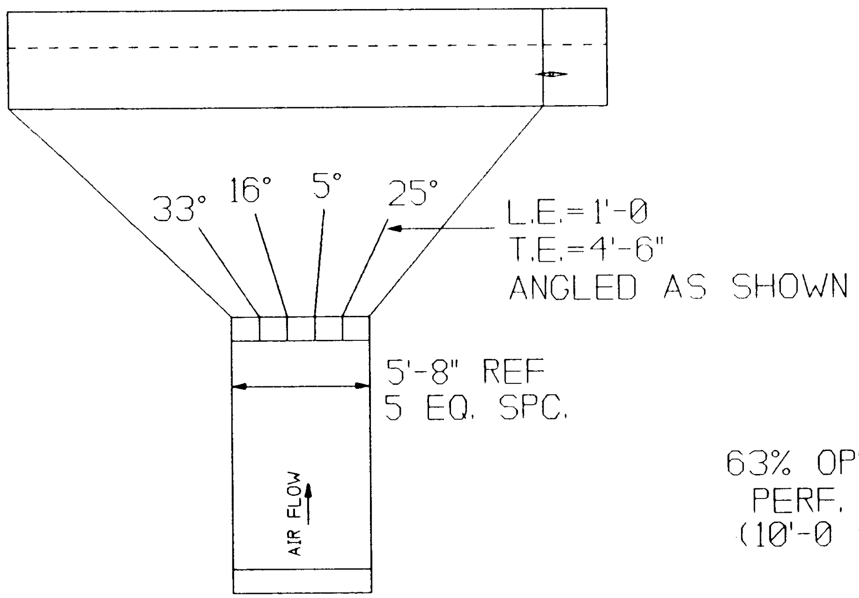


ELEVATION (LOOKING NORTH)

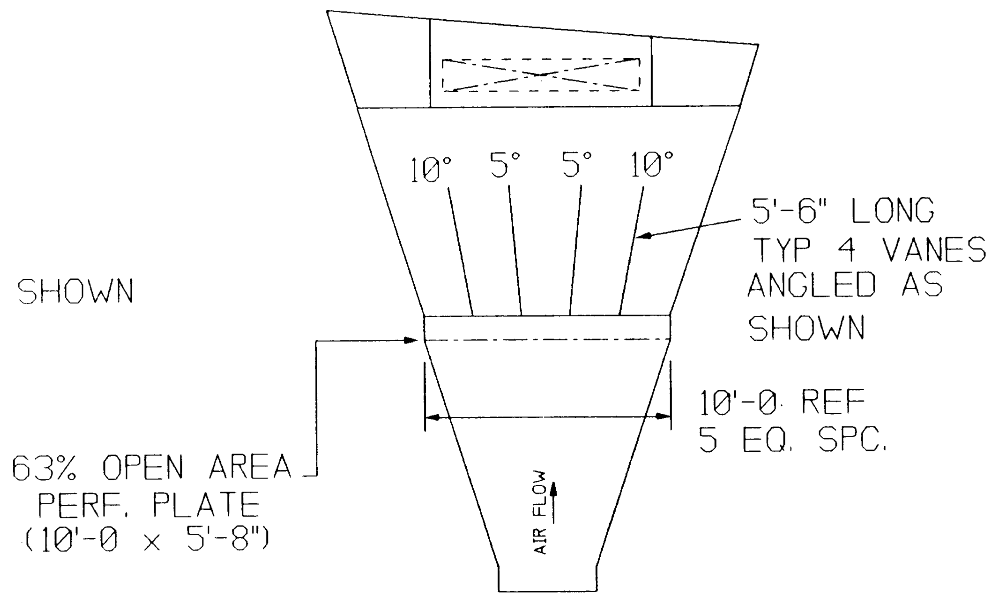
NOTES

1. 1'-6" HIGH BAFFLES TO BE INSTALLED AGAINST THE UPSTREAM SIDE OF THE TRUSS SECTIONS SHOWN

Fluid Systems Engineering, Inc.		
BELCO TECH. CORP. - NEW YORK STATE ELEC. & GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE		
DATE: 12/2/93	SCALE: NONE	REV: 0
TITLE: GAS CROSSOVER DUCT FLOW CONTROL DEVICES		
DRAWN: WJG	CHECKED: WJG	SKETCH: 3

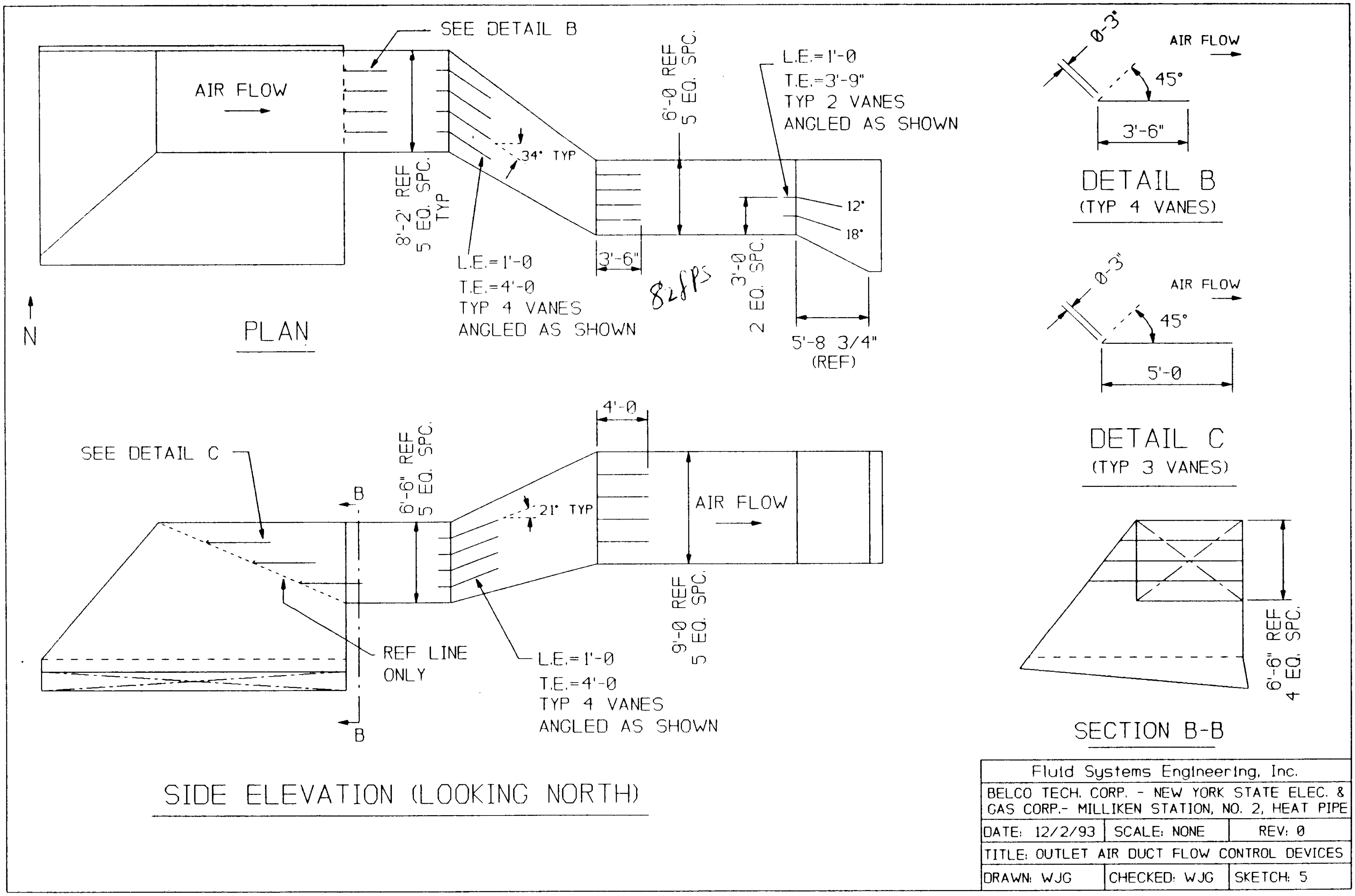


ELEVATION (LOOKING NORTH)



ELEVATION (LOOKING WEST)

Fluid Systems Engineering, Inc.		
BELCO TECH. CORP. - NEW YORK STATE ELEC. & GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE		
DATE: 12/2/93	SCALE: NONE	REV: 0
TITLE: INLET AIR DUCT FLOW CONTROL DEVICES		
DRAWN: WJG	CHECKED: WJG	SKETCH: 4


SEE DETAIL B
AIR FLOW
8'-2' REF
5 EQ. SPC.
TYP
34° TYP
L.E.=1'-0
T.E.=4'-0
TYP 4 VANES
ANGLED AS SHOWN
6'-0 REF
5 EQ. SPC.
3'-6"
82fps
3'-0
2 EQ. SPC.
L.E.=1'-0
T.E.=3'-9"
TYP 2 VANES
ANGLED AS SHOWN
12°
18°
5'-8 3/4"
(REF)
N
PLAN
0-3"
AIR FLOW
45°
3'-6"
DETAIL B
(TYP 4 VANES)
0-3"
AIR FLOW
45°
5'-0
DETAIL C
(TYP 3 VANES)
SEE DETAIL C
B
B
6'-6" REF
5 EQ. SPC.
21° TYP
4'-0
AIR FLOW
9'-0 REF
5 EQ. SPC.
REF LINE
ONLY
L.E.=1'-0
T.E.=4'-0
TYP 4 VANES
ANGLED AS SHOWN
SIDE ELEVATION (LOOKING NORTH)
6'-6" REF
4 EQ. SPC.
SECTION B-B
Fluid Systems Engineering, Inc.
BELCO TECH. CORP. - NEW YORK STATE ELEC. &
GAS CORP.- MILLIKEN STATION, NO. 2, HEAT PIPE
DATE: 12/2/93
SCALE: NONE
REV: 0
TITLE: OUTLET AIR DUCT FLOW CONTROL DEVICES
DRAWN: WJG
CHECKED: WJG
SKETCH: 5

APPENDIX C - FINAL HEAT PIPE VELOCITY MEASUREMENTS

FLUID SYSTEMS ENGINEERING, INC.
Model Velocity Data Summary (ft/min)

Project:	NYSEG Milliken Q Pipe (gas side)	Test No.:	5
Chamber:	GAS	Date:	8-Dec-93
Chamber face:	Q-Pipe center	100% Velocity (ft/min):	804

Model Velocity Data (ft/min) AIR FLOW INTO PAGE

	1	2	3	4	5	6	7	8	*Primary* 9	Row Average
A	715	749	703	670	668	635	528	607	*745*	669
B	710	779	718	711	739	686	676	727	*788*	726
C	738	812	778	760	769	700	685	776	*815*	759
D	710	832	812	736	786	704	690	782	*785*	760
E	766	809	812	751	805	730	709	783	*801*	774
F	753	782	757	768	771	718	739	732	*747*	752
Column Average	732	794	763	733	756	696	671	735	*780*	

Total Number of Points =	54
Average Velocity (ft/min):	739.94
% Design Flow:	92.03
%RMS:	7.63
Std. Dev. (ft/min):	56.46
Max. (ft/min):	832
Min. (ft/min):	528

QPGAS05.XLS

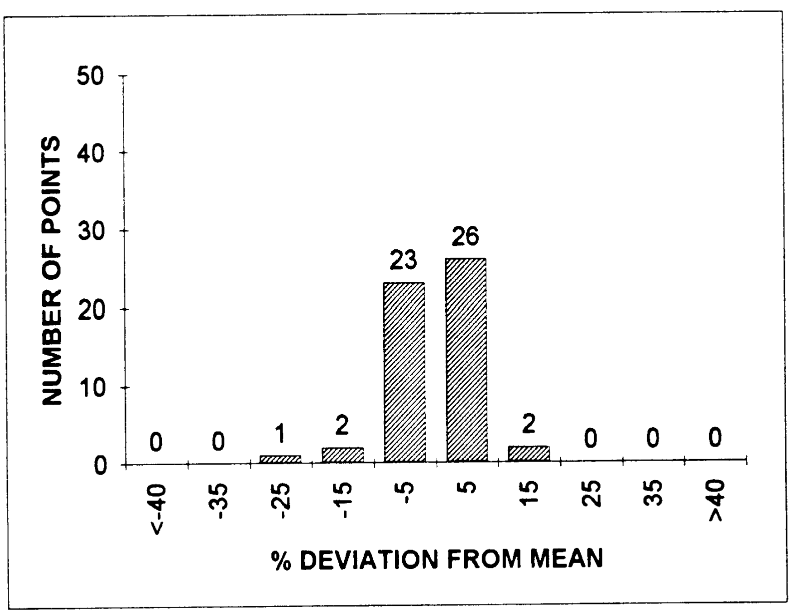
FLUID SYSTEMS ENGINEERING, INC.
Model Percent Deviation from Mean Velocity

Project:	NYSEG Milliken Q Pipe (gas side)	Test No.:	5
Chamber:	GAS	Date:	8-Dec-93
Chamber face:	Q-Pipe center	100% Velocity (ft/min):	804

Model Velocity Data (ft/min) AIR FLOW INTO PAGE

	1	2	3	4	5	6	7	8	*Primary* 9	Row Average
A	-3	+1	-5	-9	-10	-14	-29	-18	*+1*	-9.6
B	-4	+5	-3	-4	0	-7	-9	-2	*+6*	-1.9
C	0	+10	+5	+3	+4	-5	-7	+5	*+10*	+2.6
D	-4	+12	+10	-1	+6	-5	-7	+6	*+6*	+2.7
E	+4	+9	+10	+1	+9	-1	-4	+6	*+8*	+4.6
F	+2	+6	+2	+4	+4	-3	0	-1	*+1*	+1.6
Column Average	-1.1	+7.3	+3.2	-1.0	+2.2	-6.0	-9.3	-0.7	*+5.4*	

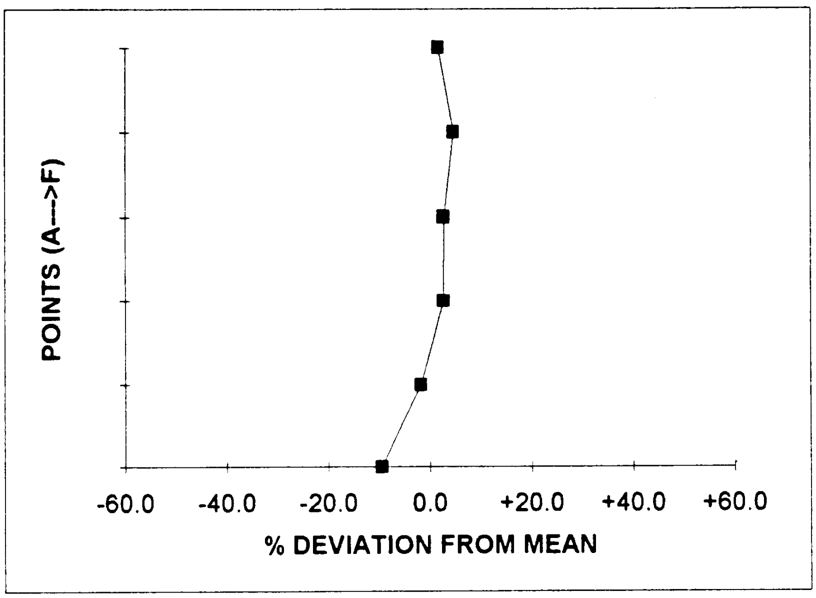
HISTOGRAM



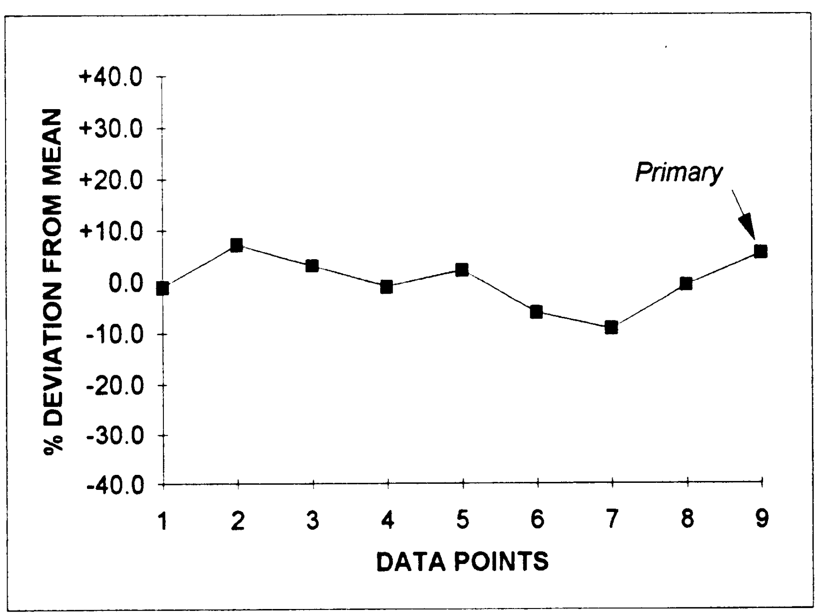
FLUID SYSTEMS ENGINEERING, INC.
Model Percent Deviation from Mean Velocity

Project:	NYSEG Milliken Q Pipe (gas side)	Test No.:	5
Chamber:	GAS	Date:	8-Dec-93
Chamber face:	Q-Pipe center	100% Velocity (ft/min):	804

ROW AVERAGE PROFILE



COLUMN AVERAGE PROFILE



FLUID SYSTEMS ENGINEERING, INC.
Model Velocity Data Summary (ft/min)

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15
Chamber:	AIR (bypass damper closed)	Date:	7-Dec-93
Chamber face:	Q-Pipe center	100% Velocity (ft/min):	338

Model Velocity Data (ft/min) AIR FLOW INTO PAGE

	1	2	3	4	5	6	7	8	Row Average
A	290	334	369	336	374	391	397	320	351
B	339	635	568	470	653	528	597	290	510
C	341	492	554	338	457	421	375	439	427
D	577	382	373	434	524	554	482	395	465
E	680	324	461	580	734	567	531	687	571
F	323	383	376	435	415	472	477	334	402
Column Average	425	425	450	432	526	489	477	411	

Total Number of Points =	48
Average Velocity (ft/min):	454.33
% Design Flow:	134.42
%RMS:	25.24
Std. Dev. (ft/min):	114.67
Max. (ft/min):	734
Min. (ft/min):	290

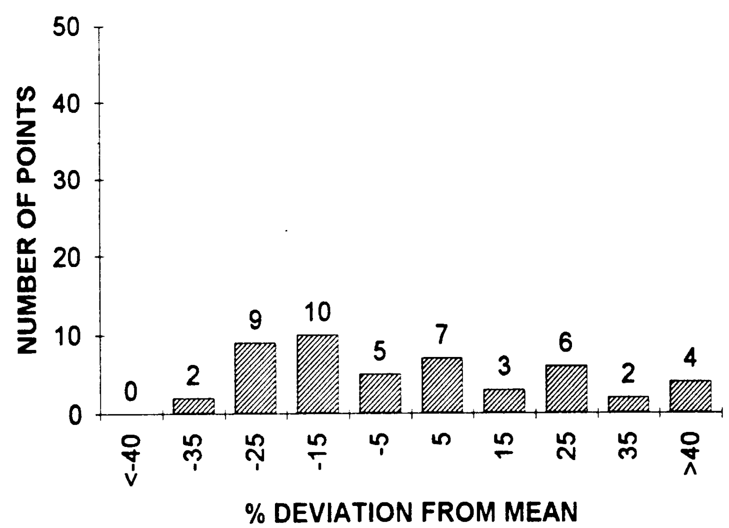
FLUID SYSTEMS ENGINEERING, INC.
Model Percent Deviation from Mean Velocity

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15
Chamber:	AIR (bypass damper closed)	Date:	7-Dec-93
Chamber face:	Q-Pipe center		

Model Velocity Data (ft/min) AIR FLOW INTO PAGE

	1	2	3	4	5	6	7	8	Row Average
A	-36	-26	-19	-26	-18	-14	-13	-30	-22.7
B	-25	+40	+25	+3	+44	+16	+31	-36	+12.3
C	-25	+8	+22	-26	+1	-7	-17	-3	-6.0
D	+27	-16	-18	-4	+15	+22	+6	-13	+2.4
E	+50	-29	+1	+28	+62	+25	+17	+51	+25.6
F	-29	-16	-17	-4	-9	+4	+5	-26	-11.5
Column Average	-6.5	-6.5	-0.9	-4.9	+15.8	+7.6	+4.9	-9.6	

HISTOGRAM

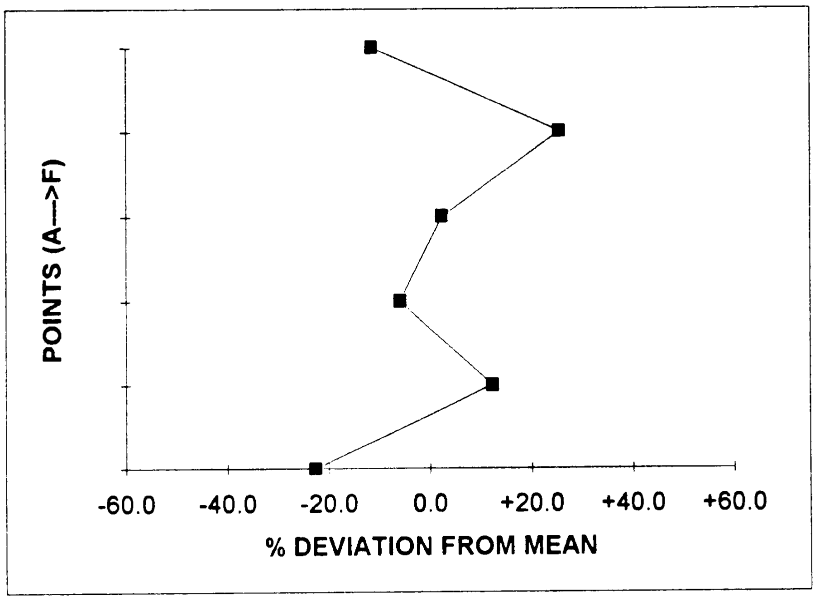


QPAIR15A.XLS

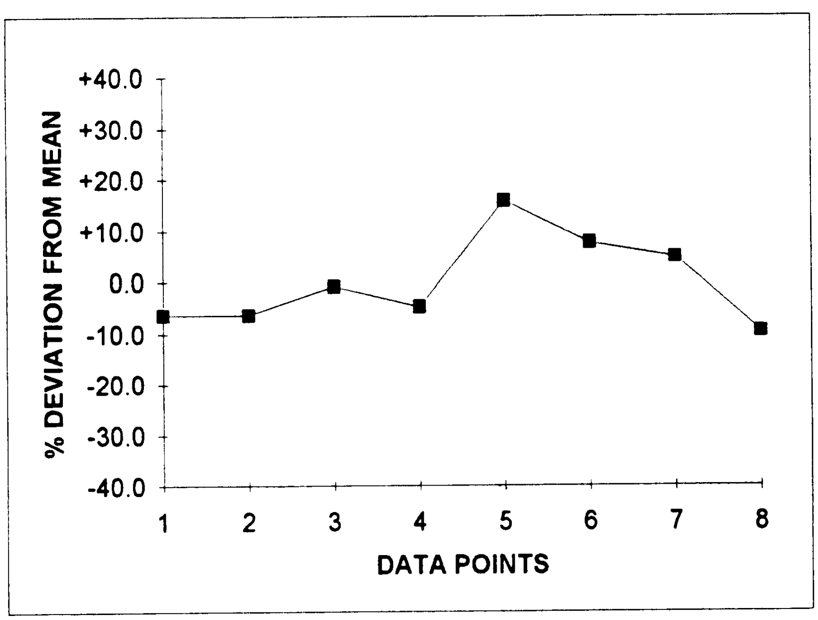
FLUID SYSTEMS ENGINEERING, INC.
Model Percent Deviation from Mean Velocity

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15
Chamber:	AIR (bypass damper closed)	Date:	7-Dec-93
Chamber face:	Q-Pipe center		

ROW AVERAGE PROFILE



COLUMN AVERAGE PROFILE



FLUID SYSTEMS ENGINEERING, INC.
Model Velocity Data Summary (ft/min)

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15A
Chamber:	AIR (bypass damper half-open)	Date:	7-Dec-93
Chamber face:	Q-Pipe center	100% Velocity (ft/min):	338

Model Velocity Data (ft/min) AIR FLOW INTO PAGE

	1	2	3	4	5	6	7	8	Row Average
A	241	274	263	288	265	324	324	224	275
B	212	487	507	372	353	450	506	217	388
C	200	274	297	410	430	427	495	350	360
D	513	266	317	436	377	397	331	370	376
E	560	341	631	586	596	524	515	660	552
F	270	262	300	375	362	323	430	367	336
Column Average	333	317	386	411	397	408	434	365	

Total Number of Points =	48
Average Velocity (ft/min):	381.23
% Design Flow:	112.79
%RMS:	30.93
Std. Dev. (ft/min):	117.90
Max. (ft/min):	660
Min. (ft/min):	200

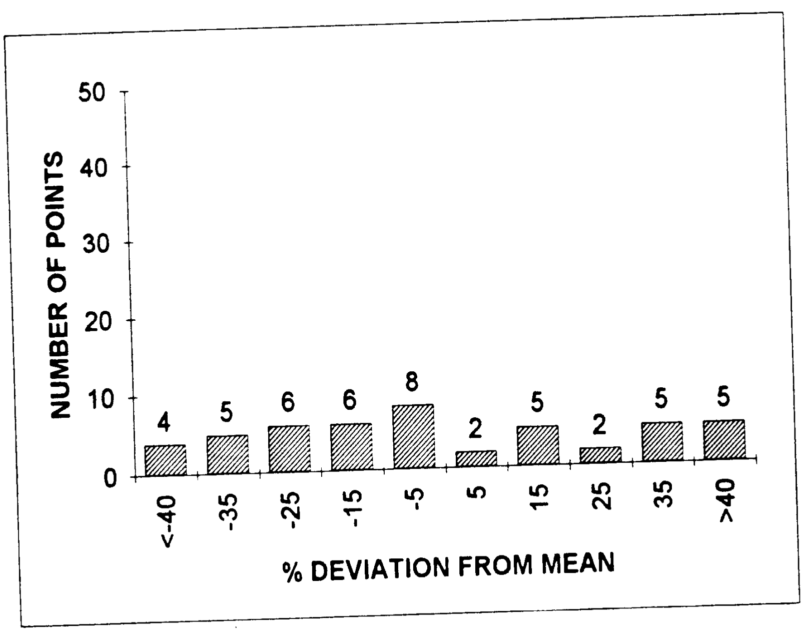
FLUID SYSTEMS ENGINEERING, INC.
Model Percent Deviation from Mean Velocity

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15A
Chamber:	AIR (bypass damper half-open)	Date:	7-Dec-93
Chamber face:	Q-Pipe center		

Model Velocity Data (ft/min) AIR FLOW INTO PAGE

	1	2	3	4	5	6	7	8	Row Average
A	-37	-28	-31	-24	-30	-15	-15	-41	-27.8
B	-44	+28	+33	-2	-7	+18	+33	-43	+1.8
C	-48	-28	-22	+8	+13	+12	+30	-8	-5.5
D	+35	-30	-17	+14	-1	+4	-13	-3	-1.4
E	+47	-11	+66	+54	+56	+37	+35	+73	+44.7
F	-29	-31	-21	-2	-5	-15	+13	-4	-11.8
Column Average	-12.7	-16.8	+1.2	+7.9	+4.2	+6.9	+13.7	-4.3	

HISTOGRAM

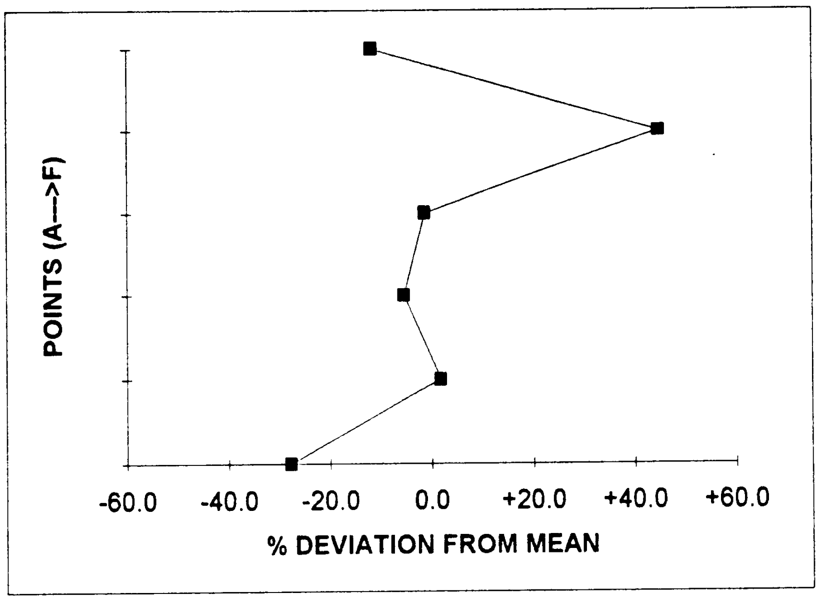


C.9

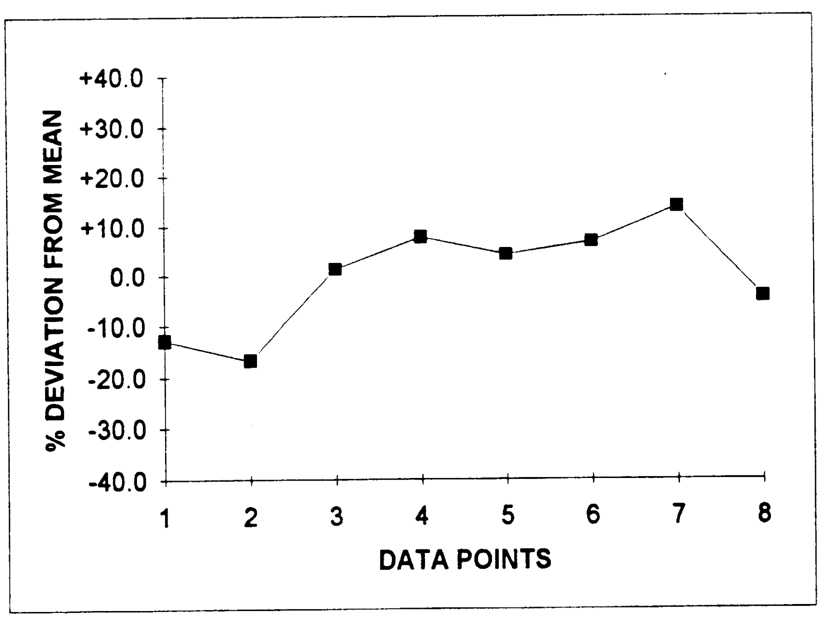
FLUID SYSTEMS ENGINEERING, INC.
Model Percent Deviation from Mean Velocity

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15A
Chamber:	AIR (bypass damper half-open)	Date:	7-Dec-93
Chamber face:	Q-Pipe center		

ROW AVERAGE PROFILE



COLUMN AVERAGE PROFILE



FLUID SYSTEMS ENGINEERING, INC.
Model Velocity Data Summary (ft/min)

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15B
Chamber:	AIR (bypass damper full-open)	Date:	7-Dec-93
Chamber face:	Q-Pipe center	100% Velocity (ft/min):	338

Model Velocity Data (ft/min) AIR FLOW INTO PAGE

	1	2	3	4	5	6	7	8	Row Average
A	237	358	226	263	302	275	274	212	268
B	166	287	467	352	319	369	436	190	323
C	190	221	195	340	388	439	447	263	310
D	488	227	327	389	332	334	339	283	340
E	573	436	671	463	578	513	470	490	524
F	241	216	296	302	320	298	370	298	293
Column Average	316	291	364	352	373	371	389	289	

Total Number of Points =	48
Average Velocity (ft/min):	343.13
% Design Flow:	101.52
%RMS:	33.30
Std. Dev. (ft/min):	114.25
Max. (ft/min):	671
Min. (ft/min):	166

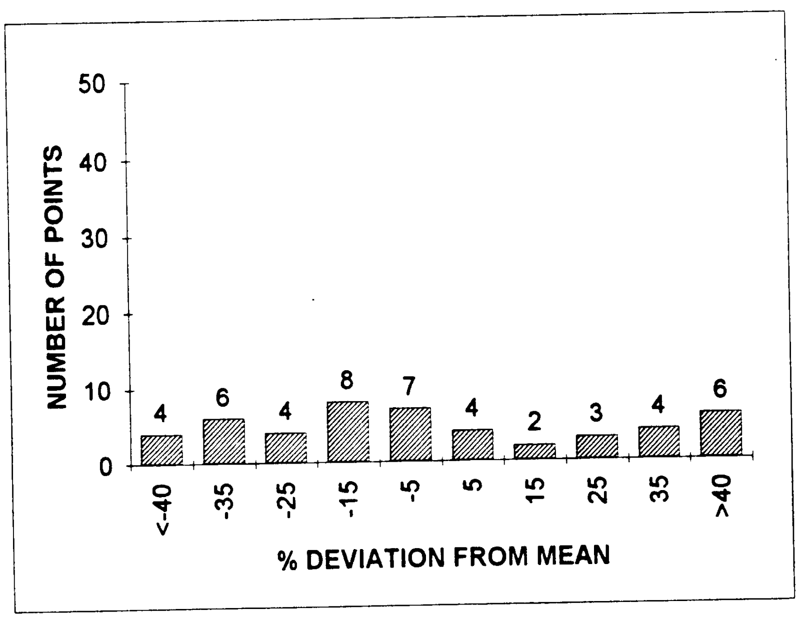
FLUID SYSTEMS ENGINEERING, INC.
Model Percent Deviation from Mean Velocity

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15B
Chamber:	AIR (bypass damper full-open)	Date:	7-Dec-93
Chamber face:	Q-Pipe center		

Model Velocity Data (ft/min) AIR FLOW INTO PAGE

	1	2	3	4	5	6	7	8	Row Average
A	-31	+4	-34	-23	-12	-20	-20	-38	-21.8
B	-52	-16	+36	+3	-7	+8	+27	-45	-5.8
C	-45	-36	-43	-1	+13	+28	+30	-23	-9.5
D	+42	-34	-5	+13	-3	-3	-1	-18	-0.9
E	+67	+27	+96	+35	+68	+50	+37	+43	+52.8
F	-30	-37	-14	-12	-7	-13	+8	-13	-14.7
Column Average	-8.0	-15.2	+6.0	+2.4	+8.8	+8.2	+13.5	-15.7	

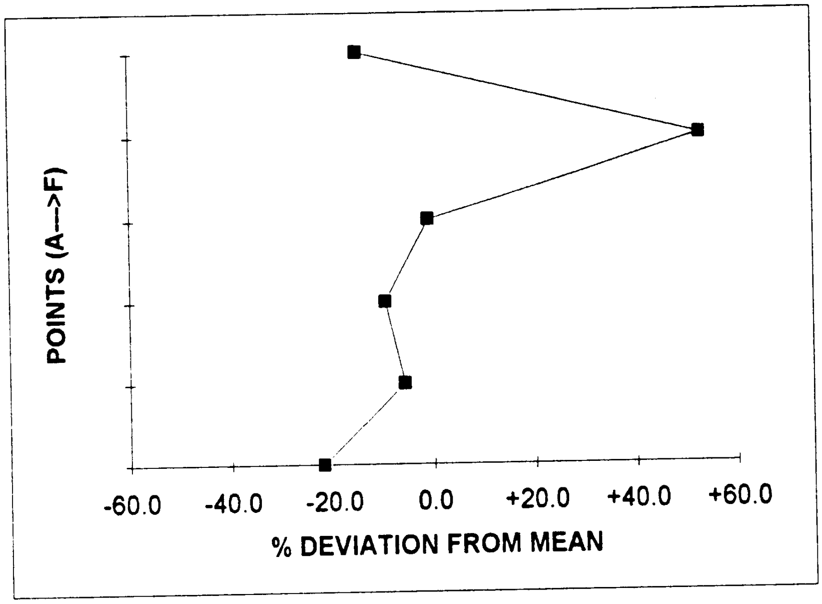
HISTOGRAM



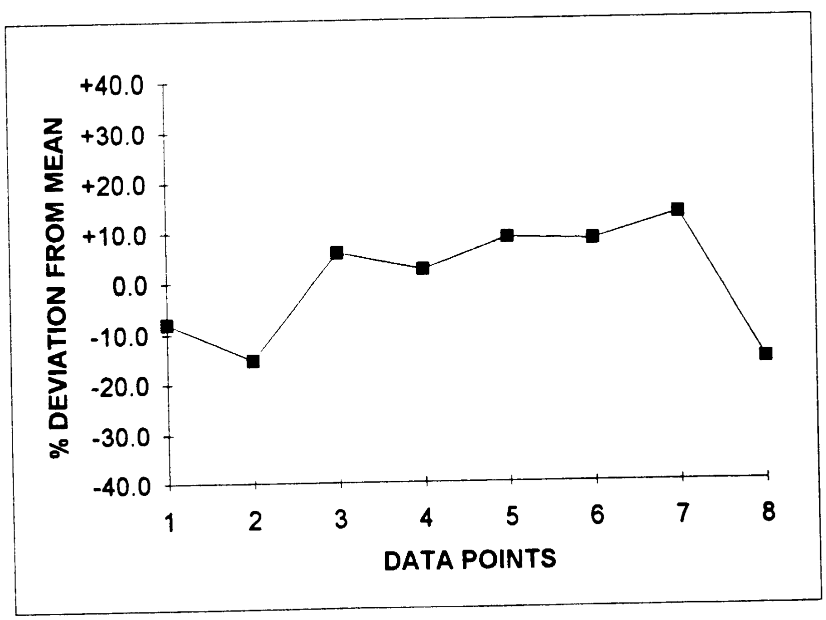
FLUID SYSTEMS ENGINEERING, INC.
Model Percent Deviation from Mean Velocity

Project:	NYSEG Milliken Q Pipe (air side)	Test No.:	15B
Chamber:	AIR (bypass damper full-open)	Date:	7-Dec-93
Chamber face:	Q-Pipe center		

ROW AVERAGE PROFILE



COLUMN AVERAGE PROFILE



APPENDIX D - FINAL DUCT PRESSURE/VELOCITY MEASUREMENTS

FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Milliken Q Pipe (gas side)	Test No.:	5
Test Station:	TS-1	Date:	7-Dec-93
Instrument:	Pitot PAC-12-KL (S/N 9319)	100% Velocity (ft/sec):	67.33

Temp. (°F) =	72
B.P. (in. Hg) =	30.14
Dens. (lbm/ft^3) =	0.0752

V.P. (in. w.g.)

	X-DATA							
	1	2	3	4	5	6	7	8
A	0.98	1.10	1.11	1.07	1.05	0.92	0.92	0.81
B	1.05	1.13	1.11	1.09	1.05	1.04	1.03	0.99
C	0.98	1.04	0.99	1.04	0.97	0.95	0.95	0.70
D	0.89	0.82	0.85	0.98	0.85	0.78	0.83	0.70

Velocity (ft/sec)

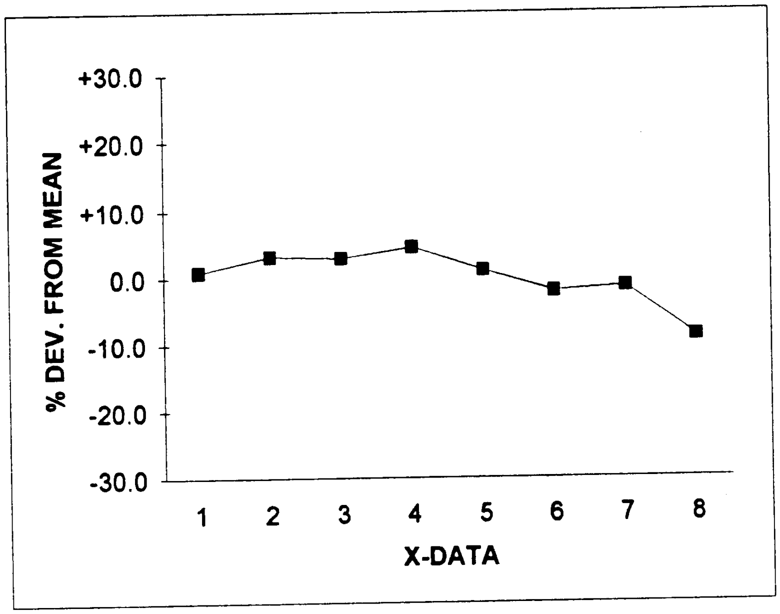
	X-DATA								
	1	2	3	4	5	6	7	8	**Row % Dev. from mean**
A	65.89	69.80	70.12	68.84	68.20	63.84	63.84	59.90	+1.8
B	68.20	70.75	70.12	69.48	68.20	67.87	67.55	66.22	+5.2
C	65.89	67.87	66.22	67.87	65.55	64.87	64.87	55.68	-0.4
D	62.79	60.27	61.36	65.89	61.36	58.78	60.63	55.68	-6.6
Column % Dev. from mean	+0.8	+3.1	+2.8	+4.4	+1.1	-2.0	-1.4	-8.9	

Average Velocity (ft/sec):	65.14
% Design Flow:	96.74
%RMS:	6.31
Std. Dev. (ft/sec):	4.11
Max. (ft/sec):	70.75
Min. (ft/sec):	55.68

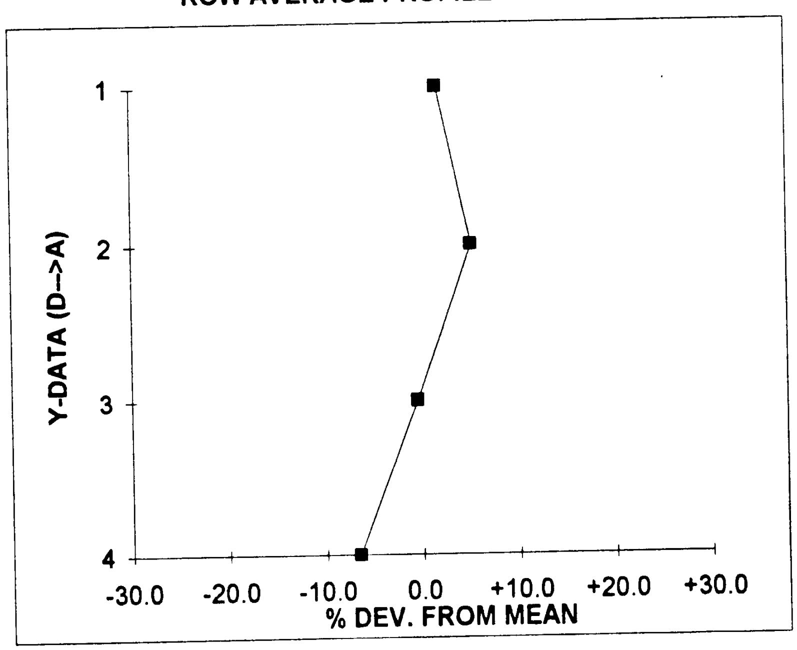
FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Milliken Q Pipe (gas side)	Test No.:	5
Test Station:	TS-1	Date:	7-Dec-93

COLUMN AVERAGE PROFILE



ROW AVERAGE PROFILE



FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

'oject:	NYSEG Milliken Q Pipe (gas side)		Test No.:	5
ːst Station:	TS-3		Date:	7-Dec-93
strument:	Pitot PAC-12-KL (S/N 9319)		100% Velocity (ft/sec):	31.83

ːmp. (°F) = 70
.P. (in. Hg) = 30.14
ens. (lbm/ft^3) = 0.0755

v.p. (in. w.g.)
X-DATA

Y-DATA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A	0.33	0.33	0.28	0.26	0.22	0.25	0.23	0.21	0.31	0.32	0.35	0.33	0.28	0.26	0.19	0.20	0.22
B	0.39	0.34	0.29	0.29	0.30	0.32	0.30	0.24	0.27	0.31	0.38	0.37	0.29	0.27	0.26	0.29	0.29
C	0.46	0.33	0.29	0.33	0.36	0.34	0.28	0.27	0.21	0.29	0.37	0.35	0.28	0.23	0.26	0.30	0.26
D	0.28	0.21	0.22	0.22	0.24	0.27	0.20	0.25	0.22	0.21	0.29	0.25	0.23	0.19	0.24	0.29	0.22

Velocity (ft/sec)
X-DATA

Y-DATA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Row % Dev. from mean
A	38.16	38.16	35.15	33.87	31.16	33.21	31.86	30.44	36.99	37.58	39.30	38.16	35.15	33.87	28.96	29.71	31.16	-1.9
B	41.49	38.73	35.77	35.77	36.38	37.58	36.38	32.54	34.52	36.99	40.95	40.41	35.77	34.52	33.87	35.77	35.77	+4.9
C	45.05	38.16	35.77	38.16	39.86	38.73	35.15	34.52	30.44	35.77	40.41	39.30	35.15	31.86	33.87	36.38	33.87	+4.7
D	35.15	30.44	31.16	31.16	32.54	34.52	29.71	33.21	31.16	30.44	35.77	33.21	31.86	28.96	32.54	35.77	31.16	-7.7
Column % Dev. 'om mean	+14.3	+4.0	-1.4	-0.6	+0.1	+3.0	-4.8	-6.5	-4.8	+0.7	+11.9	+8.0	-1.4	-7.6	-7.6	-1.6	-5.6	

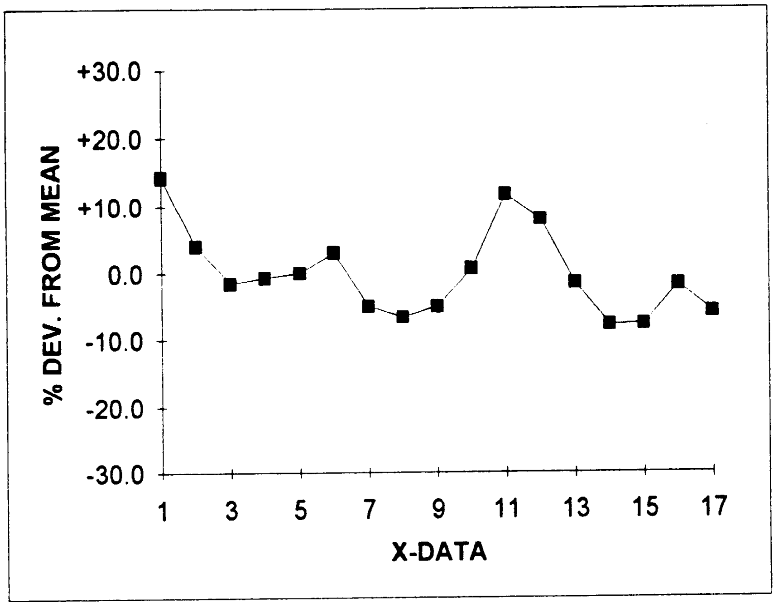
ıverage Velocity (ft/sec):	34.96
₆ Design Flow:	109.84
₆RMS:	9.72
ːtd. Dev. (ft/sec):	3.40
⁄lax. (ft/sec):	45.05
⁄lin. (ft/sec):	28.96

QPGST305.XLS

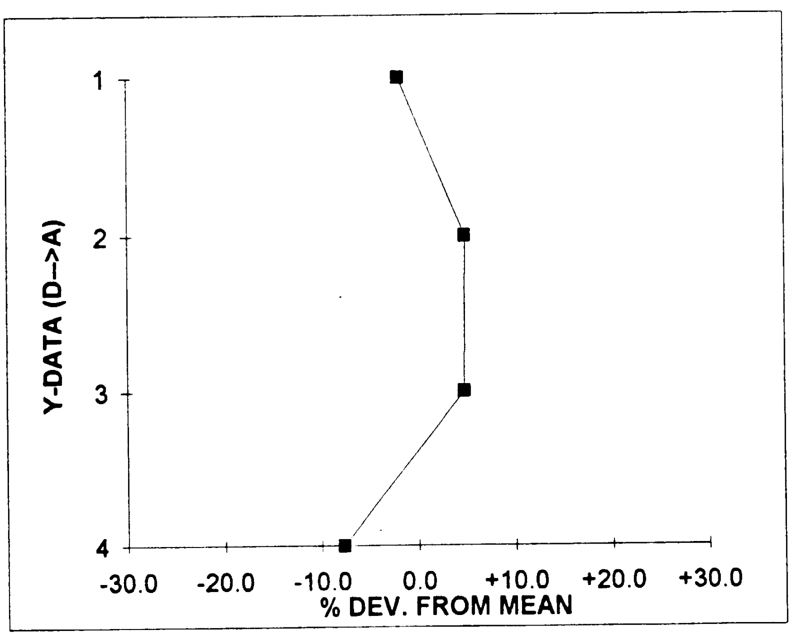
FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Milliken Q Pipe (gas side)	Test No.:	5
Test Station:	TS-3	Date:	7-Dec-93

COLUMN AVERAGE PROFILE



ROW AVERAGE PROFILE



p. 2 of 2

FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Milliken Q-Pipe (air side)	Test No.:	15
Test Station:	TS-3	Date:	7-Dec-93
Instrument:	Pitot PAC-12-KL (S/N 9319)	100% Velocity (ft/sec):	26.79 vel@ inlet (80°F)

Temp. (°F) =	63
B.P. (in. Hg) =	30.12
Dens. (lbm/ft^3) =	0.0764

V.P. (in. w.g.)

X-DATA

	1	2	3	4	5	6
A	0.39	0.37	0.13	0.15	0.14	0.03
B	0.42	0.39	0.28	0.31	0.18	0.10
C	0.37	0.40	0.32	0.37	0.27	0.11
D	0.37	0.37	0.25	0.33	0.22	0.08
E	0.33	0.31	0.16	0.25	0.21	0.06
F	0.32	0.20	0.07	0.10	0.21	0.04

Velocity (ft/sec)

X-DATA

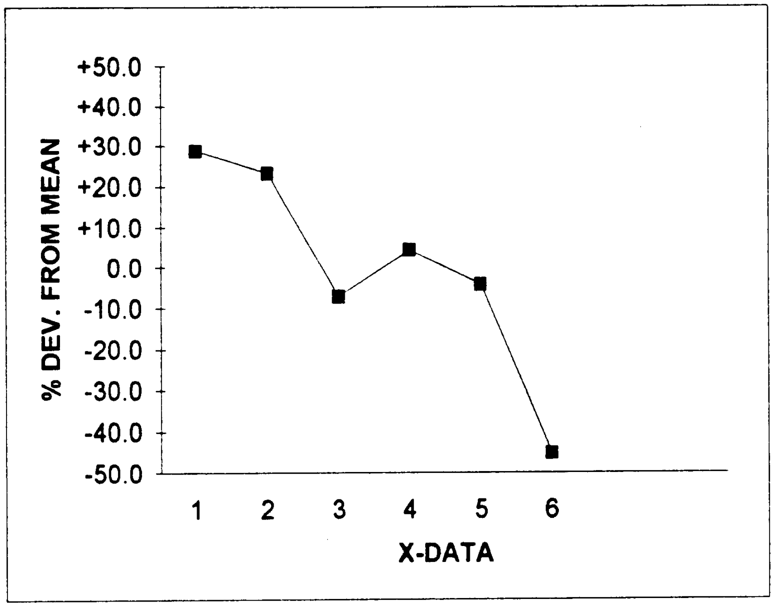
	1	2	3	4	5	6	Row % Dev. from mean
A	41.22	40.15	23.80	25.57	24.70	11.43	-10.4
B	42.78	41.22	34.93	36.75	28.01	20.87	+9.9
C	40.15	41.75	37.34	40.15	34.30	21.89	+15.8
D	40.15	40.15	33.01	37.92	30.96	18.67	+7.9
E	37.92	36.75	26.40	33.01	30.25	16.17	-3.0
F	37.34	29.52	17.46	20.87	30.25	13.20	-20.2
Column % Dev. from mean	+28.7	+23.3	-7.1	+4.3	-4.1	-45.1	

Average Velocity (ft/sec):	31.03
% Design Flow:	115.82
%RMS:	29.11
Std. Dev. (ft/sec):	9.03
Max. (ft/sec):	42.78
Min. (ft/sec):	11.43

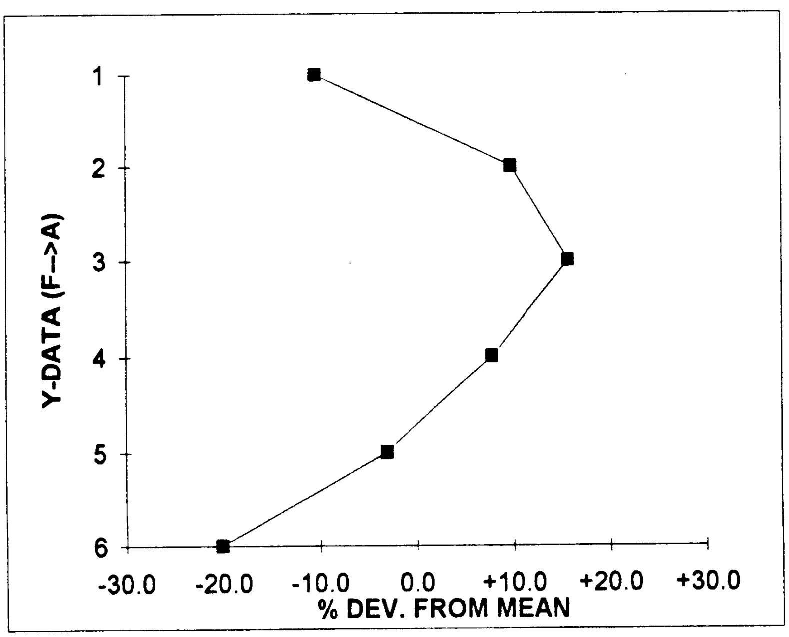
FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Milliken Q-Pipe (air side)	Test No.:	15
Test Station:	TS-3	Date:	7-Dec-93

COLUMN AVERAGE PROFILE



ROW AVERAGE PROFILE



FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Milliken Q-Pipe (air side)	Test No.:	15
Test Station:	TS-3	Date:	3-Dec-93
Instrument:	Pitot PAC-12-KL (S/N 9319)	100% Velocity (ft/sec):	53.58 vel @ outlet (616°F)

Temp. (°F) =	68
B.P. (in. Hg) =	30.27
Dens. (lbm/ft^3) =	0.0761

V.P. (in. w.g.)

X-DATA

	1	2	3	4	5	6
A	1.49	1.42	0.59	0.63	0.45	0.08
B	1.80	1.57	1.11	1.18	0.85	0.40
C	1.53	1.61	1.20	1.44	0.94	0.55
D	1.60	1.50	1.09	1.26	0.85	0.33
E	1.19	1.19	0.64	0.83	0.76	0.25
F	1.16	0.93	0.36	0.53	0.85	0.18

Velocity (ft/sec)

X-DATA

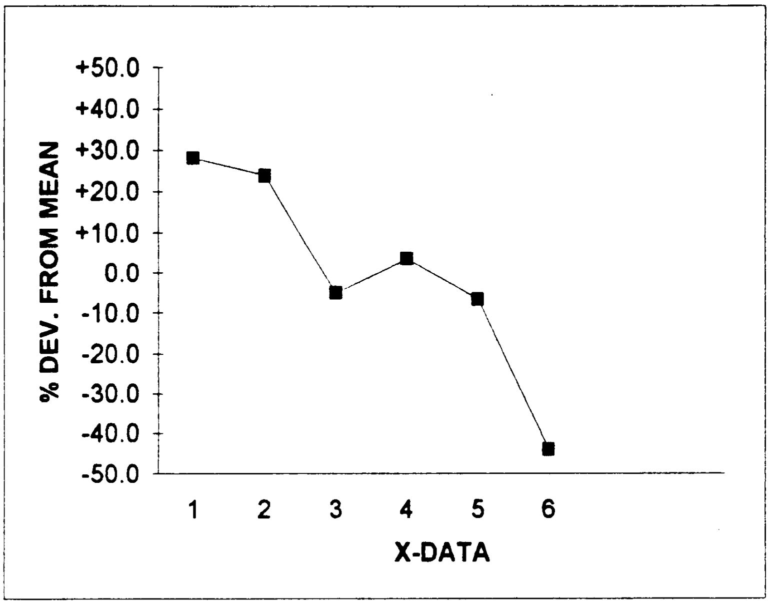
	1	2	3	4	5	6	Row % Dev. from mean
A	80.76	78.84	50.82	52.51	44.38	18.71	-12.7
B	88.76	82.90	69.71	71.87	61.00	41.84	+11.4
C	81.84	83.95	72.48	79.39	64.15	49.07	+15.4
D	83.69	81.03	69.07	74.27	61.00	38.01	+9.0
E	72.17	72.17	52.93	60.28	57.68	33.08	-6.7
F	71.26	63.80	39.70	48.17	61.00	28.07	-16.4
Column % Dev. from mean	+28.1	+23.9	-5.0	+3.5	-6.5	-44.1	

Average Velocity (ft/sec):	62.23
% Design Flow:	116.15
%RMS:	28.35
Std. Dev. (ft/sec):	17.64
Max. (ft/sec):	88.76
Min. (ft/sec):	18.71

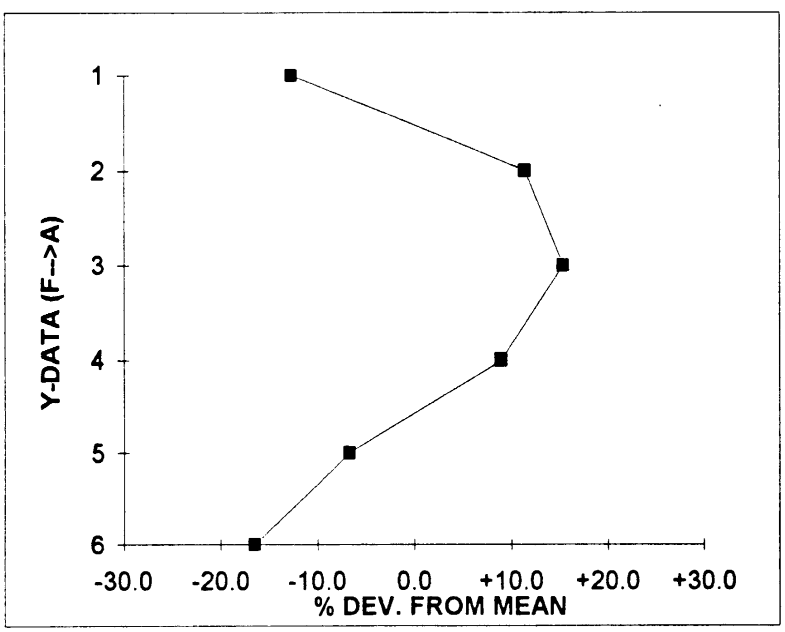
FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Milliken Q-Pipe (air side)	Test No.:	15
Test Station:	TS-3	Date:	3-Dec-93

COLUMN AVERAGE PROFILE



ROW AVERAGE PROFILE



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PROJECT: NYSEG MILLIKEN Q-PIPE (GAS SIDE INLET)
TEST NO.: 5
DATE: 12/7/93

TEMP (°F)= 72
B.P. (in. Hg)= 30.14

%FLOW = 96.74 (measured @ TS-1)

TEST STATION	AVG. VEL (ft/sec)	V.P. (in. wg)	S.P. (in. wg)	T.P. (V.P+S.P.) (in. wg)
TS-1	65.14	.96	-1.32	-.36
9 Pipe inlet	12.96	.038	-1.33	-1.29

PROJECT: NYSEG MILLIKEN Q-PIPE (GAS SIDE OUTLET)
TEST NO.: 5
DATE: 12/7/93

TEMP (°F)= 70
B.P. (in. Hg)= 30.14

%FLOW = 109.84 (measured @ TS-3)

TEST STATION	AVG. VEL (ft/sec)	V.P. (in. wg)	S.P. (in. wg)	T.P. (V.P+S.P.) (in. wg)
Q-Pipe outlet	8.39	.016	-1.12	-1.10
TS-A	48.95	.54	-2.83	-2.29
TS-3	34.96	.28	-4.50	-4.22

PROJECT: NYSEG MILLIKEN Q PIPE (AIR SIDE INLET)
TEST NO.: 15
DATE: 12/7/93

TEMP (°F)= 63
B.P. (in. Hg)= 30.12

%FLOW = 115.82 (measured @ TS-3)

TEST STATION	AVG. VEL (ft/sec)	V.P. (in. wg)	S.P. (in. wg)	T.P. (V.P+S.P.) (in. wg)
TS-1	110.88	2.82	-6.64	-3.82
Q PIPE INLET	6.53	.01	-5.61	-5.60

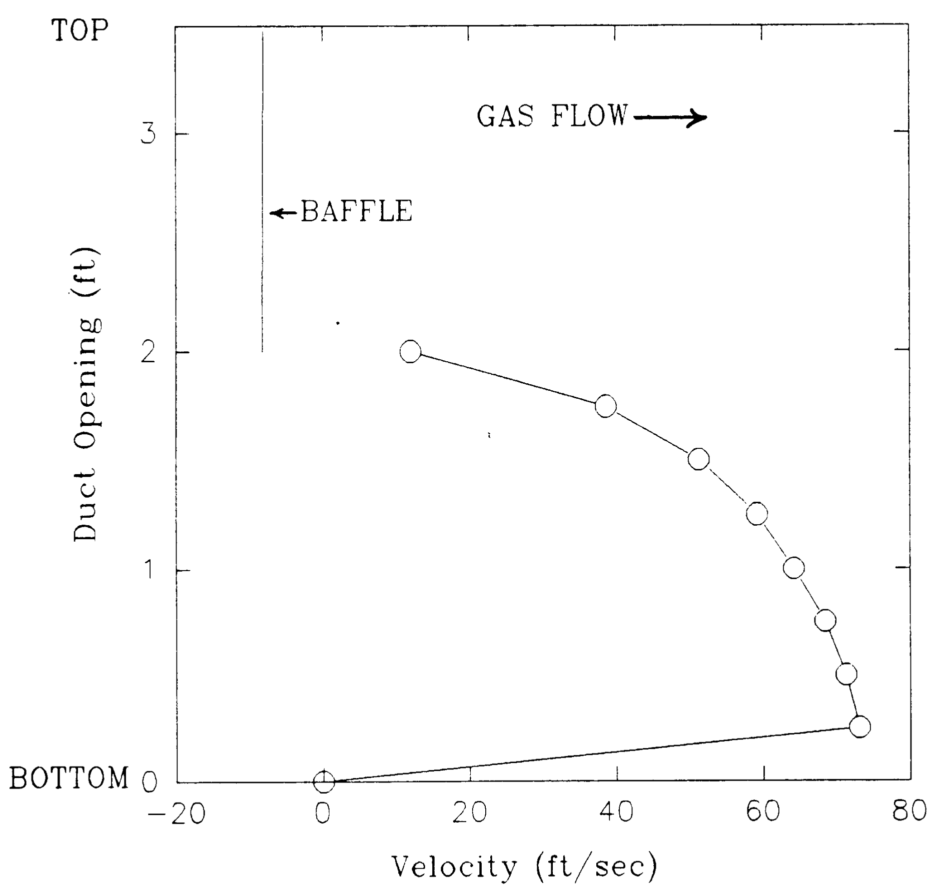
PROJECT: NYSEG MILLIKEN Q-PIPE (AIR SIDE OUTLET)
TEST NO.: 15
DATE: 12/3/93

TEMP (°F)= 68
B.P. (in. Hg)= 30.27

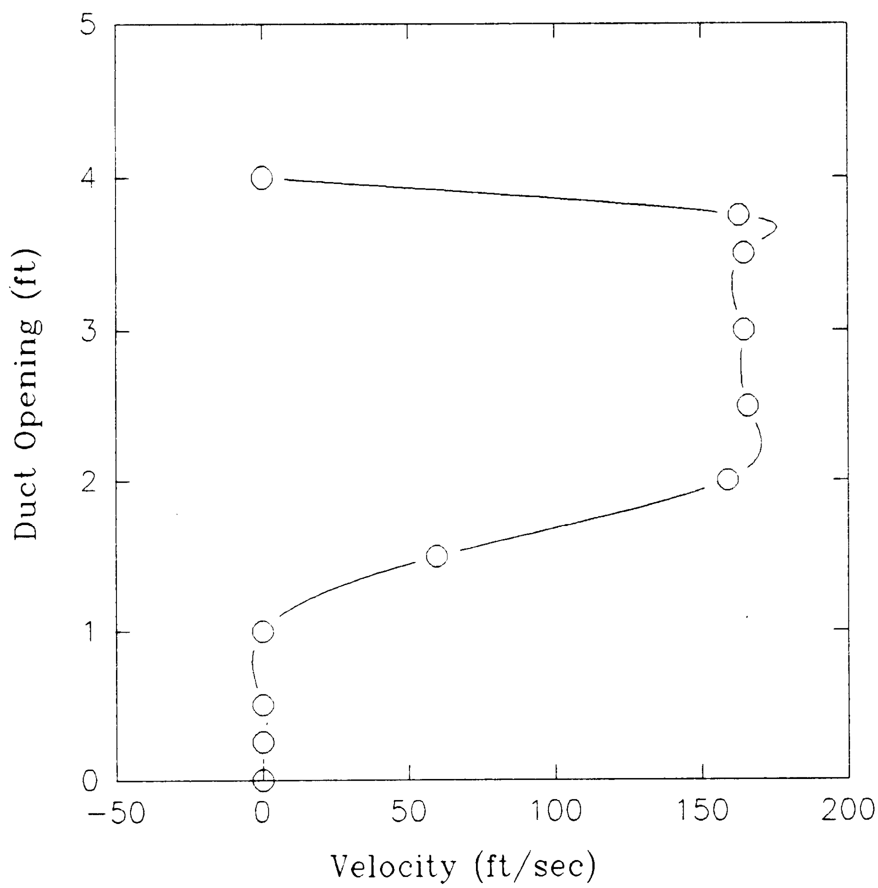
%FLOW = 116.15 (measured @ TS-3)

TEST STATION	AVG. VEL (ft/sec)	V.P. (in. wg)	S.P. (in. wg)	T.P. (V.P+S.P.) (in. wg)
Q-PIPE OUTLET	12.93	.038	-.95	-.91
TS-3	62.23	.89	-5.36	-4.48

VELOCITY PROFILE IN CROSSOVER DUCT W/ 1'-6" BAFFLES
100% FLOW



SIMULATED MODEL F.D. FAN DISCHARGE VELOCITY PROFILE



8.1.2 Centrifugal Flow Fan - Outlet Ducts. Centrifugal fans are sometimes installed with a less than optimum length of outlet duct. If it is not possible to use a full length outlet duct, a SEF must be added to the system resistance losses. *System Effect Curves* for centrifugal fans with less than optimum outlet duct length are shown in Figure 8-3.

8.2 OUTLET DIFFUSERS

The process which takes place in the outlet duct is often referred to as "static regain." The relatively high velocity airstream leaving the blast area of the fan gradually expands to fill the duct. The kinetic energy (velocity pressure) decreases and the potential energy (static pressure) increases.

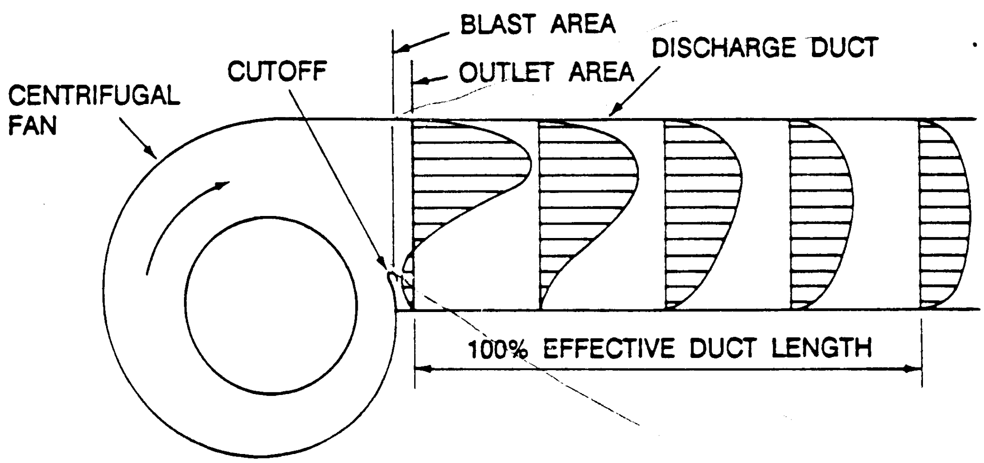
In many systems it may be feasible to use an outlet duct which is considerably larger than the fan outlet. In these cases the static pressure available to overcome system resistance can be increased by converting some of the fan's outlet velocity pressure to static pressure.

To achieve this conversion efficiently it is necessary to use a connection piece between the fan outlet and the duct which allows the airstream to expand gradually. This is called a "diffuser" or evase.

The efficiency of conversion will depend upon the angle of expansion, the length of the diffuser section, and the blast area/outlet area ratio of the fan.

The fan manufacturer will, in most cases, be able to provide design information for an efficient diffuser.

See AMCA Publication 200 for an example showing the effect of a diffuser on a duct exit.



TO CALCULATE 100% EFFECTIVE DUCT LENGTH, ASSUME A MINIMUM OF 2-1/2 DUCT DIAMETERS FOR 2500 FPM OR LESS. ADD 1 DUCT DIAMETER FOR EACH ADDITIONAL 1000 FPM.

EXAMPLE: 5000 FPM = 5 EQUIVALENT DUCT DIAMETERS. IF THE DUCT IS RECTANGULAR WITH SIDE DIMENSIONS a AND b, THE EQUIVALENT DUCT DIAMETER IS EQUAL TO $(4ab/\pi)^{0.5}$

	No Duct	12% Effective Duct	25% Effective Duct	50% Effective Duct	100% Effective Duct
Pressure Recovery	0%	50%	80%	90%	100%
Blast Area / Outlet Area	System Effect Curve				
0.4	P	R-S	U	W	—
0.5	P	R-S	U	W	—
0.6	R-S	S-T	U-V	W-X	—
0.7	S	U	W-X	—	—
0.8	T-U	V-W	X	—	—
0.9	V-W	W-X	—	—	—
1.0	—	—	—	—	—

DETERMINE SEF BY USING FIGURE 7-1

Figure 8-3 System Effect Curves for Outlet Ducts - Centrifugal Fans

APPENDIX E - UNIT 1 ESP INLET DUCT MODEL RESULTS

FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Right ESP Inlet (Dynagen report, p. 35)	Test No.:	0
Test Station:	TS-3	Date:	8-Oct-92
Instrument:		100% Velocity (ft/sec):	40.4

Velocity (ft/sec)

	X-DATA																	Row
Y-DATA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	% Dev. from mean
A	29.40	37.10	42.30	40.10	39.40	38.90	40.70	41.30	38.50	39.30	38.80	40.50	40.40	38.80	37.50	35.80	32.50	-11.2
B	33.10	43.70	49.60	49.70	48.20	48.40	49.50	48.80	47.50	46.90	47.90	47.40	46.10	45.30	44.60	42.70	33.40	+5.4
C	37.10	46.10	49.90	50.30	49.60	49.10	48.70	48.60	48.40	48.80	48.50	48.50	47.60	47.30	47.70	46.60	41.40	+9.7
D	34.20	40.40	45.90	44.20	43.10	41.70	39.40	41.90	40.20	41.40	40.90	41.10	41.70	41.00	41.80	44.00	42.00	-3.9
Column % Dev. from mean	-22.5	-3.0	+8.8	+6.8	+4.5	+3.2	+3.3	+4.7	+1.2	+2.2	+2.1	+2.9	+1.9	-0.1	-0.5	-2.0	-13.5	

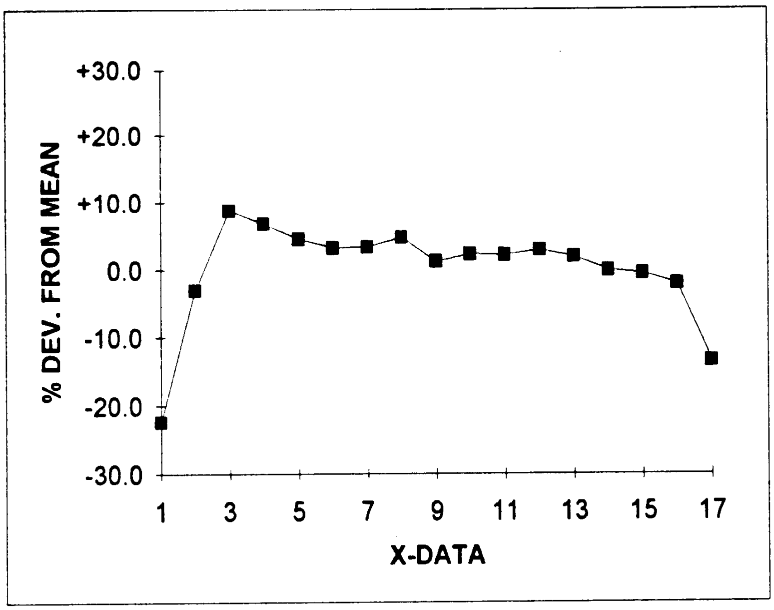
Average Velocity (ft/sec):	43.14
% Design Flow:	106.77
%RMS:	11.59
Std. Dev. (ft/sec):	5.00
Max. (ft/sec):	50.30
Min. (ft/sec):	29.40

QPGST3RS.XLS

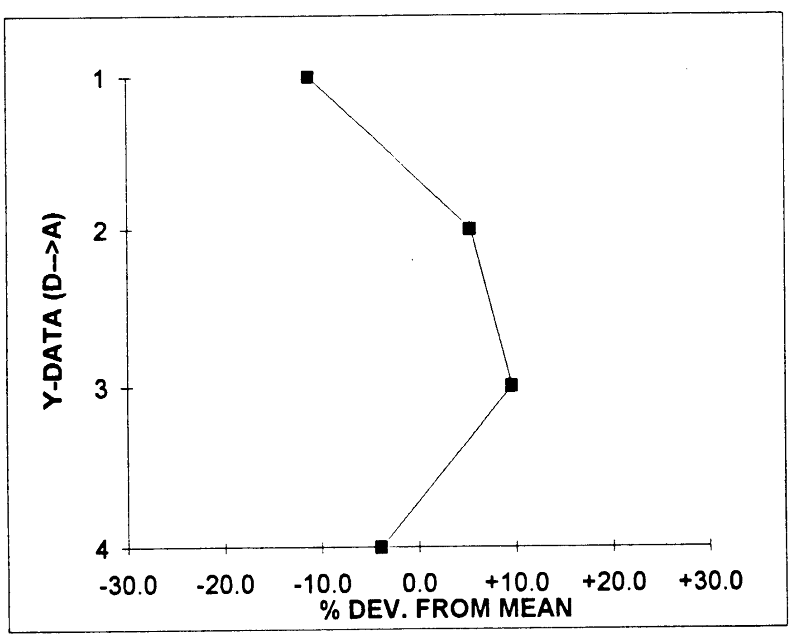
FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Right ESP Inlet (Dynagen report, p. 35)	Test No.:	0
Test Station:	TS-3	Date:	8-Oct-92

COLUMN AVERAGE PROFILE



ROW AVERAGE PROFILE



FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Left ESP Inlet (Dynagen report, p. 38)	Test No.:	0
Test Station:	TS-3	Date:	8-Oct-92
Instrument:		100% Velocity (ft/sec):	40.3

Velocity (ft/sec)

X-DATA

E.4

Y-DATA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Row % Dev. from mean
A	35.00	39.60	37.40	35.90	36.50	32.00	29.50	31.20	32.50	39.30	36.80	38.60	36.10	40.20	40.30	35.80	33.30	-12.1
B	45.00	44.80	43.40	43.20	43.40	42.40	40.40	38.90	35.30	42.50	39.40	42.10	39.70	41.30	43.40	40.00	37.10	+1.1
C	47.70	46.70	45.90	46.60	48.70	49.50	48.30	44.30	35.40	43.50	43.40	42.50	42.70	43.20	44.80	41.00	41.50	+8.8
D	44.80	46.00	42.20	43.20	42.50	43.00	39.20	37.50	32.00	42.50	42.90	41.10	44.10	39.40	45.90	38.80	44.30	+2.2
Column % Dev. from mean	+5.6	+8.4	+3.4	+3.4	+4.7	+2.2	-3.7	-7.0	-17.2	+2.7	-0.5	+0.6	-0.5	+0.4	+6.7	-4.8	-4.4	

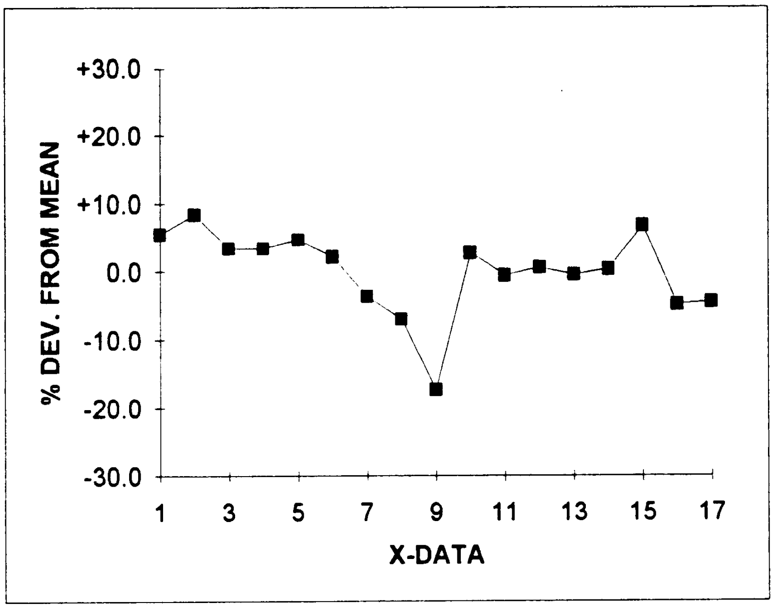
Average Velocity (ft/sec):	40.84
% Design Flow:	101.35
%RMS:	10.92
Std. Dev. (ft/sec):	4.46
Max. (ft/sec):	49.50
Min. (ft/sec):	29.50

QPGST3LS.XLS

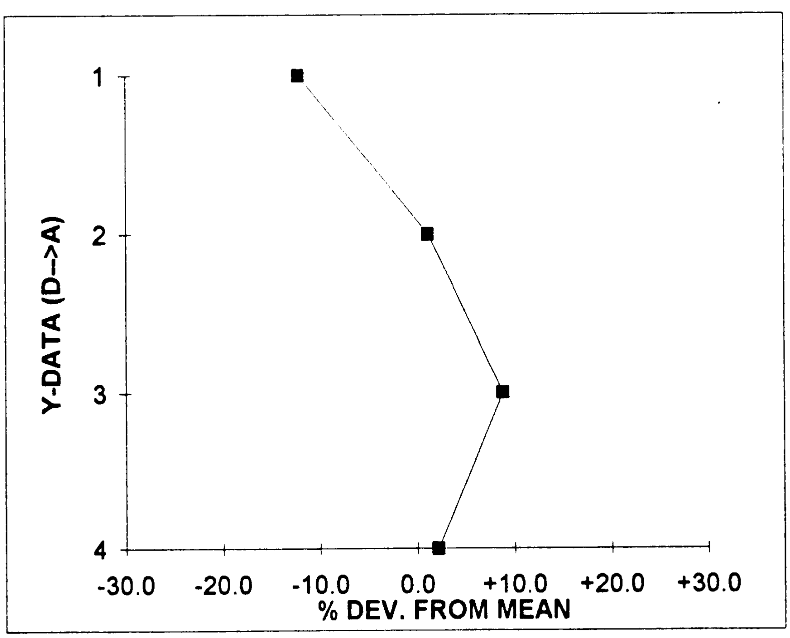
FLUID SYSTEMS ENGINEERING, INC.
Model Flue System Velocity Data Summary

Project:	NYSEG Left ESP Inlet (Dynagen report, p. 38)	Test No.:	0
Test Station:	TS-3	Date:	8-Oct-92

COLUMN AVERAGE PROFILE



ROW AVERAGE PROFILE



APPENDIX F - SAMPLE CALCULATIONS

1) PRESSURE DROP CALCULATIONS (p. F.2 - F.3)

GAS SIDE INLET

Velocity or volumetric

% FLOW = 96.74

$\rho_m = .0752$

$\rho_p = .034$ @ 680°F

$$\Delta P_p = \Delta P_m \left(\frac{100}{96.74}\right)^2 \left(\frac{.034}{.0752}\right) = .4831\, \Delta P_m$$

→ from econ. outlet to TS-1 (assume T.P. @ econ. outlet = 0)

$$\therefore \quad \Delta P_p = (.36 - 0)(.4831) = .17 \text{ in wg.}$$

→ from TS-1 to Q-pipe inlet

$$\Delta P_p = (1.29 - .36)(.4831) = .45 \text{ inwg}$$

so total ΔP for gas inlet = .17 + .45 = .62 in w.g.

GAS SIDE OUTLET

% FLOW = 109.84

$\rho_m = .0755$

$\rho_p = .055$ @ 253°F

$$\Delta P_p = \Delta P_m \left(\frac{100}{109.84}\right)^2 \left(\frac{.055}{.0755}\right) = .6038\, \Delta P_m$$

→ from Q-pipe outlet to TS-A

$$\Delta P_p = (2.29 - 1.10)\, .6038 = .72 \text{ inwg}$$

→ from TS-A to TS-3

$$\Delta P_p = (4.22 - 2.29)\, .6038 = 1.16 \text{ inwg}$$

$\therefore$ total ΔP for gas outlet duct = .72 + 1.16 = 1.88 in wg.

AIR SIDE INLET

% FLOW = 115.82

$\rho_m = .0764$

$\rho_p = \cancel{.0762}$ .072 @ 80°F

$$\Delta P_p = \Delta P_m \left(\frac{100}{115.82}\right)^2 \left(\frac{.072}{.0762}\right) = .7044 \, \Delta P_m$$

0.7045

→ from TS-1 to Q-Pipe inlet

$$\Delta P_p = (5.60 - 3.82) .7044 = 1.25 \text{ in w.g.}$$ ←

AIR SIDE OUTLET

% FLOW = 116.15

$\rho_m = .0761$

$\rho_p = .036$

$$\Delta P_p = \Delta P_m \left(\frac{100}{116.15}\right)^2 \left(\frac{.036}{.0761}\right) = .3507 \, \Delta P_m$$

→ from Q-pipe outlet to TS-3

$$\Delta P_p = (4.48 - .91)(.3507) = 1.25 \text{ in w.g}$$ ←

APPENDIX G - HOT-WIRE ANEMOMETER CALIBRATION CERTIFICATE

TSI CERTIFICATE OF CALIBRATION AND TESTING

TSI Model 8450-EB-V TSI Serial No. 93040317

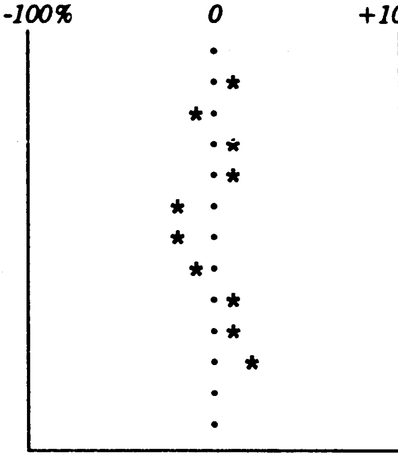
Description AIR VEL TRANSDUCER, 0-2000 STD FT/MIN = 0-5 VOLT

Calibration Standard WIND TUNNEL CALIBRATION SYSTEM, SERIAL NO. 111

CALIBRATION VERIFICATION RESULTS

Calibration Standard Std Ft/Min	*Instrument Output* Std Ft/Min	*Percent Difference*
0.0	0.6	
33.7	33.1	-1.8
70.1	70.9	1.1
199.6	200.4	0.4
280.8	277.8	-1.1
501.2	497.4	-0.8
699.4	696.6	-0.4
998.4	1001.8	0.3
1394.3	1396.7	0.2
1777.3	1784.2	0.4

Difference as a Percent of Tolerance



Standard Conditions
Ambient Temperature: 21.1°C
Barometric Pressure: 760.0 mmHg

Tolerance
± 1.5% of reading
± .5% full scale

TSI Incorporated does hereby certify that all materials, components, and workmanship used in the manufacture of this equipment are in strict accordance with the applicable specifications agreed upon by TSI and the customer and with all published specifications. All performance and acceptance tests required under this contract were successfully conducted according to required specifications. Furthermore, all test and calibration data supplied by TSI has been obtained using standards whose accuracies are traceable to the National Institute of Standards and Technology (NIST) or has been verified with respect to instrumentation whose accuracy is traceable to NIST, or is derived from accepted values of physical constants.

Applicable NIST Test Report		Report Number	Date	Date Last Verified
DC voltage		100061	7-30-92	7-30-92
Barometric Pressure		P-8077	5-13-87	5-26-92
Temperature	19-35°C	213426	3-19-80	10-28-92
	0°C	246369	9-13-90	12-08-92
	60°C	216642	1-18-93	1-18-93
Pressure		040J/34FB2:001-2	10-23-85	1-11-93
Velocity:	(Gage Blocks)	738/231633-84	6-25-84	11-06-92
	(Frequency)	84071101	7-11-84	6-11-92
Dewpoint		250371	6-10-91	12-10-92

JoAnn Bowman
Calibrated by

Apr 19, 1993
Calibration Date

TSI Incorporated
Industrial Test Instruments Group

Mailing Address: P.O. Box 64394 St. Paul, MN 55164 USA
Shipping Address: 500 Cardigan Road St. Paul, MN 55126 USA
Phone: (800) 876-9874 or (612) 490-2888 Fax: (612) 490-2874

APPENDIX H - PHOTOGRAPHS

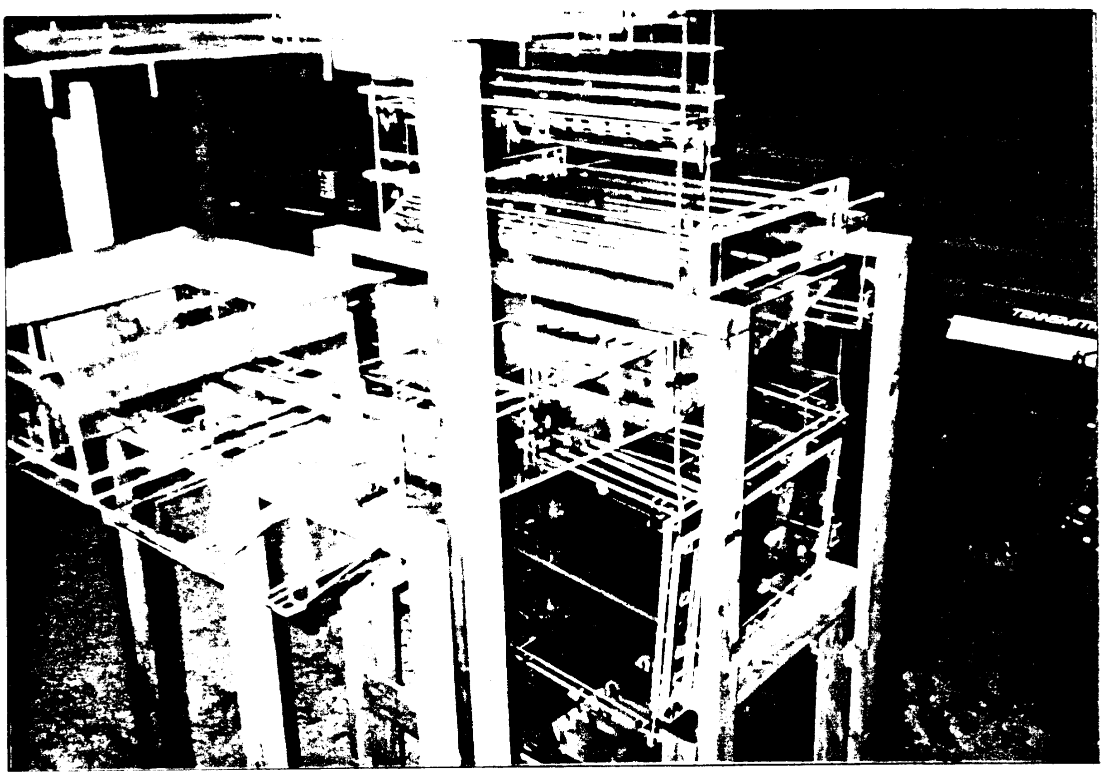


PHOTO 1 - OVERALL VIEW OF GAS SIDE INLET

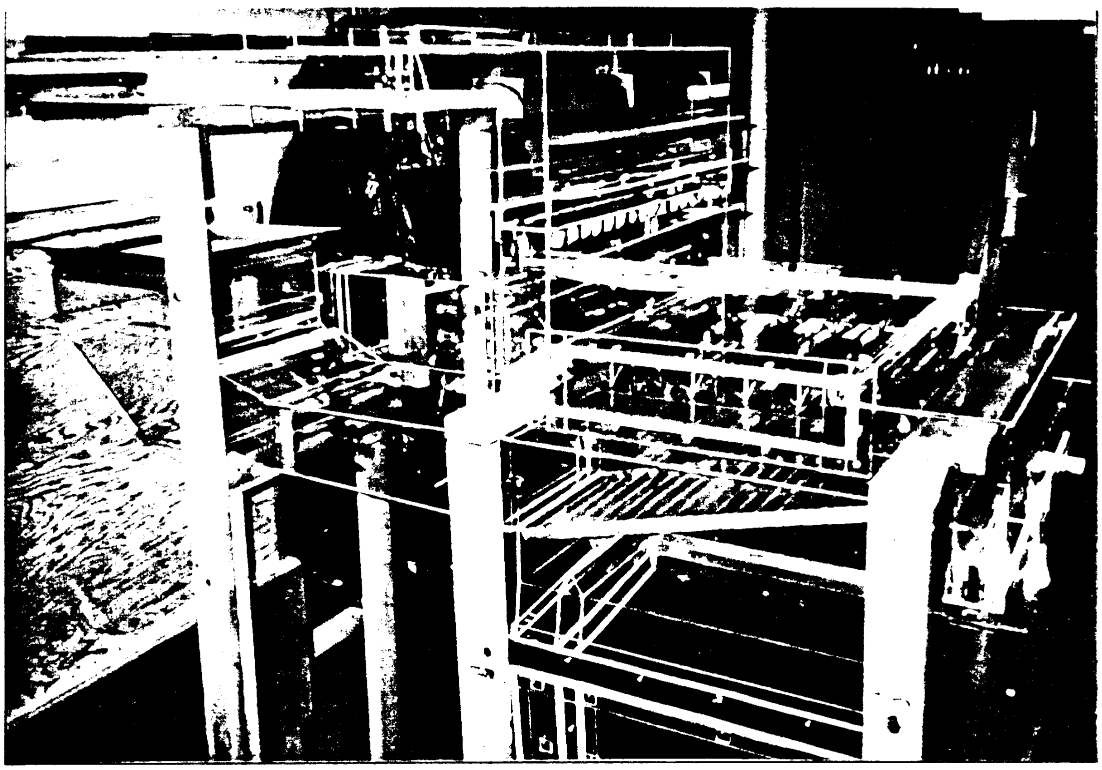


PHOTO 2 - GAS INLET HOOD WITH LADDER VANES

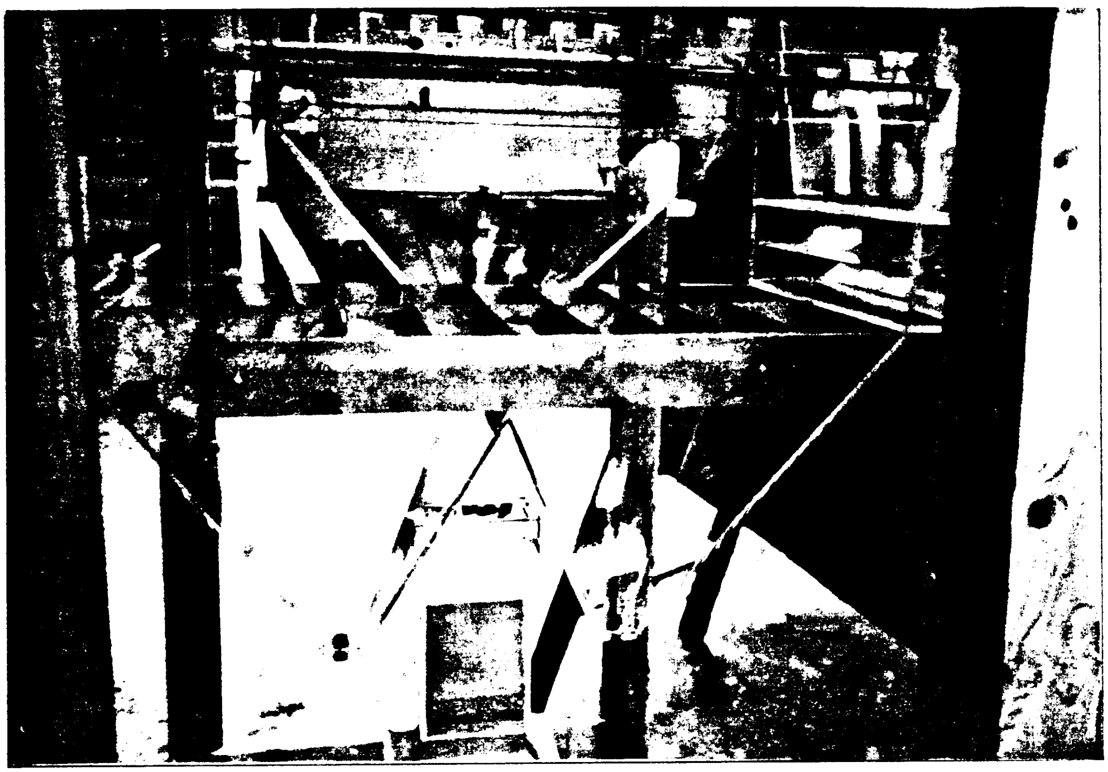


PHOTO 3 - GAS SIDE OUTLET HOPPER BAFFLES (FLOW --->)

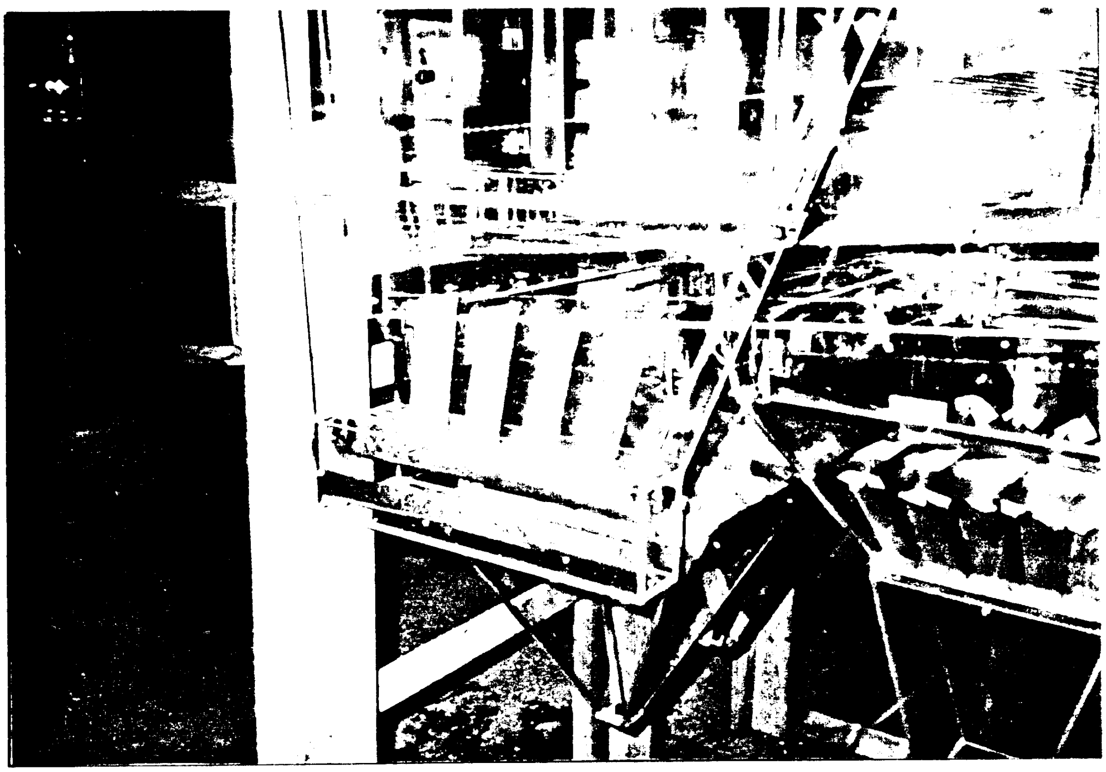


PHOTO 4 - GAS SIDE OUTLET TURNING VANES

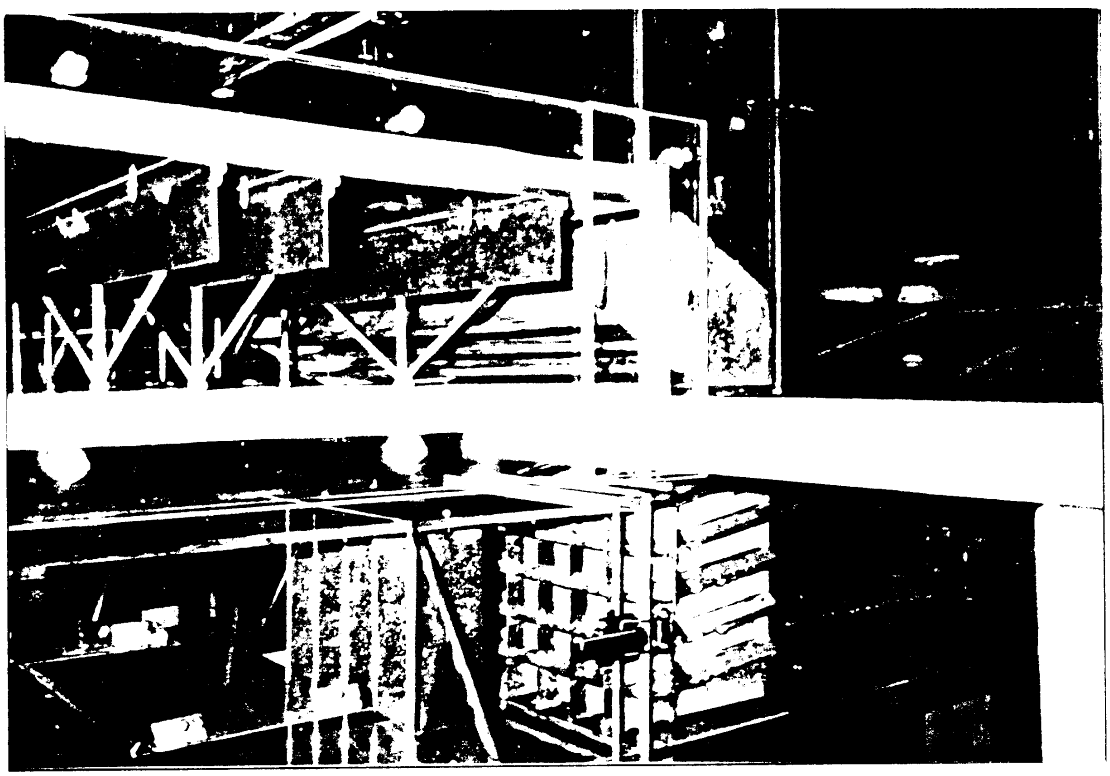


PHOTO 5 - CROSSOVER DUCT ROOF BAFFLES AND 90° ELBOW VANES

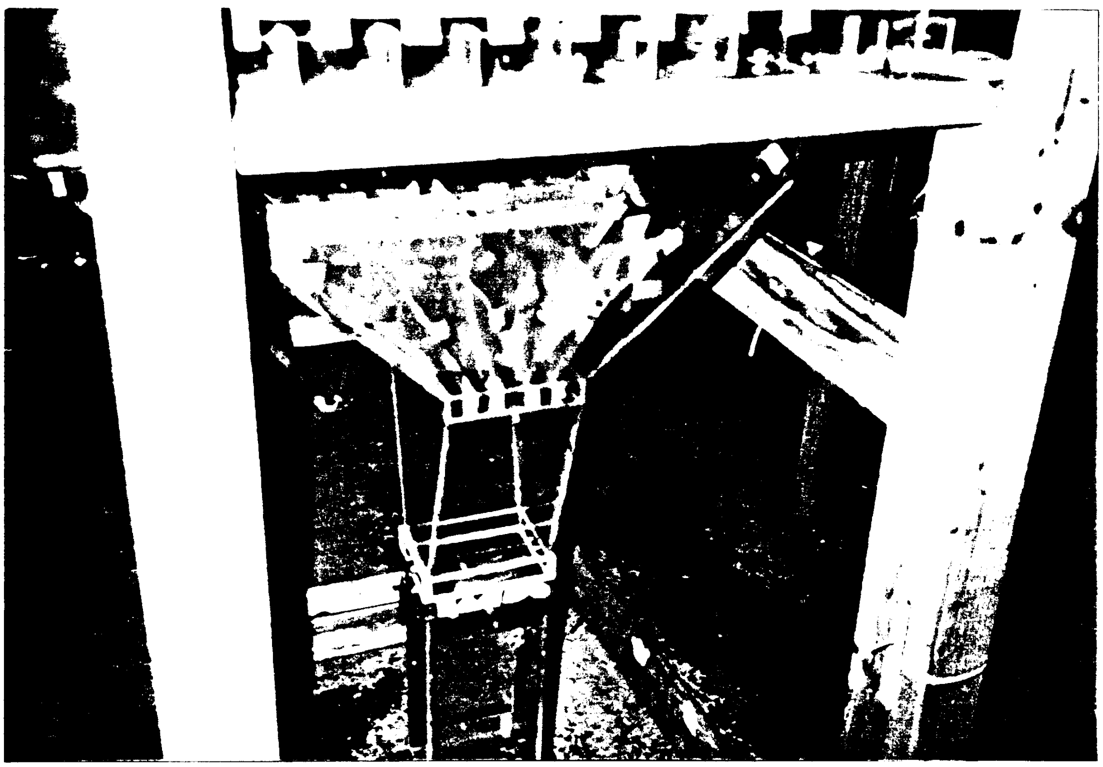


PHOTO 6 - AIR SIDE INLET DIFFUSER TURNING VANES

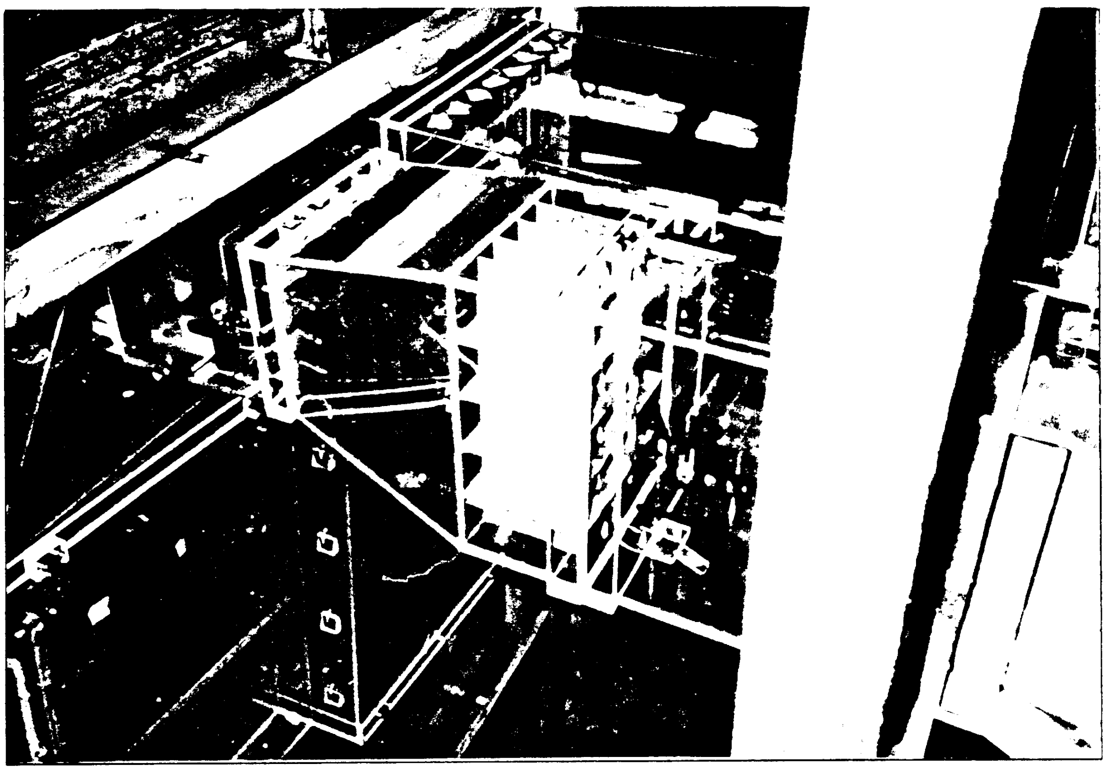


PHOTO 7 - AIR SIDE OUTLET DUCT TURNING VANES