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EMISSION SAMPLE PROBE INVESTIGATION OF A MIXED FLOW JT8D-11 TUR--ETC(U)
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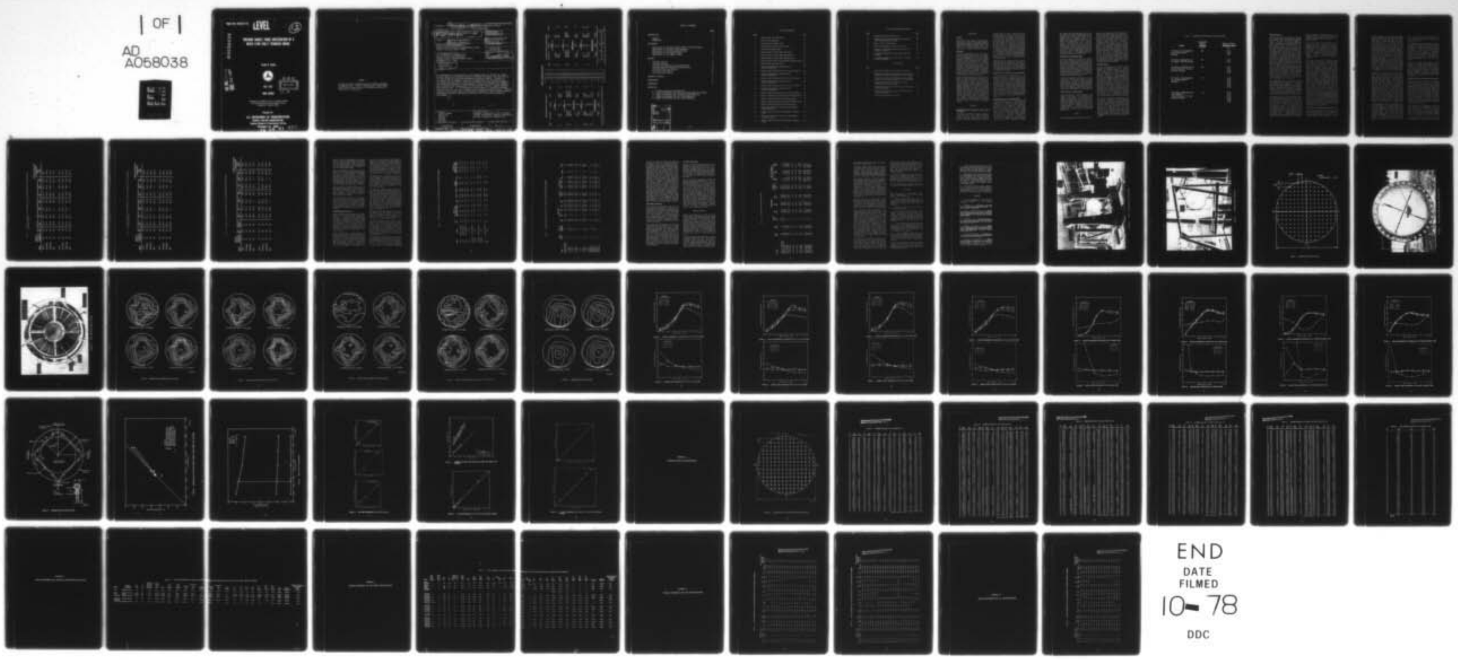

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EMISSION SAMPLE PROBE INVESTIGATION OF A MIXED FLOW JT8D-11 TURBOFAN ENGINE

Gerald R. Slusher

JULY 1978

FINAL REPORT

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16. Abstract

An investigation of the emissions in the exhaust plume of a mixed flow JT8D-11 turbofan engine was conducted in order to optimize the shape, size, and location of fixed probes for acquiring representative emission samples. Traverse of 177 points over the exhaust nozzle were accomplished on a 2-inch-square grid. The average emission levels, contours, and profile distributions were determined. The predicted performance of area weighted cruciform and diamond probe designs were calculated from interpolations of the traverse contours. Exhaust emissions were measured with: (1) five mixing cruciform probes, (2) multihole averaging probes in the core, and (3) the engine turbine discharge pressure probes. Detailed traverses across engine power are considered necessary for representative emission measurement because of limitations existing in all fixed probing techniques investigated.

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METRIC CONVERSION FACTORS

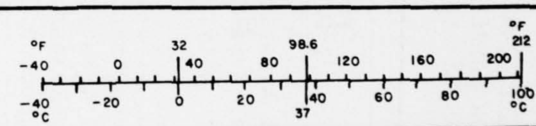
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

The purpose of this report is to define variability in aircraft turbine engine emission measurements as related to acquiring representative emission samples with fixed probes. The results of an exhaust emission probe investigation of the Pratt and Whitney (P&W) Aircraft JT8D-11 turbofan engine are reported.

BACKGROUND.

The Clean Air Amendments of 1970 (reference 1) specified that the United States (U.S.) Department of Transportation (DOT) and the Federal Aviation Administration (FAA) promulgate regulation enforcing the aircraft engine emission standards established by the Environmental Protection Agency (EPA). Emission measurements showed two major variability problems in data generated by industry and government study teams (reference 2). One problem area affecting emission measurements involved the effect of changes in ambient weather conditions, particularly temperature and humidity, on emission levels. The second problem involved acquiring a representative emission sample from the exhaust plume.

The FAA was commissioned to conduct an investigation of these variability problems at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey. From this study, ambient temperature and humidity correction factors were developed for exhaust emissions from two classes of turbine engines (reference 3). Studies of traverse emission plots indicated that the use of fixed probing techniques to provide representative samples were feasible (reference 4). The results of that portion of the investigation designed to optimize probing techniques to acquire representative emission samples from a JT8D turbine engine exhaust are reported in this document. The TF30 and JT3D turbofan engines were also tested under this program, and the results are presented in separate reports.

DISCUSSION

DESCRIPTION OF THE P&W AIRCRAFT JT8D-11 TURBOFAN ENGINE.

The mixed flow JT8D-11 engine is rated at 15,000 pounds thrust, has a compressor pressure ratio of 17.5 to 1, and features nine can-annular combustion chambers with duplex fuel nozzles. The engine incorporates a front fan having a bypass-to-engine airflow ratio of approximately 1.06 to 1, with the fan air diverted through an annular duct that forms the outer shell of the engine. The bypass air duct terminates downstream of the turbine discharge. The bypass fan airflow forms a circular envelope of relatively cool air around the core exhaust gas stream in the tailpipe and exhaust nozzle. The JT8D-11 engine was modified during the investigation by the installation of high smoke combustion chambers and fuel nozzles in the engine for the purpose of comparing exhaust emissions of high smoke versus low smoke combustion chambers (reference 5). The engine incorporated high smoke combustion chambers for all testing reporting herein, with the exception that low smoke combustion chambers were installed in the engine for the P_{T7} probe testing.

Installation of the engine for test on a thrust measuring stand is illustrated in figure 1. Engine operation was essentially under free-air conditions as the inlet air and the exhaust gases were not restricted. Test equipment and instrumentation were typical of those required for experimental engine performance testing on a static sea level stand.

DESCRIPTION OF TRAVERSE PROBE MECHANISM.

A detailed traverse investigation of the exhaust plumes of the JT8D-11 engine was necessary to establish average emission levels and to generate the emission contours and profiles required for the development and evaluation of fixed probes. The traverse mechanism shown in figure 2 was constructed to remotely position the single-point sample probe at any desired location within the vertical plane behind the engine exhaust nozzle. Emission measurements were recorded on a 2-inch grid located in the vertical plane at an axial distance of 2 inches behind the engine exhaust nozzle. Emission levels were measured at the points identified in the traverse grid shown in figure 3.

DESCRIPTION OF CRUCIFORM SAMPLE PROBES. An emission sampling probe in the shape of a cruciform (figure 4) was designed (area weighted) for an effective exhaust nozzle area diameter of 26 inches by an EPA contractor. The probe was area weighted by locating the sample orifices at centers of equal area. Although the exhaust nozzle utilized for test of the JT8D-11 engine was 30 inches in diameter, the 26-inch effective diameter had been used by EPA in previous JT8D engine emission investigations. The outer 2-inch area of the exhaust was considered to consist of undiluted fan bypass air, and representative emission sample requirements would preclude this area from the design. The sample was acquired from the centerline cross of the four legs, each located 90 degrees (°) apart. The probe was installed and tested in the upstream end of a mixer pipe 3 feet (ft) in diameter by 20 ft in length (figure 4). The sample probe was tested at axial locations behind the engine nozzle of 2, 8, and 10 inches. The sample holes were 0.089 inch diameter which produced very low samples velocities in relation to the velocity of the exhaust gases. The probe was also tested with five configurations of sample points as listed in table 1. The calculated sample velocity for each probe orifice and its immersion depth is included in table 1. A complete description of the probe is included in (reference 6).

DESCRIPTION OF CORE SAMPLE PROBES.

In order to sample the undiluted core exhaust gas, four fixed sample probes were installed throught the engine tailpipe at the core fan duct splitter and through the fan bypass air. Each probe incorporated three sample orifices 0.030 inch in diameter. Average emissions were sampled from the core probes throught an externally heated manifold. The purpose of the core probes was to establish and maintain reference emission measurements to which all subsequent probing results, at the exhaust nozzle, could be compared and evaluated. The core probes are shown in figure 5.

A random integrated sampling pattern was achieved by installing the probes on varying chord angles. The chord angles and probe locations were selected to include sampling behind the bearing support struts, where high concentrations of hydrocarbons had been reported for other engines. These probes were utilized as a constant reference for all the candidate probes throughtout the investigations.

DESCRIPTION OF P_{T7} SAMPLE PROBES.

The P_{T7} probes are a standard part of the engine utilized for turbine discharge total pressure measurement. The P_{T7} probes are located in the primary or core exhaust, and are employed to sense engine power. The JT8D-11 engine incorporated six P_{T7} probes each with six small pressure sensing orifices. The probes are manifold together to provide an average pressure. A remotely operated valve was employed at the exit of the P_{T7} probe manifold for alternate pressure and emission measurement.

RESULTS

Emission measurements recorded from the JT8D-11 engine nozzle traverse and fixed probing tests have been previously reported in references 4, 6, and 7. Reference 4 presents emission concentrations from the 177-point traverses for idle, holding (low intermediate power used in the aircraft holding mode), approach, and maximum continuous power conditions. Reference 7 includes traverse maps, profile emission distributions, and probing results. Reference 6 covers traverse maps and probing test results. In addition to the emission measurements from the references, this report includes the complete data base corrected to standard ambient temperature (59° Fahrenheit (F)) and humidity (dry air) in accordance with reference 3. These results and additional probing results are presented in appendices A through E. The complete JT8D-11 engine data base is offered in the appendices for further analysis and comparison with other sources and to aid in the developement of probe designs for acquiring representative emission samples.

TRAVERSE CONTOURS.

Traverse measurements were acquired at power settings corresponding to: idle, holding, approach, and maximum continuous. Emission concentration maps of carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC), and nitrogen oxides (NO_x) are shown in figures 6 through 9. Wide variations in pollutant concentrations, steep gradients, and the resulting probing problems are apparent. The distorted diamond shape of the emission patterns are thought to be caused by the four bearing support struts located on the vertical and horizontal centerlines. Total hydrocarbon measurements at idle power are believed to be low as a result of traverse measurements with 1-minute stabilization time per point. The 1-minute period has since been determined to be insufficient for the measurement across steep THC gradients. Stabilization times of 3 to 4 minutes were required for subsequent THC measurements on another mixed flow engine with similar gradients.

In an effort to create a uniform profile for a more accurate assessment of the average emission levels, a series of tests were conducted with the pipe 36 inches in diameter and 20 feet in length, positioned behind the engine exhaust nozzle. A 3-inch clearance between the mixer pipe and the nozzle permitted the pipe to operate as an augmenter tube. Idle power traverses of 61 points were conducted at the exit of the pipe or mixer. Figure 10 is a map of the pollutant concentrations. Considerable mixing has taken place as shown by the change in patterns and the significant reduction in gradient.

TABLE 1. CRUCIFORM PROBE SAMPLE VELOCITY AND HOLE LOCATION

Probe	Calculated Sample Velocity (ft/s)	Sample Orifice Immersion Depth (in.)
12 Points, Area Weighted for 26-inch Nozzle Diameter	140	9.70 5.80 3.15
8 Points, Combination of Two Inner 12-Point Holes	211	9.70 5.80
16 Points, Combination of Inner Points of 12- and 24-Point Probes	106	11.20 9.70 8.50 6.60
24 Points, Area Weighted for 26-inch Nozzle Diameter	70	11.20 8.50 6.60 5.05 3.75 2.55
24 Points, Combination of Area Weighted Inner Points of 12- and 24-Point Probes	70	11.20 9.70 8.50 6.60 5.80 5.05

TRAVERSE PROFILES.

Traverse profiles were established by averaging four traverse emission measurements acquired from constant radius positions each separated by 90°. Additional points were averaged by varying the radius or corresponding immersion depths. Traverse emission measurements on the four radii at 45°, 135°, 225°, and 315° were averaged for each of six (including the centerline measurement) immersion depths along the radii. A second group of traverse emissions measurements located along the four radii coinciding with the vertical and horizontal centerlines were averaged for each of eight (including the centerline measurement) immersion depths. Ratios were then established by dividing the four averaged emission concentrations at each immersion depth by the overall 177-point traverse average concentration. Ratios of emission concentrations were then plotted against immersion depth for 45° and for 90° (figures 11, 13, 15, 17, 19, 21, 23, and 25). The emission index was then calculated for each of the averaged concentrations as previously determined. Ratios of emission indices to the overall traverse average indices were determined at each immersion depth, and the ratios were plotted against immersion depth (figures 12, 14, 16, 18, 20, 22, 24, and 26). Two sets of idle profiles were included since this is a special case involving separating of the species.

The concentration profile plots show the steep emission gradients in the exhaust of the mixed flow JT8D-11 turbofan engine. At low power, the gradients show approximately 25 percent change in emission levels per inch immersion depth. Slopes were investigated in the area of traverse average levels where the average emission ratio is one. The gradients increased to 34 and 45 percent change in emission levels per inch immersion depth for NO_x and CO_2, respectively, at maximum continuous power.

The figures also show that the average levels of the emission species are separated according to power level. In general, at low power, CO_2 and NO_x are separated from the CO and THC. The levels of CO and THC at a specific point are not in proportion to the levels of CO_2 and NO_x. CO and THC are generated in the combustion chamber as a result of flame quenching. Quenching of CO and THC may occur to a significant extent in the cooling film along the combustor inner surfaces, particularly at idle power with low temperatures and low fuel-to-air ratios. Carbon dioxide and NO_x, on the other hand, are generated in the primary combustion or flame front, and are located in greater concentrations toward the center of the combustion chamber. The problems of acquiring a representative sample utilizing fixed probing is compounded by this separation of the emission species.

A trend is evident from examining the profile concentration plots. On the 45° radii, the immersion depth for average emissions remains approximately constant as power is increased, notwithstanding the separation of emissions at idle power. The immersion depth for average emissions on the vertical and horizontal centerlines decreases or moves outward approximately 2 inches as power is increased to maximum continuous. The emissions modulate outward along the centerlines as power is increased.

The profile illustrations of emission index ratio show that the rate of emission change with respect to immersion depth has signifiantly decreased from the high gradients of the concentrations profiles. Further, the slopes have changed direction and become negative. Under low engine power conditions, the CO EI, THC EI, and NO_x EI profile ratios are separated except at the immersion depth where the ratio was equal to 1 and the emission indices were representative of the traverse average. As previously discussed, this separation of the emission species compounds the problem of representative emission sampling with fixed probes. The immersion depth for emission index agreement with the traverse has increased, compared to the depth where the concentration agrees with the traverse average. Under high engine power conditions, the ratios of CO EI and NO_x EI remain fairly close together and constant with immersion depth. The THC EI ratio at high power is believed to be in error as the very-low levels are affected by background in the sample and measurement systems. The high THC EI ratios in the fan bypass areas (outer periphery) are produced by atmospheric methane and CO_2. The carbon balance relationships produce emission indices of nine and above from atmospheric methane and CO_2. When these values are ratioed with low traverse average levels, high ratios are calculated and are not representative of the products of combustion emitted by the engine under test.

CRUCIFORM AND DIAMOND PROBE CALCULATIONS.

Two area weighted cruciform sample probe designs were investigated from interpolations of the traverse maps. The first cruciform probe design was area weighted for the full 30-inch diameter nozzle utilized for test of the JT8D-11 engine. The calculated performance of the cruciform probe was based on 12 sample points, three in each leg. Calculations were completed for a probe sampling on the radii 45°, 135°, 225°, and 315°, identified as the 45° angular position. The second location was on radii of 0°, 90°, 180°, and 270°, and identified as the 90° angular location. The performance results, as related in percent to the traverse average on a concentration and emission index basis, are tabulated in table 2. Also included are sample efficiencies defined as the fuel-to-air ratio from the exhaust emission carbon balance to the measured fuel-to-air ratio expressed in percent. This parameter is a measure of representative emission sampling. As shown in table 2, calculated performance of the area weighted cruciform probe designed for a 30-inch diameter nozzle was considered excellent, based on the percent difference with the traverse average indices. However, the traverse average concentrations performance was poor and varied with engine power. On the 45-angular position, sample efficiency was good at low power and decreased to low values at high power.

The second cruciform probe design was area weighted for a 26-inch effective nozzle diameter. The outer 2-inch area in the exhaust plume consists of fan bypass air and because of representative sampling consideration, was precluded from the design. As previously discussed, cruciform probes of this design had been used by EPA in previous JT8D engine emission tests. Interpolations and calculations for this design were also completed for the 45° and 90° angular positions on the basis previously discussed. The results are presented in table 3. Calculated emission indices for the 26-inch diameter probe were also considered excellent, especially when located on the 45° angular position. The samples were rich when compared to the traverse average on a concentration and sample efficiency basis. As is evidenced by the differences in concentrations between the 45° and 90° angular positions, both cruciform probe designs are very sensitive to orinentation.

A diamond-shaped probe was recommended by the FAA in reference 7 for sampling exhaust emissions from mixed flow turbofan engines. The probe was designed to clear the exhaust centerbody which is common on a number of aircraft installed engines incorporating plug exhaust nozzle designs. The diamond probe design included 12 sample points, three in each nozzle quadrant, separated by the radius divided by nine. The diamond probe is depicted in figure 27. The first probe design investigated sampled at 62 percent of the nozzle radius, with the center points located on the 45°, 135°, 225°, and 315° radii, referred to as the 45° angular position. The results are tabulated in table 4.

The recommended diamond-shaped probe configured to sample at 62 percent of the nozzle radius will provide representative samples at power conditions of holding, approach, and maximum continuous. Because of the separation of the species at low power, the CO and NO_x concentrations will be low. A correction factor of 1.11 was recommended by reference 7 to bring the concentrations at idle power up to traverse average levels. This would also reduce the calculated CO EI to 99.2 percent of the traverse average and the THC EI to 105.0 percent.

To solve the problem at idle power, a second diamond probe design was investigated which sampled at 53 percent exhaust nozzle radius. Otherwise, the second probe design was similar to the first diamond probe. The results of interpolations and calculations of the traverse maps are presented in table 4. The results show good agreement with the traverse indices. The samples were rich; however, containing high volumetric concentrations and high sample efficiencies.

TRAVERSE EMISSION INDICES AND EFFICIENCIES.

Calculated indices corrected for ambient temperature and humidity for the 177-point nozzle traverse, the mixer traverse, and core probes are tabulated in table 5. Actual levels presented do not apply to current JT8D engines since the test vehicle had been modified to incorporate high smoke combustion chambers and fuel nozzles. Measurement or sample efficiency is defined as the ratio of carbon balance fuel-to-air ratio to the measured fuel-to-air ratio and the results expressed in percent. The efficiency parameter emphasizes the CO_2 content of the sample. An error of 10 percent in CO_2 measurement will also result in a 10 percent error in the carbon balance fuel-to-air ratio and will produce an error of 11.6 percent in the pollutant indices.

Sample efficiency is included in table 5 for the traverse and core measurement averages. Under low power, the efficiencies of the two nozzle traverses were 104.5 and 103.3 percent, slightly rich, and as power increased, sample efficiency decreased to 94.4 percent, slightly lean. The calculated efficiencies assumed correct measurement of the fuel and air.

Efficiencies of samples from the core probes were determined by using a nominal fan bypass

TABLE 2. CALCULATED CRUCIFORM PROBE PERFORMANCE--12 POINTS AREA WEIGHTED FROM THE TRAVERSE MAPS FOR 30-INCH DIAMETER

Mode	Angular Position (Degrees)	Run No.	Percent Traverse Concentration CO_2	CO	THC	NO_x	Percent Traverse EI CO	THC	NO_x	Sample Efficiency $\frac{F/A_{CB}}{F/A_M}$ X100 (%)
Idle	45	124	94.9	96.3	97.8	93.7	101.3	102.8	96.9	99.2
Holding	45	125	97.4	99.6	98.2	92.5	102.5	101.3	95.1	104.4
Approach	45	121	90.3	90.3	91.7	89.8	100.6	100.0	101.6	92.0
MCP	45	123	80.9	84.3	---	85.0	104.3	---	105.0	76.3
Idle	90	124	114.2	117.4	112.1	110.9	102.8	98.0	95.3	119.4
Holding	90	125	113.7	115.9	122.3	114.0	102.2	108.0	100.3	121.9
Approach	90	121	130.5	129.7	115.2	127.3	99.9	88.6	99.6	133.2
MCP	90	123	129.4	124.1	---	134.4	103.9	---	103.9	121.9

TABLE 3. CALCULATED CRUCIFORM PROBE PERFORMANCE--12 POINTS AREA WEIGHTED FROM THE TRAVERSE MAPS FOR 26-INCH DIAMETER

Mode	Angular Position (Degrees)	Run No.	Percent Traverse Concentration CO_2	Percent Traverse Concentration CO	Percent Traverse Concentration THC	Percent Traverse Concentration NO_x	Percent Traverse EI CO	Percent Traverse EI THC	Percent Traverse EI NO_x	Sample Efficiency $\frac{F/A_{CB}}{F/A_M}$ X100 (%)
Idle	45	124	120.1	122.2	121.2	115.9	101.7	101.1	94.9	125.6
Holding	45	125	122.7	119.5	120.5	118.8	97.7	98.7	97.0	131.6
Approach	45	121	119.9	116.7	97.7	117.9	97.9	80.0	100.5	122.3
MCP	45	123	109.7	111.1	---	109.0	101.4	---	99.3	103.6
Idle	90	124	143.8	146.4	133.8	133.9	101.9	93.0	91.4	150.4
Holding	90	125	145.4	147.9	141.5	141.2	101.9	97.6	97.4	156.1
Approach	90	121	168.5	164.7	127.0	161.3	98.2	74.3	97.9	172.3
MCP	90	123	164.5	156.0	---	165.6	95.0	---	100.7	155.8

TABLE 4. CALCULATED DIAMOND PROBE PERFORMANCE--12 POINTS INTERPOLATED FROM TRAVERSE MAPS

Mode	Angular Position (Degrees)	Run No.	Percent Radius	Percent Traverse Concentration CO_2	CO	THC	NO_x	Percent Traverse EI CO	THC	NO_x	Sample Efficiency $\frac{F/A_{CB}}{F/A_M}$ X100 (%)
Idle	45	124	62	85.1	93.6	99.3	86.3	109.4	115.9	99.2	89.3
Holding	45	125	62	94.0	92.4	99.7	84.6	98.6	106.5	90.2	100.7
Approach	45	121	62	88.5	90.9	99.2	86.2	103.2	97.5	99.6	90.1
MCP	45	123	62	105.4	102.2	---	104.0	97.1	---	98.6	99.5
Idle	45	124	53	137.0	138.8	134.1	135.4	101.3	97.8	97.3	143.7
Holding	45	125	53	137.5	144.3	140.9	114.1	104.0	101.7	96.1	149.3
Approach	45	121	53	147.7	147.1	106.7	145.1	100.1	---	100.3	150.9
MCP	45	123	53	146.7	139.6	---	145.3	95.4	---	98.5	138.8

ratio of 1.06:1 for calculating the fan airflow from the total airflow measured in the bellmouth. Under low power, the efficiency of the core probes was near ideal and decreased with the increased power. These results may be in error as the bypass ratio is expected to vary with engine power changes.

Mixer pipe traverse indices are included in table 5. Mixer THC EI is significantly greater than that of the engine traverse, and agrees with that of the core probes. The 1-minute stabilization time was sufficient for accurate measurement with the significant reduction in gradients across the mixer pipe. The THC EI from the mixer traverse is believed to be more representative of the engine because of accurate measurement resulting from less change in levels and significant reduction in gradients.

The fuel-to-air ratios calculated from the exhaust gas carbon balance are plotted versus the measured fuel-to-air ratios in figure 28 for the engine traverse and core probes. Sample efficiency of the engine traverse is also indicated in relation to the deviation from the ideal relationship.

The deviation shown in figure 28 of the carbon balance fuel-to-air ratio from the measured fuel-to-air ratio in the mixer traverse measurements is an indication of secondary air dilution in the mixer pipe. Secondary air dilution in the mixer pipe was not measured. Calculations using the ideal line as a reference indicated that secondary air dilution was 17.6 percent.

CRUCIFORM PROBE TEST RESULTS.

Sample efficiency and differences in performance of the cruciform probe configurations relative to the nozzle traverse are tabulated in table 6. The emission measurements were corrected to zero humidity and standard compressor inlet temperature in accordance with referrence 3. The traverse runs of 119 and 124 were selected for probe evaluation with the exception that the THC EI from the mixer traverse was utilized in the analysis since, as previously discussed, the measurements were considered to be more representative of the actual emissions.

Sample efficiency of the 12-point probe was excellent when aligned with the vertical and horizontal centerlines. The comparison of the EI between the 12-point probe and the traverse was poor. The poor performance is disturbing, particularly in view of the high indicated sample efficiencies. Attention is directed to the CO_2 measurements, each 5.6 percent less than that of the traverse. The excess CO and THC must have balanced out the effect of the low CO_2 on the calculation of the fuel-to-air ratios in the carbon balance relationship. A computer run was made to calculate emission indices with the traverse pollutant concentrations held constant and CO_2 varied at the following amounts: 5 percent low, 10 percent low, 5 percent high, and 10 percent high. The results are presented in figure 29. Entering the illustration at 5.6 percent low CO_2 (0.67 percent), the CO EI and THC EI have increased 6.4 and 6.8 percent, respectively.

The conclusion of this analysis is that the 12-point probe at 0° and at the 2-inch axial location sampled average concentrations of CO and hydrocarbons (in relation to the mixer traverse) and were deficient in CO_2 by 5.6 percent. Samples from the 12-point probe were low by 5.5 percent in NO_x. These results are not surprising in view of the separation of the species at idle power.

The eight-point cruciform probe consisted of the eight inner sample orifices of the 12-point probe. This probe was ranked number 1 in performance when positioned on the diagonals at 45°, and number 2 when positioned along the vertical and horizontal centerlines. The probe results are ranked in table 6, based on the difference of the three-pollutant EI's from the traverse average. Sample efficiency at 45° was 119.4, which indicates the sample was somewhat rich. When the probe was aligned with the vertical and horizontal centerlines, sample efficiency was 178.2, which indicates a very rich sample with the majority of the sample coming from the core.

Performance of the area weighed, 24-point probe was extremely poor. The errors of the 12-point probe were magnified several times. The 24-point combination probe acquired rich samples of THC and CO, but performed better than the 24-point area weighted probe.

The 16-point combination probe consisted of the inside points of both the 12- and 24-point probes. All of the probe points were inside the outer holes of the eight-point probe. The 16-point probe at 0° obtained 82 percent of the sample from the core. The THC EI essentially agreed with the traverse, CO EI and NO_x EI, however, were higher than the traverse levels. Performance of the 16-point probe when located at 22.5° and 45° was worse than when located at 0°.

The comparison of test results of the 12 point, 26-inch diameter cruciform probe (table 6) with the calculated results (table 3) was very poor. With the probe located at the 45° angular position, the calculated CO_2 at idle power was 120.1 percent of the traverse average or 0.85 percent CO_2. This compares to the measured

TABLE 5. TRAVERSE EMISSION INDICES AND EFFICIENCIES--HIGH SMOKE COMBUSTION CHAMBERS

Mode	Probe	Run No.	Observed Emission Indices lbs/1000 lbs Fuel			CO_2 (%)	F/A(M)	F/A(CB)	Sample Efficiency (%)	t_2 (°F)	Corrected Emission Indices lbs/1000 lbs Fuel		
			THC	CO	NO_x						THC	CO	NO_x
Idle	Nozzle Traverse	124	18.7	62.9	2.56	0.71	.00344	00360	104.5	46	15.9	58.9	2.94
Idle	Nozzle Traverse	119	19.6	63.9	2.56	0.71	.00348	00360	103.3	42	16.0	58.8	3.09
Idle	Mixer Traverse	136-139	23.6	62.8	2.28	0.55	.00343	0028	-----	46	20.3	59.0	2.81
Idle	Core	124	23.0	64.8	2.42	1.39	.00344	00715	101.1	46	19.7	60.7	2.83
Holding	Nozzle Traverse	125	4.6	38.4	3.05	0.75	.00346	00370	107.0	47	3.0	35.0	3.66
Holding	Core	125	7.3	36.4	3.86	----	.00346	-----	-----	47	4.8	33.2	4.53
Approach	Nozzle Traverse	121	0.4	8.4	5.66	0.83	.00395	0040	101.8	36-54	.40	8.1	6.71
Approach	Core	121	0.0	7.6	5.59	----	.00395	00758	93.2	36-54	--	7.3	6.63
MCP	Nozzle Traverse	123	0.1	2.8	11.02	1.29	.00662	00625	94.4	29	--	2.1	14.20
MCP	Core	123	0.0	2.7	11.37	2.50	.00662	0122	89.5	29	--	2.0	14.65

TABLE 6. CRUCIFORM PROBE TEST RESULTS--IDLE POWER--HIGH SMOKE COMBUSTION CHAMBERS

Probe	Axial Distance (in.)	Angular Position (degrees)	Run No.	Mixer THC EI	Corrected THC EI	Corrected CO EI	Corrected NO_x EI	Sample Efficiency (%)	% Difference to Nozzle Traverse THC	% Difference to Nozzle Traverse CO	% Difference to Nozzle Traverse NO_x	Rank	CO_2 (%)
Nozzle Traverse	2	--	124	20.3	15.9	58.9	2.94	104.5	--	--	--	--	.71
Nozzle Traverse	2	--	119	20.3	16.0	58.8	3.09	103.3	--	--	--	--	.71
12 Point	2	0	148	--	21.8	62.57	2.85	100.9	+7.4	+6.3	-5.5	8	.65
12 Point	2	22 1/2	147	--	23.2	61.4	3.28	40.9	+14.3	+4.2	+8.8	10	.27
12 Point	2	45	146	--	21.9	63.1	2.95	60.3	+7.9	+7.3	-2.2	4	.40
12 Point	2	90	149	--	23.4	65.4	2.85	101.8	+15.3	+11.1	-5.5	8	.67
12 Point	8	0	137	--	23.1	63.8	2.95	100.0	+13.8	+8.4	-2.2	6	.67
12 Point	8	0	139	--	21.7	64.4	2.90	97.7	+6.9	+9.4	-3.8	6	.67
12 Point	8	45	145	--	22.1	60.5	3.26	98.0	+8.9	+2.8	+8.1	5	.37
12 Point	12	0	150	--	19.7	62.8	2.82	99.1	-3.0	+6.7	-6.5	3	.67
8 Point	8	0	140	--	18.2	58.8	3.01	178.1	-10.3	-0.1	-1.7	2	1.20
8 Point	8	0	141	--	18.6	60.5	2.87	178.4	-8.4	+2.8	-4.8	2	1.20
8 Point	8	45	143	--	19.1	61.5	2.91	118.1	-5.9	+4.5	-3.5	1	.80
8 Point	8	45	144	--	19.2	59.5	3.04	120.9	-5.4	+1.1	+0.8	1	.77
16 Point Combination	12	0	153	--	20.2	63.9	2.60	169.4	-0.5	+8.6	-13.8	7	1.15
16 Point Combination	12	22 1/2	155	--	22.1	66.2	2.63	116.5	+8.9	+12.5	-12.8	12	.77
16 Point Combination	12	45	154	--	21.4	63.8	2.63	121.4	+5.4	+8.4	-12.8	9	1.40
24 Point	12	0	151	--	25.9	73.6	2.52	76.7	+27.6	+25.0	-16.4	13	1.42
24 Point Combination	12	0	152	--	21.8	63.8	2.53	122.1	+7.4	+8.4	-16.1	11	.82

values of 0.37 and 0.40 percent CO_2 presented in table 6. When the cruciform probe was positioned at 90°, the calculated CO_2 was 1.02 percent and the measured was 0.67 percent. Reference is made to table 1 and the sample orifice size of 0.089-inch diameter which produces velocities at the orfices of 140 feet per second for the 12-point probe. This compares to the engine exhaust velocity of approximately 400 feet per second at idle power. Test results of a similar mixed-flow turbofan engine has shown that the total pressure in the fan bypass area was greater than the total pressure in the core exhaust at idle power. Therefore, the sample quantity from the outer point (3.15 inch immersion) of the cruciform probe is considered to exceed the flow from the points located in the core exhaust, resulting in dilution of the sample. This problem is evident from the test results in table 6 which show that the performance of the cruciform probes improves as the number of sample orifices decreased. Testing the cruciform probes installed in the up-stream end of the mixer pipe is considered to have caused additional mixing of fan bypass air into the core exhaust. A properly designed cruciform probe positioned in the exhaust without augmented mixer air could be expected to perform better than the test results shown in table 6.

CORE PROBE TEST RESULTS.

The corrected EI measurements from the core probes installed through the tailpipe on chords to sample only the primary or core gasses are compared to the traverse average across engine power ranges in figure 30. The core probes provided representative samples of CO and NO_x. The variability of the THC measurements at idle power was determined by calculation to be one standard deviation of 1.08 for a mean of 15.84 or 6.8 percent experimental error. The core probes provided representative samples of THC at idle power.

The core probe measurements were acquired concurrently with the testing of the cruciform probes and are listed in table 7. These results are included to permit further analysis of the cruciform probes. The order of the core probe measurements in table 7 corresponds to the grouping of the cruciform probe runs in table 6. Thirteen measurements from the core probes were also recorded at intervals during the nozzle traverse. The results of averaging these measurements are tabulated under run 124. Sample efficiency of the core probes averaged 101.9 percent as calculated on an equivalent dilution basis by utilizing the nominal fan bypass ratio and the total airflow measured in the bellmouth.

P_{T7} PROBE TEST RESULTS.

Testing to evaluate emission samples from the P_{T7} probes, which are an integral part of the engine, was conducted with the low smoke combustion chambers installed in the engine. Since the traverses and other test results were conducted with high smoke combustion chambers in the engine, the P_{T7} emission measurements are not directly compared with the data of the traverse or the core probes previously discussed.

The P_{T7} probes were evaluated by comparing emission sampling performance with data recorded simultaneously from the core probes. Measurements recorded for the P_{T7} probes and the core probes are shown in figures 31, 32, and 33. The carbon balance fuel-to-air ratios are plotted versus the measured fuel-to-air ratios in figure 31. This relationship shows that the P_{T7} probes provide samples richer than samples from the core. By relating the core probe performance to the traverse shown in figure 30, samples from the P_{T7} probes are higher than the traverse average. Carbon monoxide EI from the P_{T7} probes (figure 32) was somewhat higher (approximately 6 percent) than that from the core probes and traverse. Total hydrocarbon EI from P_{T7} probes was significantly higher (approximately 47 percent) than the core probes and traverse. Nitrogen oxides EI were only 3.5 percent higher than that of the core probes and traverse.

SUMMARY OF RESULTS

Emissions were measured on a 2-inch grid in the exhaust plume of the mixed flow JT8D-11 engine at four engine power settings from idle through maximum continuous. The objective was to establish a data base required for calculating average emissions, and to generate the emission maps and profiles required to design and evaluate fixed probing for acquiring representative samples. The emission profiles or gradients were unusually steep, with changes in emission levels of 25 to 45 percent-per-inch. Measurement efficiency of the traverses were slightly high or rich (2.4 to 4.6 percent) at low power and lean by 5.6 percent at high power.

The emission species were separated in relation to immersion depth at low power with CO and THC separated from CO_2 and NO_x. Separation of emissions further complicates the problem of acquiring average emission samples with fixed probes. When engine power is increased, emissions move outward along the vertical and horizontal centerlines; however, average emission

TABLE 7. CORE PROBE TEST RESULTS--IDLE POWER

Probe	Run No.	CO_2 (%)	Mixer THC EI	Corrected THC EI	Corrected CO EI	Corrected NO_x EI	Sample Efficiency (%)	(%) Difference to Nozzle Traverse THC EI	(%) Difference to Nozzle Traverse CO EI	(%) Difference to Nozzle Traverse NO_x EI
Nozzle Traverse	124	.71	20.3	15.9	58.9	2.94	104.5	--	--	--
Nozzle Traverse	119	.71	20.3	16.0	58.8	3.09	103.3	--	--	--
Core Probe	124	1.39	--	19.8	60.8	2.83	101.1	-2.5	+3.31	-6.14
Core Probe	148	1.35	--	20.4	61.2	2.72	101.8	+0.5	+0.40	-9.78
Core Probe	147	1.40	--	21.2	58.7	2.77	102.8	+4.43	-0.26	-8.12
Core Probe	149	1.40	--	19.8	60.3	2.67	103.2	-2.46	+2.50	-11.14
Core Probe	145	1.40	--	20.5	58.5	2.77	100.8	+0.98	-0.60	-8.13
Core Probe	150	1.37	--	19.5	60.0	2.62	98.6	-3.45	+1.95	-13.1
Core Probe	140	1.42	--	20.5	60.9	2.90	102.9	+0.98	+3.48	-3.81
Core Probe	141	1.40	--	21.4	63.17	2.73	101.6	+5.42	+7.34	-9.45
Core Probe	153	1.40	--	23.2	62.50	2.55	101.4	+14.3	+6.20	-15.4
Core Probe	155	1.40	--	23.2	62.0	2.49	--	+14.3	+5.35	-17.4
Core Probe	154	1.40	--	22.8	62.5	2.42	103.1	+1.23	+6.20	-19.7
Core Probe	151	1.42	--	22.9	61.9	2.34	103.1	12.80	+5.18	-22.4
Core Probe	152	1.40	--	23.2	61.4	2.39	102.1	+14.3	+4.33	-20.7

levels remain essentially constant with immersion depth on the 45° radii.

Calculations based on the traverse maps indicate that area weighted (30-inch nozzle) cruciform probes provide emission samples indices within 5 percent of the traverse average. Under high engine power conditions, the sample efficiencies and volumetric concentrations from the cruciform probe calculations were low in relation to that of the traverse.

Calculations show that the FAA recommended diamond-shaped probe should provide representative emission samples at power conditions of holding, approach, and maximum continuous. The calculated concentrations would have to be increased by 11 percent at idle power to be representative of the traverse average concentrations and emission indices. Calculations indicate that a diamond probe designed to sample at 53 percent nozzle radius would provide representative emission indices across engine power. The samples, however, would be rich with high efficiencies and volumetric concentrations.

The exit of a 20 foot exhaust mixer pipe was traversed for emissions at idle power. Considerable mixing occurred as noted by the change in patterns and significant reduction in gradients. This improvement of conditions would be expected to deteriorate with increased engine power as the result of reduced mixing.

Five cruciform probe configurations were investigated and installed for test in the upstream or forward end of the mixer pipe. The probes consisted of two types: (1) 12 points based on equal areas for a 26-inch diameter nozzle, and (2) 24 points also based on equal areas for a 26-inch diameter nozzle. The remaining probes are combinations of (1) and (2). Measurement efficiency of the 12-point probe was excellent when located at 0° with values near 100 percent. Comparison of performance with that of the traverse was poor. The THC and CO registered 8.1 to 8.4 percent high, while the NO_x showed 2.2 to 6.5 percent low. The problem was brought about in part by low CO_2 measurements which increases the calculated pollutant levels through the carbon balance relationship. The primary problem was attributed to low sample velocity of the cruciform probes.

The eight-point cruciform probe consisted of the two inner holes of the 12-point probe. This probe sampled 86 percent from the core. The THC were 5.4 to 10.3 percent less than that of the mixer traverse. The CO and NO_x were very close to that of the nozzle traverse. This probe was ranked number 1 in the cruciform family when aligned with the 45° radii, and and was ranked number 2 when aligned with the centerlines. The 16-point probe consisting of the four inner holes from both the 12-point probe and the 24-point combination probe was good for THC but high for CO and low for NO_x. The cruciform probes that sampled to a large extent from the core came closest to the traverse average.

At idle power, performance of the core probes, installed to sample only primary or core gasses, was 99.0 percent efficient. The core probes provided representative samples of emissions across engine power ranges, except for THC which was low at holding power.

The P_{T7} probes provided samples richer than the traverse average by as much as 47 percent.

CONCLUSIONS

Based on the results of the emission sample probe investigation of the JT8D-11 turbofan engine, it is concluded that:

1. Detailed traverses across engine power are required for emission measurements which are representative of the entire exhaust because of limitations existing in all fixed probing techniques.

2. Based on interpolations and calculations from the traverse maps:

a. A cruciform sample probe which is area weighted for the full exhaust nozzle will provide representative emission indices and volumetric concentrations and good sample efficiencies at low engine power, but nonrepresentative volumetric concentrations and poor sample efficiencies under high engine power conditions.

b. The recommended diamond-shaped sample probe will provide representative volumetric concentrations, good sample efficiencies, and good emission indices at high engine power, but the performance of the sample probe will be compromised at idle power.

c. The recommended diamond probe which was specifically designed to measure representative volumetric concentrations, would require resizing for optimum emission index measurements, but would then have poor sample efficiencies.

3. The exhaust pattern of mixed flow turbofan engines is characterized by steep emission gradients which significantly affects the representativeness of the sample provided by fixed probing techniques.

4. Test results indicate that the most representative emission indices which can be obtained from cruciform probes with large sample orifices are those designed to sample essentially from the undiluted core exhaust.

5. Performance of the cruciform probes tested was significantly poorer than that predicted from interpolations of the traverse contours, because these probes were designed with large sample orifices. Probe performance improved as the number of orifices was decreased, due to the resultant increase in the sample velocity through each orifice.

6. Core probes designed to sample undiluted exhaust gasses will provide representative emission indices but very high volumetric concentrations which are not representative averages for the entire exhaust nozzle area.

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5. Imbrogno, S. L. and Rust, T., Jr., Comparison of Exhaust Emission of a Low-Time JT8D-11 Engine: High-Smoke versus Low-Smoke Combustion Chamber Configurations, Technical Report FAA-RD-74-87, 1974.

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7. Klueg, P. E. and Slusher, G. R., Exhaust Emission Probe Investigation of a Mixed Flow Turbofan Engine, Technical Paper Presented before October, 1974, Meeting of the Instrument Society of America, New York, New York.

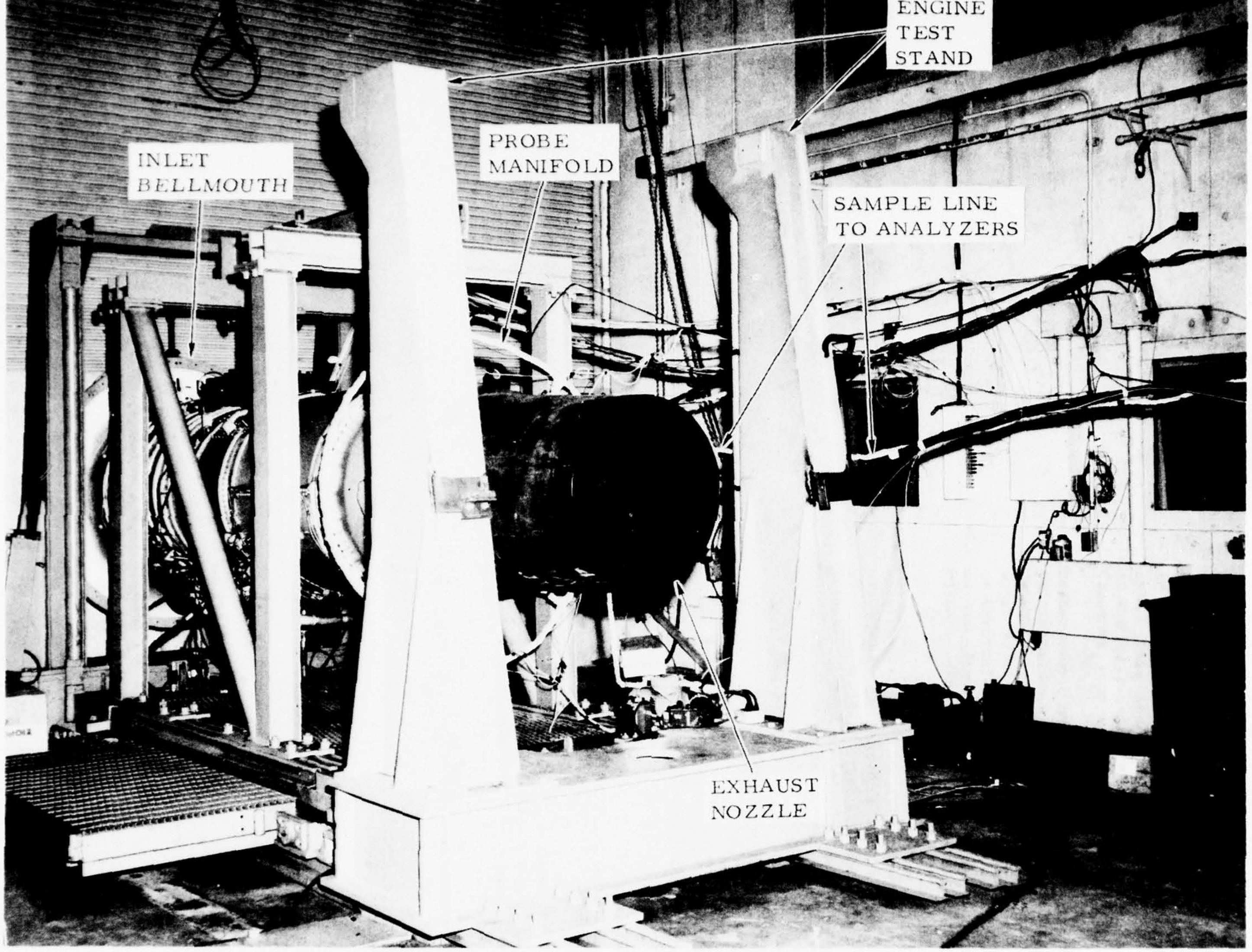

FIGURE 1. JT8D-11 ENGINE TEST INSTALLATION

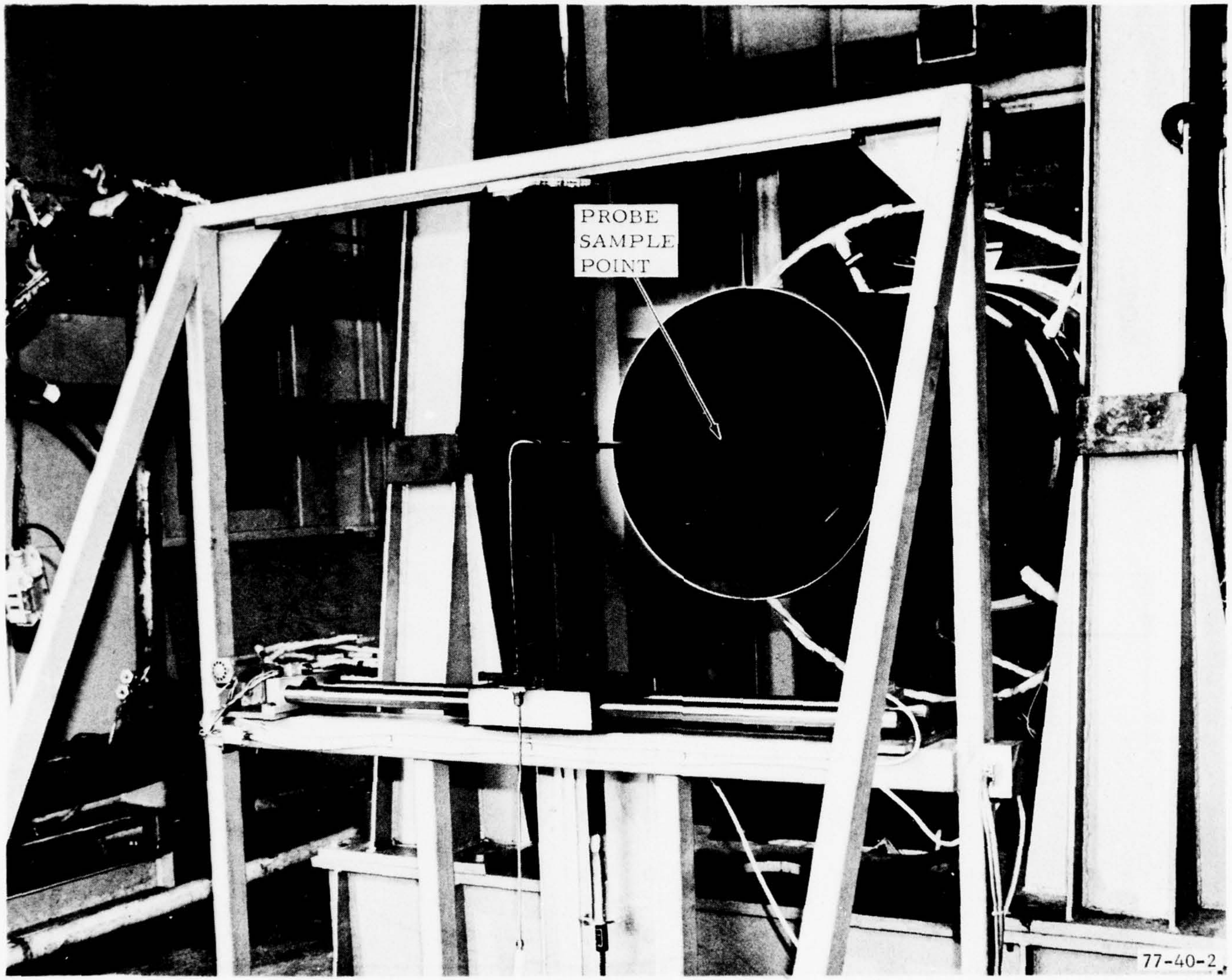

FIGURE 2. TRAVERSE PROBE MECHANISM

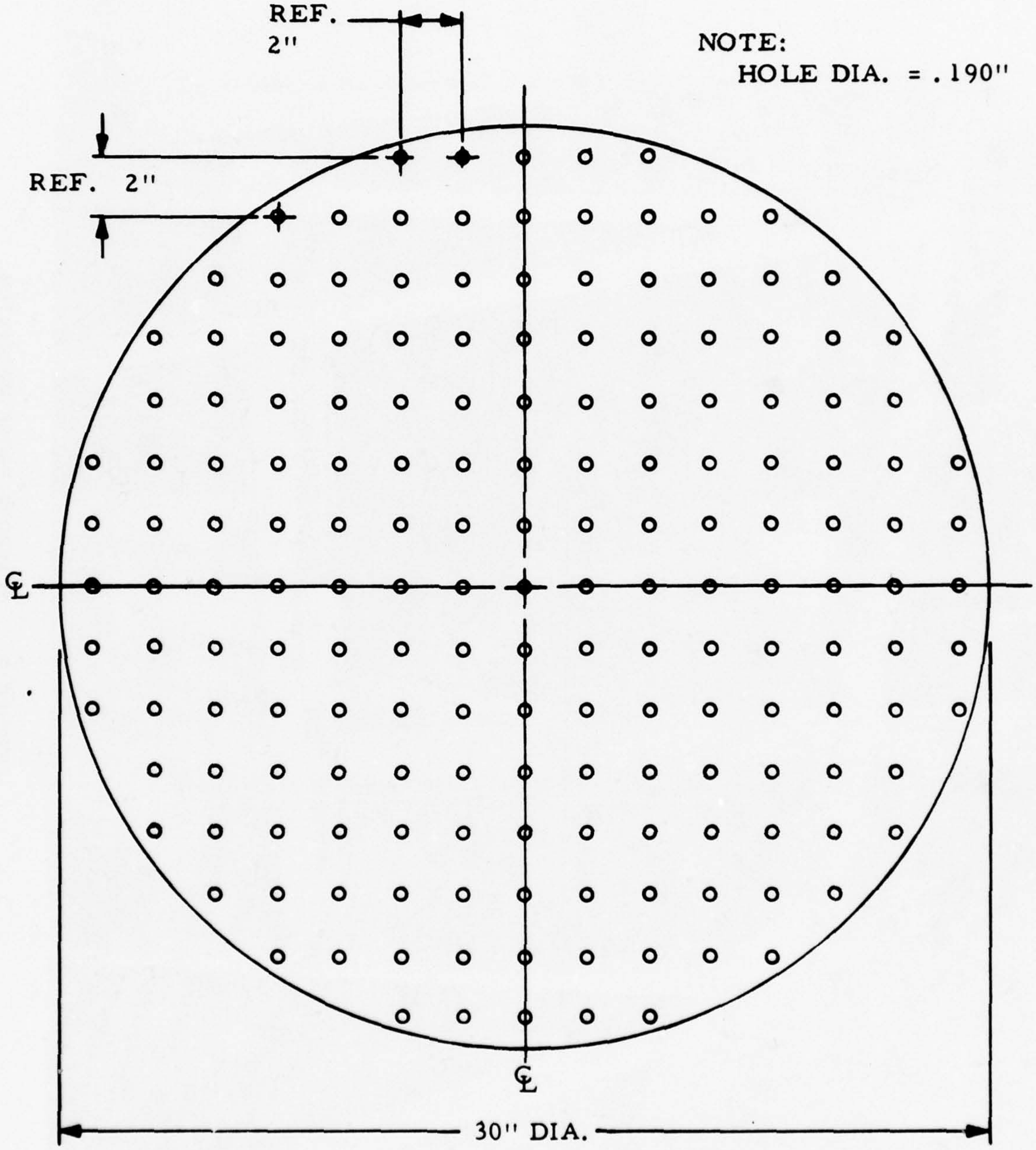

FIGURE 3. TRAVERSE EMISSION SAMPLE POINTS

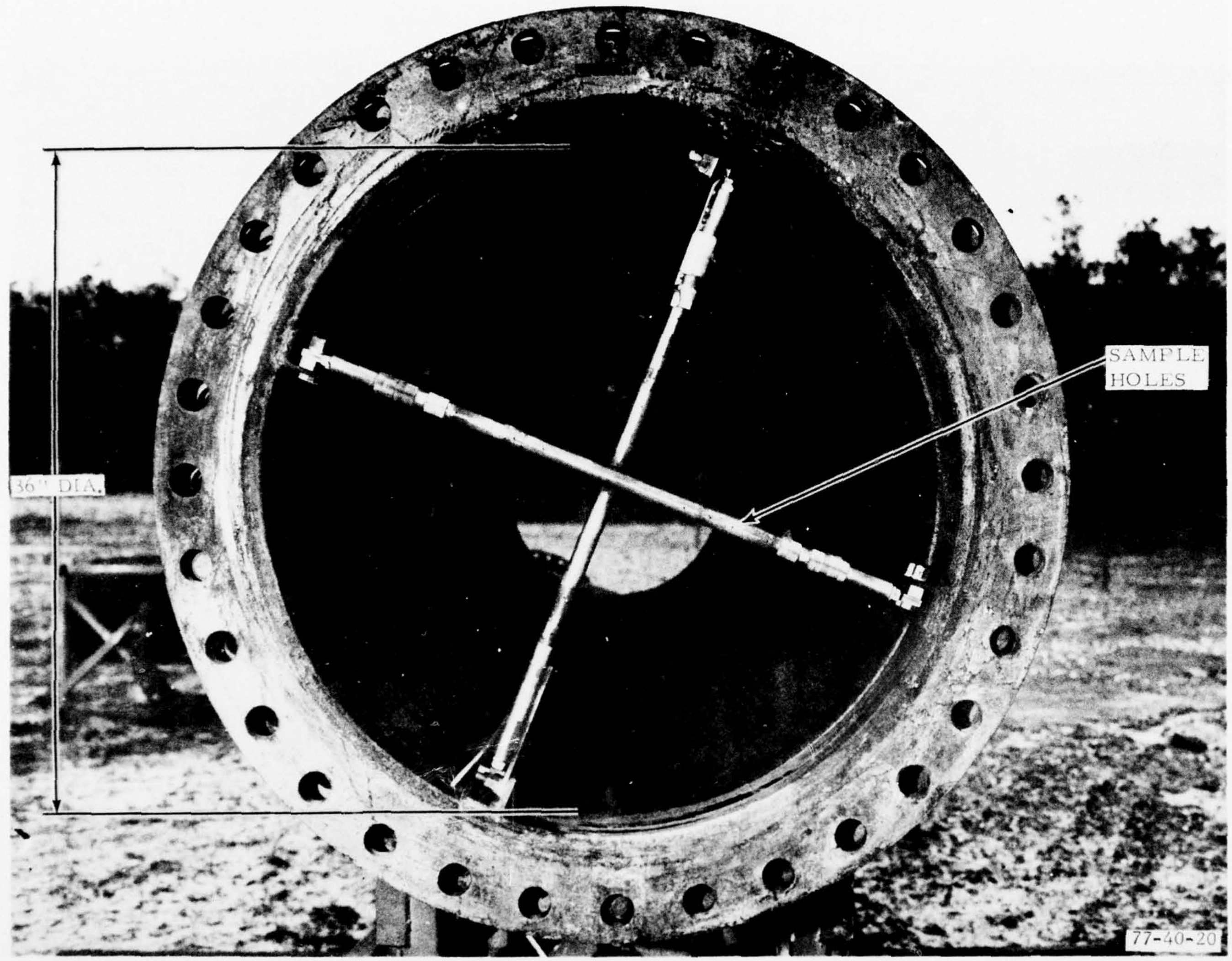

FIGURE 4. CRUCIFORM PROBE INSTALLED IN MIXER PIPE

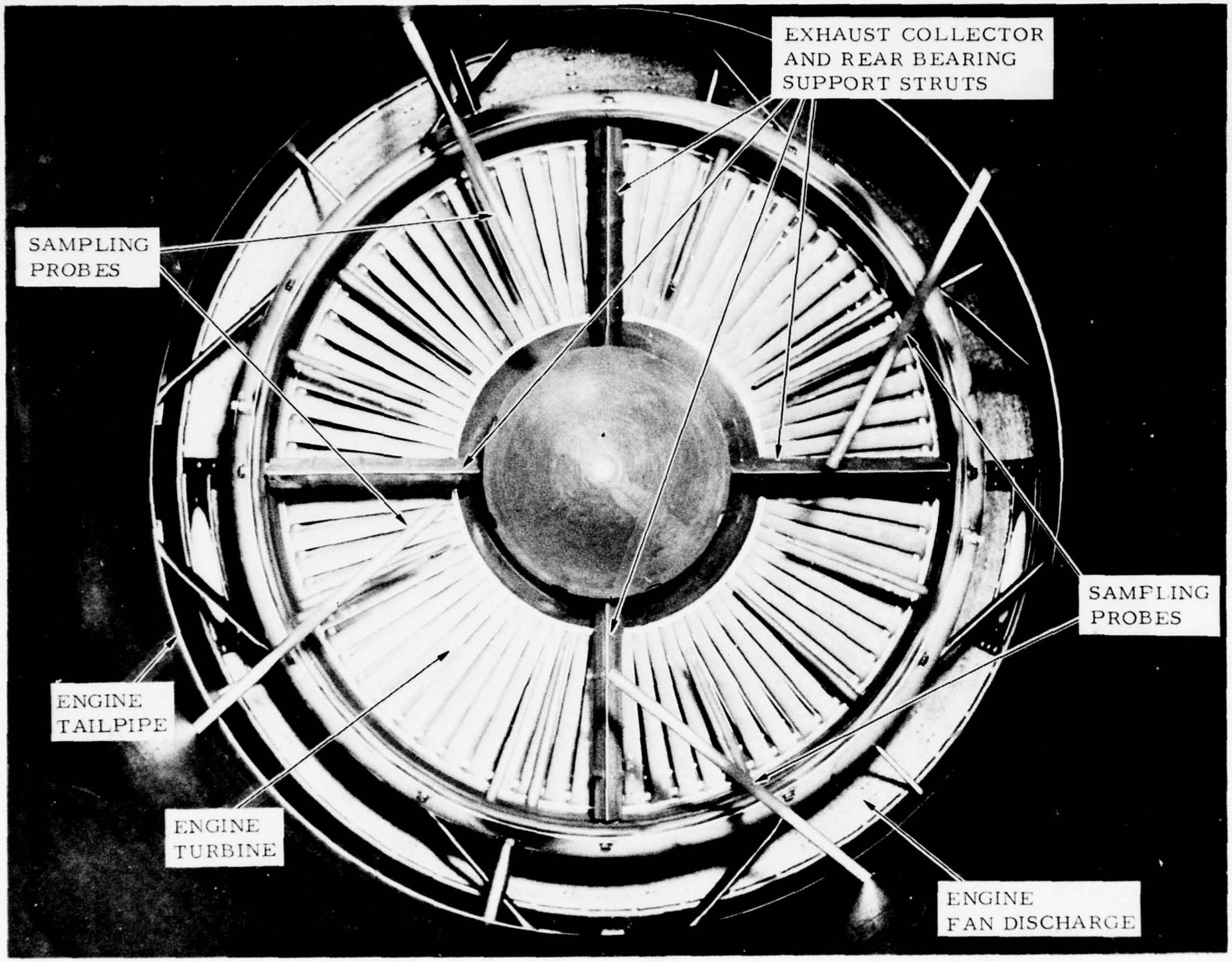

FIGURE 5. CORE EMISSION SAMPLE PROBES

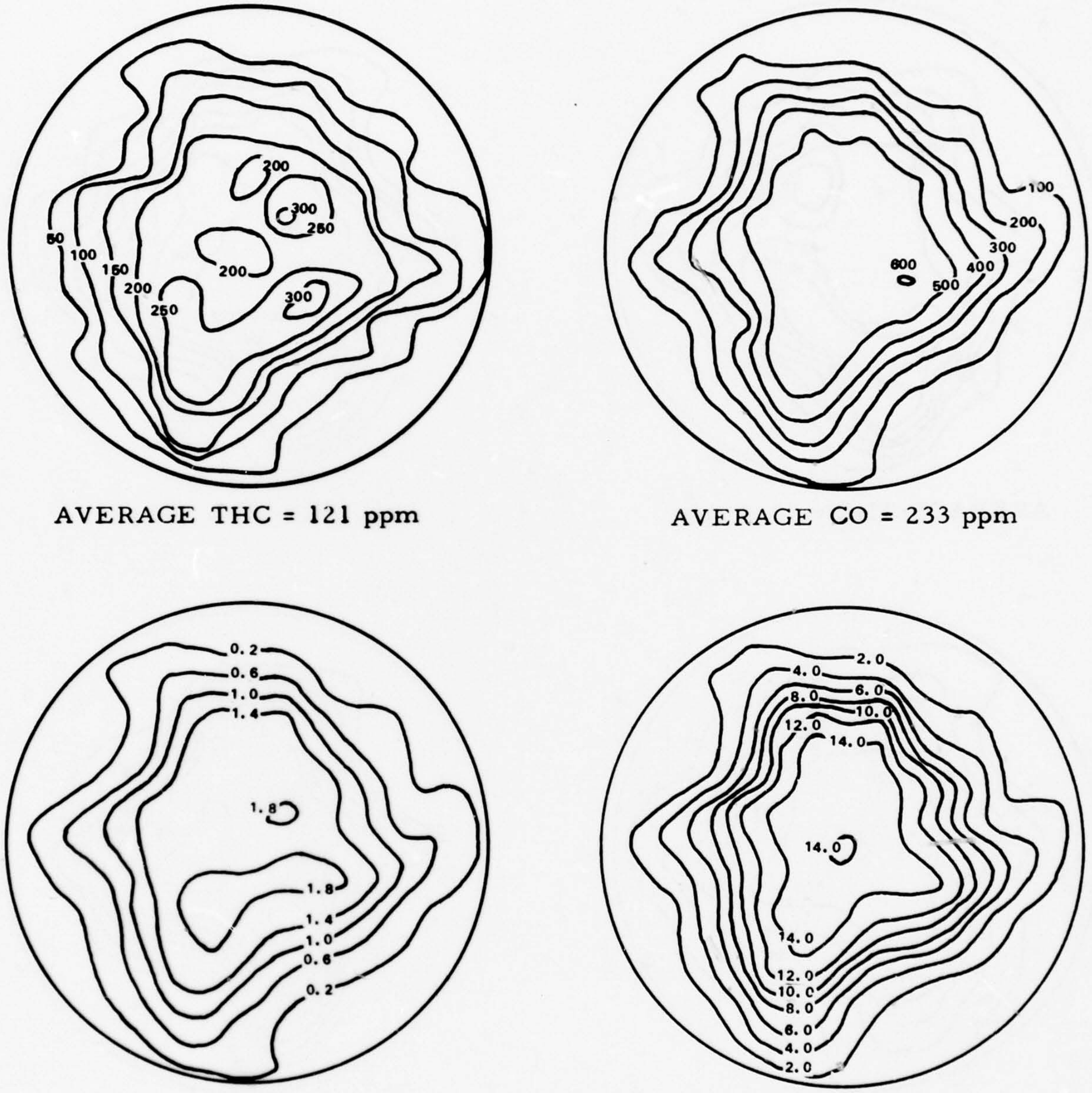

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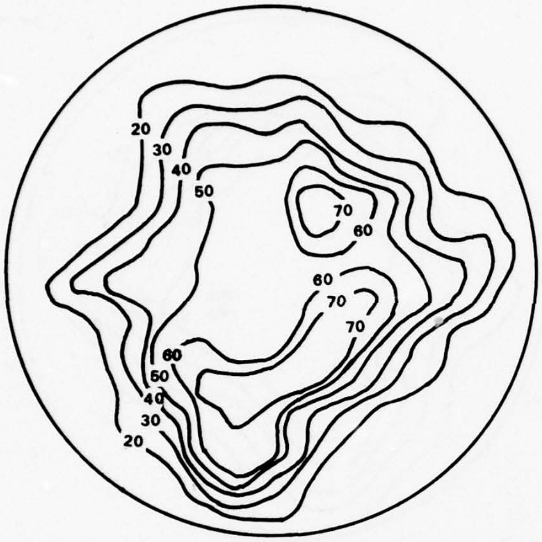
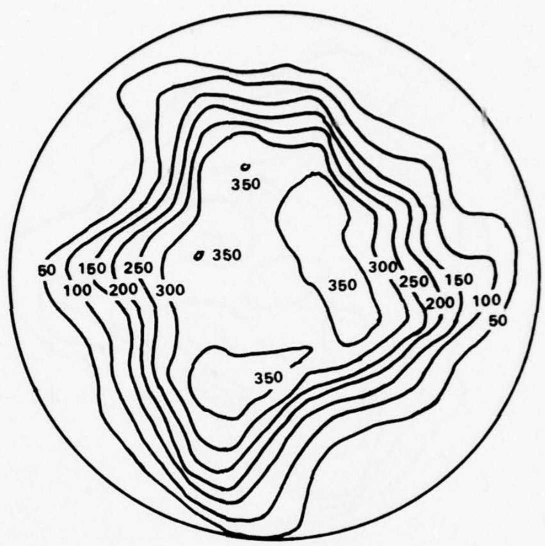
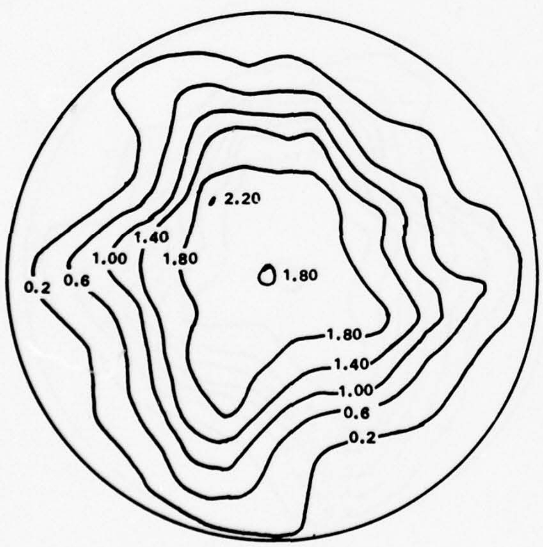
FIGURE 6. EXHAUST EMISSION TRAVERSE MAPS--IDLE POWER



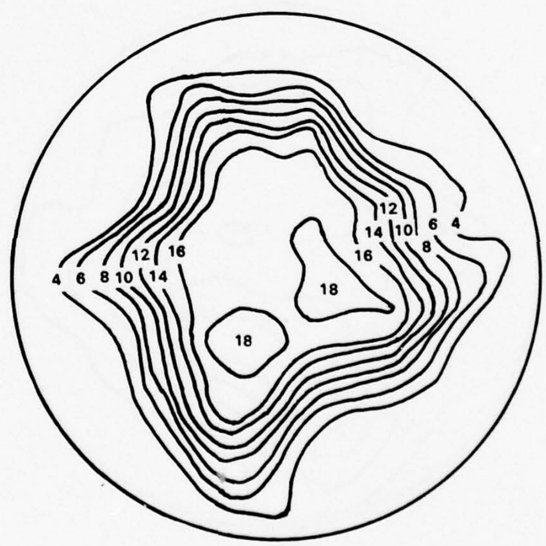
AVERAGE THC = 30.8 ppm



AVERAGE CO = 147 ppm



AVERAGE CO_2 = 0.75%



AVERAGE NO_x = 7.1 ppm

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FIGURE 7. EXHAUST EMISSION TRAVERSE MAPS--HOLDING POWER

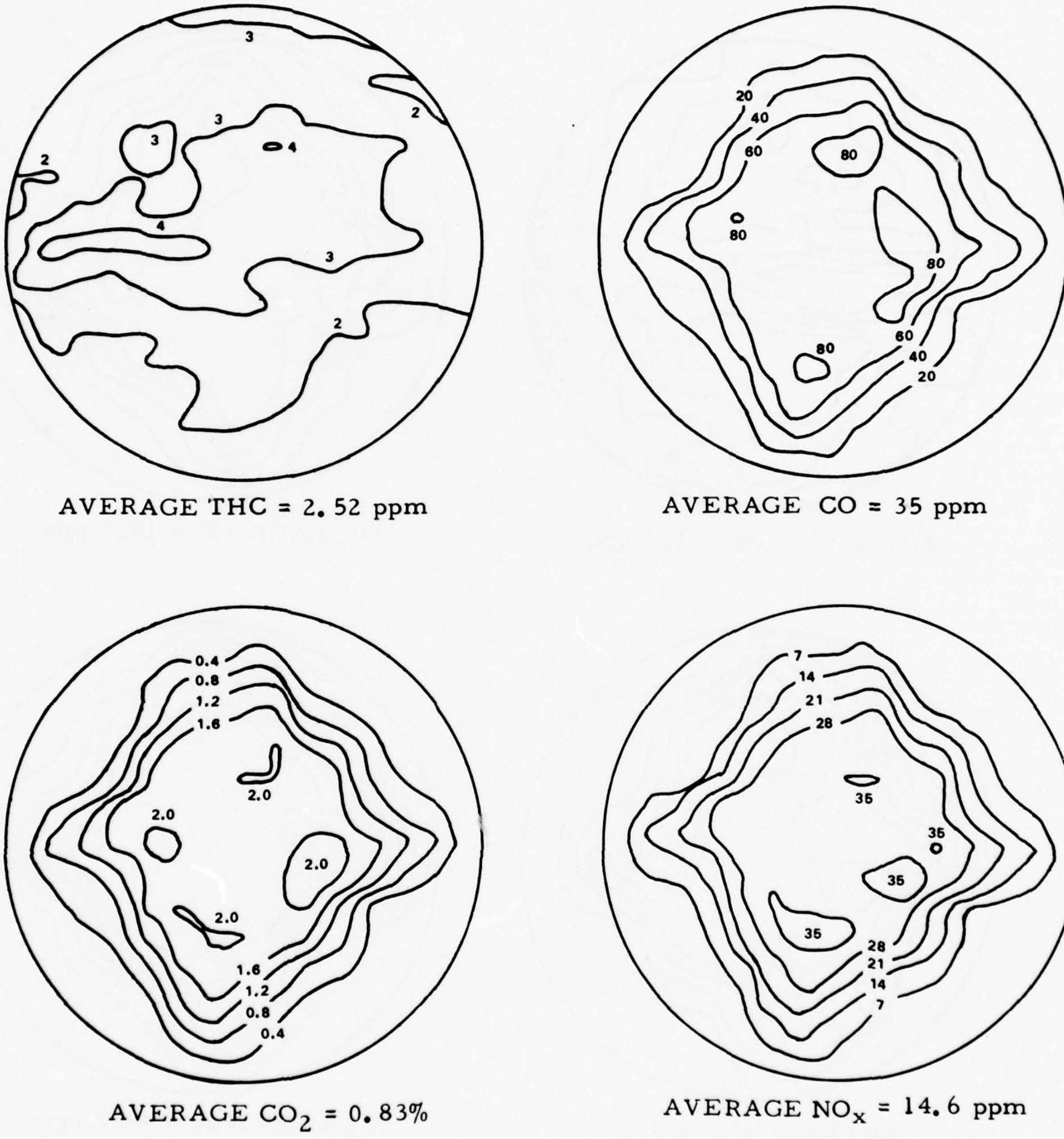

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FIGURE 8 EXHAUST EMISSION TRAVERSE MAPS--APPROACH POWER

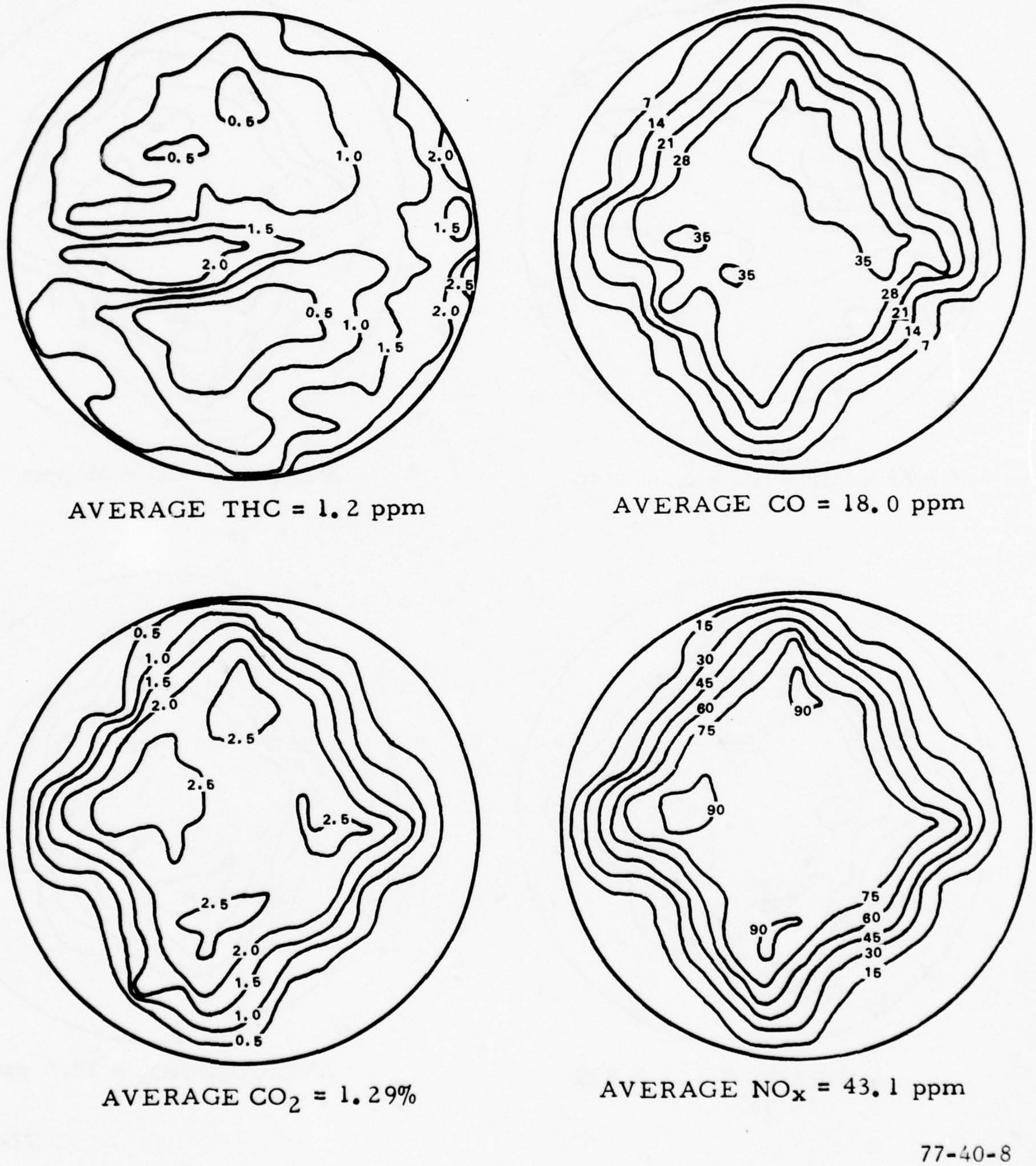


FIGURE 9. EXHAUST EMISSION TRAVERSE MAPS--MAXIMUM CONTINUOUS POWER

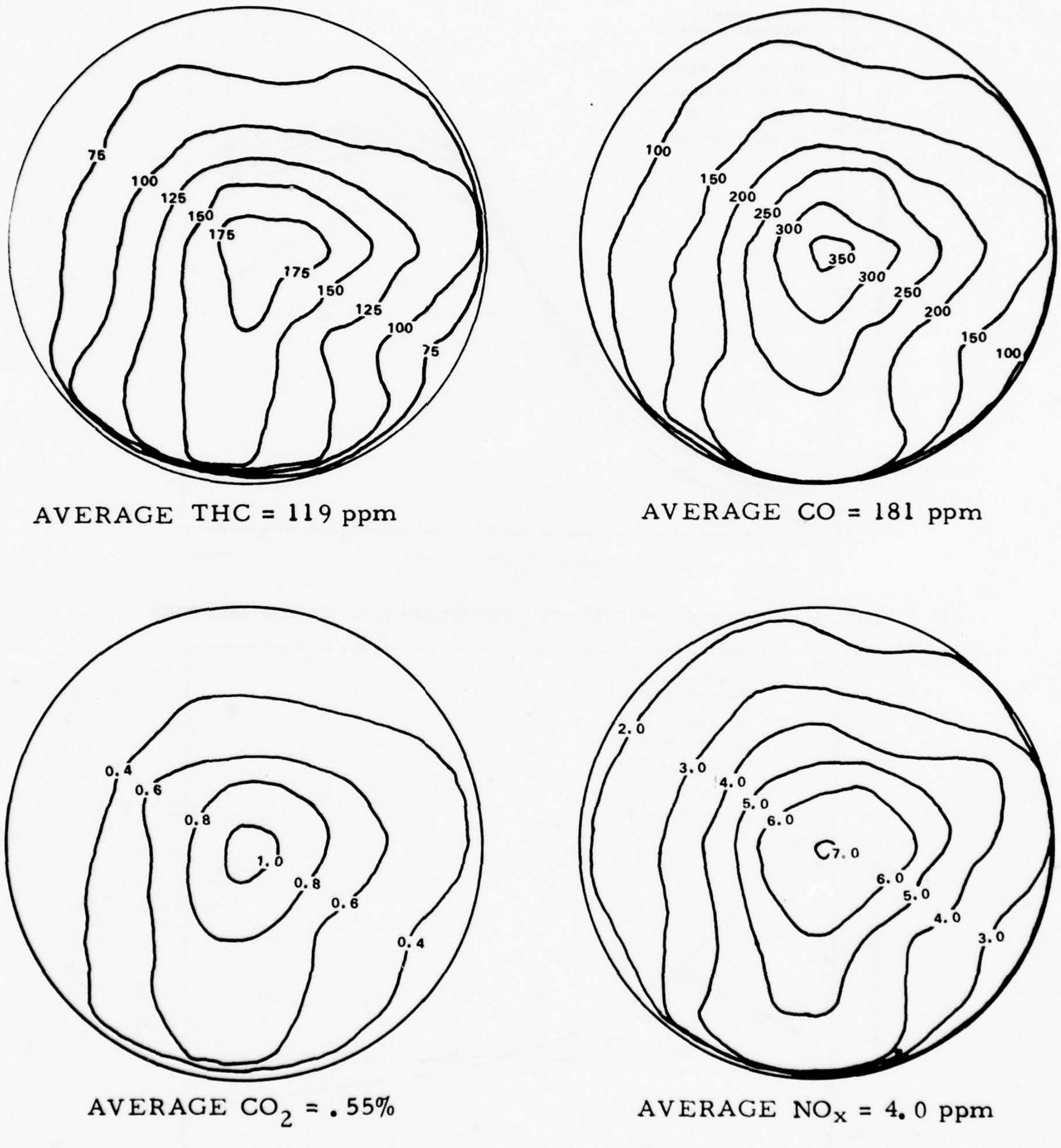


FIGURE 10. MIXER-TRAVERSE MAPS--IDLE POWER

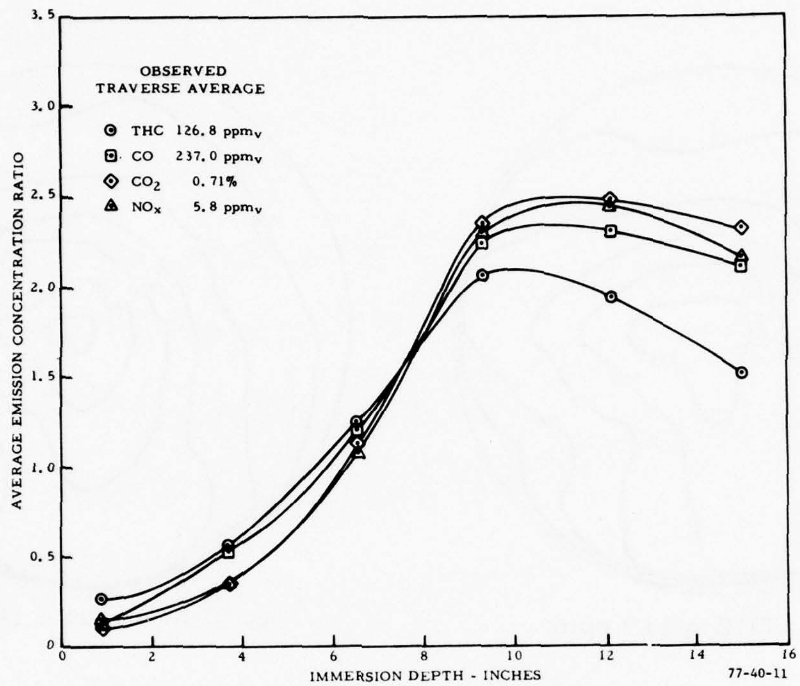


FIGURE 11. EMISSION CONCENTRATION DISTRIBUTION--45°, RUN 119--IDLE POWER

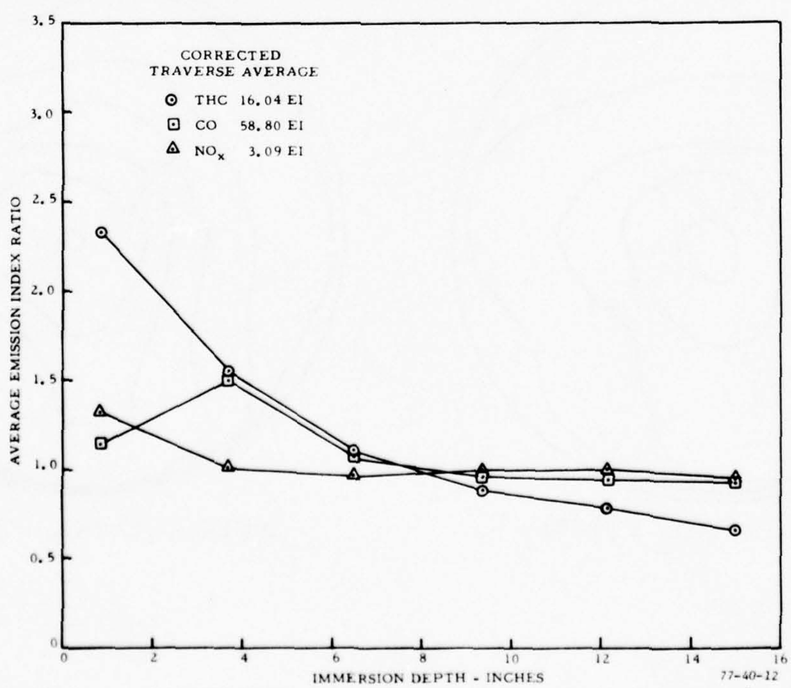


FIGURE 12. EMISSION INDEX DISTRIBUTION--45°, RUN 119--IDLE POWER

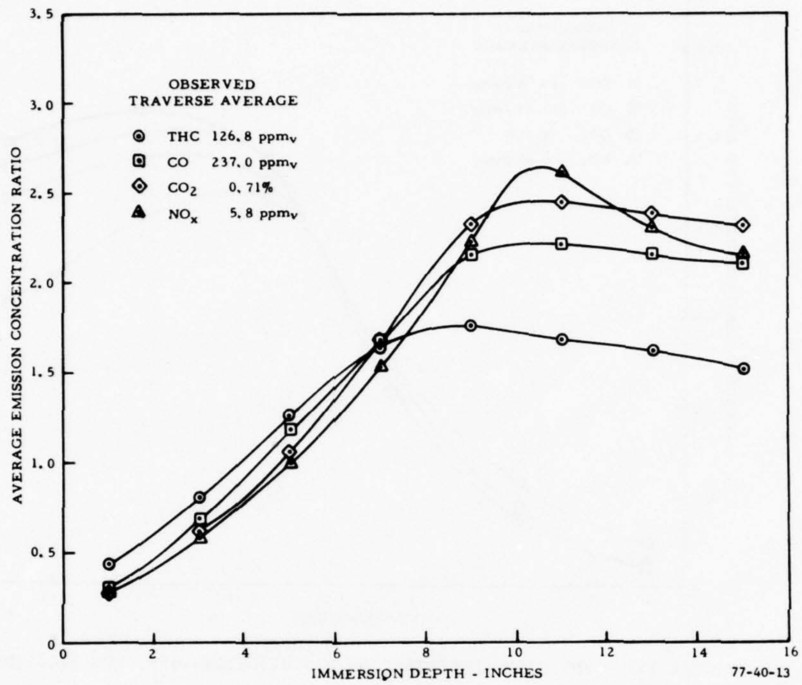


FIGURE 13. EMISSION CONCENTRATION DISTRIBUTION--90°, RUN 119--IDLE POWER

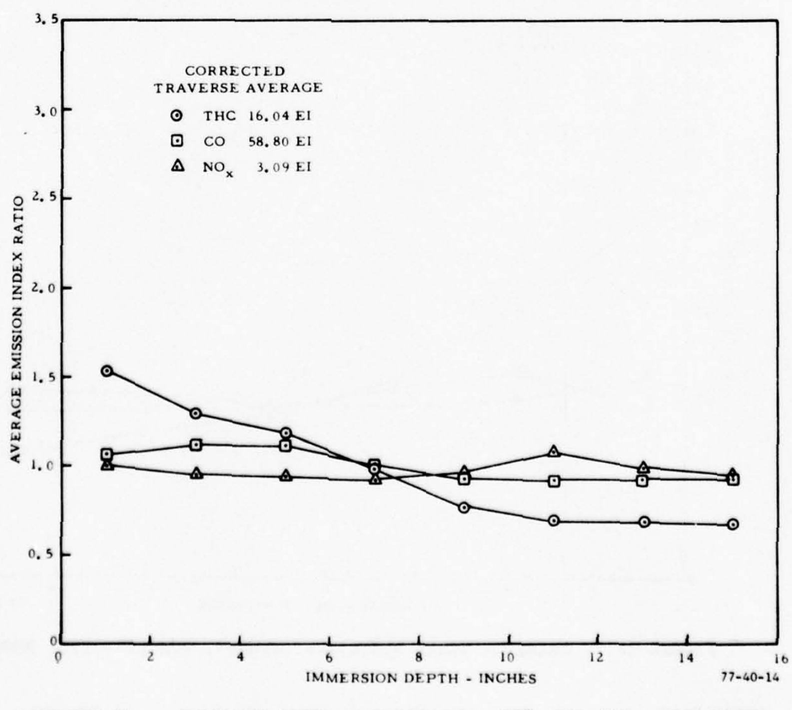


FIGURE 14. EMISSION INDEX DISTRIBUTION--90°, RUN 119--IDLE POWER

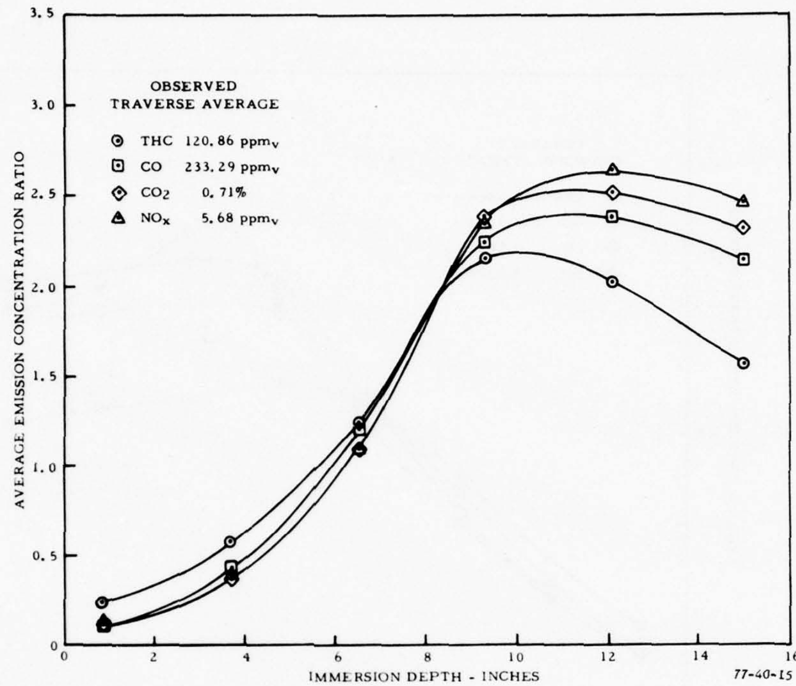


FIGURE 15. EMISSION CONCENTRATION DISTRIBUTION--45°, RUN 124--IDLE POWER

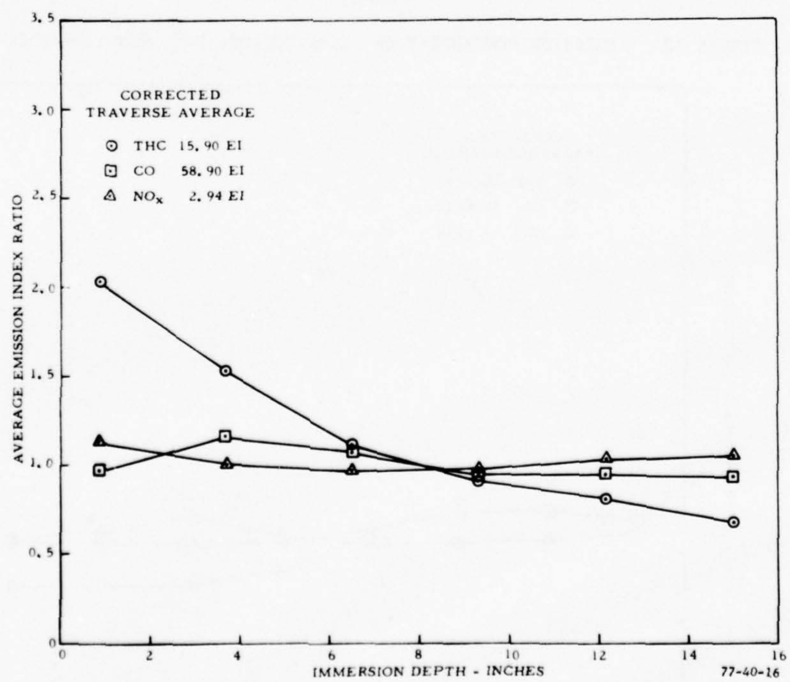


FIGURE 16. EMISSION INDEX DISTRIBUTION--45°, RUN 124--IDLE POWER

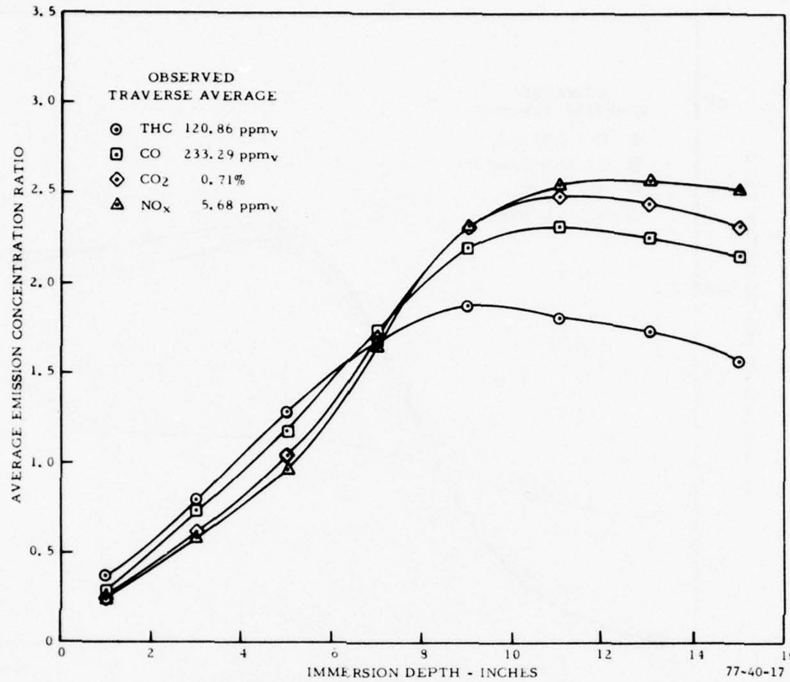


FIGURE 17 EMISSION CONCENTRATION DISTRIBUTION--90°, RUN 124--IDLE POWER

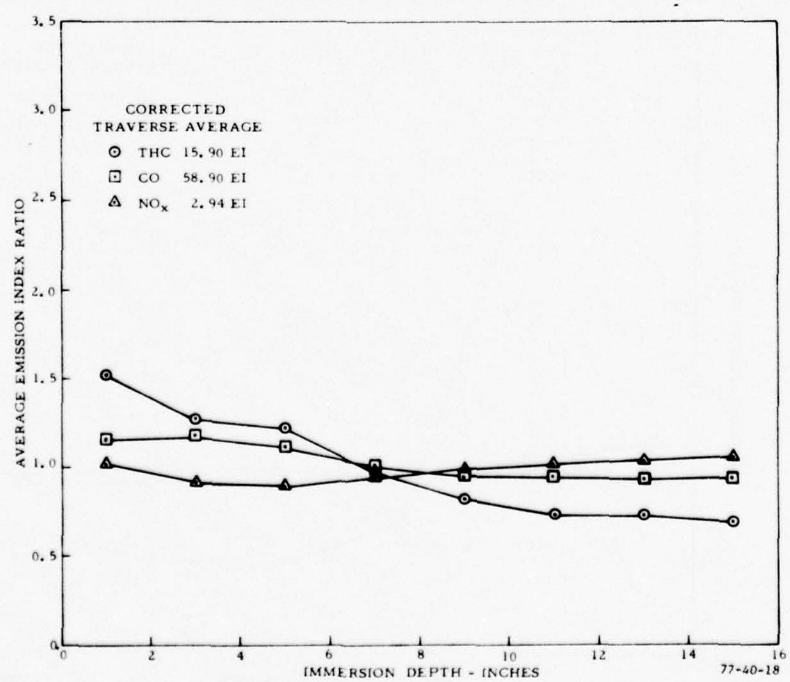


FIGURE 18. EMISSION INDEX DISTRIBUTION--90°, RUN 124--IDLE POWER

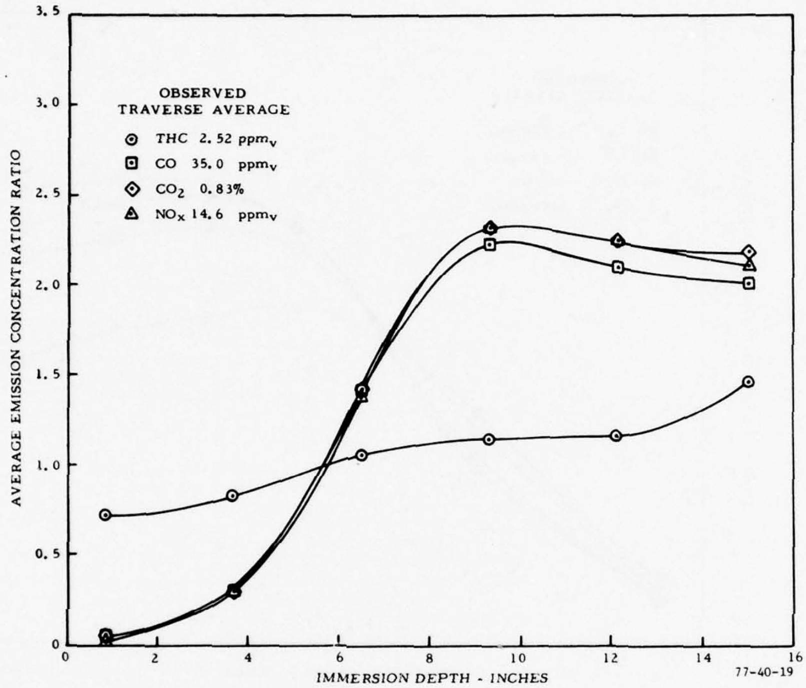


FIGURE 19. EMISSION CONCENTRATION DISTRIBUTION--45°--APPROACH POWER

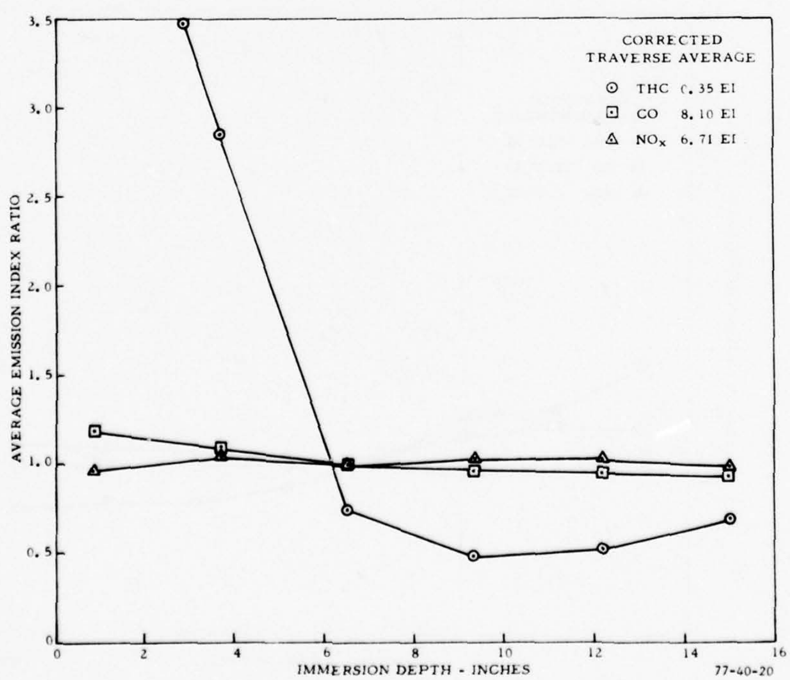


FIGURE 20. EMISSION INDEX DISTRIBUTION--45°--APPROACH POWER

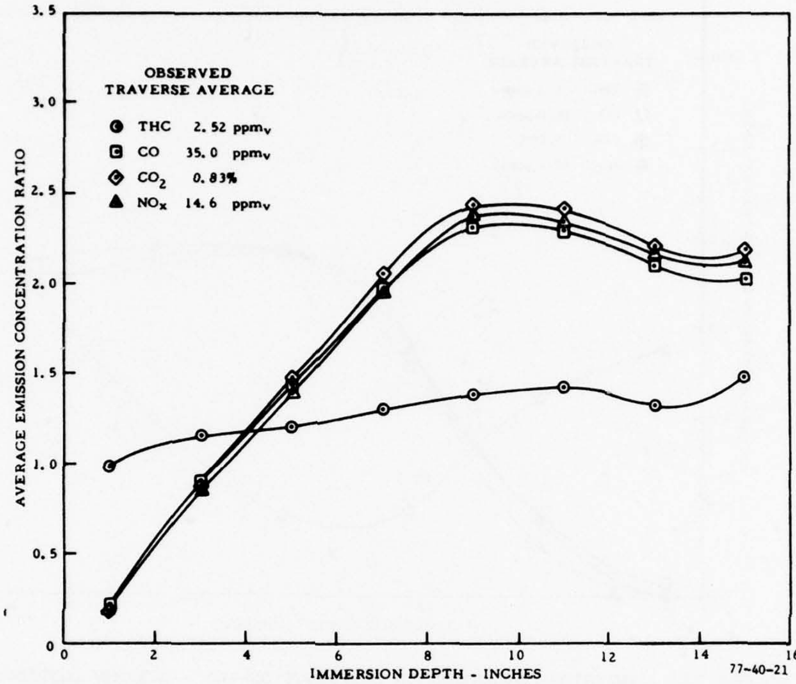


FIGURE 21. EMISSION CONCENTRATION DISTRIBUTION--90°--APPROACH POWER

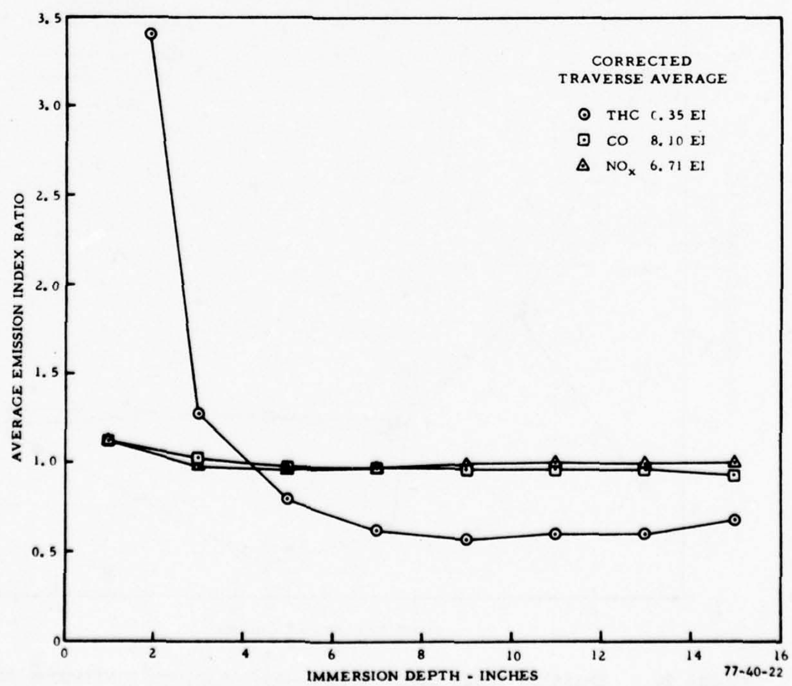


FIGURE 22. EMISSION INDEX DISTRIBUTION--90°--APPROACH POWER

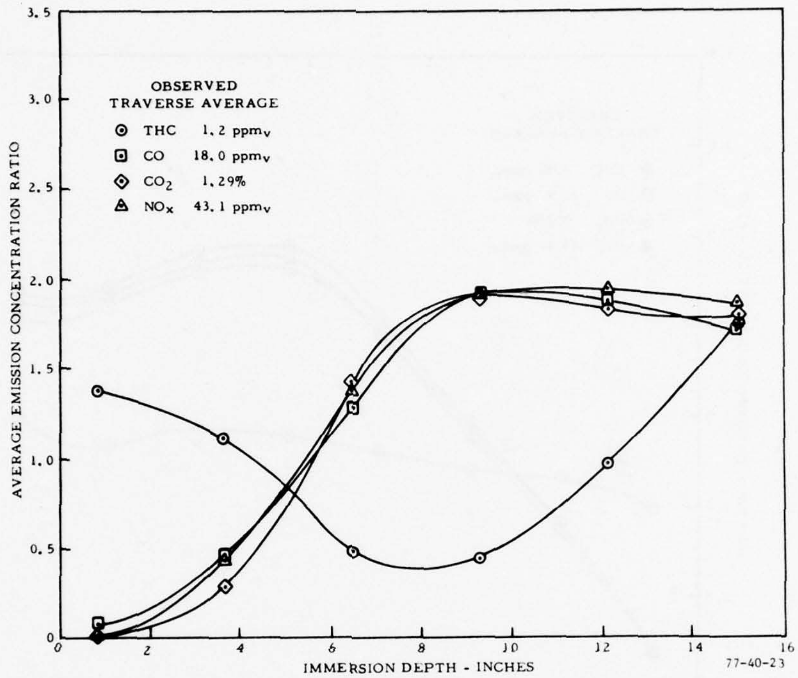


FIGURE 23. EMISSION CONCENTRATION DISTRIBUTION--45°--MAXIMUM CONTINUOUS POWER

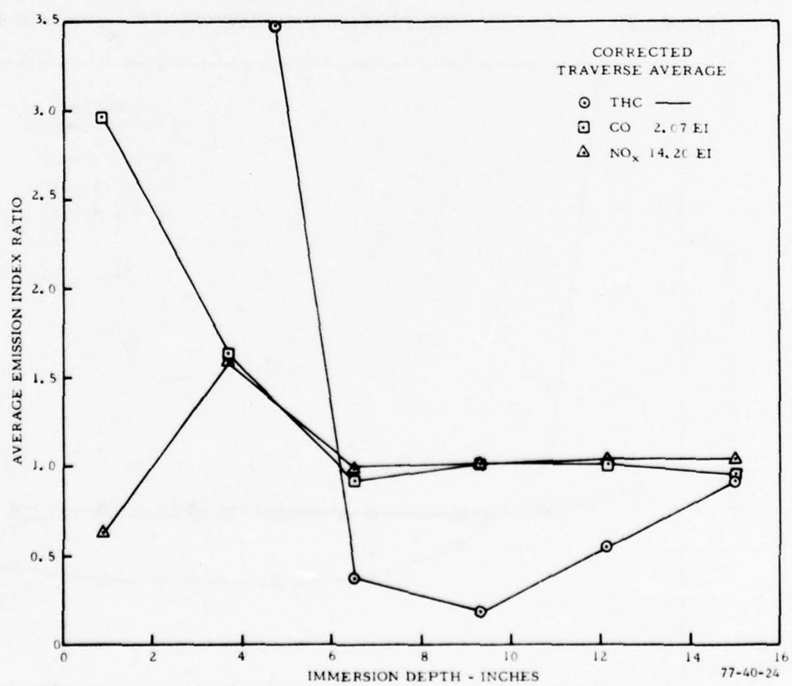


FIGURE 24. EMISSION INDEX DISTRIBUTION--45°--MAXIMUM CONTINUOUS POWER

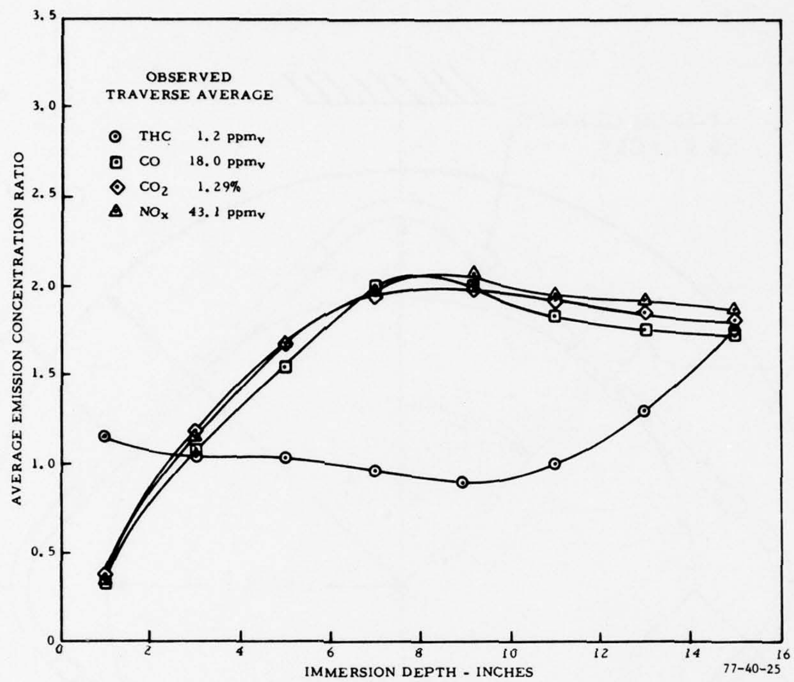


FIGURE 25. EMISSION CONCENTRATION DISTRIBUTION--90°--MAXIMUM CONTINUOUS POWER

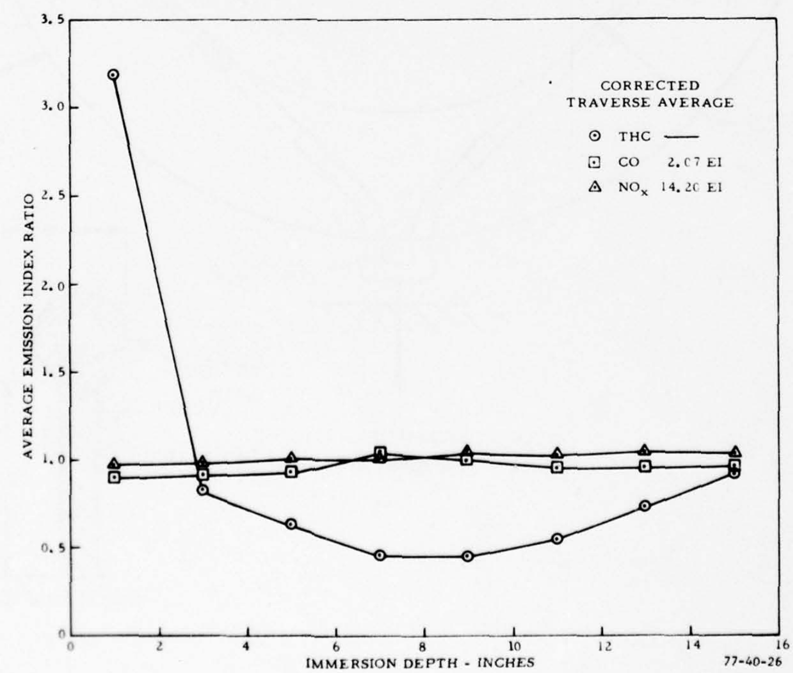


FIGURE 26. EMISSION INDEX DISTRIBUTION--90°--MAXIMUM CONTINUOUS POWER

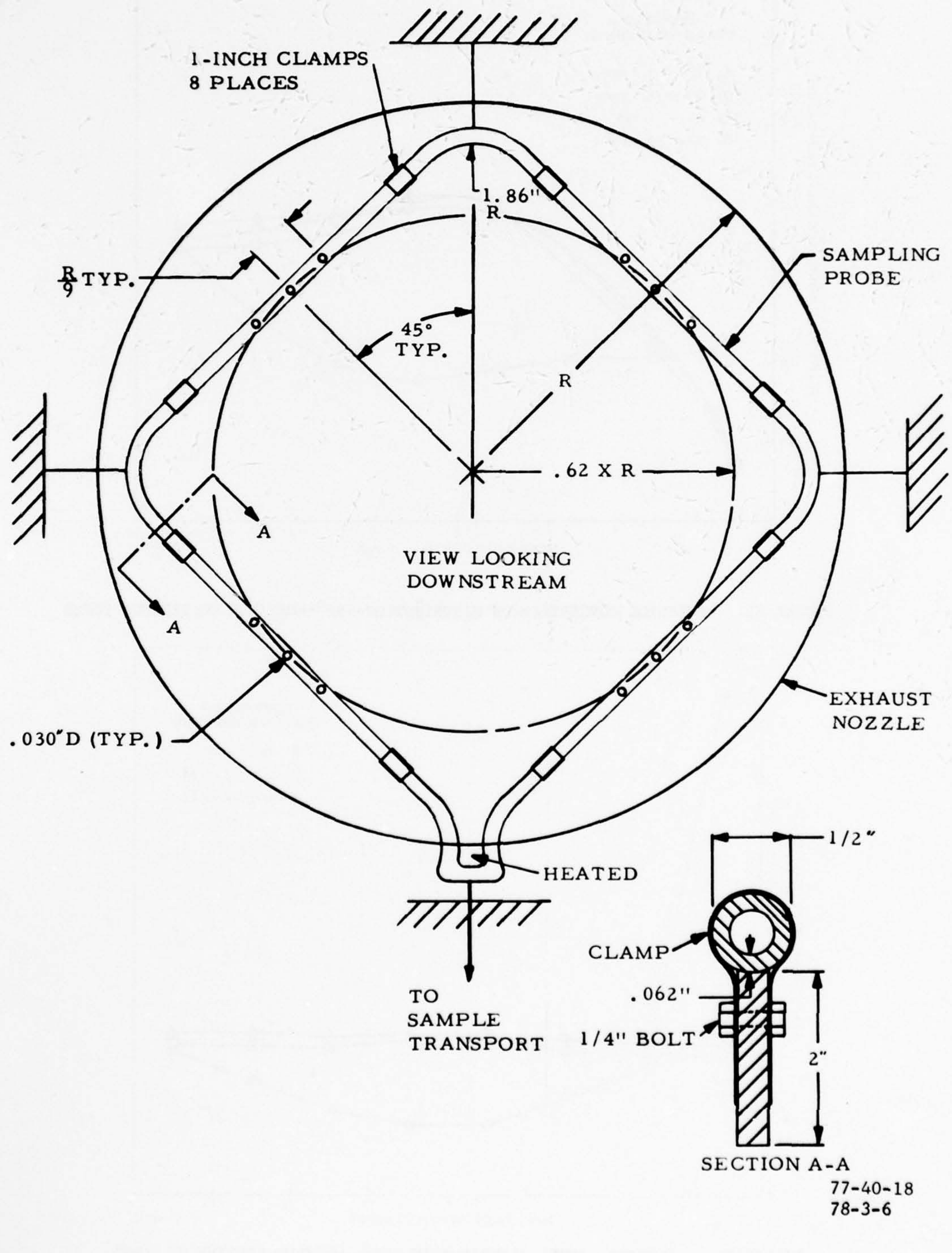


FIGURE 27. RECOMMENDED EMISSION SAMPLING PROBE

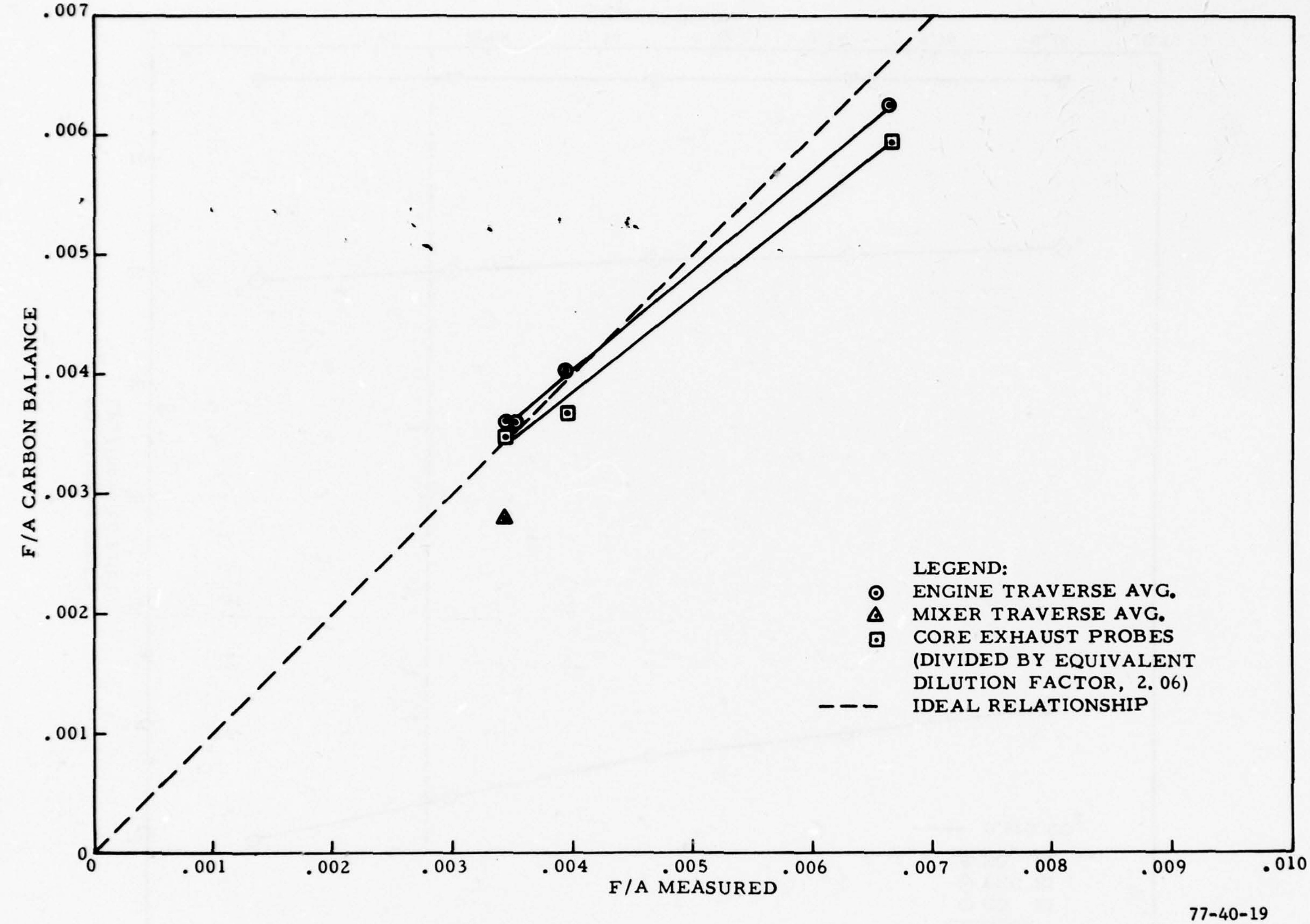


FIGURE 28. COMPARISON FUEL-TO-AIR RATIOS--ENGINE TRAVERSE, MIXER TRAVERSE, AND CORE PROBES

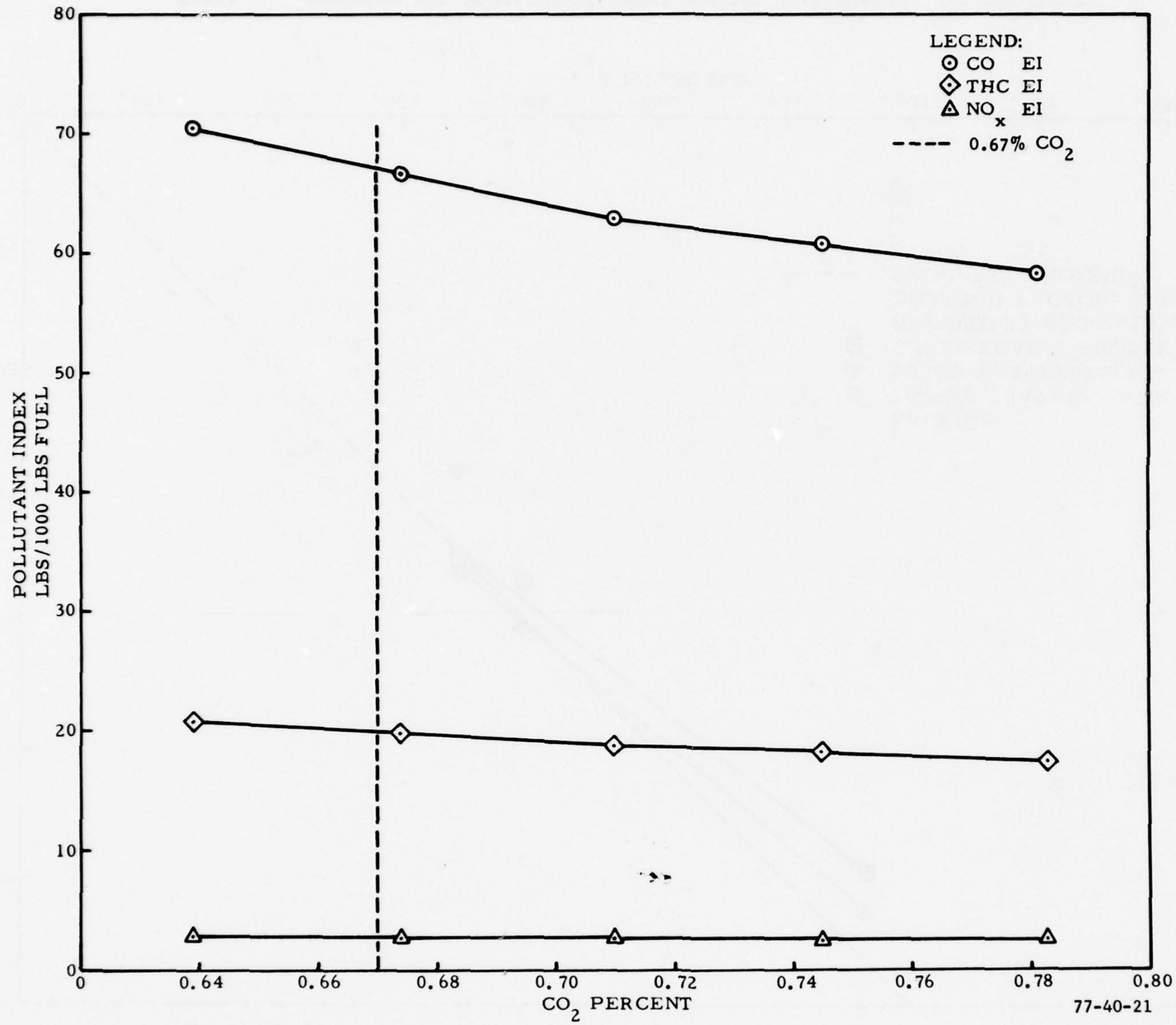


FIGURE 29. EFFECT OF CO_2 ON THE POLLUTANTS

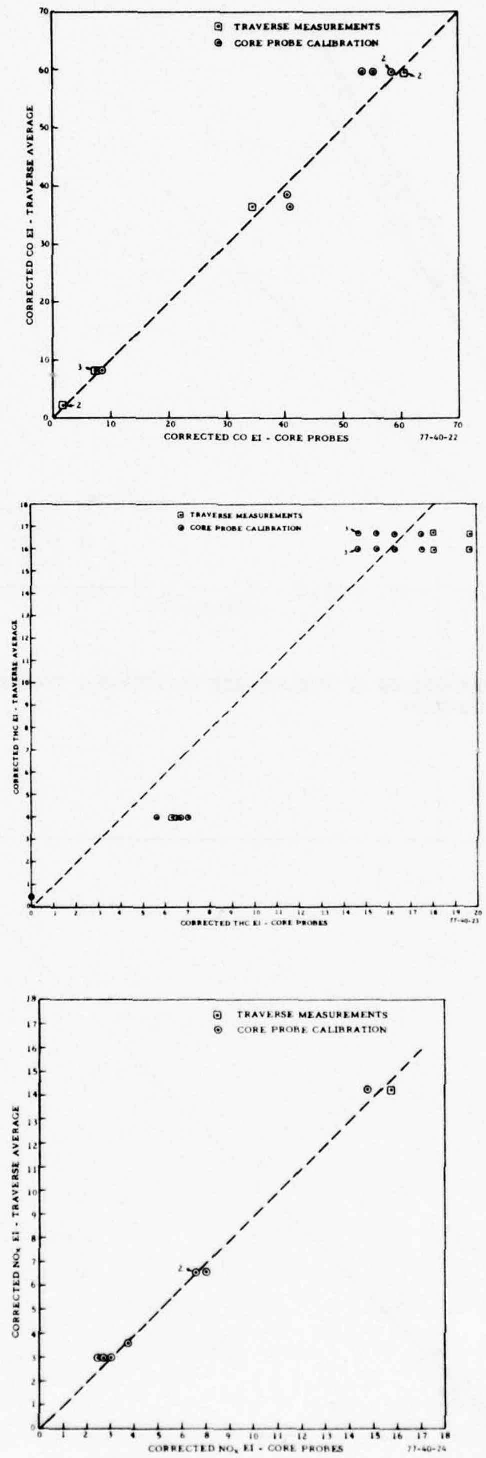


FIGURE 30. CORE PROBE PERFORMANCE--CO EI, THC EI, NO_x EI

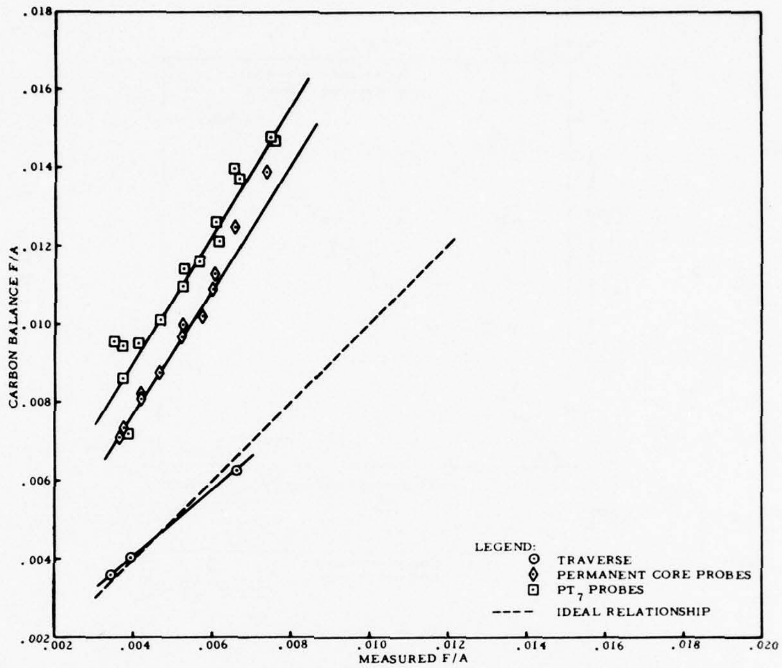


FIGURE 31. COMPARISON OF FUEL-TO-AIR RATIOS--P_{T7} PROBES, CORE PROBES, AND TRAVERSE

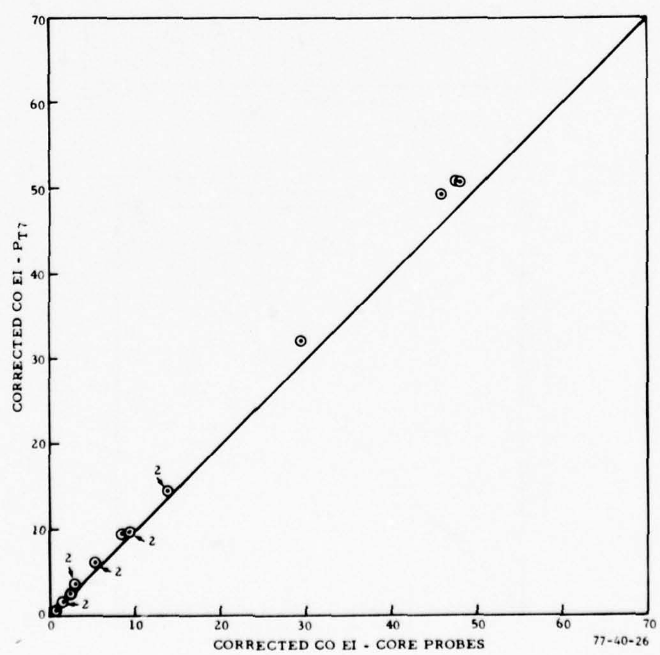
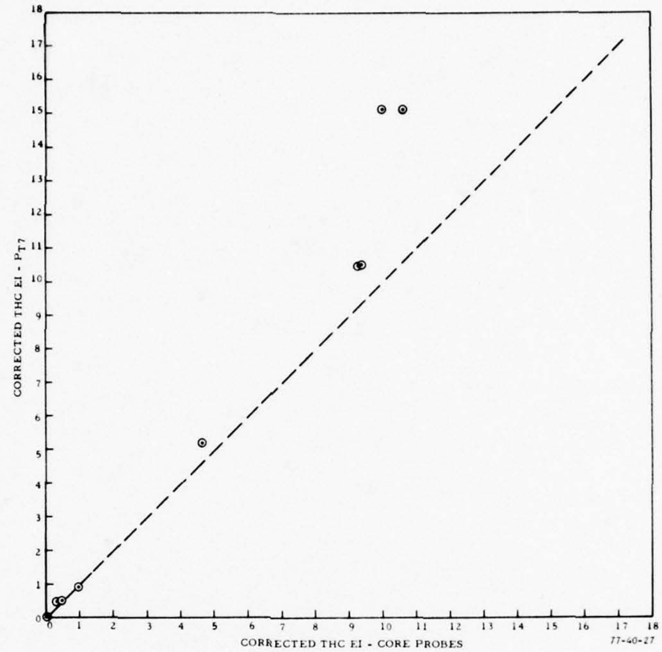


FIGURE 32. P_{T7} PROBE PERFORMANCE--CO EI--LOW SMOKE COMBUSTION CHAMBERS



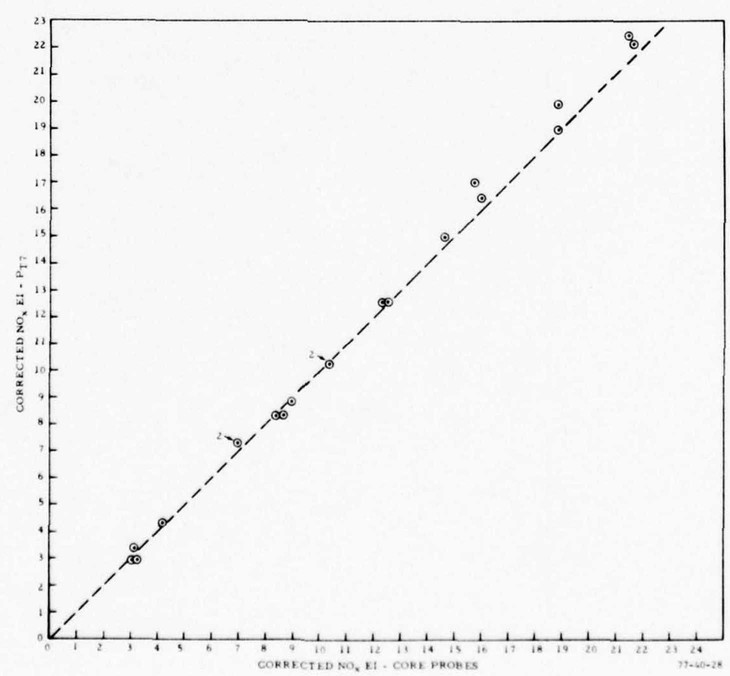


FIGURE 33. P_{T7} PROBE PERFORMANCE--THC EI AND NO_x EI--LOW SMOKE COMBUSTION CHAMBERS

APPENDIX A

TRAVERSE EMISSION CONCENTRATIONS

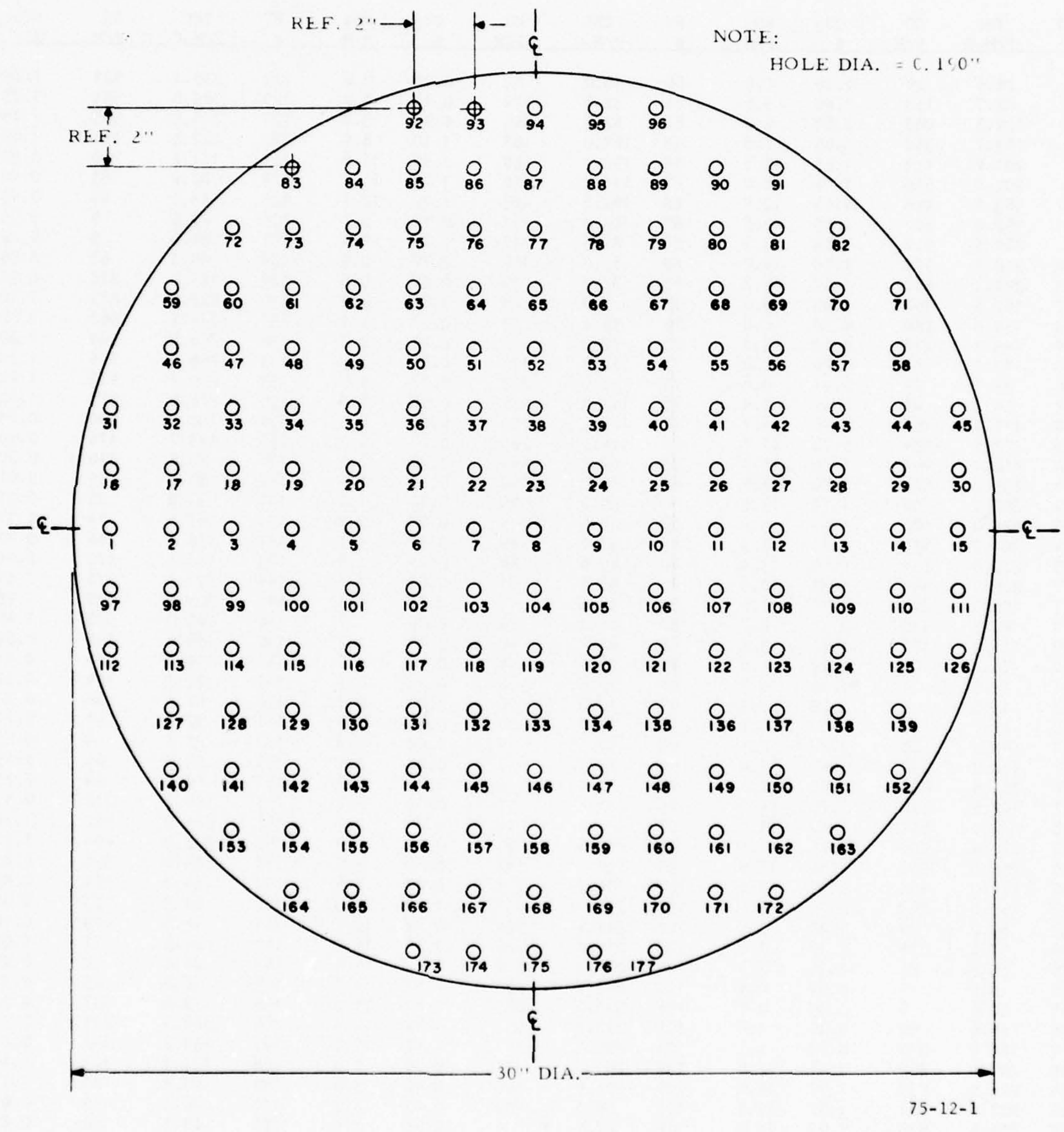


FIGURE A-1. IDENTIFICATION OF TRAVERSE EMISSION SAMPLING POINTS

TABLE A-1. TRAVERSE EMISSIONS AT IDLE POWER--RUN 119

PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M
1	28.6	29	0.10	1.0	60	18.0	52	0.05	0.6	119	236.1	527	1.82	15.0
2	82.7	153	0.46	3.6	61	37.6	171	0.12	1.0	120	305.0	551	1.75	14.0
3	129.3	280	0.80	6.0	62	82.7	245	0.46	3.8	121	335.5	555	1.75	14.0
4	183.7	352	1.05	7.8	63	164.0	367	1.10	8.9	122	222.5	465	1.60	12.9
5	201.6	473	1.55	11.5	64	195.7	456	1.40	11.6	123	141.2	290	0.90	7.3
6	207.8	526	1.70	18.0	65	174.3	410	1.27	10.1	124	82.9	189	0.40	3.3
7	183.7	496	1.65	12.5	66	192.8	448	1.40	12.1	125	43.0	44	0.15	1.2
8	192.8	501	1.65	12.5	67	147.3	263	0.72	6.1	126	27.6	9	0.05	0.6
9	204.5	517	1.75	13.7	68	88.8	110	0.27	2.4	127	24.6	9	0.02	0.6
10	218.1	534	1.75	14.0	69	82.7	107	0.27	2.3	128	49.1	61	0.15	1.5
11	224.1	480	1.57	12.2	70	37.6	29	0.07	0.8	129	125.9	218	0.51	4.1
12	192.8	367	1.05	8.0	71	21.0	4	0.02	0.4	130	222.0	413	1.10	8.6
13	159.5	280	0.72	6.0	72	39.2	47	0.12	1.1	131	289.7	567	1.72	13.7
14	143.0	228	0.62	4.8	73	72.2	114	0.27	2.3	132	266.5	584	1.90	15.2
15	72.2	88	0.26	2.0	74	118.8	198	0.50	3.8	133	266.5	576	1.77	14.5
16	33.1	14	0.07	0.6	75	146.0	273	0.72	5.5	134	289.7	493	1.42	11.1
17	54.1	49	0.15	1.4	76	112.8	234	0.65	4.9	135	228.5	387	1.20	9.3
18	114.2	154	0.45	3.7	77	108.2	223	0.60	4.5	136	156.7	290	0.88	7.2
19	177.6	304	0.92	11.7	78	144.3	280	0.75	6.1	137	113.7	176	0.50	4.1
20	218.1	461	1.50	11.9	79	69.2	114	0.32	2.6	138	70.6	110	0.20	1.9
21	233.2	526	1.70	13.9	80	39.2	40	0.10	1.1	139	35.3	19	0.07	0.8
22	207.7	506	1.70	13.9	81	39.2	40	0.10	1.0	140	36.8	25	0.07	0.8
23	225.8	506	1.65	13.2	82	19.5	9	0.02	0.4	141	67.5	74	0.17	1.7
24	301.0	576	1.75	13.9	83	37.6	49	0.12	1.1	142	116.8	168	0.42	3.3
25	270.8	534	1.70	13.4	84	49.6	88	0.25	1.8	143	181.1	316	0.80	6.4
26	225.9	444	1.35	10.4	85	48.1	81	0.22	1.8	144	297.4	576	1.57	12.7
27	176.0	263	0.72	5.5	86	34.6	47	0.12	1.1	145	305.0	610	1.75	14.0
28	90.3	135	0.37	2.7	87	48.1	74	0.20	1.7	146	282.0	508	1.40	10.8
29	111.2	167	0.46	3.2	88	42.1	56	0.15	1.3	147	188.8	305	0.82	6.4
30	76.7	94	0.27	2.0	89	25.6	16	0.06	0.5	148	110.6	176	0.47	3.8
31	13.5	1	0.02	0.3	90	18.0	6	0.02	0.3	149	72.1	114	0.32	2.6
32	13.5	3	0.02	0.3	91	18.0	6	0.02	0.3	150	47.6	68	0.20	1.8
33	21.1	25	0.06	0.7	92	12.0	10	0.02	0.4	151	32.2	31	0.10	1.0
34	48.1	88	0.22	2.1	93	10.5	4	0.02	0.3	152	21.5	9	0.06	0.6
35	108.3	234	0.65	5.4	94	13.5	9	0.02	0.4	153	53.7	61	0.15	1.4
36	186.4	489	1.50	12.0	95	12.0	6	0.02	0.3	154	69.1	94	0.25	2.1
37	192.8	526	1.75	14.0	96	10.5	1	0.02	0.2	155	116.8	216	0.51	4.2
38	188.0	513	1.70	13.5	97	23.0	14	0.06	0.7	156	264.0	462	1.20	9.2
39	270.8	585	1.77	13.8	98	62.9	94	0.27	2.3	157	305.0	494	1.30	9.9
40	255.9	546	1.65	12.8	99	118.1	187	0.50	3.9	158	244.0	331	0.86	6.7
41	221.0	422	1.25	9.5	100	164.2	273	0.72	5.6	159	144.3	174	0.45	3.4
42	155.0	253	0.70	5.2	101	236.1	437	1.32	10.3	160	81.3	71	0.17	1.7
43	69.2	74	0.20	1.5	102	245.9	534	1.72	13.7	161	44.5	29	0.10	0.9
44	67.6	74	0.17	1.6	103	216.4	526	1.75	14.2	162	29.2	11	0.05	0.6
45	55.7	56	0.15	1.4	104	207.3	521	1.72	14.0	163	24.6	9	0.05	0.6
46	16.5	1	0.02	0.4	105	259.7	585	1.82	14.7	164	36.8	25	0.10	1.2
47	22.6	9	0.05	0.5	106	320.0	605	1.87	15.0	165	79.8	107	0.27	2.3
48	55.6	59	0.15	1.6	107	282.0	551	1.82	14.5	166	189.9	291	0.71	5.5
49	124.9	210	0.60	4.5	108	259.3	461	1.47	11.9	167	234.8	346	0.82	6.4
50	201.6	464	1.45	12.5	109	201.2	315	0.88	7.0	168	136.7	203	0.46	3.6
51	216.5	539	1.77	14.5	110	125.9	160	0.42	3.9	169	61.4	81	0.71	1.8
52	201.6	521	1.72	13.5	111	58.3	99	0.15	1.3	170	26.1	19	0.05	0.8
53	216.5	538	1.72	13.5	112	21.5	4	0.05	0.4	171	18.4	6	0.02	0.4
54	192.8	402	1.25	9.6	113	38.4	25	0.10	0.9	172	18.4	4	0.02	0.4
55	130.9	223	0.60	4.7	114	82.9	91	0.26	2.2	173	58.3	77	0.22	1.8
56	118.9	198	0.51	4.2	115	150.4	216	0.57	4.6	174	101.3	164	0.42	3.3
57	48.1	56	0.15	1.4	116	251.7	415	1.22	9.8	175	107.6	160	0.42	3.2
58	37.6	25	0.10	0.8	117	274.2	530	1.77	14.5	176	70.6	94	0.26	2.1
59	16.0	30	0.02	0.4	118	236.1	525	1.87	15.6	177	29.2	19	0.07	0.8
									WEIGHTED AVERAGE		126.8	237	.71	5.8

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TABLE A-2. TRAVERSE EMISSIONS AT IDLE POWER--RUN 124

PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M
1	13.3	44	0.11	0.8	60	17.8	9	0.05	0.5	119	245.9	548	1.80	14.5
2	67.7	180	0.51	3.4	61	38.8	60	0.15	1.6	120	296.0	557	1.70	13.2
3	143.0	237	0.82	5.4	62	104.3	205	0.55	4.4	121	301.9	543	1.70	12.7
4	183.0	367	1.10	7.3	63	177.8	421	1.25	10.3	122	200.9	434	1.50	11.5
5	217.9	436	1.55	11.4	64	195.1	486	1.50	12.9	123	121.0	254	0.82	6.2
6	217.9	540	1.75	14.0	65	167.3	478	1.35	11.9	124	64.4	11[illegible]	0.35	2.8
7	189.6	508	1.70	14.5	66	178.3	448	1.45	12.4	125	28.8	35	0.10	1.1
8	189.6	501	1.65	14.0	67	131.0	244	0.70	5.8	126	18.9	5	0.02	0.5
9	217.9	540	1.77	14.7	68	88.8	120	0.30	2.6	127	18.9	10	0.05	0.6
10	217.9	545	1.7[illegible]	14.2	69	83.2	120	0.30	2.5	128	44.4	69	0.15	1.6
11	223.4	496	1.57	12.9	70	37.8	31	0.10	0.9	129	106.5	212	0.55	4.2
12	201.0	377	1.10	9.0	71	17.8	4	0.02	0.3	130	200.9	397	1.12	8.3
13	167.3	290	0.77	6.2	72	35.5	44	0.12	1.2	131	262.1	553	1.75	13.0
14	145.1	230	0.57	4.3	73	71.0	120	0.32	2.5	132	251.0	553	1.85	14.0
15	65.5	73	0.20	1.7	74	108.9	205	0.55	4.0	133	267.9	543	1.75	13.5
16	25.6	18	0.06	0.6	75	142.0	290	0.80	6.0	134	267.9	439	1.30	10.0
17	51.1	63	0.17	1.6	76	108.9	241	0.70	5.3	135	206.3	347	1.10	8.5
18	122.9	203	0.52	4.2	77	106.6	229	0.65	5.2	136	146.5	254	0.82	6.4
19	189.9	352	1.05	8.5	78	117.8	263	0.72	5.[illegible]	137	100.0	154	0.47	3.9
20	212.0	508	1.60	12.9	79	57.6	94	0.25	2.1	138	56.5	62	0.20	1.8
21	223.5	550	1.75	14.5	80	41.1	49	0.12	1.2	139	27.8	15	0.02	0.6
22	212.0	525	1.72	15.0	81	35.5	44	0.11	1.1	140	34.4	22	0.07	0.6
23	234.1	525	1.70	14.5	82	16.6	3	0.02	0.4	141	62.1	69	0.17	1.5
24	307.0	592	1.80	15.5	83	40.0	65	0.15	1.4	142	117.8	161	0.42	3.1
25	268.0	545	1.70	13.4	84	60.0	103	0.26	2.2	143	184.0	310	0.[illegible]	6.5
26	228.5	451	1.30	9.7	85	54.4	10	0.25	2.1	144	279.0	540	1.[illegible]7	12.5
27	140.0	252	0.[illegible]0	5.0	86	38.8	51	0.15	1.5	145	301.9	565	1.75	13.0
28	94.3	138	0.35	2.7	87	48.8	80	0.22	2.1	146	256.5	443	1.30	9.3
29	113.2	176	0.45	3.2	88	40.0	49	0.15	1.4	147	146.5	280	0.70	4.7
30	65.5	93	0.25	1.9	89	22.2	14	0.05	0.5	148	84.4	145	0.40	3.0
31	13.3	4	0.02	0.2	90	20.0	9	0.05	0.4	149	52.1	95	0.27	2.1
32	12.2	4	0.02	0.2	91	17.8	9	0.05	0.4	150	35.5	60	0.17	1.4
33	22.2	31	0.10	0.8	92	13.3	9	0.02	0.5	151	23.3	30	0.10	0.7
34	59.9	120	0.32	2.6	93	11.1	4	0.02	0.3	152	15.5	2	0.02	0.2
35	135.3	315	0.90	6.8	94	14.4	9	0.02	0.6	153	41.0	50	0.12	1.1
36	212.0	505	1.55	12.4	95	13.3	4	0.02	0.4	154	55.5	89	0.25	1.7
37	200.9	540	1.[illegible]	16.3	96	11.1	1	0.02	0.3	155	107.5	200	0.51	3.7
38	195.1	535	1.[illegible]2	15.0	97	14.4	16	0.06	0.[illegible]	156	234.0	431	1.20	8.0
39	273.5	592	1.77	15.0	98	46.6	103	0.27	2.2	157	268.0	439	1.22	8.2
40	256.5	550	1.67	13.7	99	104.5	172	0.4[illegible]	3.4	158	200.9	281	0.72	5.0
41	212.0	444	1.30	10.3	100	153.2	269	0.[illegible]2	5.3	159	10[illegible].5	128	0.34	2.4
42	135.3	252	0.67	5.7	101	223.1	436	1.40	10.4	160	57.6	50	0.15	1.1
43	62.1	74	0.20	1.8	102	245.5	534	1.75	13.4	161	36.6	20	0.07	0.5
44	65.4	81	0.20	1.7	103	212.0	525	1.80	14.7	162	24.4	10	0.06	0.3
45	46.6	47	0.12	1.1	104	200.9	525	1.80	14.[illegible]	163	20.0	[illegible]	0.05	0.3
46	16.6	1	0.02	0.3	105	250.9	580	1.85	14.[illegible]	164	32.2	20	0.07	0.5
47	23.3	9	0.05	0.5	106	301.0	601	1.90	14.[illegible]	165	[illegible]4.4	101	0.27	2.0
48	54.4	73	0.20	1.8	107	262.0	545	1.87	14.[illegible]	166	161.9	268	0.70	4.8
49	123.2	229	0.60	5.2	108	223.1	436	1.45	11.6	167	189.8	310	0.80	5.6
50	206.5	487	1.47	12.4	109	167.2	283	0.82	6.1	168	121.0	188	0.47	3.4
51	206.5	552	1.77	15.2	110	100.3	126	0.35	2.8	169	55.5	82	0.20	1.6
52	200.9	527	1.72	15.0	111	44.6	35	0.11	1.1	170	20.0	15	0.06	0.4
53	212.0	543	1.72	15.0	112	21.1	4	0.02	0.4	171	15.5	2	0.02	0.1
54	185.2	408	1.20	9.5	113	38.8	29	0.10	1.0	172	15.5	2	0.02	0.1
55	131.0	238	0.62	5.0	114	84.4	96	0.26	2.2	173	41.0	50	0.15	1.2
56	113.1	211	0.51	4.1	115	156.2	234	0.62	5.0	174	77.6	132	0.34	2.5
57	46.6	56	0.12	1.3	116	245.9	299	1.2[illegible]	10.0	175	84.4	136	0.35	2.6
58	35.5	31	0.10	0.8	117	273.9	550	1.82	14.5	176	62.2	82	0.25	1.7
59	15.6	1	0.02	0.3	118	234.4	540	1.8[illegible]	15.2	177	22.2	10	0.06	0.4
										WEIGHTED AVERAGE	120.9	233	0.71	5.7

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TABLE A-3. TRAVERSE EMISSIONS AT HOLDING POWER--RUN 125

PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M
1	11.6	16	0.11	1.2	60	6.4	9	0.06	0.5	119	55.5	346	1.87	18.5
2	26.2	96	0.51	4.9	61	11.8	40	0.20	1.8	120	75.8	356	1.75	16.9
3	38.8	175	0.86	7.9	62	26.7	130	0.60	5.6	121	79.0	337	1.72	16.3
4	45.6	233	1.22	11.0	63	43.8	268	1.32	12.4	122	54.4	286	1.62	15.8
5	53.3	325	1.75	15.6	64	44.8	303	1.52	14.5	123	29.9	169	0.90	8.9
6	50.4	344	1.85	17.2	65	38.4	271	1.37	13.2	124	17.1	76	0.40	3.9
7	47.5	329	1.82	17.7	66	44.8	296	1.52	14.5	125	8.5	21	0.11	1.2
8	48.5	325	1.77	16.9	67	28.8	130	0.60	5.8	126	5.3	4	0.02	0.2
9	54.3	355	1.90	18.3	68	21.4	68	0.30	2.9	127	6.4	6	0.02	0.3
10	60.1	370	1.92	18.3	69	20.3	61	0.27	2.7	128	11.8	37	0.15	1.6
11	60.1	322	1.72	16.1	70	10.7	19	0.10	0.9	129	27.8	132	0.55	5.1
12	51.4	233	1.20	10.8	71	6.4	4	0.02	0.2	130	57.7	272	1.17	10.3
13	42.6	173	0.84	7.7	72	8.5	31	0.15	1.5	131	79.0	374	1.80	16.3
14	34.9	126	0.60	5.5	73	17.1	77	0.37	3.5	132	72.6	373	1.87	18.0
15	15.5	25	0.15	1.5	74	23.5	120	0.57	5.3	133	77.9	371	1.75	16.3
16	7.8	4	0.06	0.5	75	28.8	170	0.82	7.7	134	77.9	279	1.27	11.7
17	11.6	25	0.15	1.6	76	23.5	134	0.65	6.3	135	60.8	215	1.15	9.8
18	25.2	106	0.51	4.9	77	25.6	146	0.71	7.0	136	38.4	166	1.01	8.7
19	35.9	209	1.10	10.5	78	29.9	163	0.77	7.6	137	26.7	106	0.55	5.7
20	43.6	307	1.65	15.6	79	13.9	49	0.22	2.2	138	17.1	49	0.26	2.6
21	50.4	351	1.85	17.5	80	10.7	25	0.11	1.2	139	8.5	11	0.07	0.8
22	46.5	340	1.82	17.5	81	8.5	16	0.07	0.8	140	8.5	14	0.06	0.5
23	52.4	344	1.82	17.7	82	6.4	4	0.02	0.2	141	13.9	37	0.15	1.6
24	67.9	365	1.92	18.5	83	8.5	31	0.15	1.6	142	24.6	93	0.40	3.8
25	62.1	344	1.80	16.9	84	12.8	56	0.27	2.6	143	38.4	184	0.84	7.5
26	56.2	278	1.42	12.9	85	11.8	47	0.25	2.2	144	64.1	337	1.70	15.8
27	34.9	156	0.75	6.9	86	8.5	31	0.15	1.6	145	74.8	362	1.82	16.9
28	25.2	82	0.40	3.7	87	13.9	56	0.27	2.7	146	65.1	276	1.32	12.2
29	27.2	93	0.45	3.9	88	9.6	31	0.15	1.5	147	39.5	140	0.70	6.3
30	15.5	35	0.17	1.8	89	6.4	9	0.06	0.4	148	23.5	76	0.40	3.7
31	8.5	1	0.02	0.1	90	5.3	6	0.05	0.2	149	17.1	56	0.30	2.9
32	7.5	1	0.02	0.2	91	4.3	6	0.05	0.2	150	12.8	40	0.22	2.1
33	8.5	14	0.10	0.8	92	4.3	6	0.02	0.3	151	8.5	21	0.11	1.2
34	17.1	64	0.34	3.2	93	5.3	4	0.02	0.2	152	6.4	4	0.02	0.2
35	32.0	183	0.88	8.5	94	5.3	9	0.02	0.5	153	10.7	31	0.12	1.3
36	49.1	324	2.17	15.6	95	4.3	4	0.02	0.2	154	12.8	49	0.20	1.9
37	51.3	347	1.85	17.7	96	4.3	1	0.02	0.1	155	24.6	113	0.46	4.4
38	55.5	351	1.82	17.5	97	4.3	9	0.07	0.7	156	61.9	277	1.15	10.2
39	75.8	385	1.90	17.7	98	13.9	56	0.32	2.8	157	81.2	297	1.25	10.9
40	71.5	351	1.77	16.4	99	21.4	106	0.51	4.6	158	63.0	187	0.75	6.5
41	59.8	286	1.42	12.9	100	29.9	156	0.77	6.8	159	33.1	88	0.32	2.8
42	40.6	163	0.77	7.0	101	47.0	276	1.50	13.6	160	18.2	29	0.12	1.0
43	21.4	52	0.25	4.6	102	53.4	329	1.80	17.4	161	9.6	14	0.07	0.5
44	19.2	47	0.22	2.1	103	44.8	329	1.85	18.0	162	7.4	9	0.05	0.3
45	12.8	21	0.11	1.1	104	49.2	340	1.85	17.7	163	6.4	6	0.05	0.2
46	6.4	4	0.02	0.1	105	61.9	281	1.92	18.5	164	8.5	9	0.06	0.4
47	8.5	9	0.02	0.4	106	75.8	389	1.95	18.3	165	17.1	52	0.25	2.2
48	13.9	44	0.20	1.9	107	68.4	355	1.92	18.5	166	39.5	159	0.71	6.2
49	28.8	146	0.70	6.8	108	55.5	282	1.57	14.7	167	51.3	202	0.88	7.8
50	50.2	322	1.60	15.1	109	41.6	172	0.86	8.1	168	34.2	134	0.57	5.1
51	51.3	351	1.82	17.5	110	21.4	70	0.35	3.2	169	18.2	63	0.71	2.6
52	53.4	344	1.80	17.2	111	9.6	14	0.07	0.7	170	7.4	16	0.10	0.8
53	58.7	351	1.80	17.2	112	6.4	4	0.02	0.2	171	5.3	4	0.02	0.1
54	45.9	244	1.17	10.8	113	10.7	16	0.10	0.9	172	5.3	1	0.02	0.1
55	32.0	140	0.60	5.8	114	19.2	56	0.25	2.5	173	10.7	31	0.15	1.4
56	31.0	130	0.55	5.4	115	37.4	146	0.62	5.8	174	19.2	83	0.37	3.4
57	15.0	40	0.15	1.8	116	58.7	278	1.35	12.5	175	22.4	93	0.42	3.8
58	9.6	16	0.07	0.9	117	63.0	355	1.90	18.5	176	17.1	59	0.27	2.6
59	5.3	4	0.02	0.2	118	51.3	343	1.92	19.1	177	8.5	11	0.07	0.7
									WEIGHTED AVERAGE		30.8	147	0.75	7.1

TABLE A-4. TRAVERSE EMISSIONS AT APPROACH POWER--RUN 121

PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M
1	2.64	7	0.15	2.9	60	2.31	2	0.02	0.6	119	3.41	79	1.95	34.4
2	4.29	40	0.95	16.3	61	2.42	7	0.12	2.8	120	2.75	77	1.97	34.2
3	4.18	53	1.32	22.4	62	2.75	20	0.47	8.0	121	2.75	86	2.05	34.2
4	4.29	67	1.70	28.8	63	2.86	49	1.10	18.4	122	2.31	49	1.20	20.2
5	4.18	79	2.05	34.6	64	2.64	62	1.55	25.6	123	1.98	13	0.35	6.1
6	4.18	76	2.00	33.0	65	2.64	62	1.60	26.6	124	1.98	5	0.10	1.7
7	3.96	73	1.85	31.4	66	3.52	77	1.80	29.6	125	1.98	1	0.02	0.6
8	3.74	71	1.82	30.9	67	2.64	34	0.72	12.8	126	2.09	1	0.02	0.1
9	3.62	74	1.85	31.4	68	2.64	23	0.47	8.0	127	2.09	1	0.02	0.6
10	3.74	88	2.05	34.1	69	2.42	15	0.30	4.9	128	1.98	3	0.10	1.6
11	3.63	83	2.07	35.2	70	2.20	3	0.06	1.0	129	1.98	22	0.50	8.4
12	3.52	67	1.72	28.8	71	1.98	1	0.02	0.3	130	1.87	48	1.25	28.8
13	3.30	52	1.30	21.4	72	2.09	3	0.06	1.0	131	2.09	76	1.92	34.1
14	2.75	36	0.82	14.4	73	2.20	8	0.20	3.1	132	2.42	78	2.02	37.2
15	2.20	6	0.10	1.9	74	2.20	17	0.42	7.0	133	2.20	77	2.00	36.2
16	1.98	6	0.10	1.6	75	2.31	35	0.80	13.8	134	2.20	79	1.95	34.1
17	2.64	23	0.45	7.7	76	2.09	38	0.90	15.3	135	2.42	72	1.70	29.0
18	3.41	47	0.95	16.7	77	1.98	44	1.10	18.4	136	1.98	41	1.01	17.6
19	3.41	72	1.65	28.2	78	1.98	45	1.10	18.4	137	1.98	17	0.40	7.2
20	2.75	80	1.95	33.0	79	1.98	10	0.25	4.1	138	1.87	4	0.07	1.4
21	2.97	79	1.90	33.0	80	2.09	5	0.11	1.9	139	1.65	1	0.02	0.4
22	3.08	74	1.80	30.8	81	1.98	5	0.10	1.4	140	1.87	1	0.02	0.3
23	2.97	74	1.80	30.8	82	1.87	1	0.02	0.4	141	1.87	3	0.05	0.7
24	3.08	79	1.82	31.4	83	2.09	5	0.11	2.0	142	1.87	11	0.26	4.4
25	3.08	83	1.85	32.4	84	2.31	9	0.22	3.6	143	1.98	29	0.67	11.5
26	3.30	74	1.70	29.2	85	2.42	11	0.27	4.7	144	1.95	65	1.55	26.1
27	3.19	47	1.10	18.8	86	2.53	9	0.25	3.9	145	2.20	83	1.95	33.4
28	2.64	31	0.65	11.5	87	2.53	17	0.42	7.2	146	2.64	80	1.77	30.2
29	2.42	19	0.45	7.5	88	2.53	16	0.40	6.5	147	2.53	55	1.25	20.9
30	2.20	5	0.07	1.6	89	2.86	2	0.06	0.8	148	2.09	34	0.71	12.5
31	1.98	3	0.02	0.4	90	2.86	1	0.02	0.4	149	1.65	20	0.47	8.9
32	1.87	3	0.05	0.7	91	2.97	1	0.02	0.4	150	1.65	11	0.27	5.2
33	2.20	7	0.15	2.7	92	3.08	2	0.05	0.7	151	1.65	3	0.05	1.3
34	2.75	26	0.55	9.4	93	3.08	2	0.05	0.5	152	1.65	1	0.01	0.4
35	2.97	60	1.50	25.1	94	3.08	3	0.06	1.0	153	1.65	1	0.02	0.3
36	2.75	79	1.95	32.9	95	3.08	3	0.06	1.0	154	1.54	3	0.06	1.0
37	3.08	77	1.90	32.4	96	3.08	1	0.02	0.5	155	1.54	13	0.27	4.9
38	3.08	79	2.00	35.0	97	3.52	6	0.07	1.9	156	1.56	56	1.15	18.8
39	3.08	79	2.00	35.0	98	3.74	20	0.51	9.8	157	2.42	74	1.65	27.2
40	2.97	77	1.70	33.4	99	3.30	25	0.60	11.9	158	2.64	52	1.15	18.8
41	3.30	66	1.65	28.8	100	2.86	41	1.05	18.1	159	2.20	34	0.72	12.5
42	3.30	87	0.82	14.2	101	3.62	71	1.75	30.5	160	1.87	15	0.32	5.4
43	2.58	17	0.35	6.0	102	3.85	77	1.95	34.6	161	1.54	5	0.10	1.8
44	2.20	8	0.12	2.5	103	3.19	73	1.90	33.6	162	1.54	1	0.02	0.5
45	2.20	6	0.02	0.4	104	2.97	73	1.82	33.1	163	1.65	1	0.02	0.3
46	2.42	1	0.02	0.4	105	2.42	69	1.95	35.6	164	1.76	3	0.02	0.3
47	2.42	3	0.06	1.2	106	2.64	76	2.10	37.8	165	1.87	6	0.12	2.1
48	2.85	17	0.35	6.6	107	2.86	83	2.00	34.1	166	1.98	25	0.57	9.7
49	3.41	53	1.15	17.2	108	2.81	86	1.50	25.8	167	1.98	44	1.03	16.7
50	2.97	77	1.85	30.6	109	2.81	85	0.82	15.0	168	1.90	31	0.71	11.5
51	3.19	78	1.85	31.1	110	2.09	17	0.40	7.2	169	1.76	12	0.30	4.8
52	3.85	86	1.95	33.2	111	2.20	3	0.06	1.0	170	1.76	3	0.06	1.1
53	4.07	88	2.00	34.2	112	1.98	1	0.02	0.6	171	1.76	2	0.02	0.4
54	3.74	67	1.60	26.4	113	2.20	5	0.12	2.3	172	1.76	1	0.01	0.3
55	3.52	55	1.32	22.3	114	2.20	29	0.67	4.4	173	1.98	6	0.12	12.0
56	3.30	29	0.60	10.4	115	2.31	30	0.71	12.4	174	1.87	14	0.32	27.2
57	3.08	5	0.15	2.6	116	2.53	62	1.65	27.9	175	1.98	14	0.32	26.7
58	2.42	1	0.05	0.6	117	3.08	77	2.00	35.2	176	1.98	7	0.12	11.0
59	2.31	1	0.02	0.3	118	3.08	79	1.95	34.2	177	1.98	2	0.02	1.7
								WEIGHTED AVERAGE			2.52	35	0.83	14.6

TABLE A-5. TRAVERSE EMISSIONS AT MAXIMUM CONTINUOUS POWER--RUN 123

PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M	PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M
1	1.9	4	0.46	15.5	60	1.4	5	0.32	10.3	119	0.1	31	2.48	86.8
2	1.9	20	1.72	56.3	61	1.1	14	0.11	31.5	120	0.1	31	2.50	87.8
3	2.3	27	2.40	81.6	62	1.0	21	1.65	53.7	121	0.4	35	2.45	81.6
4	2.4	35	2.70	93.0	63	0.7	30	2.25	75.4	122	0.7	28	2.10	67.2
5	2.4	36	2.47	89.9	64	0.6	34	2.50	88.8	123	1.3	11	0.75	23.5
6	2.4	31	2.53	87.8	65	0.5	37	2.65	94.0	124	1.7	5	0.15	5.1
7	2.4	30	2.38	86.8	66	0.5	36	2.55	88.8	125	1.7	2	0.06	2.0
8	2.1	31	2.32	80.6	67	0.6	31	2.25	75.4	126	2.6	2	0.01	0.3
9	1.7	31	2.35	80.6	68	1.0	19	1.40	45.4	127	1.4	2	0.06	1.9
10	1.5	35	2.50	83.7	69	1.4	7	0.47	16.0	128	1.4	3	0.15	4.6
11	1.2	38	2.65	87.8	70	1.5	4	0.11	3.6	129	1.2	10	0.72	24.2
12	1.2	34	2.57	82.6	71	1.7	2	0.02	0.6	130	0.6	21	1.75	56.8
13	1.4	25	1.97	64.0	72	1.7	2	0.06	1.3	131	0.4	31	2.50	86.8
14	1.8	11	0.75	23.7	73	1.4	5	0.30	9.8	132	0.2	32	2.55	89.9
15	1.3	3	0.05	0.7	74	1.2	12	0.97	31.7	133	0.2	32	2.58	90.9
16	1.9	6	0.46	14.4	75	0.8	21	1.70	54.2	134	0.4	33	2.28	74.4
17	1.4	17	1.50	48.6	76	0.7	28	2.20	72.8	135	0.4	32	2.10	66.1
18	0.6	28	2.35	80.6	77	0.2	36	2.68	93.0	136	0.6	22	1.55	47.5
19	0.6	34	2.70	93.0	78	0.7	24	1.97	65.1	137	1.2	11	0.65	20.1
20	0.7	34	2.68	91.9	79	0.8	17	1.40	44.9	138	1.5	4	0.06	1.9
21	0.8	31	2.80	87.8	80	1.1	12	0.95	30.4	139	1.4	1	0.02	0.3
22	1.1	31	2.45	84.7	81	1.3	5	0.25	7.3	140	1.7	1	0.02	0.1
23	1.2	32	2.40	81.6	82	1.4	1	0.02	0.5	141	1.8	4	0.10	3.0
24	1.1	38	2.42	79.5	83	1.5	3	0.15	6.2	142	1.4	9	0.55	18.6
25	1.0	38	2.52	83.7	84	1.2	9	0.65	21.7	143	1.0	17	1.35	43.4
26	1.1	33	2.38	77.5	85	1.2	14	1.10	36.1	144	0.2	28	2.33	79.5
27	1.4	21	1.65	51.6	86	1.0	21	1.72	55.8	145	0.1	32	2.63	93.0
28	1.5	18	1.32	41.8	87	0.7	28	2.27	77.5	146	0.5	28	2.13	70.2
29	1.7	9	0.65	20.1	88	1.3	16	1.12	36.2	147	1.0	18	1.45	45.9
30	1.3	2	0.05	0.8	89	1.5	6	0.37	12.6	148	1.0	14	0.95	31.5
31	1.8	3	0.12	4.1	90	1.5	5	0.27	8.5	149	1.2	9	0.52	17.5
32	1.5	5	0.46	15.0	91	1.5	4	0.07	2.3	150	1.4	3	0.30	10.3
33	1.4	12	1.01	35.1	92	1.2	7	0.55	18.1	151	1.7	1	0.02	0.6
34	1.2	25	2.10	70.2	93	1.1	12	0.97	31.5	152	2.1	1	0.02	0.1
35	1.1	34	2.60	88.8	94	1.1	10	0.90	29.9	153	1.4	1	0.02	0.6
36	1.0	34	2.52	86.8	95	1.2	5	0.45	14.4	154	1.4	2	0.15	5.7
37	1.0	34	2.42	83.7	96	1.7	2	0.05	1.0	155	1.2	9	1.65	20.1
38	0.8	35	2.35	78.5	97	1.7	6	0.42	14.7	156	0.8	18	1.55	50.6
39	0.8	37	2.35	78.5	98	1.4	16	1.20	41.3	157	0.6	31	2.30	78.0
40	0.6	38	2.42	80.6	99	1.5	17	1.27	43.9	158	1.0	23	1.60	50.6
41	0.6	29	1.97	64.1	100	1.7	23	1.70	58.9	159	1.3	12	1.07	25.3
42	1.1	16	1.12	37.2	101	2.1	32	2.42	85.7	160	1.8	6	0.35	11.1
43	1.2	14	0.90	29.9	102	2.3	36	2.52	88.8	161	1.7	2	0.10	2.5
44	1.4	7	0.45	14.4	103	1.9	34	2.38	83.7	162	1.5	2	0.05	0.7
45	2.4	3	0.02	0.5	104	1.1	33	2.35	82.6	163	2.1	1	0.02	0.1
46	1.5	5	0.15	5.4	105	0.6	32	2.40	86.3	164	1.4	1	0.05	0.8
47	1.4	11	0.65	21.2	106	0.6	34	2.42	84.7	165	1.4	5	0.26	8.3
48	0.8	23	1.75	57.8	107	0.5	36	2.42	80.6	166	1.1	13	0.82	27.1
49	0.5	32	2.45	83.7	108	0.7	25	1.65	52.7	167	0.6	21	1.55	49.6
50	0.4	32	2.50	86.8	109	1.2	28	1.01	32.0	168	0.6	18	1.35	42.0
51	0.5	36	2.50	86.8	110	1.5	10	0.45	13.9	169	1.1	8	0.51	16.5
52	0.5	37	2.53	86.8	111	2.6	3	0.01	0.5	170	1.3	3	0.10	2.7
53	0.6	36	2.45	83.7	112	1.4	4	0.12	4.1	171	1.5	1	0.02	0.2
54	0.8	33	2.30	77.5	113	1.2	7	0.46	14.4	172	2.1	1	0.02	0.1
55	0.8	18	1.55	50.1	114	1.1	8	0.50	16.0	173	1.8	3	0.20	6.9
56	1.3	9	0.65	21.7	115	0.8	34	0.97	31.5	174	1.5	6	0.42	13.9
57	1.1	5	0.32	10.8	116	0.2	23	1.87	61.0	175	1.2	6	0.42	13.4
58	1.8	1	0.10	3.2	117	0.1	31	2.43	82.6	176	1.4	3	0.15	5.0
59	1.6	1	0.02	0.9	118	0.1	33	2.45	84.7	177	2.3	1	0.02	0.2
									WEIGHTED AVERAGE		1.2	18	1.29	43.1

TABLE A-6. MIXER TRAVERSE EMISSIONS AT IDLE THROTTLE POWER

PT #	THC P/M-C	CO P/M	CO_2 %	NO_x P/M
1	59.6	77	0.22	1.5
2	73.2	103	0.27	1.9
3	99.0	143	0.37	2.6
4	140.7	238	0.65	4.5
5	196.9	267	1.07	7.6
6	208.0	283	1.12	8.0
7	166.5	273	0.77	5.6
8	126.0	191	0.52	3.8
9	101.2	146	0.40	2.9
10	52.9	88	0.22	1.6
11	70.9	96	0.27	2.0
12	90.0	126	0.37	2.8
13	123.8	203	0.60	4.5
14	172.1	315	0.95	6.9
15	176.6	323	0.95	6.9
16	146.2	253	0.72	5.3
17	119.2	191	0.51	3.9
18	103.5	153	0.42	3.0
19	69.8	106	0.30	2.2
20	86.7	130	0.37	2.8
21	106.6	130	0.51	3.8
22	124.8	228	0.65	4.8
23	128.1	218	0.62	4.6
24	114.6	184	0.51	3.8
25	104.3	159	0.46	3.2
26	68.0	103	0.30	2.2
27	85.0	134	0.37	2.8
28	89.6	149	0.42	3.1
29	95.2	156	0.45	3.3
30	90.5	143	0.40	3.1
31	90.5	134	0.35	2.7
32	92.9	134	0.35	2.6
33	77.1	116	0.32	2.4
34	74.8	109	0.32	2.4
35	70.3	96	0.27	2.3
36	62.4	91	0.26	1.9
37	77.1	120	0.34	2.4
38	106.6	159	0.46	3.3
39	147.3	145	0.71	4.9
40	193.0	134	1.01	7.2
41	174.6	297	0.90	6.5
42	137.2	213	0.62	4.6
43	110.0	156	0.46	3.3
44	86.1	120	0.35	2.7
45	97.5	143	0.42	3.1
46	122.5	187	0.55	3.9
47	152.0	253	0.72	5.3
48	165.6	280	0.84	6.1
49	145.1	234	0.70	4.9
50	111.1	173	0.50	3.8
51	88.4	130	0.40	2.8
52	106.8	167	0.47	3.4
53	132.8	213	0.60	4.4
54	148.6	245	0.72	5.2
55	149.8	245	0.72	5.2
56	137.2	205	0.62	4.4
57	112.3	159	0.50	3.5
58	87.3	120	0.40	2.7
59	153.1	234	0.70	4.8
60	153.1	230	0.70	4.7
61	135.0	205	0.60	4.2
WEIGHTED AVERAGE	119.2	181.0	0.55	4.0

APPENDIX B

ENGINE PERFORMANCE AND TRAVERSE AVERAGE EMISSION INDICES

TABLE B-1. ENGINE PERFORMANCE AND TRAVERSE EMISSION

Mode	Engine Traverse	Run No.	T_2 °F	Specific Humidity Grains (H_2O/lb)	Bar Press inH_g A	EPR	Air Flow (lb/S)	Fuel Flow (lb/h)	Thrust (lb)	Observed T_3 (°F)	P_3 (inH_g)
Idle	Exhaust Nozzle	119	42	19.5	30.2	1.041	78.75	987.7	834.6	175.8	197.9
Idle	Exhaust Nozzle	124	46	20.4	30.10	1.042	81.7	1012.7	849.2	175.0	---
Idle	Mixer	136-139	46	40	30.19	1.040	81.2	1004	803.5	171.7	---
Holding	Exhaust Nozzle	125	47	47	30.03	1.070	109.3	1360.6	1384.4	238.5	254.2
Approach	Exhaust Nozzle	121	54	43.5	29.50	1.303	212	3012.5	5235.7	451.4	460.6
Maximum Continuous	Exhaust Nozzle	123	29	15.4	29.38	1.873	303.8	7247.8	12697.0	---	373.4

MANCE AND TRAVERSE EMISSION INDICES--HIGH SMOKE COMBUSTION CHAMBERS

Thrust (lb)	Observed T_3 (°F)	P_3 (inHg)	CO EI	THC EI	NO_x EI	CO_2 (%)	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	F/A (CB)	F/A Measured	Sample Efficiency $\frac{F/A_{CB}}{F/A_M} X100$ (%)
834.6	175.8	197.9	63.87	19.60	2.56	0.71	58.80	16.04	3.09	.00360	.003484	103.3
849.2	175.0	---	62.95	18.70	2.56	0.71	58.90	15.90	2.94	.00360	.003443	104.5
803.5	171.7	---	62.76	23.64	2.28	0.55	58.97	20.31	2.81	.0028	.003435	---
1384.4	238.5	254.2	38.4	4.6	3.05	0.75	35.0	3.0	3.66	.00370	.003458	107.0
5235.7	451.4	460.6	8.4	0.35	5.66	0.83	8.1	0.35	6.71	.00402	.003947	101.8
12697.0	---	373.4	2.8	0.1	11.02	1.29	2.07	--	14.20	.00625	.006624	94.4

APPENDIX C

ENGINE PERFORMANCE AND CRUCIFORM PROBE EMISSIONS

TABLE C-1. ENGINE PERFORMANCE AND CRUCIFORM PROBE EMISS

Probe	Probe Ang. Pos. (Deg.)	Probe Axial Pos. (In.)	Run No.	t_2 °F	Specific Humidity Grains H_2O/lb	Bar Press inH_g A	EPR	Air Flow lbs/S	Fuel Flow lbs/h	Thrust lbs	t_3 °F	P_3 inH_g	CO EI	THC EI
Nozzle Traverse	--	--	119	42.0	19.5	30.21	1.04	78.7	987.7	834	175.8	197.9	63.9	19.6
Nozzle Traverse	--	--	124	46.0	20.4	30.10	1.04	81.7	1012.7	849	175.0	--	62.9	18.70
Mixer Traverse Average	--	--	136 139	46	40	30.10	1.04	81.7	1012.7	803	171.7	--	62.76	23.64
12 Point Cruciform	0	2	148	33	21	30.19	1.04	82.3	990	788	160	--	71.1	29.7
12 Point Cruciform	90	2	149	34	21	30.19	1.04	83.8	1013	787	--	--	73.9	31.5
12 Point Cruciform	45	2	146	32	21	30.18	1.04	83.8	1016	773	160	--	72.1	30.3
12 Point Cruciform	22 1/2	2	147	33	21	30.18	1.04	82	1015	698	160	--	69.8	31.7
12 Point Cruciform	0	8	137	45	41	30.22	1.04	81	1000	804	170	--	68.2	27.2
12 Point Cruciform	0	8	139	47	41	30.22	1.04	82	1021	798	175	--	68.3	25.0
12 Point Cruciform	45	8	145	34	22	30.23	1.04	84	1035	797	160	--	68.4	29.8
12 Point Cruciform	0	12	150	33	11	30.32	1.04	84	1034	814	160	--	71.4	26.8
8 Point Cruciform	0	8	140	44	44	30.20	1.04	82	1001	748	175	--	63.2	21.7
8 Point Cruciform	0	8	141	44	44	30.20	1.04	82	1001	772	--	--	65.0	22.0
8 Point Cruciform	45	8	143	33	19	30.24	1.04	82	1013	796	160	--	69.9	26.1
8 Point Cruciform	45	8	144	34	22	30.23	1.04	84	998	998	160	--	67.3	25.9

PERFORMANCE AND CRUCIFORM PROBE EMISSIONS--HIGH SMOKE COMBUSTION CHAMBERS

t_3 °F	P_3 inHg	CO EI	THC EI	NO_x EI	CO EI Corr.	THC EI Corr.	NO_x EI Corr.	CO % Trav. Avg.	THC % Trav. Avg.	NO % Trav. Avg.	F/A(CB)	F/A Measured	Sample Efficiency $\frac{F/A_{CB}}{F/A_M}$ X100 X1.0 (%)
175.8	197.9	63.9	19.6	2.56	58.8	16.04	3.09	--	--	--	.0036	.003484	103.3
175.0	--	62.9	18.70	2.56	58.9	15.90	2.94	--	--	--	.0036	.00344	104.5
171.7	--	62.76	23.64	2.28	58.97	20.31	2.81	--	--	--	.0028	.00343	81.6
					58.85	20.31	3.01	--	--	--			
160	--	71.1	29.7	2.19	62.57	21.75	2.85	106.3	107.1	94.7	.00334	.00331	100.9
--	--	73.9	31.5	2.21	65.37	23.36	2.85	111.1	115.0	94.7	.00345	.00339	101.8
160	--	72.1	30.3	2.25	63.12	21.91	2.95	107.3	107.9	98.0	---	.0034	60.3
160	--	69.8	31.7	2.52	61.42	23.21	3.28	104.4	114.3	109.0	---	.0034	40.9
170	--	68.2	27.2	2.37	63.77	23.09	2.95	108.4	113.7	98.0	.00343	.00343	100.0
175	--	68.3	25.0	2.37	64.4	21.74	2.90	109.4	107.0	96.3	.00342	.0035	97.7
160	--	68.4	29.8	2.52	60.50	22.10	3.26	102.8	108.8	108.3	---	.00346	98.0
160	--	71.4	26.8	2.23	62.83	19.67	2.82	106.8	96.6	93.7	.00343	.00346	99.1
175	--	63.2	21.7	2.38	58.8	18.20	3.01	99.9	89.6	100.0	.00611	.00343	178.1
--	--	65.0	22.0	2.27	60.48	18.62	2.87	102.8	91.7	95.3	.00612	.00343	178.4
160	--	69.9	26.1	2.25	61.51	19.11	2.91	104.5	94.1	96.7	.0041	.00347	118.1
160	--	67.3	25.9	2.35	59.53	19.21	3.04	101.2	94.6	101.0	.00394	.00326	120.9

APPENDIX D

ENGINE PERFORMANCE AND CORE PROBE EMISSIONS

TABLE D-1. ENGINE PERFORMANCE AND CORE PROBE EMISSIONS--LOW SMOKE COMBUSTION CHAMBERS

Run No.	t_2 °F	Specific Humidity Grain/lb of Air	Bar Press inH_g A	EPR	Air Flow lbs/S	Fuel Flow lbs/h	Thrust (lbs)	t_3 °F	P_3 inH_g	CO EI	THC EI	NO_x EI	CO EI CORR	THC EI CORR	NO_x EI CORR	F/A CB	F/A Measured	Sample Efficiency $\frac{F/A_{CB}}{F/A_M}$ X100 X2.06 (%)
59	33	8	30.14	1.04	79	1020	974	180	-	54.44	13.68	2.60	47.91	10.02	3.27	.00695	.00359	94.0
61	33	8	30.14	1.04	77	1021	1,103	180	-	54.84	14.50	2.467	48.26	10.62	3.10	.00680	.00368	89.7
62	32	8	30.14	1.208	178	2407	4,125	380	143	17.39	2.54	5.56	14.04	0.975	7.03	.00705	.003756	91.1
64	32	8	30.14	1.208	179	2407	4,156	380	143	17.08	2.18	5.52	13.79.	.837	6.99	.00724	.00373	94.2
65	29	8	30.14	1.285	204	3068	5,290	440	179	11.47	1.101	6.46	9.02	.377	8.38	.00780	.00418	90.6
67	30	8	30.14	1.282	203	3039	5,237	440	177	11.54	1.137	6.58	9.16	.405	8.47	.00775	.00416	90.4
68	30	8	30.15	1.394	231	3898	6,757	475	222	6.89	.49	8.09	5.47	.177	10.40	.00851	.00469	88.1
70	28	8	30.15	1.397	232	3934	6,808	475	222	6.88	.374	7.91	5.37	.123	10.36	.00866	.00471	89.2
71	28	8	30.19	1.512	257	4846	8,371	525	265	4.23	.136	9.43	2.98	-	12.50	.00943	.00524	87.4
73	30	8	30.19	1.512	255	4834	8,368	525	265	4.22	.113	9.43	3.05	-	12.28	.00943	.00526	87.0
74	26	8	30.01	1.577	260	5368	9,128	550	285	3.23	.132	10.85	2.22	-	14.65	.00977	.00573	82.8
76	30	8	30.01	1.680	287	6,222	10,614	590	323	2.25	.026	12.26	1.62	-	15.97	.01060	.00602	85.5
78	31	8	30.00	1.885	303	7,189	12,865	600	380	1.22	.014	15.10	0.92	-	18.80	.01187	.00659	87.4
80	30	8	29.92	2.048	319	8,489	14,562	665	427	0.800	.089	17.98	0.64	-	21.65	.01315	.00739	86.4
82	35	7	29.87	2.049	319	8,575	14,683	665	431	.728	.013	18.36	0.61	-	21.40	.01335	.00747	86.7
84	34	7	29.87	1.887	304	7,192	12,925	610	380	1.197	.005	15.50	0.93	-	18.82	.01187	.00657	87.7
86	32	7	29.87	1.738	287	6,259	11,222	600	334	1.77	.005	12.33	1.31	-	15.74	.01143	.00606	91.6
90	32	7	29.85	1.303	218	3,032	5,260	440	185	10.75	.687	7.126	8.68	0.264	8.99	.00804	.00386	101.1
92	33	7	29.85	1.070	114	1,317	1,364	240	-	33.52	6.34	3.35	29.50	4.64	4.19	.00688	.00321	104.4
94	35	7	29.85	1.059	92	980	850	180	-	51.75	1.241	2.60	46.01	9.32	3.20	.00683	.00296	112.0

TABLE D-2. ENGINE PERFORMANCE AND CORE PROBE EMISSIONS--HIGH SMOKE COMBUSTION CHAMBERS

Run No.	t_2 °F	Specific Humidity Grain/lb of Air	Bar Press inH_g A	EPR	Air Flow lbs/S	Fuel Flow lbs/h	Thrust (lbs)	t_3 °F	P_3 inH_g	CO EI	THC EI	NO_x EI	CO EI CORR	THC EI CORR	NO_x EI CORR	F/A CB	F/A Measured	Sample Efficiency $\frac{F/A_{CB}}{F/A_M}$ X100 X2.06 (%)
96	25	7	30.17	1.043	82.5	1053	892	170	-	59.05	24.66	0.645	49.82	16.30	.87	.00683	.00355	93.4
97	25	7	30.17	1.065	102	1317	1317	210	-	43.13	10.67	1.493	36.39	7.05	2.00	.00708	.00358	96.0
98	25	7	30.17	1.209	175	2424	3840	370	144	13.95	.653	3.604	10.61	.19	4.82	.00756	.00385	95.3
99	25	7	30.17	1.281	198.5	3004	-	415	176	10.94	.183	4.364	8.32	.05	5.84	.00794	.0042	91.8
100	25	7	30.17	1.043	88	1053	902	180	-	59.2	22.16	1.32	49.94	14.64	1.77	.00681	.00332	99.6
101	28	7	30.10	1.043	81	1076	854	175	-	62.45	25.57	0.902	53.53	17.57	1.18	.00664	.00369	87.4
102	27	7	30.10	1.397	209	3939	6591	470	220	5.525	.22	5.812	4.20	.07	7.78	.00833	.00523	77.3
103	27	7	30.10	1.518	246.5	4890	8197	525	266	4.85	-	7.33	3.38	-	9.78	.00934	.00551	82.3
104	27	7	30.10	1.585	267	5396	9103	540	289	4.133	-	8.41	2.88	-	11.22	.00972	.00561	84.1
105	30	7	30.10	1.690	277	6228	10475	580	320	2.99	-	9.06	2.16	-	11.77	.01058	.00624	82.3
106	28	7	30.18	1.833	291.5	7219	12070	600	368	2.34	-	10.45	1.71	-	13.90	.01119	.00688	78.9
107	30	7	30.18	2.025	316.5	8898	14332	630	427	1.66	-	13.05	1.34	-	15.67	.01261	.00781	78.4
108	30	7	30.18	2.022	332	8897	14311	630	427	1.358	-	13.05	1.09	-	15.67	.01286	.00744	83.9
109	28	7	30.18	1.819	291	7238	12070	600	367	1.99	-	10.25	1.46	-	13.02	.01141	.00691	80.2
110	37	11	30.37	1.041	74.0	985	852	185	-	57.62	18.98	2.08	51.75	14.61	2.55	.00719	.00370	94.3
111	35	11	30.38	2.012	311	8833	14270	650	426	1.738	-	13.20	1.45	-	15.56	.01306	.00789	80.3
112	34	11	30.38	1.934	302.5	8131	13353	600	400	1.545	-	11.36	1.21	-	13.94	.01241	.00747	80.6
113	34	11	30.38	1.887	299	7740	12844	630	384	1.754	-	10.51	1.37	-	12.90	.01197	.00719	80.8
114	35	11	30.38	1.690	278	6228	10478	580	323	2.69	-	9.25	2.06	-	11.63	.01058	.00622	82.6
115	35	10	30.41	1.513	252	4914	8164	-	267	3.95	-	7.50	3.02	-	9.40	.00972	.00542	87.1
116	35	10	30.41	1.284	202	3041	4915	-	179	34.43	.21	5.27	28.50	.09	6.54	.00821	.00418	95.3
117	35	10	30.41	1.064	101	1315	1262	-		44.08	8.71	2.65	39.19	6.54	3.29	.00666	.00362	89.3
118	35	10	30.41	1.041	83	1057	845	-		64.21	20.67	2.13	57.10	15.52	2.65	.00702	.00354	96.3

APPENDIX E

ENGINE PERFORMANCE AND P_{T7} PROBE EMISSIONS

TABLE E-1. ENGINE PERFORMANCE AND P_{T7} PROBE EMISSIONS--LOW SMOKE COMBUSTION CHAMBERS

Run No.	t_2 °F	Specific Humidity Grain/lb of Air	Bar Press inH_g A	EPR	Air Flow lbs/S	Fuel Flow lbs/h	Thrust (lbs)	t_3 °F	P_3 inH_g	CO EI	THC EI	NO_x EI	CO EI CORR	THC EI CORR	NO_x EI CORR	F/A CB	F/A Measured	Sample Efficiency $\frac{F/A_{CB} \times 100}{F/A_M \times 2.06}$ (%)
60	33	8	30.14	1.04	79	1020	974	180	-	57.7	20.63	2.318	50.78	15.11	2.91	.00711	.00359	96.1
63	32	8	30.14	1.208	179	2408	4126	380	143	17.92	2.404	5.55	14.47	0.922	7.02	.00848	.00374	110.0
66	29	8	30.14	1.285	204	3063	5237	440	177	12.46	1.296	6.42	9.81	0.444	8.33	.00919	.00417	107.0
69	30	8	30.15	1.395	232	3921	6808	475	222	7.731	.5467	7.98	6.14	0.194	10.27	.01004	.00469	103.9
72	30	8	30.19	1.512	257	4860	8371	525	265	4.88	.203	9.65	3.52	-	12.57	.01076	.00525	99.5
75	30	8	30.01	1.577	264	5401	9170	550	287	3.73	.112	11.48	2.69	-	14.69	.01095	.00568	93.6
77	30	8	30.01	1.681	280	6224	10,566	590	318	2.44	.018	12.59	1.76	-	16.40	.01203	.00617	94.6
79	31	8	30.00	1.885	305	7215	12,920	600	383	1.21	.004	15.24	0.92	-	18.97	.0133	.00657	98.3
81	32	7	29.92	2.047	318	8566	14,602	665	428	0.855	.012	18.69	0.70	-	22.18	.01399	.00748	90.8
83	32	7	29.87	2.049	319	8684	14,708	665	431	0.755	.004	18.90	0.62	-	22.43	.01438	.00756	92.3
85	32	7	29.87	1.888	303	7291	12,981	610	381	1.25	.004	16.11	0.95	-	19.85	.0134	.00688	94.5
87	33	7	29.87	1.738	288	6307	11,217	600	339	1.809	.004	13.45	1.35	-	17.02	.01291	.00608	103.1
89	32	7	29.87	1.551	256	4888	8,782	550	274	3.675	0.12	10.78	2.72	-	13.76	.0112	.00530	102.6
91	32	7	29.85	1.303	217	2985	5,190	440	183	11.80	0.863	6.97	9.52	0.331	8.79	.00952	.00382	121.0
93	35	7	29.85	1.070	113	1314	1,364	734	-	36.07	6.919	3.47	32.07	5.20	4.28	.00909	.00323	136.6
95	35	7	29.85	1.059	91	980	850	180	-	55.25	13.97	2.68	49.12	10.49	3.30	.00904	.00294	149.3