WIND TUNNEL SIMULATION OF
THE JOHNSON MATTHEY INC.
PLACERITA SPARGER SYSTEM

Final Report

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Dr. Jane H. Davidson
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FLUID MECHANICS AND
WIND ENGINEERING PROGRAM

COLLEGE OF ENGINEERING

COLORADO STATE UNIVERSITY
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1.0 Introduction

The Catalytic Systems Division of Johnson Matthey Inc. designs and manufactures catalytic reduction systems to remove environmental pollutants from the exhaust gases of large gas turbines. Exhaust gases pass through a large duct in which catalytic panels are strategically located to selectively remove pollutants. At one location along the duct, just upstream of a series of catalyst panels, chemical sprays are mixed with the exhaust gas stream via the Johnson Matthey Placerita Sparger System. Efficient reduction of pollutants requires homogeneous mixing of the exhaust gases and chemical sprays before the exhaust stream passes over the catalyst. The degree of mixing is dependent upon a number of design variables including duct design, placement of the sparger system in relation to the location of the catalytic panels, and sparger spray nozzle design and configuration.

Johnson Matthey designs each catalytic system to fit the specific requirements of the gas turbine manufacturer's particular application. Space constraints in a current application require placement of the sparger system in close proximity to the downstream catalytic panels. Because the duct length in which the chemical spray and exhaust gases can mix is relatively short, the design of the Placerita Sparger System is critical. The spray nozzles must be configured to produce optimum mixing.

This report presents the results of an experimental study of the efficacy of the Johnson Matthey SE Placerita Sparger System to produce a homogeneous mixture of spraying fluid and exhaust gas. The goal of the study was to determine the nozzle type and configuration which provides the best mixture of exhaust gas and spray fluid at a point 2 feet downstream of the spargers. To accomplish this goal, a full scale model of a 6 ft. by 6 ft. segment of the sparger system was constructed and tested in the Industrial Wind Tunnel (IWT) located in the Fluid Dynamics and Diffusion Laboratory (FDDL) at Colorado State University (CSU). The mixing characteristics of a variety of nozzle types, spray angles and orientations were evaluated by introducing hydrocarbon tracers to the nozzle spray and then measuring tracer dilution using gas chromatography.

A full description of the testing program including the model, the instrumentation, and data analysis is given in Section 2.0. A summary of the results is presented in Section 3.0. The complete set of results is included in the Appendix to this report. The implications of the testing program to the Johnson Matthey SE Placerita Sparger Design are discussed in Section 4.0.

2.0 <u>Experimental Facility and Technical Approach</u>

2.1 The Model Sparger System

A full scale model of the Johnson Matthey Placerita Sparger System was constructed at CSU and installed in the IWT. The model tested was a 6 ft. by 6 ft. quarter section of one panel of the Brown Boyeri Corporation Ammonia Injection Grid as shown in the Johnson Matthey drawing number 02-0D0605, revision A, dated 3-2-87. Figure 1 is a sketch of the model injection grid as it was installed in the wind tunnel. The model consisted of three sparger pipes connected to a manifold riser pipe. The piping was supported in the wind tunnel by

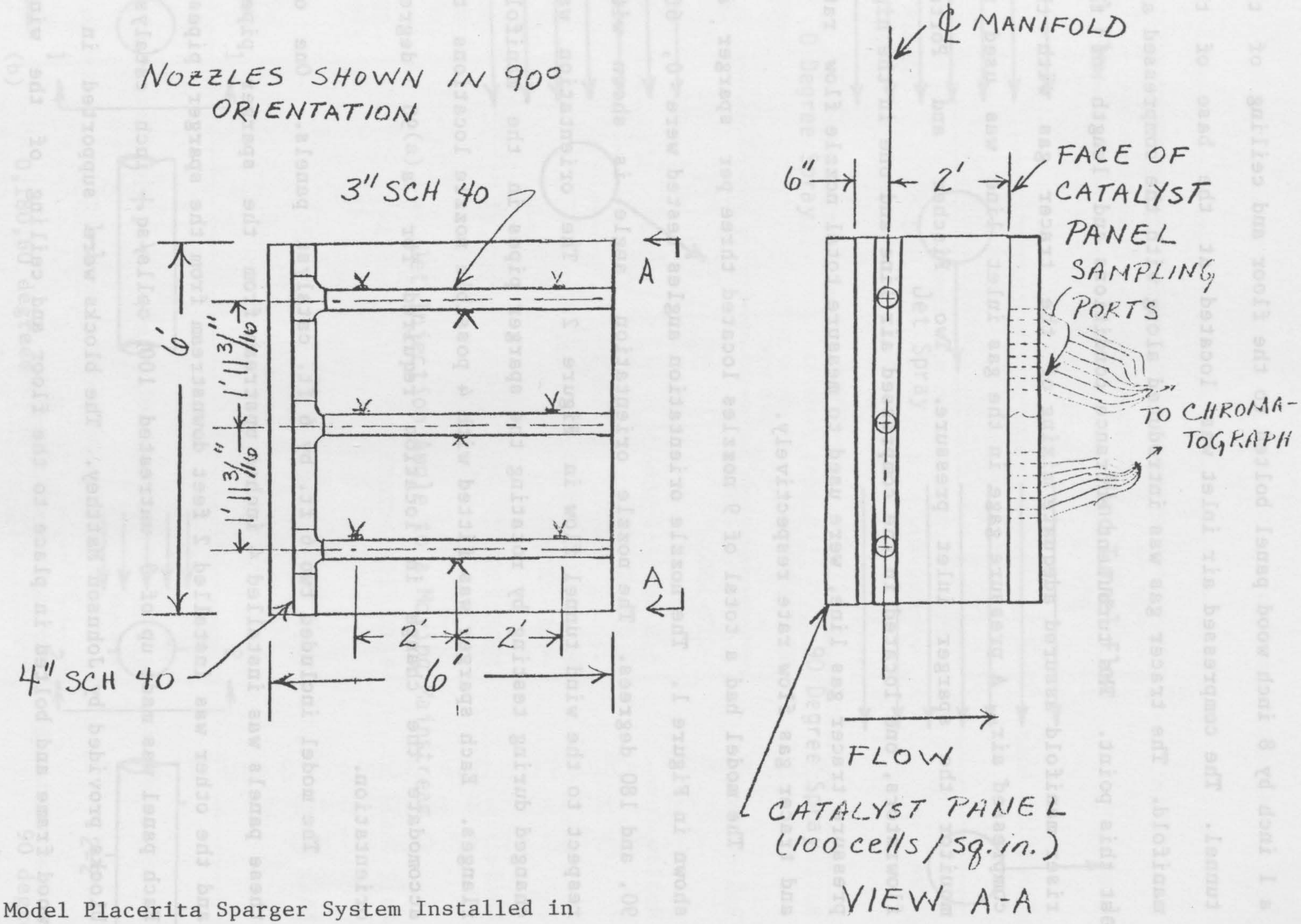


Figure 1. Model Placerita Sparger System Installed in Industrial Wind Tunnel

a 1 inch by 8 inch wood panel bolted to the floor and ceiling of the tunnel. The compressed air inlet was located at the base of the manifold. The tracer gas was introduced along with the compressed air at this point. The turbulent entrance conditions and length of the riser manifold assured adequate mixing of the tracer gas with the compressed air. A pressure gage in the gas inlet line was used to monitor the sparger inlet pressure. Two Fischer and Porter flowrators, one located in the compressed air line and one in the high pressure tracer gas line, were used to measure total nozzle flow rate and tracer gas flow rate respectively.

The model had a total of 9 nozzles located three per sparger as shown in Figure 1. The nozzle orientation angles tested were 0, 60, 90, and 180 degrees. The nozzle orientation angle is shown with respect to the wind tunnel flow in Figure 2. The orientation was changed during testing by rotating the sparger pipes in the manifold flanges. Each sparger was fitted with 4 possible nozzle locations to accomodate the change in location required for a 90 degree orientation.

The model included two 6 ft. by 6 ft. catalyst panels. One of these panels was installed 4 inches upstream from the sparger pipes and the other was installed 2 feet downstream from the sparger pipes. Each panel was made up of 9 untreated 100 cells/sq. inch catalyst blocks provided by Johnson Matthey. The blocks were supported in a wood frame and bolted in place to the floor and ceiling of the wind tunnel.

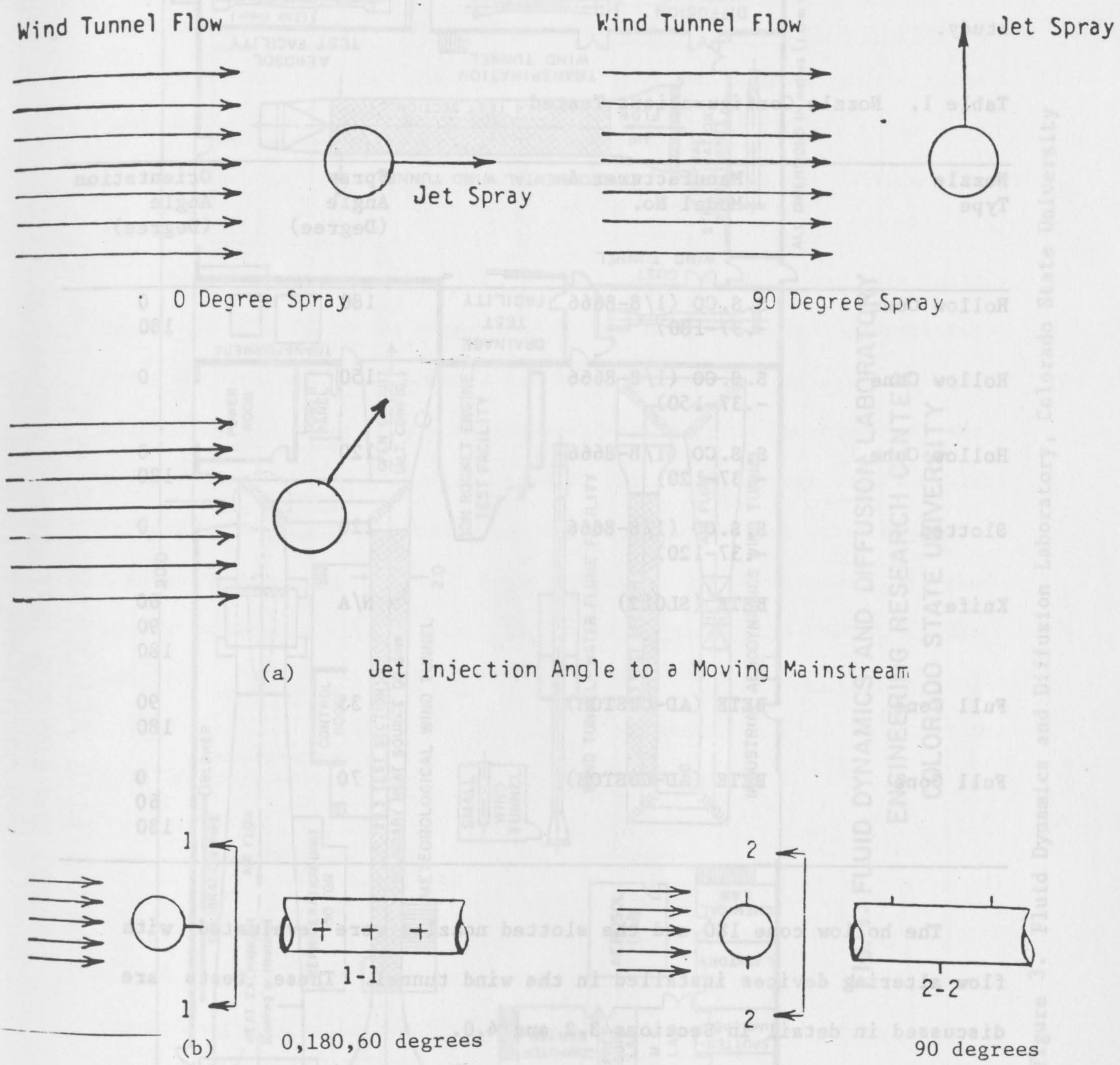


Figure 2. (a) Jet Injection Angle to a Moving Mainstream
(b) Nozzle Location for 0,180,60 and 90° Orientation

2.2 Nozzle Configurations

Table 1 is a listing of the nozzle configurations examined in the study.

Table 1. Nozzle Configurations Tested

Nozzle Type	Manufacturer & Model No.	Spray Angle (Degree)	Orientation Angle (Degree)
Hollow Cone	S.S.CO (1/8-8666 -.37-180)	180	0 180
Hollow Cone	S.S.CO (1/8-8666 -.37-150)	150	0
Hollow Cone	S.S.CO (1/8-8666 -.37-120)	120	0 180
Slotted	S.S.CO (1/8-8666 -.37-120)	120	0
Knife	BETE (SL012)	N/A	60 90 180
Full Cone	BETE (AD-CUSTOM)	35	90 180
Full Cone	BETE (AD-CUSTOM)	70	0 60 180

The hollow cone 180 and the slotted nozzles were evaluated with flow altering devices installed in the wind tunnel. These tests are discussed in detail in Sections 3.2 and 4.0.

2.3 Industrial Wind Tunnel

Location of the IWT in the FDDL is shown in Figure 3. Figure 4

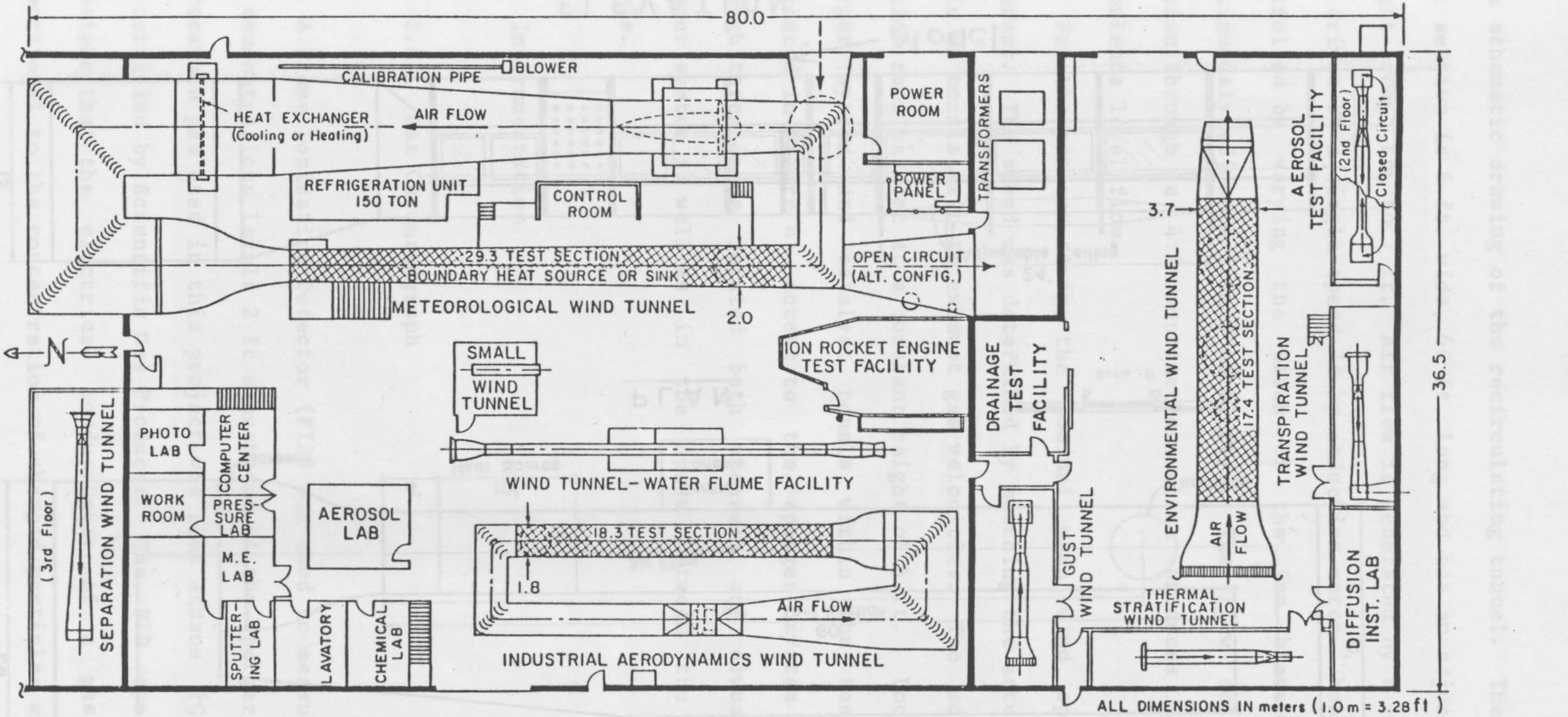


FIG. 3. FLUID DYNAMICS AND DIFFUSION LABORATORY
ENGINEERING RESEARCH CENTER
COLORADO STATE UNIVERSITY

Figure 3. Fluid Dynamics and Diffusion Laboratory, Colorado State University

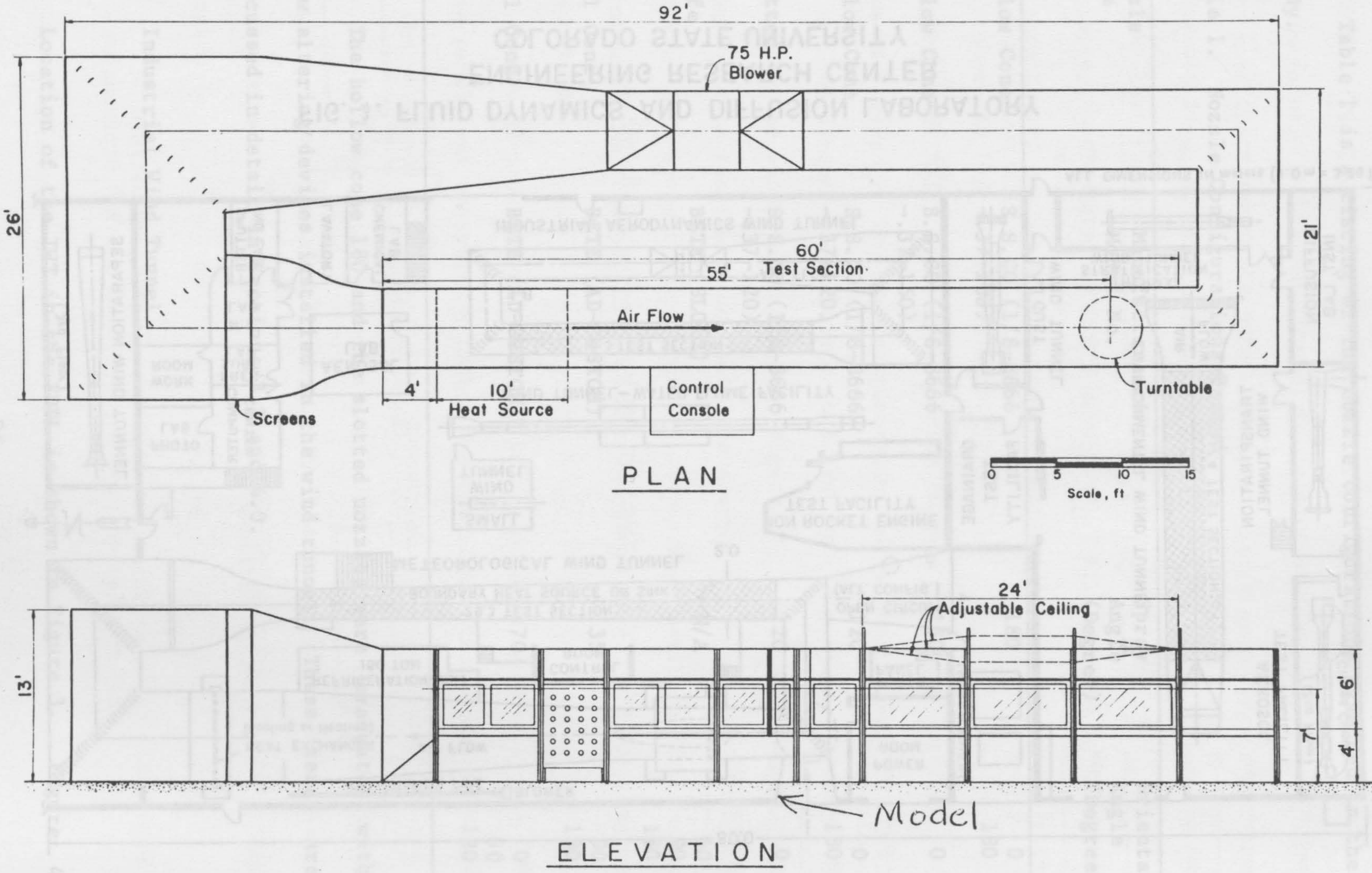


Figure 4. INDUSTRIAL AERODYNAMICS WIND TUNNEL
FLUID DYNAMICS & DIFFUSION LABORATORY
COLORADO STATE UNIVERSITY

is a schematic drawing of the recirculating tunnel. The wind tunnel test section is 6 ft. wide, 60 ft. long and has an adjustible ceiling height from 5 ft. to 7 ft. Air flow is generated by a 16-blade axial fan driven by a single-speed 75 hp induction motor. Mean air speed is controlled by varying the pitch of the fan blades and can be continuously adjusted from 0 to 80 ft/s. The flow enters the test section through a 4:1 contraction which produces a uniform low turbulence level flow.

For the present study, the nominal mean wind speed was held constant. The speed was determined by matching the actual operational ratio of nozzle exit to exhaust gas velocities. The adjustible test section roof was set at a constant height of 6 ft. Location of the sparger system and catalyst panels within the test section is indicated in Figure 4. Access to the sparger system was possible through three doors located both upstream and downstream of the sparger system as well as in the space between the two catalyst panels.

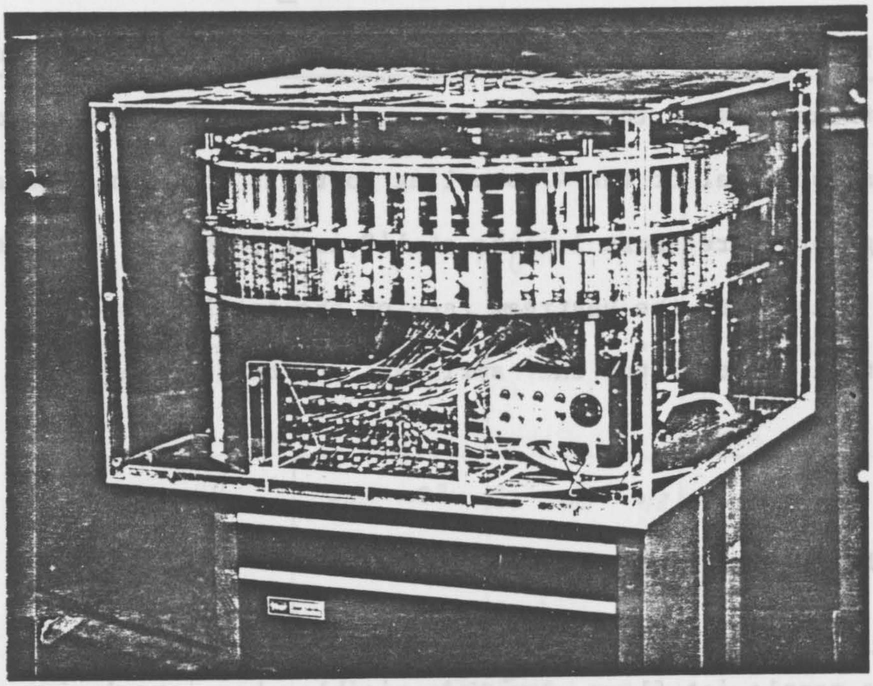
2.4 Instrumentation

2.4.1 Gas Chromatograph

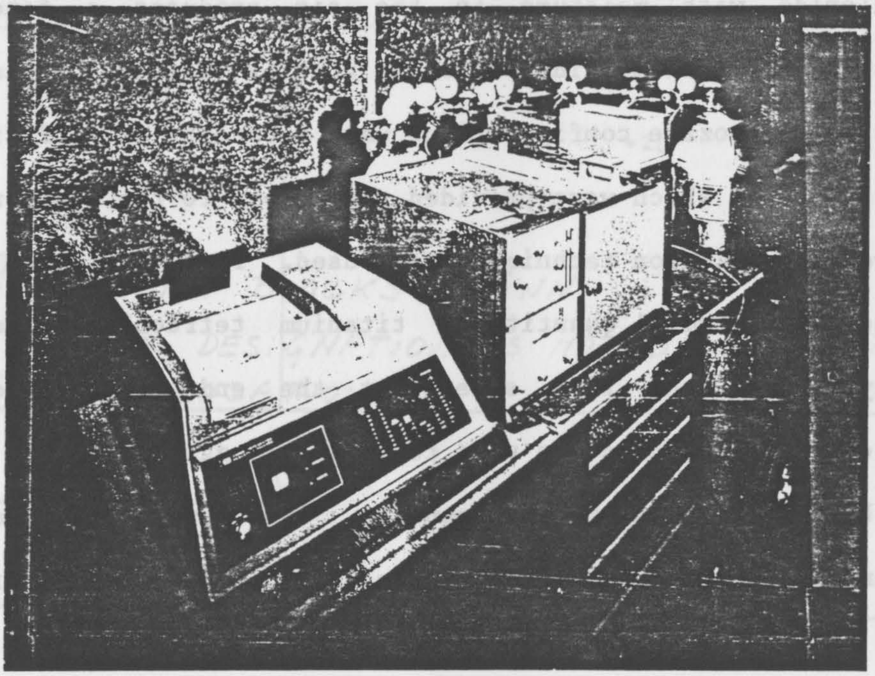
A Flame Ionization Detector (FID) was used to measure hydrocarbon gas concentrations levels 2 ft downstream of the sparger piples. The hydrocarbon gas used in this project was 100% ethane (C_2H_6) supplied and certified by Scientific Gas Products. The FID operates on the principle that the electrical conductivity of a gas is directly proportional to the concentration of charged particles within the gas.

Ions are formed by the hydrocarbon tracer in a gas sample being combusted in an hydrogen-air flame within the FID. The ions and electrons formed enter an electrode gap and decrease the gap resistance. The resulting voltage drop is amplified by an electrometer and fed to an Hewlett packard 3380 (HP 3380) integrator. The output of the integrator is connected to an IBM-AT microcomputer. When no sample is flowing, a carrier gas (nitrogen) flows through the FID. Due to certain impurities in the carrier, some ions and electrons are formed creating a background voltage. When the sample of interest enters the FID, the voltage increase above this background level is proportional to the degree of ionization and correspondingly the amount of tracer gas present. The lower limit of measurement is imposed by the instrument sensitivity and the background concentration of tracer gas in the wind tunnel. Background concentrations were measured and subtracted from all the reported data.

The tracer gas sampling system consists of a series of fifty 30 cc syringes mounted between two circular aluminum plates. A variable speed motor controlled by the microcomputer raises a third plate which lifts the plunger on all 50 syringes simultaneously. When the syringe plunger is raised, a sample from the tunnel is drawn into the syringe container. The sampling procedure consists of flushing the syringe three times and then drawing the actual test sample. Photographs of the sampling system and the FID are shown in Figure 5. The 28 cc samples were drawn into each syringe over a 1 minute time period and consecutively injected into the FID. The output signal from the HP 3380 is input to the computer and displayed on the computer output as measured concentration minus background concentration in parts per million (ppm). Background measurements were obtained approximately 10



(a)



(b)

Figure 5. Photographs of (a) the Gas Sampling System, and (b) the HP Integrator and Gas Chromatograph

feet upstream of the model sparger. The maximum error in concentration measurements is estimated at ± 10%.

Instrumentation ports for the gas chromatograph are located on the upstream face of the downstream catalyst panel. The location on the catalyst panel of the 47 sampling ports is shown in Figure 6. The sampling ports are short lengths of 1/8 inch OD brass tubing that are mounted flush with the upstream face of the catalyst block to flexible tubing that attach to the syringes of the tracer gas sampling system.

2.4.2 Flow Visualization

The nozzle jet flows were made visible by introducing titanium tetrachloride into the wind tunnel. A reaction of the titanium tetrachloride with moisture in the air produces a fine white suspension of titanium oxide, which is clearly visible. Visualization studies of two nozzle configurations were recorded on 1/2 inch VHS color videotapes which were provided separately to the sponsor.

Two visualization techniques were used. First, a cotton ball was saturated with a small quantity of titanium tetrachloride and then manually held in the flow stream at the end of a wand. This relatively simple method was used to avoid clogging of the sparger system by the titanium oxide suspension. The nozzle jet deflection experienced under the influence of the duct flow was difficult to clearly distinguish using this technique. The nozzle flow patterns were easier to see when the titanium tetrachloride was introduced directly into the sparger gas flow. Unfortunately, the nozzles were quickly clogged and the flow was completely plugged within a couple of

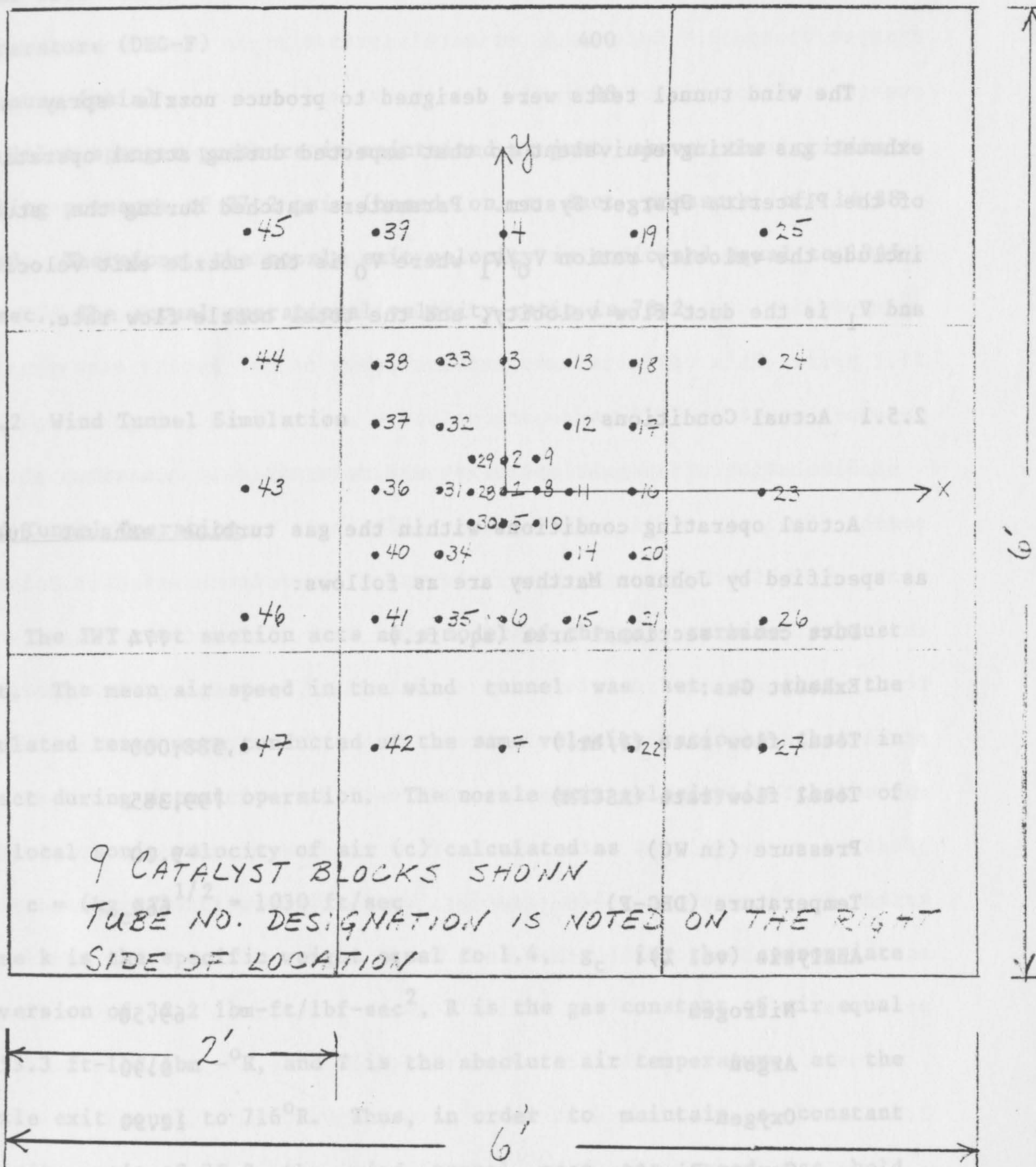


Figure 6. Gas Chromatograph Sampling Port Location on Face of Downstream Catalyst Panel

minutes.

2.5 Operating Conditions

The wind tunnel tests were designed to produce nozzle spray and exhaust gas mixing equivalent to that expected during actual operation of the Placerita Sparger System. Parameters matched during the study include the velocity ration V_0/V_1 where V_0 is the nozzle exit velocity and V_1 is the duct flow velocity, and the total nozzle flow rate.

2.5.1 Actual Conditions

Actual operating conditions within the gas turbine exhaust duct as specified by Johnson Matthey are as follows:

Duct cross sectional area (sq. ft.)	774
Exhaust Gas:	
Total flow rate (#/hr.)	1,588,000
Total flow rate (ASCFM)	799,385
Pressure (in WC)	-9.00
Temperature (DEG-F)	662
Analysis (vol %):	
Nitrogen	69.50
Argon	0.90
Oxygen	12.90
Carbon-Dioxide	2.90
Water	13.80
Molecular Weight	27.22

The resulting nominal exhaust gas velocity V_1 is 17.2 ft/sec.

Actual nozzle operating conditions as stated by Johnson Matthey are:

Total flow (SCFM)	1.6/nozzle
Temperature (DEG-F)	400
Pressure (psia)	28

The inlet sparger pressure is maintained at just above the critical choking pressure of 27.2 psia (based on a duct pressure of 14.38 psia). Therefore, the nozzle exit velocity is sonic and equal to 1345 ft/sec. The actual operational velocity ratio is 78.2.

2.5.2 Wind Tunnel Simulation

Wind Tunnel Operation

The IWT test section acts as a model of the gas turbine exhaust duct. The mean air speed in the wind tunnel was set so that the simulated tests were conducted at the same velocity ratio as that in effect during actual operation. The nozzle exit velocity is that of the local sonic velocity of air (c) calculated as

$$c = (kg_c RT)^{1/2} = 1030 \text{ ft/sec}$$

where k is the specific weight equal to 1.4, g_c is the appropriate conversion of 32.2 lbm-ft/lbf-sec^2, R is the gas constant of air equal to 53.3 ft-lbf/lbm -^{O}R, and T is the absolute air temperature at the nozzle exit equal to 716^{O}R. Thus, in order to maintain a constant velocity ratio of 79.2, the wind tunnel mean gas speed was held constant at 13 ft/sec. Wind tunnel speed was monitored with a pitot tube mounted in the tunnel. The tube was connected to an electric manometer, and the tranducer output voltage was monitored on a digital voltmeter.

Sparger Operation

The sparger nozzle flow was controlled by regulating the inlet sparger pressure. Once the critical pressure is reached in the sparger, the nozzles are choked and the mass flow rate ($\dot{m}$) through the nozzles increases with increasing inlet pressure (p) as

$$\dot{m} = 0.63\ pAc/RT$$

where A is the nozzle exit area, R is the gas constant, and T is the sparger absolute gas temperature. The critical pressure in the IWT is 23.1 psia. This value is calculated based on a local atmospheric pressure equal to 12.2 psia.

Simulation of sparger operation was determined by a maximum total nozzle flow rate of 14.4 SCFM (1.6 SCFM per nozzle). Preliminary tests, in which the nozzle flow rate was allowed to exceed this value, indicate that mixing improves with higher mass flow rates. Based on these results, the final tests were controlled by setting the sparger pressure as high as possible above the critical pressure without exceeding the stated maximum permissible flow rate. The operating pressure and resulting total nozzle flow rate were recorded for each test. If the measured flow rate at critical pressure exceeded or equalled the 14.4 SCFM, the test was conducted at the critical pressure.

2.6 Data Analysis

The tracer gas concentration measurements were designed to provide a basis for evaluating and differentiating the mixing performance of the various nozzle types and orientations tested. Gas concentration measurements were obtained for each test at the 47 points described in Section 2.4.1 and shown in Figure 6. An example of the data obtained during a test of the hollow cone 180 nozzle at an orientation of zero degrees to the flow is shown in Figure 7. The tube number, located in the far left column, corresponds to the physical location of the sampling location as indicated in Figure 6. The X and Y locations indicate the horizontal and vertical distances of the probe from the tunnel center. Point tracer gas concentrations in ppm shown in column 4 are obtained by subtracting the background tracer concentration from the measured concentration:

Conc. (ppm) = Meas. value - background value.

In order to quantify the difference in mixing efficiency of the various nozzle options, statistical properties of each test were computed. The mean value is the arthmetic average of the 47 point values:

$$\text{Sample Mean (ppm)} = \sum \text{Conc.}/47$$

The deviation (Dev) of each sample is simply the difference between the sample concentration and the mean concentration.

$$\text{Dev (ppm)} = \text{Conc} - \text{Mean.}$$

The standard deviation (Std) gives a global description of how the concentrations are distributed about the mean and is determined as

$$\text{Std (ppm)} = [\sum (\text{Conc.} - \text{Mean})^2/47]^{1/2}.$$

The standard deviation divided by the mean (Std/Mean) is an average measure of how well the tracer gas is mixed with the duct air flow. A complete homogeneous mixing would result in a Std/Mean equal to zero. In comparing the various tested options, the best mixing is indicated by the lowest value of this ratio.

The mixing distribution among the 47 locations is easier to see

RUN NUMBER 30
NOZZLE TYPE HOLLOW CONE 180 AT 0
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 31.52
SAMPLE STD. (PPM) 24.29
STD/MEAN .770

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	84.6	1.684	2.186
2	.00	5.00	71.5	1.269	1.647
3	.00	20.00	18.7	-.408	-.530
4	.00	40.00	22.7	-.280	-.364
5	.00	-5.00	91.7	1.909	2.478
6	.00	-20.00	18.6	-.409	-.531
7	.00	-40.00	16.6	-.474	-.615
8	5.00	.00	58.5	.856	1.110
9	5.00	5.00	51.2	.625	.811
10	5.00	-5.00	64.9	1.059	1.375
11	10.00	.00	35.7	.133	.172
12	10.00	10.00	25.7	-.185	-.240
13	10.00	20.00	15.1	-.521	-.677
14	10.00	-10.00	35.1	.114	.148
15	10.00	-20.00	17.0	-.461	-.598
16	20.00	.00	20.8	-.340	-.442
17	20.00	10.00	15.8	-.500	-.649
18	20.00	20.00	15.0	-.524	-.680
19	20.00	40.00	14.7	-.532	-.691
20	20.00	-10.00	16.5	-.476	-.618
21	20.00	-20.00	14.6	-.536	-.696
22	20.00	-40.00	14.7	-.535	-.695
23	40.00	.00	21.8	-.309	-.401
24	40.00	20.00	14.2	-.551	-.715
25	40.00	40.00	14.2	-.549	-.712
26	40.00	-20.00	15.3	-.515	-.669
27	40.00	-40.00	15.2	-.518	-.672
28	-5.00	.00	86.2	1.733	2.249
29	-5.00	5.00	73.1	1.318	1.711
30	-5.00	-5.00	91.4	1.900	2.466
31	-10.00	.00	63.4	1.012	1.314
32	-10.00	10.00	48.2	.528	.686
33	-10.00	20.00	18.9	-.400	-.520
34	-10.00	-10.00	56.9	.804	1.044
35	-10.00	-20.00	22.5	-.286	-.372
36	-20.00	.00	25.5	-.191	-.248
37	-20.00	10.00	22.6	-.282	-.366
38	-20.00	20.00	14.5	-.541	-.702
39	-20.00	40.00	13.7	-.564	-.732
40	-20.00	-10.00	23.4	-.258	-.335
41	-20.00	-20.00	15.5	-.507	-.658
42	-20.00	-40.00	14.0	-.555	-.720
43	-40.00	.00	18.3	-.418	-.543
44	-40.00	20.00	12.9	-.592	-.768
45	-40.00	40.00	12.8	-.593	-.769
46	-40.00	-20.00	13.5	-.571	-.741
47	-40.00	-40.00	13.8	-.562	-.729

Figure 7. Gas Chromatograph data obtained for Hollow Cone 180^{o} nozzle at 0^{o} orientation

in the plots shown in Figures 8 and 9. Figure 8 is a grid plot of the deviation of each point divided by the mean concentration value. (The actual data is listed in Figure 7 in column 5.) The plot indicates that tracer concentrations are significantly higher just downstream of the nozzle than in the areas between nozzles. Negative values indicate concentration levels lower than the mean. Correspondingly, positive values reflect higher readings than the mean. The same data is plotted in Figure 9 in the form of contours of constant values. The contour map again shows high concentration levels in the immediate area of the nozzle and lower levels throughout the remaining space. The map is approximated in areas between sampling ports by linear interpolation.

3.0 Experimental Results

Table 2 indicates the test conditions and the standard deviation to mean ratios for the 18 wind tunnel simulations completed. The Appendix to this report gives a complete data listing of these test runs. The decision as to which combinations of nozzle type and orientation to simulate initially was made on the basis of the suggestions of Johnson Matthey (reference is made to the specifications in the March 24 document no. 040-6-0082). Based on the results of these first nine simulations, the nine additional wind tunnel tests indicated in Table 2 were completed.

RUN NO.= 30

-.593	-.564			-.280			-.532	-.549
-.592	-.541	-.400		-.408		-.521	-.524	-.551
	-.282	.528				-.185	-.500	
			1.318	1.269	.625			
-.418	-.191	1.012	1.733	1.684	.856	.133	-.340	-.309
			1.900	1.909	1.059			
	-.258	.804				.114	-.476	
-.571	-.507	-.286		-.409		-.461	-.536	-.515
-.562	-.555			-.474			-.535	-.518

Figure 8. Grid Plot of Deviation/Mean Concentration for Hollow Cone 180° Nozzle at 0° Orientation

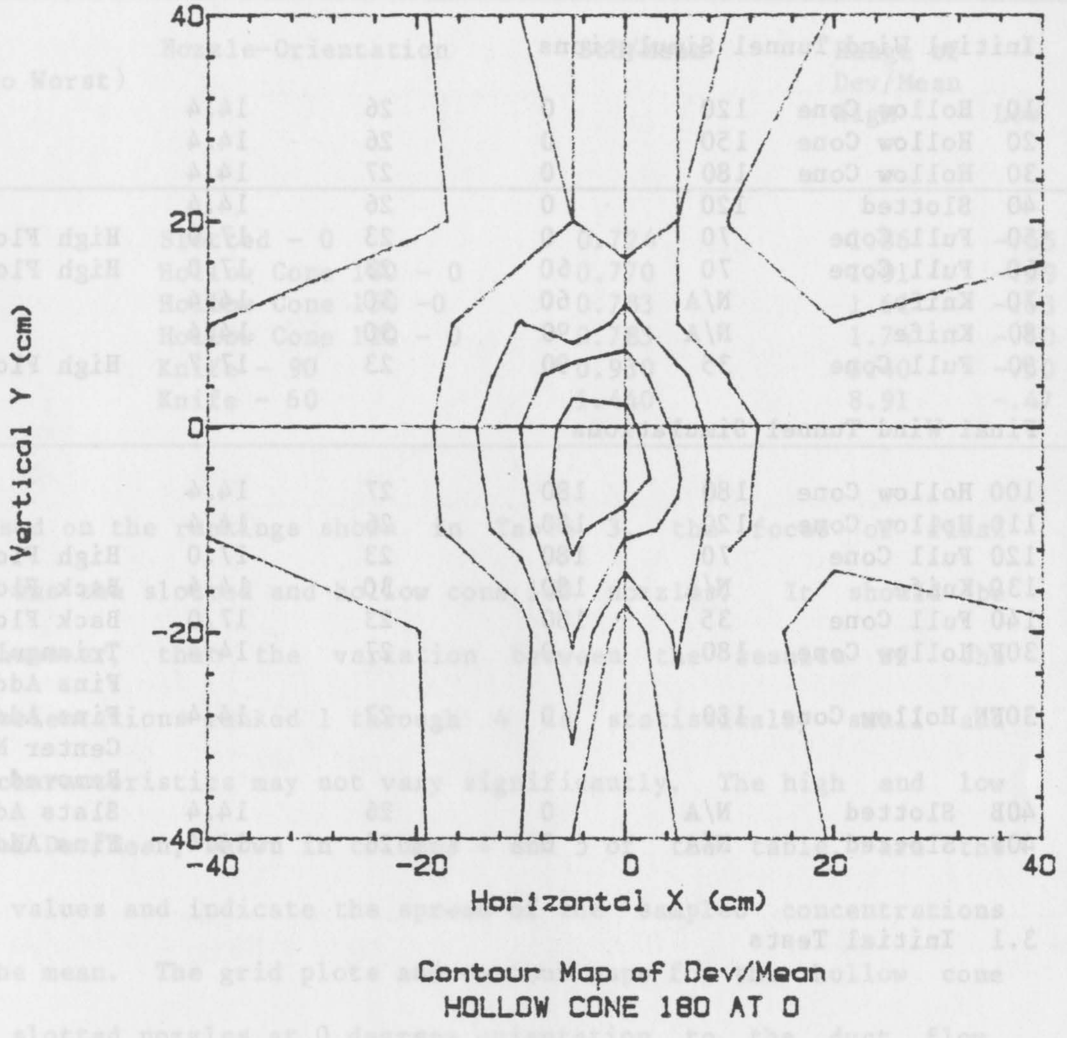


Figure 9. Contours of Constant Deviation/Mean Concentration for Hollow Cone 180^{0} Nozzle at 0^{o} Orientation.

Table 2. Test Conditions

Run #	Nozzle Type	Spray Angle	Orientation Angle	Pressure (psia)	Flow (SCFM)	Comments	Std/Mean
Initial Wind Tunnel Simulations							
10	Hollow Cone	120	0	26	14.4		0.783
20	Hollow Cone	150	0	26	14.4		0.783
30	Hollow Cone	180	0	27	14.4		0.770
40	Slotted	120	0	26	14.4		0.724
50	Full Cone	70	0	23	17.0	High Flow	0.935
60	Full Cone	70	60	23	17.0	High Flow	0.840
70	Knife	N/A	60	30	14.4		1.440
80	Knife	N/A	90	30	14.4		0.930
90	Full Cone	35	90	23	17.7	High Flow	0.853
Final Wind Tunnel Simulations							
100	Hollow Cone	180	180	27	14.4		0.844
110	Hollow Cone	120	180	26	14.4		0.961
120	Full Cone	70	180	23	17.0	High Flow	0.912
130	Knife	N/A	180	30	14.4	Back Flow	
140	Full Cone	35	180	23	17.0	Back Flow	
30F	Hollow Cone	180	0	27	14.4	Triangular Fins Added	0.577
30FN	Hollow Cone	180	0	27	14.4	Fins Added Center Nozzle Removed	****
40B	Slotted	N/A	0	26	14.4	Slats Added	0.963
40F	Slotted	N/A	0	26	14.4	Fins Added	0.545

3.1 Initial Tests

The results of the initial nine test runs are reported in the first section of Table 2. The operating pressure indicated in the table is that required to maintain the desired flow rate. The measured total flow rate for all nine nozzles is reported in column six of the table. It is not possible to operate either of the full cone nozzles choked without exceeding the maximum permissable flow rate of 1.6 SCFM per nozzle. Based on a comparison of the ratios of

Std/Mean, a ranking of the nozzle-orientation combinations is given in Table 3. The full-cone nozzles are eliminated from the ranking since they do not meet the flow rate restriction.

Table 3. Initial Comparative Rankings of Nozzles

Ranking (Best to Worst)	Nozzle-Orientation	Std/Mean	Range of Dev/Mean High	Low
1	Slotted - 0	0.724	1.86	-.55
2	Hollow Cone 180 - 0	0.770	1.91	-.59
3	Hollow Cone 150 -0	0.783	1.61	-.63
	Hollow Cone 120 - 0	0.783	1.74	-.60
4	Knife - 90	0.930	3.40	-.50
5	Knife - 60	1.440	8.91	-.47

Based on the rankings shown in Table 3, the focus of final testing was the slotted and hollow cone 180 nozzles. It should be noted however, that the variation between the results of the nozzle-orientations ranked 1 through 4 is statistically small and mixing characteristics may not vary significantly. The high and low values of Dev/Mean, shown in columns 4 and 5 of the table, are the extreme values and indicate the spread of the sampled concentrations about the mean. The grid plots and contour maps for the hollow cone 180 and slotted nozzles at 0 degrees orientation to the duct flow, shown in Figures 8 - 11, indicate that neither nozzle results in a completely homogeneous mixture of spray fluid and duct flow. In both cases, the concentrations of tracer gas are higher immediately downstream of the center nozzle than they are in the space between nozzles. Most importantly however, the results show that some spraying fluid reaches every sampling location on the face of the downstream catalyst panel.

RUN NO.= 40

-.551	-.528			-.419			-.495	-.504
-.539	-.487	-.443		-.481		-.487	-.480	-.505
	-.100	.767				-.304	-.452	
			1.412	.897	.235			
-.303	.215	1.788	1.859	1.138	.337	-.161	-.276	.080
			1.857	1.181	.400			
	.252	1.319				-.198	-.421	
-.519	-.466	-.377		-.445		-.463	-.494	-.402
-.517	-.506			-.464			-.484	-.465

Figure 10. Grid Plot of Deviation/Mean Concentration for Slotted Nozzle at 0^{o} Orientation

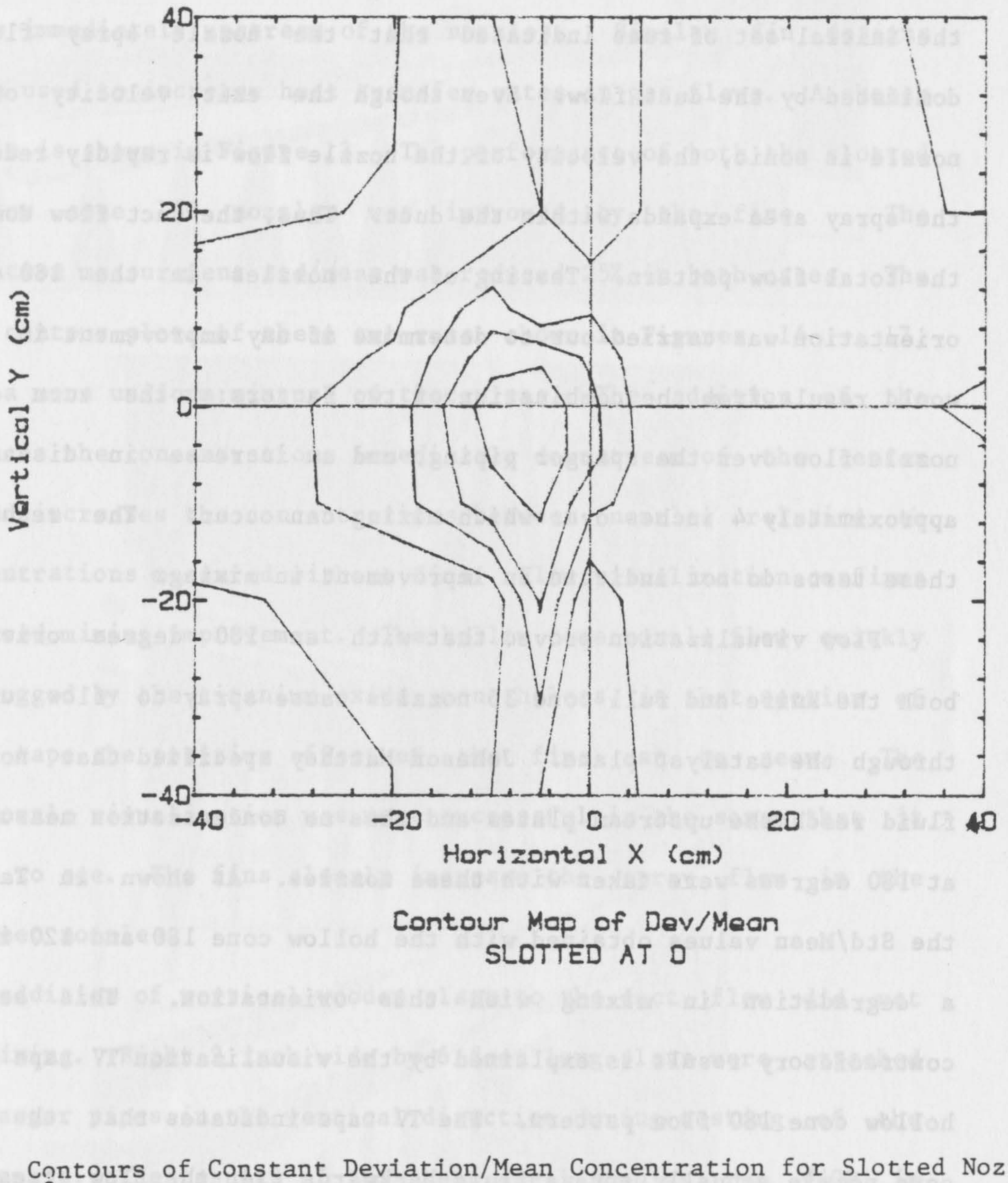


Figure 11. Contours of Constant Deviation/Mean Concentration for Slotted Nozzle at 0^{o} Orientation

3.2 Final Tests

During the nine final tests of the project, a nozzle orientation of 180 degrees was tested as well as the addition of flow altering devices to the sparger pipes. Flow visualization carried out during the initial set of runs indicated that the nozzle spray flow was dominated by the duct flow. Even though the exit velocity of each nozzle is sonic, the velocity of the nozzle flow is rapidly reduced as the spray area expands within the duct. Thus, the duct flow dominates the total flow pattern. Testing of the nozzles in the 180 degree orientation was carried out to determine if any improvement in mixing would result from the combination of two factors: the turn of the nozzle flow over the sparger piping, and an increase in distance of approximately 4 inches over which mixing can occur. The results of these tests do not indicate an improvement in mixing.

Flow visualization proved that with an 180 degree orientation both the knife and full cone 35 nozzles cause spray to flow upstream through the catalyst plate. Johnson Matthey specified that no spray fluid reach the upstream plates and thus no concentration measurements at 180 degrees were taken with these nozzles. As shown in Table 2, the Std/Mean values obtained with the hollow cone 180 and 120 indicate a degradation in mixing with this orientation. This seemingly contradictory result is explained by the visualization TV tape of the hollow cone 180 flow pattern. The TV tape indicates that the hollow cone nozzle actually sprays fluid backwards (ie. the flow stream moves back over the body of the nozzle). Thus the zero degree orientation is more favorable to increased mixing than the 180 degree orientation.

The runs presented in Table 2 designated by a number followed by the letter F are simulations in which triangular fins were added to the sparger pipes. Photographs of the fins on the pipes are shown in Figure 12. The fins are aluminum and were connected to the top and bottom of each sparger pipe. The fins were designed to increase mixing by introducing large scale vorticity and turbulence into the duct flow immediately upstream of the nozzles. Similar fin designs are often used to increase heat transfer rates in gas flows. A sketch of the fin is shown in Figure 13. The performance of both the slotted and hollow cone 180 nozzles was improved by the fins. The concentration measurement std/mean was reduced 25% in both cases. The grid and contour plots of these two runs, shown in Figures 14 - 17, indicate a more uniform mixture of tracer gas. The addition of the fins reduces the concentrations immediately downstream of the center nozzle and increases the concentrations between nozzles relative to the concentrations measured without fins. Flow visualization confirms the measured mixing improvement. The hollow cone nozzle flow quickly became plugged by the titanium oxide; nonetheless, in that section of the video tape the positive effect of the fins can be seen. The slotted nozzle visualization was more successful in the sense that it is easier to see. The fins clearly increase the spray flow in the area between nozzles.

The addition of vertical wooden slats to the duct flow did not improve mixing. Eight 2 inch wide by 6 feet long slats were attached to the sparger pipes in the vertical direction during testing of the slotted nozzle. The results of this test are listed as run #40B in Table 2.

As a worst case test of the sparger system, one simulation was

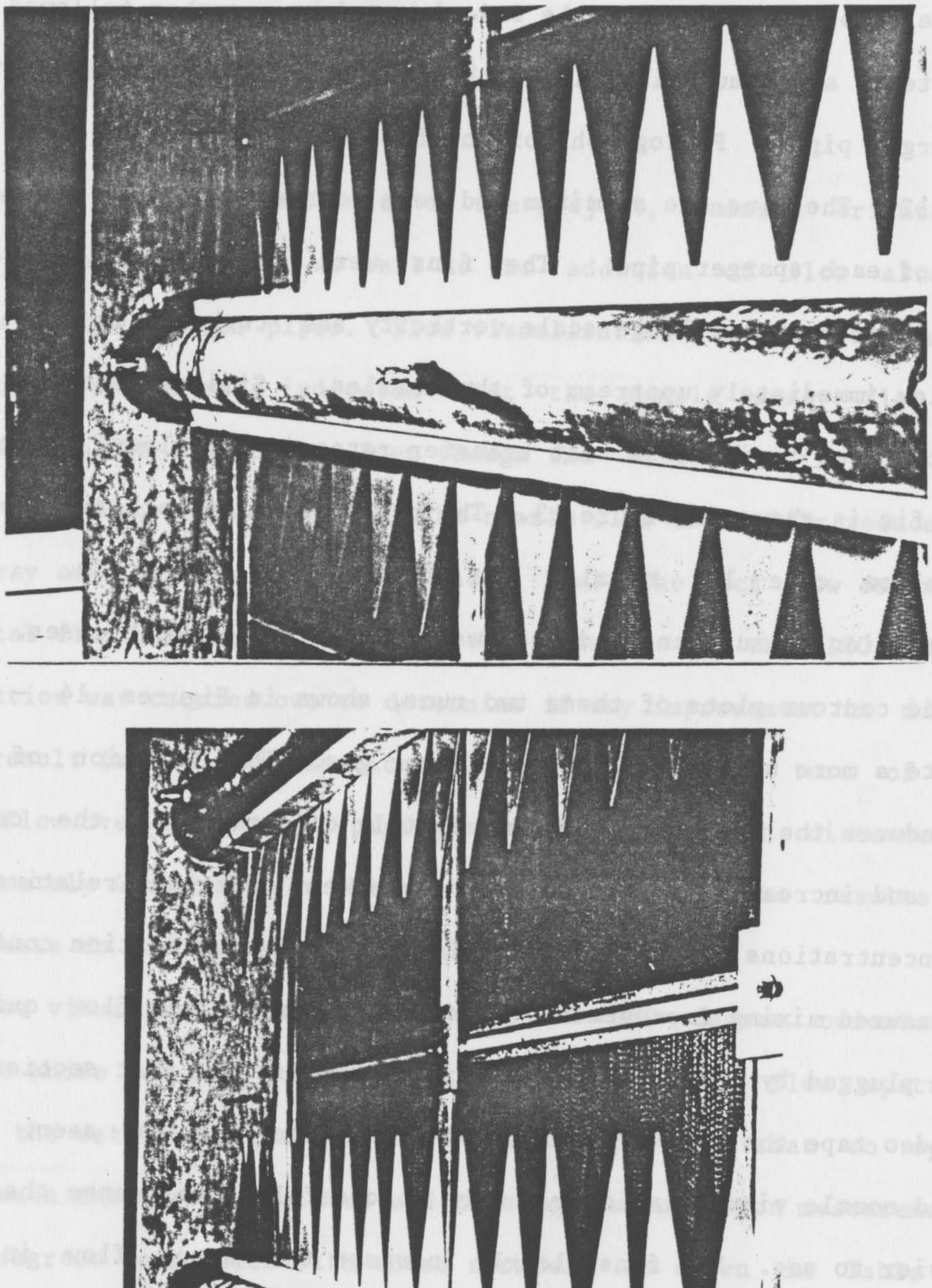


Figure 12. Photographs of Triangular Fins on Sparger Pipes

Figure 13. Triangular Fin

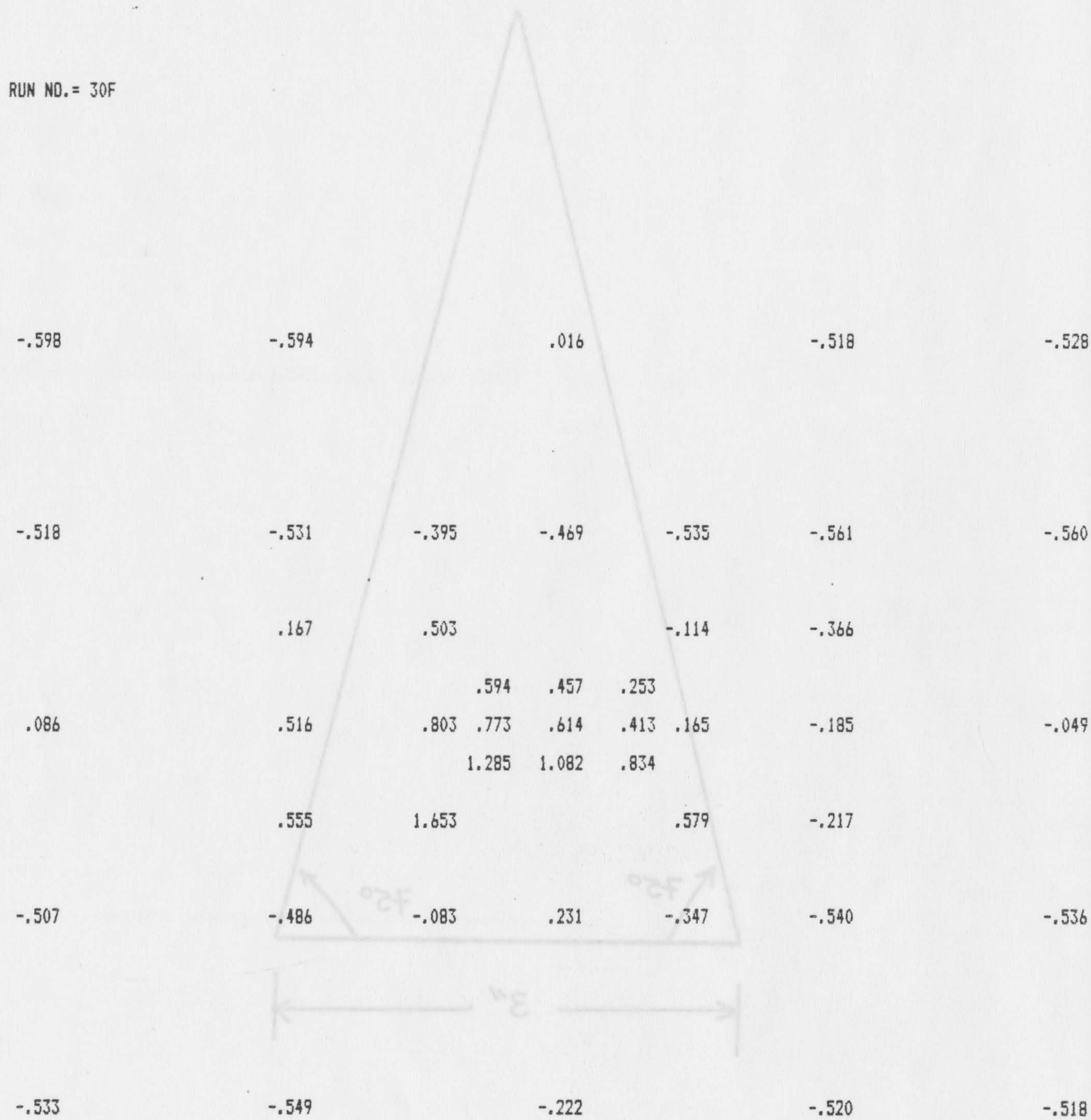


Figure 14. Grid Plot of Deviation/Mean Concentration for Hollow Cone 180° Nozzle at 0° Orientation with Fins

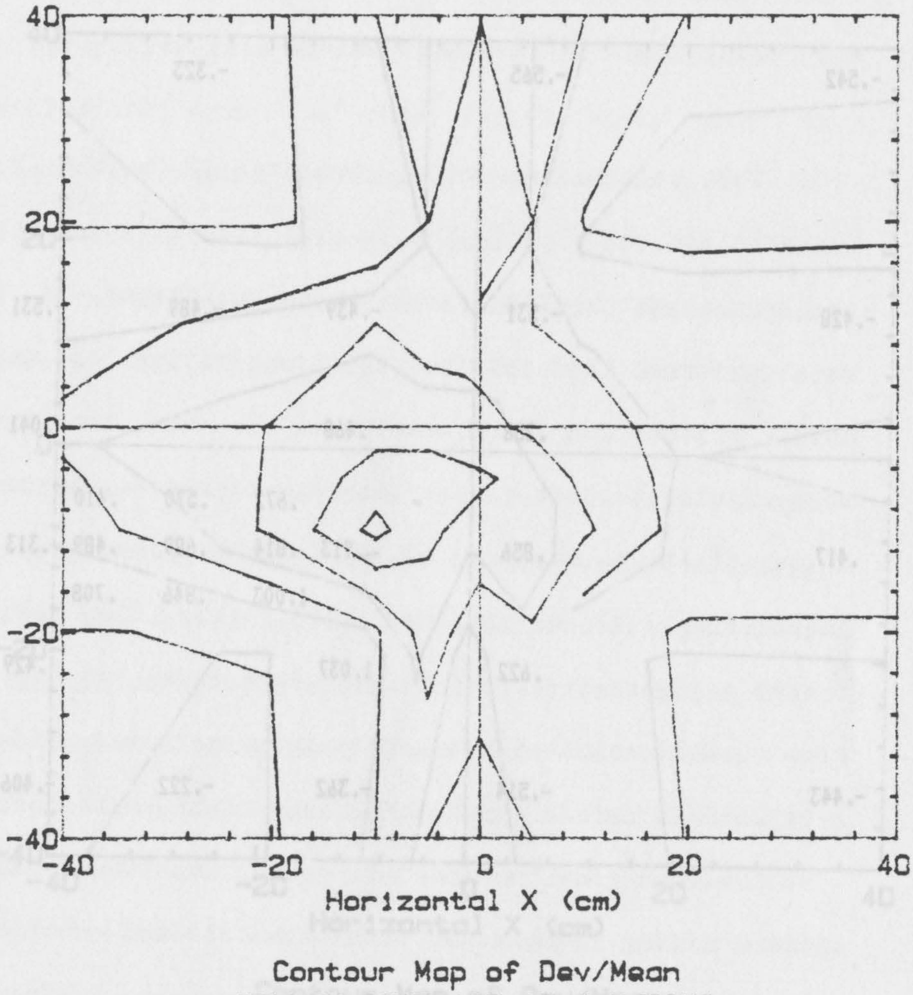


Figure 15. Contours of Constant Deviation/Mean Concentration for Hollow Cone 180° Nozzle at 0° Orientation with Fins

RUN NO.= 40F

-.542	-.565			-.323			-.463	-.483
-.428	-.531	-.439		-.489		-.531	-.571	-.551
	.258	.468				.041	-.259	
			.672	.570	.410			
.417	.856	.913	.814	.689	.489	.313	-.014	.141
			1.003	.846	.708			
	.622	1.037				.429	-.081	
-.443	-.514	-.362		-.222		-.406	-.537	-.514
-.486	-.562			-.346			-.520	-.514

Figure 16. Grid Plot of Deviation/Mean Concentration for Slotted Nozzle at 0° Orientation with Fins

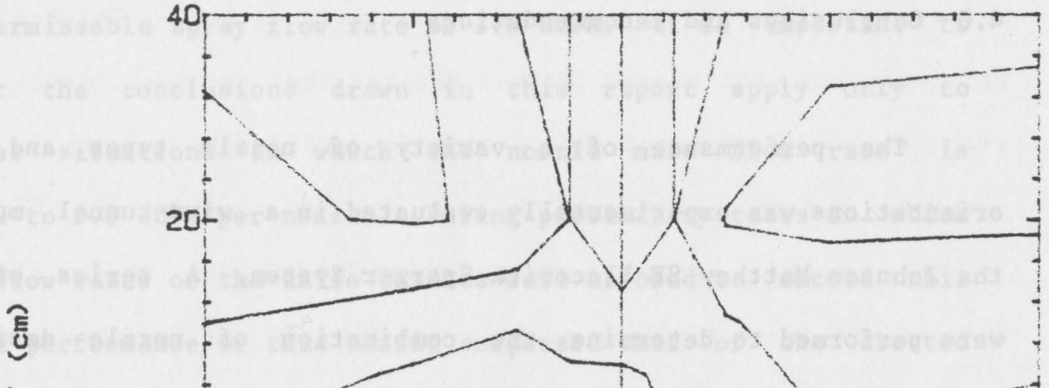


Figure 17. Contours of Constant Deviation/Mean for Slotted Nozzle at 0^{o} Orientation with Fins

carried out in which the center nozzle was removed. This test is an indication of the mixing characteristics of the system in the event of a nozzle failure. The statistical analysis of this test is misleading and thus the actual numerical results are not reported in Table 2. The loss of a nozzle resulted in virtually no spraying fluid downstream of that nozzle.

4.0 Conclusions and Recommendations

The performance of a variety of nozzle types and nozzle orientations was experimentally evaluated in a wind-tunnel model of the Johnson Matthey SE Placerita Sparger System. A series of tests were performed to determine the combination of nozzle design and nozzle orientation which results in the most homogeneous mixture of spray fluid and duct gas at the face of the downstream catalyst panel. A quantitative measure of mixing performance was obtained by introducing a tracer gas into the nozzle flow and then measuring tracer gas concentrations 2 feet downstream of the sparger pipes. Flow visualization of the nozzle spray patterns aided in the final selection of nozzle types and orientations to be tested.

The test results indicate that, of the combinations tested, optimum mixing is obtained with the slotted nozzle oriented at 0 degrees to the duct flow. However, the differences in mixing efficiencies of the slotted nozzle and the hollow cone nozzles oriented at 0 degrees to the main flow is within the experimental margin of error. It is recommended that one of these nozzles oriented at 0 degrees be selected for the final sparger design. All other nozzle types and orientations should be excluded from consideration.

The final selection criteria should be based on cost and operational reliability rather than on the small numerical differences of tracer gas concentration measured in the model tests.

The knife and full cone nozzles exhibited substantial degradation in mixing performance in comparison to the slotted and hollow cone nozzles. In addition, at pressures sufficiently high to choke the nozzle, the flow rate of the full cone nozzle is higher than the maximum permissable spray flow rate of 1.6 SCFM. It is important to note that the conclusions drawn in this report apply only to operational situations in which the nozzle mass flow rate is restricted to 1.6 SCFM per nozzle. During preliminary tests in which the mass flow rates of the knife nozzles were allowed to exceed this value, the performance of this nozzle surpassed that of the slotted nozzle.

The mixing characteristics of the "best" nozzles (ie. the slotted and hollow cone 180 oriented at 0 degrees) can be improved by altering the flow pattern within the duct itself. The addition of six rows (one along the top and bottom of each sparger pipe) of triangular fins or spikes to the flow improved the mixing 25 percent. The effect of the fins on the flow pattern within the duct is shown in the video taped flow visualizations. The fins appear to bend and spread the nozzle spray away from the immediate area of the nozzle itself and also to create circulatory motions in the flow. It is difficult to predict if the inclusion of similar fins in an actual sparger system would result in the same magnitude of improvement. The wind tunnel flow has a low turbulence level uniform flow. The addition of the fins to this flow increases turbulence diffusivities and thus mixing rates. The exhaust duct flow of a gas turbine is likely to be highly turbulent and contain large nonuniformities in the flow pattern. Thus the mixing characteristics of such a flow may not be changed as substantially by the addition of vortex generating devices such as the triangular fins. Additional testing with the wind tunnel flow altered by turbulence generating devices could be performed to determine the benefits of the fins under more realistic conditions.

The tests performed during this project were designed to help select the "best" nozzle type and orientation. Colorado State University can not assure Johnson Matthey that the performance of the recommended combination will provide sufficient mixing for the catalytic process. However, the test data do provide some information in this regard. First, during testing, nozzle spray fluid was detected at every sampling port on the face of the downstream catalyst panel. The lowest measured concentration for both the slotted and hollow cone 180 nozzles is approximately 60% less than the mean concentration. Second, the tests indicate where the problem areas are located along the catalyst face. The highest concentration levels are immediately downstream of each nozzle in an area approximately 10 inches in diameter. The spraying fluid concentration decreases with increasing radial distance from the nozzle until the spraying pattern of the adjacent nozzles is seen. The nozzles are located nominally every 2 feet. Thus high concentration levels account for nearly 55% of the total catalyst cross sectional area. These high concentrations are approximately 2 times that of the mean concentration. The failure of a nozzle creates large areas of low concentration.

The tests performed were designed to predict actual sparger operation. The low turbulence level and uniformity of the wind tunnel flow should result in a conservative estimate of mixing in an actual exhaust duct.

APPENDIX

Complete Set of Test Results

Appendix

The appendix to this report contains the data of the test runs listed in Table 2. The results of each test run are presented in three parts. The first data sheet lists the run number and test description, the standard deviation/mean, and the measured concentrations, the deviation/mean, and the deviation/standard deviation at each sampling port. The second and third data sheets are a grid map of the deviation/mean and a plot of contours of constant values of deviation/mean, respectively.

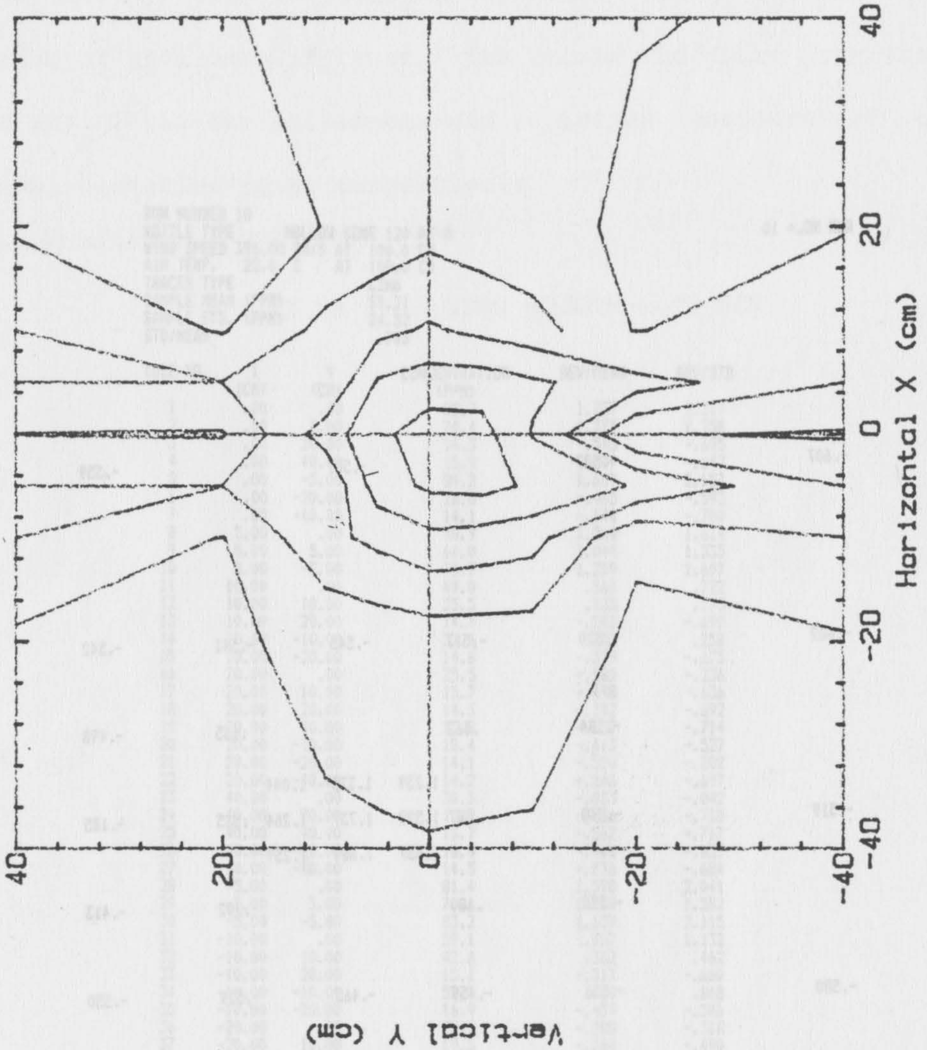
RUN 10 - HOLLOW CONE 120^{o} AT 0^{o}

RUN NUMBER 10
NOZZLE TYPE HOLLOW CONE 120 AT 0
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 31.31
SAMPLE STD. (PPM) 24.52
STD/MEAN .783

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	85.7	1.737	2.217
2	.00	5.00	74.4	1.375	1.756
3	.00	20.00	14.3	-.545	-.695
4	.00	40.00	15.4	-.507	-.647
5	.00	-5.00	84.2	1.689	2.157
6	.00	-20.00	16.8	-.465	-.593
7	.00	-40.00	14.1	-.548	-.700
8	5.00	.00	70.9	1.264	1.614
9	5.00	5.00	64.0	1.044	1.333
10	5.00	-5.00	70.7	1.259	1.607
11	10.00	.00	49.0	.565	.722
12	10.00	10.00	35.5	.135	.173
13	10.00	20.00	14.4	-.541	-.691
14	10.00	-10.00	37.6	.202	.258
15	10.00	-20.00	14.8	-.529	-.675
16	20.00	.00	25.5	-.185	-.236
17	20.00	10.00	15.7	-.498	-.636
18	20.00	20.00	14.3	-.542	-.692
19	20.00	40.00	13.8	-.559	-.714
20	20.00	-10.00	18.4	-.413	-.527
21	20.00	-20.00	14.1	-.550	-.702
22	20.00	-40.00	14.2	-.546	-.697
23	40.00	.00	30.3	-.033	-.042
24	40.00	20.00	13.9	-.556	-.710
25	40.00	40.00	13.7	-.562	-.717
26	40.00	-20.00	16.0	-.488	-.623
27	40.00	-40.00	14.5	-.536	-.684
28	-5.00	.00	81.4	1.598	2.041
29	-5.00	5.00	70.1	1.239	1.582
30	-5.00	-5.00	83.2	1.657	2.115
31	-10.00	.00	59.1	.887	1.132
32	-10.00	10.00	42.6	.362	.462
33	-10.00	20.00	15.1	-.517	-.660
34	-10.00	-10.00	52.6	.680	.868
35	-10.00	-20.00	16.9	-.459	-.586
36	-20.00	.00	22.3	-.288	-.368
37	-20.00	10.00	19.3	-.384	-.490
38	-20.00	20.00	13.5	-.570	-.728
39	-20.00	40.00	12.9	-.587	-.749
40	-20.00	-10.00	22.3	-.288	-.368
41	-20.00	-20.00	13.9	-.556	-.710
42	-20.00	-40.00	13.8	-.559	-.713
43	-40.00	.00	15.1	-.519	-.663
44	-40.00	20.00	12.5	-.602	-.769
45	-40.00	40.00	12.3	-.607	-.775
46	-40.00	-20.00	13.2	-.580	-.740
47	-40.00	-40.00	13.2	-.578	-.737

RUN NO.= 10

-.607	-.587			-.507			-.559	-.562
-.602	-.570	-.517		-.545		-.541	-.542	-.556
	-.384	.362				.135	-.498	
			1.239	1.375	1.044			
-.519	-.288	.887	1.598	1.737	1.264	.565	-.185	-.033
			1.657	1.689	1.259			
	-.288	.680				.202	-.413	
-.580	-.556	-.459		-.465		-.529	-.550	-.488
-.578	-.559			-.548			-.546	-.536



Contour Map of Dev/Mean
HOLLOW CONE 120 AT 0

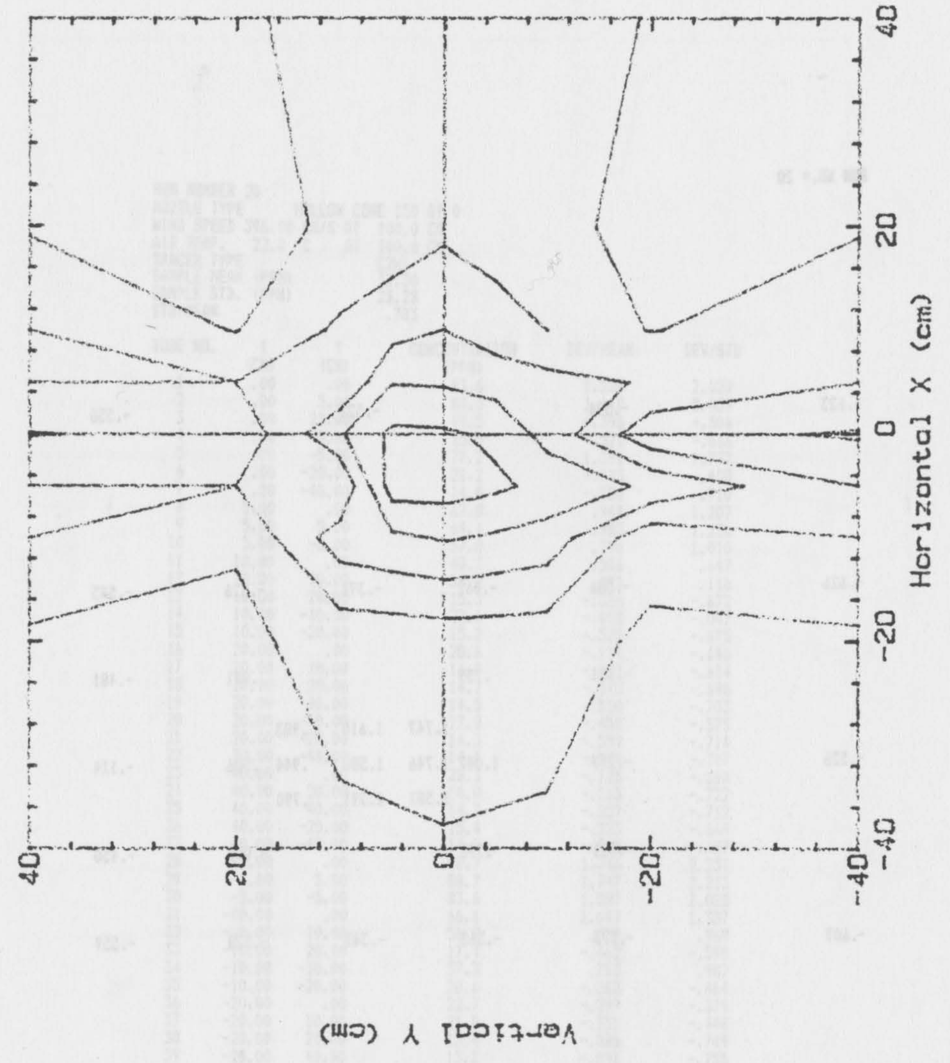
RUN 20 - HOLLOW CONE 150° AT 0°

RUN NUMBER 20
NOZZLE TYPE HOLLOW CONE 150 AT 0
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 32.30
SAMPLE STD. (PPM) 25.28
STD/MEAN .783

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	83.6	1.588	2.028
2	.00	5.00	84.3	1.610	2.057
3	.00	20.00	19.5	-.396	-.506
4	.00	40.00	15.5	-.521	-.666
5	.00	-5.00	77.2	1.391	1.777
6	.00	-20.00	21.2	-.343	-.438
7	.00	-40.00	14.4	-.556	-.710
8	5.00	.00	62.8	.944	1.207
9	5.00	5.00	64.1	.983	1.256
10	5.00	-5.00	57.8	.790	1.010
11	10.00	.00	48.7	.506	.647
12	10.00	10.00	35.2	.091	.116
13	10.00	20.00	15.3	-.526	-.672
14	10.00	-10.00	32.1	-.005	-.007
15	10.00	-20.00	15.2	-.528	-.675
16	20.00	.00	28.6	-.114	-.146
17	20.00	10.00	16.8	-.481	-.614
18	20.00	20.00	14.7	-.545	-.696
19	20.00	40.00	14.5	-.550	-.703
20	20.00	-10.00	17.8	-.450	-.575
21	20.00	-20.00	14.3	-.559	-.714
22	20.00	-40.00	14.4	-.554	-.707
23	40.00	.00	28.3	-.125	-.160
24	40.00	20.00	14.0	-.565	-.722
25	40.00	40.00	14.3	-.557	-.712
26	40.00	-20.00	15.4	-.523	-.669
27	40.00	-40.00	14.7	-.545	-.697
28	-5.00	.00	88.7	1.746	2.231
29	-5.00	5.00	88.7	1.747	2.233
30	-5.00	-5.00	83.6	1.587	2.028
31	-10.00	.00	66.1	1.047	1.337
32	-10.00	10.00	56.8	.759	.969
33	-10.00	20.00	17.4	-.462	-.590
34	-10.00	-10.00	57.3	.773	.987
35	-10.00	-20.00	20.6	-.363	-.464
36	-20.00	.00	22.7	-.297	-.379
37	-20.00	10.00	21.0	-.351	-.448
38	-20.00	20.00	13.4	-.586	-.749
39	-20.00	40.00	13.2	-.591	-.755
40	-20.00	-10.00	21.9	-.321	-.410
41	-20.00	-20.00	13.8	-.573	-.732
42	-20.00	-40.00	13.2	-.592	-.756
43	-40.00	.00	15.3	-.526	-.672
44	-40.00	20.00	12.1	-.626	-.799
45	-40.00	40.00	12.2	-.623	-.796
46	-40.00	-20.00	12.6	-.609	-.778
47	-40.00	-40.00	12.9	-.600	-.767

RUN NO.= 20

-.623	-.591			-.521			-.550	-.557
-.626	-.586	-.462		-.396		-.526	-.545	-.565
	-.351	.759				.091	-.481	
			1.747	1.610	.983			
-.526	-.297	1.047	1.746	1.588	.944	.506	-.114	-.125
			1.587	1.391	.790			
	-.321	.773				-.005	-.450	
-.609	-.573	-.363		-.343		-.528	-.559	-.523
-.600	-.592			-.556			-.554	-.545



Contour Map of Dev/Mean
HOLLOW CONE 150 AT 0

RUN 30 - HOLLOW CONE 180° AT 0°

RUN NUMBER 30
NOZZLE TYPE HOLLOW CONE 180 AT 0
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 31.52
SAMPLE STD. (PPM) 24.29
STD/MEAN .770

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	84.6	1.684	2.186
2	.00	5.00	71.5	1.269	1.647
3	.00	20.00	18.7	-.408	-.530
4	.00	40.00	22.7	-.280	-.364
5	.00	-5.00	91.7	1.909	2.478
6	.00	-20.00	18.6	-.409	-.531
7	.00	-40.00	16.6	-.474	-.615
8	5.00	.00	58.5	.856	1.110
9	5.00	5.00	51.2	.625	.811
10	5.00	-5.00	64.9	1.059	1.375
11	10.00	.00	35.7	.133	.172
12	10.00	10.00	25.7	-.185	-.240
13	10.00	20.00	15.1	-.521	-.677
14	10.00	-10.00	35.1	.114	.148
15	10.00	-20.00	17.0	-.461	-.598
16	20.00	.00	20.8	-.340	-.442
17	20.00	10.00	15.8	-.500	-.649
18	20.00	20.00	15.0	-.524	-.680
19	20.00	40.00	14.7	-.532	-.691
20	20.00	-10.00	16.5	-.476	-.618
21	20.00	-20.00	14.6	-.536	-.696
22	20.00	-40.00	14.7	-.535	-.695
23	40.00	.00	21.8	-.309	-.401
24	40.00	20.00	14.2	-.551	-.715
25	40.00	40.00	14.2	-.549	-.712
26	40.00	-20.00	15.3	-.515	-.669
27	40.00	-40.00	15.2	-.518	-.672
28	-5.00	.00	86.2	1.733	2.249
29	-5.00	5.00	73.1	1.318	1.711
30	-5.00	-5.00	91.4	1.900	2.466
31	-10.00	.00	63.4	1.012	1.314
32	-10.00	10.00	48.2	.528	.686
33	-10.00	20.00	18.9	-.400	-.520
34	-10.00	-10.00	56.9	.804	1.044
35	-10.00	-20.00	22.5	-.286	-.372
36	-20.00	.00	25.5	-.191	-.248
37	-20.00	10.00	22.6	-.282	-.366
38	-20.00	20.00	14.5	-.541	-.702
39	-20.00	40.00	13.7	-.564	-.732
40	-20.00	-10.00	23.4	-.258	-.335
41	-20.00	-20.00	15.5	-.507	-.658
42	-20.00	-40.00	14.0	-.555	-.720
43	-40.00	.00	18.3	-.418	-.543
44	-40.00	20.00	12.9	-.592	-.768
45	-40.00	40.00	12.8	-.593	-.769
46	-40.00	-20.00	13.5	-.571	-.741
47	-40.00	-40.00	13.8	-.562	-.729

Figure 7. Gas Chromatograph data obtained for Hollow Cone 180° nozzle at 0° orientation

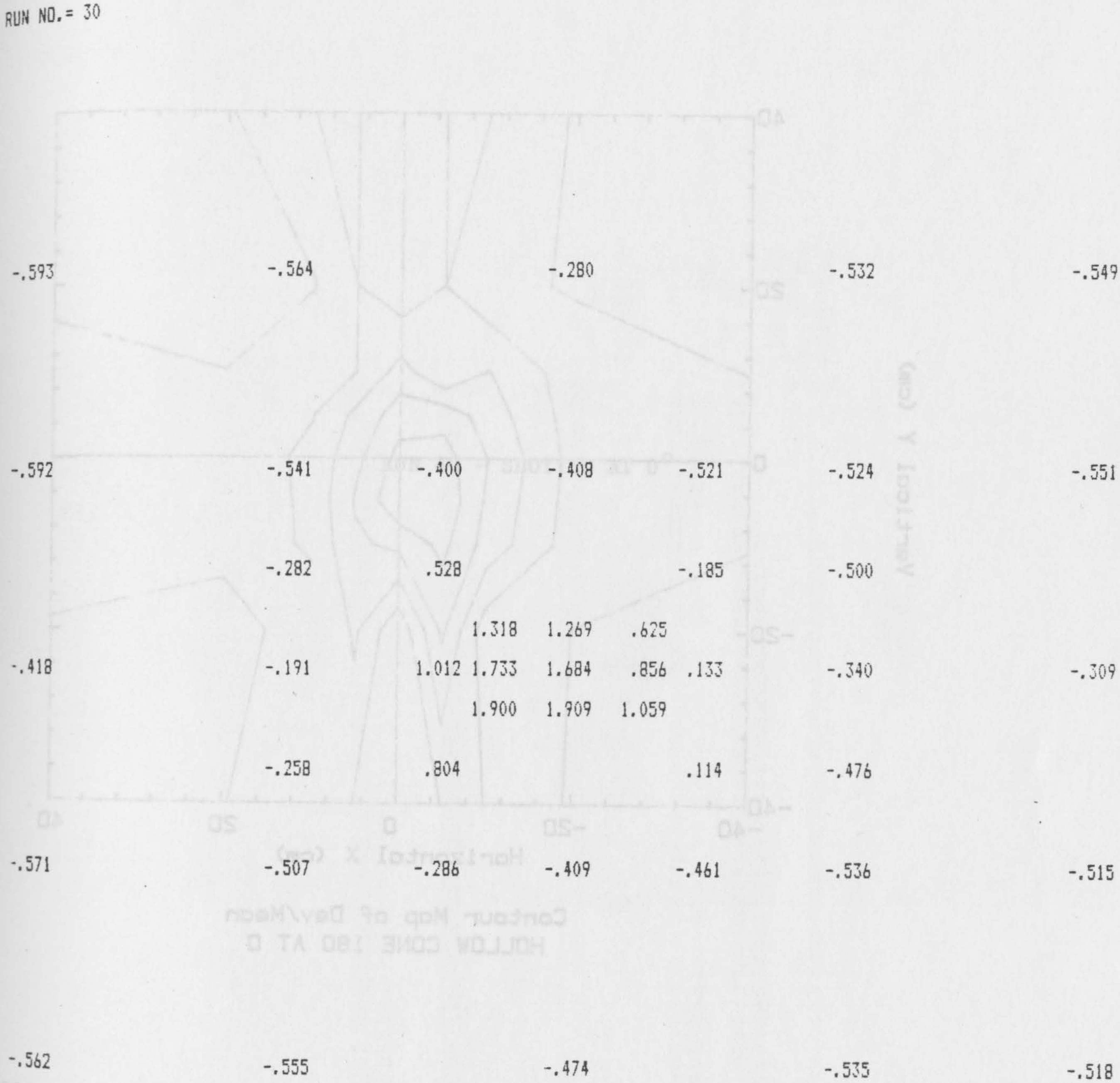


Figure 8. Grid Plot of Deviation/Mean Concentration for Hollow Cone 180^{o} Nozzle at 0^{o} Orientation

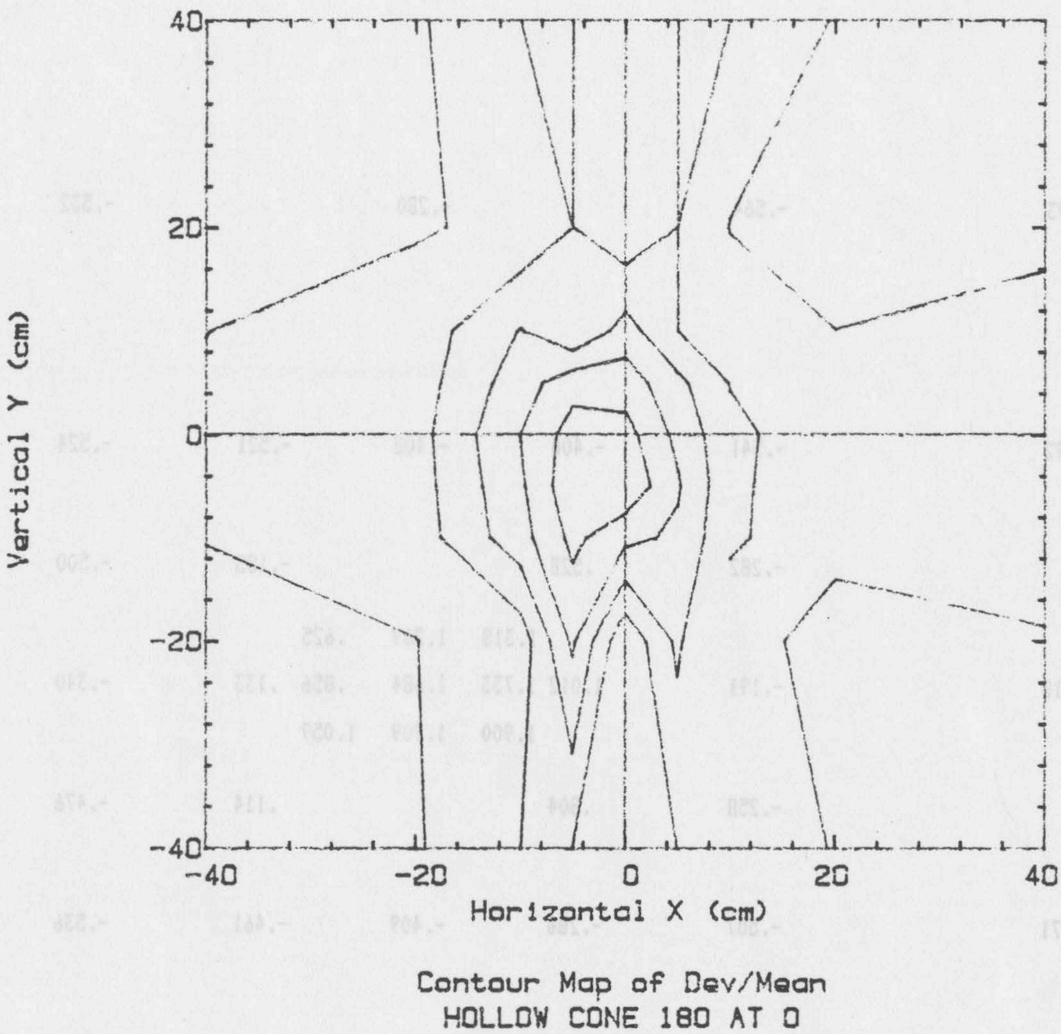


Figure 9. Contours of Constant Deviation/Mean Concentration for Hollow Cone 180° Nozzle at 0° Orientation.

RUN 40 - SLOTTED AT 0^{o}

RUN NUMBER 40
NOZZLE TYPE SLOTTED AT 0
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 28.96
SAMPLE STD. (PPM) 20.97
STD/MEAN .724

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	61.9	1.138	1.571
2	.00	5.00	54.9	.897	1.239
3	.00	20.00	15.0	-.481	-.664
4	.00	40.00	16.8	-.419	-.579
5	.00	-5.00	63.2	1.181	1.630
6	.00	-20.00	16.1	-.445	-.615
7	.00	-40.00	15.5	-.464	-.641
8	5.00	.00	38.7	.337	.466
9	5.00	5.00	35.8	.235	.324
10	5.00	-5.00	40.5	.400	.552
11	10.00	.00	24.3	-.161	-.222
12	10.00	10.00	20.2	-.304	-.420
13	10.00	20.00	14.9	-.487	-.672
14	10.00	-10.00	23.2	-.198	-.273
15	10.00	-20.00	15.6	-.463	-.639
16	20.00	.00	21.0	-.276	-.381
17	20.00	10.00	15.9	-.452	-.625
18	20.00	20.00	15.1	-.480	-.662
19	20.00	40.00	14.6	-.495	-.684
20	20.00	-10.00	16.8	-.421	-.582
21	20.00	-20.00	14.6	-.494	-.683
22	20.00	-40.00	15.0	-.484	-.668
23	40.00	.00	31.3	.080	.110
24	40.00	20.00	14.3	-.505	-.698
25	40.00	40.00	14.4	-.504	-.695
26	40.00	-20.00	17.3	-.402	-.556
27	40.00	-40.00	15.5	-.465	-.642
28	-5.00	.00	82.8	1.859	2.567
29	-5.00	5.00	69.8	1.412	1.949
30	-5.00	-5.00	82.7	1.857	2.564
31	-10.00	.00	80.7	1.788	2.469
32	-10.00	10.00	51.2	.767	1.059
33	-10.00	20.00	16.1	-.443	-.611
34	-10.00	-10.00	67.2	1.319	1.822
35	-10.00	-20.00	18.1	-.377	-.520
36	-20.00	.00	35.2	.215	.297
37	-20.00	10.00	26.1	-.100	-.138
38	-20.00	20.00	14.9	-.487	-.672
39	-20.00	40.00	13.7	-.528	-.730
40	-20.00	-10.00	36.3	.252	.348
41	-20.00	-20.00	15.5	-.466	-.644
42	-20.00	-40.00	14.3	-.506	-.698
43	-40.00	.00	20.2	-.303	-.419
44	-40.00	20.00	13.3	-.539	-.744
45	-40.00	40.00	13.0	-.551	-.761
46	-40.00	-20.00	13.9	-.519	-.716
47	-40.00	-40.00	14.0	-.517	-.714

RUN NO.= 40

-.551	-.528			-.419			-.495	-.504
-.539	-.487	-.443		-.481		-.487	-.480	-.505
	-.100	.767				-.304	-.452	
			1.412	.897	.235			
-.303	.215	1.788	1.859	1.138	.337	-.161	-.276	.080
			1.857	1.181	.400			
	.252	1.319				-.198	-.421	
-.519	-.466	-.377		-.445		-.463	-.494	-.402
-.517	-.506			-.464			-.484	-.465

Figure 10. Grid Plot of Deviation/Mean Concentration for Slotted Nozzle at 0° Orientation

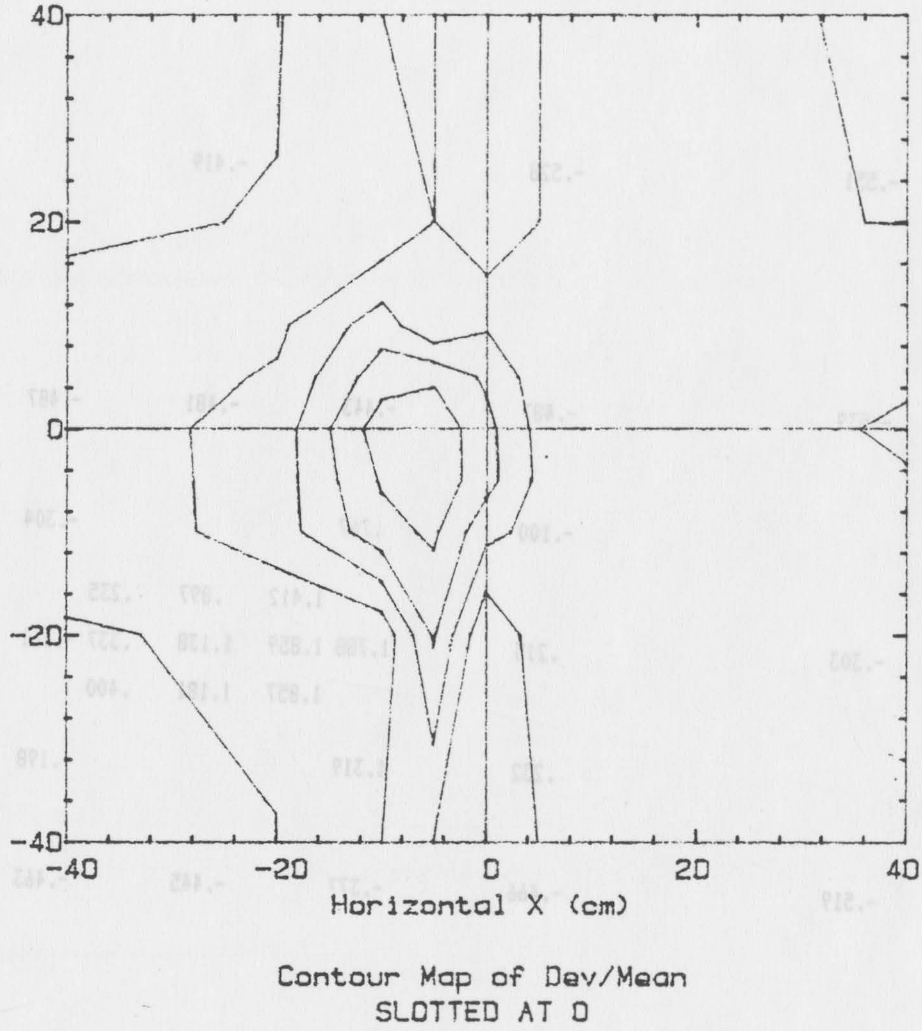


Figure 11. Contours of Constant Deviation/Mean Concentration for Slotted Nozzle at 0^{o} Orientation

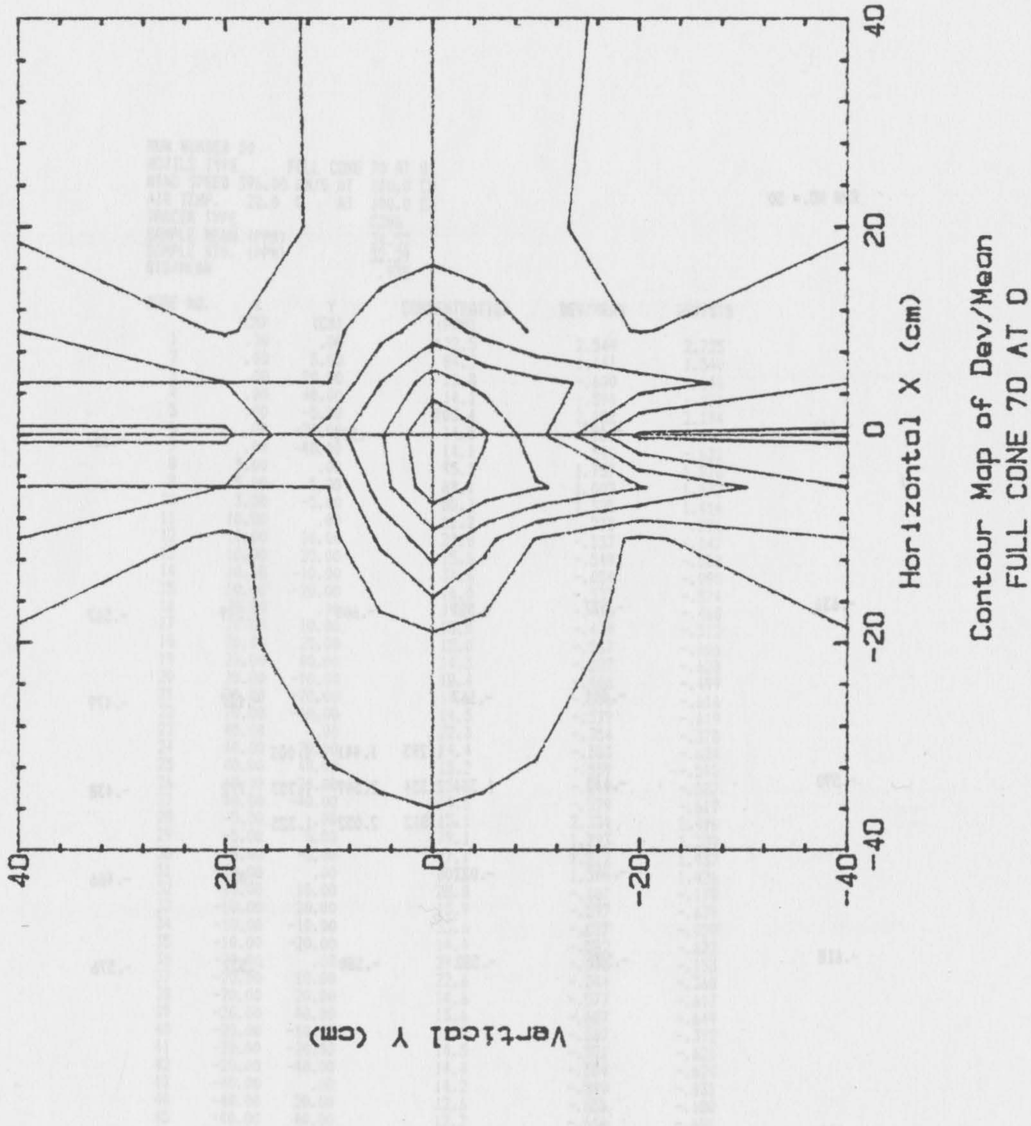
RUN 50 - FULL CONE 70° AT 0°

RUN NUMBER 50
NOZZLE TYPE FULL CONE 70 AT 0
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 34.52
SAMPLE STD. (PPM) 32.29
STD/MEAN .935

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	122.5	2.549	2.725
2	.00	5.00	84.3	1.441	1.540
3	.00	20.00	13.8	-.600	-.641
4	.00	40.00	14.1	-.590	-.631
5	.00	-5.00	105.4	2.052	2.194
6	.00	-20.00	14.5	-.580	-.620
7	.00	-40.00	14.1	-.591	-.632
8	5.00	.00	95.2	1.757	1.878
9	5.00	5.00	69.1	1.003	1.072
10	5.00	-5.00	80.2	1.325	1.416
11	10.00	.00	61.2	.772	.826
12	10.00	10.00	29.8	-.137	-.147
13	10.00	20.00	15.6	-.549	-.588
14	10.00	-10.00	31.6	-.084	-.090
15	10.00	-20.00	16.0	-.537	-.574
16	20.00	.00	19.4	-.438	-.468
17	20.00	10.00	18.0	-.479	-.512
18	20.00	20.00	15.0	-.567	-.606
19	20.00	40.00	14.3	-.587	-.628
20	20.00	-10.00	18.4	-.466	-.499
21	20.00	-20.00	14.6	-.576	-.616
22	20.00	-40.00	14.5	-.579	-.619
23	40.00	.00	22.3	-.354	-.378
24	40.00	20.00	14.4	-.583	-.624
25	40.00	40.00	15.2	-.559	-.598
26	40.00	-20.00	15.6	-.549	-.587
27	40.00	-40.00	14.5	-.579	-.619
28	-5.00	.00	115.1	2.334	2.496
29	-5.00	5.00	79.1	1.293	1.382
30	-5.00	-5.00	97.1	1.812	1.937
31	-10.00	.00	80.6	1.334	1.426
32	-10.00	10.00	28.8	-.167	-.178
33	-10.00	20.00	13.9	-.597	-.639
34	-10.00	-10.00	33.6	-.027	-.029
35	-10.00	-20.00	14.4	-.582	-.622
36	-20.00	.00	29.6	-.143	-.153
37	-20.00	10.00	22.6	-.344	-.368
38	-20.00	20.00	14.6	-.577	-.617
39	-20.00	40.00	13.6	-.607	-.649
40	-20.00	-10.00	21.9	-.367	-.392
41	-20.00	-20.00	14.5	-.581	-.621
42	-20.00	-40.00	14.4	-.584	-.624
43	-40.00	.00	14.2	-.590	-.631
44	-40.00	20.00	12.6	-.636	-.680
45	-40.00	40.00	12.2	-.646	-.691
46	-40.00	-20.00	13.2	-.618	-.661
47	-40.00	-40.00	13.2	-.619	-.662

RUN NO.= 50

-.646	-.607			-.590			-.587	-.559
-.636	-.577	-.597		-.600		-.549	-.567	-.583
	-.344	-.167				-.137	-.479	
			1.293	1.441	1.003			
-.590	-.143	1.334	2.334	2.549	1.757	.772	-.438	-.354
			1.812	2.052	1.325			
	-.367	-.027				-.084	-.466	
-.618	-.581	-.582		-.580		-.537	-.576	-.549
-.619	-.584			-.591			-.579	-.579


Horizontal X (cm)
Vertical Y (cm)
40
20
0
-20
-40
Contour Map of Dev/Mean
FULL CONE 7D AT D

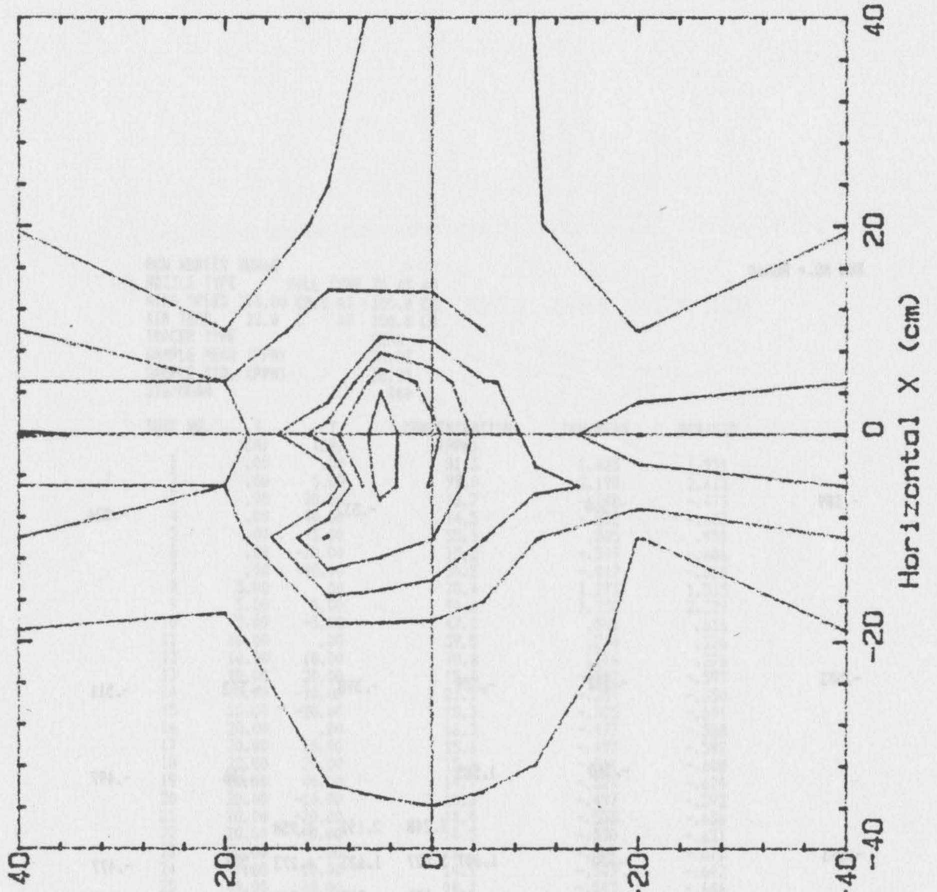
RUN 60 - FULL CONE 70° AT 60°

RUN NUMBER RUN60
NOZZLE TYPE FULL CONE 70 AT 60
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 30.97
SAMPLE STD. (PPM) 26.03
STD/MEAN .840

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	81.3	1.623	1.931
2	.00	5.00	99.0	2.198	2.615
3	.00	20.00	18.7	-.398	-.473
4	.00	40.00	14.5	-.532	-.633
5	.00	-5.00	55.9	.805	.958
6	.00	-20.00	15.2	-.509	-.606
7	.00	-40.00	30.5	-.017	-.020
8	5.00	.00	70.4	1.273	1.515
9	5.00	5.00	91.6	1.958	2.329
10	5.00	-5.00	47.0	.518	.616
11	10.00	.00	39.5	.274	.326
12	10.00	10.00	40.8	.316	.376
13	10.00	20.00	15.4	-.502	-.597
14	10.00	-10.00	21.9	-.294	-.350
15	10.00	-20.00	15.3	-.505	-.601
16	20.00	.00	16.2	-.477	-.568
17	20.00	10.00	15.6	-.497	-.592
18	20.00	20.00	15.1	-.511	-.608
19	20.00	40.00	14.7	-.524	-.624
20	20.00	-10.00	15.6	-.497	-.592
21	20.00	-20.00	14.4	-.535	-.636
22	20.00	-40.00	14.5	-.530	-.631
23	40.00	.00	16.1	-.479	-.570
24	40.00	20.00	14.1	-.543	-.647
25	40.00	40.00	14.2	-.543	-.646
26	40.00	-20.00	14.8	-.522	-.621
27	40.00	-40.00	14.6	-.528	-.628
28	-5.00	.00	75.2	1.427	1.698
29	-5.00	5.00	100.6	2.248	2.675
30	-5.00	-5.00	52.0	.680	.809
31	-10.00	.00	62.2	1.007	1.198
32	-10.00	10.00	80.1	1.585	1.885
33	-10.00	20.00	18.9	-.389	-.462
34	-10.00	-10.00	31.3	.012	.014
35	-10.00	-20.00	15.2	-.509	-.606
36	-20.00	.00	22.9	-.261	-.311
37	-20.00	10.00	20.4	-.340	-.404
38	-20.00	20.00	14.2	-.542	-.645
39	-20.00	40.00	13.6	-.560	-.667
40	-20.00	-10.00	18.5	-.402	-.479
41	-20.00	-20.00	14.2	-.540	-.643
42	-20.00	-40.00	13.6	-.560	-.667
43	-40.00	.00	13.5	-.563	-.669
44	-40.00	20.00	12.9	-.583	-.694
45	-40.00	40.00	12.7	-.589	-.700
46	-40.00	-20.00	13.3	-.571	-.679
47	-40.00	-40.00	13.3	-.570	-.678

RUN NO.= RUN60

-.589	-.560			-.532			-.524	-.543
-.583	-.542	-.389		-.398		-.502	-.511	-.543
	-.340	1.585				.316	-.497	
			2.248	2.198	1.958			
-.563	-.261	1.007	1.427	1.623	1.273	.274	-.477	-.479
			.680	.805	.518			
	-.402	.012				-.294	-.497	
-.571	-.540	-.509		-.509		-.505	-.535	-.522
-.570	-.560			-.017			-.530	-.528



Contour Map of Dev/Mean
FULL CONE 70 AT 60

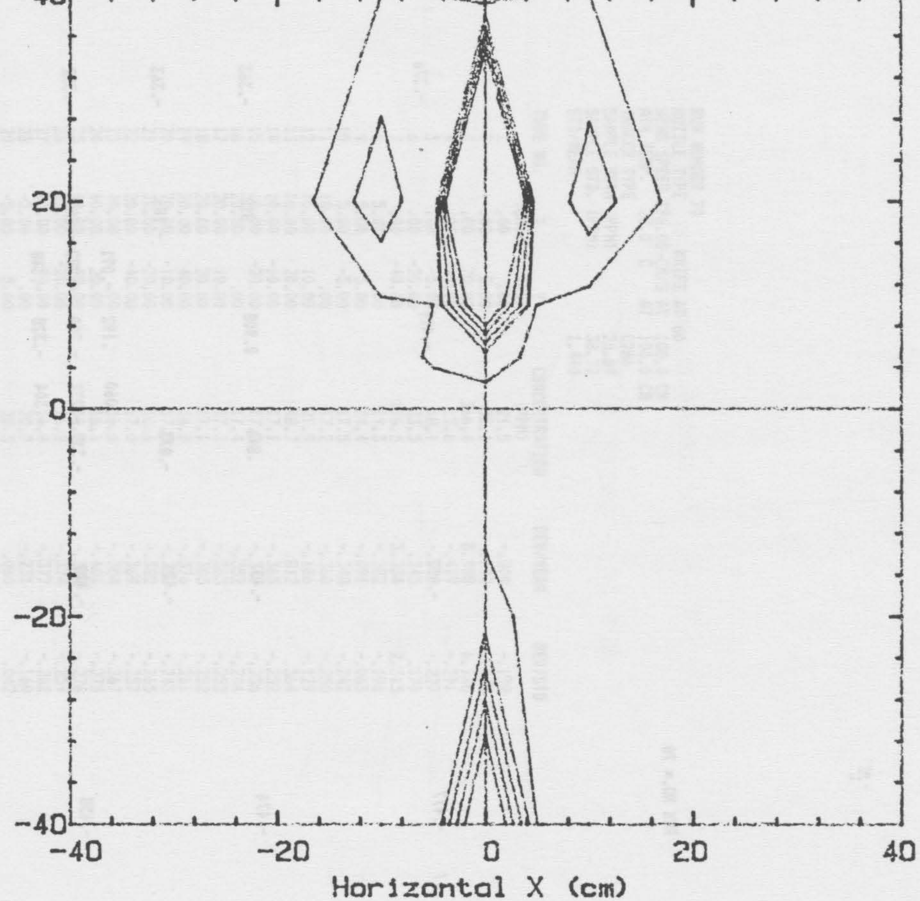
RUN 70 - KNIFE AT 60^{o}

RUN NUMBER 70
NOZZLE TYPE KNIFE AT 60
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 26.89
SAMPLE STD. (PPM) 38.72
STD/MEAN 1.440

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	21.5	-.200	-.139
2	.00	5.00	32.1	.192	.133
3	.00	20.00	266.4	8.908	6.186
4	.00	40.00	15.6	-.419	-.291
5	.00	-5.00	18.1	-.328	-.227
6	.00	-20.00	33.5	.245	.170
7	.00	-40.00	116.5	3.334	2.315
8	5.00	.00	19.3	-.282	-.196
9	5.00	5.00	24.4	-.091	-.063
10	5.00	-5.00	17.5	-.348	-.242
11	10.00	.00	17.2	-.360	-.250
12	10.00	10.00	21.9	-.186	-.129
13	10.00	20.00	48.7	.812	.564
14	10.00	-10.00	17.1	-.363	-.252
15	10.00	-20.00	17.8	-.340	-.236
16	20.00	.00	17.4	-.352	-.244
17	20.00	10.00	17.1	-.363	-.252
18	20.00	20.00	17.1	-.363	-.252
19	20.00	40.00	16.8	-.376	-.261
20	20.00	-10.00	17.5	-.350	-.243
21	20.00	-20.00	16.6	-.382	-.265
22	20.00	-40.00	17.0	-.369	-.257
23	40.00	.00	16.6	-.384	-.267
24	40.00	20.00	16.1	-.401	-.278
25	40.00	40.00	16.2	-.398	-.276
26	40.00	-20.00	16.8	-.374	-.259
27	40.00	-40.00	16.8	-.377	-.262
28	-5.00	.00	20.7	-.231	-.160
29	-5.00	5.00	28.5	.060	.042
30	-5.00	-5.00	18.7	-.304	-.211
31	-10.00	.00	17.8	-.339	-.235
32	-10.00	10.00	24.9	-.073	-.051
33	-10.00	20.00	49.6	.846	.588
34	-10.00	-10.00	16.6	-.382	-.265
35	-10.00	-20.00	17.4	-.351	-.244
36	-20.00	.00	15.6	-.420	-.292
37	-20.00	10.00	15.5	-.424	-.294
38	-20.00	20.00	15.1	-.437	-.303
39	-20.00	40.00	14.7	-.452	-.314
40	-20.00	-10.00	15.6	-.419	-.291
41	-20.00	-20.00	15.3	-.430	-.299
42	-20.00	-40.00	15.4	-.428	-.298
43	-40.00	.00	14.6	-.458	-.318
44	-40.00	20.00	14.1	-.474	-.329
45	-40.00	40.00	14.1	-.477	-.332
46	-40.00	-20.00	14.8	-.448	-.311
47	-40.00	-40.00	14.9	-.445	-.309

RUN NO.= 70

-.477	-.452			-.419			-.376	-.398
-.474	-.437	.846		8.908		.812	-.363	-.401
	-.424	-.073				-.186	-.363	
			.060	.192	-.091			
-.458	-.420	-.339	-.231	-.200	-.282	-.360	-.352	-.384
			-.304	-.328	-.348			
	-.419	-.382				-.363	-.350	
-.448	-.430	-.351		.245		-.340	-.382	-.374
-.445	-.428			3.334			-.369	-.377



Contour Map of Dev/Mean
KNIFE AT 60

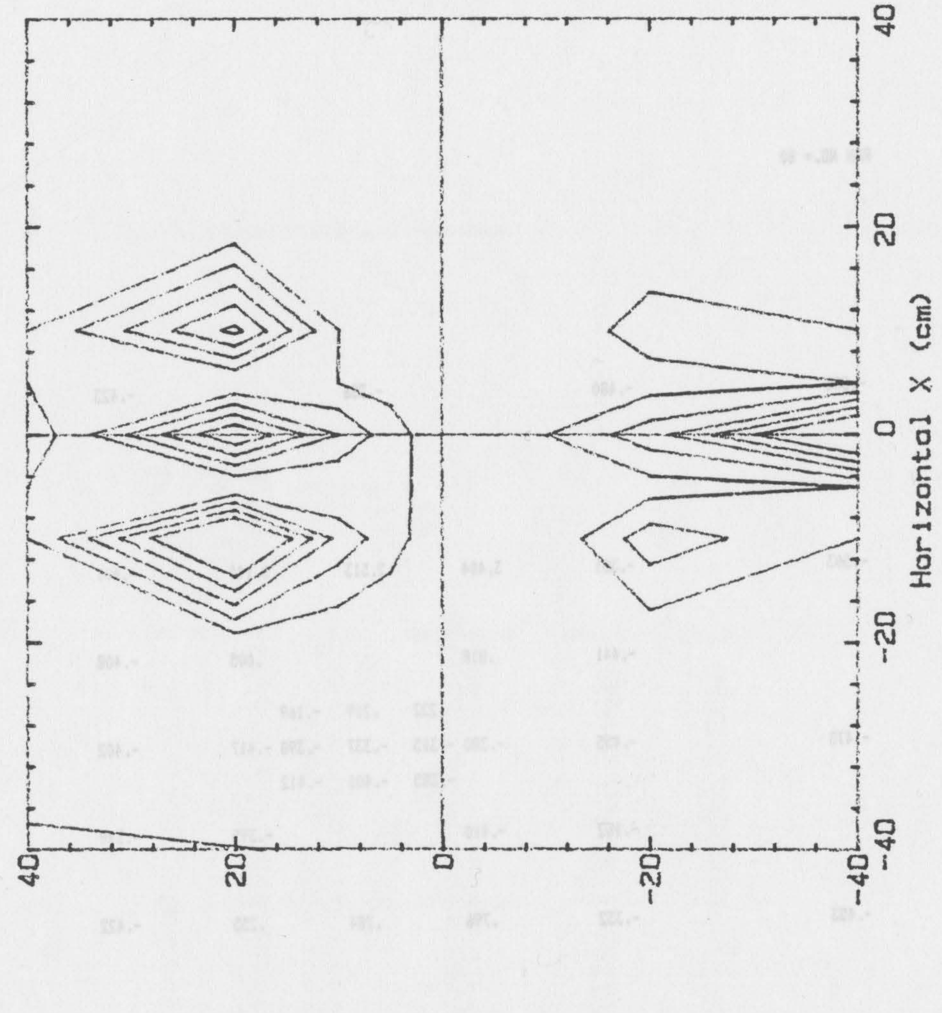
RUN 80 - KNIFE AT 90°

RUN NUMBER 80
NOZZLE TYPE KNIFE AT 90
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 29.34
SAMPLE STD. (PPM) 27.30
STD/MEAN .930

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	19.5	-.337	-.362
2	.00	5.00	35.8	.219	.235
3	.00	20.00	103.1	2.513	2.701
4	.00	40.00	18.0	-.386	-.415
5	.00	-5.00	17.6	-.401	-.431
6	.00	-20.00	52.4	.784	.843
7	.00	-40.00	123.0	3.192	3.430
8	5.00	.00	17.7	-.398	-.428
9	5.00	5.00	24.4	-.169	-.182
10	5.00	-5.00	17.3	-.412	-.443
11	10.00	.00	17.1	-.417	-.448
12	10.00	10.00	29.5	.005	.006
13	10.00	20.00	92.1	2.140	2.301
14	10.00	-10.00	17.8	-.395	-.424
15	10.00	-20.00	36.8	.255	.274
16	20.00	.00	17.6	-.402	-.432
17	20.00	10.00	17.4	-.408	-.439
18	20.00	20.00	17.6	-.401	-.431
19	20.00	40.00	16.9	-.423	-.454
20	20.00	-10.00	17.6	-.399	-.428
21	20.00	-20.00	17.0	-.422	-.454
22	20.00	-40.00	17.0	-.420	-.452
23	40.00	.00	16.8	-.429	-.461
24	40.00	20.00	16.4	-.443	-.476
25	40.00	40.00	16.4	-.440	-.473
26	40.00	-20.00	18.5	-.371	-.399
27	40.00	-40.00	18.0	-.387	-.416
28	-5.00	.00	20.1	-.315	-.339
29	-5.00	5.00	35.9	.222	.239
30	-5.00	-5.00	18.0	-.385	-.414
31	-10.00	.00	18.2	-.380	-.408
32	-10.00	10.00	53.3	.818	.879
33	-10.00	20.00	129.2	3.404	3.659
34	-10.00	-10.00	17.3	-.410	-.441
35	-10.00	-20.00	52.7	.796	.856
36	-20.00	.00	16.0	-.455	-.489
37	-20.00	10.00	16.4	-.441	-.474
38	-20.00	20.00	20.5	-.301	-.324
39	-20.00	40.00	15.3	-.480	-.516
40	-20.00	-10.00	16.1	-.452	-.486
41	-20.00	-20.00	19.0	-.352	-.378
42	-20.00	-40.00	25.9	-.118	-.127
43	-40.00	.00	15.3	-.478	-.514
44	-40.00	20.00	14.6	-.503	-.541
45	-40.00	40.00	14.6	-.503	-.541
46	-40.00	-20.00	16.0	-.453	-.487
47	-40.00	-40.00	15.8	-.462	-.497

RUN NO.= 80

-.503	-.480			-.386			-.423	-.440
-.503	-.301	3.404		2.513		2.140	-.401	-.443
	-.441	.818				.005	-.408	
			.222	.219	-.169			
-.478	-.455	-.380	-.315	-.337	-.398	-.417	-.402	-.429
			-.385	-.401	-.412			
	-.452	-.410				-.395	-.399	
-.453	-.352	.796		.784		.255	-.422	-.371
-.462	-.118			3.192			-.420	-.387



Contour Map of Dev/Mean
KNIFE AT 90

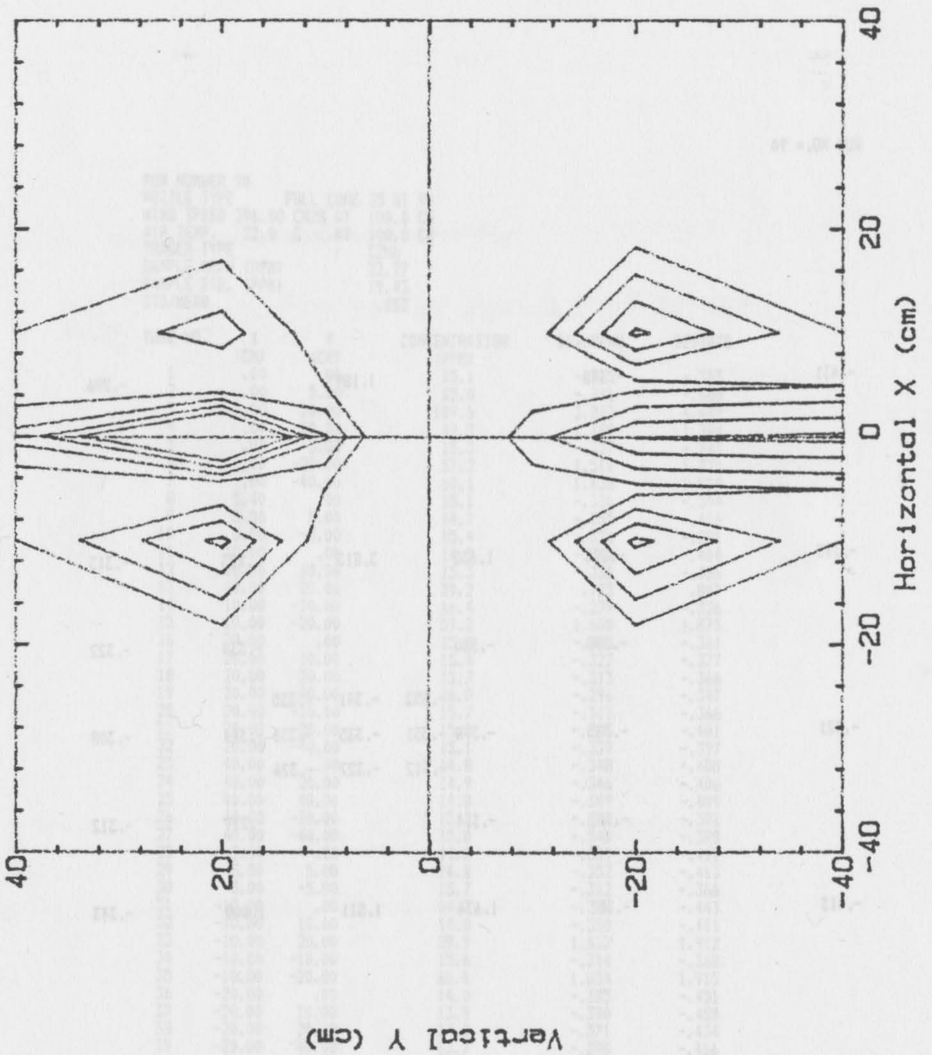
RUN 90 - FULL CONE 35° AT 90°

RUN NUMBER 90
NOZZLE TYPE FULL CONE 35 AT 90
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 22.77
SAMPLE STD. (PPM) 19.43
STD/MEAN .853

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	15.1	-.335	-.393
2	.00	5.00	15.0	-.341	-.400
3	.00	20.00	109.6	3.813	4.469
4	.00	40.00	49.8	1.189	1.394
5	.00	-5.00	15.3	-.327	-.383
6	.00	-20.00	57.2	1.511	1.771
7	.00	-40.00	60.1	1.638	1.919
8	5.00	.00	15.1	-.336	-.394
9	5.00	5.00	14.7	-.355	-.416
10	5.00	-5.00	15.4	-.326	-.381
11	10.00	.00	14.9	-.344	-.404
12	10.00	10.00	15.3	-.330	-.386
13	10.00	20.00	39.2	.723	.847
14	10.00	-10.00	16.4	-.279	-.326
15	10.00	-20.00	59.2	1.600	1.875
16	20.00	.00	15.8	-.308	-.361
17	20.00	10.00	15.4	-.322	-.377
18	20.00	20.00	15.7	-.313	-.366
19	20.00	40.00	16.0	-.296	-.347
20	20.00	-10.00	15.7	-.312	-.366
21	20.00	-20.00	15.0	-.343	-.401
22	20.00	-40.00	15.1	-.339	-.397
23	40.00	.00	14.8	-.348	-.408
24	40.00	20.00	14.9	-.346	-.406
25	40.00	40.00	14.8	-.349	-.409
26	40.00	-20.00	15.2	-.334	-.391
27	40.00	-40.00	15.0	-.340	-.398
28	-5.00	.00	14.8	-.351	-.412
29	-5.00	5.00	14.8	-.352	-.413
30	-5.00	-5.00	15.7	-.312	-.366
31	-10.00	.00	14.2	-.378	-.443
32	-10.00	10.00	14.8	-.350	-.411
33	-10.00	20.00	59.9	1.632	1.912
34	-10.00	-10.00	15.6	-.314	-.368
35	-10.00	-20.00	60.0	1.634	1.915
36	-20.00	.00	14.0	-.385	-.451
37	-20.00	10.00	13.9	-.390	-.458
38	-20.00	20.00	14.3	-.371	-.434
39	-20.00	40.00	13.7	-.398	-.466
40	-20.00	-10.00	14.1	-.382	-.447
41	-20.00	-20.00	14.1	-.381	-.447
42	-20.00	-40.00	14.1	-.382	-.448
43	-40.00	.00	13.2	-.421	-.493
44	-40.00	20.00	13.8	-.395	-.463
45	-40.00	40.00	13.0	-.431	-.505
46	-40.00	-20.00	13.4	-.413	-.484
47	-40.00	-40.00	13.4	-.411	-.482

RUN NO.= 90

-.431	-.398			1.189			-.296	-.349
-.395	-.371	1.632		3.813		.723	-.313	-.346
	-.390	-.350				-.330	-.322	
			-.352	-.341	-.355			
-.421	-.385	-.378	-.351	-.335	-.336	-.344	-.308	-.348
			-.312	-.327	-.326			
	-.382	-.314				-.279	-.312	
-.413	-.381	1.634		1.511		1.600	-.343	-.334
-.411	-.382			1.638			-.339	-.340



Contour Map of Dev/Mean
FULL CONE 35 AT 90

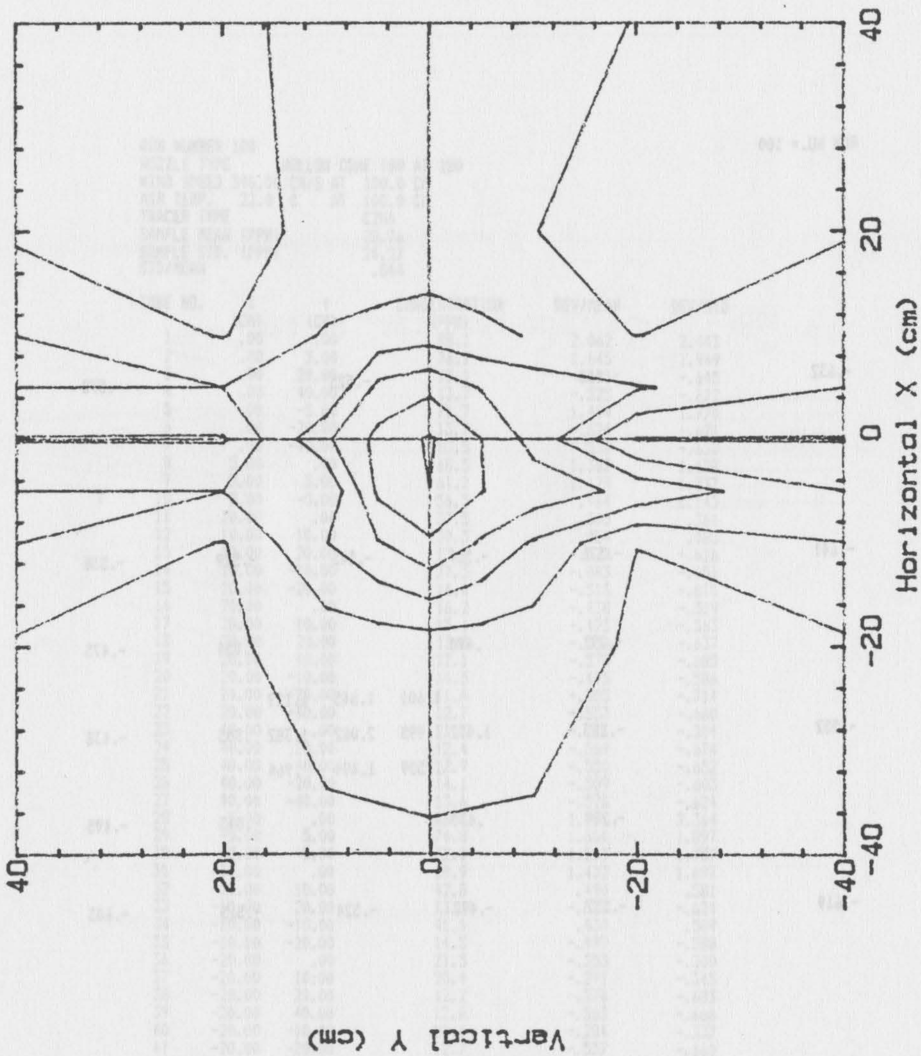
RUN 100 - HOLLOW CONE 180° AT 180°

RUN NUMBER 100
NOZZLE TYPE HOLLOW CONE 180 AT 180
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 28.76
SAMPLE STD. (PPM) 24.27
STD/MEAN .844

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	88.1	2.062	2.443
2	.00	5.00	76.1	1.645	1.949
3	.00	20.00	13.1	-.545	-.645
4	.00	40.00	13.7	-.525	-.622
5	.00	-5.00	71.7	1.494	1.770
6	.00	-20.00	13.7	-.524	-.621
7	.00	-40.00	13.5	-.532	-.630
8	5.00	.00	68.5	1.382	1.638
9	5.00	5.00	61.2	1.129	1.337
10	5.00	-5.00	56.5	.964	1.142
11	10.00	.00	37.5	.305	.361
12	10.00	10.00	30.3	.054	.063
13	10.00	20.00	13.6	-.529	-.626
14	10.00	-10.00	27.5	-.043	-.051
15	10.00	-20.00	14.0	-.515	-.610
16	20.00	.00	16.2	-.438	-.519
17	20.00	10.00	15.1	-.475	-.563
18	20.00	20.00	13.3	-.538	-.637
19	20.00	40.00	12.1	-.578	-.685
20	20.00	-10.00	14.5	-.495	-.586
21	20.00	-20.00	11.4	-.603	-.714
22	20.00	-40.00	12.7	-.557	-.660
23	40.00	.00	21.3	-.261	-.309
24	40.00	20.00	12.4	-.569	-.674
25	40.00	40.00	12.9	-.550	-.652
26	40.00	-20.00	14.1	-.509	-.603
27	40.00	-40.00	13.6	-.526	-.624
28	-5.00	.00	86.1	1.995	2.364
29	-5.00	5.00	74.8	1.601	1.897
30	-5.00	-5.00	72.1	1.509	1.787
31	-10.00	.00	69.9	1.432	1.697
32	-10.00	10.00	42.8	.490	.581
33	-10.00	20.00	13.6	-.527	-.624
34	-10.00	-10.00	41.1	.430	.509
35	-10.00	-20.00	14.5	-.497	-.588
36	-20.00	.00	21.5	-.253	-.300
37	-20.00	10.00	20.4	-.291	-.345
38	-20.00	20.00	12.2	-.576	-.683
39	-20.00	40.00	12.6	-.563	-.666
40	-20.00	-10.00	20.6	-.284	-.337
41	-20.00	-20.00	12.7	-.557	-.660
42	-20.00	-40.00	12.1	-.578	-.684
43	-40.00	.00	12.9	-.552	-.654
44	-40.00	20.00	10.3	-.641	-.759
45	-40.00	40.00	10.6	-.632	-.749
46	-40.00	-20.00	11.0	-.619	-.733
47	-40.00	-40.00	11.2	-.612	-.725

RUN NO.= 100

-.632	-.563			-.525			-.578	-.550
-.641	-.576	-.527		-.545		-.529	-.538	-.569
	-.291	.490				.054	-.475	
			1.601	1.645	1.129			
-.552	-.253	1.432	1.995	2.062	1.382	.305	-.438	-.261
			1.509	1.494	.964			
	-.284	.430				-.043	-.495	
-.619	-.557	-.497		-.524		-.515	-.603	-.509
-.612	-.578			-.532			-.557	-.526



Contour Map of Dev/Mean
HOLLOW CONE 180 AT 180

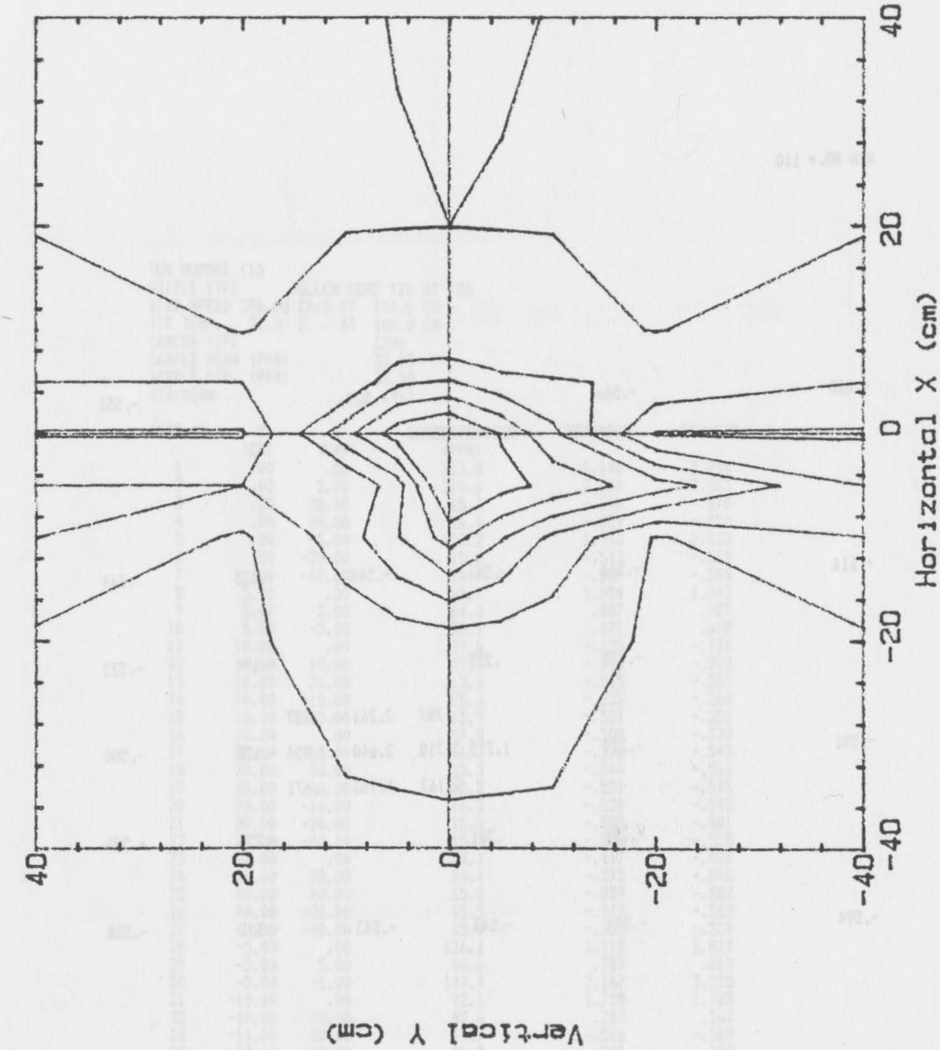
RUN 110 - HOLLOW CONE 120^{o} AT 180^{o}

RUN NUMBER 110
NOZZLE TYPE HOLLOW CONE 120 AT 180
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 33.93
SAMPLE STD. (PPM) 32.60
STD/MEAN .961

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	123.5	2.640	2.748
2	.00	5.00	110.6	2.261	2.353
3	.00	20.00	15.3	-.548	-.570
4	.00	40.00	16.0	-.529	-.550
5	.00	-5.00	100.2	1.953	2.033
6	.00	-20.00	15.5	-.543	-.565
7	.00	-40.00	14.9	-.560	-.583
8	5.00	.00	69.7	1.054	1.097
9	5.00	5.00	64.0	.887	.923
10	5.00	-5.00	56.7	.671	.698
11	10.00	.00	29.6	-.128	-.134
12	10.00	10.00	27.3	-.194	-.202
13	10.00	20.00	15.8	-.535	-.557
14	10.00	-10.00	25.3	-.255	-.266
15	10.00	-20.00	15.9	-.531	-.553
16	20.00	.00	17.0	-.500	-.520
17	20.00	10.00	16.2	-.522	-.543
18	20.00	20.00	15.5	-.544	-.566
19	20.00	40.00	15.2	-.551	-.573
20	20.00	-10.00	16.3	-.520	-.542
21	20.00	-20.00	15.0	-.558	-.581
22	20.00	-40.00	15.1	-.556	-.578
23	40.00	.00	18.1	-.467	-.486
24	40.00	20.00	14.4	-.575	-.598
25	40.00	40.00	15.0	-.559	-.582
26	40.00	-20.00	15.5	-.542	-.565
27	40.00	-40.00	15.9	-.532	-.554
28	-5.00	.00	126.1	2.718	2.829
29	-5.00	5.00	60.6	.787	.819
30	-5.00	-5.00	107.4	2.167	2.255
31	-10.00	.00	92.1	1.715	1.785
32	-10.00	10.00	42.6	.257	.267
33	-10.00	20.00	14.7	-.566	-.589
34	-10.00	-10.00	46.9	.381	.397
35	-10.00	-20.00	15.5	-.543	-.565
36	-20.00	.00	26.2	-.229	-.238
37	-20.00	10.00	23.1	-.318	-.331
38	-20.00	20.00	14.7	-.566	-.589
39	-20.00	40.00	14.0	-.586	-.610
40	-20.00	-10.00	24.0	-.291	-.303
41	-20.00	-20.00	14.9	-.561	-.584
42	-20.00	-40.00	14.5	-.573	-.596
43	-40.00	.00	14.2	-.581	-.604
44	-40.00	20.00	13.0	-.616	-.641
45	-40.00	40.00	12.8	-.623	-.649
46	-40.00	-20.00	13.8	-.594	-.618
47	-40.00	-40.00	13.8	-.594	-.618

RUN NO.= 110

-.623	-.586			-.529			-.551	-.559
-.616	-.566	-.566		-.548		-.535	-.544	-.575
	-.318	.257				-.194	-.522	
			.787	2.261	.887			
-.581	-.229	1.715	2.718	2.640	1.054	-.128	-.500	-.467
			2.167	1.953	.671			
	-.291	.381				-.255	-.520	
-.594	-.561	-.543		-.543		-.531	-.558	-.542
-.594	-.573			-.560			-.556	-.532



Contour Map of Dev/Mean
HOLLOW CONE 120 AT 180

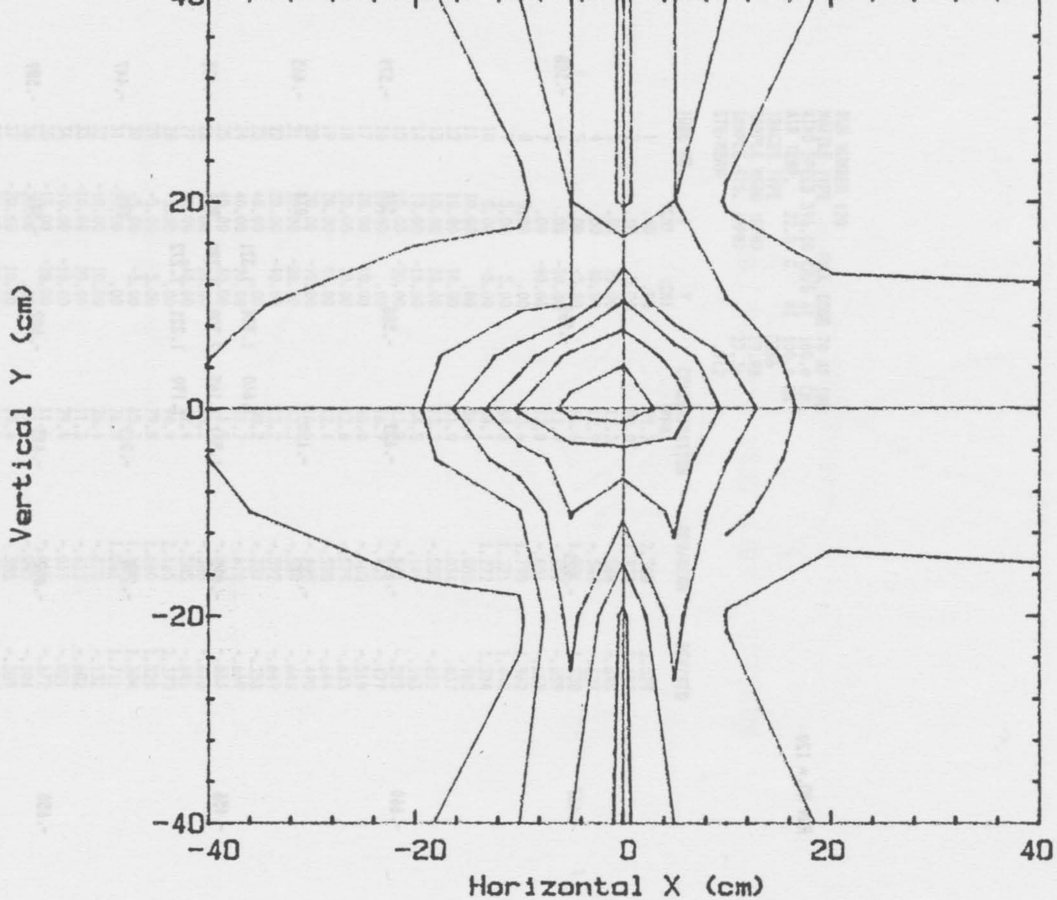
RUN 120 - FULL CONE 70° AT 180°

RUN NUMBER 120
NOZZLE TYPE FULL CONE 70 AT 180
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 29.98
SAMPLE STD. (PPM) 27.36
STD/MEAN .912

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	99.2	2.308	2.529
2	.00	5.00	88.0	1.934	2.120
3	.00	20.00	12.3	-.588	-.645
4	.00	40.00	12.9	-.569	-.624
5	.00	-5.00	66.6	1.221	1.338
6	.00	-20.00	11.9	-.602	-.659
7	.00	-40.00	12.0	-.601	-.658
8	5.00	.00	83.6	1.790	1.962
9	5.00	5.00	69.6	1.321	1.448
10	5.00	-5.00	68.1	1.272	1.394
11	10.00	.00	56.4	.880	.965
12	10.00	10.00	31.0	.034	.037
13	10.00	20.00	13.3	-.558	-.611
14	10.00	-10.00	34.5	.149	.163
15	10.00	-20.00	13.8	-.541	-.593
16	20.00	.00	16.9	-.435	-.477
17	20.00	10.00	16.0	-.465	-.510
18	20.00	20.00	12.6	-.579	-.635
19	20.00	40.00	12.4	-.588	-.644
20	20.00	-10.00	16.6	-.447	-.490
21	20.00	-20.00	12.3	-.589	-.646
22	20.00	-40.00	12.2	-.592	-.649
23	40.00	.00	20.2	-.327	-.358
24	40.00	20.00	11.7	-.610	-.669
25	40.00	40.00	11.9	-.604	-.663
26	40.00	-20.00	13.2	-.560	-.613
27	40.00	-40.00	12.4	-.585	-.641
28	-5.00	.00	94.9	2.165	2.373
29	-5.00	5.00	79.8	1.660	1.820
30	-5.00	-5.00	65.7	1.190	1.304
31	-10.00	.00	76.8	1.561	1.711
32	-10.00	10.00	26.4	-.120	-.132
33	-10.00	20.00	11.3	-.622	-.682
34	-10.00	-10.00	29.4	-.019	-.021
35	-10.00	-20.00	11.6	-.613	-.672
36	-20.00	.00	27.1	-.095	-.104
37	-20.00	10.00	19.4	-.355	-.389
38	-20.00	20.00	11.8	-.606	-.665
39	-20.00	40.00	11.2	-.625	-.685
40	-20.00	-10.00	21.0	-.298	-.327
41	-20.00	-20.00	11.9	-.602	-.660
42	-20.00	-40.00	11.8	-.607	-.666
43	-40.00	.00	16.3	-.456	-.499
44	-40.00	20.00	10.2	-.660	-.723
45	-40.00	40.00	10.0	-.667	-.731
46	-40.00	-20.00	10.5	-.650	-.712
47	-40.00	-40.00	10.5	-.648	-.711

RUN NO.= 120

-.667	-.625			-.569			-.588	-.604
-.660	-.606	-.622		-.588		-.558	-.579	-.610
	-.355	-.120				.034	-.465	
			1.660	1.934	1.321			
-.456	-.095	1.561	2.165	2.308	1.790	.880	-.435	-.327
			1.190	1.221	1.272			
	-.298	-.019				.149	-.447	
-.650	-.602	-.613		-.602		-.541	-.589	-.560
-.648	-.607			-.601			-.592	-.585



Contour Map of Dev/Mean
FULL CONE 70 AT 180

RUN 30F - HOLLOW CONE 180^{o} AT 0^{o} WITH FINS

RUN NUMBER 30F
NOZZLE TYPE HOLLOW CONE 180 @ 0 W/FIN
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 36.29
SAMPLE STD. (PPM) 20.94
STD/MEAN .577

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	58.6	.614	1.065
2	.00	5.00	52.9	.457	.793
3	.00	20.00	19.3	-.469	-.813
4	.00	40.00	36.9	.016	.028
5	.00	-5.00	75.5	1.082	1.875
6	.00	-20.00	44.7	.231	.401
7	.00	-40.00	28.3	-.222	-.384
8	5.00	.00	51.3	.413	.715
9	5.00	5.00	45.5	.253	.438
10	5.00	-5.00	66.6	.834	1.446
11	10.00	.00	42.3	.165	.286
12	10.00	10.00	32.2	-.114	-.197
13	10.00	20.00	16.9	-.535	-.927
14	10.00	-10.00	57.3	.579	1.003
15	10.00	-20.00	23.7	-.347	-.601
16	20.00	.00	29.6	-.185	-.320
17	20.00	10.00	23.0	-.366	-.634
18	20.00	20.00	15.9	-.561	-.973
19	20.00	40.00	17.5	-.518	-.897
20	20.00	-10.00	28.4	-.217	-.376
21	20.00	-20.00	16.7	-.540	-.936
22	20.00	-40.00	17.4	-.520	-.902
23	40.00	.00	34.5	-.049	-.085
24	40.00	20.00	16.0	-.560	-.971
25	40.00	40.00	17.1	-.528	-.916
26	40.00	-20.00	16.9	-.536	-.928
27	40.00	-40.00	17.5	-.518	-.898
28	-5.00	.00	64.3	.773	1.339
29	-5.00	5.00	57.8	.594	1.029
30	-5.00	-5.00	82.9	1.285	2.227
31	-10.00	.00	65.4	.803	1.392
32	-10.00	10.00	54.5	.503	.871
33	-10.00	20.00	22.0	-.395	-.685
34	-10.00	-10.00	96.3	1.653	2.865
35	-10.00	-20.00	33.3	-.083	-.143
36	-20.00	.00	55.0	.516	.895
37	-20.00	10.00	42.3	.167	.289
38	-20.00	20.00	17.0	-.531	-.921
39	-20.00	40.00	14.7	-.594	-1.029
40	-20.00	-10.00	56.4	.555	.963
41	-20.00	-20.00	18.6	-.486	-.843
42	-20.00	-40.00	16.4	-.549	-.952
43	-40.00	.00	39.4	.086	.149
44	-40.00	20.00	17.5	-.518	-.897
45	-40.00	40.00	14.6	-.598	-1.037
46	-40.00	-20.00	17.9	-.507	-.879
47	-40.00	-40.00	17.0	-.533	-.924

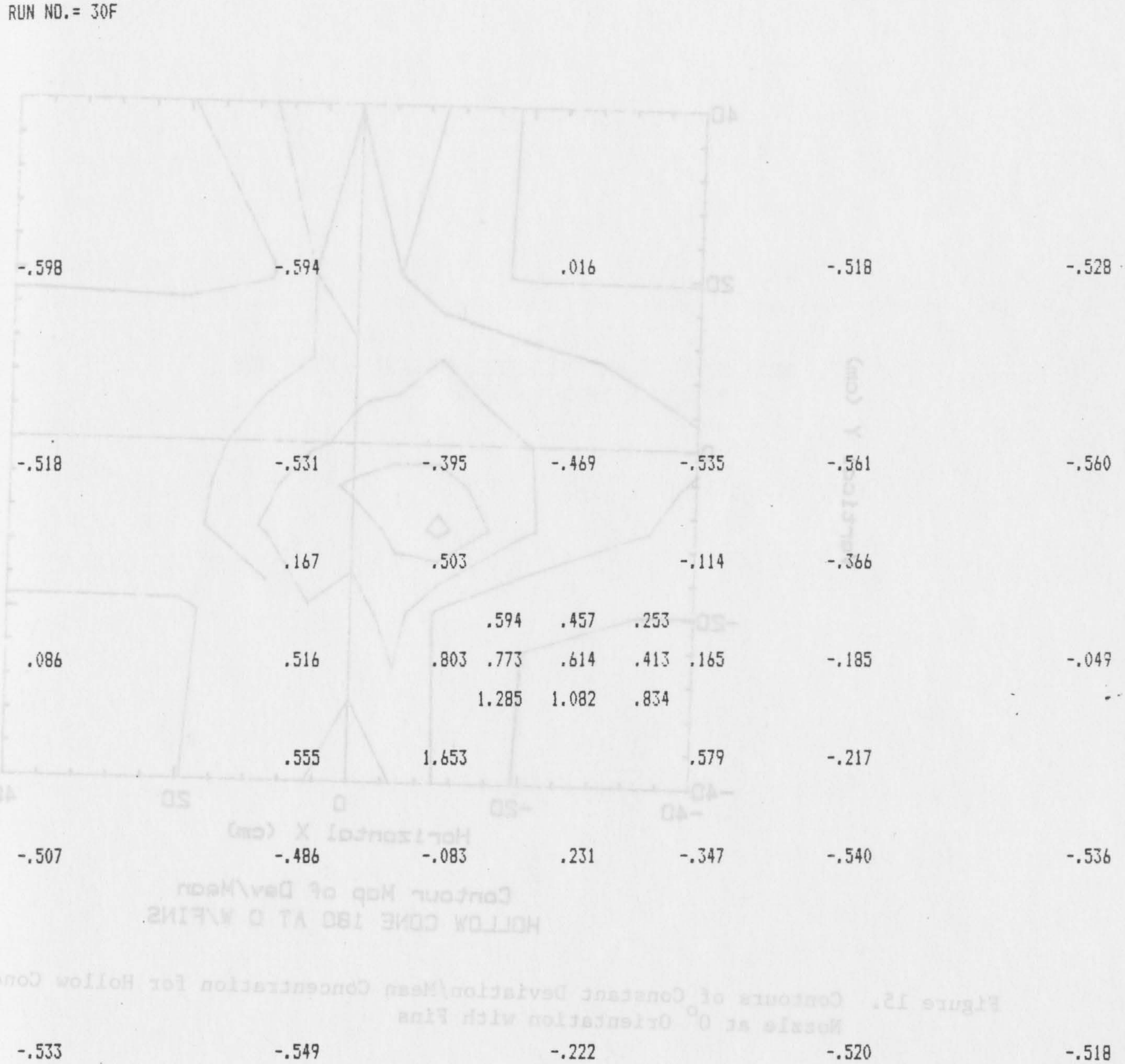


Figure 14. Grid Plot of Deviation/Mean Concentration for Hollow Cone 180° Nozzle at 0° Orientation with Fins

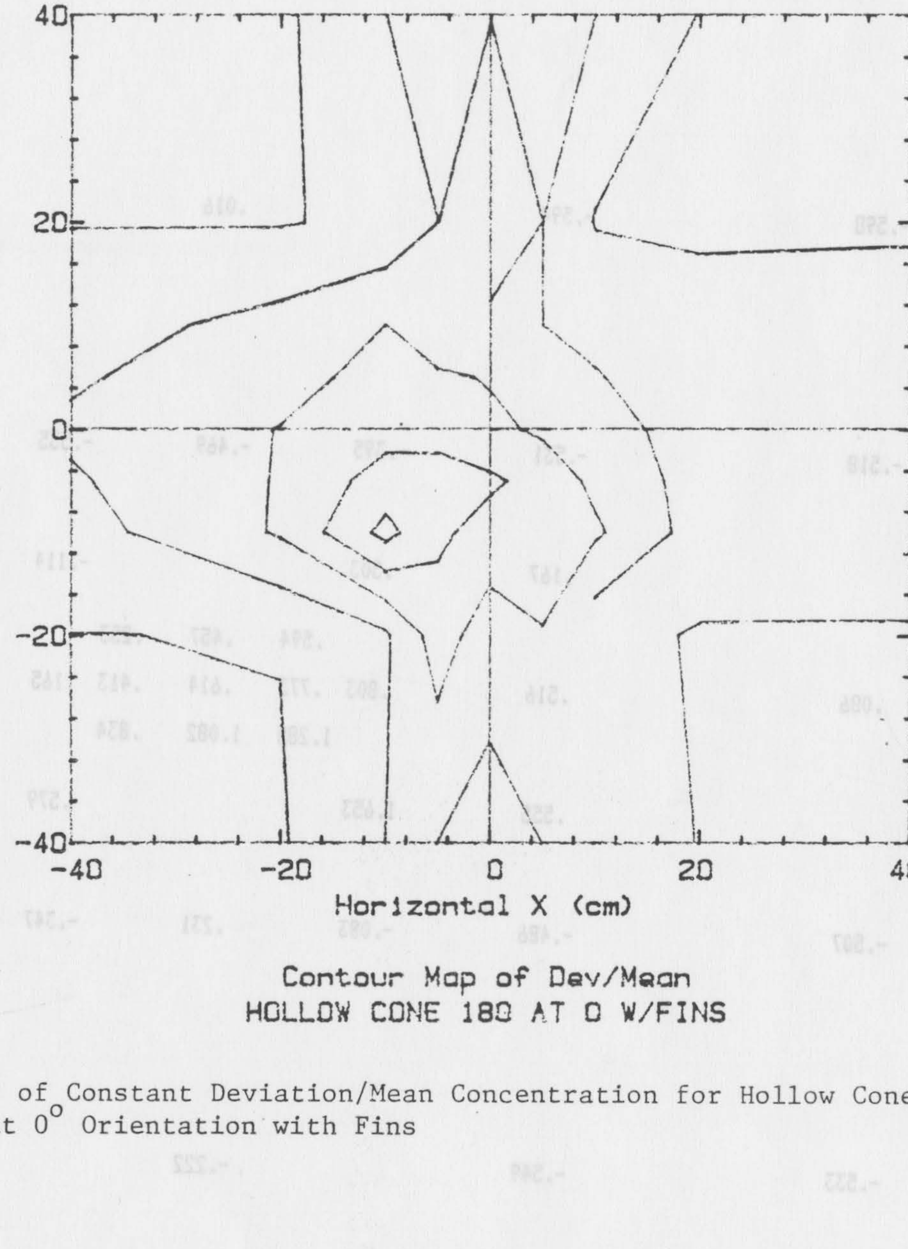


Figure 15. Contours of Constant Deviation/Mean Concentration for Hollow Cone 180° Nozzle at 0° Orientation with Fins

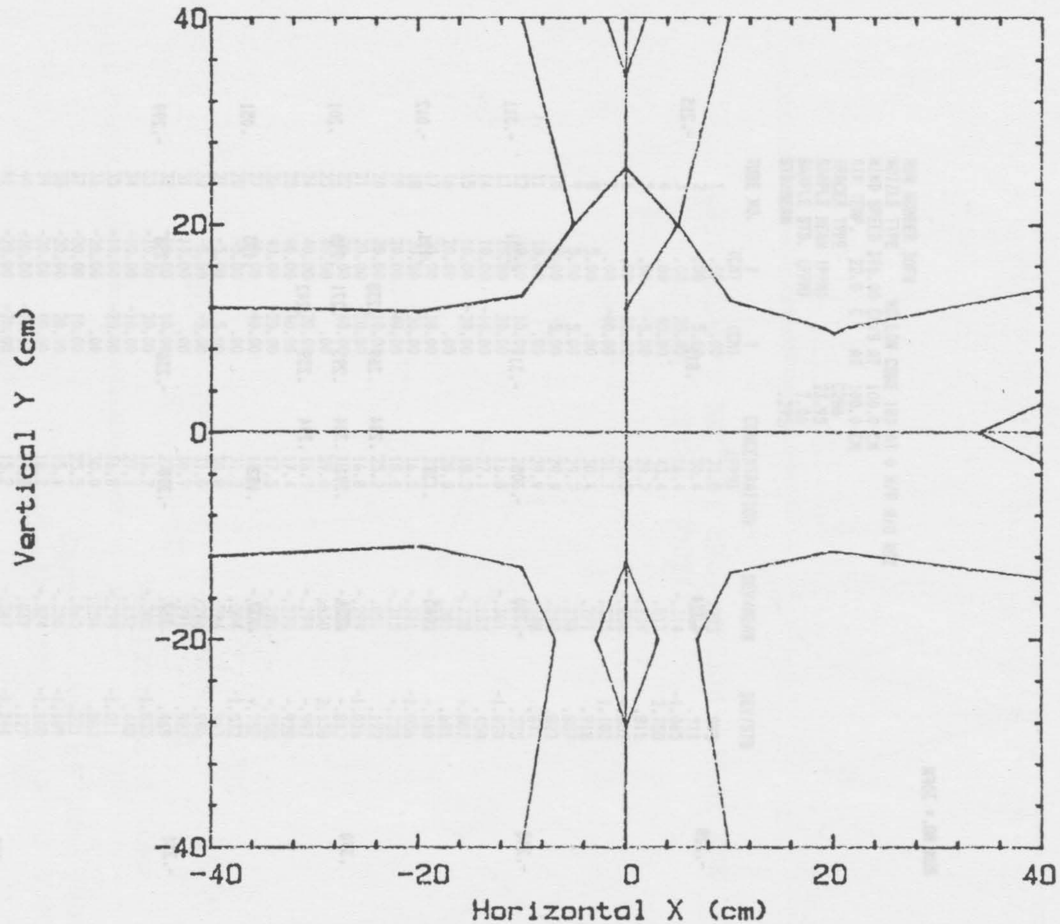
RUN 30FN - HOLLOW CONE 180° AT 0° WITH FINS
WITHOUT CENTER NOZZLE

RUN NUMBER 30FN
NOZZLE TYPE HOLLOW CONE 180 AT 0 W/F W/O NOZ
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 23.95
SAMPLE STD. (PPM) 7.06
STD/MEAN .295

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	31.0	.293	.995
2	.00	5.00	30.4	.269	.911
3	.00	20.00	16.4	-.314	-1.065
4	.00	40.00	43.4	.813	2.758
5	.00	-5.00	29.7	.239	.811
6	.00	-20.00	18.3	-.236	-.802
7	.00	-40.00	31.7	.325	1.102
8	5.00	.00	30.4	.271	.918
9	5.00	5.00	29.7	.238	.807
10	5.00	-5.00	29.8	.242	.822
11	10.00	.00	29.9	.248	.841
12	10.00	10.00	26.6	.111	.375
13	10.00	20.00	16.8	-.301	-1.020
14	10.00	-10.00	27.1	.133	.450
15	10.00	-20.00	18.3	-.238	-.807
16	20.00	.00	28.8	.201	.681
17	20.00	10.00	23.7	-.012	-.040
18	20.00	20.00	16.5	-.311	-1.056
19	20.00	40.00	18.8	-.215	-.728
20	20.00	-10.00	25.2	.051	.172
21	20.00	-20.00	16.8	-.299	-1.016
22	20.00	-40.00	18.2	-.239	-.812
23	40.00	.00	39.0	.630	2.138
24	40.00	20.00	16.9	-.294	-.997
25	40.00	40.00	17.4	-.273	-.928
26	40.00	-20.00	17.5	-.268	-.908
27	40.00	-40.00	18.6	-.222	-.752
28	-5.00	.00	31.2	.304	1.032
29	-5.00	5.00	30.8	.284	.963
30	-5.00	-5.00	31.0	.294	.996
31	-10.00	.00	30.9	.291	.987
32	-10.00	10.00	27.3	.138	.469
33	-10.00	20.00	16.7	-.305	-1.033
34	-10.00	-10.00	27.1	.132	.448
35	-10.00	-20.00	16.8	-.298	-1.011
36	-20.00	.00	30.0	.254	.863
37	-20.00	10.00	25.5	.065	.221
38	-20.00	20.00	15.6	-.350	-1.189
39	-20.00	40.00	16.2	-.324	-1.100
40	-20.00	-10.00	24.8	.037	.127
41	-20.00	-20.00	15.2	-.367	-1.244
42	-20.00	-40.00	17.2	-.281	-.954
43	-40.00	.00	32.8	.370	1.254
44	-40.00	20.00	18.0	-.248	-.842
45	-40.00	40.00	16.1	-.328	-1.114
46	-40.00	-20.00	17.9	-.251	-.853
47	-40.00	-40.00	17.8	-.257	-.870

RUN NO.= 30FN

-.328	-.324			.813			-.215	-.273
-.248	-.350	-.305		-.314		-.301	-.311	-.294
	.065	.138				.111	-.012	
			.284	.269	.238			
.370	.254	.291	.304	.293	.271	.248	.201	.630
			.294	.239	.242			
	.037	.132				.133	.051	
-.251	-.367	-.298		-.236		-.238	-.299	-.268
-.257	-.281			.325			-.239	-.222



Contour Map of Dev/Mean
HOLLOW CONE 180 AT 0 W/FIN-NOZZLE

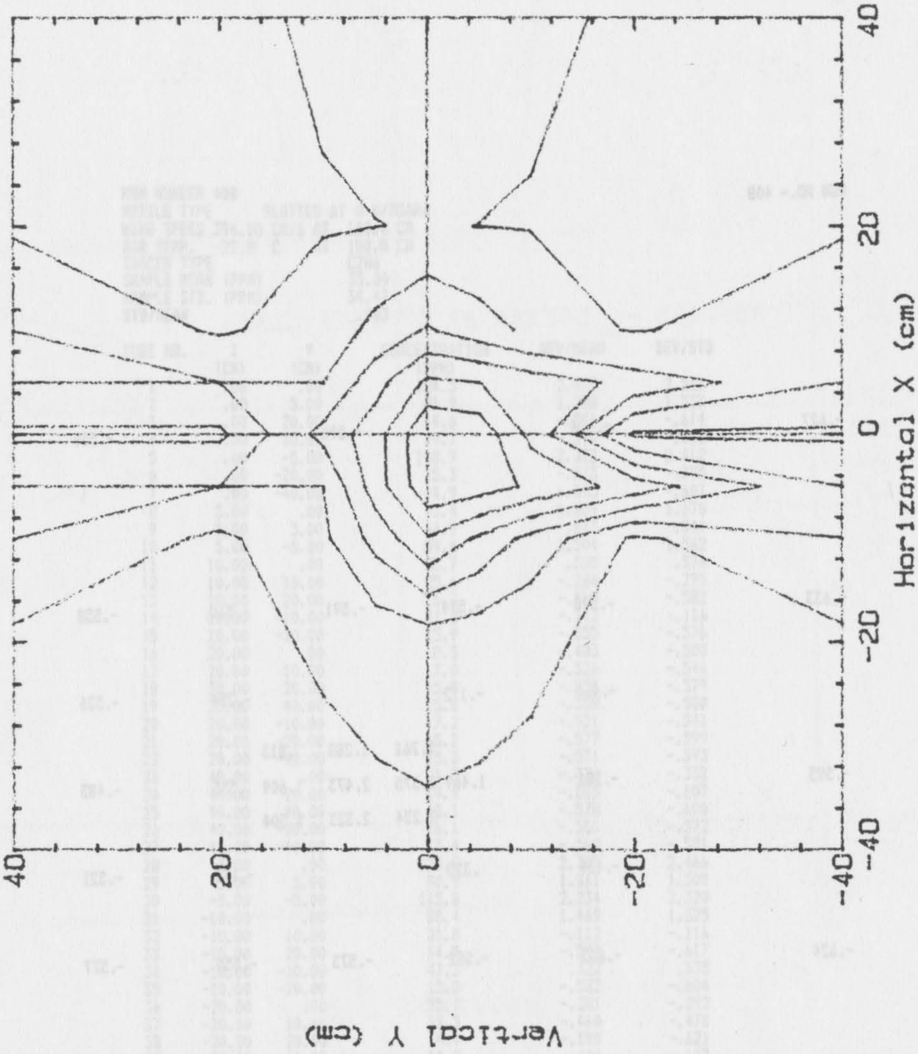
RUN 40B - SLOTTED AT 0° WITH SLATS

RUN NUMBER 40B
NOZZLE TYPE SLOTTED AT 0 W/BOARD
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 35.80
SAMPLE STD. (PPM) 34.47
STD/MEAN .963

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	124.3	2.473	2.568
2	.00	5.00	81.9	1.288	1.337
3	.00	20.00	14.6	-.591	-.614
4	.00	40.00	14.7	-.590	-.613
5	.00	-5.00	118.9	2.323	2.412
6	.00	-20.00	15.3	-.573	-.595
7	.00	-40.00	14.9	-.585	-.607
8	5.00	.00	93.4	1.609	1.670
9	5.00	5.00	64.9	.813	.844
10	5.00	-5.00	89.6	1.504	1.562
11	10.00	.00	55.7	.555	.576
12	10.00	10.00	25.6	-.284	-.295
13	10.00	20.00	15.7	-.560	-.582
14	10.00	-10.00	31.8	-.112	-.116
15	10.00	-20.00	15.9	-.555	-.576
16	20.00	.00	18.5	-.483	-.502
17	20.00	10.00	17.0	-.526	-.546
18	20.00	20.00	15.8	-.558	-.579
19	20.00	40.00	15.8	-.559	-.580
20	20.00	-10.00	17.2	-.521	-.541
21	20.00	-20.00	15.2	-.577	-.599
22	20.00	-40.00	15.3	-.571	-.593
23	40.00	.00	24.3	-.320	-.332
24	40.00	20.00	14.9	-.585	-.607
25	40.00	40.00	15.1	-.578	-.600
26	40.00	-20.00	16.1	-.551	-.572
27	40.00	-40.00	15.4	-.569	-.591
28	-5.00	.00	120.8	2.375	2.466
29	-5.00	5.00	80.9	1.261	1.309
30	-5.00	-5.00	115.8	2.234	2.320
31	-10.00	.00	88.4	1.469	1.525
32	-10.00	10.00	31.8	-.112	-.116
33	-10.00	20.00	14.5	-.594	-.617
34	-10.00	-10.00	47.3	.322	.335
35	-10.00	-20.00	15.0	-.582	-.604
36	-20.00	.00	25.7	-.281	-.292
37	-20.00	10.00	19.3	-.460	-.478
38	-20.00	20.00	14.4	-.598	-.621
39	-20.00	40.00	14.2	-.604	-.627
40	-20.00	-10.00	20.1	-.439	-.456
41	-20.00	-20.00	14.2	-.603	-.627
42	-20.00	-40.00	13.9	-.611	-.634
43	-40.00	.00	14.5	-.595	-.618
44	-40.00	20.00	13.2	-.633	-.657
45	-40.00	40.00	13.4	-.627	-.651
46	-40.00	-20.00	13.5	-.624	-.648
47	-40.00	-40.00	13.8	-.614	-.638

RUN NO.= 40B

-.627	-.604			-.590			-.559	-.578
-.633	-.598	-.594		-.591		-.560	-.558	-.585
	-.460	-.112				-.284	-.526	
			1.261	1.288	.813			
-.595	-.281	1.469	2.375	2.473	1.609	.555	-.483	-.320
			2.234	2.323	1.504			
	-.439	.322				-.112	-.521	
-.624	-.603	-.582		-.573		-.555	-.577	-.551
-.614	-.611			-.585			-.571	-.569



Contour Map of Dev/Mean
SLOTTED AT 0 W/BOARD

RUN 40F - SLOTTED AT 0° WITH FINS

RUN NUMBER 40F
NOZZLE TYPE SLOTTED AT 0 W/FINS
WIND SPEED 396.00 CM/S AT 100.0 CM
AIR TEMP. 22.0 C AT 100.0 CM
TRACER TYPE C2H6
SAMPLE MEAN (PPM) 36.46
SAMPLE STD. (PPM) 19.86
STD/MEAN .545

TUBE NO.	X (CM)	Y (CM)	CONCENTRATION (PPM)	DEV/MEAN	DEV/STD
1	.00	.00	61.6	.689	1.265
2	.00	5.00	57.2	.570	1.046
3	.00	20.00	18.6	-.489	-.898
4	.00	40.00	24.7	-.323	-.593
5	.00	-5.00	67.3	.846	1.553
6	.00	-20.00	28.3	-.222	-.408
7	.00	-40.00	23.8	-.346	-.635
8	5.00	.00	54.3	.489	.897
9	5.00	5.00	51.4	.410	.752
10	5.00	-5.00	62.3	.708	1.299
11	10.00	.00	47.9	.313	.574
12	10.00	10.00	38.0	.041	.076
13	10.00	20.00	17.1	-.531	-.974
14	10.00	-10.00	52.1	.429	.788
15	10.00	-20.00	21.7	-.406	-.745
16	20.00	.00	36.0	-.014	-.025
17	20.00	10.00	27.0	-.259	-.476
18	20.00	20.00	15.6	-.571	-1.048
19	20.00	40.00	19.6	-.463	-.849
20	20.00	-10.00	33.5	-.081	-.149
21	20.00	-20.00	16.9	-.537	-.986
22	20.00	-40.00	17.5	-.520	-.955
23	40.00	.00	41.6	.141	.259
24	40.00	20.00	16.4	-.551	-1.011
25	40.00	40.00	18.8	-.483	-.887
26	40.00	-20.00	17.7	-.514	-.944
27	40.00	-40.00	17.7	-.514	-.943
28	-5.00	.00	66.2	.814	1.495
29	-5.00	5.00	61.0	.672	1.234
30	-5.00	-5.00	73.0	1.003	1.841
31	-10.00	.00	69.7	.913	1.676
32	-10.00	10.00	53.5	.468	.858
33	-10.00	20.00	20.4	-.439	-.806
34	-10.00	-10.00	74.3	1.037	1.903
35	-10.00	-20.00	23.3	-.362	-.664
36	-20.00	.00	67.7	.856	1.572
37	-20.00	10.00	45.9	.258	.473
38	-20.00	20.00	17.1	-.531	-.975
39	-20.00	40.00	15.8	-.565	-1.038
40	-20.00	-10.00	59.2	.622	1.143
41	-20.00	-20.00	17.7	-.514	-.943
42	-20.00	-40.00	16.0	-.562	-1.032
43	-40.00	.00	51.6	.417	.765
44	-40.00	20.00	20.9	-.428	-.786
45	-40.00	40.00	16.7	-.542	-.994
46	-40.00	-20.00	20.3	-.443	-.813
47	-40.00	-40.00	18.8	-.486	-.891

RUN NO.= 40F

-.542	-.565			-.323			-.463	-.483
-.428	-.531	-.439		-.489		-.531	-.571	-.551
	.258	.468				.041	-.259	
			.672	.570	.410			
.417	.856	.913	.814	.689	.489	.313	-.014	.141
			1.003	.846	.708			
	.622	1.037				.429	-.081	
-.443	-.514	-.362		-.222		-.406	-.537	-.514
-.486	-.562			-.346			-.520	-.514

Figure 16. Grid Plot of Deviation/Mean Concentration for Slotted Nozzle at 0° Orientation with Fins

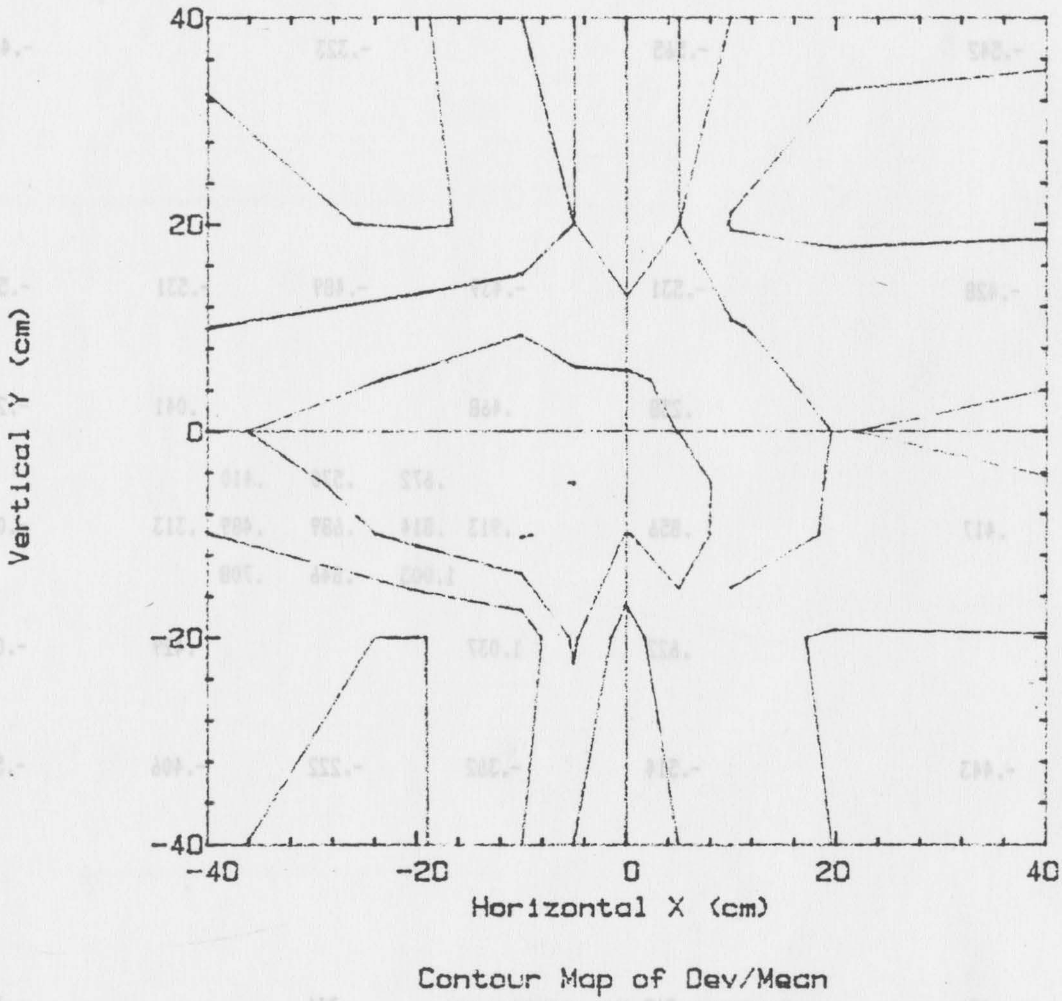


Figure 17. Contours of Constant Deviation/Mean for Slotted Nozzle at 0^{o} Orientation with Fins