COLLECTION AND ASSESSMENT OF AIRCRAFT EMISSIONS BASELINE DATA - TURBINE ENGINES

PWA-4339

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION

EAST HARTFORD, CONNECTICUT

COLLECTION AND ASSESSMENT OF AIRCRAFT EMISSIONS BASELINE DATA - TURBINE ENGINES

PWA-4339

Prepared for
Environmental Protection Agency

Under Contract 68-04-0027

Final Report
February 1972

Written by: AWNelson
A.W. Nelson
Program Manager

Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION

EAST HARTFORD, CONNECTICUT

FOREWORD

This report discusses the results of an investigation to measure, record, and analyze the smoke, NO_x, CO, THC, CO_2, dry particulates, aldehyde, and olefin exhaust emissions at four (4) power settings for JT9D, JT8D, and JT3D engines. This investigation was conducted by Pratt & Whitney Aircraft under the terms of Environmental Protection Agency Contract 68-04-0027. The work covered by this report was performed during the period 1 May through 1 November 1971.

This work was carried out under the direction of Mr. C. W. Bristol with Mr. A. W. Nelson assuming Project responsibility. Other principal participants in this program were Mr. P. W. Pillsbury, Mr. J. W. Evans, and Mr. J. H. Elwood.

The Government Project Officer for this program was Mr. C. L. Gray, Jr. of the Division of Emission Control Technology, Mobile Sources Pollution Control Program, Office of Air Programs, Environmental Protection Agency.

ABSTRACT

During the period of this report, the design and fabrication of a multipoint sampling rake was completed. A check-out test of the rake using a JT9D experimental engine indicated that the exhaust emission sample obtained from the rake was very close to the average of the samples obtained from the individual probes located adjacent to the 12 rake sampling points. This probe was then used to sample the exhaust emission from an experimental engine of each of the JT3D, JT8D, and JT9D engine models, plus the exhaust emissions from nine (9) JT3D, nine (9) JT8D, and four (4) JT9D production engines.

The method used for converting the "as measured" emission values to mass (pound) units involved the core engine fuel/air ratio computation. This method is valid if proper account can be taken of the amount of dilution of the emission sample by air which did not enter into the combustion process. Accounting for sample dilution by fan air for mixed flow engines such as the JT8D was found to be very difficult using the sampling method employed.

All of the mass emission results obtained during the program were subjected to a statistical analysis.

The results of this analysis were then used in a hypothetical aircraft operational cycle. This cycle indicated that the JT3D engine emitted the largest amount of those emissions termed pollutants. The JT9D engine was second, and the JT8D engine, a low third. The low level of JT8D emissions is probably due to the difficulty of accurately sampling mixed flow tailpipe engines. The levels of JT8D emissions at low and intermediate powers are unrealistically low while those taken at the high power settings appear to be more reasonable.

Measurements of smoke, dry particulates, total particulates, aldehydes, and olefins were also recorded. In general, the data showed good repeatability except for total particulates, where considerable scatter was noted. In most cases, the JT3D engine produced the highest level of these emissions with the JT8D engine second and the JT9D engine the lowest.

Analysis of transient data indicates generally low emission levels.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

I. INTRODUCTION

Under the terms of a contract with the Environmental Protection Agency (EPA), Pratt & Whitney Aircraft has conducted a program for the collection and assessment of aircraft emission baseline data from the JT3D, JT8D, and JT9D experimental and production engine models. The program consisted of the design and fabrication of an emission sampling rake, a rake evaluation test, measurement of the exhaust emissions from experimental models of the JT3D, JT8D, and JT9D engines, and the measurement of exhaust emissions from production models of the same engines. This report includes an analysis of all of the emission measurement tests for experimental engines and for twenty-two (22) production engines. Due to funding limitations, it was not possible to measure the emission from five (5) JT9D engines which were originally scheduled by the contract.

II. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The multipoint sampling rake used for emission measurement in this program appears to provide a fairly representative (average) sample of the exhaust emissions from the JT3D and JT9D turbofan engines which have separate fan and gas generator (core) engine tailpipes. The JT8D turbofan engine, which has a common flow tailpipe for both the fan and core engine exhaust flows, is more difficult to sample accurately.

2. The difficulty of accurately computing primary (core) engine fuel/air ratios for turbofan engines at low power settings is evident from the data scatter when mass emission values are plotted versus this parameter. This inaccuracy is directly reflected in the computation of emission level in mass units (pounds) from the measured (parts per million by volume) units when such a computation requires fuel/air ratio inputs.

3. Additional inaccuracies can be introduced into the computation of emission level in mass units (pounds) for turbojet or turbofan engines having significant turbine cooling air flows. The primary (core) engine fuel-air ratios must be adjusted for the cooling airflow added between the burner exit plane and the plane of emission measurements.

4. It was not possible to accurately assess the effect of humidity and ambient (inlet) temperature on exhaust emission level. This is attributed to the small range of these two variables encountered during the testing, together with the random nature of the test program schedule.

5. The limited testing conducted using JP5 fuel (two tests per engine model) was insufficient to define accurately exhaust emission level differences between these tests and the significantly larger number of tests conducted using JP4 fuel.

6. The engine-to-engine variation could not be adequately assessed from the data set obtained from this test series. Uncontrolled and/or undetermined variables such as humidity, inlet temperature, fuel-air ratio determination, stand effects, etc., affected the results.

7. There was no apparent significant difference between data obtained from experimental engines and from production engines.

8. The accuracy and real value of measurements of exhaust emissions obtained during transient operations (starts, accelerations, decelerations and shutdowns) are questionable, primarily because the instrumentation response time is inadequate. The rough data obtained indicates emission levels not significantly different from those produced by comparable steady state operation.

9. There does not appear to be any significant advantage of the chemiluminescent NO_x analyzer over the NDIR/NDUV NO/NO_2 (NO_x) emission measurement equipment for sampling gas turbine engines under normal operating conditions.

B. RECOMMENDATIONS

1. It is recommended that programs be established to improve emission sampling techniques, especially for turbofan engines having common tailpipes (mixed fan and engine airflows). Such programs should include traverse testing with the fan and engine airflows artifically separated to accurately determine representative exhaust emissions. This testing should also be used to evaluate the suitability of engine exhaust pressure probes for measurement of exhaust emissions, as well as substantiating the suitability of "carbon balance" method of mass emission computation.

2. It is recommended that specific programs be established to define the effects of inlet (ambient) temperature and humidity on exhaust emission levels. The accurate definition of these effects is necessary for proper correction of emission levels to "standard" conditions. It is seldom practical to operate aircraft turbine engines under controlled temperature and humidity conditions.

3. It is also desirable to define the emission level differences between the use of JP5 (or Jet A) fuel and JP4 fuel. This would permit substantiation testing on either fuel in the event regulations are established.

4. It is recommended that transients not be included in any proposed aircraft engine emission regulations because of the extreme difficulty in obtaining accurate transient emission measurements.

5. In the event that emission regulations are established, it is recommended that NO_x substantiation measurements be permitted by NDIR/NDUV equipment even though other methods, such as the chemiluminescent NO_x analyzer, may be specified.

III. DISCUSSION

The purpose of the program was to document the exhaust emissions of the major commercial engines currently being manufactured by Pratt & Whitney Aircraft. The program and the accomplishments achieved are shown in Figure 1. As illustrated in the figure, the program consisted of the design and fabrication of an emission sampling rake, a rake evaluation test, measurement of the exhaust emissions from experimental models of the JT9D, JT8D, and JT3D engines, and the measurement of exhaust emissions from production models of the same engines.

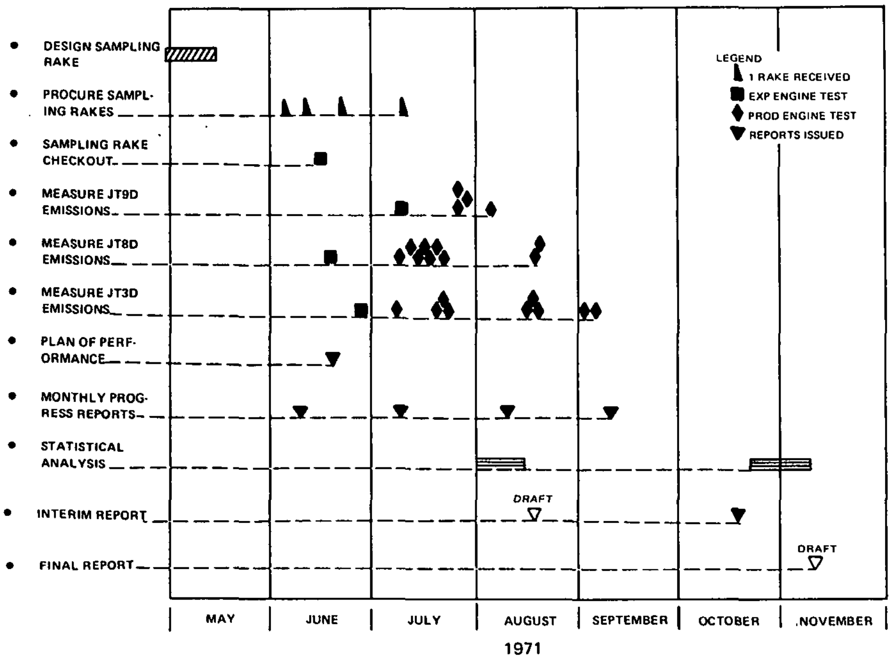


Figure 1 Program Accomplishments

A. RAKE DESIGN

In the past, exhaust emission data for P&WA engines has been based on the analysis of gas samples taken from a single location at the exit of the engine tailpipe. This location was established as 2 inches aft and 10 inches up from "bottom dead center" of the engine vertical centerline. This program utilized an exhaust sampling method which provided a substantial improvement over the single-point sampling method. A multipoint sampling rake, shown in Figure 2, was designed to sample the engine exhaust stream at three (3) different radial locations for each of four (4) different circumferential positions. The twelve (12) sampling tubes are manifolded together at the center of the rake. The probe tips were designed to produce a mass flow rate into the individual sampling lines that is representative of the engine mass flow at the point of sampling. The Mach number in each sampling tip is very close to the Mach number in the engine jet stream at the point of sampling. This is accomplished by making the probe orifice pressure drop equal to the pressure drop across the engine tail pipe. By positioning the probe tips so as to sample from equal areas of the tail pipe, the composition of the sample in the rake manifold is considered to be more representative of the actual average emission composition of the exhaust gas stream than was provided by past sampling methods. The shape of the inlet orifice is conical and was designed to prevent the formation of shock waves which could interfere with the uniform sampling of the exhaust stream. The probes were sized to provide adequate flow for simultaneous smoke and gas analysis.

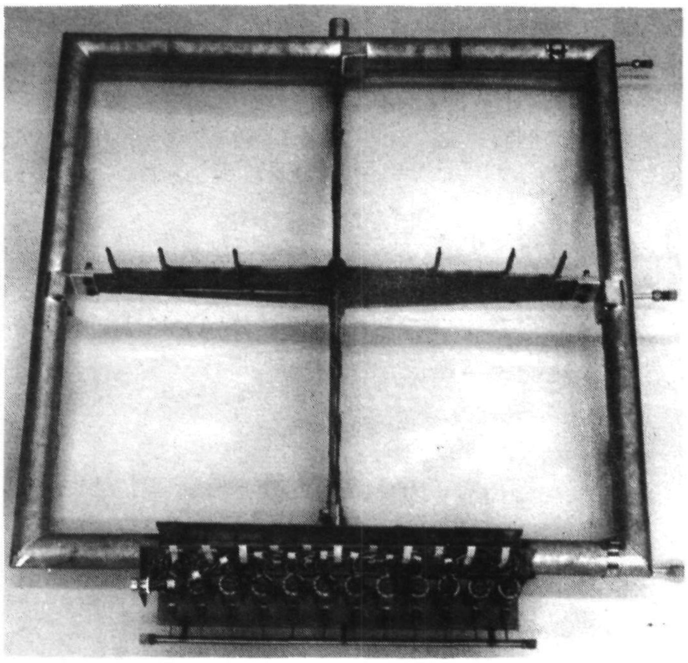


Figure 2 Exhaust Emission Rake XR-549248 With Temporary Check Out Probes (XPN-22201)

Two lines were used to extract emission samples from the rake manifold; one to the emissions measurement van for gaseous emission measurement and the other for measurement of smoke and particulates. A third line was used to record the pressure in the manifold chamber.

Two basically similar rake designs were made, one for the JT9D engine and the other for use with JT3D and JT8D engines. The only difference between the rake designs was the positioning of the probe tips. For the JT9D engine,which has the largest diameter tailpipe, the probe tips were radially located at centers of equal areas for this tailpipe. The other rake, for the JT3D and JT8D engines, was designed so that the probe tips were positioned at centers of equal areas for the JT3D engine. This same rake design is used for the JT8D engine even though the tailpipe for this engine is larger than the JT3D engine tailpipe.

The JT8D engine is a turbofan engine which utilizes a common tailpipe for discharge of both the fan and gas generator air flows, as differentiated from separated fan and engine air flows which are characteristic of the JT3D and JT9D engines in the production test configuration. The common flow tailpipe and the resultant mixing of the two gas streams makes the assessment of emission levels from this type of engine difficult. At the time of the rake design, the only information available for the design of a rake suitable for JT8D engine use was a series of traverses to determine the variation of smoke level in the tailpipe area. These traverses, which were made at high power settings, suggested that locating the individual probes at the same position as that for the JT3D engine rake would minimize the amount of expected emission dilution by fan air at the high power settings. There was no data available for low power operation.

A two piece stand was designed to support the emission sampling rake behind the engine tail pipe. The basic support unit consisted of a modified "A" frame design and was fabricated from standard steel pipe. This unit was designed so that there is no interference with either the fan or gas generator exhaust streams when the rake is removed. The second part of the stand is a square frame which directly supports the emissions sampling rake. This unit is also fabricated from steel pipe. Provision is made in this unit for thermal expansion of the rake. This square frame, with the rake attached, can be mounted to the basic support frame over a wide range of vertical positions thus permitting accurate alignment of the rake with the engine tailpipe centerline. Provision is made in both units for water cooling although this feature was found to be unnecessary.

Two rakes of the JT3D-JT8D design, two rakes of the JT9D design, and four support units were procured for the emission test program. Figure 3 shows the support stand and rake in place behind an experimental JT3D engine.

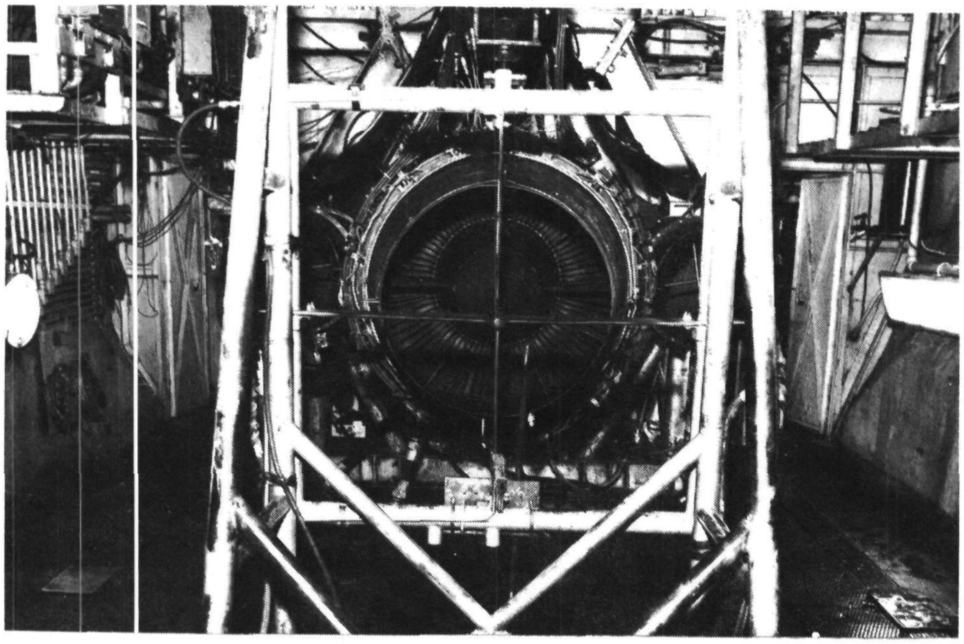


Figure 3 Rear View of Sampling Rake Installation, JT3D Engine X-315-44

(X-36263)

Testing of the emissions sampling rake behind the JT8D engine indicated that additional support was necessary in order to prevent cracking of the sampling tubes at the bend locations. Although this cracking only occurred during JT8D engine testing, gussets were applied to all probes in the critical bend locations.

Long term testing with both JT9D and JT3D/JT8D emission sampling rakes indicated a tendency to develop cracks at the junction of the sampling tubes with the manifold body. This cracking is attributed to thermal stress and could be corrected by design revision to provide greater expansion freedom of the tubes. The cracks were temporarily repaired by furnace brazing with high temperature braze material.

B. EMISSIONS MEASUREMENTS

1. Gaseous Emissions

The gaseous exhaust emissions, nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and total hydrocarbons (THC) were measured using modern Beckman instrumentation housed in a mobile laboratory specifically designed for measurement of gaseous exhaust emissions from gas turbine engines. The mobile laboratory is completely self supporting and, as shown in Figure 4, includes a power generator for use when 440 volt power is not available. Communication from the mobile laboratory to the test control station is accomplished by using an intercom system.

Figure 4 Engine Emission Analysis Mobile Laboratory (J2503-1)

The following table lists the ranges and characteristics of the analyzer units used to measure the above gases:

Component	Range	Detection Method	Minimum Error % Full Scale
THC	0-1 ppmv	Flame Ionization Detector	±5.0%
(as methane)	through 50K ppmv	Beckman-Model 402	±1.0%
NO	0-200 ppmv	Non-dispersive infrared	±2.5%
	0-500 ppmv	Beckman-Model 315AL	±1.0%
NO_2	0-200 ppmv	Non-dispersive ultra violet	±2.0%
	0-500 ppmv	Beckman-Model 255A	±1.0%
CO	0-100 ppmv	Non-dispersive infrared	±2.0%
	through 2.5K ppmv	Beckman-Model 315AL	±1.0%
CO_2	0-2%	Non-dispersive infrared	±1%
	0-5%	Beckman-Model 315A	±1%
	0-11.25%		±1%
O_2	0-10%	Polarographic	±1%
	0-25%	Beckman-Model 715	±1%

The six electrical outputs from these analyzer units are recorded continuously on two - three pen analog recorders and also "on command" by a punched paper tape recorder for steady state recording. The paper tape format is compatible with the IBM 360 computer which is used for data reduction.

Figure 5 shows a schematic of the sample handling system of the mobile laboratory. A heated sample line with a variable temperature range of 0 to 400°F is used to carry the gas sample to a 350°F to 400°F oven which houses a stainless steel bellows sample pump along with the appropriate valving and filtering. The temperature setting for the heated sample line is generally 375°F with a sample gas flow rate of approximately 5 SCFM. The heated sample line and the heated THC analyzer are used to prevent condensation or adsorption of the hydrocarbons on the cool surfaces. During combustor start ups where raw fuel is flowing, a nitrogen purge is used to insure that there will be no collection of fuel on the sample line walls. For the recording of emissions during starts and shutdown, a single point sampling probe was used. The use of this probe and a separate sampling line eliminated the possibility of contamination of the multipoint sampling rake with raw fuel and other contaminants.

One branch of the heated sample goes directly to the Flame Ionization Detector (F.I.D.) heated hydrocarbon analyzer. The other branch is split again, one section going to the NO and NO_2 analyzers and the second, through a refrigerator condenser (for water removal), to the CO, CO_2, and O_2 analyzers. Dual dryers are used to take out moisture to the inlet of the NO analyzer. Appropriate valving is used for venting and for introducing the zero and span gases to each analyzer.

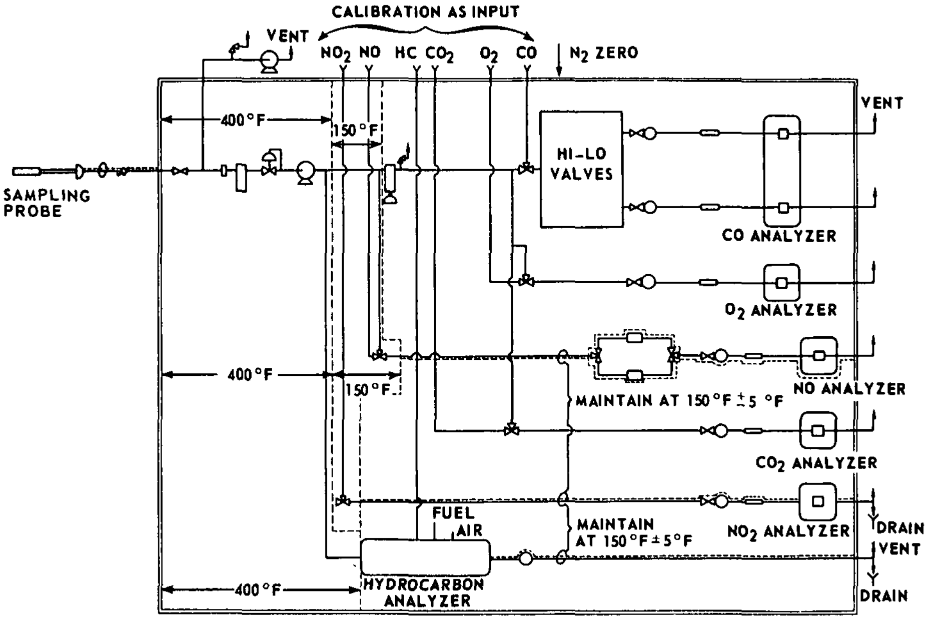


Figure 5 Sample Analyzer Handling System (J2503-6)

Prior to running a test, during the test, and at the completion of the test, zero and span gases are introduced into the analyzers to check the calibration of each analyzer.

2. Chemiluminescent Analyzer Evaluation

The chemiluminescent technique for measurement of NO/NO_x is specified as the standard method of measurement of this emission for automotive control purposes. The chemiluminescent method is also being seriously considered as a standard method for measurement of aircraft NO_x exhaust emissions. As an effort separate from the emissions documentation contract, Pratt & Whitney Aircraft conducted an evaluation of a Thermo Electron Corporation (TECO), Model 10A chemiluminescent NO_x analyzer (0 129/#24) which was provided on a loan basis by the Environmental Protection Agency (EPA).

The evaluation of this analyzer was conducted in both the laboratory and on the test stand. The laboratory evaluation was used for familiarization with the unit and for evaluation of its performance using "clean" sample gases. The test stand evaluation consisted of three engine emission tests, two JT4 and one JT9D, for evaluation under service conditions and for comparison with NDIR/NDUV equipment.

In the course of the laboratory evaluation, some anomalous results were observed with the unit. During calibration with 91 ppm NO in N_2 sample gas with the instrument in the NO mode, the NO_2 converter (650°C) was switched in the sample circuit and the observed reading increased from 91 ppm to 95 ppm. Repeated switching of the converter in and out of the circuit continued to verify the 4 ppm differential. The calibration sample gas was checked using Saltzman reagent to qualitatively determine the presence of NO_2, but none was found. The reason for this change in calibration has not been explained; however, subsequent repeat tests over an extended time period have dropped this differential to approximately 1 ppm.

On another occasion, a sample gas consisting of 76 ppm NO_2 in air was introduced into the converter (650°C) resulting in an initial meter indication of 32 ppm. The meter indication increased slowly with time and, in 60 minutes, a level of 67.5 ppm was indicated. The test was repeated on the following day with similar results except that the initial reading was 45 ppm instead of 32 ppm and the stabilization time was much shorter. During additional testing and use for a 2½ month time period, this slow time response phenomenon did not reoccur, or was not noticed, indicating the possibility that either the converter had "conditioned" or the instrument response was dependent upon the converter history. A special test was arranged to isolate this characteristic of the TECO chemiluminescent analyzer and converter combination. Both units were permitted to be dormant for a period of four days. A Beckman NDUV NO_2 analyzer was mounted near the TECO units and both analyzers were "teed" into the regulator outlet fitting of an NO_2 gas cylinder. The outputs of both analyzer units were connected to strip chart recorders for simultaneous recording of the NO_2 level as measured by each unit. The TECO unit was placed in the converter mode and both units were permitted to warm up. The NO_2 gas cylinder regulator was then opened and the response of both instruments was monitored. The Beckman instrument reached 90 percent of maximum reading in ten seconds, however, the TECO unit required 30 minutes to reach the same level. Following a purge of both instruments using dry nitrogen, the test was repeated. The response of the Beckman instrument was the same as that of the first test. The TECO unit response on the second test was markedly improved, with only fifteen minutes required to achieve the 90 percent of maximum reading level. It would appear, from this limited laboratory testing, that the converter efficiency of the TECO instrument is related to the past history of the unit and that precautionary procedures are in order to properly condition the unit for measurement of NO_x, emission levels when significant quantities of NO_2 may be present in the sample.

This problem should have been indicated when a check of converter efficiency was conducted in accordance with the EPA recommended procedures as outlined in the Federal Register, Volume 36, Number 128, Part II, dated July 2, 1971. This check of converter efficiency was made by filling a bag with NO and air and sampling the mixture at specified time intervals. The sampling was done alternately in the NO and NO_x modes and the results indicated a constant indicated level of NO_x and a smoothly decreasing level of NO. These results reportedly indicate a 100 percent NO_2 converter efficiency; however, the previously described tests had shown that, during the initial time period, the converter efficiency was considerably less than 100 percent. A possible reason for these results was suggested by additional testing. It was shown that when the increase in converter efficiency is substantially faster (on the order of 4 to 5 times) than the NO to NO_2 conversion in air, it is very unlikely that the reduced converter efficiency during the initial time period (30 minutes or less) would be detected by the EPA procedure. Although additional testing is indicated to further define whether this effect is general or confined only to this particular instrument, it is suggested that the possibility of error is a distinct possibility when sampling for NO_x with high NO_2/NO_x ratios during the initial phases of the testing.

The field or test stand evaluation of the chemiluminescent NO_x analyzer consisted of three tests, one on a JT9D engine and two separate tests on a JT4 engine.

The JT9D test was conducted on experimental JT9D engine X-501-10 on 20 July 1971. Although NDIR/NDUV equipment was not available for a direct comparison, a previous exhaust emission survey using Beckman NDIR/NDUV equipment had been conducted three weeks earlier. Since no changes in engine configuration had been made during this time period, a useful comparison could be made. Comparison of the two tests is shown in Figure 6.

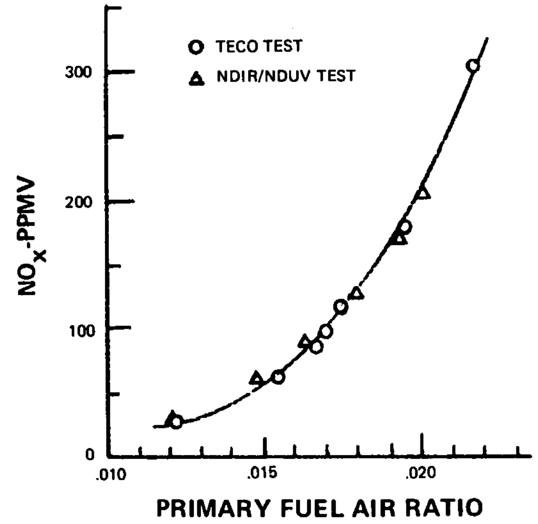


Figure 6 Comparison of Chemiluminescence NO_x Analyzer and NDIR/NDUV Analyzer, JT9D Engine

The first test of a JT4 engine was conducted on experimental engine X-313-42 on 18 August 1971. Samples were taken using a single point smoke probe and the exhaust pressure manifold (Station P_{t7}) probes. Availability problems prevented a comparison between TECO and NDIR/NDUV equipment for this test. The results are shown in the following table.

Smoke Probe Results		Station P_{t7} Probe Results	
CO_2* Percent by Volume	NO_X** PPMV	CO_2* Percent by Volume	NO_X** PPMV
1.40	13.0	1.40	8.0
1.42	23.0	1.42	17.0
2.34	59.0	2.34	58.0
2.92	93.5	2.92	92.5
3.14	110.0	3.14	105.0

*CO_2 values were calculated from fuel/air ratio
**NO_X TECO in converter mode only.

The second JT4 engine test was conducted on 3 September 1971 using experimental engine X-313-42. For this test, both the TECO Model 10A Chemiluminescent analyzer and the Beckman NDIR/NDUV analyzers were used to evaluate the NO_X exhaust emissions as sampled by a conventional single point smoke sampling probe and by the exhaust pressure manifold (station P_{T7}) probes. The results are shown in the table below.

CO_2 Percent By Volume	NO PPMV		NO_2 PPMV		NO_X PPMV	
Beckman	Beckman	TECO	Beckman	TECO	Beckman	TECO
			Smoke Probe Results			
1.32	3.1	2.8	2.5	1.9	5.6	4.7
1.41	5.3	4.0	4.3	2.6	9.6	6.6
1.51	7.0	7.5	0.5	3.5	7.5	11.0
3.10	95.0	95.0	1.9	6.0	96.9	101.0
2.47	51.0	65.0	13.0	0.0	70.0	65.0
			Station P_{T7} Probe Results			
1.28	2.6	3.1	3.0	1.6	5.6	4.7
1.31	4.1	4.2	3.6	1.0	7.7	5.2
1.37	5.4	6.5	1.0	0.6	6.4	7.1
3.23	111.0	112.0	7.4	5.0	118.4	117.0
2.57	62.0	64.0	8.7	5.0	70.7	69.0

CO_2: Beckman NDIR
NO: Beckman NDIR; TECO without converter
NO_2: Beckman NDUV; TECO Difference NO_X-NO
NO_X: Beckman sum of NO & NO_2; TECO in converter mode

A comparison of all of the JT4 engine results is shown in Figure 7.

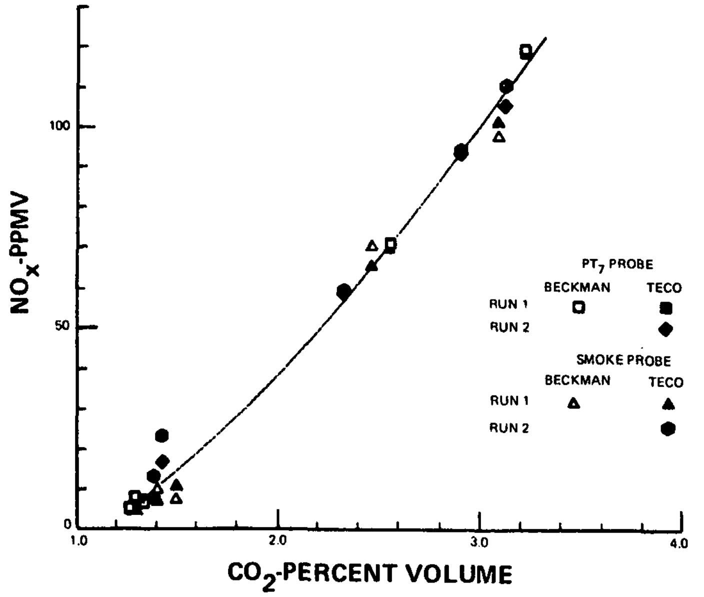


Figure 7 Comparison of NO_X Emissions From JT4A Engine With Two Different Burner Configurations

The results of the evaluation of the TECO model 10A chemilumenescent NO_X analyzer can be summarized as follows:

a. There appears to be little practical difference or advantage between the TECO chemiluminescent analyzer and the Beckman combined NDIR and NDUV analyzers for measurement of NO_X emissions from aircraft gas turbine engines.

b. For the chemuluminescent analyzer, care must be taken when measuring NO_X that the converter is properly conditioned if significant amounts of NO_2 are suspected to be present in the sample being analyzed.

c. The EPA recommended practice for determining converter efficiency should be reviewed with regard to possible error of converter efficiency during the initial (thirty minutes or less) measurement period.

The following comments are offered with regard to the design of the unit tested.

a. Consideration should be given to provide a more efficient ozone scrubber for the vacuum pump. Six weeks operation resulted in seal breakdown and oil leakage.

b. Care must be taken to prevent plugging or partial plugging of the sample capillary. Partial plugging can result in an undetected shift in calibration. Capillaries should be made more readily accessable for replacement.

c. The photo detection tube should be shielded to prevent stray light from reaching the tube when the sample line is changed or disconnected.

3. Smoke Emissions

Relative smoke densities were measured using a Pratt & Whitney Aircraft modification of the Von Brand continuous filtering smoke meter (Figure 8). Modifications were made to make this device more accurate and sufficiently rugged for test stand use. The meter draws a sample through a continuously moving strip of Whatman No. 4 filter paper. The sample size is 0.3 standard cubic feet per square inch (scf/in^2) of filter paper corresponding to 0.02294 lbs/in^2 (59°F 29.92 inches Hg). Relative smoke measurements are made by measuring the loss of reflectance of the filter paper with clean paper assumed to be 100. This reflectance measurement is made using a Photovolt Model 610 diffuse reflectance meter, Figure 9. Smoke numbers, as reported, correspond to 100 - relative reflectance, i.e., a perfectly clean engine would have a measured smoke number of zero.

A direct relationship can be made between the Von Brand system, as used at Pratt & Whitney Aircraft, and the SAE ARP 1179 system. ARP 1179 is a closed spot meter system having narrow tolerances on the flow measurement instrumentation and sample handling procedures. At least four distinct sample weights are taken and the reporting value extrapolated to

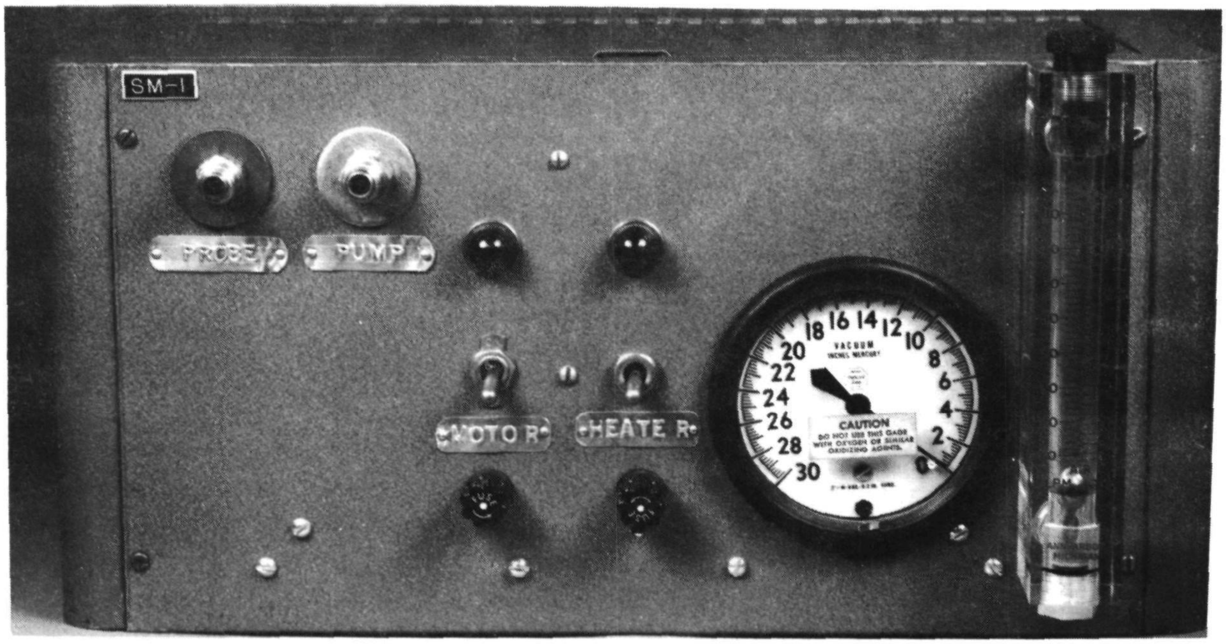


Figure 8 Pratt & Whitney Aircraft Modified Von Brand Meter (XP-71876)

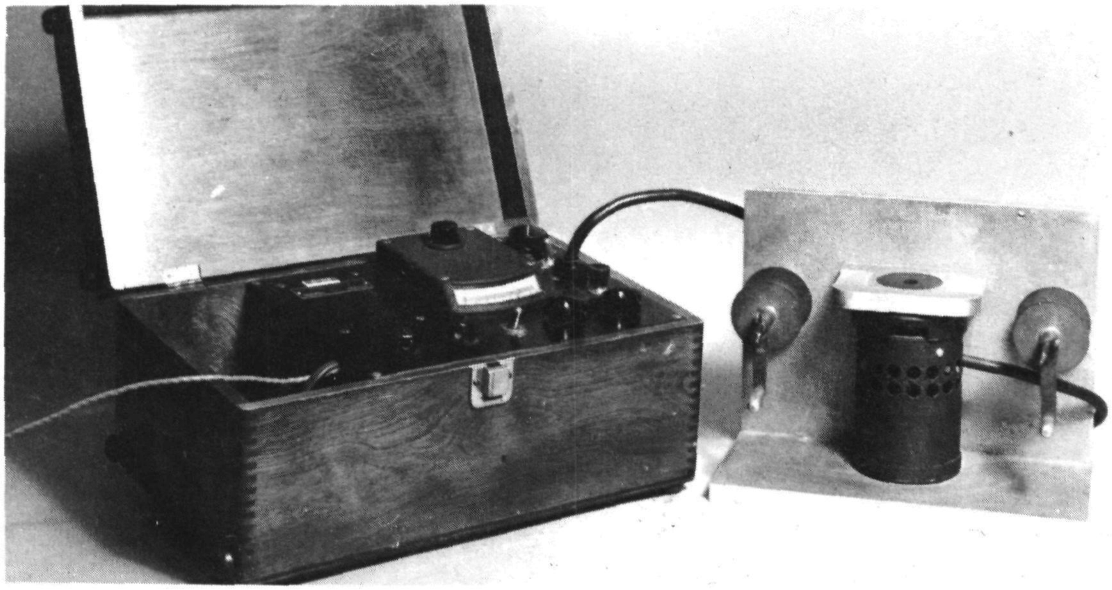


Figure 9 Read Out Meter and Light Source for Von Brand Smoke Tape (XP-51675)

0.0230 lb exhaust gas per sq in. of filter. The filtering medium is Whatman No. 4 filter paper and the reflectance meter corresponds to ASA standards for diffuse reflection density. Because the filtering media is the same, Whatman No. 4, and the reporting sample weight is, for all practical purposes, the same, it is expected that smoke numbers for the two systems, allowing for reduced tolerances in the Von Brand, will be the same.

4. Dry Particulate Emissions

Solid dry particulates were collected by a Millipore inline vacuum filtering unit (Figure 10) using Type HA cellulose ester filters with an average pore size of 0.45 microns. Measurements were made gravimetrically following normal procedures for reducing errors due to water absorption.

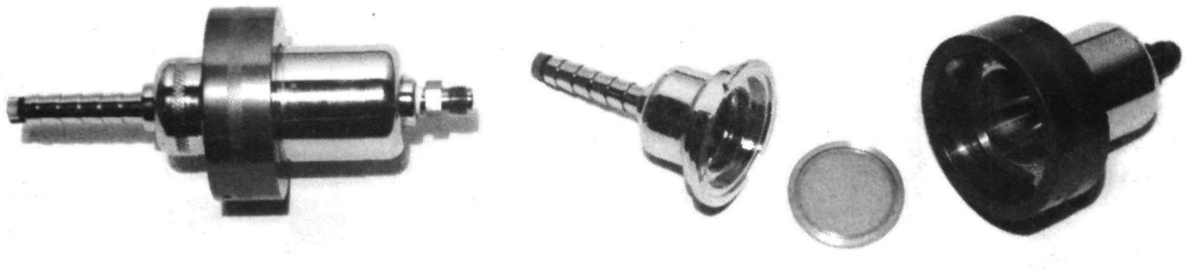


Figure 10 Millipore In-Line Filtering Unit for Collection of Particulate Matter (XP-47644)

5. Total Particulate Emissions

The measurement of total particulates for this test program was made utilizing the Los Angeles County Air Pollution Control District (LACAPCD) method.

The sampling system for the LACAPCD impinger method consisted of a gas sampling probe, a four foot piece of Resistoflex line, three Greenberg-Smith impingers connected in series, and a Whatman thimble filter as shown in Figure 11. The first two impingers in the sample

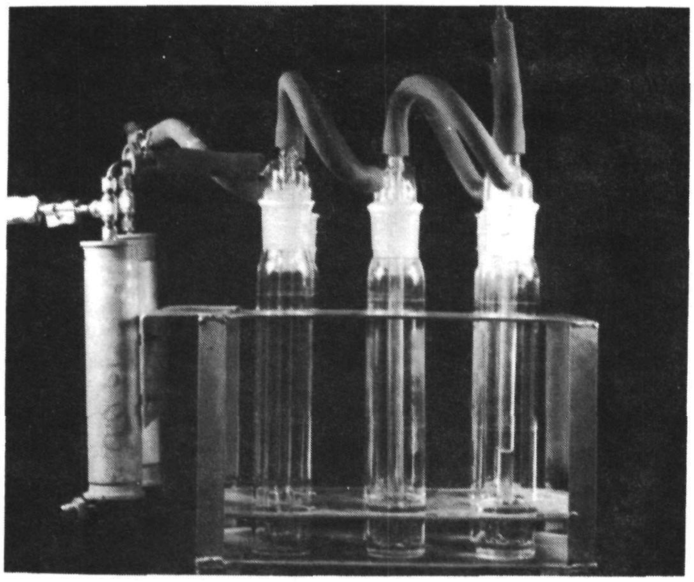


Figure 11 Particulate Sampling Train With Impingers and Thimble Filter in Series (XP-93426)

train contained 100 ml of water and the third was dry. All three impingers were encased in an ice bath during the sample collection. A 7.2 cubic foot per minute vacuum pump was used to pull the sample through the impingers. The flow was measured with an American dry test meter and was corrected for pressure and temperature.

The probes, lines, and impingers were cleaned with Alconox, then rinsed with distilled water and rerinsed with chloroform before the test. The probes and lines were dried with a nitrogen purge and the glassware was dried in an oven at 115°C. Numbered Whatman thimble filters were treated in an oven for two hours then placed in a dry box overnight before weighing. A separate system consisting of probe, line, Greenberg-Smith impingers, and thimble filter were used for each power level sampled. The samples were collected in the impingers by installing a gas sampling probe into the exhaust stream of the engine.

After collection of the samples at the various power settings, the sampling system was returned to the Physics and Chemistry Laboratory. The connecting lines from the impingers were dismantled and the solution from the impingers decanted into a preweighed flask. The flask was then weighed and the percent by volume of the engine water emission calculated. Next, the lines, probes, and impingers were rinsed with water and the washings added to the flask which was then reweighed. The probes, lines, and impingers were then rinsed with chloroform. These washings were also added to the flask which was again weighed. From the weights obtained after each water and chloroform rinse, a correction can now be made for the impurities in the rinsing solutions. The average corrections have been 0.7 mg per 100 ml of water and 2.0 mg per 100 ml of chloroform.

These solutions were then analyzed for insolubles, solvent solubles, and water solubles by the UAC Research Labs. The insolubles were extracted by filtering the solution through a weighed 0.45 micron Millipore-filter. To insure that all insoluble material was removed from the flask, the flask was rinsed with chloroform and the washings filtered. The filter was dried and reweighed. The difference in the initial and final weights of the filter paper is the weight of impinger insolubles. The total insolubles are the impinger insolubles plus the material collected on the Whatman thimble filters. The thimble filters were also conditioned before and after test. Additional filters were weighed before and after test to use as controls. These control filters are used to correct for any atmospheric humidity changes that may occur between weighings of the test filters.

The organic material (fuel and oil) in the flask was removed by extraction with an organic solvent. The solvent extract was then evaporated at room temperature. The solution (water and chloroform) was divided into two phases, water solubles and solvent solubles. This was achieved by transferring the solution to a separatory funnel and extracting with five 25-ml portions of reagent grade chloroform. About 25 shakings were performed for each extraction. Adequate time was alloted after each shaking to allow the two liquids to separate as much as possible before the solvent extract was removed from the lower section of the separatory funnel. After the chloroform had been completely extracted from the solution, the water in the separatory funnel was transferred to a beaker and evaporated on a hot plate to a volume of about 25 ml. The reduced volume was then transferred to a small weighed beaker and evaporated to dryness in a 105°C constant temperature oven. The water residue was then cooled in a desiccator for one hour and weighed. The differential of the two weights is the weight of water solubles.

The chloroform solution containing the solvent solubles was placed in a beaker equipped with inlet and exhaust lines inserted in a two-hole stopper. With a vacuum pump connected to the exhaust line, dry room air was passed through the solution from the inlet line which contained Drierite desiccant. This process was continued until the solution was reduced to 10-15 ml. The solution was then transferred to a small weighed crucible and placed under a bell jar equipped with inlet and exhaust fittings. The dry air evaporation process was then continued until all of the solvent had evaporated and only the organic particulate matter remained. The crucible was then placed in a desiccator for one hour before weighing. The solvent solubles are the difference of the two weighings of the crucible.

6. Olefin Emissions

Olefin emissions were measured during this test program by use of the DAB method.

The emission sample is collected in a two liter evacuated flask containing 20 ml of a solution consisting of dimethylaminobenzaldehyde in concentrated sulfuric acid. Exposed samples are allowed a minimum of 6 hours for complete absorption and are periodically swirled. Development of the sample involves the heating of a fraction at 100°C for 20 minutes. Readout is at 500 milli-micron (mu). The method is sensitive to olefins containing 4 or more carbon atoms.

7. Aldehyde Emissions

Aldehyde emissions were measured during this test program by the use of the MBTH method.

The emission sample is collected in a two liter evacuated flask containing 70 ml of a 0.05 percent aqueous solution of 3-methyl-2-benzothiazolone hydrazone hydrocloride. Development of the sample involves the addition of an oxidizing reagent consisting of sulfamic acid and ferric chloride in aqueous solution. The method is sensitive to aliphatic aldehydes and produces a stable blue cationic dye. Read-out is at 628 milli-micron (mu).

C. EXPERIMENTAL TESTING PROCEDURES

1. General Test Description

The experimental testing portion of the program was designed to evaluate measurement repeatability, emission differences between fuels, and to determine the total particulate emissions for the three engine models tested. Because of the relatively long engine running times involved, these tests were conducted on experimental engines having substantially the same Bill of Material as the production engines to be measured.

Emission tests were run on one experimental JT3D, JT8D, and JT9D engine. A series of four different tests were run for each of the experimental engines tested. The first two runs were run on JP4 type fuel. Both tests consisted of 10 power level points spaced so as to obtain good definition of the characteristics of the low and high power emissions. Only a short duration engine shutdown separated the two test runs so that measurement repeatability could be evaluated. These tests also define the engine emission characteristics of JP4 fuel which is the fuel used for all production engine testing at Pratt & Whitney Aircraft. In addition to the measurement of the gaseous emissions, NO, NO_2, CO, CO_2, O_2, and THC at each of the test points, smoke measurements were taken at four of the test points. Dry particulates were measured at three of the test points and aldehydes were measured at the idle test point for each run.

Following the two test runs on JP4 fuel, a similar test run was made using JP5R fuel which is similar to the Jet A and Jet A-1 fuels used in commercial airline operation. This test run was used for a determination of the emission differences between the two fuels. A fourth and last test run was made on an experimental engine to determine total particulates, olefins, and aldehydes as well as the other emission constituents which were recorded on the other three test runs. This test run, which consists of four power settings each having 35 minutes duration, was run on JP5R fuel thus adding additional information on the emission characteristics of this fuel.

In addition to the above information, measurements were taken of the gaseous emissions during startups, shutdowns, and during accelerations from idle to takeoff power and for decelerations from takeoff to idle power. The startups and shutdowns were recorded by the use of a specially mounted single point sampling probe mounted 2 inches aft and 10 inches up from bottom dead center of the engine vertical centerline. This probe was used in order to avoid contaminating the multipoint rake with raw fuel during startups and shutdowns. A nitrogen purge was used on the rake during these transients.

Also, when practical, a portion of the test series was conducted with the pressurizing and dump valve plugged in order to determine any change in startup or shutdown emissions characteristics which may be attributable to this plugging.

Fuel samples for analysis were also taken during this test series.

2. Rake Checkout

In order to demonstrate that the multipoint rake would provide a representative average of the emissions at the 12 points being sampled, a JT9D type rake was modified by the addition of individual sampling probes located adjacent to each of the 12 sampling points of the rake. As shown in Figure 2, the lines from these individual probes were directed to a junction box containing 12 solenoid valves. By suitable connection and manifolding, it was possible to separately record the gaseous emissions at each of the 12 individual probe locations for comparison of this average with that recorded from the rake manifold.

The modified rake was then mounted behind JT9D engine X-564 and a probe checkout test was conducted. At power settings of idle (where CO and THC are highest) and maximum continuous power (where NO_x is high), readings of the individual probes were taken for comparison with average readings from the multipoint rake. At each of the two power settings, three rake readings were recorded during the course of recording the 12 individual probe values in order to average out any changes in engine power setting which may have taken place during the test recording time period (over one hour.) The test results are shown in the table below:

IDLE POWER SETTING

Probe Type	NO_x	CO	THC
		Emission (PPMV)	
Probe 1	18.7	619.4	321.1
Probe 2	15.5	626.1	405.3
Probe 3	16.0	635.1	409.7
Probe 4	16.5	620.1	305.8
Probe 5	14.6	779.5	510.1
Probe 6	12.9	733.8	618.8
Probe 7	16.8	426.5	235.3
Probe 8	17.6	551.5	284.2
Probe 9	18.9	554.2	370.8
Probe 10	19.4	491.5	308.3
Probe 11	21.6	496.6	271.0
Probe 12	20.5	327.1	148.9
Individual Probe Average	17.4	571.8	349.1
1st Rake Reading	18.4	568.4	331.2
2nd Rake Reading	15.9	589.0	366.6
3rd Rake Reading	17.5	600.9	378.6
Rake Average	17.26	586.1	358.8
Rake-Probe Difference (PPMV)	0.14	14.3	9.7
Rake-Probe Difference (Percent)	0.81%	2.43%	2.72%

MAXIMUM CONTINUOUS POWER SETTING

Probe Type	NO_x	CO	THC
		Emission (PPMV)	
Probe 1	335.8	9.0	7.0
Probe 2	286.5	13.7	5.4
Probe 3	306.9	17.7	4.8
Probe 4	295.5	9.8	5.6
Probe 5	300.0	11.7	5.1
Probe 6	273.5	13.2	5.3
Probe 7	266.5	17.1	2.6
Probe 8	301.8	15.6	2.7
Probe 9	293.1	12.0	3.1
Probe 10	282.8	8.5	2.8
Probe 11	327.5	9.1	2.7
Probe 12	308.1	8.8	2.5
Individual Probe Average	298.2	12.18	4.13
1st Rake Reading	300.7	11.8	1.6
2nd Rake Reading	300.9	11.6	0.3
3rd Rake Reading	292.7	12.5	3.3
Rake Average	298.1	11.96	1.73
Rake-Probe Difference (PPMV)	0.1	0.22	2.40
Rake-Probe Difference (Percent)	0.03%	1.81%	~

This testing verified that the average rake data are in very close agreement with the average data of the 12 individual probes and therefore is a representative average of 12 selected sampling points.

Following the rake checkout a series of high power performance calibrations were run to establish the effect of the rake proximity on engine performance parameters. Calibrations were run with the rake positioned at 2 inches, 6 inches and 10 inches behind the engine tailpipe and also with the rake entirely removed. Preliminary analysis of the data indicated that 10 inches behind the tailpipe was the closest position that would not affect engine performance. This position was then established as the standard position for this program.

Later more detailed analysis of this same data indicated that there was a slight performance affect at 10 inches and that 14 inches was a better setting for the JT9D production engine. This setting was used for all JT9D production engine testing.

3. JT3D Testing

The experimental portion of the JT3D engine testing was conducted using experimental engine X-315-44. Prior to this testing, the fuel nozzles and burner cans were changed to the configuration currently used in production engines. With this change, the engine configuration was substantially the same as the JT3D-7 engine. The experimental test series was run on 28 and 29 June 1971. For the first three tests of the series, the following power settings were run:

1. Idle
2. Idle plus 1000 lbs Thrust
3. 6500 lbs Thrust
4. *14,500 lbs Thrust
5. 19500 lbs Thrust
6. *Takeoff Power
7. *18,500 lbs Thrust
8. 10,500 lbs Thrust
9. 2,500 lbs Thrust
10. Idle plus 500 lbs Thrust

*Dry Particulates Recorded For These Power Settings

The final test run, for the measurement of total particulates, olefins and aldehydes, was made at the following power settings:

1. 9,000 lbs Thrust
2. 20,000 lbs Thrust
3. 18,000 lbs Thrust
4. Idle

For all of the above testing the rake was set 10 inches aft of the engine tailpipe. Figure 3 shows the test arrangement.

4. JT8D Testing

The experimental portion of the JT8D engine testing was conducted using experimental engine X-370-47. This engine was used at P&WA for endurance testing and was the only experimental JT8D engine available in the June through August time period. The engine configuration was substantially in accordance with the JT8D-15 version of the engine which represents a thrust improvement over the D-7, D-9, and D-11 versions. The latter engines, however, represent the bulk of current production orders. On the first attempt to run the experimental test series a number of the sampling probes on the rake failed after a short exposure to the JT8D engine exhaust. These were repaired and all of the individual sampling tubes were strengthened by the addition of gussets to either side. This strengthening was incorporated on all four emissions sampling rakes. This modification corrected the problem and the tests were completed on 23 June 1971.

For the first three tests of the series, the following power settings were run:

1. Idle
2. Idle plus 1000 lbs Thrust
3. 6000 lbs Thrust
4. *10,000 lbs Thrust
5. 13,000 lbs Thrust
6. *Takeoff Power
7. 12,000 lbs Thrust
8. 7000 lbs Thrust
9. *5000 lbs Thrust
10. Idle plus 500 lbs Thrust

*Dry Particulates Recorded For These Power Settings

The final test run, for the measurement of total particulates, olefins and aldehydes, was made at the following power settings:

1. 5000 lbs Thrust
2. 14,500 lbs Thrust
3. 12,000 lbs Thrust
4. Idle Plus 500 lbs Thrust

For all of the above testing, the rake was set 10 inches aft of the engine tailpipe.

5. JT9D Testing

The experimental portion of the JT9D engine testing was conducted using experimental engine X-495-14, which is a performance development engine having a configuration substantially in accordance with the JT9D-7 production engine configuration. The D-7 model is the current major JT9D production engine model. The experimental test series was run on 8 and 9 July 1971. For the first three tests of the series, the following settings were run:

1. *Idle
2. Idle plus 1000 lbs Thrust
3. 12,000 lbs Thrust
4. *33,000 lbs Thrust
5. 40,000 lbs Thrust
6. *Takeoff Power
7. *36,000 lbs Thrust
8. 23,000 lbs Thrust
9. 8,100 lbs Thrust
10. Idle plus 500 lbs Thrust

*Dry particulates recorded for these power settings.

The final test run, for the measurement of total particulates, olefins and aldehydes, was made at the following power settings:

1. Idle
2. 12,000 lbs Thrust
3. 36,000 lbs Thrust
4. 33,000 lbs Thrust

For all of the above testing, the rake was set 10 inches aft of the engine tailpipe.

D. PRODUCTION TESTING PROCEDURES

1. General Test Description

The production portion of the program was designed to evaluate the engine to engine variation in emission level by conducting a significant number of tests on different engines of the same model. In addition, it was hoped that these tests would expand and amplify data concerning the effects of inlet (ambient) temperature and humidity on emission levels. These tests, which were conducted with minimum interference to the normal testing of production engines, were run with JP4 fuel, the fuel normally used for all production engine testing.

Emission tests were run for nine (9) different engines for each of the JT3D and JT8D engine models and for four (4) JT9D engine models for a total of 22 different tests.

Each test consisted of a minimum of five test points, one at idle, one at takeoff, and the remaining points spaced in between depending upon the type of production test being run. For green and final acceptance testing, 6 or more test points were taken. The gaseous emissions, NO, NO_2, O_2, CO, CO_2, and THC were taken for all of the test points. Smoke and dry particulates were taken at idle, takeoff, and two other points. For two production engines of each model, the measurement of aldehydes were made in place of the dry particulates at the idle power setting.

2. JT3D Testing

The current JT3D production engine model is the JT3D-3B version. The emissions multipoint sampling rake and support stand were mounted in production test stand P-68. It was discovered that, because different fan air discharge ducts are used in production from those used in experimental testing, a portion of the fan air impinged on the upright supports of the rake. There was concern that this would affect engine performance measurements at the 10 inch aft position. Consequently, using JT3D engine P-668816, calibration tests were run with and without the rake and support stand in place. Analysis of the data did not show any effect on engine performance. The emission testing on engine P-668816 was completed on 7 July 1971. Emission testing on engines P-668817, P-669797, and P-668815 was completed on 21,22, and 23 July 1971, respectively. A fifth emission test on engine P-669796 was attempted but the engine was rejected for vibration before a sufficient number of test points could be obtained.

The emission testing of JT3D production engines was temporarily suspended in order to measure JT9D production engines at the Middletown facility. JT3D production engine emission testing was resumed in the latter part of August when three-3B engines, P-668821, P-668820 and P-668822 were measured on August 18, 19, and 20, respectively. These engines completed the production run of JT3D engines until late October. Permission was requested and granted to build two of the October engines in September so as to complete the emissions testing program. These -3B production engines, P-669798 and P-669799, were emission tested on September 2 and September 9. This completed the testing of nine (9) JT3D-3B engines.

3. JT8D Testing

The current JT8D production engine models are the JT8D-9 and -11 with a few JT8D-7 and -15 being produced during this time period. For this emissions measurement program, the multipoint sampling rake and support stand were mounted in production test stand P-67. To insure that the positioning of the emissions rake 10 inches aft of the engine did not affect performance, calibration tests were run, using JT8D-9 engine P-674552, with and without the rake and support stand in place. No affect on engine performance was detected. Emissions testing on this engine was completed on 9 July 1971. An emission test on JT8D-11 engine P-676215 was completed on 12 July 1971 and emission tests on JT8D-9 engines P-665705, P-665706 and P-665708 were completed on 14, 15, and 16 July 1971, respectively. Two additional JT8D-9 engines, P-665709 and P-674550, were measured on 20 and 21 July 1971, respectively. Two additional JT8D-9 engines, P-666987 and P-666988 were measured on August 19 and August 20, respectively. This testing completed the emission measurement of JT8D engines with eight (8) JT8D-9 and one (1) JT8D-11 being measured during the program.

4. JT9D Testing

The current JT9D production engine schedule includes mostly JT9D-7 engine models with a lesser number of JT9D-3A and -15 engine models. For JT9D production engine emission testing, two test stands, P-3 and P-7, at the Middletown, Connecticut test facility, were outfitted with the multipoint sampling rake and support. The rakes were positioned 14 inches aft of the engine tailpipe, because a more detailed analysis of the data run on JT9D engine X-564 showed that there was a slight effect on engine performance at the 10 inch position and that 14 inches aft of the tailpipe was the closest position permissable for the emissions testing. Emission testing of two JT9D-7 engines, P-685605 and P-685602, was accomplished on 28 July 1971. On 29 July 1971, emissions testing was completed on JT9D-3A engine P-663071. It was not possible to obtain smoke or particulate measurements on engines P-685602 or P-663071 because of lack of manpower. On 5 August 1971, emissions testing was completed on JT9D-7 engine P-685614. Funding limitations prevented the emission testing of additional JT9D engines.

IV. ANALYSIS OF RESULTS

A. STATISTICAL ANALYSIS OF PRIMARY GASEOUS EMISSIONS

1. Conversion of Emission Data to Mass Units

Conversion of the gaseous emission data (NO, NO_2, CO, THC) from the measured parts per million by volume (PPMV) units to the desired pounds of emission per pound of fuel (LBS/LB Fuel) or pounds of emission per hour (LBS/HR) was accomplished in accordance with the following equations:

$$(1) \quad \frac{\text{Emission (PPMV)}}{10^6} \text{ X } \frac{MW_E}{MW_A} \text{ X } \frac{1}{F/A} = \text{Emission (LB/LB Fuel)}$$

$$(2) \quad \text{Emission (LBS/LB Fuel) X Fuel Flow } \left(\frac{\text{LBS}}{\text{HR}}\right) = \text{Emission (LBS/HR)}$$

where, MW_E = Molecular Weight of Emission

MW_A = Molecular Weight of Air

For NO_2, MW_E = 46

For NO, MW_E = 30

For CO, MW_E = 28

For THC (CH_4)MW_E = 16

For Air, MW_A = 29

$$F/A_P = \text{Fuel to Air Ratio (Primary, Core, Engine)} = \frac{\text{Fuel Flow, LBS/HR}}{\text{Combustor Airflow, LBS/HR}}$$

The accuracy of this conversion method therefore depends on the accuracy of the fuel/air ratio calculation, the accuracy of the measuring instruments, as well as the ability of the sampling method selected to provide a representative emission sample for analysis. In the case of turbojet engines, both the fuel flow and airflow are directly measured and therefore the accuracy of the fuel/air ratio calculation is considered to be good over the entire operating range. In the case of turbofan engines, however, generally only the total airflow is directly measured and the airflow portion of interest for mass emissions computations, the core engine airflow, must be computed. This airflow computation is considered to be accurate over most of the operating range except for the very low power range (idle) where light engine loadings reduce the computation accuracy.

The fuel/air ratio method of mass emission computation was the standard method used by P&WA during the duration of this contract. The "carbon balance" method, as recommended by the Society of Automotive Engineers, Inc. (SAE), Aerospace Recommended Practice, ARP 1256, is now being implemented as an additional method of determining mass emission measurement.

2. Analysis Objective

Statistical methods were employed for the analysis of the gaseous emissions produced by the three engine models tested during the program. The intent of this analysis was:

- to obtain estimates of the arithmetic average and standard deviation of the gaseous exhaust emissions at four selected engine power settings; idle, approach, climb, and takeoff.

- to attempt to assess the effects of humidity, temperature, and the difference of fuel type on exhaust emission levels.

- to evaluate, within the limitations of the data, the changes in exhaust emissions due to engine to engine variation among the different engines of the same model and the run to run differences as determined by repeat runs of the same engine.

3. Conditions of the Data

The bulk of the gaseous emission data collected during the program was obtained from the "run in prior" test, the green test, or the final acceptance test of production engines. Because the number of specific test points required for any of these tests is small, this necessarily limited the number of engine power settings at which emission data could be collected. Thus data was not often obtained near the power settings of approach and climb during the course of the program which made analysis of emission level at these points more difficult to assess.

Tests of an experimental engine were used to determine the run to run differences for each engine model. Each experimental test required a relatively long time to complete which resulted in a considerable time period between repeat runs. Thus, the run to run analysis is affected by uncontrolled changes in atmospheric conditions. Because corrections for these uncontrolled effects on exhaust emission level are unknown, a pure run to run variation cannot be determined.

The attempt to determine the effects of humidity and temperature can also only be estimated on a gross basis since a controlled test or tests of a single engine over a range of temperatures or of humidities was not a part of the program. The analysis that was undertaken by necessity involved a number of different engines which were tested over a small range of temperatures and humidities (all of the testing was done during the summer months) and thus the results can be confused or affected by a number of factors. These factors could include:

- time of day,
- slight changes in fuel composition during testing,
- test stand differences, and
- change in inlet (ambient) air composition.

In fact, all of the emission measurements recorded during the program are affected by these and other factors since it was not practical at this time to run controlled tests to determine in detail these individual effects.

It should be realized that the basic purpose of the program conducted for the EPA was to document the emission characteristics of a significant number of engines of the same model. The program was not designed to accurately determine the effects of temperature, humidity, run to run variation and engine to engine variation. A limited amount of information on the effect of these variables was, however, compiled during the course of the program. Because there is little or no past data available concerning the effects of these variables on emission level, efforts were made to extend the data analysis to cover these variables. Statistical methods were employed when practical.

4. Analysis Approach

As described in the preceeding section, gaseous emission measurements were not always obtained exactly at the nominal conditions of idle, approach, climb, and takeoff. Therefore, consideration had to be given as to how to best estimate emission level for these conditions from available data. Two basic approaches were considered:

- draw a line through the data by eye and correct the points to the desired conditions, and
- average the data through use of regression analysis techniques.

Regression analysis was chosen because it offered several major advantages over the eye correction of the data while at the same time providing maximum flexibility for satisfying the objectives of the study. The basic flow path taken to arrive at the averages as well as assess the effect of humidity, temperature, fuel type, and run to run and engine to engine differences is presented in Figure 12. Discussion of details associated with the method of analysis chosen is given in the following sections. A general discussion of regression analysis is presented in Appendix A for reference.

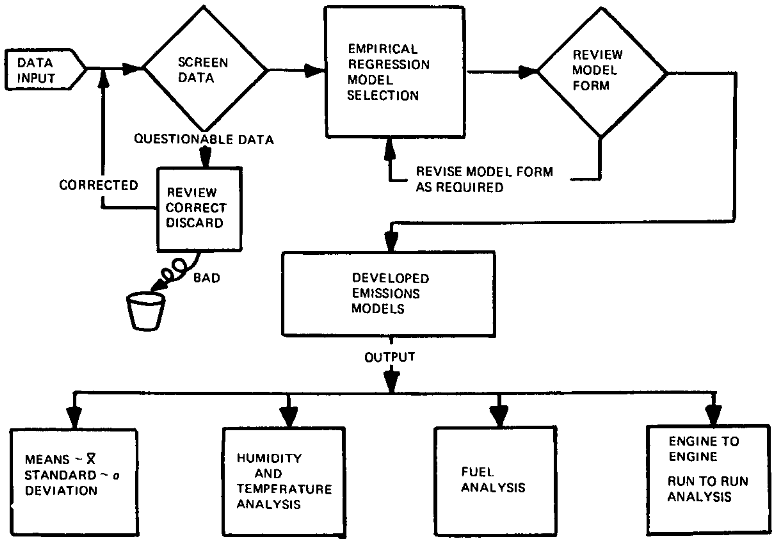


Figure 12 Statistical Analysis Flow Path

5. Empirical Model Building

When a unique relationship exists between two variables, Y (e.g., NO_X) and X (e.g., EPR), they are said to be functionally related. If the exact relationship is not known it can be approximated mathematically over a range of values by obtaining pairs of X and Y observations in this range. A most important consideration is the choice of the functional relationship which is to be used as the approximation. This can be done in essentially two ways. These are:

- Theoretical knowledge of the type of relationship
- Empirical examination of a scatter diagram or plot of the data and hypothesize the relationship.

The first method is preferred as it is naturally useful to have prior knowledge of the form of the relationship between two variables. However, often little is known about this relationship, as is the case for correct gaseous emission predictions, and the use of a scatter diagram is valuable in providing ideas as to the true relationship. Through inspection of the individual scatter plots, (see paragraph B5 of this section) the basic shapes of the exhaust emission data are determined. For each of these basic curve shapes, a mathematical model is fitted. Typical shapes and corresponding mathematical models are shown in Figures 13 and 14.

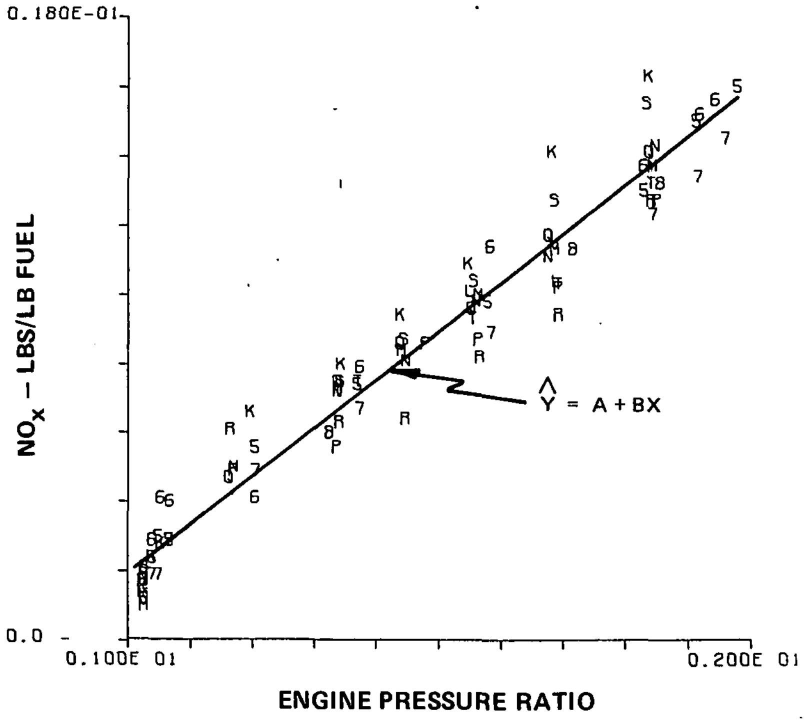


Figure 13 Oxides of Nitrogen (NO_X) Versus Engine Pressure Ratio Emission Measurement Results, JT3D Engine

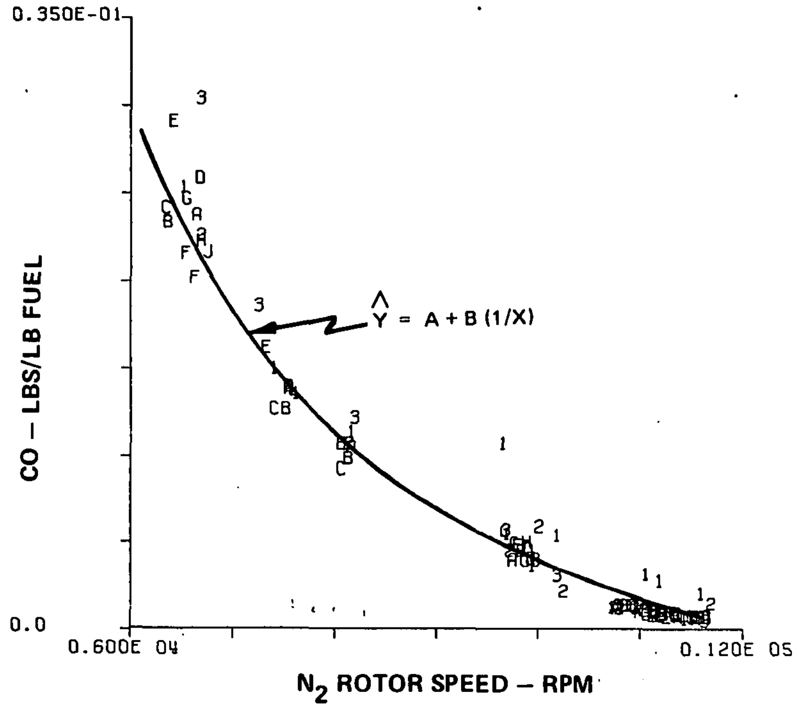


Figure 14 Carbon Monoxide (CO) Versus N_2 Rotor Speed Emission Measurement Results, JT8D Engine

With this hypothesis of basic shapes, empirical models for the exhaust emissions were developed using only statistical decision rules to determine inclusion or exclusion of the independent variables (i.e., N_2, EPR, etc). However, it was noted that the models differed from engine model to engine model and the inclusion of more than one or two independent variables did not significantly improve the precision of the estimates of the exhaust emission results. It was also noted from the interim analysis to the final analysis that there were still further changes in the development of empirical models due solely to the inclusion of additional data.

Because of these inconsistencies with the available data set, it was considered that a detailed and exhaustive multiple regression analysis was not warranted. Therefore, simplified final models were selected to provide estimates of the average exhaust emissions and for providing insight into the possible effects of humidity, inlet temperature, and fuel type. These models are shown below:

$\underline{NO_x}$

JT8D	$NO_x = .0237 + .0171\ EPR - .214 \times 10^{-5}\ H\ of\ C^*$
JT3D	$NO_x = -.0098 + .0140\ EPR - .194\ Humidity$
JT9D	$NO_x = -.093 + .0770\ EPR + .000263\ Temp. - .313\ Humidity$

* Heat of Combustion (H of C)
Test Average For JP4 Fuel ~ 18,784 BTU/LB
Test Average For JP5 Fuel ~ 18,487 BTU/LB

CO

JT8D	$CO = -.00763 + .102 \times 10^{9} (1/N_2)^{2.5} + .0971$ Humidity
JT3D	$CO = -.5004 + .133 \times 10^{4} (1/N_2) + .0000196$ H of C
JT9D	$CO = -.0128 + .181 \times 10^{18} (1/N_2)^{5} + .446$ Humidity

THC

JT8D	$THC = .000107 + .1504 \times 10^{29} (1/N_2)^{8}$
JT3D	$THC = -.232 + .256 \times 10^{22} (1/N_2)^{6} + .0000123$ H of C
JT9D	$THC = -.00433 + .259 \times 10^{32} (1/N_2)^{9} + .384$ Humidity

Smoke

JT8D	Smoke = −248.12 + 27.43 EPR + .012 H of C
JT3D	Smoke = −564.32 + 29.09 EPR + .030 H of C
JT9D	Smoke = −20.261 + 10.80 EPR + .121 Temp.

A representation of the precision of the prediction of exhaust emission level using the developed models can be shown by plotting the observed emission values versus the emission values calculated by the model. A typical example is shown in Figure 15.

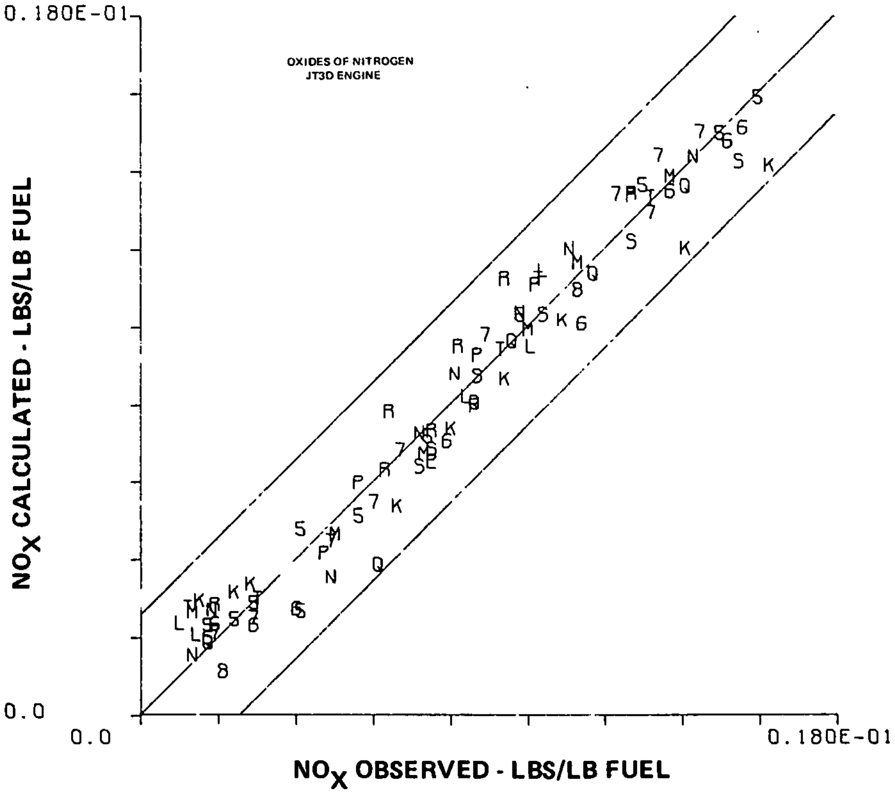


Figure 15 Observed Versus Calculated Values of NO_X

6. Mean and Standard Deviations Emission Levels

a. Oxides of Nitrogen (NO_x)

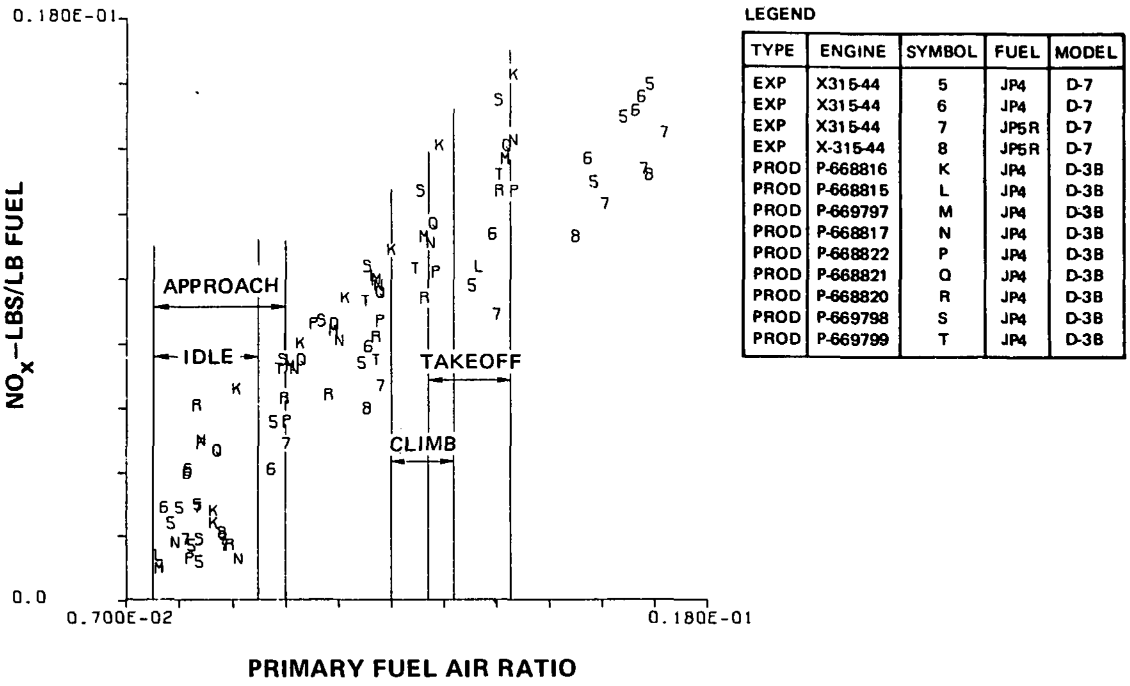
The maximum concentration of NO_x occurs at the highest power settings. Curves of the relationship of NO_x to rotor speed, thrust, engine pressure ratio, fuel air ratio and percent rated thrust are shown in Figures 16 through 30 for the JT3D, JT8D, and JT9D engines.

The statistical analysis has also indicated the mean value and the 1 sigma (σ) variation of the NO_x data taken for each engine model at power settings of idle, approach, maximum continuous (climb), and takeoff.

These results are summarized below:

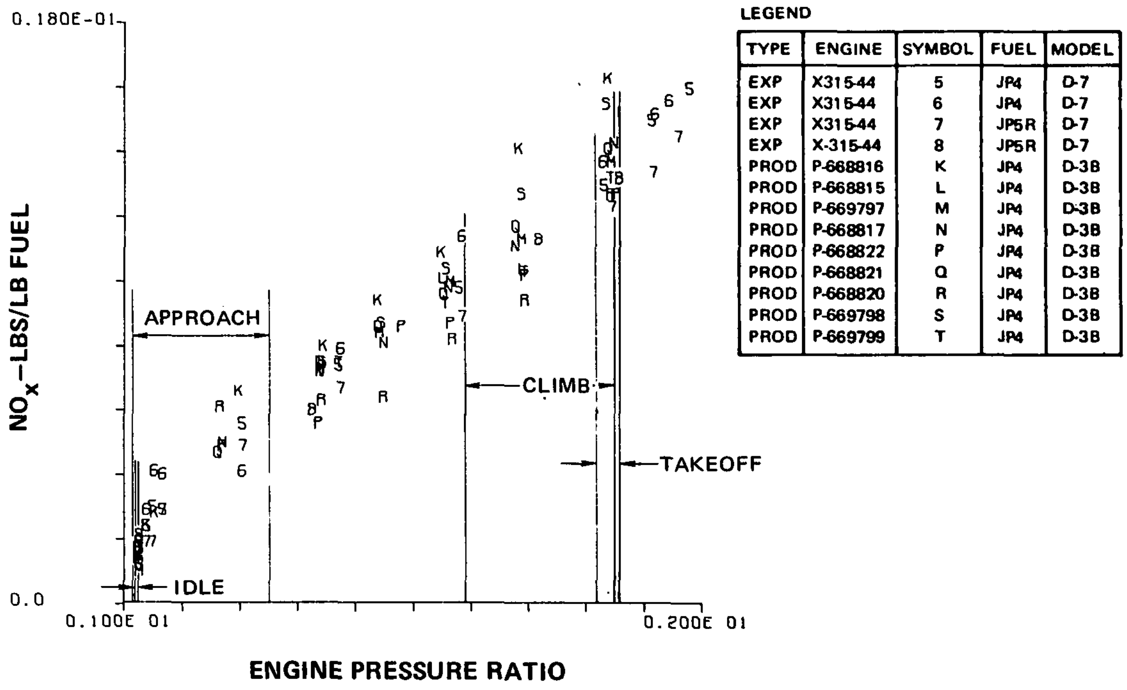
NO_x RESULTS

Engine	Mode	Thrust lbs	Fuel Flow lbs/hr	NO_x lbs/ 1000 lbs Fuel	NO_x 1 Sigma Variation
JT3D	Idle	900	1,070	2.25	0.85
	Approach	5,228	3,573	4.87	0.85
	Climb	16,400	8,120	11.92	0.85
	Takeoff	18,000	9,420	13.63	0.85
JT8D	Idle	800	920	1.71	0.78
	Approach	3,555	2,700	5.39	0.78
	Climb	12,600	7,020	15.60	0.78
	Takeoff	14,500	8,400	18.60	0.78
JT9D	Idle	3,550	1,976	3.41	1.9
	Approach	15,009	7,515	11.42	1.9
	Climb	39,650	14,109	30.00	1.9
	Takeoff	45,500	16,641	36.80	1.9



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 16 Oxides of Nitrogen (NO_X) Versus Primary Fuel Air Ratio Emission Measurement Results, JT3D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 17 Oxides of Nitrogen (NO_X) Versus Engine Pressure Ratio Emission Measurement Results, JT3D Engine

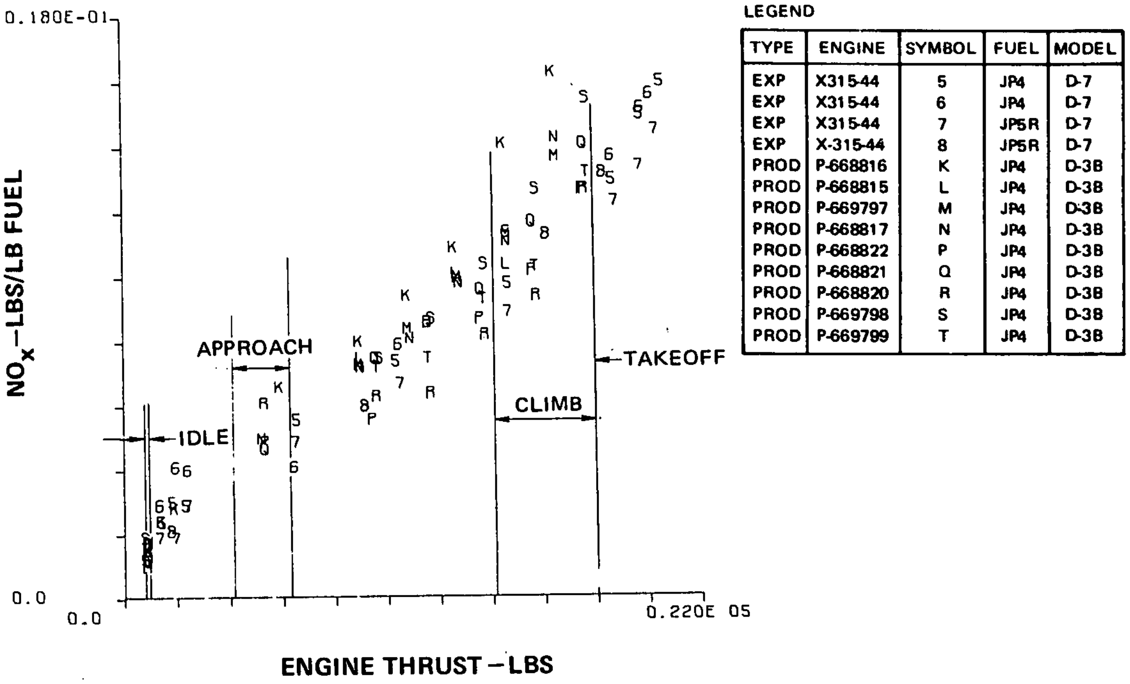


Figure 18 Oxides of Nitrogen (NO_X) Versus Engine Thrust Emission Measurement Results, JT3D Engine

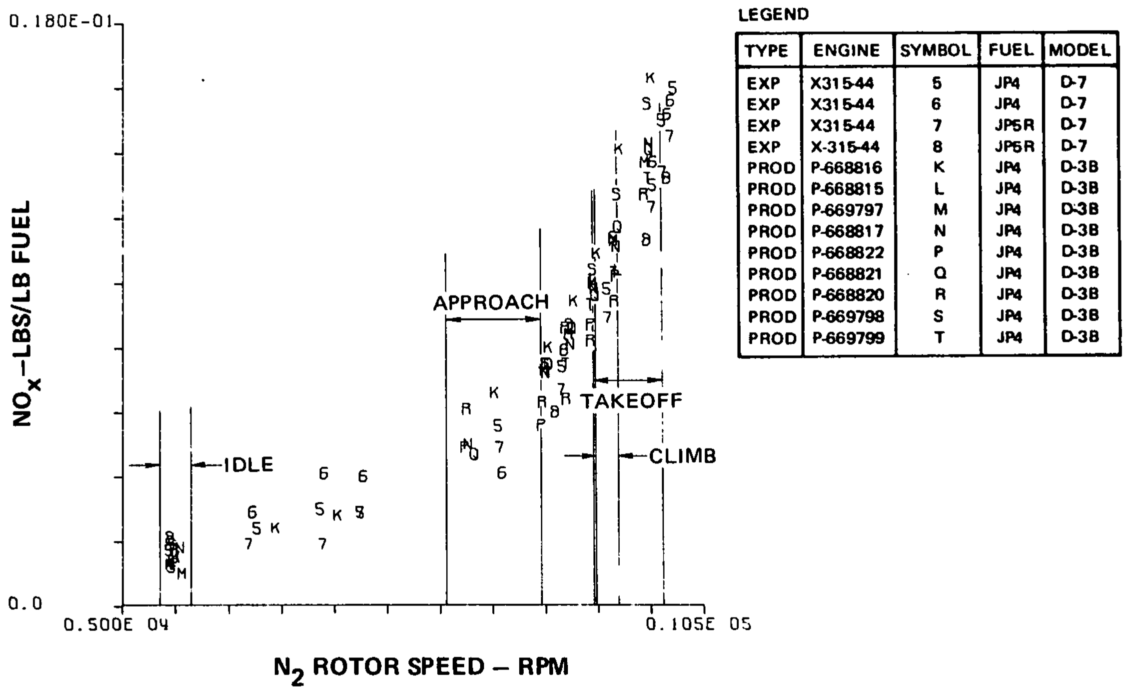
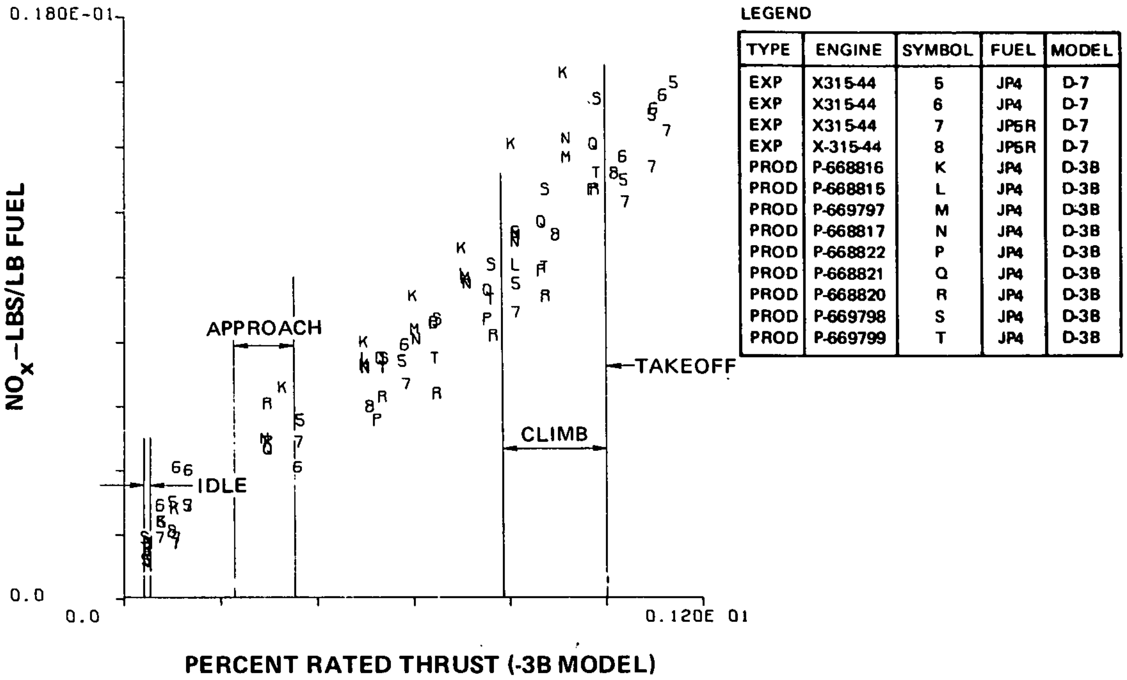
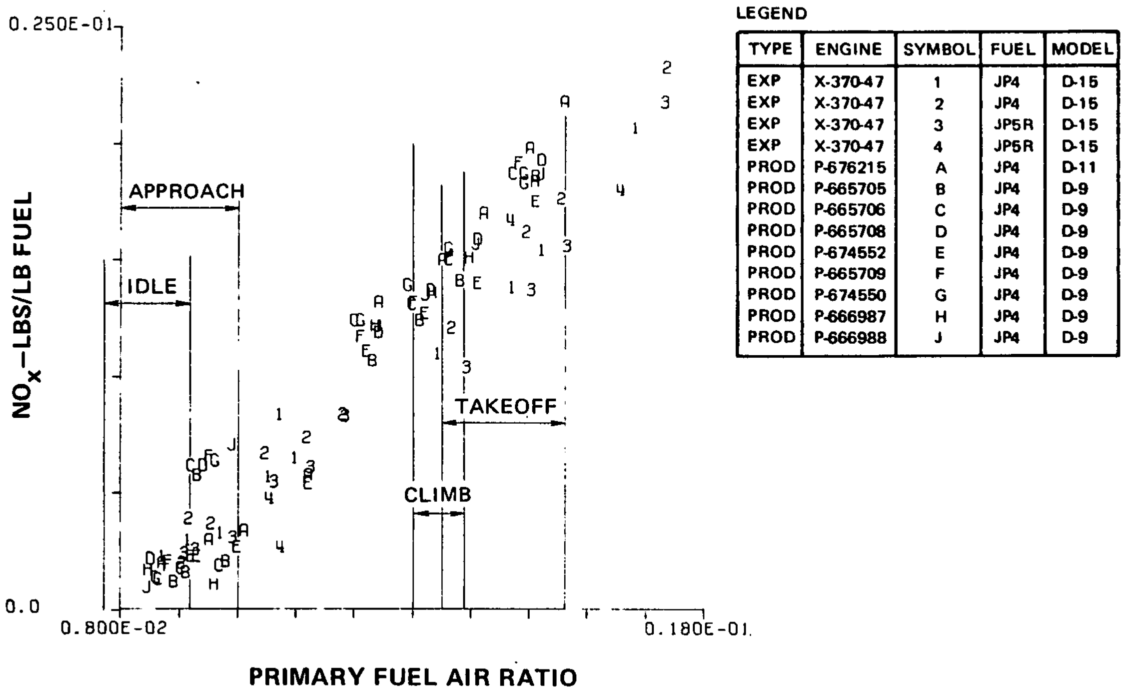


Figure 19 Oxides of Nitrogen (NO_X) Versus N_2 Rotor Speed Emission Measurement Results, JT3D Engine



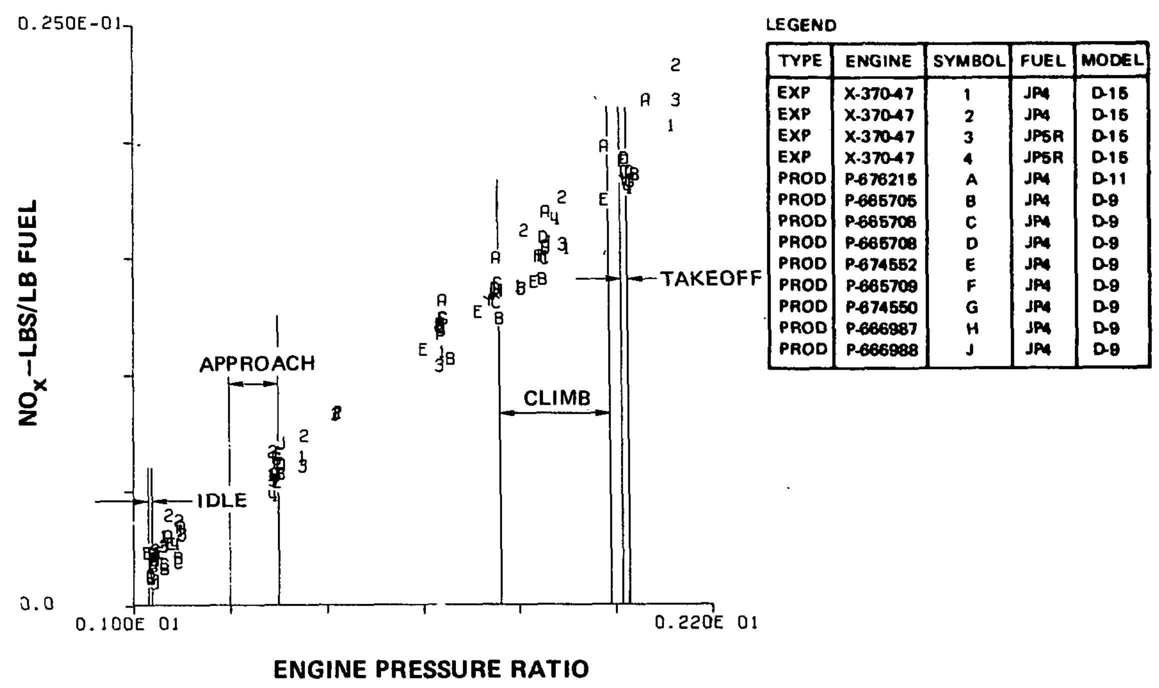
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 20 Oxides of Nitrogen (NO_X) Versus Percent Rated Thrust Emission Measurement Results, JT3D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

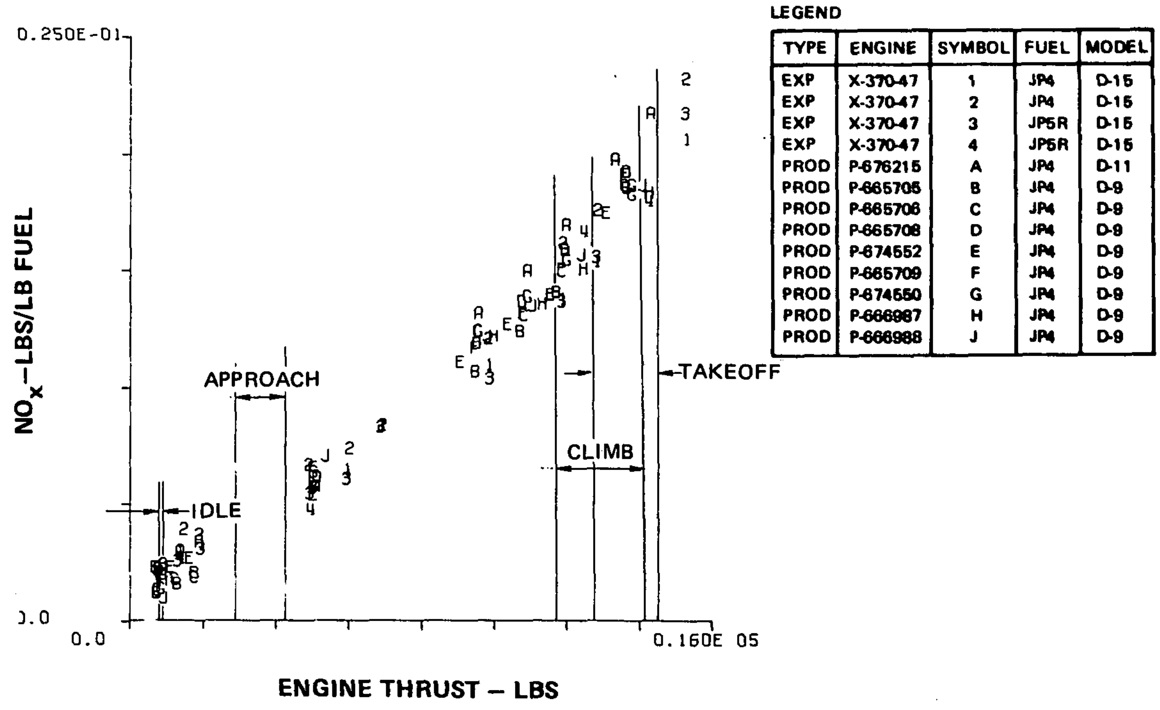
Figure 21 Oxides of Nitrogen (NO_X) Versus Primary Fuel Air Ratio Emission Measurement Results, JT8D Engine



LEGEND

TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

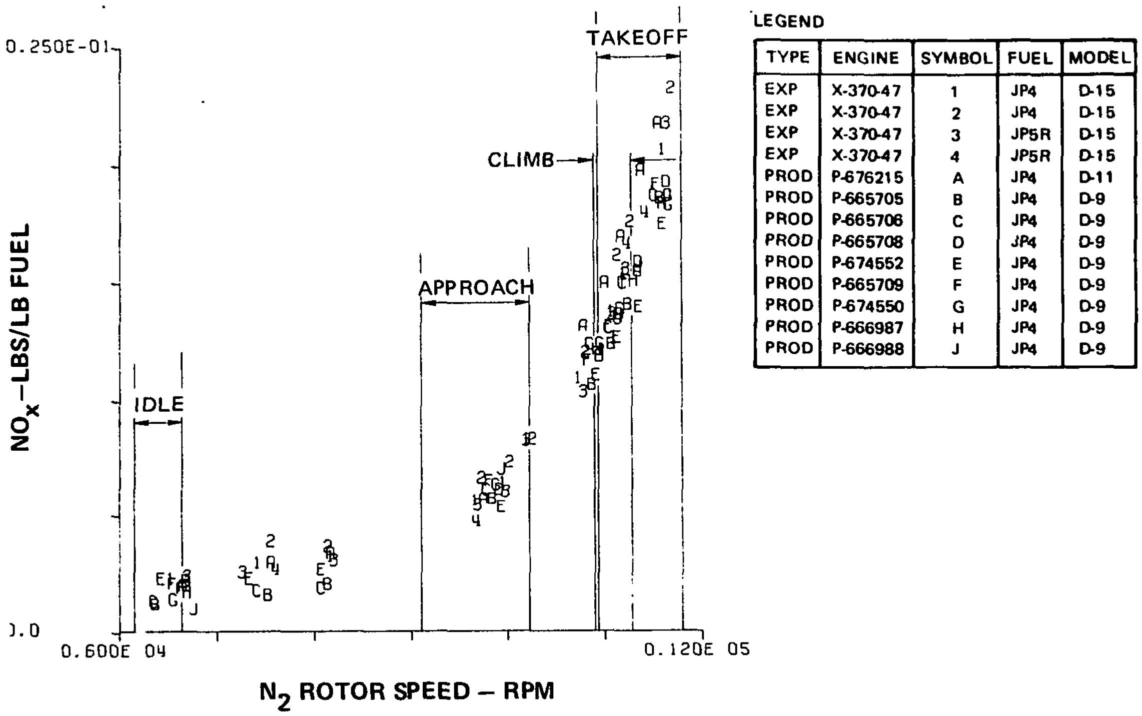
Figure 22 Oxides of Nitrogen (NO_X) Versus Engine Pressure Ratio Emission Measurement Results, JT8D Engine



LEGEND

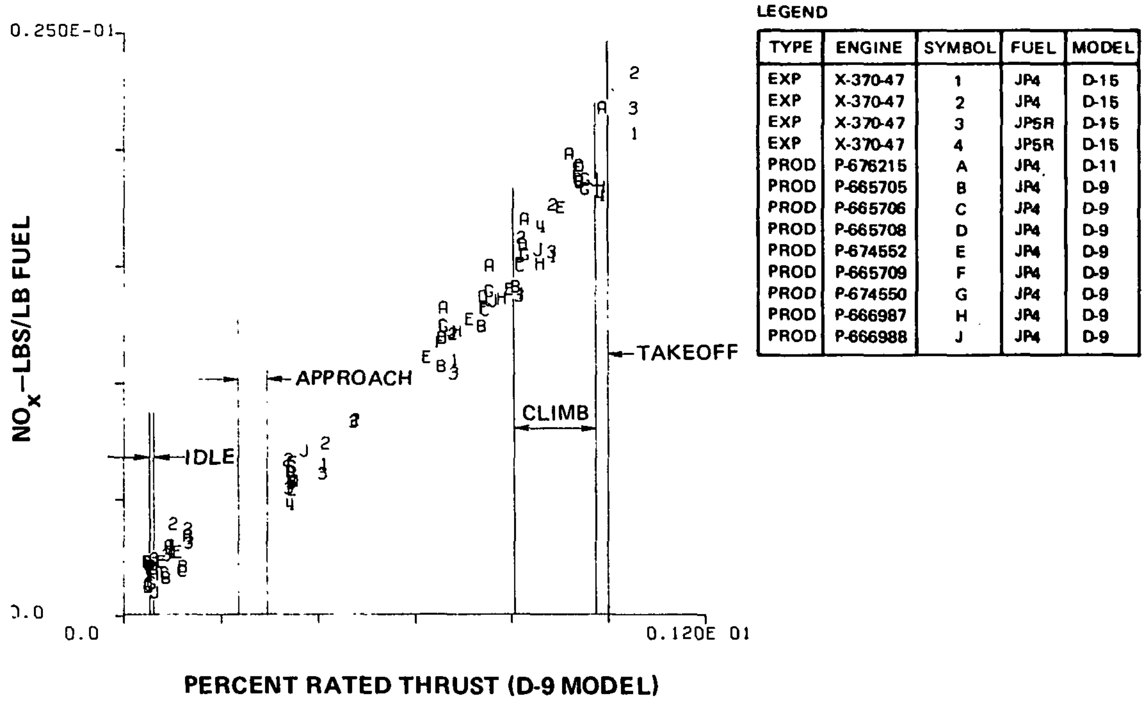
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 23 Oxides of Nitrogen (NO_X) Versus Engine Thrust Emission Measurement Results, JT8D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 24 Oxides of Nitrogen (NO_x) Versus N_2 Rotor Speed Emission Measurement Results, JT8D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 25 Oxides of Nitrogen (NO_x) Versus Percent Rated Thrust Emission Measurement Results, JT8D Engine

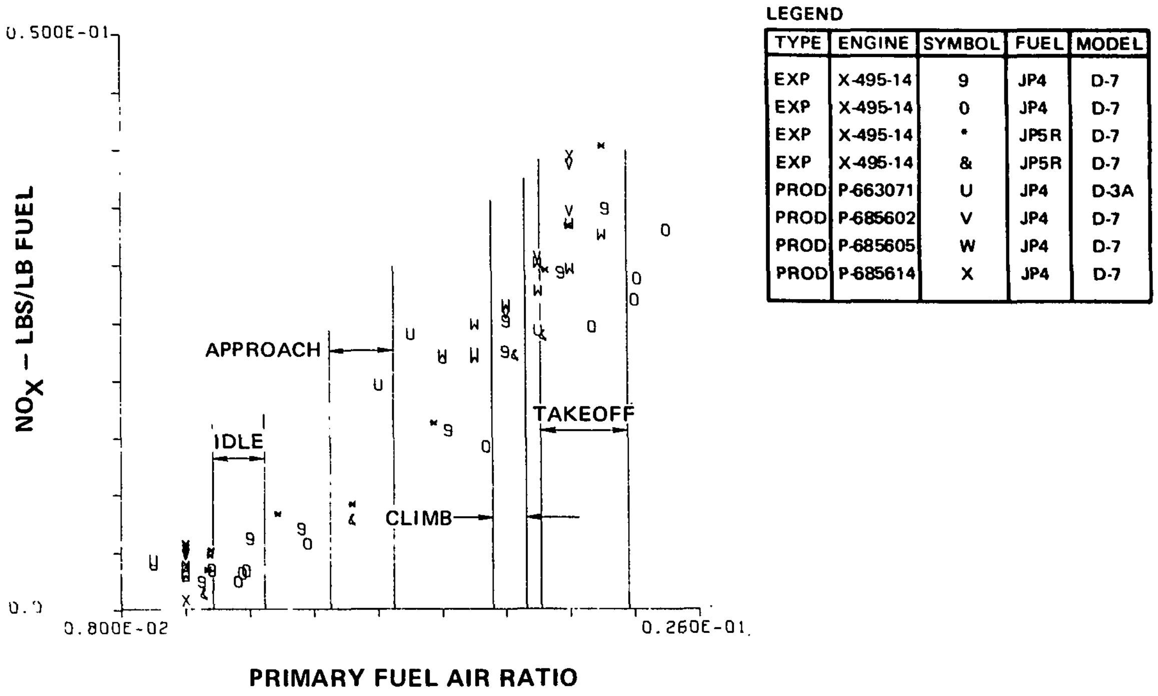


Figure 26 Oxides of Nitrogen (NO_X) Versus Primary Fuel Air Ratio Emission Measurement Results, JT9D Engine

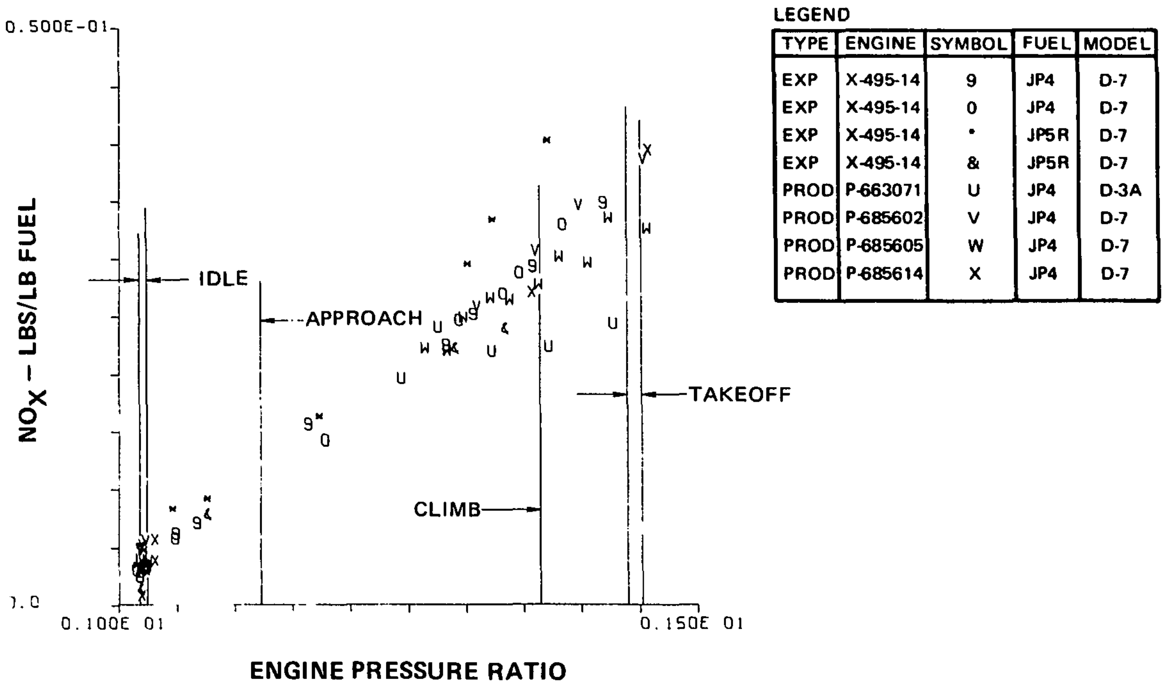
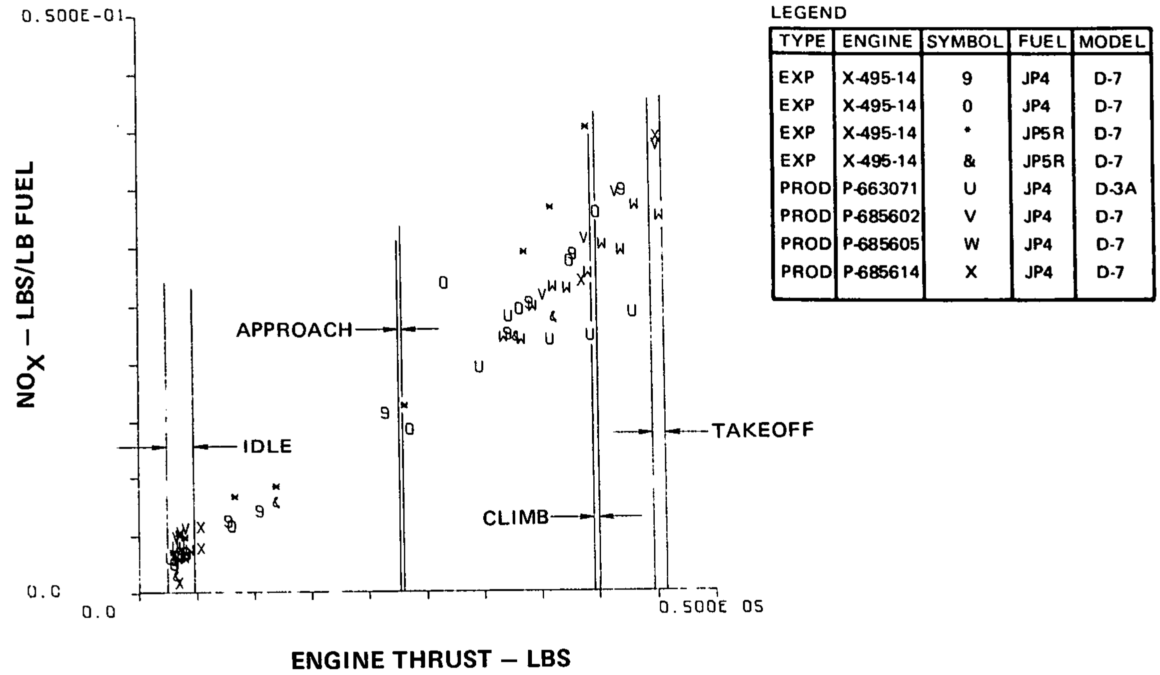
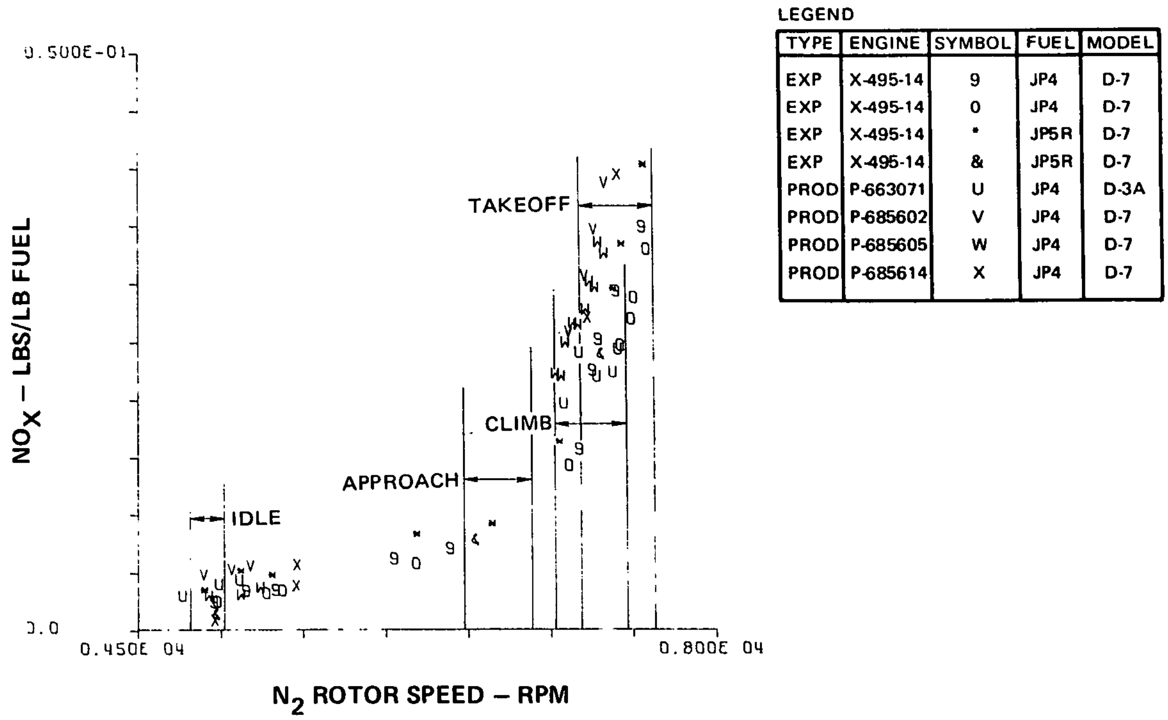


Figure 27 Oxides of Nitrogen (NO_X) Versus Engine Pressure Ratio Emission Measurement Results, JT9D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-495-14	9	JP4	D-7
EXP	X-495-14	0	JP4	D-7
EXP	X-495-14	*	JP5R	D-7
EXP	X-495-14	&	JP5R	D-7
PROD	P-663071	U	JP4	D-3A
PROD	P-685602	V	JP4	D-7
PROD	P-685605	W	JP4	D-7
PROD	P-685614	X	JP4	D-7

Figure 28 Oxides of Nitrogen (NO_x) Versus Engine Thrust Emission Measurement Results, JT9D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-495-14	9	JP4	D-7
EXP	X-495-14	0	JP4	D-7
EXP	X-495-14	*	JP5R	D-7
EXP	X-495-14	&	JP5R	D-7
PROD	P-663071	U	JP4	D-3A
PROD	P-685602	V	JP4	D-7
PROD	P-685605	W	JP4	D-7
PROD	P-685614	X	JP4	D-7

Figure 29 Oxides of Nitrogen (NO_x) Versus N_2 Rotor Speed Emission Measurement Results, JT9D Engine

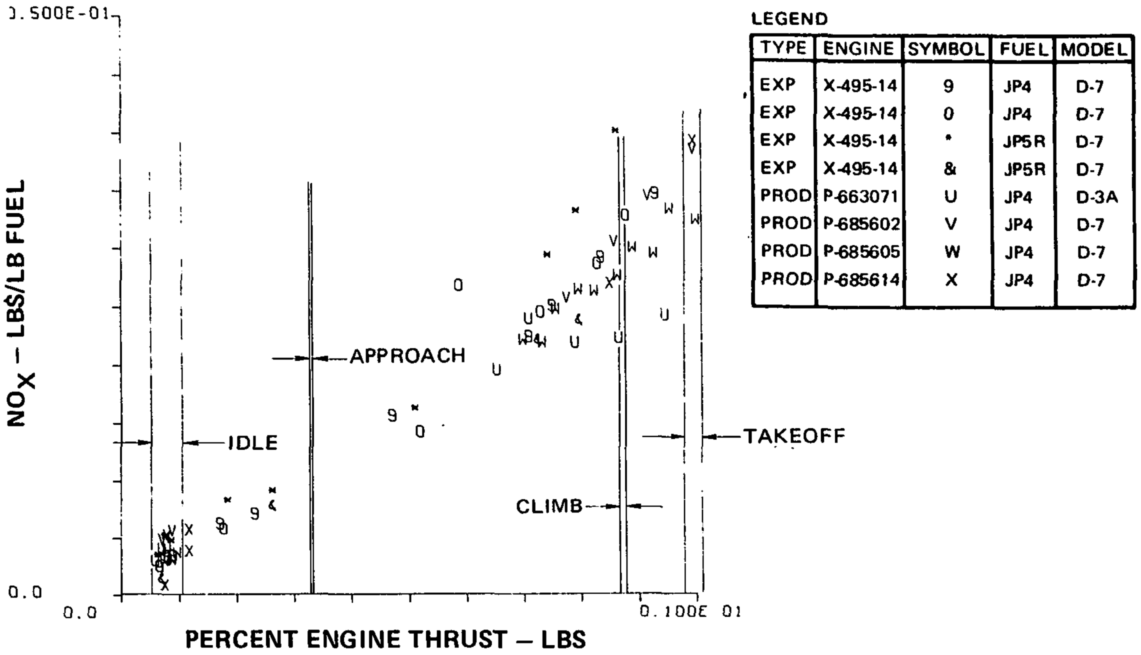


Figure 30 Oxides of Nitrogen (NO_X) Versus Percent Rated Thrust Emission Measurement Results, JT9D Engine

b. Carbon Monoxide (CO)

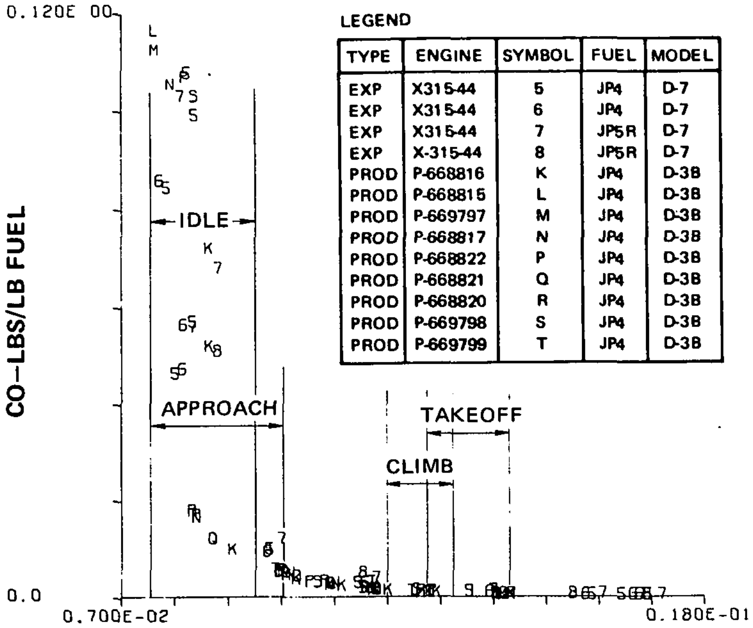
The maximum concentration of CO occurs at the lowest power setting, idle power. Curves of the relationship of CO to rotor speed, thrust, engine pressure ratio, fuel air ratio and percent rated thrust are shown in Figures 31 through 45 for the JT3D, JT8D, and JT9D engines.

The statistical analysis has also indicated the mean value and the 1 sigma (σ) variation of the CO data taken for each engine model at power settings of idle, approach, maximum continuous (climb), and takeoff.

These results are summarized below:

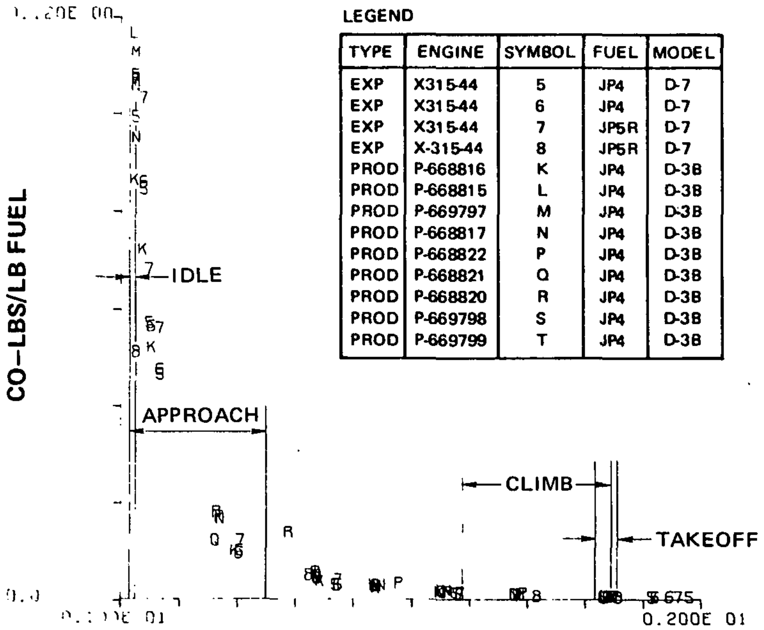
CO RESULTS

Engine	Mode	Thrust lbs	Fuel Flow lbs/hr	CO Lbs/ 1000 lbs Fuel	1 Sigma Variation
JT3D	Idle	900	1,070	104.20	6.0
	Approach	5,228	3,573	19.00	6.0
	Climb	16,400	8,120	1.41	6.0
	Takeoff	18,000	9,420	NIL	–
JT8D	Idle	800	920	24.55	0.88
	Approach	3,555	2,700	4.66	0.88
	Climb	12,600	7,020	1.44	0.88
	Takeoff	14,500	8,400	0.92	0.88
JT9D	Idle	3,550	1,976	54.13	2.65
	Approach	15,009	7,515	5.33	2.65
	Climb	39,650	14,109	.75	2.65
	Takeoff	45,500	16,641	NIL	–



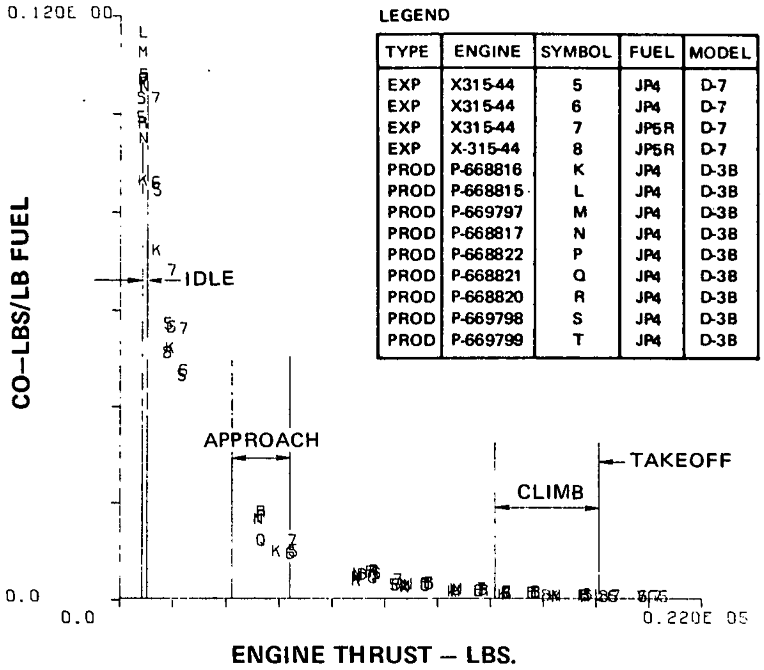
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X31544	5	JP4	D-7
EXP	X31544	6	JP4	D-7
EXP	X31544	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 31 Carbon Monoxide (CO) Versus Primary Fuel Air Ratio Emission Measurement Results, JT3D Engine



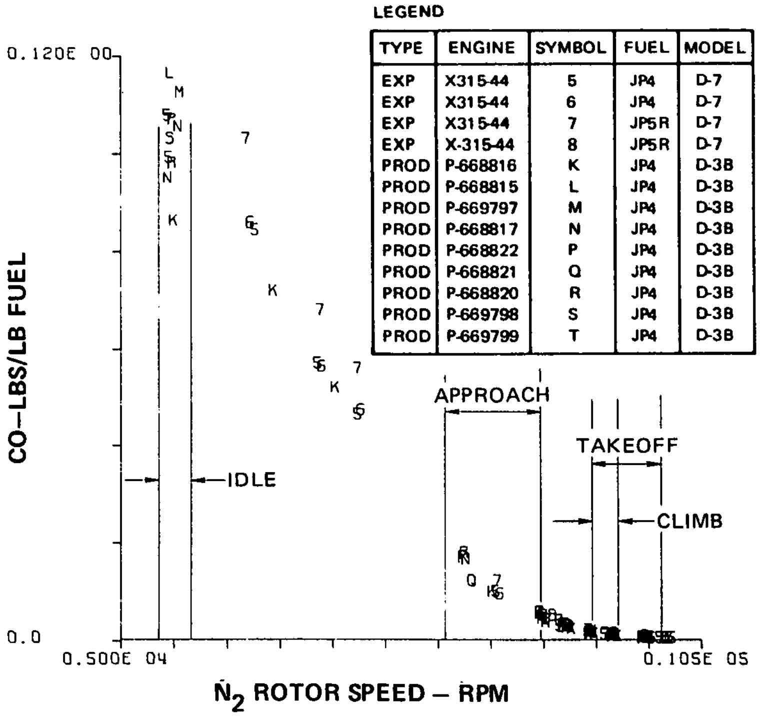
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X31544	5	JP4	D-7
EXP	X31544	6	JP4	D-7
EXP	X31544	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 32 Carbon Monoxide (CO) Versus Engine Pressure Ratio Emission Measurement Results, JT3D Engine



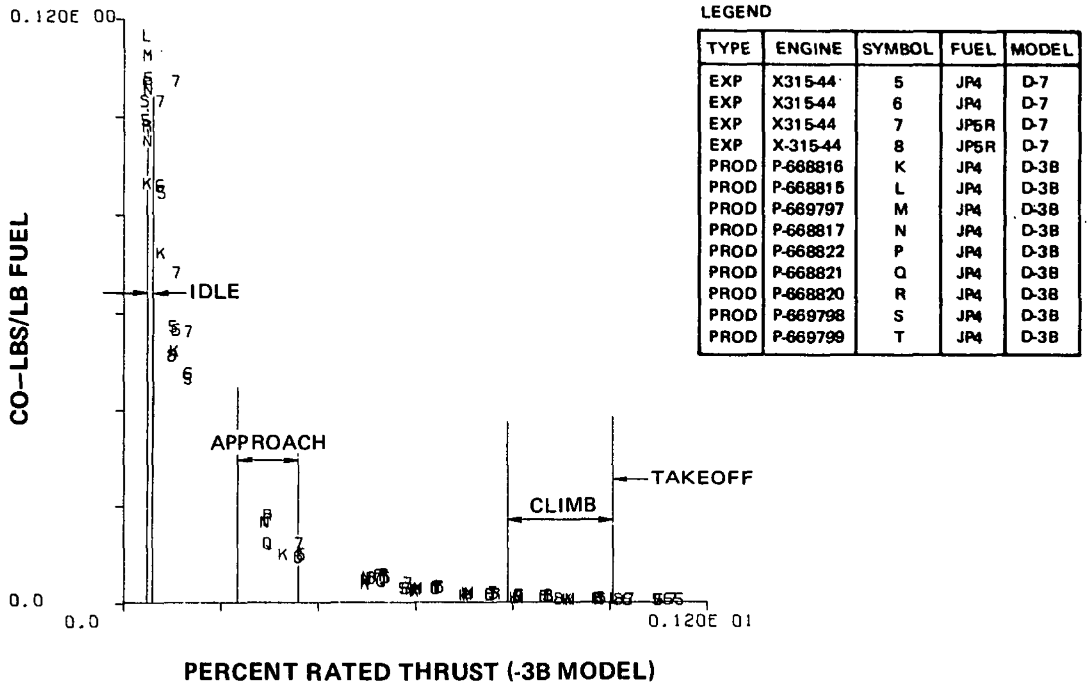
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 33 Carbon Monoxide (CO) Versus Engine Thrust Emission Measurement Results, JT3D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

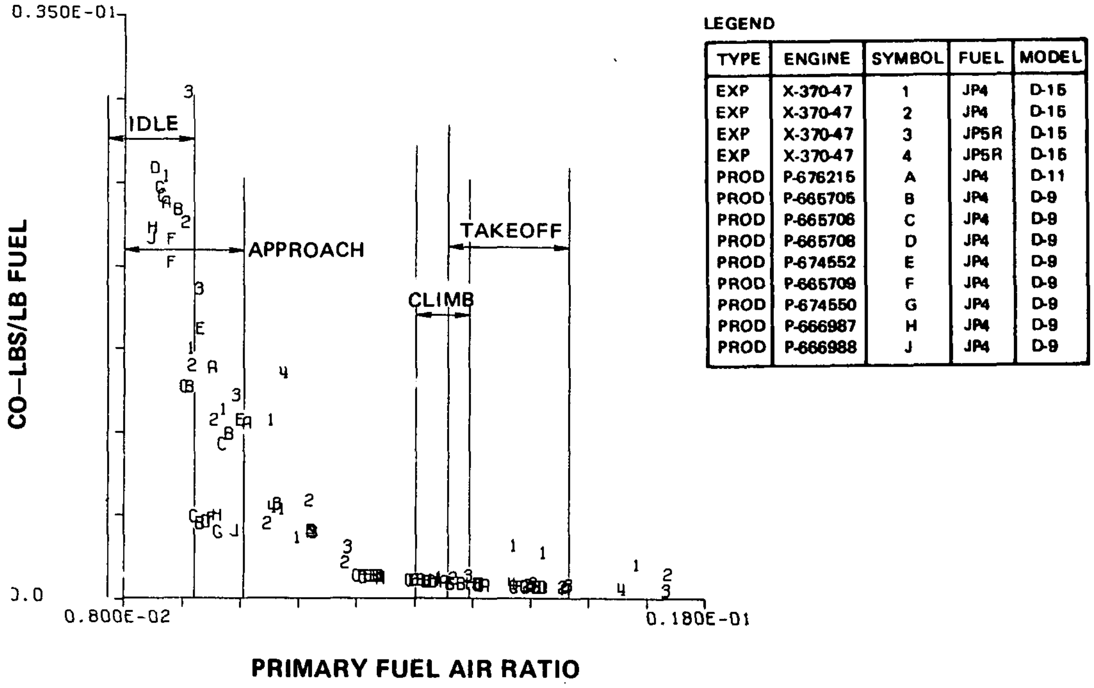
Figure 34 Carbon Monoxide (CO) Versus N_2 Rotor Speed Emission Measurement Results, JT3D Engine



LEGEND

TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

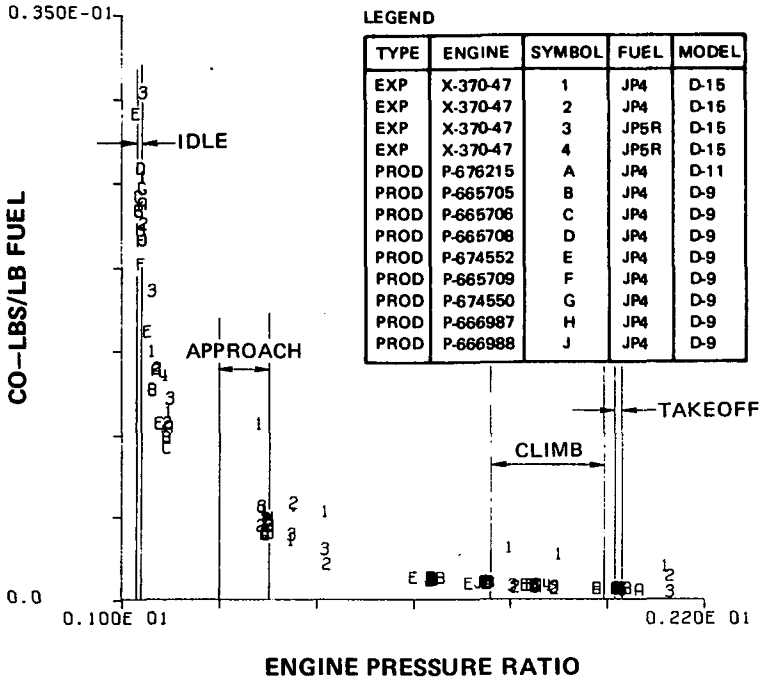
Figure 35 Carbon Monoxide (CO) Versus Percent Rated Thrust Emission Measurement Results, JT3D Engine



LEGEND

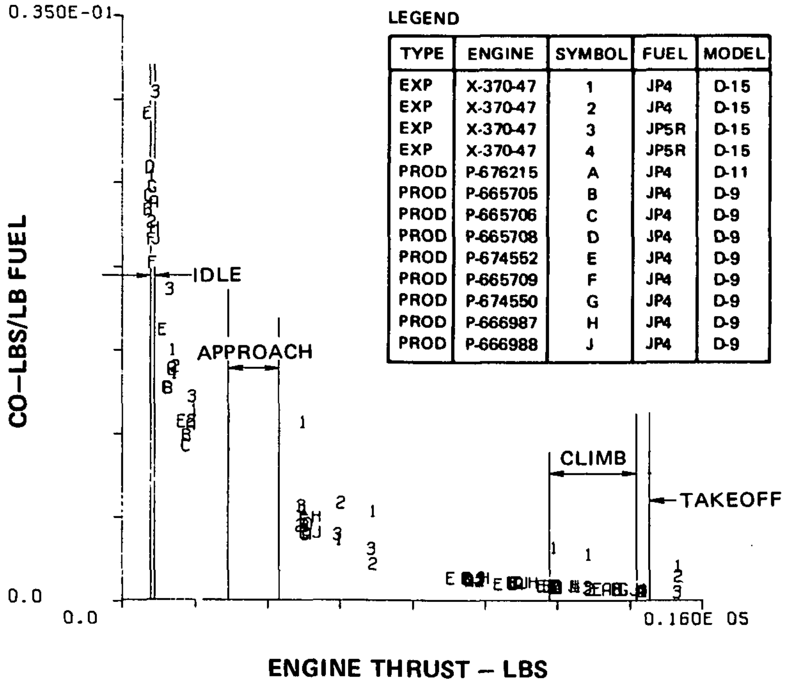
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 36 Carbon Monoxide (CO) Versus Primary Fuel Air Ratio Emission Measurement Results, JT8D Engine



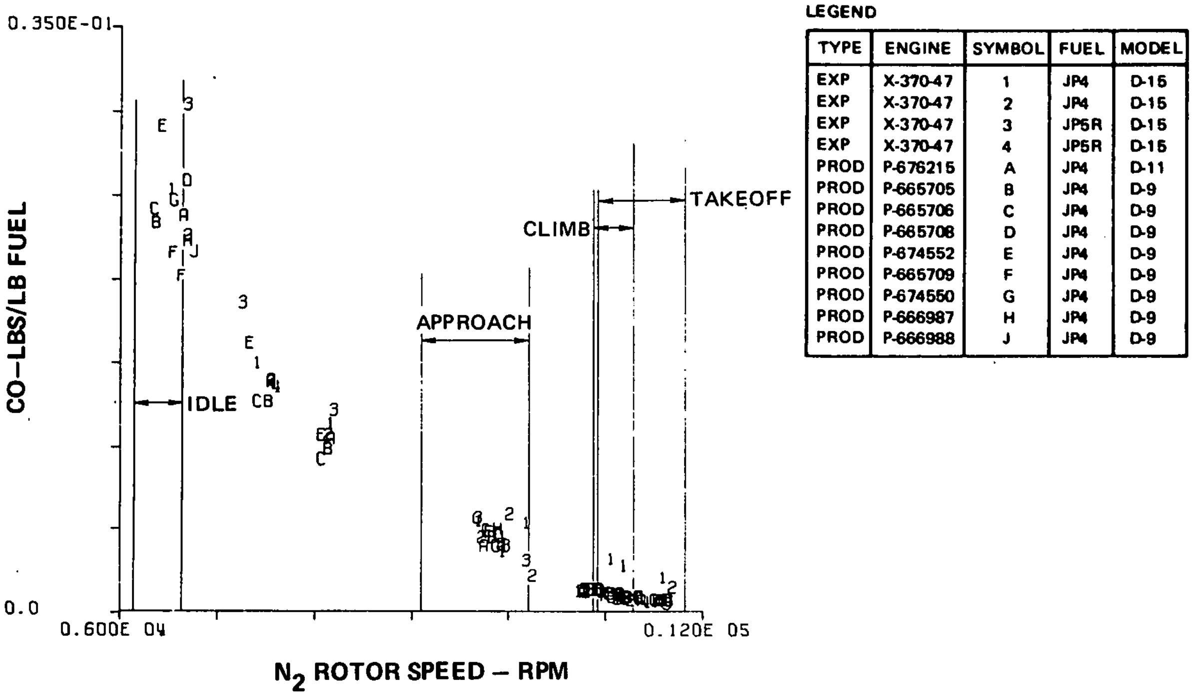
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 37 Carbon Monoxide (CO) Versus Engine Pressure Ratio Emission Measurement Results, JT8D Engine



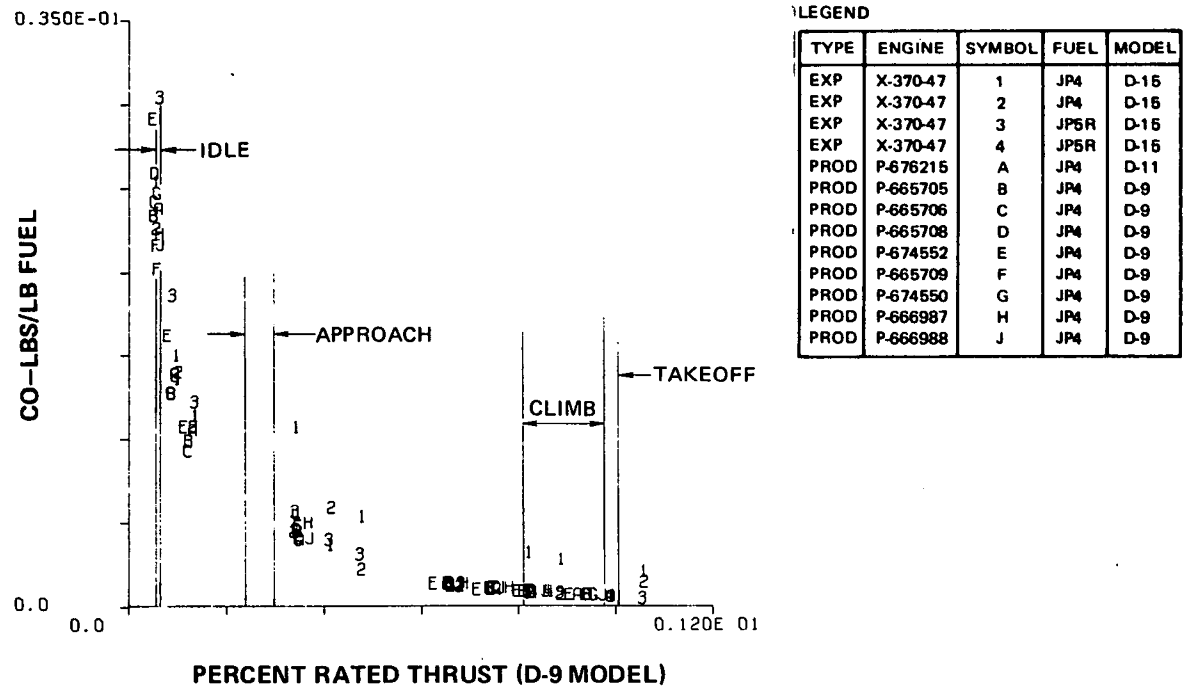
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 38 Carbon Monoxide (CO) Versus Engine Thrust Emission Measurement Results, JT8D Engine



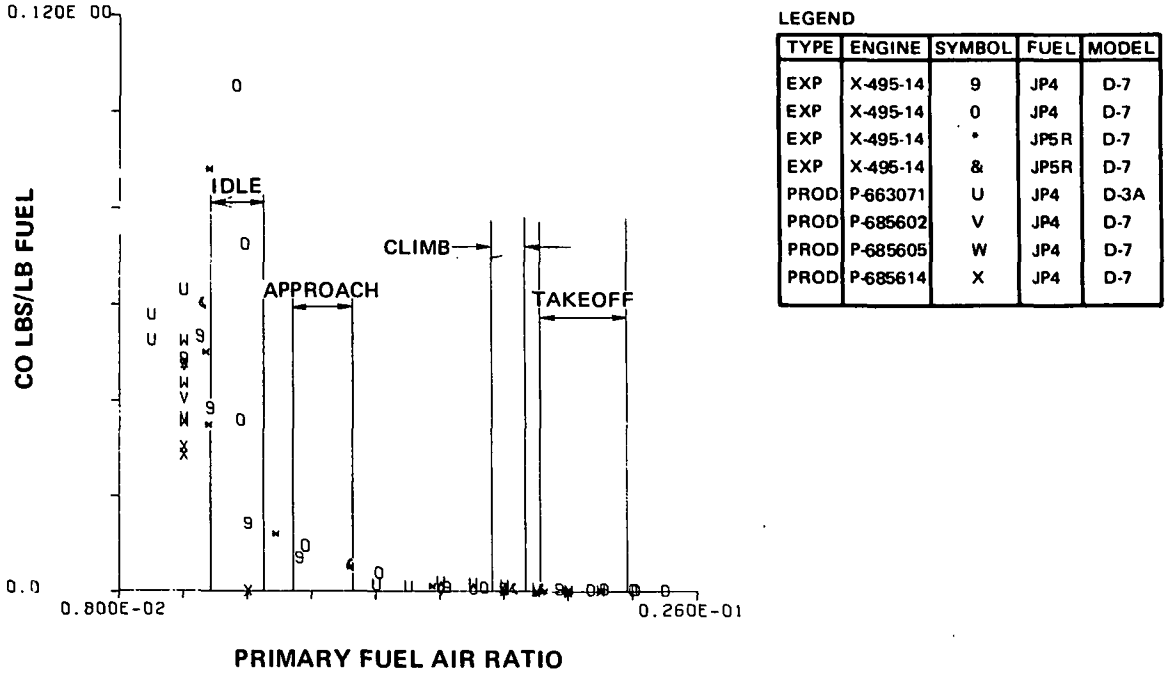
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 39 Carbon Monoxide (CO) Versus N_2 Rotor Speed Emission Measurement Results, JT8D Engine



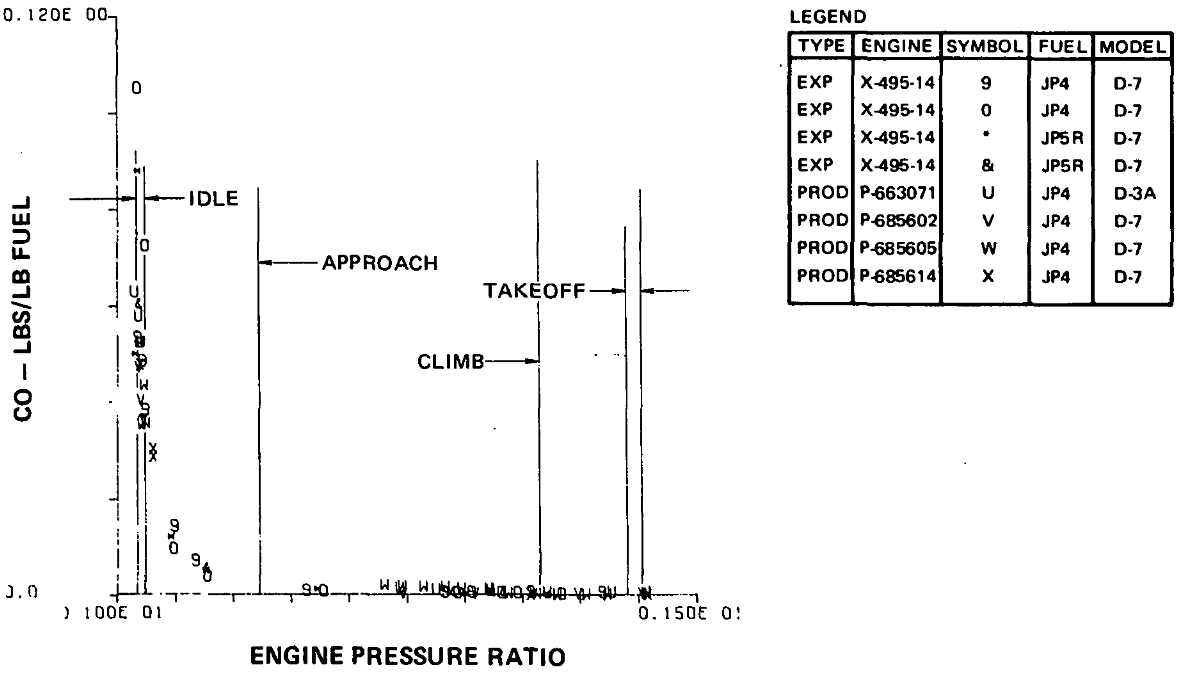
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 40 Carbon Monoxide (CO) Versus Percent Rated Thrust (D-9 Model) Emission Measurement Results, JT8D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-495-14	9	JP4	D-7
EXP	X-495-14	0	JP4	D-7
EXP	X-495-14	•	JP5R	D-7
EXP	X-495-14	&	JP5R	D-7
PROD	P-663071	U	JP4	D-3A
PROD	P-685602	V	JP4	D-7
PROD	P-685605	W	JP4	D-7
PROD	P-685614	X	JP4	D-7

Figure 41 Carbon Monoxide (CO) Versus Primary Fuel Air Ratio Emission Measurement Results, JT9D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-495-14	9	JP4	D-7
EXP	X-495-14	0	JP4	D-7
EXP	X-495-14	•	JP5R	D-7
EXP	X-495-14	&	JP5R	D-7
PROD	P-663071	U	JP4	D-3A
PROD	P-685602	V	JP4	D-7
PROD	P-685605	W	JP4	D-7
PROD	P-685614	X	JP4	D-7

Figure 42 Carbon Monoxide (CO) Versus Engine Pressure Ratio Emission Measurement Results, JT9D Engine

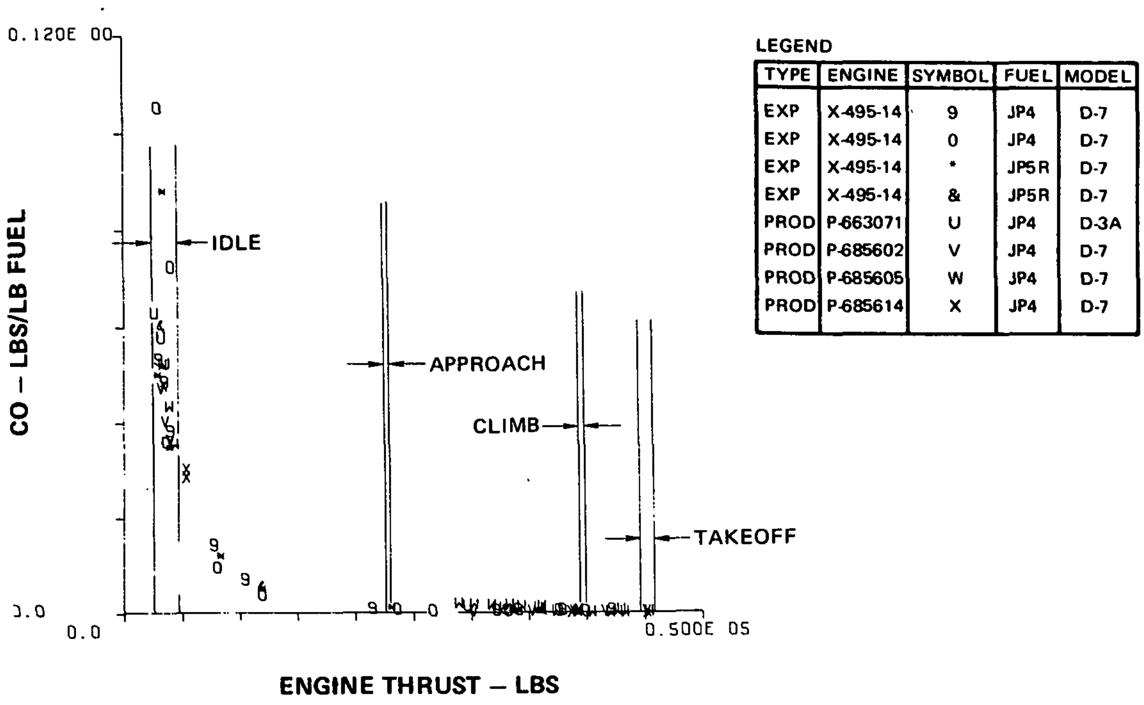


Figure 43 Carbon Monoxide (CO) Versus Engine Thrust Emission Measurement Results, JT9D Engine

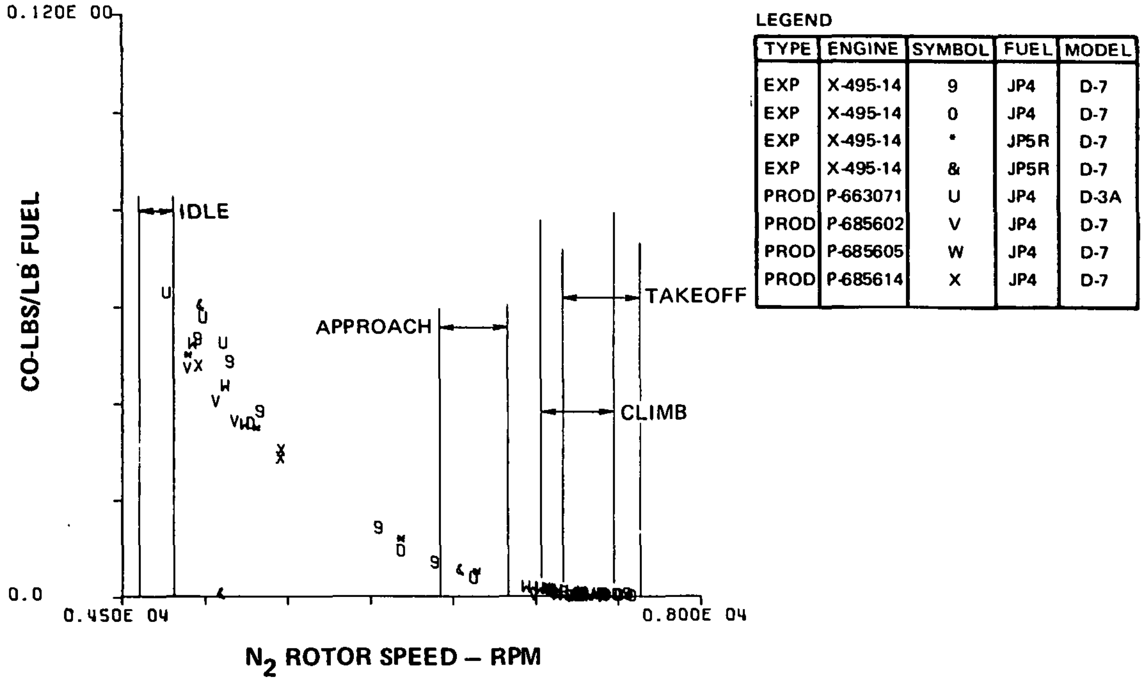


Figure 44 Carbon Monoxide (CO) Versus N_2 Rotor Speed Emission Measurement Results, JT9D Engine

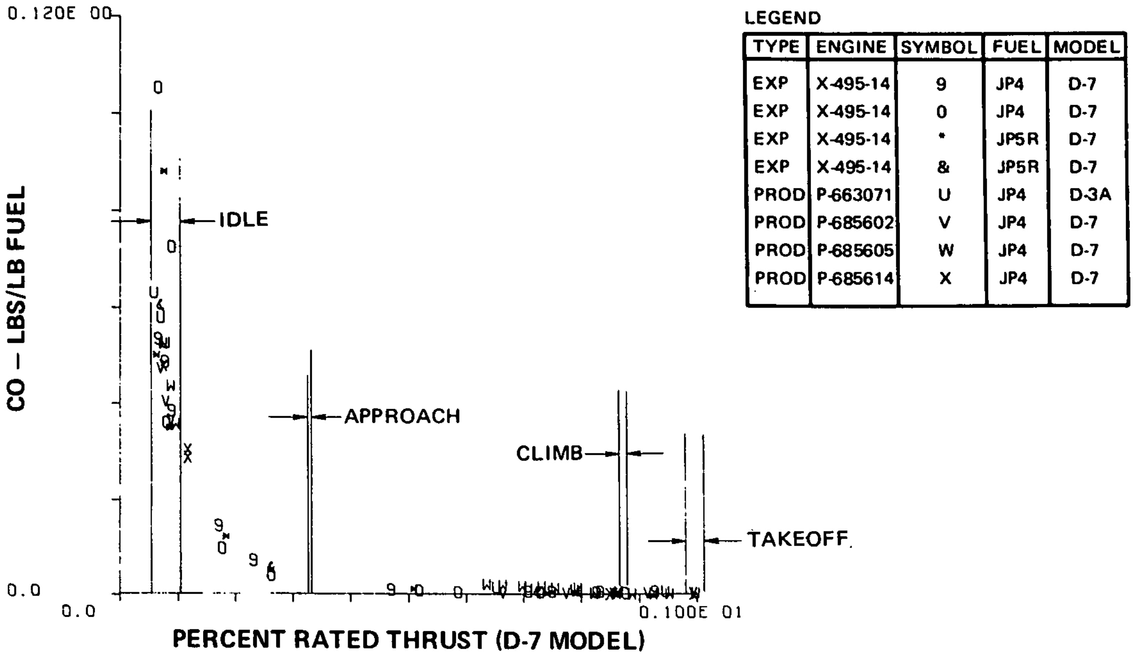


Figure 45 Carbon Monoxide (CO) Versus Percent Rated Thrust Emission Measurement Results, JT9D Engine

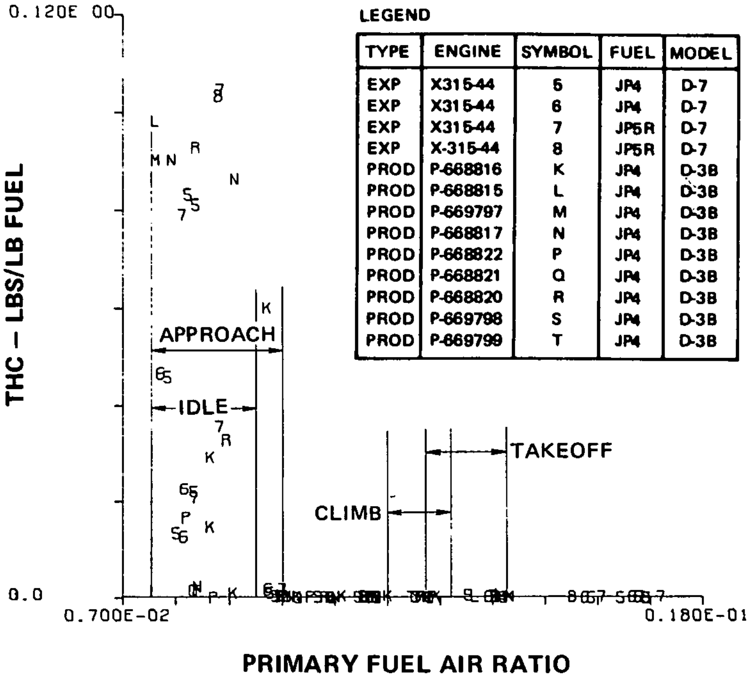
c. Total Hydrocarbons (THC)

The maximum concentration of THC also occurs at the lowest engine power setting. Curves of the relationship of THC to rotor speed, thrust, engine pressure ratio, fuel air ratio and percent rated thrust are shown in Figures 46 through 60 for the JT3D, JT8D, and JT9D engines.

The statistical analysis has also indicated the mean value and the 1 sigma (σ) variation of the THC data taken for each engine model at power settings of idle, approach, maximum continuous (climb), and takeoff. These results are summarized below:

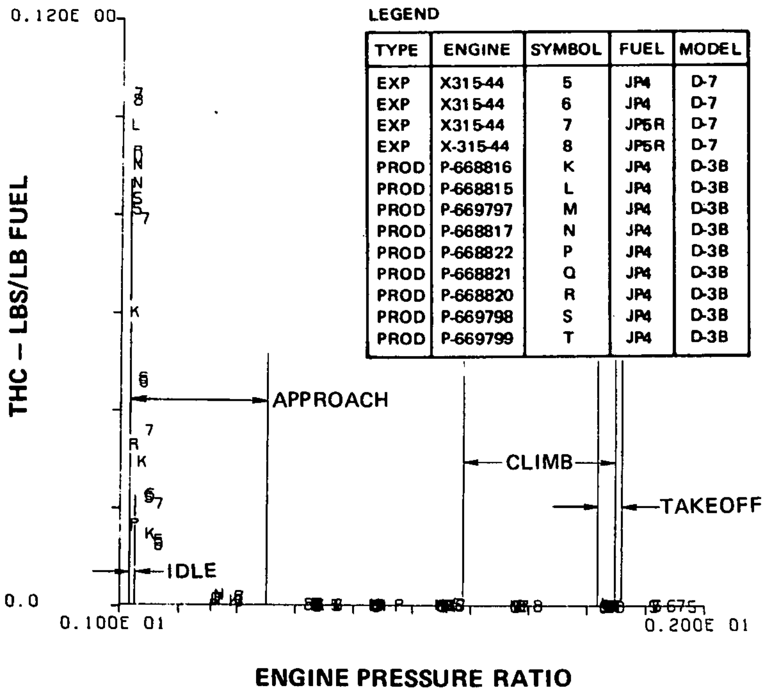
THC RESULTS

Engine	Mode	Thrust lbs	Fuel Flow lbs/hr	THC lbs/ 1000 lbs Fuel	1 Sigma Variation
JT3D	Idle	900	1,070	91.00	3.4
	Approach	5,228	3,573	3.44	3.4
	Climb	16,400	8,120	NIL	–
	Takeoff	18,000	9,420	NIL	–
JT8D	Idle	800	920	5.40	0.39
	Approach	3,555	2,700	.30	0.39
	Climb	12,600	7,020	.17	0.39
	Takeoff	14,500	8,400	.16	0.39
JT9D	Idle	3,550	1,976	14.81	1.85
	Approach	15,009	7,515	.54	1.85
	Climb	39,650	14,109	.02	1.85
	Takeoff	45,500	16,641	NIL	––



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 46 Total Hydrocarbons (THC) Versus Primary Fuel Air Ratio Emission Measurement Results, JT3D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 47 Total Hydrocarbons (THC) Versus Engine Pressure Ratio Emission Measurement Results, JT3D Engine

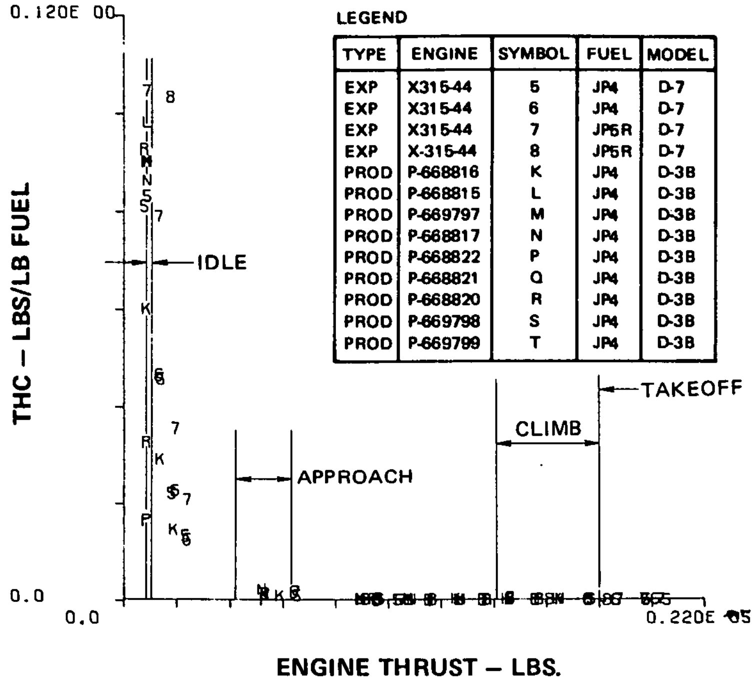


Figure 48 Total Hycrocarbons (THC) Versus Engine Thrust Emission Measurement Results, JT3D Engine

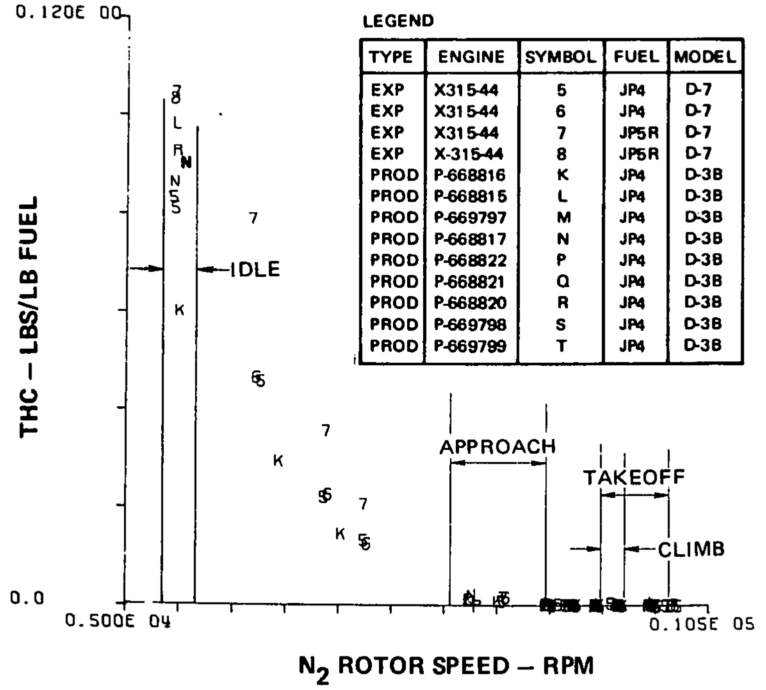
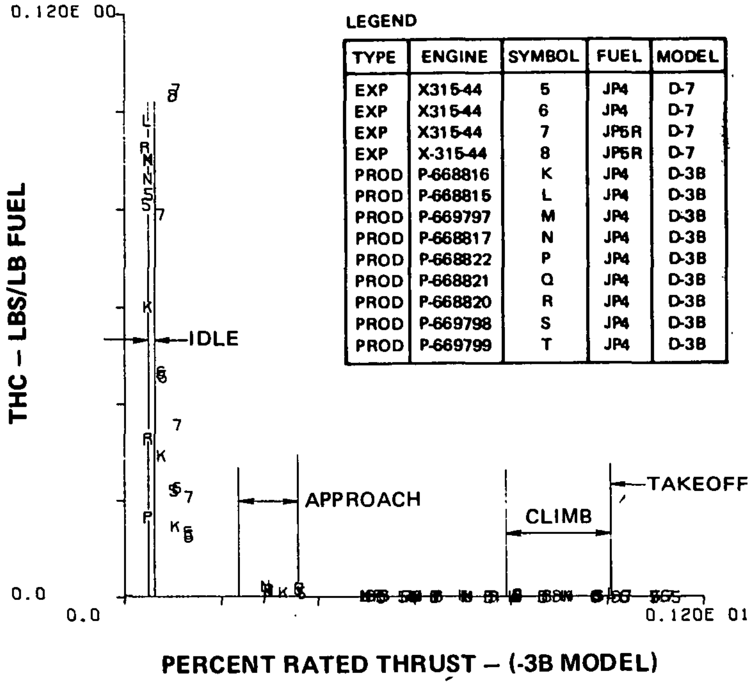
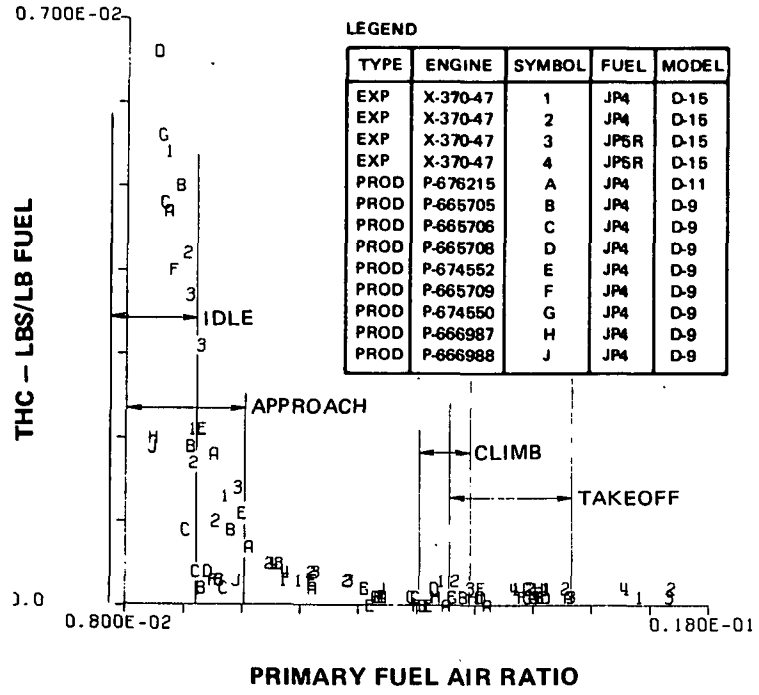


Figure 49 Total Hycrocarbons (THC) Versus N_2 Rotor Speed Emission Measurement Results, JT3D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 50 Total Hydrocarbons (THC) Versus Percent Rated Thrust (-3B Model) Emission Measurement Results, JT3D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP6R	D-15
EXP	X-370-47	4	JP6R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 51 Total Hydrocarbons (THC) Versus Primary Fuel Air Ratio Emission Measurement Results, JT8D Engine

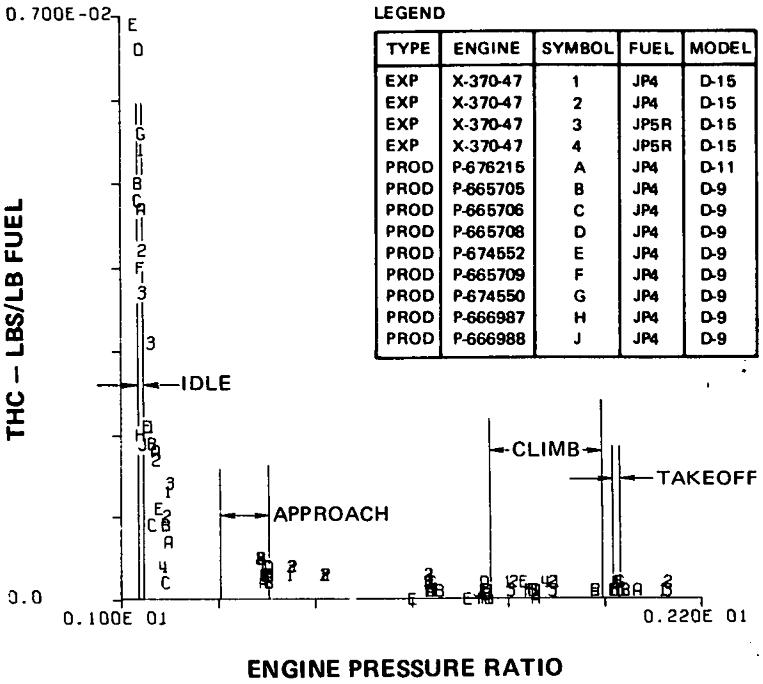


Figure 52 Total Hydrocarbons (THC) Versus Engine Pressure Ratio Emission Measurement Results, JT8D Engine

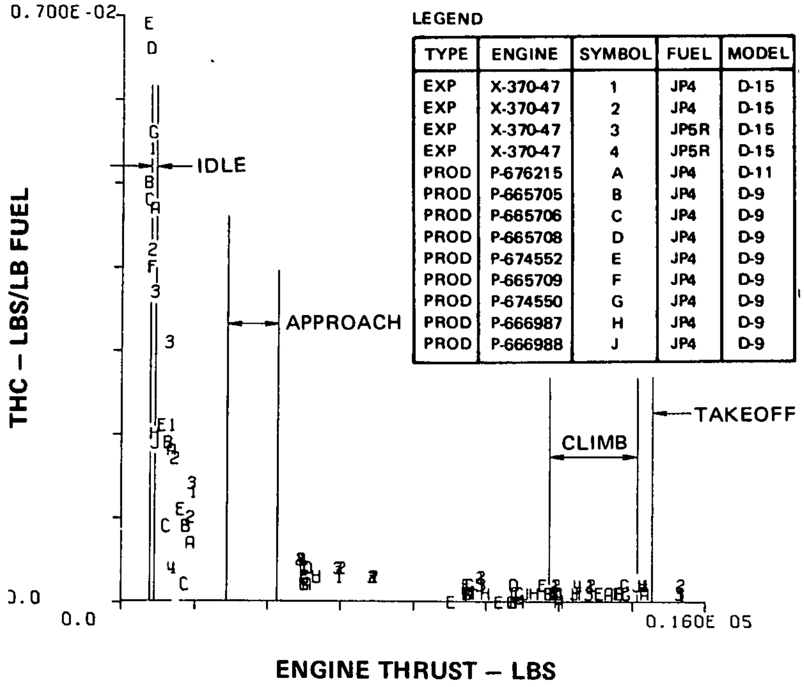
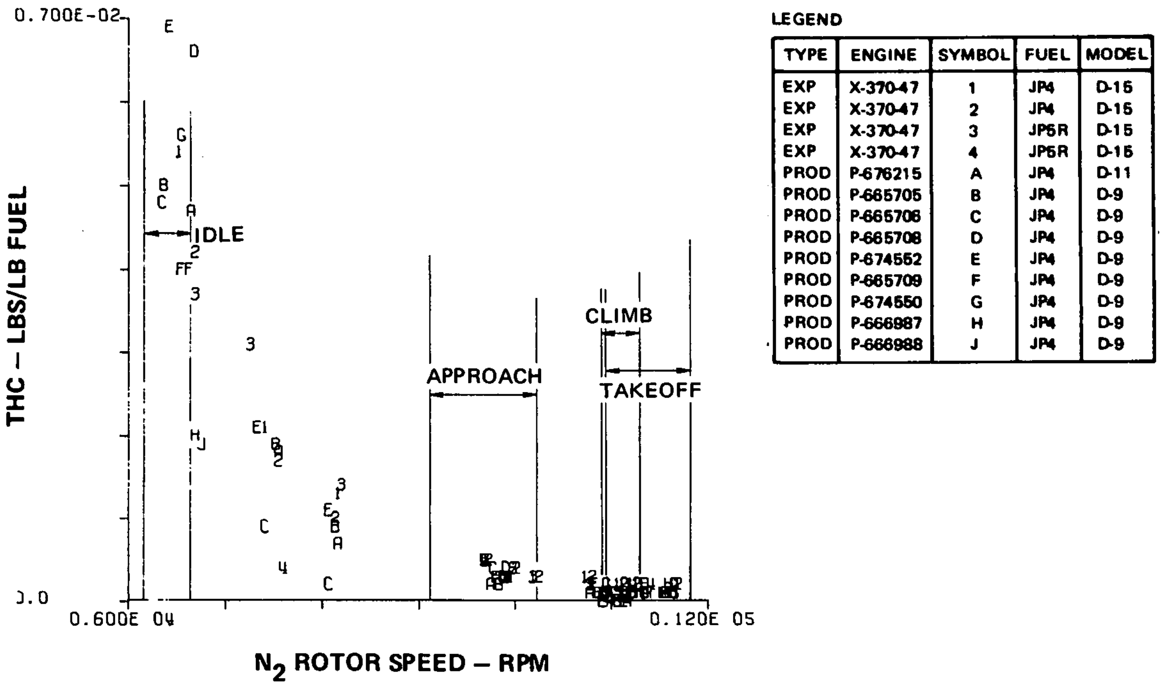
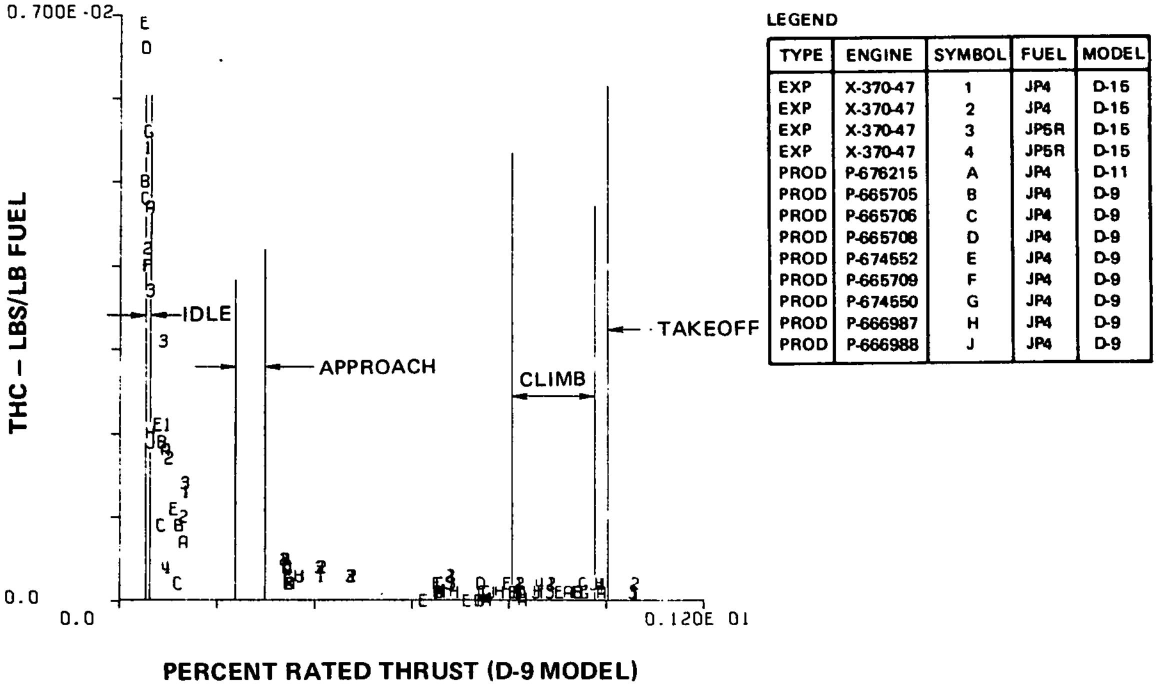


Figure 53 Total Hydrocarbons (THC) Versus Engine Thrust Emission Measurement Results, JT8D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 54 Total Hydrocarbons (THC) Versus N_2 Rotor Speed Emission Measurement Results, JT8D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 55 Total Hydrocarbons (THC) Versus Percent Rated Thrust (D-9 Model) Emission Measurement Results, JT8D Engine

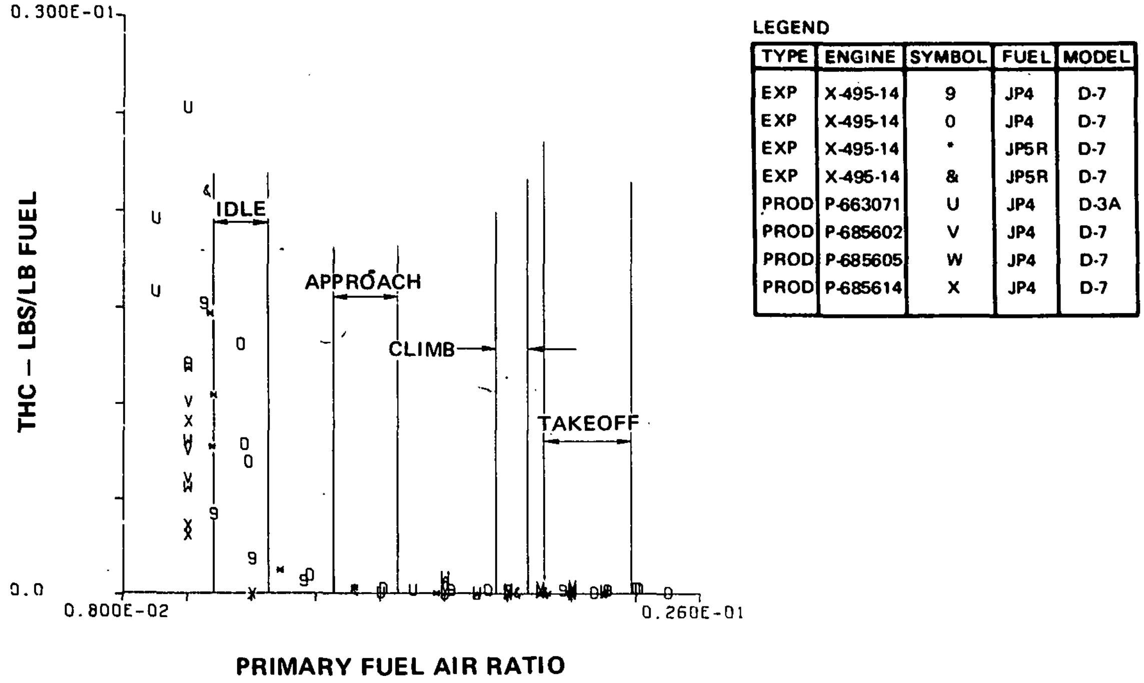


Figure 56 Total Hydrocarbons (THC) Versus Primary Fuel Air Ratio Emission Measurement Results, JT9D Engine

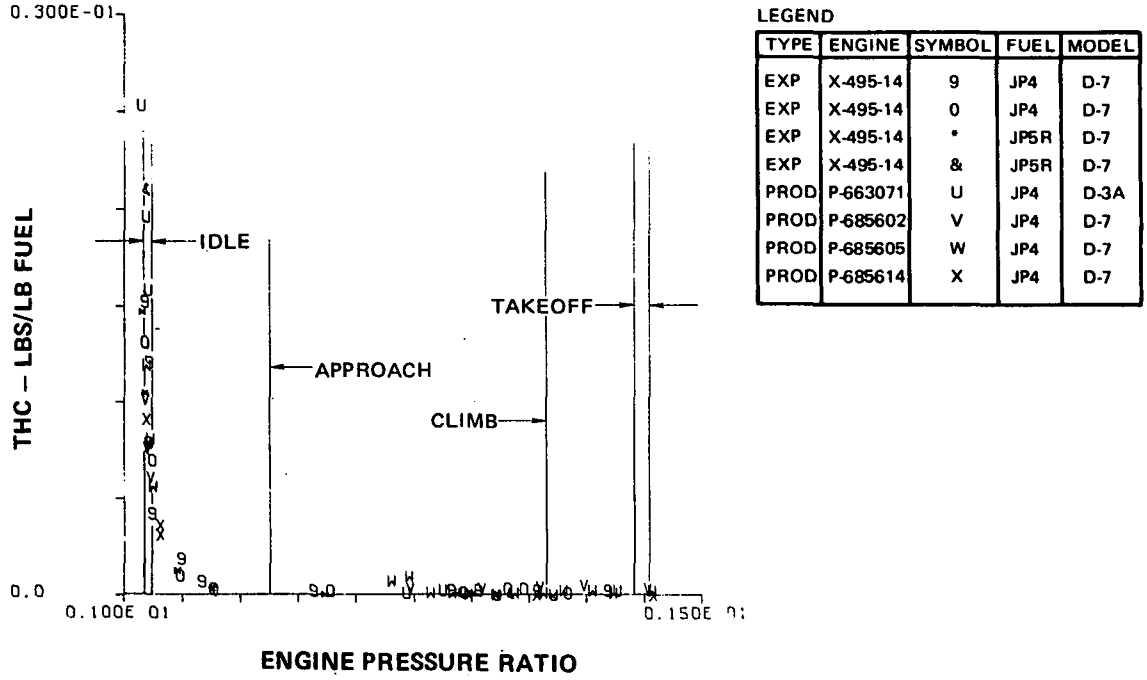


Figure 57 Total Hydrocarbons (THC) Versus Engine Pressure Ratio, Emission Measurement Results, JT9D Engine

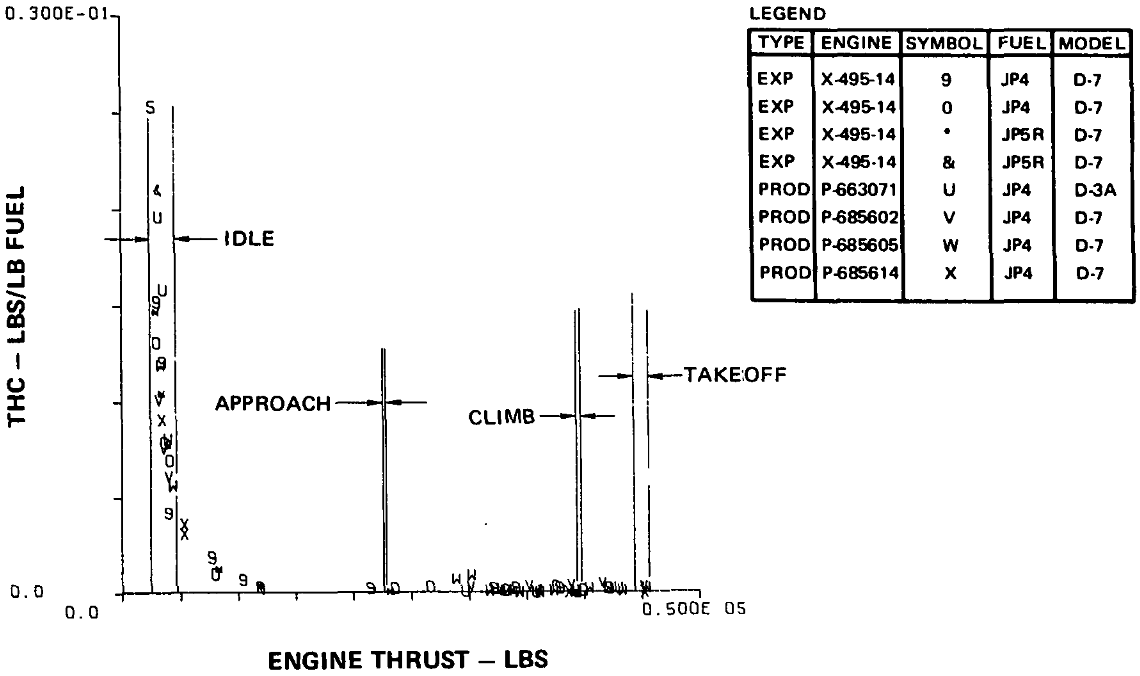


Figure 58 Total Hydrocarbons (THC) Versus Engine Thrust Emission Measurement Results, JT9D Engine

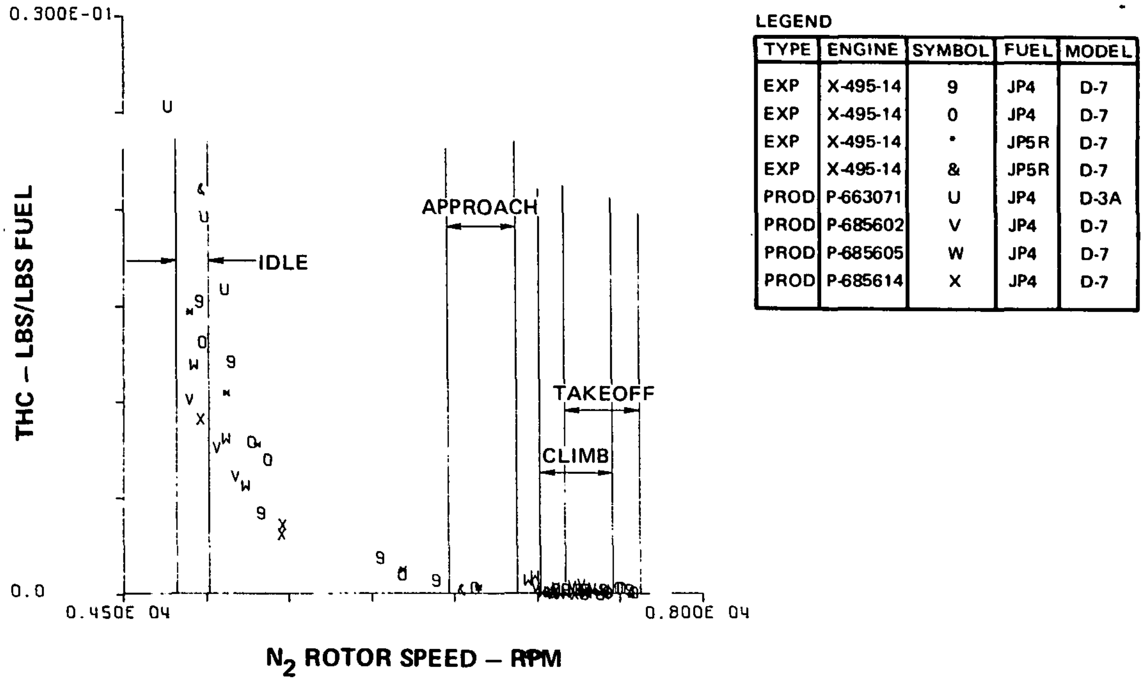


Figure 59 Total Hydrocarbons (THC) Versus N_2 Rotor Speed Emission Measurement Results, JT9D Engine

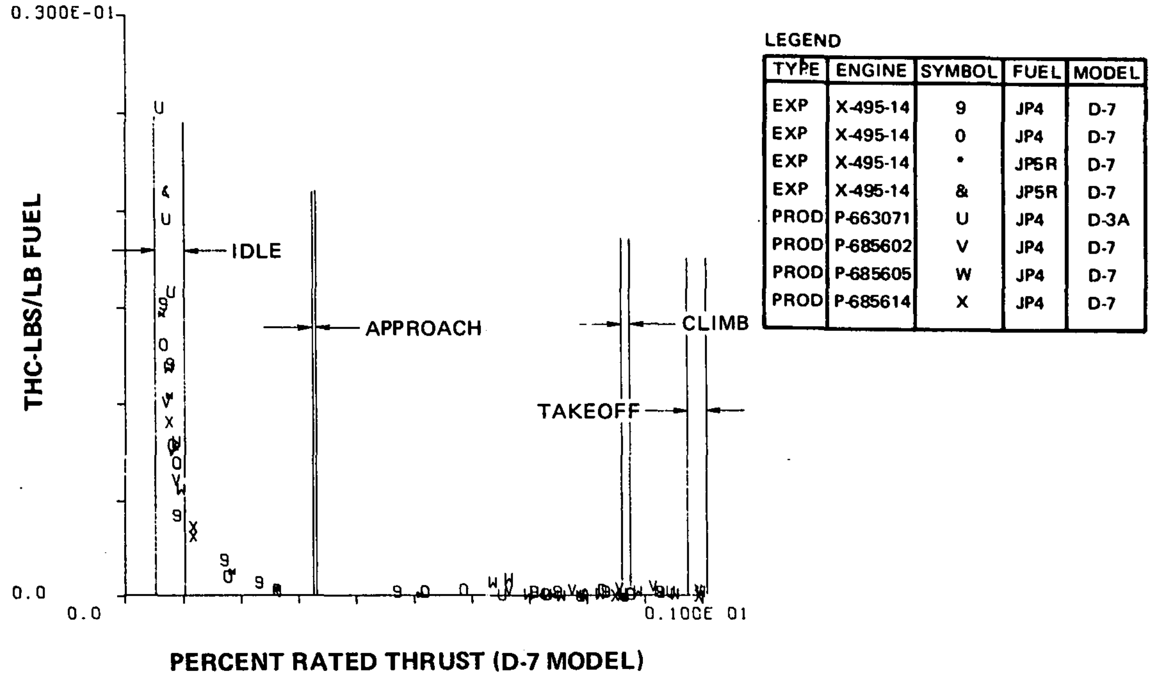


Figure 60 Total Hydrocarbons (THC) Versus Percent Rated Thrust Emission Measurement Results, JT9D Engine

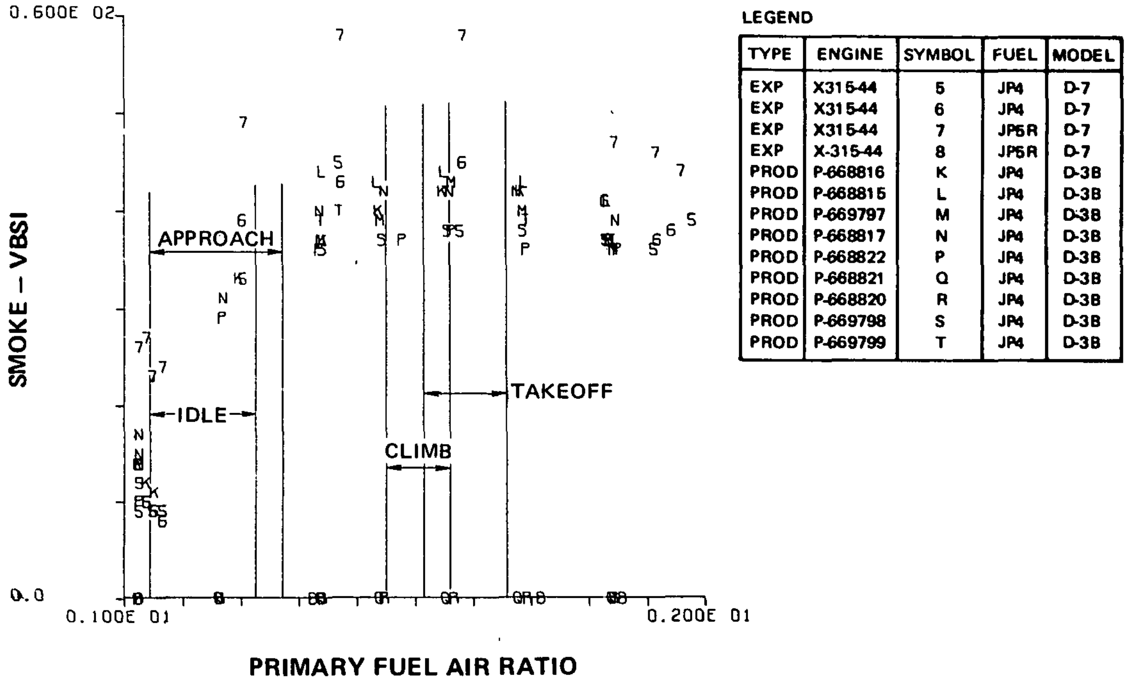
d. Smoke

The maximum concentration of smoke occurs at the higher engine power settings. Curves of the relationship of smoke to rotor speed, thrust, engine pressure ratio, fuel air ratio, and percent rated thrust are shown in Figures 61 through 75 for the JT3D, JT8D, and JT9D engines.

The statistical analysis has also indicated the mean value and the 1 sigma (σ) variations of the smoke data taken for each engine at power settings of idle, approach, maximum continuous (climb), and takeoff. These results are summarized below:

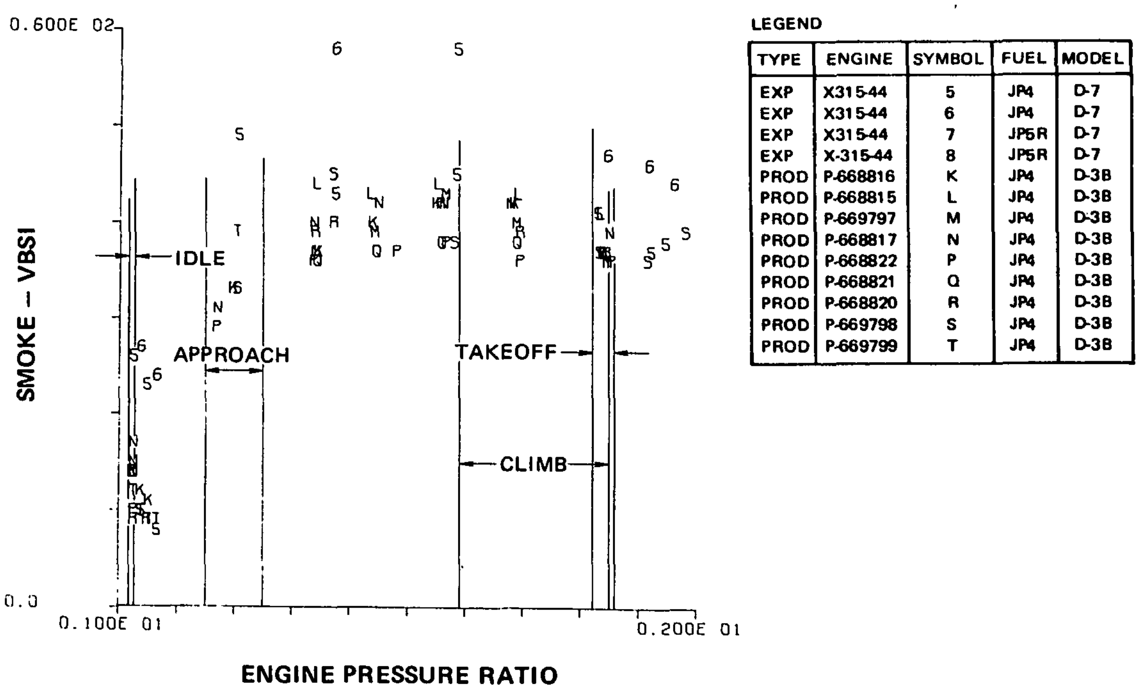
SMOKE RESULTS

Engine	Mode	Thrust	Smoke VBSI	Smoke 1 Sigma Variation
JT3D	Idle	900	21.2	8.6
	Approach	5,228	26.4	8.6
	Climb	16,400	41.3	8.6
	Takeoff	18,000	44.0	8.6
JT8D	Idle	800	3.3	3.9
	Approach	3,555	9.2	3.9
	Climb	12,600	25.6	3.9
	Takeoff	14,500	30.4	3.9
JT9D	Idle	3,550	.88	.9
	Approach	15,009	2.00	.9
	Climb	36,650	4.60	.9
	Takeoff	45,500	5.60	.9



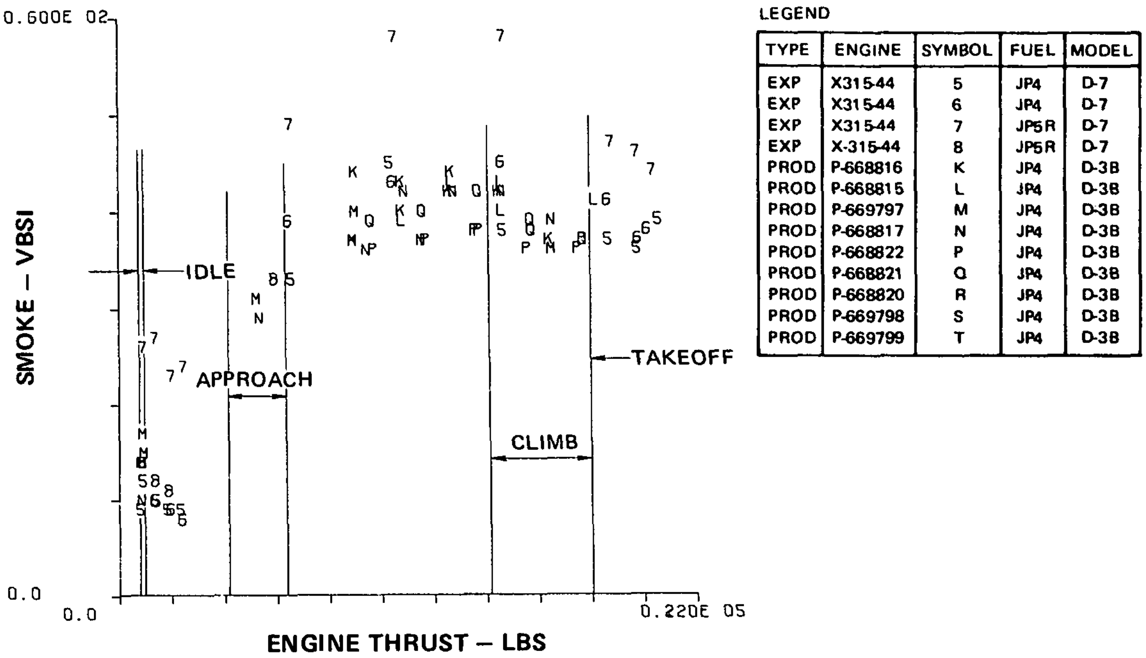
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 61 Smoke Versus Primary Fuel Air Ratio Emission Measurement Results, JT3D Engine



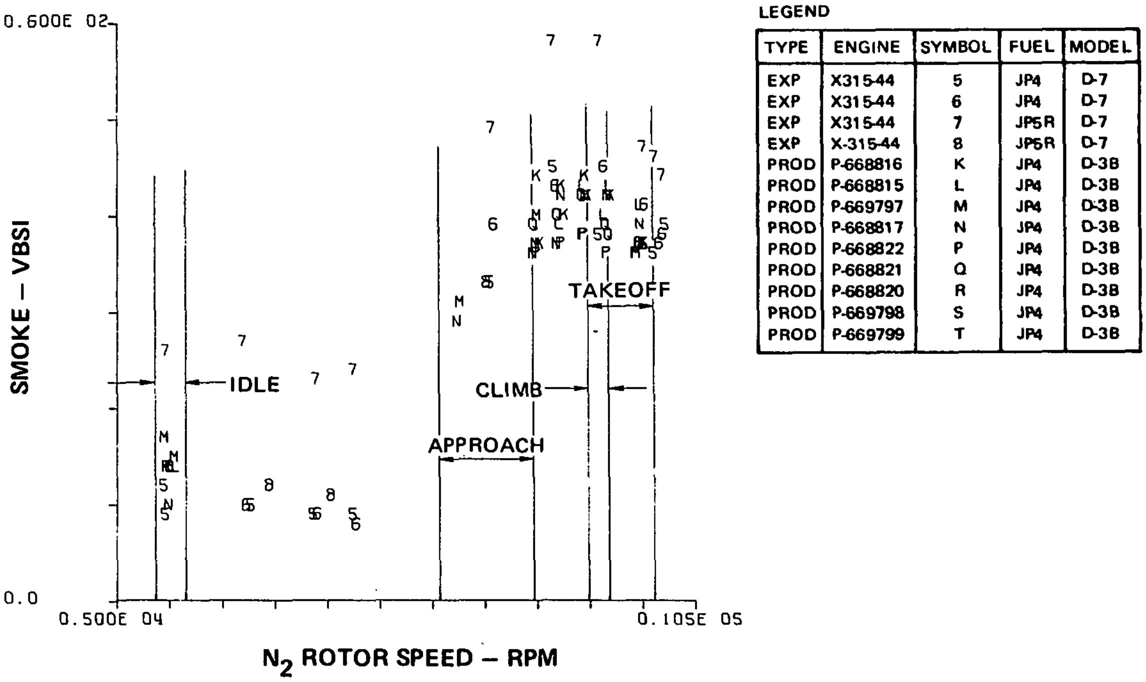
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 62 Smoke Versus Engine Pressure Ratio Emission Measurement Results, JT3D Engine



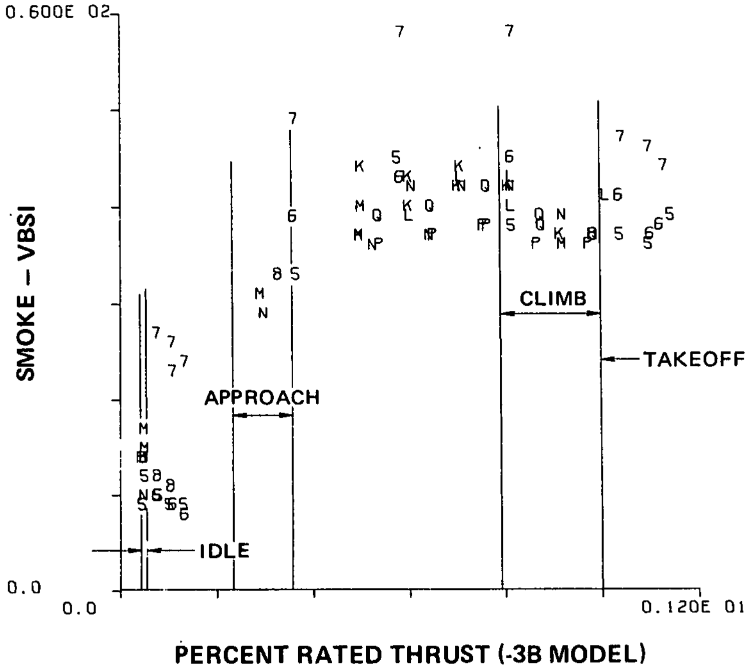
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X31544	5	JP4	D-7
EXP	X31544	6	JP4	D-7
EXP	X31544	7	JP5R	D-7
EXP	X-31544	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

Figure 63 Smoke Versus Engine Thrust Emission Measurement Results, JT3D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X31544	5	JP4	D-7
EXP	X31544	6	JP4	D-7
EXP	X31544	7	JP5R	D-7
EXP	X-31544	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

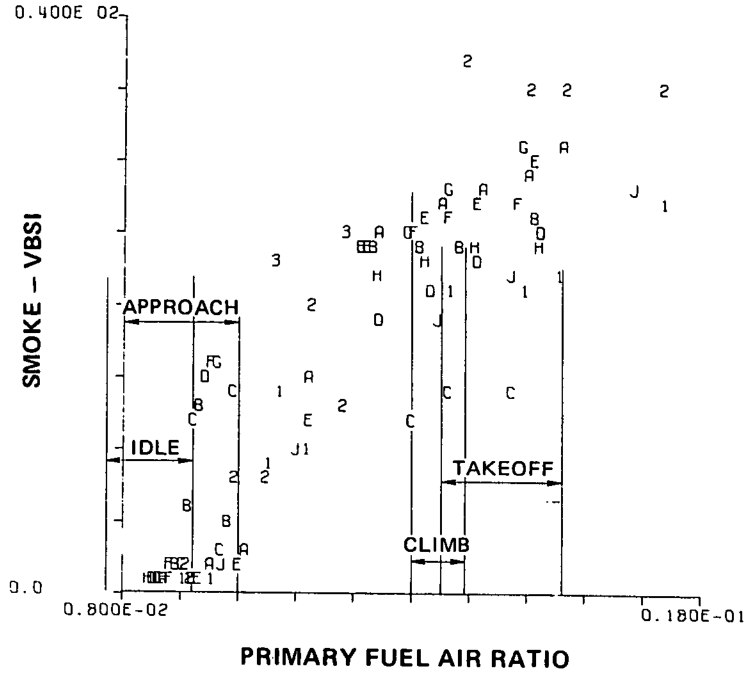
Figure 64 Smoke Versus N_2 Rotor Speed Emission Measurement Results, JT3D Engine



LEGEND

TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X315-44	5	JP4	D-7
EXP	X315-44	6	JP4	D-7
EXP	X315-44	7	JP5R	D-7
EXP	X-315-44	8	JP5R	D-7
PROD	P-668816	K	JP4	D-3B
PROD	P-668815	L	JP4	D-3B
PROD	P-669797	M	JP4	D-3B
PROD	P-668817	N	JP4	D-3B
PROD	P-668822	P	JP4	D-3B
PROD	P-668821	Q	JP4	D-3B
PROD	P-668820	R	JP4	D-3B
PROD	P-669798	S	JP4	D-3B
PROD	P-669799	T	JP4	D-3B

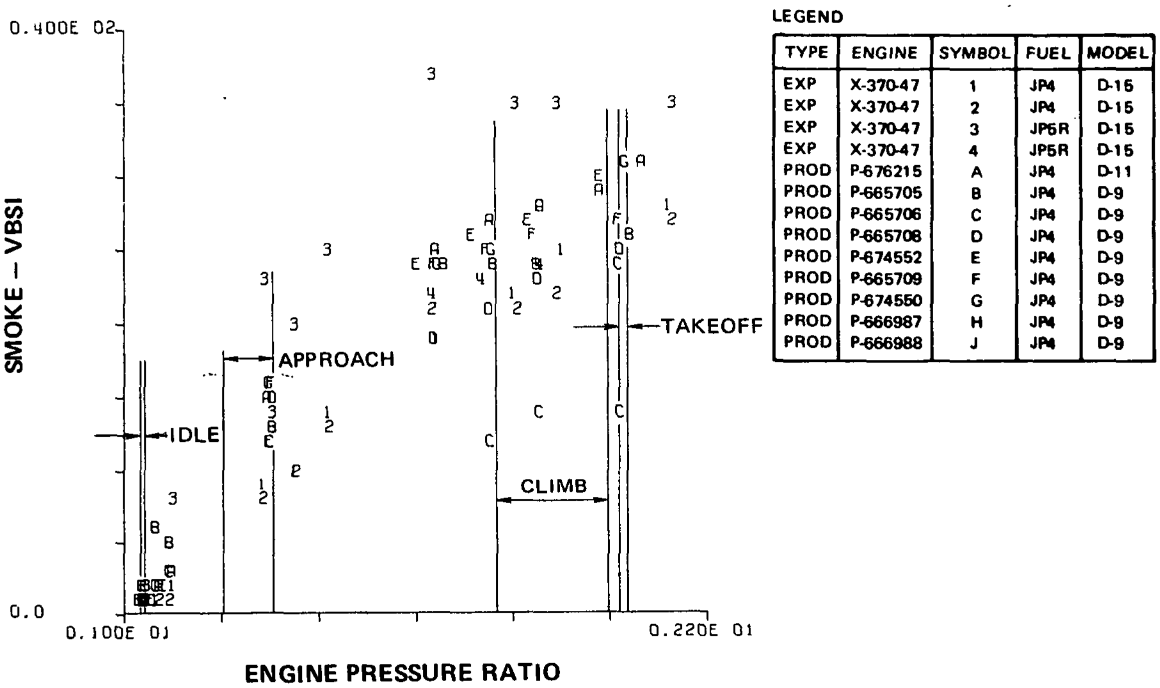
Figure 65 Smoke Versus Percent Rated Thrust Emission Measurement Results, JT3D Engine



LEGEND

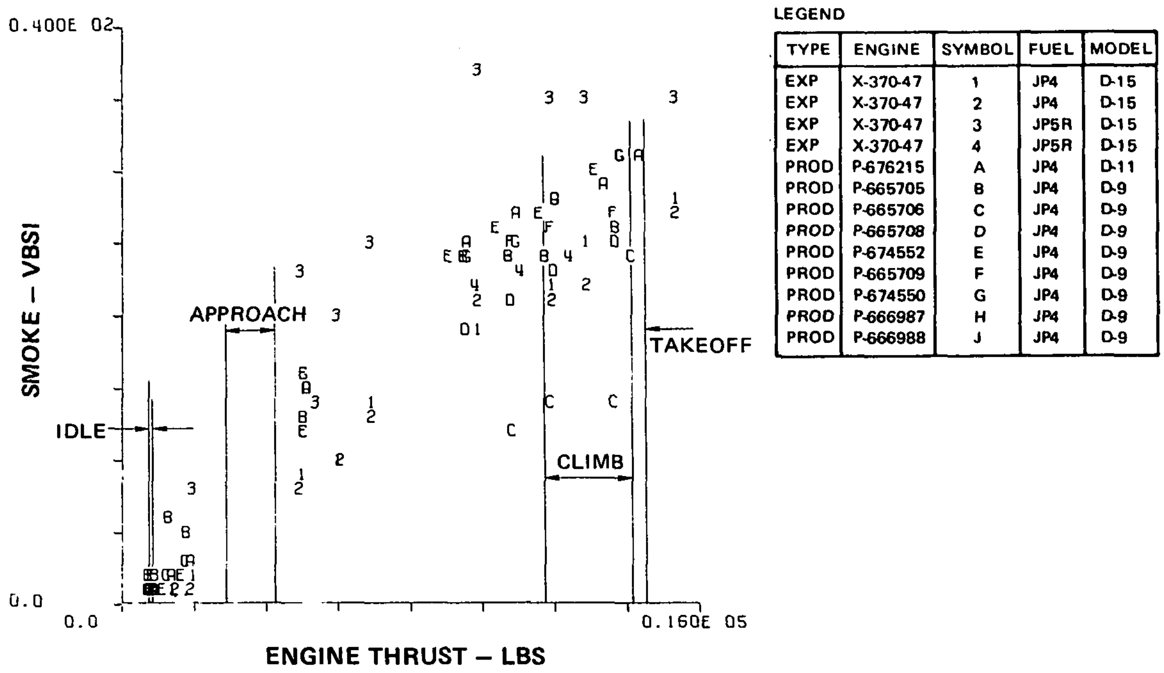
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-16
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 66 Smoke Versus Primary Fuel Air Ratio Emission Measurement Results, JT8D Engine



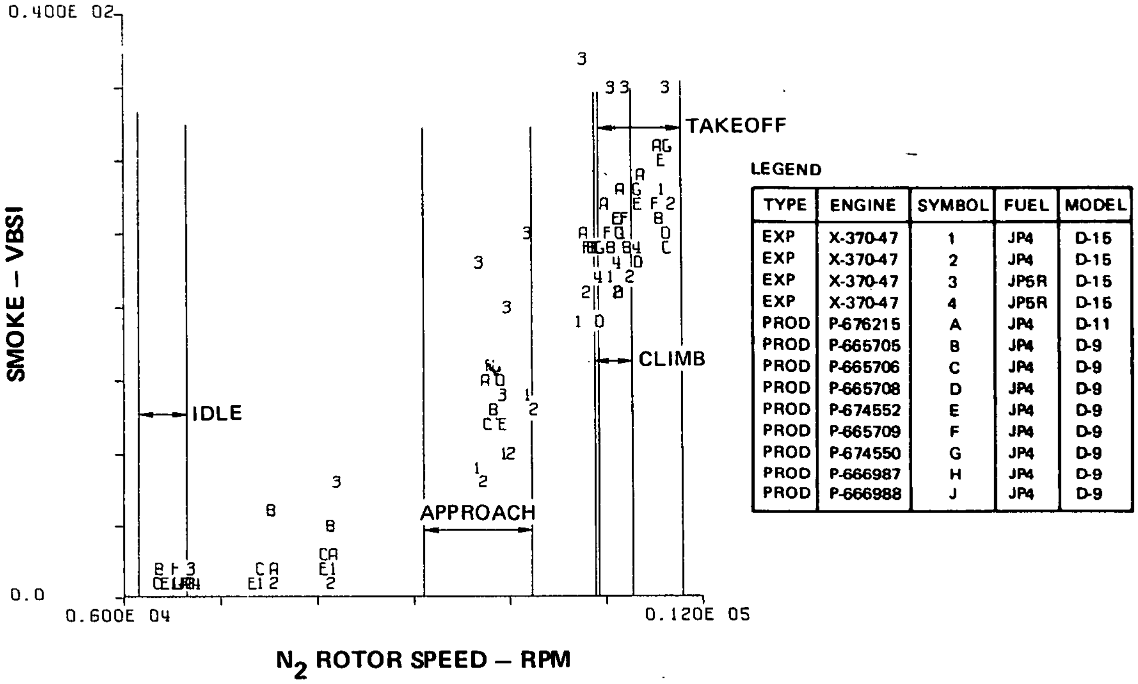
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 67 Smoke Versus Engine Pressure Ratio Emission Measurement Results, JT8D Engine



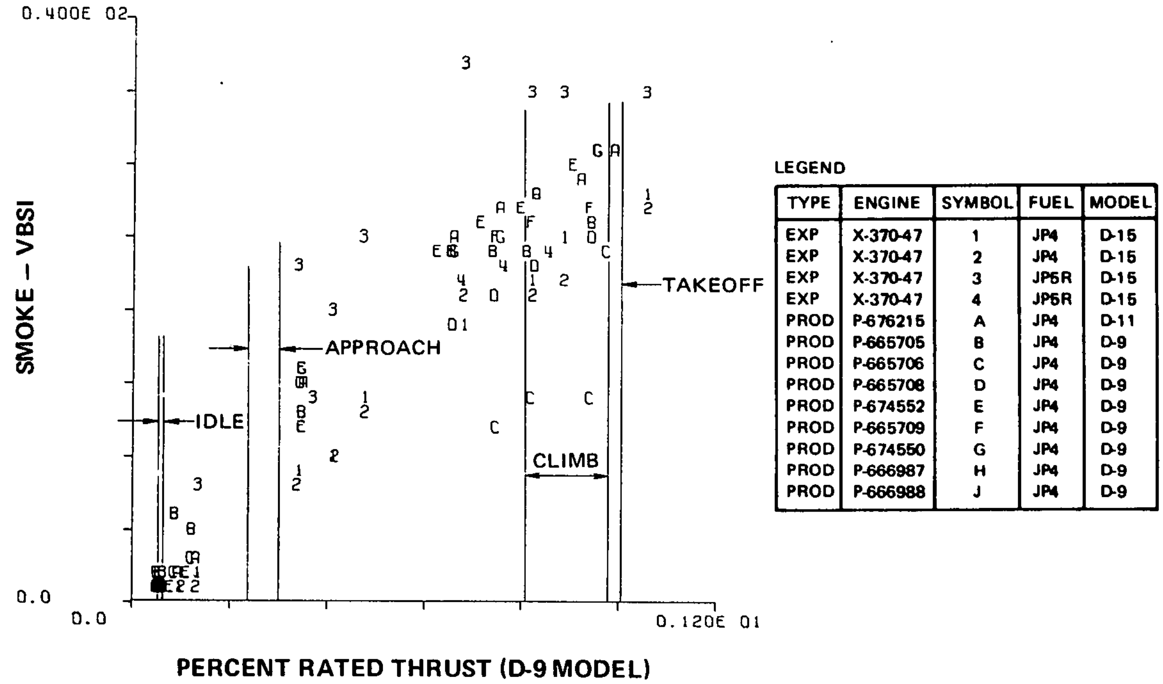
TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 68 Smoke Versus Engine Thrust Emission Measurement Results, JT8D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 69 Smoke Versus N_2 Rotor Speed Emission Measurement Results, JT8D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-370-47	1	JP4	D-15
EXP	X-370-47	2	JP4	D-15
EXP	X-370-47	3	JP5R	D-15
EXP	X-370-47	4	JP5R	D-15
PROD	P-676215	A	JP4	D-11
PROD	P-665705	B	JP4	D-9
PROD	P-665706	C	JP4	D-9
PROD	P-665708	D	JP4	D-9
PROD	P-674552	E	JP4	D-9
PROD	P-665709	F	JP4	D-9
PROD	P-674550	G	JP4	D-9
PROD	P-666987	H	JP4	D-9
PROD	P-666988	J	JP4	D-9

Figure 70 Smoke Versus Percent Rated Thrust (D-9 Model) Emission Measurement Results, JT8D Engine

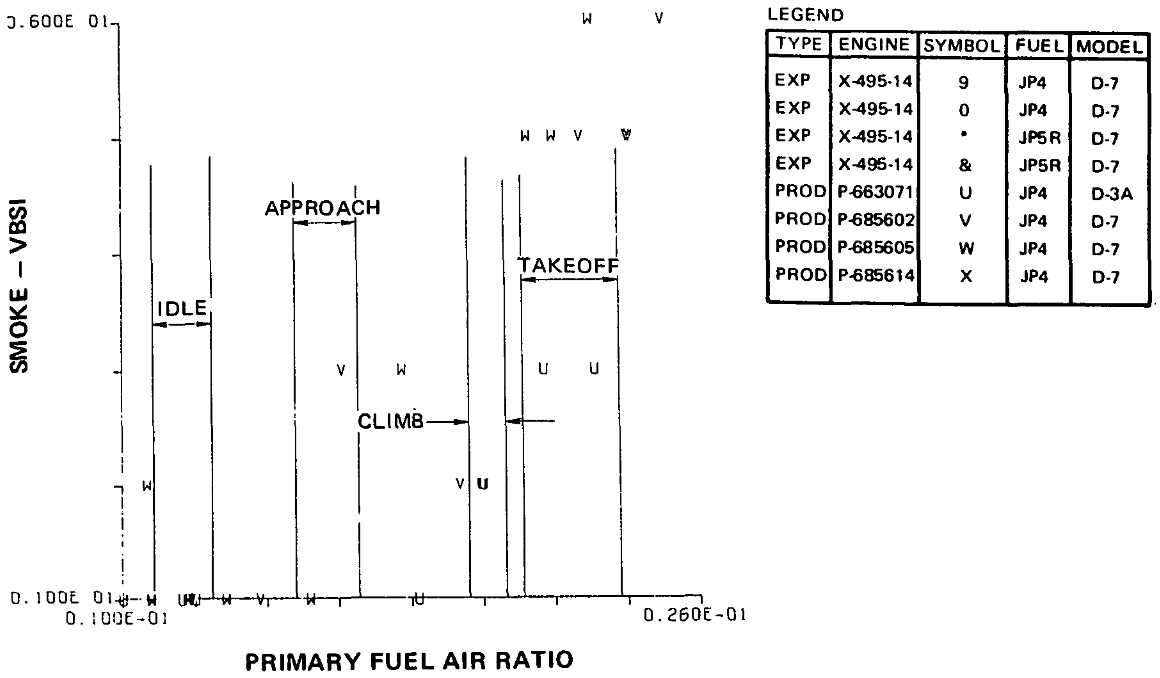


Figure 71 Smoke Versus Primary Fuel Air Ratio Emission Measurement Results, JT9D Engine

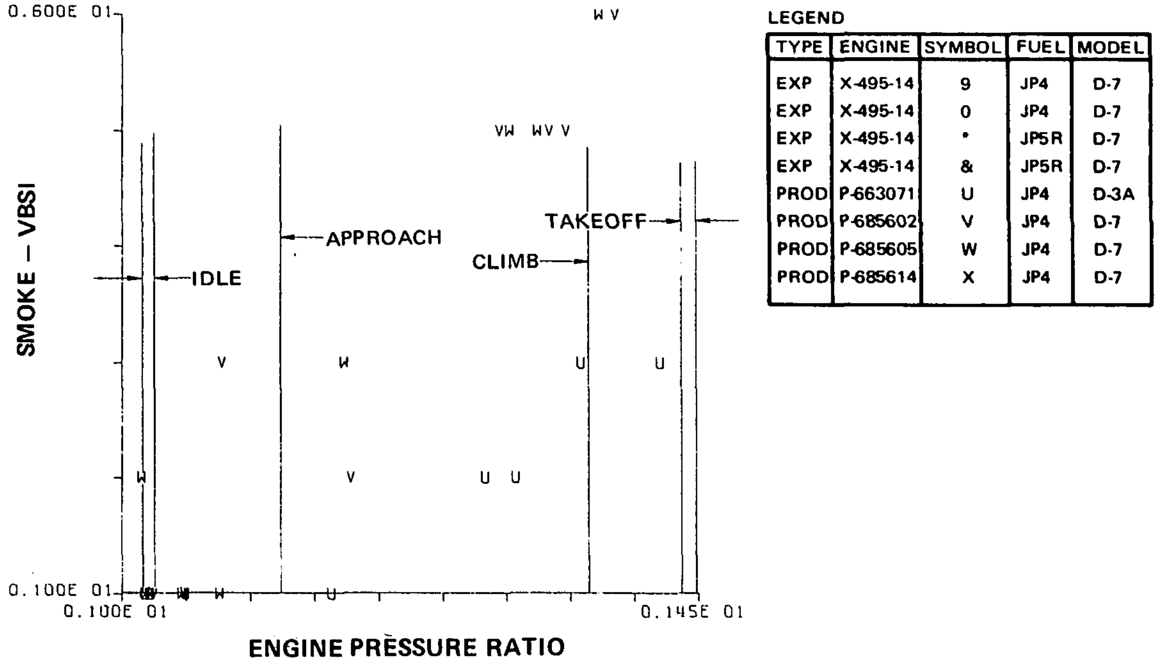
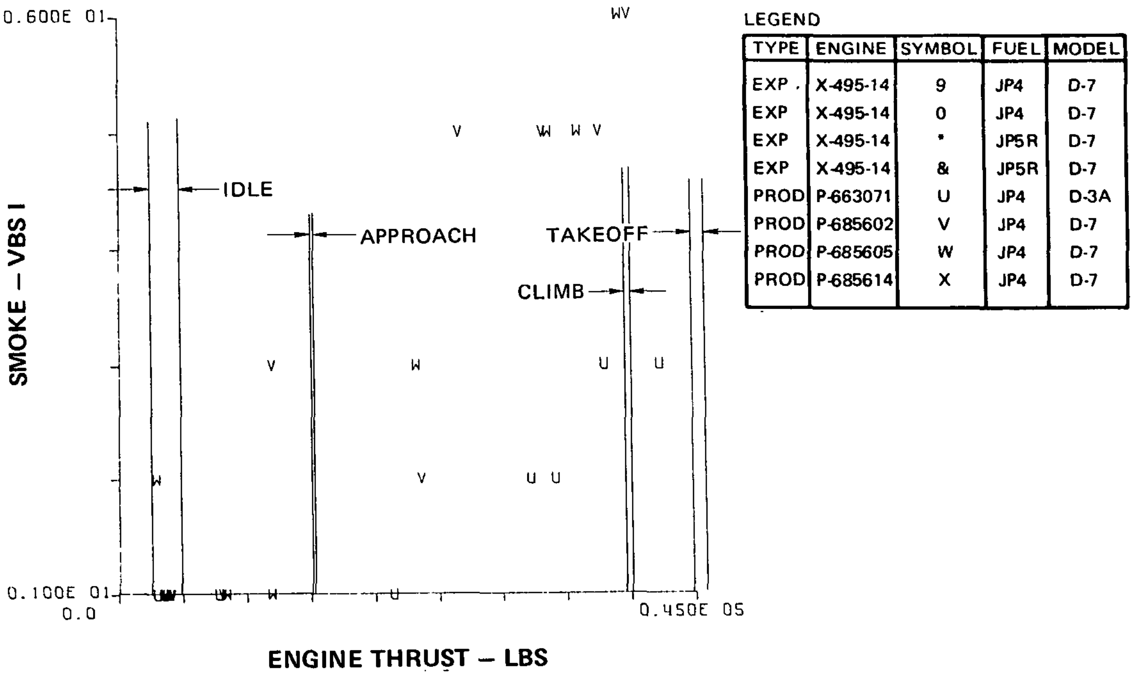
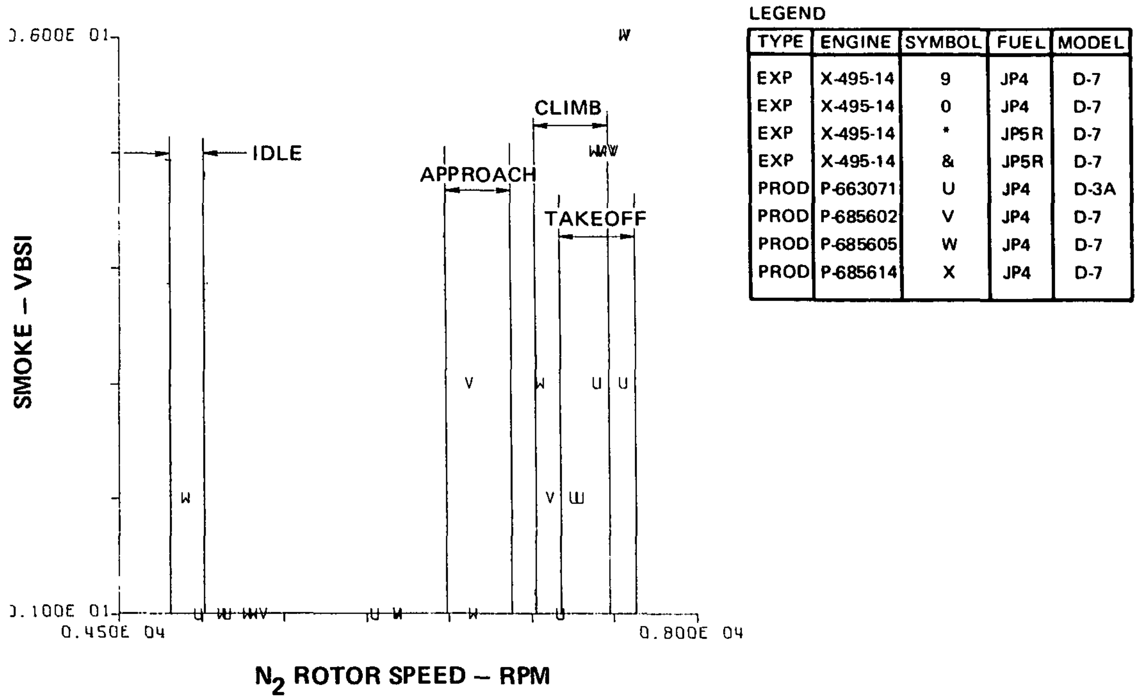


Figure 72 Smoke Versus Engine Pressure Ratio Emission Measurement Results, JT9D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-495-14	9	JP4	D-7
EXP	X-495-14	0	JP4	D-7
EXP	X-495-14	*	JP5R	D-7
EXP	X-495-14	&	JP5R	D-7
PROD	P-663071	U	JP4	D-3A
PROD	P-685602	V	JP4	D-7
PROD	P-685605	W	JP4	D-7
PROD	P-685614	X	JP4	D-7

Figure 73 Smoke Versus Engine Thrust Emission Measurement Results, JT9D Engine



TYPE	ENGINE	SYMBOL	FUEL	MODEL
EXP	X-495-14	9	JP4	D-7
EXP	X-495-14	0	JP4	D-7
EXP	X-495-14	*	JP5R	D-7
EXP	X-495-14	&	JP5R	D-7
PROD	P-663071	U	JP4	D-3A
PROD	P-685602	V	JP4	D-7
PROD	P-685605	W	JP4	D-7
PROD	P-685614	X	JP4	D-7

Figure 74 Smoke Versus N_2 Rotor Speed Emission Measurement Results, JT9D Engine

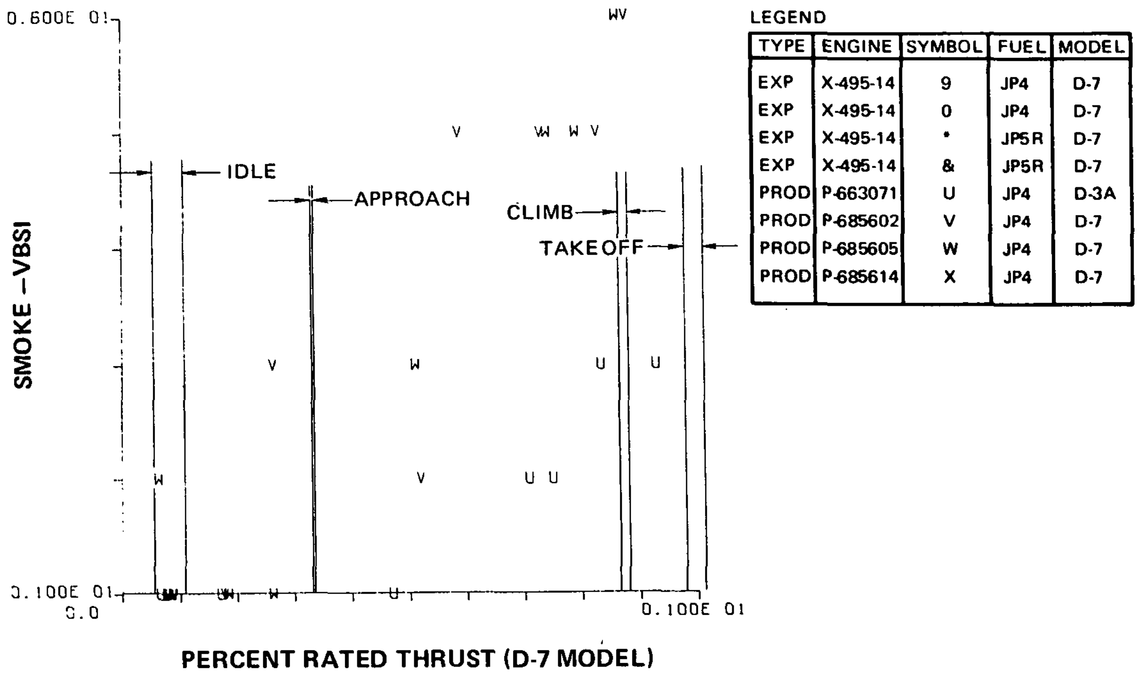


Figure 75 Smoke Versus Percent Rated Thrust Emission Measurement Results, JT9D Engine

6. Hypothetical Cycle Results

An evaluation of the amount of pollution produced by an aircraft engine during a hypothetical operational cycle can be determined by using the mean emission values resulting from the statistical analysis described in the preceding sections. The cycle selected is similar to the hypothetical cycle used by the Cornell Aeronautical Laboratory, Inc., in the Technical Report, "Analysis of Aircraft Exhaust Emission Measurements", CAL No. NA-5007-K-1, dated October 15, 1971 for their analysis of EPA exhaust emission data. The principal modification of the cycle as used in this report is to include the results of the start and shutdown analysis which are described in a subsequent section of this report.

The hypothetical cycle used for the evaluation is as follows:

(a) Engine Start: Time as required
(b) Idle and Taxi: 19.0 minutes
(c) Takeoff Run: 0.7 minutes
(d) Climb out: 2.2 minutes
(e) Approach: 4.0 minutes
(f) Land/Taxi in: 7.0 minutes
(g) Engine Shutdown: Time as required.

The results of using the hypothetical cycle are indicated in the tables below. The mass emission levels for the JT8D engine were computed using primary (core) engine fuel-air ratio input and therefore do not reflect corrections for dilution of the gas sample by fan air during the sampling process. Therefore, the results shown for the JT8D engine are considered to be low. The problems of sampling mixed flow or common tailpipe turbofan engines such as the JT8D are discussed in section IVD.

JT3D ENGINE

Mode	Power Lbs Thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	NO_x Mass lbs.	Fuel Mass lbs.	lbs NO_x/ 1K lb Fuel	Energy #th - hr	LB NO_x/ #th - hr
Start					.006				
Taxi-Idle	900	2.41	1070	19.00	.763	339	2.25	285	.0027
Takeoff	18000	128.58	9420	.7	1.50	110.0	13.63	210	.0072
Climbout	16400	96.63	8120	2.2	3.55	298	11.92	602	.0059
Approach	5228	16.94	3573	4.0	1.13	238	4.75	348	.0032
Taxi-Idle	900	2.41	1070	7.0	.2805	125	2.258	105	.0027
Shutdown					.0014				
		Total for Cycles			7.23	1110		1550	
		LBS Pollutant/1K Lb Fuel/Cycle			6.50				
		LBS Pollutant/1K Lb Th-Hr/Cycle			4.66				

JT3D ENGINE

Mode	Power lbs Thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	CO Mass lbs.	Fuel Mass lbs.	lb CO/ 1K lb Fuel	Energy # th-hr	lb CO/ # th-hr
Start					.896				
Taxi-Idle	900	111.70	1070	19.0	35.40	339	104.2	285	.124
Takeoff	18000	0	9420	.7	0	110	0	210	0
Climbout	16400	11.45	8120	2.2	.42	298	1.41	602	.0007
Approach	5228	67.64	3573	4.0	4.51	238	19.0	348	.013
Taxi-Idle	900	111.70	1070	7.0	13.03	125	104.2	105	.1240
Shutdown					.104				
		Total For Cycles			54.36	1110		1550	
		LBS Pollutant/1K Lb Fuel/Cycle			48.9				
		LBS Pollutant/1K Lb th-hr/Cycle			35.0				

JT3D ENGINE

Mode	Power lbs Thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	THC Mass lbs.	Fuel Mass lbs	lb THC/ 1K lb Fuel	Energy # th - hr	lb THC/ # th-hr
Start					.907				
Taxi-Idle	900	95.39	1070	19.00	30.8	338	91	285	.107
Takeoff	18000	0	9420	.7	0	110	0	210	0
Climbout	16400	0	8120	2.2	0	298	0	602	0
Approach	5228	12.29	3573	4.0	.82	238	3.44	348	.0024
Taxi-Idle	900	95.39	1070	7.0	11.15	125	90.5	105	.106
Shutdown					.667				
		Total For Cycles			44.34	1110		1550	
		LBS Pollutant/1K Lb Fuel/Cycle			39.97				
		LBS Pollutant/1K Lb th-hr/Cycle			28.6				

JT8D ENGINE

Mode	Power lbs Thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	NO_x Mass lbs	Fuel Mass lbs	lb NO_x/ 1K lb Fuel	Energy # th-hr	lb NO_x/ # th-hr
Start					.0067				
Taxi-Idle	800	1.58	920	19.0	.50	292	1.71	253.5	.0020
Take off	14500	156.58	8400	.7	1.82	98	18.6	169.0	.0108
Climbout	12600	109.86	7020	2.2	4.01	257.5	15.6	462.0	.0087
Approach	3555	14.58	2700	4.0	.97	180	5.39	237.5	.0041
Taxi-Idle	800	1.58	920	7.0	.18	107	1.68	93.2	.0019
Shutdown					.0082				
		Total for Cycles			7.50	934.5		1215.2	
		LBS Pollutant/1K LB Fuel/Cycle			8.04				
		LBS Pollutant/1K LB th-hr/Cycle			6.19				

JT8D ENGINE

Mode	Power lbs Thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	CO Mass lbs.	Fuel Mass lbs.	lb CO/ 1K lb Fuel	Energy # th-hr	lb CO/ # th-hr
Start					.421				
Taxi-Idle	800	22.71	920	19.0	7.18	292	24.55	253.5	.0284
Takeoff	14500	7.81	8400	.7	.09	98	.92	169	.0005
Climbout	12600	10.11	7020	2.2	.37	257.5	1.44	462	.0008
Approach	3555	12.56	2700	4.0	.84	180	4.66	237.5	.0035
Taxi-Idle	800	22.71	920	7.0	2.65	107	24.615	93.2	.0284
Shutdown					.0635				
		Total for Cycles			11.21	934.5		1215.2	
		LBS Pollutant /1K lb Fuel/Cycle			12.01				
		LBS Pollutant/1K Lb th-hr/Cycle			9.25				

JT8D ENGINE

Mode	Power lbs thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	THC Mass lbs	Fuel Mass lbs	lb THC/ 1K lb Fuel	Energy #th-hr	lb THC/ #th-hr
Start					.086				
Taxi-Idle	800	5.01	920	19.0	1.58	292	5.40	253.5	.0064
Takeoff	14500	1.35	8400	.7	.0158	98	.16	169.0	.0001
Climbout	12600	1.21	7020	2.2	.0431	257.5	.17	462	.0001
Approach	3555	.82	2700	4.0	.0548	180	.30	237.5	.0002
Taxi-Idle	800	5.01	920	7.0	.587	107	5.48	93.2	.0630
Shutdown					.116				
		Total For Cycles			2.48	934.5		1215.2	
		LBS Pollutant/1K Lb Fuel/Cycle			2.66				
		LBS Pollutant/1K Lb th-hr/Cycle			2.04				

JT9D ENGINE

Mode	Power lbs thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	NO_x Mass lbs.	Fuel Mass lbs.	lb NO_x/ 1K lb Fuel	Energy #th-hr	lb NO_x/ #th-hr
Start					.026				
Taxi-Idle	3550	6.74	1976	19.0	2.13	625.0	3.41	1124	.0019
Takeoff	45500	612.4	16641	.7	7.14	196	36.8	531	.0134
Climbout	39650	423.3	14109	2.2	15.52	518	30.0	1450	.0107
Approach	15009	85.82	7515	4.0	5.72	501.0	11.42	1001	.0057
Taxi-Idle	3550	6.74	1976	7.0	.79	231	3.41	414	.0019
Shutdown					.004				
		Total for Cycles			31.33	2070		4520	
		LBS Pollutant/1K Lb Fuel/Cycle			15.13				
		LBS Pollutant/1K Lb th-hr/Cycle			6.93				

JT9D ENGINE

Mode	Power lbs Thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	CO Mass lbs.	Fuel Mass lbs.	lb CO/ 1K lb Fuel	Energy #th-hr	lb CO/ # th-hr
Start					.903				
Taxi-Idle	3550	107	1976	19.00	33.88	625	54.13	1124	.0301
Takeoff	45500	0	16641	.7	0	195	0	531	0
Climbout	39650	10.58	14109	2.2	.39	518	.75	1450	.0003
Approach	15009	40.05	7515	4.0	2.67	501	5.33	1001	.0027
Taxi-Idle	3550	107	1976	7.0	12.48	231	54.13	414	.0301
Shutdown					.077				
		Total For Cycles			50.40	2070		4520	
		LBS Pollutant/1K Lb Fuel/Cycle			24.35				
		LBS Pollutant/1K Lb th-hr/Cycle			11.15				

JT9D ENGINE

Mode	Power lbs Thrust	Emission Rate lb/hr	Fuel Rate lb/hr	Time In Mode Min.	THC Mass lbs.	Fuel Mass lbs.	lb THC/ 1K lb Fuel	Energy # th-hr	lb THC/ # th-hr
Start					.463				
Taxi-Idle	3550	29.26	1976	19.00	9.27	625	14.81	1124	.0082
Takeoff	45500	0	16641	.7	0	195	0	531	0
Climbout	39650	.28	14109	2.2	.0103	518	.02	1450	0
Approach	15009	4.06	7515	4.0	.271	501	.54	1001	.0003
Taxi-Idle	3550	29.26	1976	7.0	3.41	231	14.81	414	.0082
Shutdown					1.201				
		Total For Cycles			14.62	2070		4520	
		LBS Pollutant/1K lb Fuel/Cycle			7.06				
		LBS Pollutant/1K lb th-hr/Cycle			3.23				

7. Assessing Humidity, Temperature and Fuel Effects

The observed humidity and inlet temperature were treated as independent variables in the regression analysis. Plots of the results of a typical humidity analysis are shown in Figures 76 and 77. The range of both the humidity and temperature in the data set obtained from this program is small as compared with that expected during normal year round airline or engine testing operation. The data set for this assessment was obtained as a fall out from the overall test program and not from a program designed to specifically determine the effects of these two variables. Thus, the data is affected by the previously described restraints. It was possible, however, to obtain an indication of trends which may be representative of the effect of these variables on emission level. These trends are indicated in the table below:

ESTIMATED TEMPERATURE & HUMIDITY EFFECT

		Range Investigated		Emission Change lbs/1000 lbs Fuel	
Engine	Emission	Temp (°F)	Spec Humidity	Per 10° ΔT	Per .010 ΔH
JT3D	NO_x	68-87	.007 - .017	N.D.	–1.940
	CO	68-87	.007 - .017	N.D.	N.D.
	THC	68-87	.007 - .017	N.D.	N.D.
JT8D	NO_x	70-97	.008 - .016	N.D.	N.D.
	CO	70-97	.008 - .016	N.D.	0.970
	THC	70-97	.008 - .016	N.D.	N.D.
JT9D	NO_x	70-91	.007 - .016	2.63	–2.13
	CO	70-91	.007 - .016	N.D.	4.46
	THC	70-91	.007 - .016	N.D.	3.84

N.D. – Trend of emission change could not be determined from the available data set.

The rate of change of emission level with changes in humidity and temperature shown above can only be considered as gross estimates. To more fully understand the importance of humidity and temperature on emission level, it is strongly recommended that programs be specifically established to investigate these two variables in detail. Reliable emission correction factors for these two variables are a requisite if realistic emission regulations are to be established.

The trend of the effect of fuel type on emission level was not clearly established in this program. It was found that two tests per engine model using JP5 fuel was insufficient to determine a reliable trend of effect on emissions. In spite of the low number of tests using JP5 fuel, a small affect of fuel type did show up in the regression analysis (Section IVA4). For this analyses, the heat of combustion of the fuel, which is rather easily determined, was used to represent fuel difference.

It should be noted that JP4 fuel, which was used for most of the testing in this program, is representative of the fuel used for international airline operation. Jet A fuel, which is close in composition to JP5 fuel, is used for domestic airline operation. In order to more clearly understand the effect of fuel type difference on emission level, it is recommended that a more comprehensive test program be conducted.

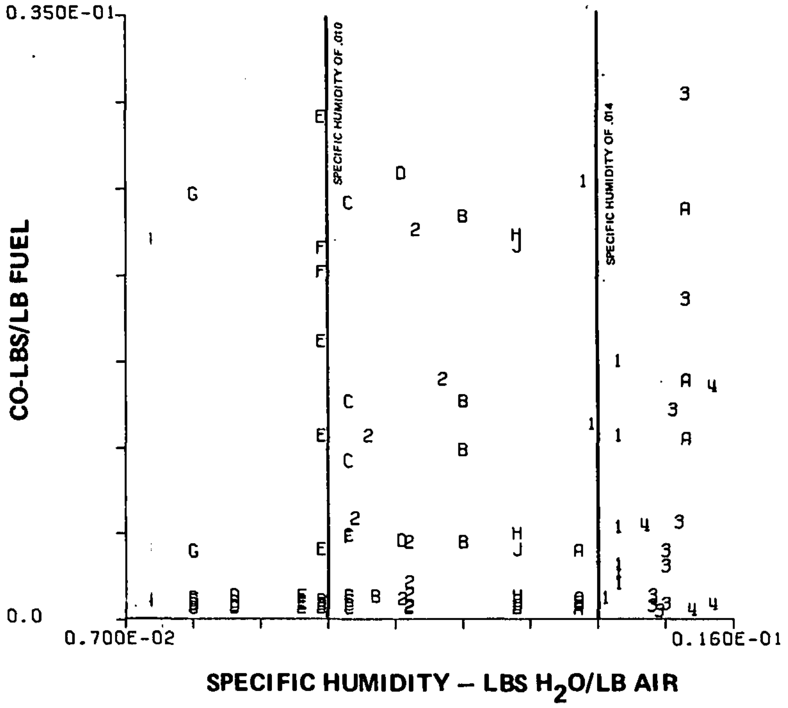


Figure 76 Carbon Monoxide (CO) Versus Specific Humidity Emission Measurement Results, JT8D Engine

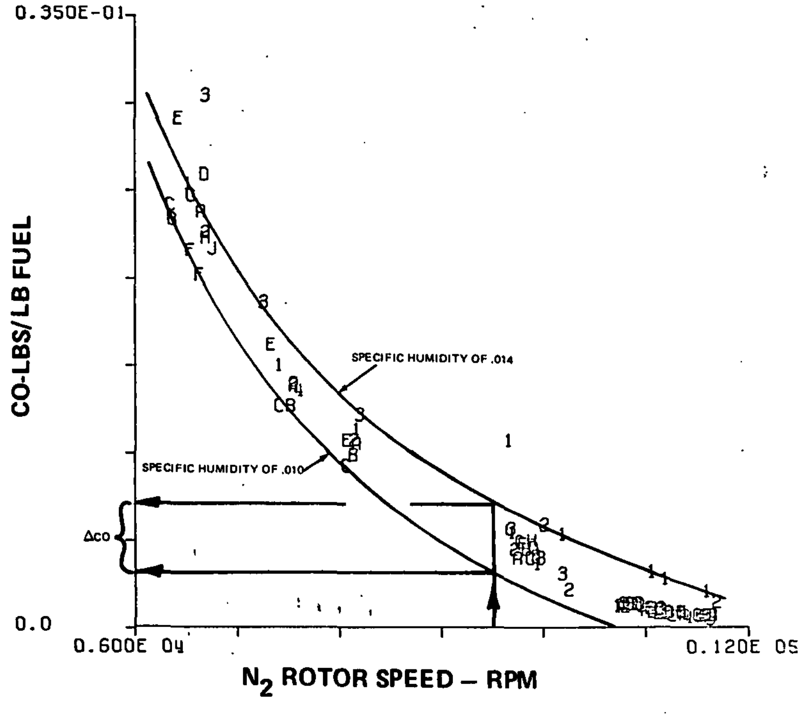


Figure 77 Carbon Monoxide (CO) Versus N_2 Rotor Speed Emission Measurement Results, JT8D Engine

8. Engine and Run Variation Analysis

Knowledge of the engine to engine variation and run to run variation for a program of this type is useful in the overall analysis of the collected data. These variations are most meaningful if the factors affecting the differences (variations) are minimized. As normally defined,

- the between engine difference is the error associated with running various engines under approximately similar environmental and testing conditions.

- The within engine difference is the error associated with the same engine running under approximately similar environmental conditions.

The available data set was investigated to determine these differences as experienced in this testing program. It was found during inspection of the data set that, because of the number of uncontrolled and unexplained variables, a sophisticated assessment of the engine to engine and run to run differences was not warranted. These uncontrolled and unexplained variables include:

- Humidity variation,
- Inlet temperature variations,
- Fuel variations,
- Determination of primary fuel-air ratio at low powers.

A gross assessment of the two variations was made through regression analysis and the results are presented below.

ENGINE-TO-ENGINE AND RUN-TO-RUN VARIATIONS*

		Variations ~ σ		
		Engine to Engine	Run to Run	
Engine	Emission	Production Engines	Exp. Engines JP4 Fuel	Exp. Engines JP5 Fuel
JT3D	NO_X	0.923	0.703	0.703
	CO	5.188	5.738	5.813
	THC	4.310	4.565	5.122
	SMOKE	6.76 VBSI	10.36 VBSI	11.38 VBSI
JT8D	NO_X	0.681	0.959	0.856
	CO	0.746	0.978	0.978
	THC	0.290	0.164	0.164
	SMOKE	3.05 VBSI	1.76 VBSI	5.96 VBSI
JT9D	NO_X	1.619	1.069	1.069
	CO	1.760	2.549	2.549
	THC	0.470	0.409	0.409
	SMOKE	–	0.91 VBSI	0.91 VBSI

Note: Variation units are in Lbs/1000 lbs fuel, except smoke which is given in VBSI units.

* Caution – The engine-to-engine and run-to-run variations noted above are only indications of this particular data set and may not be representative of results obtained from specifically controlled tests of a larger number of engines.

The gross engine to engine variation as determined from production engine data is not significantly different from the run to run variation for production engines.

Inspection of the plots of emission level versus various engine parameters, Figures 16 through 75, does not indicate any significant differences between data obtained from production engines and that obtained from experimental engines. This was expected because the running time was low on the combustion sections of each of the experimental engines tested.

The following is a summary of the major component running times for each of the experimental engines tested.

Model	Engine No.	Component	Average Test Hours
JT3D	X-315-44	Fan/Low Compressor	1450
		High Compressor	720
		Fuel Nozzles	54
		Burners	54
		High Turbine	140
		Low Turbine	800
JT8D	X-370-47	Fan/Low Compressor	911
		High Compressor	1050
		Fuel Nozzles	105
		Burners	55
		High Turbine	138
		Low Turbine	1017
JT9D	X-495-14	Fan/Low Compressor	225
		High Compressor	60
		Fuel Nozzles	31
		Burners	31
		High Turbine	31
		Low Turbine	31

B. OTHER EMISSIONS

The other emissions measured during the course of the program included aldehydes, olefins, dry particulates, and total particulates. The following paragraphs discuss the results of measurement of these emissions. It should be noted that the low levels of these emissions for the JT8D engine are likely to be incorrect because of sampling difficulties with mixed flow or common tailpipe turbofan engines. These sampling difficulties are discussed more fully later on in this section.

1. Aldehydes

The results of the measurements of aldehydes in the exhaust of JT3D, JT8D and JT9D engines at idle power are shown in Figures 78 and 79. One of the curves, Figure 78, is plotted on the basis of pounds of aldehydes per pound of fuel burned and the other, Figure 79, is plotted on a pound per hour basis. Of the three engines tested, the highest producer of aldehydes at idle power is the JT3D engine, which, as noted previously, also has the highest output of total hydrocarbons (THC). The lowest aldehyde producer is the JT8D engine. The JT9D engine, the most modern of the three engines, is about halfway in between. There does not appear to be any significant difference in aldehyde output between JP4C and JP5R fuels. The level of aldehydes was found to be insignificant at higher power settings for all engine models.

2. Olefins

The results of the testing for olefins in the exhaust of JT3D, JT8D, and JT9D engines are shown in Figure 80. Measurements of olefins were taken over a wide range of powers for each engine tested, however, measurable values except for the JT3D engine, were only noted at very low engine powers. As in the case of aldehydes, the JT3D engine produced the highest levels of olefins, the JT9D was second. No measurable values of olefins were recorded for the JT8D engine, probably because the power setting selected for this engine in the low power range was too high. Overall, the data on olefin emissions is too limited to permit an accurate assessment of a representative level for any of the engines tested.

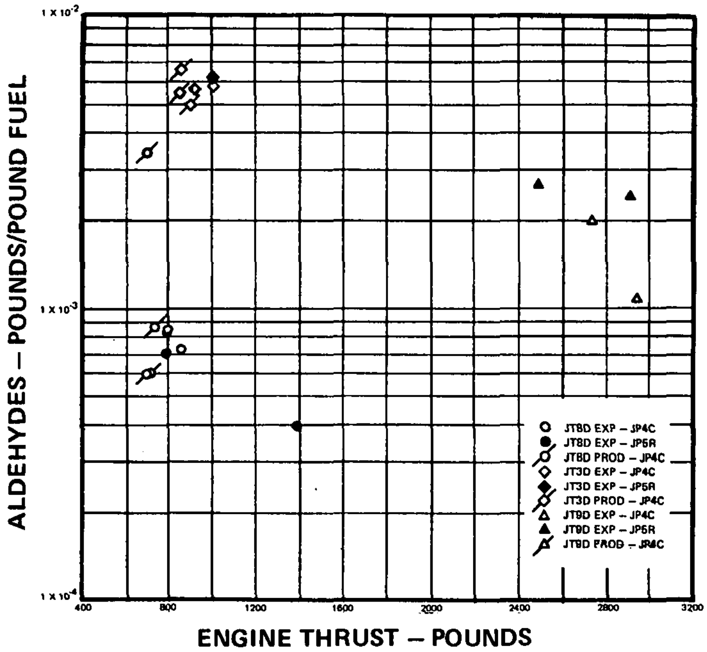


Figure 78 Aldehydes Versus Engine Thrust

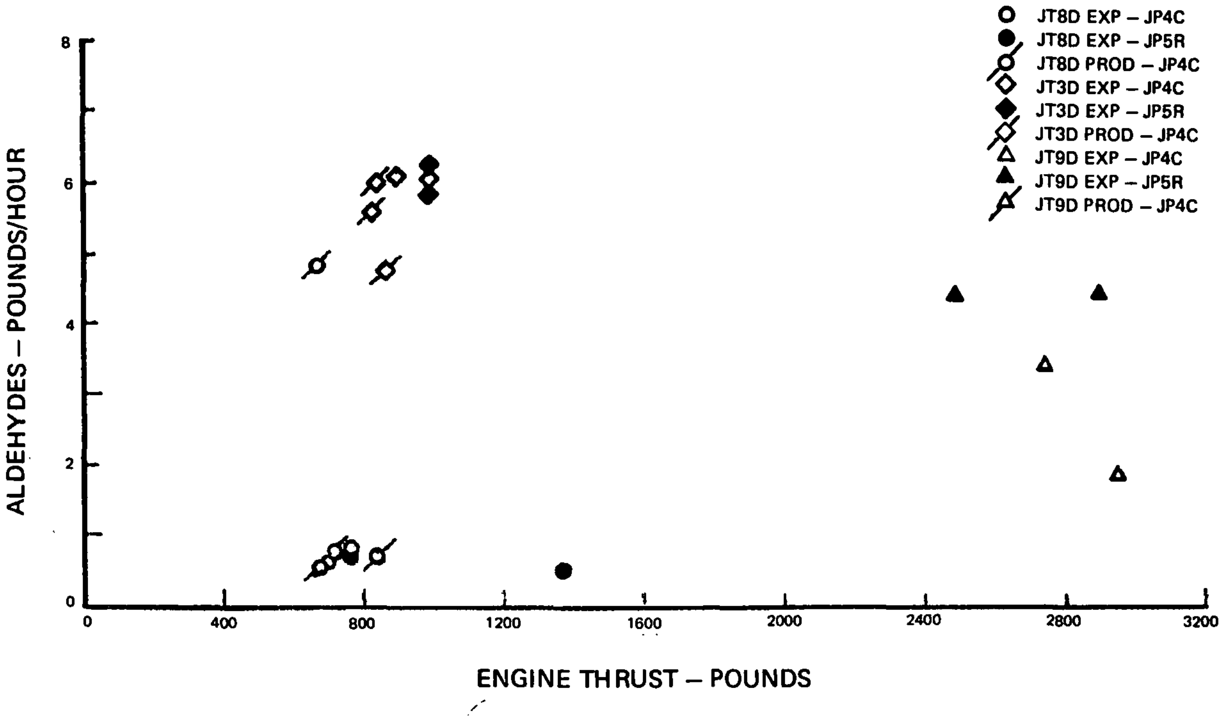


Figure 79 Aldehydes Versus Engine Thrust

JT3D ENGINE

THRUST, LBS	1000	9150	15975	18100
FUEL FLOW, LB/HR	1020	4740	8862	10228
OLEFINS PPMV	83	3	2	4
OLEFINS LBS/LB	.0273	.000754	.000374	.000685
OLEFINS LBS/HR	27.87	3.574	3.310	7.049

JT8D ENGINE

THRUST, LBS	1374	4993	12686	14510
FUEL FLOW, LB/HR	1390	2982	7463	8792
OLEFINS, PPMV	<1	<1	<1	<1
OLEFINS, LBS/LB	–	–	–	–
OLEFINS, LBS/HR	–	–	–	–

JT9D ENGINE

THRUST, LBS	2909	10962	30560	33733
FUEL FLOW, LB/HR	1827	4925	12255	13540
OLEFINS, PPMV	46	<1	<1	<1
OLEFINS, LBS/LB	.0126	–	–	–
OLEFINS, LBS/HR	23.01	–	–	–

Figure 80 Olefins in Engine Exhaust, JP5R Fuel

3. Dry Particulates

The results of the testing for dry particulates by the Millipore method are shown in Figure 81, on a pounds per pound of fuel burned basis and in Figure 82, on a pounds per hour basis. The data was recorded for both experimental and production engines and shows very good repeatibility. The JT3D engine emits the highest level of dry particulates, and within the power range tested, 70 percent to over 100 percent of maximum thrust, the emission rate is not significantly affected as the engine power is reduced. The JT8D engine, which is significantly lower in dry particulate emission than the JT3D engine, does show a distinct trend toward diminishing dry particulate emission as engine power is reduced. The dry particulate emission levels recorded for the JT9D engine were very low. The bulk of the dry particulate emission data were recorded using JP4C fuel. The limited number of data points taken using JP5R fuel indicate a marked trend to higher relative levels of dry particulate emissions for all of the engine models tested.

4. Total Particulates

Figure 83 shows the results of the total particulate emission measurements, taken by the LACAPCD method, for the JT3D, JT8D and JT9D engines. The data are plotted in grains per standard cubic foot (GR/SFC), pounds per hour, and pounds per pound of fuel burned versus percent engine power. As might be expected from this method, the scatter of the data was great. From the data taken, it was not possible to differentiate between engine models in the level of total particulates emitted. On a GR/SFC or pounds per pound of fuel basis, the data suggest a decreasing trend in total particulate emissions as engine power is increased. On a pounds per hour basis, however, the total particulate emissions increase with an increase in engine power setting.

The data were recorded by two probes inserted in the engine exhaust, one on the left side, the other on the right. The level of total particulates in the inlet air was recorded by an additional probe installed in front of the engine. For the JT3D test, higher than normal values were recorded for two of the points, one because of liquid fuel in the sample analyzed from the left probe, and the other because of a high organic content in the inlet probe sample which was not representative of inlet air. The reason the fuel and organic concentration showed up on these particular points and not on others is not known.

No attempt was made in plotting the data to subtract the total particulate level recorded by the inlet probe from that recorded by the two probes in the engine exhaust. In most cases, the total particulate level recorded by the inlet probe would not have a significant affect on the results.

The levels of particulates recorded for this test may be influenced by the fuel used. JP5R fuel, which is a "referee" fuel used for engine certification and qualification testing, was the only JP5 fuel grade available. This fuel contains artificially added sulfur to bring the sulfur content up to the specification 0.3 percent, whereas Jet A or Jet A-1 fuels used for commercial airline service typically only contain 0.05 percent sulfur or less.

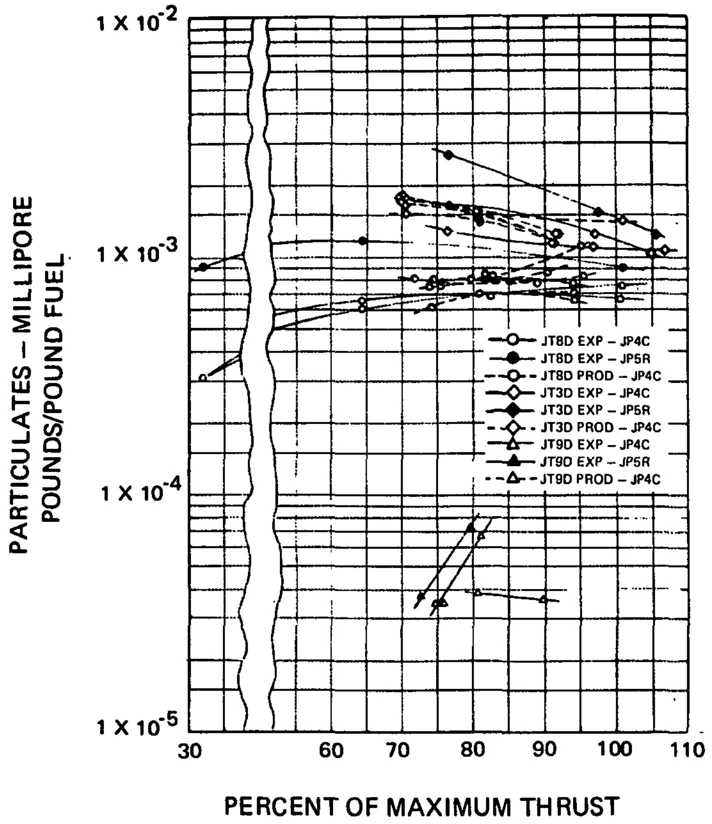


Figure 81 Dry Particulates Versus Percent Maximum Thrust

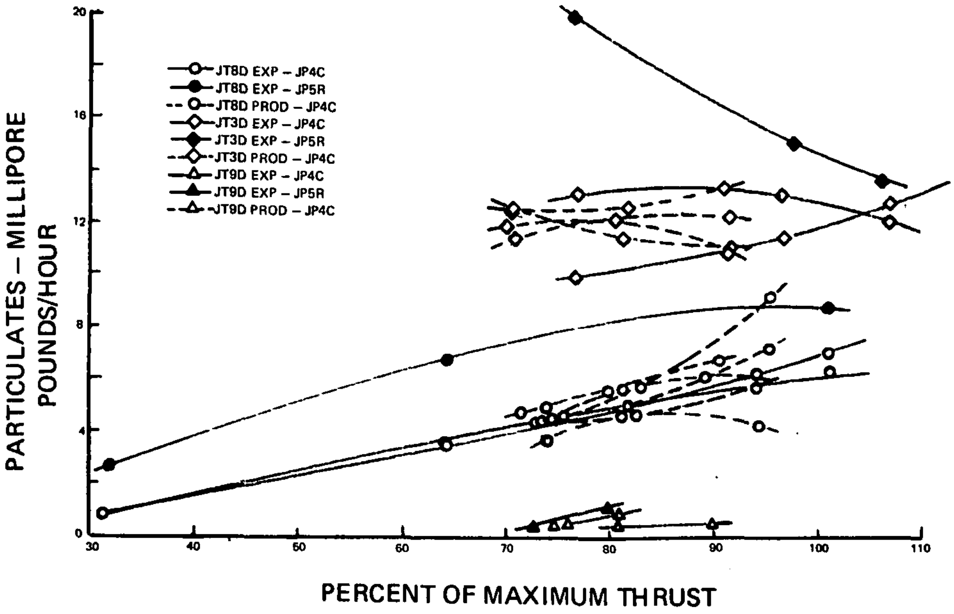


Figure 82 Dry Particulates Versus Percent Maximum Thrust

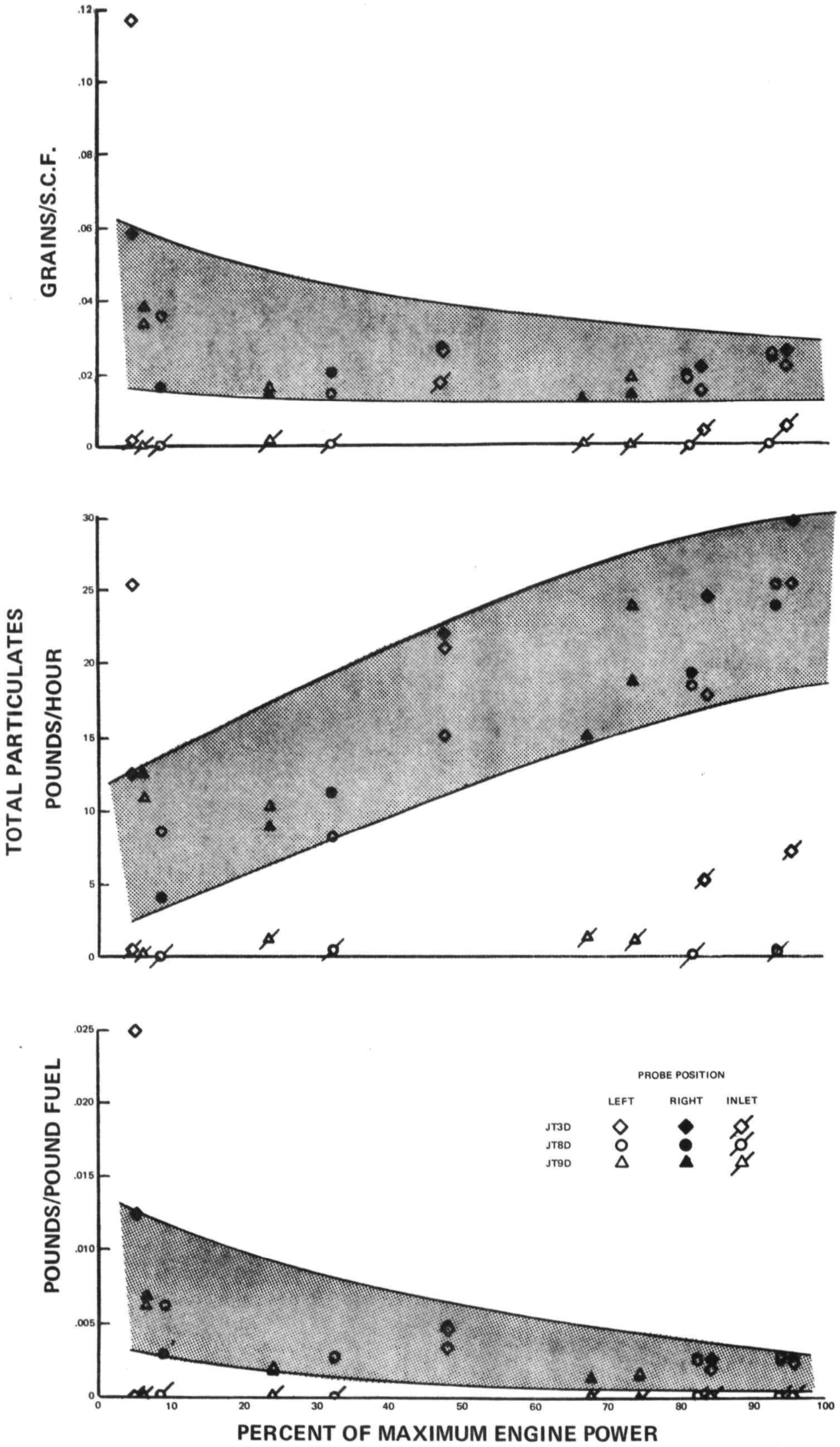


Figure 83 Total Particulates Measured by LACAPCD Method Versus Percent Maximum Engine Power

Recently it has been noted that when particulates are measured by the LACAPCD method, the portion of the combusted sulfur which forms sulfur trioxide (ordinarily on the order of one percent of the sulfur dioxide formed) appears as sulfuric acid combined with water which is counted as a particulate. For high sulfur fuels, preliminary rig and limited engine testing indicates that the major portion of the total particulate matter is in the water soluable fraction. More testing of rigs or or engines with high and low sulfur fuels is required to better substantiate these observations.

C. TRANSIENT EMISSIONS

1. Introduction

In addition to the measurement of exhaust emissions from the JT3D, JT8D, and JT9D engines during stabilized operation, exhaust emissions were also measured during starts, accelerations, decelerations, and shutdowns to permit estimation of the total amount of gas generated for each of these transient conditions. It must be realized that the transient results were obtained using equipment not specifically designed for transient emission measurement. In addition, estimates of fuel flow and airflow were required since these parameters were not measured. Thus, the results should only be considered as gross estimates of possible levels occurring during the transient operations investigated. The levels shown for the JT8D engine are subject to the sampling errors described in Section IVD.

2. Method of Measuring Start-Up Emission Effects

Continuous on-line emission recording equipment was used to record the transient levels of gaseous emissions generated during starts, accelerations, decelerations, and shutdowns for JT3D, JT8D, and JT9D engines. Gases measured were CO, NO, NO_2, and total hydrocarbons (THC). During the transient, sample gases were continuously drawn from the probe through a heated sample line into the emissions monitoring van. Multiple pen paper strip chart recorders were connected to the gas detectors so that a time history of each exhaust component was obtained. Typical strip charts are shown in Figures 84 and 85.

To estimate the total amount of each constituent produced during the start, the following procedure was used:

a. The length of time of the start is estimated from the known chart speed, and the distance from the point where the trace for the flame ionization detector first responds to the presence of fuel to the point where it reaches a stabilized reading. (The F.I.D. total hydrocarbon detector is chosen because it has the fastest response and also responds to any fuel injected before ignition).

b. The area of chart under the hydrocarbon gas trace is measured with a polar planimeter for the time period estimated in step a.

c. The average concentration level is calculated by dividing the area (Step b), by the time period estimated in Step a.

d. This is repeated for each of the 4 gases.

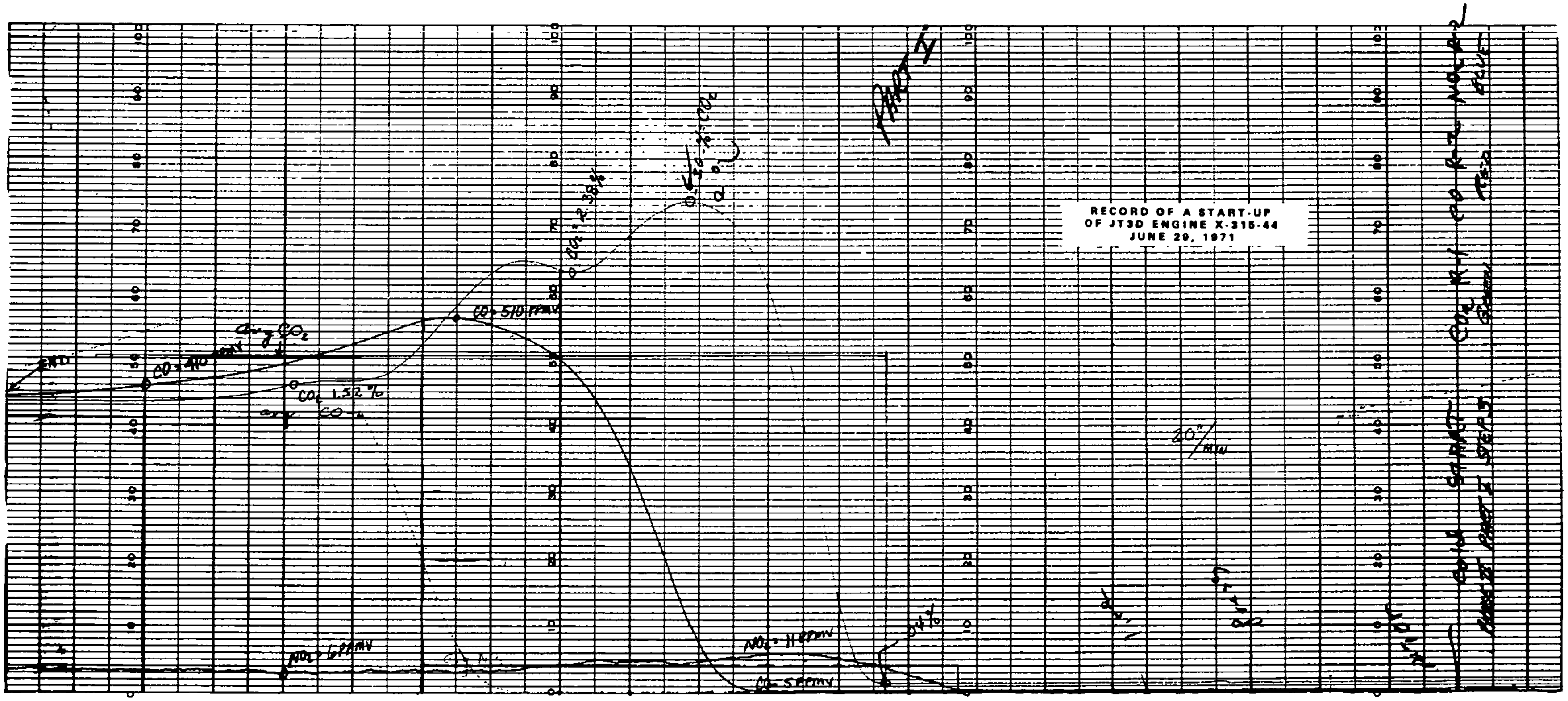


Figure 84 Start-Up Time History of Exhaust Components, JT3D Engine

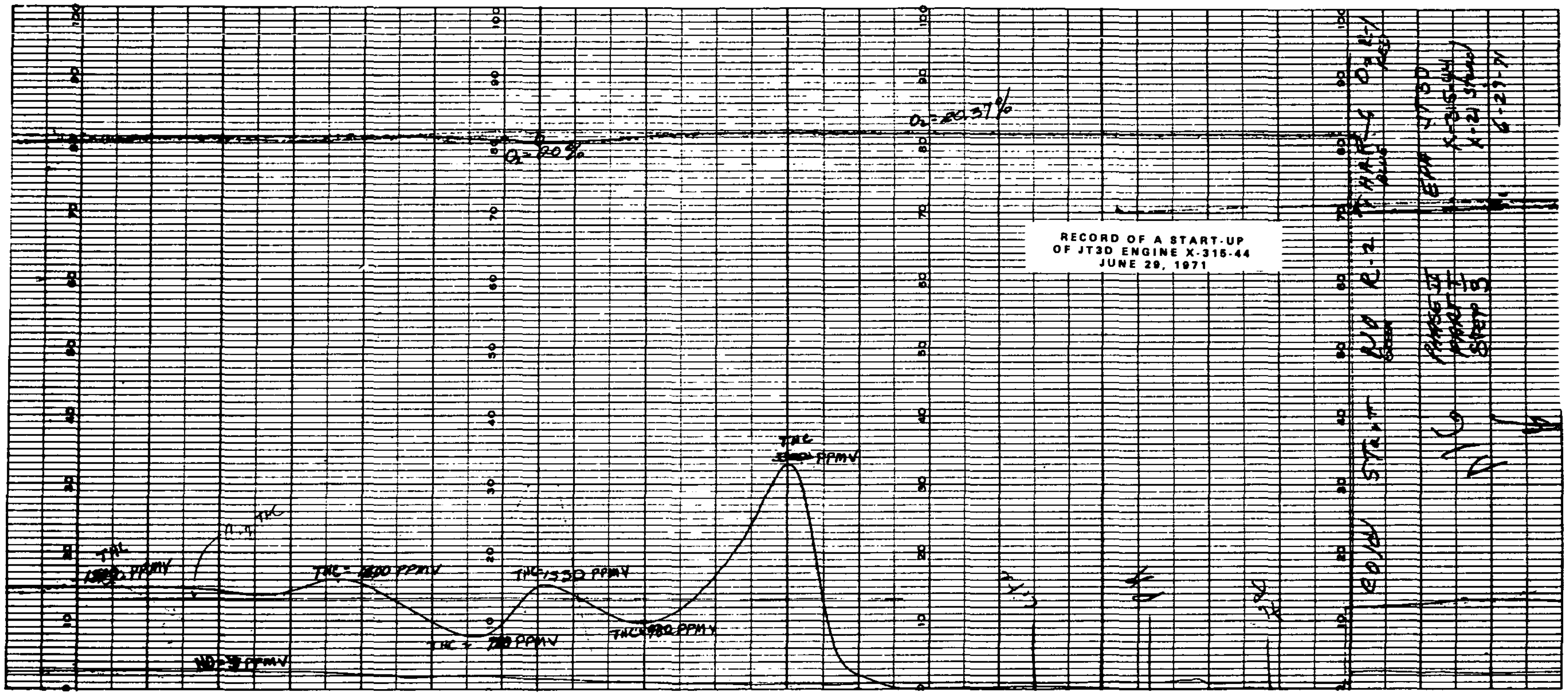


Figure 85   Start-Up Time History of Exhaust Components, JT3D Engine

e. A similar procedure is used to calculate the average fuel flow during the starting period, using an oscillograph trace made from a fuel flow meter.

f. The average fuel/air ratio during a start is estimated as being the average of two known values:

   1) the non-lit cranking fuel/air ratio.

   2) the steady-state idling fuel/air ratio.

g. Average concentrations from (c) are in volume percentages. To convert to weight percent, they are multiplied by the ratio of the constituent molecular weight to the average exhaust gas molecular weight.

h. The mass of constituent per mass of fuel is found using this relationship:

$$\frac{Mi}{Mf} = \frac{\% \text{ i (by wgt.) x } 100}{\left(\dfrac{\frac{(f)}{(a)} \text{ avg}}{1 + \frac{(f)}{(a)} \text{ avg}} \right)}$$

i. Total fuel used during the start is the product of Wf_{average} (Item e) and t_{start} (Item a).

j. Total mass of each gas produced during the start is the product of the emission factor, Mi/Mf, (Item h) times the fuel consumed, (Item i).

One representative oscillograph trace of starting fuel flow was used for calculating Item e for all the starts of any particular engine model, since individual recordings of this variable were not made for each start.

Undue significance should not be attached to the fact that traces for certain of the gases rise to a peak earlier on the chart than others. This is not necessarily a characteristic of the engine, but rather of the van instrumentation. Here, the gas from the heated line branches off first to F.I.D., then to the NO detector, then to CO_2 and NO_2, and then to the others. Also, the CO and NO detectors have a slower response, being longer path recorders.

The procedure for calculating the emission during accelerations, decelerations, and shutdowns was exactly the same as that for starts, using the strip chart records taken during each of these particular operations.

3. Analysis of Transient Results

Representative strip charts of each of the transients were analyzed in the manner described above for each of the three engine models tested in this program. The emissions generated during any of the transient modes of operation are small. This is attributable to the smooth operation of the continuous-flow gas turbine engine during transient operation.

The following is a discussion of the emission characteristics noted during the analysis of the emission traces for each of the engine transients.

a. Cold Starts

The results of the analysis of cold start data for the engine models tested is shown in the table below:

COLD START ANALYSIS RESULTS

Start	Fuel Type	CO Lbs	THC Lbs	NO Lbs	NO_2 Lbs
			JT3D		
1	JP4	0.315	0.692	0.003	0.008
2	JP4	1.033	0.825	0.001	0.001
3	JP4	1.261	0.816	0.004	0.001
4	JP4	0.974	1.294	0.005	0.001
	AVG	0.896	0.907	0.003	0.003
			JT8D		
1	JP4	0.455	0.132	0.003	0.004
*2	JP4	0.347	0.085	0.002	0.003
3	JP5	0.461	0.041	0.004	0.004
	AVG	0.421	0.086	0.003	0.004
			JT9D		
1	JP4	1.134	0.458	0.054	0.012
2	JP4	0.739	0.669	0.003	0.003
3	JP5	0.838	0.262	0.002	0.003
	AVG	0.903	0.463	0.019	0.006

Analysis of the data indicates that the average amount of pollutant emission during a cold start varies from about 0.5 to 1.8 pounds, depending upon the engine model. The JT3D engine was the highest producer of pollutants during starts of the three engines tested. Carbon monoxide (CO) was produced in the greatest amount during a start. The traces indicated

*Plugged Pressurizing and Dump (P&D) Valve that, following ignition, the levels of carbon monoxide and hydrocarbons rise sharply to a peak level that is 1.2 to 3 times the steady state idle value. For the JT3D engine, which has the highest steady state idle value of CO and THC of the three engines tested, the overshoot was only 20 to 40 percent above the steady state idle level. By comparison the JT9D engine, which has a low steady state idle CO and THC emission level, had a peak level which was three times higher than the steady state idle level. This peak level persisted for about 45 to 60 seconds even though the engine rotor speed stabilized at the idle level within 15 seconds after start initiation. In calculating the total pounds of pollutant emitted during a start, the start time was defined by the time required to reach steady state emission levels rather than rotor acceleration time.

b. Hot Starts

The results of the analysis of hot start data for the engine models tested is shown in the table below:

HOT START ANALYSIS RESULTS

Start	Fuel Type	CO Lbs	THC Lbs	NO Lbs	NO_2 Lbs
			JT3D		
1	JP4	0.775	1.219	0.001	0.001
2	JP4	0.998	0.579	0.002	0.001
3	JP5	1.000	0.953	0.002	0.000
4	JP5	0.931	0.932	0.004	0.001
	AVG	0.926	0.921	0.002	0.001
			JT8D		
1	JP4	0.550	0.131	0.002	0.029
*2	JP4	0.445	–	0.033	0.003
3	JP5	0.335	0.090	0.001	0.001
	AVG	0.443	0.110	0.012	0.011
			JT9D		
1	JP4	0.830	0.279	0.002	0.003

Hot starts produced about the same pollutant emission amounts as cold starts. The shape of the emission versus time traces indicate no particular differences between hot and cold starts.

c. Accelerations and Decelerations

The results of the analysis of accelerations and decelerations for the engine models tested is shown in the table below:

*Plugged P&D Valve

ACCELERATION AND DECELERATION ANALYSIS RESULTS

Run	Fuel Type	CO Lbs	THC Lbs	NO Lbs	NO_2 Lbs
JT3D ACCELERATIONS					
1	JP4	1.437	0.713	0.323	0.020
2	JP4	1.204	1.146	0.462	0.020
3	JP5	2.349	1.851	0.482	0.006
4	JP5	1.598	0.938	0.543	0.068
	AVG	1.647	1.162	0.452	0.028
JT3D DECELERATIONS					
1	JP4	2.849	0.509	0.173	0.011
2	JP4	1.237	0.648	0.172	0.002
3	JP5	3.095	2.563	0.200	0.022
4	JP5	2.876	2.249	0.347	0.006
	AVG	2.514	1.492	0.223	0.008
JT8D ACCELERATION					
1	JP4	0.085	0.012	0.013	0.018
2	JP4	0.904	0.014	0.141	0.320
3	JP5	0.103	0.016	0.149	0.029
	AVG	0.364	0.014	0.101	0.122
JT8D DECELERATION					
1	JP4	0.113	0.018	0.228	0.036
2	JP4	0.128	0.023	0.130	0.003
3	JP5	0.198	0.021	0.101	0.003
	AVG	0.146	0.021	0.153	0.014
JT9D ACCELERATION					
1	JP4	0.671	0.159	0.599	0.044
2	JP4	0.849	0.124	1.468	0.421
3	JP5	0.913	0.093	1.057	0.089
	AVG	0.811	0.125	1.041	0.185
JT9D DECELERATION					
1	JP4	2.849	0.509	0.173	0.011
2	JP4	1.237	0.648	0.172	0.002
3	JP5	1.023	0.242	0.400	0.049
	AVG	1.703	0.466	0.248	0.021

During accelerations as well as decelerations between idle and takeoff power, the emission traces were smooth and without discontinuities, suggesting that the transient emission levels are very close to corresponding steady state levels. No overshoots were noted on accelerations.

A deceleration takes 5 to 15 seconds longer to complete from an emissions standpoint than from an engine standpoint because of the slow rise of CO and THC to their steady state idle values. The NO and NO_2 traces decrease smoothly to their idle values during the deceleration.

d. Shutdowns

The results of the analysis of shutdowns for the engine models tested is shown in the table below:

SHUTDOWN ANALYSIS RESULTS

Shutdown	Fuel Type	CO Lbs	THC Lbs	NO Lbs	NO_2 Lbs
JT3D					
1	JP4	0.090	0.039	0.000	0.001
2	JP4	0.090	0.028	0.000	0.001
3	JP4	0.088	0.040	0.001	0.000
4	JP4	0.104	0.042	0.001	0.001
5	JP5	0.127	0.162	0.001	0.001
6	JP5	0.064	0.166	0.001	–
7	JP5	0.137	0.001	0.001	0.000
8	JP5	0.133	0.056	0.000	0.000
	AVG	0.104	0.067	<0.001	<0.001
JT8D					
1	JP4	0.058	0.005	0.014	0.002
2	JP4	0.060	0.083	0.004	0.003
*3	JP4	0.111	0.026	0.005	0.003
*4	JP4	0.062	0.432	0.006	0.003
5	JP5	0.052	0.109	0.005	0.001
6	JP5	0.038	0.039	0.002	0.001
	AVG	0.063	0.116	0.006	0.002
JT9D					
1	JP4	0.083	–	0.002	0.000
2	JP4	0.067	0.575	0.003	0.002
3	JP4	0.073	2.390	0.002	0.003
4	JP4	0.085	0.639	0.003	0.002
	AVG	0.077	0.901	0.002	0.002

*Plugged P&D Valve

The shutdown of an aircraft gas turbine engine is accomplished by simply turning off the fuel. The emission traces of THC for the JT8D and JT9D, after fuel cutoff, increased briefly to several times the steady state idle value before decaying zero. This increase was not noted for the JT3D engine. The CO, NO, and NO_2 traces did not increase for any of the three engine models. The rise could have been caused by fuel draining from the manifold after flameout.

D. SAMPLING PROBLEMS

The use of a multipoint sampling rake for the measurement of emissions from turbofan gas turbine engine exhausts is a distinct improvement over the single point probe technique used previously. When used to sample exhaust emissions for engines having separate discharge ducts for fan and gas generator (core) engine airflows, the multipoint rake can provide an average emission value close to the true average emission level of the engine being tested. For engines which utilize a common tailpipe for the discharge of both the fan and the core engine flows, such as the JT8D engine, the rake does not appear to provide a representative average emission level. This is possibly due to the dilution of the core engine exhaust gases by the fan airstream. The amount of dilution of the core engine flow depends on the mixing occurring upstream of the tailpipe discharge plane.

A comparison was made of the multipoint rake data obtained in this program with single point probe measurements taken previously on an experimental engine having substantially the same configuration as the engine measured in this program, both using the same instrumentation. This comparison is shown in Figures 86 through 89. All four curves show the greatest discrepancy occurs at low powers with practically none occurring at the higher powers, indicating that the amount of dilution is greatest at idle and decreases as power is increased.

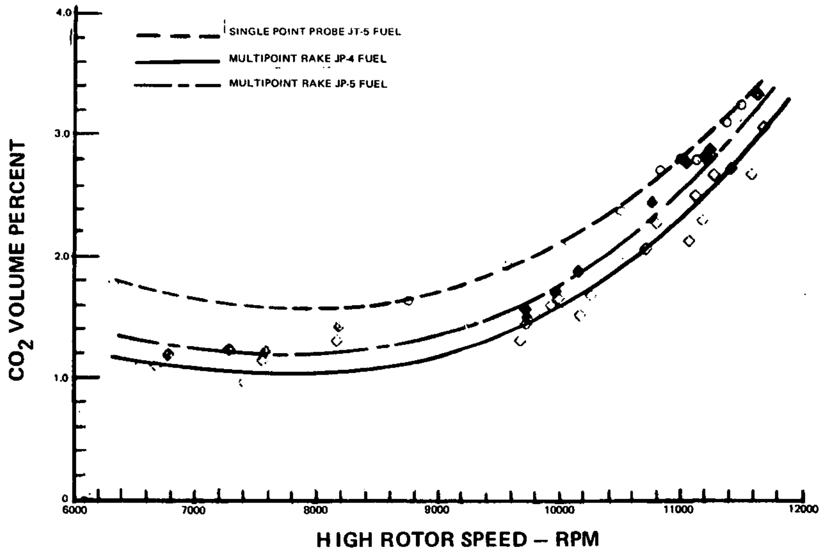


Figure 86 Carbon Dioxide as Recorded By Multipoint and Single Point Probes For JT8D Engine

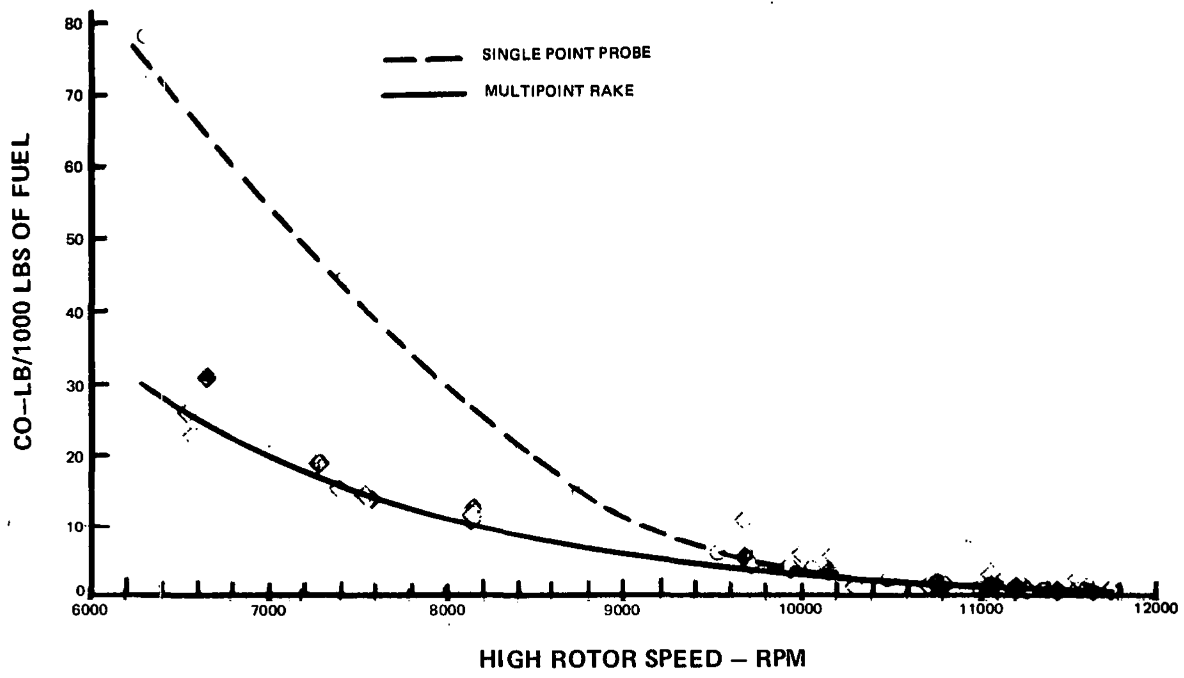


Figure 87 Carbon Monoxide as Recorded By Multipoint and Single Point Probes For JT8D Engine

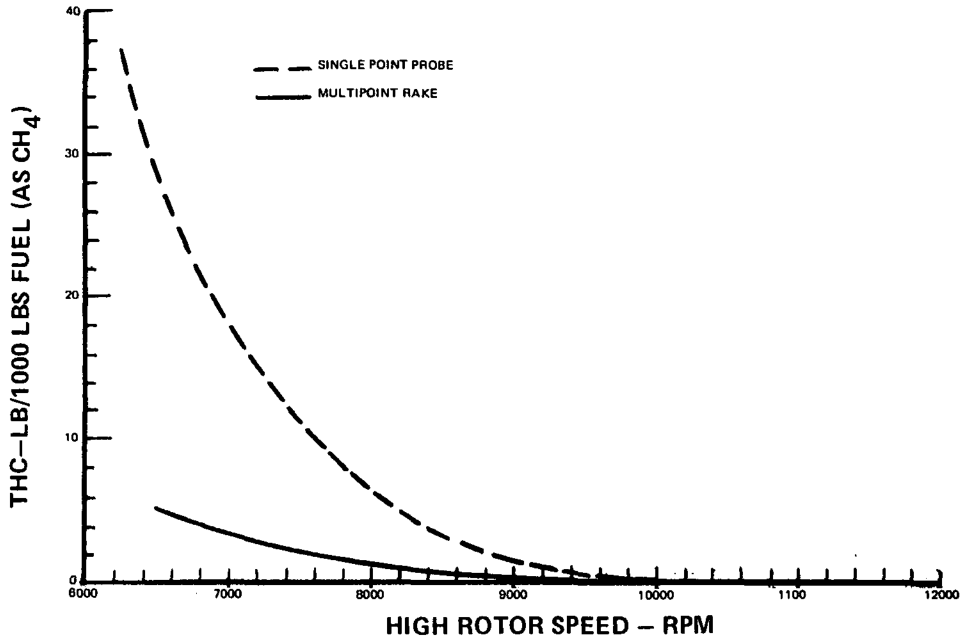


Figure 88 Unburned and Partially Burned Hydrocarbons as Recorded By Multipoint and Single Point Probes For JT8D Engine

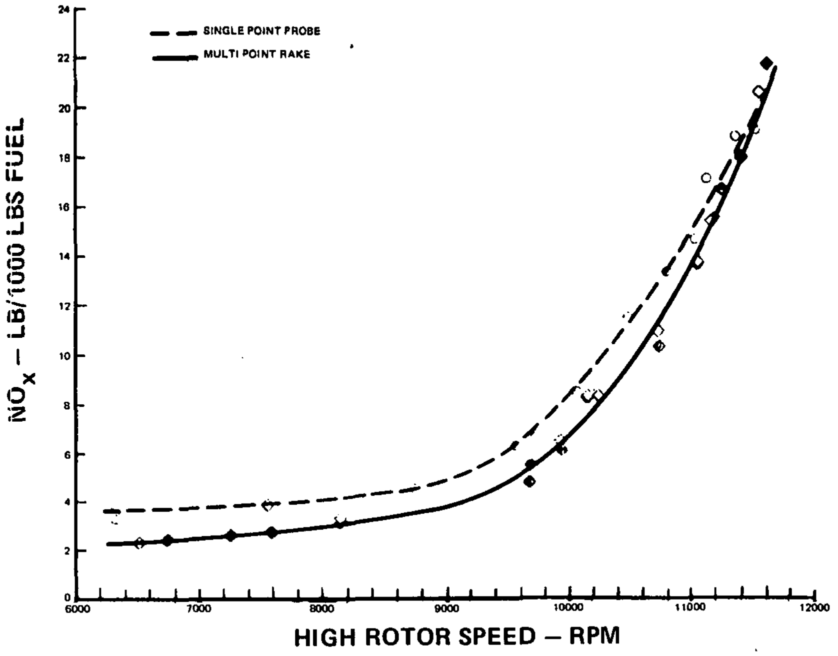


Figure 89 Oxides of Nitrogen as Recorded By Multipoint and Single Point Probes For JT8D Engine

Selection of the rake sampling point locations for the JT8D engine was based on smoke traverses taken on an experimental JT8D-15 engine; a typical example is shown in Figure 90. At the time it appeared that the probe positions selected for the JT3D sampling rake would be in unmixed locations of the JT8D engine exhaust as indicated by the smoke density recorded during high power traverses of the JT8D engine tailpipe.

Unfortunately, similar traverses were not available for the low power settings which probably would have indicated the greater mixing occuring at the lower power settings.

It is possible then that, for the JT8D engine, the emission values recorded by the multipoint sampling rake for most of the operating range are low because of fan air dilution. Most affected are the values of CO and THC at idle power. Attempts were made to estimate the dilution effect by a carbon balance equation using the measured CO and CO_2 levels. For the lowest RPM condition shown in Figure 88, the carbon balance equation indicates the level of THC measured should be increased by a factor of 1.61. Multiplying the measured THC value, 0.0052 pounds/pound of fuel, by this factor results in 0.0084 pounds/pound fuel which is considerably below the 0.027 pounds/pound of fuel level indicated by emission testing with a single point probe.

There is considerable evidence that at idle power, where gradients of CO and THC level are steep, the emission level indicated by a single point probe can be considerably in error. Testing at P&WA for the development of a reduced smoke and hydrocarbon burner has shown that the single point probe cannot be relied on to give a representative emission level for the evaluation of burner changes designed to effect THC reduction. It was found necessary to use

38 point traverses behind the core engine tailpipe to accurately assess emission level changes affected by modifications to the combustor design. Inspection of the results of one of these traverse runs, Figure 91, indicates the extreme difficulty of locating a single point probe in an area which represents an average emission level. This difficulty is compounded when trying to obtain a representative single point emission level from a mixed flow tailpipe engine such as the JT8D.

Testing conducted on the JT3D engine, however, is indicating a close correlation between the emission level indicated by a sample taken from the engine P_{T7} pressure probes and the arithmatical average of the tailpipe traverse. To determine whether this relationship is also valid for the JT8D engine would require testing of the JT8D engine with a special tailpipe configuration which separates the fan and core engine exhaust streams. A series of traverse tests at the exit of the core engine tailpipe at various engine power settings would be required for comparison with emission readings taken with the P_{T7} probes. This method is probably the only way of determining representative emission values for the JT8D engine, particularly at the low power settings.

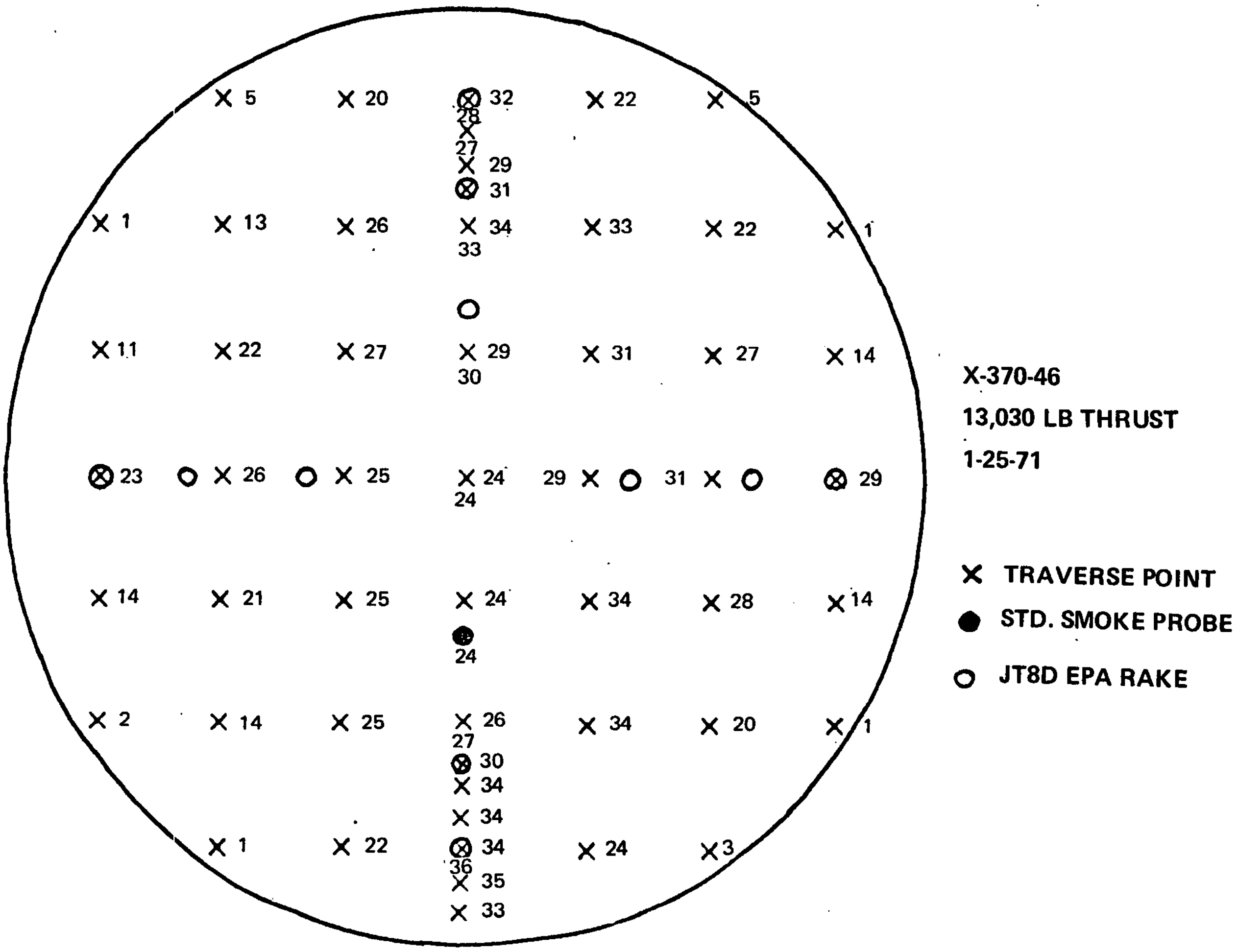
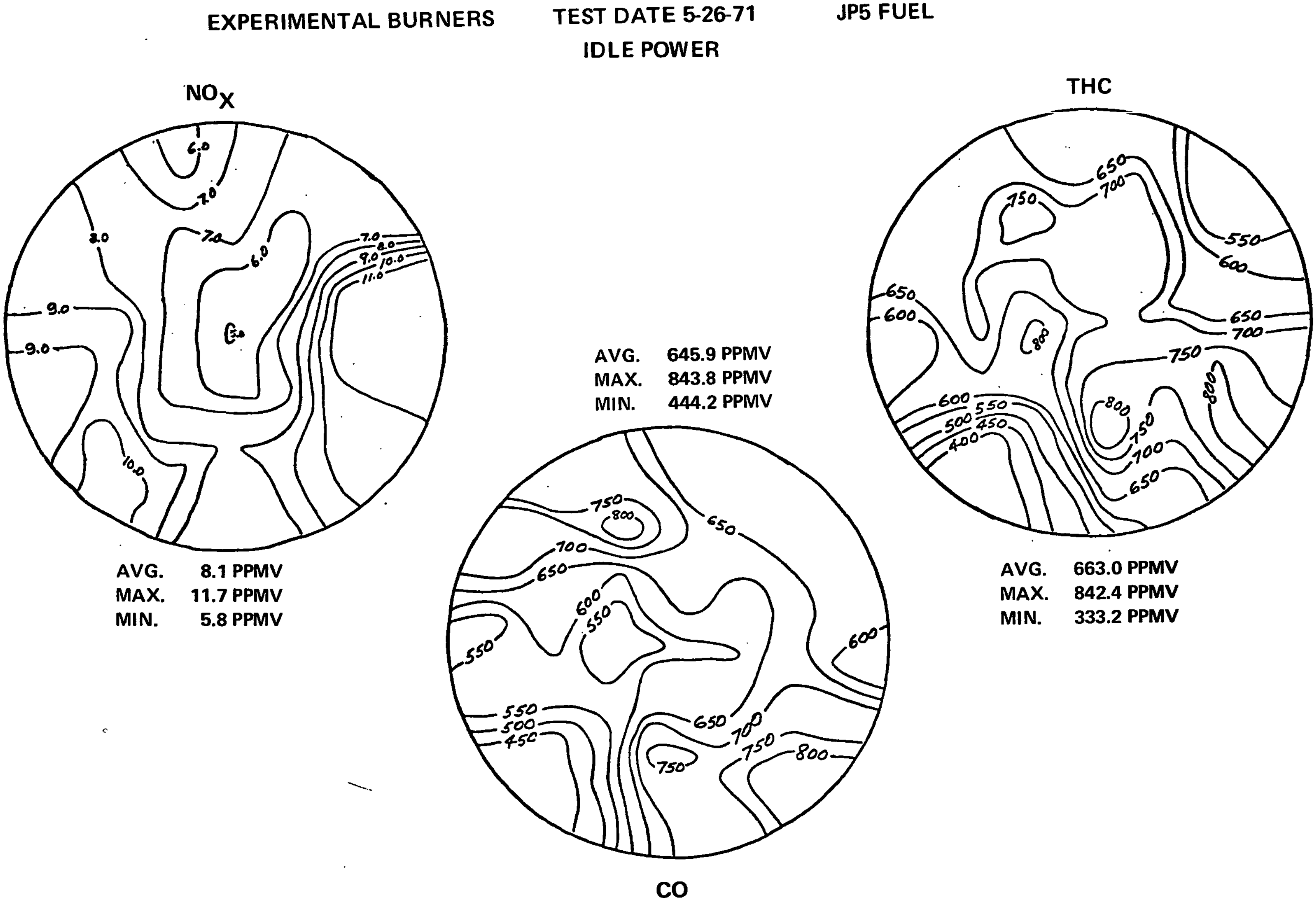


Figure 90 JT8D Tail Pipe Traverse VBSI Smoke Numbers



EXPERIMENTAL BURNERS **TEST DATE 5-26-71** **JP5 FUEL**
IDLE POWER

NO$_X$

AVG. 8.1 PPMV
MAX. 11.7 PPMV
MIN. 5.8 PPMV

CO

AVG. 645.9 PPMV
MAX. 843.8 PPMV
MIN. 444.2 PPMV

THC

AVG. 663.0 PPMV
MAX. 842.4 PPMV
MIN. 333.2 PPMV

Figure 91 JT3D Experimental Engine X-315-44 Tail Pipe Traverse

When using mass emission level computation methods that are sensitive to sample dilution by air not involved in the combustion process, special precautions must be taken to account for all possible dilution sources. This is especially true in the determination of the mass emission rates from engines which have large amounts of cooling airflow to provide for the cooling of the blades and vanes which are subjected to high gas temperatures. It was realized during the course of this program, that the fuel/air ratio existing in the plane of the tail pipe (station 7) should be used in converting the measured PPMV to the desired pounds per pound or pounds per hour for the JT9D engine instead of the usual burner fuel/air ratio (station 5). This was necessary because a significant quantity of cooling air is injected between the burner exit and the tail pipe plane where the emissions are measured, thus adding dilution which must be accounted for in the mass conversion. Since this cooling airflow is calculated, rather than directly measured, the necessary introduction of this airflow may introduce additional error into the data, over the above that which can be attributed to the calculation of the primary airflow (fuel/air ratio) of a turbofan engine.

V. APPENDICES

APPENDIX A
REGRESSION ANALYSIS

1. Purpose

Regression Analysis was the major analytical method used to reduce the gaseous emission results. It is the purpose of this appendix to give a brief general discussion of the regression analysis method used in the data reduction for this program.

2. Introduction

Regression, which concerns itself with the fitting of a line through data, and correlation, which is a measure of how well one variable is related to another, refer to an analysis procedure intuitively used by every analyst who plots data and, by eye, draws a curve through the points. He "fits" an average response line to the data.

While the "eye fit" might be satisfactory in some cases, it is far too subjective in general for engine pressure ratio to engine pressure ratio (EPR), thrust to thrust, etc. level change comparisons. Regression analysis is a technique whereby the best line is mathematically determined from the sample data.

3. Functional Relationship

When a unique relationship exists between two variables Y (e.g. NO_X) and X (e.g. EPR) they are said to be functionally related. If the exact relationship is not known it can be approximated mathematically over a range of values by obtaining pairs of X and Y values in this range. A most important consideration is the choice of the functional relationship which is to be used as the approximation. This can be done in essentially two ways. These are:

(1) Theoretical knowledge of the type of relationship.

(2) Empirical examination of a scatter diagram or plot of the data.

The first method is to be preferred as it is naturally quite useful to have prior knowledge of the form of the relationship between two variables. However, often little is known about this relationship, as is the case for correct gaseous emission predictions, and the use of a scatter diagram is quite helpful in providing ideas as to the true relationship.

4. Estimation of Regression Line and the Method of Least Squares

Suppose that two variables X and Y are thought to be linearily related, i.e., $\hat{Y} = A + BX$. A sample of n paired observations of X and Y might appear as in Figure A-1. The parameters A and B must be estimated from this data. The parameter A is the Y intercept, or that value of Y where X = O. The parameter B is the slope of the line of regression, or the amount the line rises for each unit increase of X.

The procedure perhaps most commonly used to obtain estimates a and b of A and B in a linear model is the Method of Least Squares.

The Principles of Least Squares as stated formally is as follows:

> "When a set of empirical observations is used to establish the constraints of a mathematical function, the best solution is that which reduces the sums of squares of the residual errors to a minimum."

The problem, as represented graphically in Figure A-1, is to establish a line that minimizes the squares of the distances from the observed point to the line. Mathematical derivation using this criteria leads to the following least square estimates of B and A:

$$B = \frac{n\,\Sigma XY - (\Sigma X)\ (\Sigma Y)}{n\,\Sigma X^2 - (\Sigma X)^2}$$

$$A = \frac{\Sigma Y - B\Sigma X}{n}$$

5. Partitioning the Sum of Squares - Variation About the Regression

A concept which is both meaningful and useful in the gaseous emission analysis is that of the partitioning of the total variation in the data into two parts, the variation due to regression and the variation about regression. These are sometimes called the variation explained by the regression equation and the unexplained variation, respectively. Suppose, for example, that Y_i and X_i represent any pair of observed values and that $\hat{Y}_i$ is the corresponding value calculated from $\hat{Y}_i \doteq A + B\,X_i$, then the identity

$$(Y_i - \bar{Y}) = (\hat{Y}_i - \bar{Y}) + (Y_i - \hat{Y}_i)$$

says that the deviation of Y_i from the mean $\bar{Y}$ is equal to the deviation due to regression plus the deviation about regression. This can be seen graphically from Figure A-2.

If both sides of the identity are squared and summed over all n values, the following important result is obtained.

$$\underbrace{\sum (Y_i - \bar{Y})^2}_{\text{total sum of squares}} = \underbrace{\sum (\hat{Y}_i - \bar{Y})^2}_{\text{sum of squares due to regression}} + \underbrace{\sum (Y_i - \hat{Y}_i)^2}_{\text{sum of squares about regression}}$$

This identity states that the total sum of squares, $\sum(Y_i - \bar{Y})^2$,
is equal to the sum of squares due to regression, $\sum(\hat{Y}_i - \bar{Y})^2$,
plus the sum of squares about regression, $\sum(Y_i - \hat{Y}_i)^2$.

In the gaseous emissions analysis, the sum of squares due to regression quantitizes the amount of variability which can be relatable to the gas turbine parameters under investigation. The sum of squares about regression is that of the data variability which can be associated with experimental, error of the program, perhaps due to engine-to-engine and within engine instrumentation repeatability.

6. Correlation Coefficient

Occasionally the terms "Regression" and "Correlation" are confused with one another. Although the subjects are related, the distinction between the two should be made clear. Regression concerns itself with the fitting of a preconceived (i.e., linear, curvilinear, etc.) line through data. Correlation deals with the degree of relationship between two variables. Correlation does not require that two variables be designated as independent and dependent since no cause-and-effect relationship can be implied.

The relationship between regression and correlation is illustrated in Figure A-3. The diagram shows the line of regression, a line representing the average of all the Y's, and an actual Y value. The quantity $\sum(Y_i - \bar{Y})^2$ is the sum of squares of deviations of the Y values from the mean of the Y's. The quantity $\sum(\hat{Y}_i - \bar{Y})^2$ is the sum of squares of deviations between the points on the line of regression and the mean of the Y values. The following relationship holds:

$$r^2 = \frac{\sum(\hat{Y}_i - Y)^2}{\sum(Y_i - \bar{Y})^2} = \frac{\text{explained variation}}{\text{total variation}}$$

It is thus shown that the square of the correlation coefficient is the fraction of the total sum of squares in Y that is accounted for by the regression line. A correlation coefficient of $r = 0.5$ means that only 25 percent of the variation in Y is accounted for by the regression line. The other 75 percent is accounted for by other factors.

The correlation coefficient which describes the degree of association between the two variables is constructed in such a way that it is bounded by the interval $-1 \leq r \leq +1$. The sign indicates whether the slope, b, of the regression line is positive or negative. At the boundaries of the interval for r we have the case of perfect correlation: $r = +1$ (perfect correlation with positive slope), $r = -1$ (perfect correlation with negative slope). In these instances all the sample points would lie exactly on the regression line. When there is no correlation between the variables whatsoever, $r = 0$ (Figure A-4).

7. Statistical Significance of Correlation

Has sufficient data been gathered to show a statistically significant correlation?

One can pre-select the minimum assurance he would like in concluding that the real population $r > 0.00$; meaning that there is some real association of y with x; not a chance sample result from a true r of 0.00, which just looks like there is an association.

Table A-I of sample r values for each number of plotted points furnishes the needed reference numbers. A level of 95 percent confidence is typically used throughout statistical literature and is also used here as good practice. The tabulated r for n points has to be exceeded by our r calculated from the n data points in order for us to be at least 0.95 percent sure we have a correlation coefficient greater than zero. The question of the minimum number of points necessary to establish a valid plot is accordingly answered by such a significance testing procedure.

8. Multiple Correlation and Regression

A straight line can often represent a response adequately for short ranges of the variable x. When the response over a longer range is desired, a higher order functional equation can be elected and a curvilinear regression study conducted. When the relationship of more than one independent variable (x, u, w, etc.) with y is being studied as is the case for the gaseous emission analysis, a multiple regression analysis is conducted.

9. Multiple Regression Equation

In multiple regression we have a dependent variable Y which is a function of j independent variables x of the form

$$Y = A + B_1 X_1 + B_2 X_2 + \ldots + B_j X_j$$

It is important to note that the model expressed is linear so that the method of least squares is applicable.

The expression to be minimized is

$$Q = \Sigma \, (Y - A - B_1 X_1 - B_2 X_2 - \ldots - B_j X_j)^2$$

Therefore by differentiating Q with respect to A, $B_1, \ldots, B_j$, successively, and equating the resulting derivatives to zero, a set of n simultaneous equations with j unknowns is obtained. These equations are called normal equations and are used to estimate the parameters A, $B_1, \ldots, B_j$.

10. Multiple Correlation Coefficient

In simple correlation a correlation coefficient r expressed the degree of linear relationship between two variables. In multiple correlation a coefficient of multiple correlation expresses the degree of linear relationship between a variable Y and a group of variables $X_1, X_2, \ldots,$ X_j. The coefficient of multiple correlation is denoted by the symbol $R_{Y\,.\,1,2,\ldots,j}$, the subscripts indicating the variables involved. This coefficient is always positive or zero and may have any value between 0 and 1, inclusive. The coefficient of multiple correlation may be defined as the square root of the fraction of the total sum of squares in Y accounted for by the regression equation. That is

$$R_{Y.\,1,2,\ldots,j} = \sqrt{\frac{\Sigma\,(\hat{Y_i} - \bar{Y})^{2}}{\Sigma\,(Y_i - \bar{Y})^2}}$$

There are some rather obvious limitations to the usefulness of this statistic. For instance, each new independent variable added in sequence tends to increase the coefficient. This would lead to the belief that the more terms added the better the equation. However, there is a point of diminishing returns. A decision should be made each time a new independent variable is added about its usefulness in predicting exhaust emissions based on some apriori rule. This is effectively done by use of additional statistical decision rules, namely the F-ratio and/or t-tests. These decision rules were employed in the exhaust emissions analysis. However, a complete discussion of these decision techniques are beyond the scope of this Appendix. The reader is, however, referred to the following text if a better understanding is desired.

Statistical Methods in Research and Production, Edited by O. L. Davies, Hafner Publishing Company, 1958 edition.

TABLE A-I

THE CORRELATION COEFFICIENT

Values of the Correlation Coefficient for Different Levels of Significance

Confidence Level

j	.90	.95	.98	.99	.999	j	.90	.95	.98	.99	.999
1	.98769	.99692	.999507	.999877	.9999988	16	.4000	.4683	.5425	.5897	.7084
2	.90000	.95000	.98000	.990000	.99900	17	.3887	.4555	.5285	.5751	.6982
3	.8054	.8783	.93433	.95873	.99116	18	.3783	.4438	.5155	.5614	.6787
4	.7293	.8114	.8822	.91720	.97406	19	.3687	.4329	.5034	.5487	.6652
5	.6694	.7545	.8329	.8745	.95074	20	.3598	.4227	.4921	.5368	.6524
6	.6215	.7067	.7887	.8343	.92493	25	.3233	.3809	.4451	.4869	.5974
7	.5822	.6664	.7498	.7977	.8982	30	.2960	.3494	.4093	.4487	.5541
8	.5494	.6319	.7155	.7646	.8721	35	.2746	.3246	.3810	.4182	.5189
9	.5214	.6021	.6851	.7348	.8471	40	.2573	.3044	.3578	.3932	.4896
10	.4973	.5760	.6581	.7079	.8233	45	.2428	.2875	.3384	.3721	.4648
11	.4762	.5529	.6339	.6835	.8010	50	.2306	.2732	.3218	.3541	.4433
12	.4575	.5324	.6120	.6614	.7800	60	.2108	.2500	.2948	.3248	.4078
13	.4409	.5139	.5923	.6411	.7603	70	.1954	.2319	.2737	.3017	.3799
14	.4259	.4973	.5742	.6226	.7420	80	.1829	.2172	.2565	.2830	.3568
15	.4124	.4821	.5577	.6055	.7246	90	.1726	.2050	.2422	.2673	.3375
						100	.1638	.1946	.2301	.2540	.3211

* The table should be entered with j = N - (no. parameters contained in equation) where N = no. of observations or data points.

For the linear case, $\hat{Y} = A + BX$, the table is entered where j = N - 2

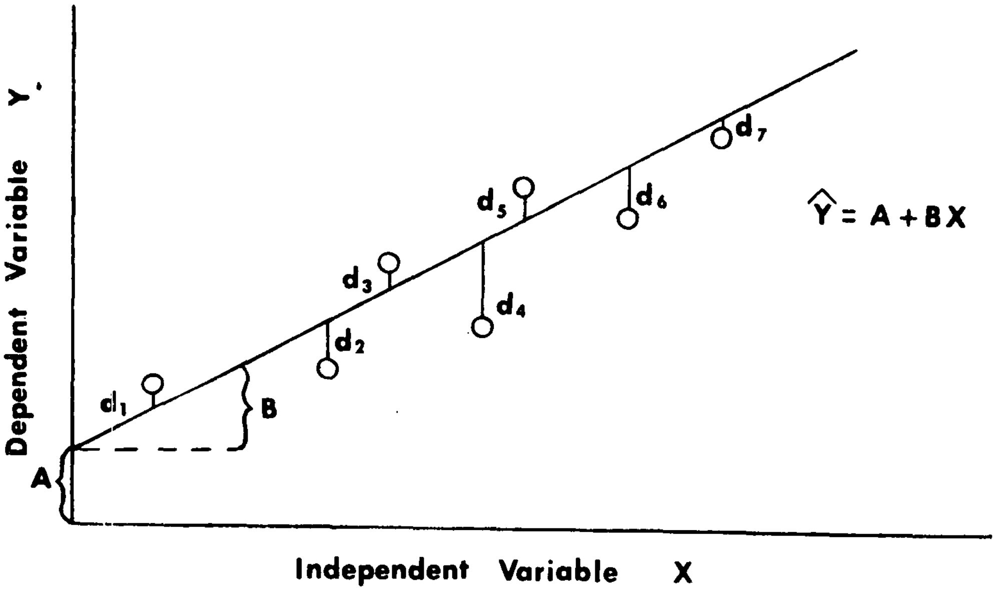


Figure A-1

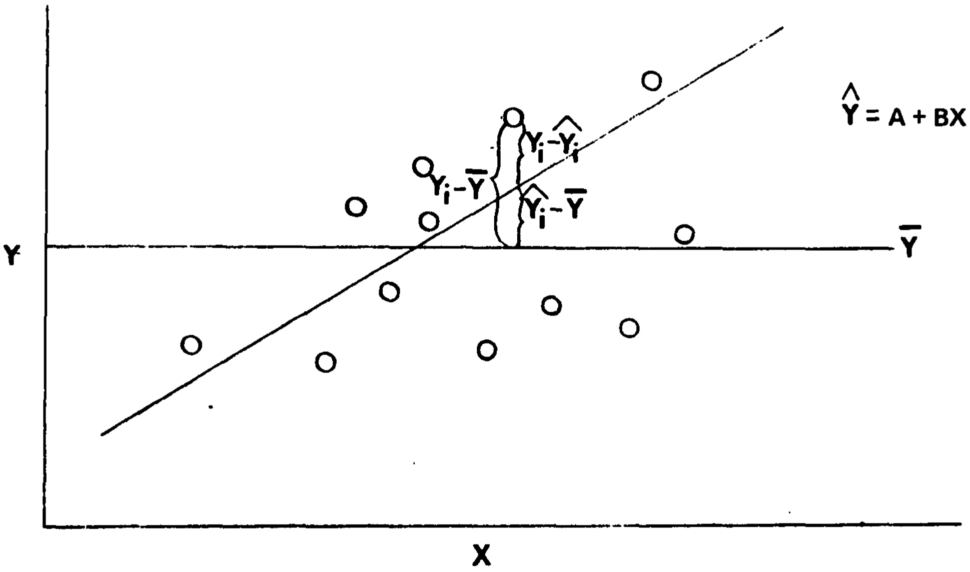


Figure A-2

$$\text{Correlation coefficient} = \sqrt{\frac{\Sigma(\hat{Y}_i - \bar{Y})^2}{\Sigma(Y_i - \bar{Y})^2}}$$

$$\text{Regression line} \quad \hat{Y} = A + BX$$

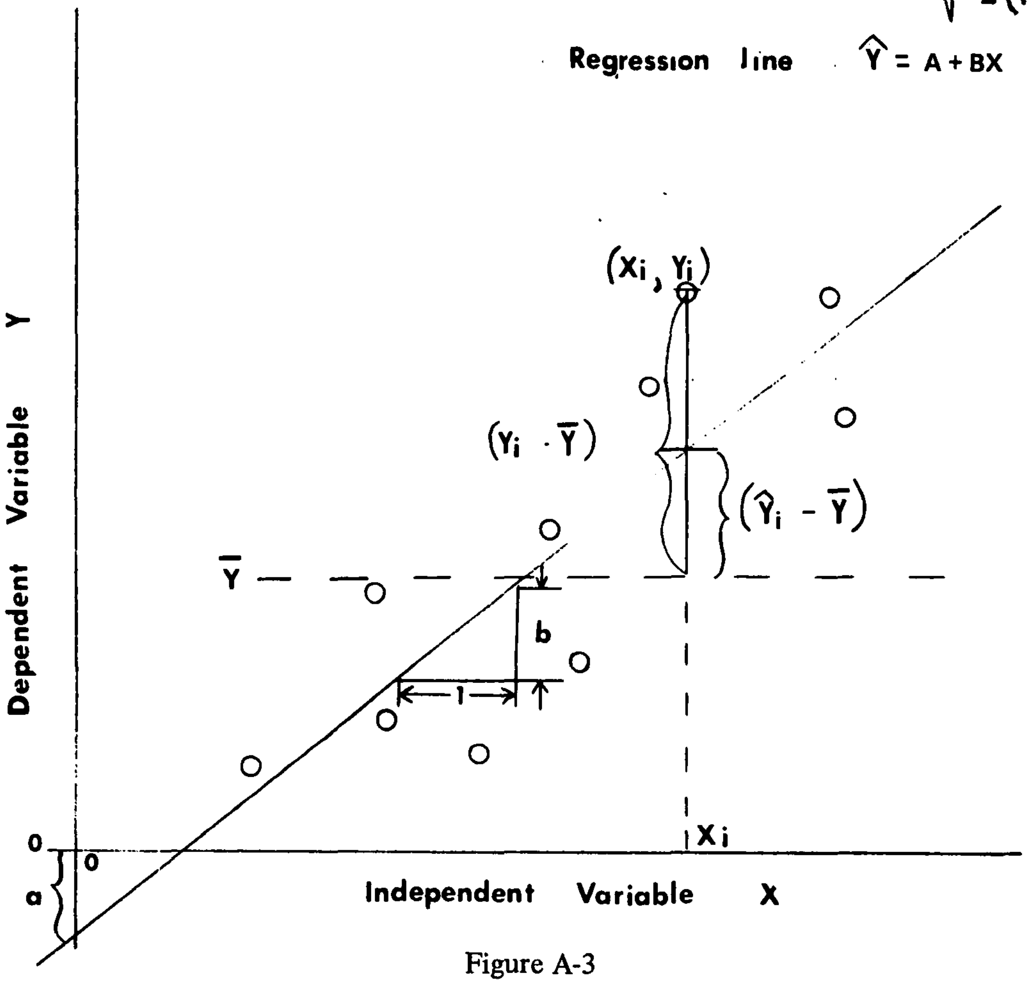


Figure A-3

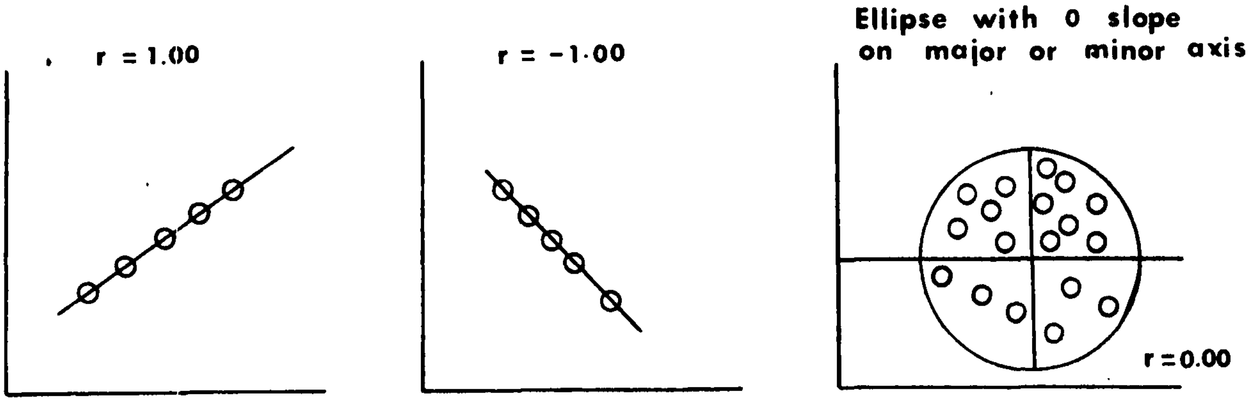


Figure A-4

APPENDIX B

FUEL ANALYSIS

Part I – Principle Characteristics of the Fuel for Representative Engine Tests.

Engine Type and Serial Number	Test Date and Test Type	Sp. Gr.	Heat of Combustion	H/C Ratio	Sulfur % by Weight	Ash % by Weight
JT8D, X-370-47	6-23; JP4	.7571	18755	2.02	.0116	<.0020
JT8D, X-370-47	6-23; JP4	.7567	18720	–	–	–
JT8D, X-370-47	6-24; JP5	.8241	18500	1.92	.2750	<.0020
JT8D, X-370-47	6-24; JP5	–	–	1.90	.2528	–
JT3D, X-315-44	6-29; JP4	.7587	18790	2.01	.0116	–
JT3D, X-315-44	6-30; JP5	.8260	18470	1.90	.2766	<.0010
JT3D, X-315-44	6-30; JP5	.8251	18490	–	–	–
JT9D, X-495-15	7-7; JP4	.7571	18750	2.05	.0117	<.0013
JT9D, X-495-15	7-7; JP4	.7567	18740	–	–	–
JT9D, X-495-15	7-8; JP5	–	–	1.88	.2829	<.0010
JT9D, X-495-15	7-8; JP5	–	–	1.89	.2938	–
JT8D, P-674552	7-8; JP4	.7579*	18880*	2.09	.0116	<.0010

* NOTE: These two values from Dept. 815 sample taken 7/6/71.

JT8D, P-665708	7-16; JP4	.7559	18730	2.06	.0223	<.0010
JT3D, P-668817	7-21; JP4	.7559	18800	2.04	.0144	<.0010
JT8D, P-674550	7-21; JP4	.7555	18815	2.06	.0106	<.0010
JT3D, P-669797	7-22; JP4	.7555	18810	2.03	.0110	<.0010
JT3D, P-668815	7-23; JP4	.7559	18785	2.11	.0106	<.0010
JT9D, P-685605	7-28; JP4	.7555**	18720*	2.08	.0100	<.0010

** These two values taken from a sample taken from nearby P-6 stand, 7/26/71.

JT9D, P-663071	7-29; JP4	.7563	18860	–	–	–

(NOTE: The above values taken from a fuel sample taken 7/30/71.)

JT8D, P-668821	8-18; JP4	–	18815	–	–	–

(NOTE: The above value taken from a Dept. 825 sample taken 8/16/71.)

JT3D, P-668799	9-7; JP4					

Part 2 Percentage Composition of Fuel Ash for Representative Engine Tests.

Engine Type, Fuel, Type, and Serial No.	Fe	Si	B	Al	Mg	Pb	Cr	Na	Ca	Nb	Ni	Mo	Zn	Ti	Mn	Cu	Sn	Ir	V
JT8D, X-370-47, JP4	9	5	0	3	.7	20	.2	2.5	1.5	1.7	.4	.1	0	.2	.2	.08	.4	0	.4
JT8D, X-370-47, JP5	12	3	0	3	.1	2.5	1.5	<5	9	.7	1	.2	0	.1	.1	.5	2.5	0	<.01
JT8D, X-370-47, JP5	9	12	0	7	.3	.5	.5	<5	6	1	.4	4	0	.2	.2	3	2.5	0	<.1
JT3D, X-315-44, JP4	2.5	3.5	.3	6.5	.1	2	1.2	7	2.5	0	15	4	1	0	.1	2	1.5	0	<.1
JT3D, X-315-44, JP5	14	9	.5	3	1	1	1	4	5	<2	1	1	<1	.3	.3	.3	6	<.2	<.1
JT9D, X-495-15, JP4	3.5	4	.2	2	.7	5	1	11	0	1	10	1	1.6	.05	.2	.5	3	.1	.05
JT9D, X-495-15, JP5	3	5	1.5	4	3	.5	1	6	4	3	10	.3	<.1	.4	.5	2	7	.2	.1
JT9D, X-495-15, JP5	7.5	7	1	3	1	2	1	5	8	1	3	.6	<.1	.8	.6	1	7	<.2	<.1
JT8D, P-674552, JP4	10	7	1	2	1	3.5	1	7	7	.5	2	.3	<1	.1	.3	1	7	<.2	<.1
JT8D, P-665708, JP4	15	5	0	2	1	8	.8	7	3	2	1.5	.5	0	0	.3	.5	1	0	0

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST   6/29/71

ENGINE NUMBER          - X-315-44

ENGINE TYPE            - JT3D

TEST STAND             - X-  21

BURNER CONFIGURATION - B/M

FUEL                   - JP4C


   POINT NUMBER                       1          2          3          4          5
E  TIME                        11: 1:54   11:30:14   11:39:21   11:48:12   12: 3:24
X  F/A                          0.00836    0.00833    0.00977    0.01354    0.01642
H  WF(LB/HR)                     1088.0     1540.0     3636.0     7882.0    11384.0
A  HIGH ROTOR SPEED(RPM)          5450.      6861.      8545.      9575.     10095.
U  THRUST(LBS)                     910.      1940.      6600.     14550.     19500.
S  TT2(DEG F)                      68.0       68.0       68.0       70.0       70.0
T
   N2(%V BY DIFFERENCE)           78.65      79.14      79.03      78.64      77.76
   O2(%V)                         18.22      17.75      17.23      16.20      15.43
   H2O(%V) CALCULATED              1.48       1.51       1.84       2.55       3.37

   NO2(PPMV)                        6.4        8.6        6.9        2.9       11.0
C  NO(PPMV)                         0.0        7.2       27.9       80.5      144.2
O  NOX(LB/LB FUEL AS NO2)        0.0012     0.0030     0.0056     0.0098     0.0150
N  NOX(LB/HR AS NO2)                1.3        4.6       20.5       77.0      170.7
S
T  CO2(%V)                         1.44       1.51       1.88       2.60       3.42
I  CO2(LB/LB FUEL)                2.621      2.751      2.925      2.917      3.160
T  CO2(LB/HR)                     2852.      4237.     10636.     22989.     35974.
U
E  CO(PPMV)                       859.6      493.5      102.2       18.2       11.6
N  CO(LB/LB FUEL)                0.0993     0.0572     0.0101     0.0013     0.0007
T  CO(LB/HR)                      108.0       88.1       36.7       10.2        7.7
S
   THC(PPMV AS CH4)              1227.2      333.1       16.9       11.6        1.2
   THC(LB/LB FUEL)               0.0810     0.0221     0.0010     0.0005     0.0000
   THC(LB/HR)                      88.1       34.0        3.5        3.7        0.5


                  *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/29/71

ENGINE NUMBER - X-315-44

ENGINE TYPE - JT3D

TEST STAND - X- 21

BURNER CONFIGURATION - B/M

FUEL - JP4C

	POINT NUMBER	6	7	8	9	10
E	TIME	12:19:37	15:16:39	15:42:25	15:52:30	16: 2:27
X	F/A	0.01692	0.01585	0.01144	0.00800	0.00783
H	WF(LB/HR)	12070.0	10604.0	5522.0	1720.0	1280.0
A	HIGH ROTOR SPEED(RPM)	10210.	10008.	9150.	7234.	6260.
U	THRUST(LBS)	20300.	18475.	10350.	2450.	1525.
S	TT2(DEG F)	70.0	72.0	72.0	72.0	74.0
T						
	N2(%V BY DIFFERENCE)	78.03	77.55	77.65	78.12	77.96
	O2(%V)	15.09	16.39	17.67	18.62	18.97
	H2O(%V) CALCULATED	3.41	3.00	2.31	1.59	1.48
	NO2(PPMV)	8.9	15.5	8.3	11.1	8.6
C	NO(PPMV)	161.4	11.50	45.0	3.6	3.3
C	NOX(LB/LB FUEL AS NO2)	0.0160	.0131	0.0074	0.0029	0.0024
N	NOX(LB/HR AS NO2)	192.8	139.0	40.8	5.0	3.1
S						
T	CO2(%V)	3.46	3.05	2.36	1.60	1.46
I	CO2(LB/LB FUEL)	3.100	2.924	3.132	3.037	2.835
T	CO2(LB/HR)	37418.	31003.	17295.	5223.	3629.
U						
E	CO(PPMV)	10.5	11.9	38.4	386.5	685.7
N	CO(LB/LB FUEL)	0.0006	0.0007	0.0032	0.0466	0.0846
T	CO(LB/HR)	7.2	7.7	17.9	80.2	108.2
S						
	THC(PPMV AS CH4)	1.0	1.3	2.4	194.2	649.3
	THC(LB/LB FUEL)	0.0000	0.0000	0.0001	0.0134	0.0458
	THC(LB/HR)	0.4	0.5	0.7	23.0	58.6

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/29/71

ENGINE NUMBER - X-315-44

ENGINE TYPE - JT3D

TEST STAND - X- 21

BURNER CONFIGURATION - B/M

FUEL - JP4C

	POINT NUMBER	11	12	13	14	15
E	TIME	17: 2:55	17:13:10	17:21:50	17:31:16	17:52:51
X	F/A	0.00821	0.00815	0.00973	0.01393	0.01665
H	WF(LB/HR)	1062.0	1556.0	3604.0	8006.0	11554.0
A	HIGH ROTOR SPEED(RPM)	5433.	6902.	8582.	9627.	10152.
U	THRUST(LBS)	1000.	2050.	6500.	14525.	19550.
S	TT2(DEG F)	74.0	74.0	74.0	74.0	74.0
T						
	N2(%V BY DIFFERENCE)	77.92	77.75	77.72	77.17	76.93
	O2(%V)	18.87	19.08	18.42	17.02	16.12
	H2O(%V) CALCULATED	1.52	1.52	1.90	2.88	3.44
	NO2(PPMV)	4.2	10.0	13.0	7.9	8.0
C	NO(PPMV)	4.7	11.0	12.0	92.0	151.0
O	NOX(LB/LB FUEL AS NO2)	0.0017	0.0041	0.0041	.0114	0.0152
N	NOX(LB/HR AS NO2)	1.8	6.3	14.7	91.0	175.1
S						
T	CO2(%V)	1.47	1.57	1.95	2.93	3.49
I	CO2(LB/LB FUEL)	2.725	2.92	3.03	3.191	3.179
T	CO2(LB/HR)	2894.	4560.	10930.	25544.	36728.
U						
E	CO(PPMV)	917.3	477.0	97.0	17.1	11.3
N	CO(LB/LB FUEL)	0.1079	0.0564	0.0096	0.0012	0.0007
T	CO(LB/HR)	114.6	88.0	34.7	9.5	7.6
S						
	THC(PPMV AS CH4)	1236.8	334.0	29.4	2.6	1.9
	THC(LB/LB FUEL)	0.0831	0.0226	0.0017	0.0001	0.0001
	THC(LB/HR)	88.3	35.2	6.0	0.8	0.7

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT – MEASURED

ENGINE EMISSION ANALYSIS GROUP – (PHONE 203-565-7764)

DATE OF TEST 6/29/71

ENGINE NUMBER – X-315-44

ENGINE TYPE – JT3D

TEST STAND – X- 21

BURNER CONFIGURATION – B/M

FUEL – JP4C

	POINT NUMBER	16	17	18	19	20
EXHAUST	TIME	18:00:00	18:13:21	18:29:41	18:44:39	18:53: 6
	F/A	0.01676	0.01574	0.01157	0.00814	0.00771
	WF(LB/HR)	11772.0	10570.0	5612.0	1740.0	1262.0
	HIGH ROTOR SPEED(RPM)	10185.	10017.	9172.	7265.	6225.
	THRUST(LBS)	19900.	18450.	10450.	2500.	1480.
	TT2(DEG F)	74.0	74.0	74.0	74.0	73.0
CONSTITUENTS	N2(%V BY DIFFERENCE)	76.70	77.30	77.96	79.26	78.49
	O2(%V)	16.37	16.22	17.45	18.31	18.56
	H2O(%V) CALCULATED	3.43	3.21	2.26	1.58	1.42
	NO2(PPMV)	9.0	8.8	8.6	11.3	5.0
	NO(PPMV)	156.0	127.3	48.7	9.1	9.2
	NOX(LB/LB FUEL AS NO2)	0.0156	0.0137	0.0079	0.0040	0.0029
	NOX(LB/HR AS NO2)	183.8	144.9	44.1	6.9	3.7
	CO2(%V)	3.50	3.26	2.32	1.59	1.40
	CO2(LB/LB FUEL)	3.16	3.141	3.037	2.969	2.745
	CO2(LB/HR)	37200.	33195.	17041.	5166.	3465.
	CO(PPMV)	11.5	11.6	36.6	400.6	686.4
	CO(LB/LB FUEL)	0.0007	0.0007	0.0031	0.0475	0.0860
	CO(LB/HR)	7.8	7.5	17.1	82.7	108.5
	THC(PPMV AS CH4)	1.5	1.4	1.5	187.7	649.8
	THC(LB/LB FUEL)	0.0001	0.0000	0.0001	0.0127	0.0465
	THC(LB/HR)	0.6	0.5	0.4	22.1	58.7

* ALL DATA REPORTED WET *

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST   6/29/71

ENGINE NUMBER          - X-315-44

ENGINE TYPE            - JT3D

TEST STAND             - X-  21

BURNER CONFIGURATION - B/M

FUEL                   - JP5

    POINT NUMBER                    21          22          23          24          25
E   TIME                      20:54:38    21:10:13    21:22:24    21:23:36    21:40: 3
X   F/A                        0.00883     0.00882     0.01001     0.01400     0.01681
H   WF(LB/HR)                   1044.0      1474.0      3400.0      7414.0     10644.0
A   HIGH ROTOR SPEED(RPM)        5445.       6880.       8557.       9580.      10108.
U   THRUST(LBS)                  1000.       2050.       6550.      14550.      19500.
S   TT2(DEG F)                    71.0        71.0        71.0        69.0        69.0
T
    N2(%V BY DIFFERENCE)         78.10       78.69       78.20       77.59       76.00
    O2(%V)                       18.80       17.96       17.78       16.59       16.76
    H2O(%V) CALCULATED            1.44        1.62        1.98        2.88        3.59

    NO2(PPMV)                      1.4         5.9         9.9         5.9         5.3
C   NO(PPMV)                       7.8         4.8        21.0        72.5       136.3
O   NOX(LB/LB FUEL AS NO2)      0.0017      0.0019      0.0049      0.0089      0.0134
N   NOX(LB/HR AS NO2)              1.7         2.8        16.7        65.9       142.3
S
T   CO2(%V)                       1.39        1.62        2.02        2.93        3.63
I   CO2(LB/LB FUEL)              2.394       2.778       3.069       3.173       3.276
T   CO2(LB/HR)                   2500.       4095.      10433.      23522.      34873.
U
E   CO(PPMV)                     980.6       620.9       126.6        23.0        12.3
N   CO(LB/LB FUEL)              0.1072      0.0680      0.0122      0.0016      0.0007
T   CO(LB/HR)                    111.9       100.2        41.5        11.8         7.5
S
    THC(PPMV AS CH4)            1674.0       570.3        31.5         8.0         5.4
    THC(LB/LB FUEL)             0.1046      0.0357      0.0017      0.0003      0.0002
    THC(LB/HR)                   109.2        52.6         5.9         2.4         1.9


                  *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/29/71

ENGINE NUMBER - X-315-44

ENGINE TYPE - JT3D

TEST STAND - X- 21

BURNER CONFIGURATION - B/M

FUEL - JP5

	POINT NUMBER	26	27	28	29	30
E	TIME	21:49:24	22: 3:32	22:11: 5	22:28: 7	22:33:37
X	F/A	0.01719	0.01607	0.01180	0.00833	0.00811
H	WF(LB/HR)	11048.0	9898.0	5208.0	1624.0	1206.0
A	HIGH ROTOR SPEED(RPM)	10176.	10000.	9138.	7240.	6182.
U	THRUST(LBS)	20075.	18550.	10500.	2500.	1450.
S	TT2(DEG F)	69.0	69.0	68.0	68.0	68.0
T						
	N2(%V BY DIFFERENCE)	76.54	77.03	77.69	78.16	78.18
	O2(%V)	16.06	16.29	17.61	18.39	18.57
	H2O(%V) CALCULATED	3.67	3.31	2.32	1.68	1.54
	NO2(PPMV)	6.7	6.4	7.9	4.9	2.7
C	NO(PPMV)	150.0	118.7	41.9	10.5	7.2
O	NOX(LB/LB FUEL AS NO2)	0.0145	0.0123	0.0067	0.0029	0.0019
N	NOX(LB/HR AS NO2)	159.7	122.2	34.8	4.8	2.3
S						
T	CO2(%V)	3.71	3.36	2.37	1.69	1.51
I	CO2(LB/LB FUEL)	3.276	3.172	3.045	3.075	2.823
T	CO2(LB/HR)	36192.	31395.	15858.	4994.	3405.
U						
E	CO(PPMV)	11.6	13.4	51.8	483.3	866.7
N	CO(LB/LB FUEL)	0.0007	0.0008	0.0042	0.0560	0.1032
T	CO(LB/HR)	7.2	8.0	22.1	91.0	124.4
S						
	THC(PPMV AS CH4)	3.5	3.1	5.1	313.3	1159.8
	THC(LB/LB FUEL)	0.0001	0.0001	0.0002	0.0208	0.0789
	THC(LB/HR)	1.3	1.1	1.3	33.7	95.2

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/30/71

ENGINE NUMBER - X-315-44

ENGINE TYPE - JT3D

TEST STAND - X- 21

BURNER CONFIGURATION - B/M

FUEL - JP5

	POINT NUMBER	31	32	33	34
EXHAUST	TIME	10:30: 0	12:11:51	13:21:25	15:33:21
	F/A	0.01153	0.01691	0.01551	0.00880
	WF(LB/HR)	4740.0	10288.0	8862.0	1020.0
	HIGH ROTOR SPEED(RPM)	9085.	10145.	9955.	5440.
	THRUST(LBS)	9150.	18100.	15975.	1000.
	TT2(DEG F)	81.0	83.0	87.0	87.0
	N2(%V BY DIFFERENCE)	77.44	77.16	77.15	78.08
	O2(%V)	18.07	15.78	16.09	18.56
	H2O(%V) CALCULATED	2.21	3.50	3.36	1.57
	NO2(PPMV)	6.0	6.0	3.5	2.1
CONSTITUENTS	NO(PPMV)	37.4	134.7	107.0	9.3
	NOX(LB/LB FUEL AS NO2)	0.0060	0.0132	.0113	0.0021
	NOX(LB/HR AS NO2)	28.3	135.8	98.6	2.1
	CO2(%V)	2.27	3.55	3.40	1.57
	CO2(LB/LB FUEL)	2.981	3.182	3.327	2.710
	CO2(LB/HR)	14130.	32737.	29484.	2764.
	CO(PPMV)	63.5	12.5	14.1	466.0
	CO(LB/LB FUEL)	0.0053	0.0007	0.0009	0.0511
	CO(LB/HR)	25.2	7.4	7.8	52.1
	THC(PPMV AS CH4)	5.4	1.1	4.6	1650.0
	THC(LB/LB FUEL)	0.0003	0.0000	0.0002	0.1034
	THC(LB/HR)	1.2	0.4	1.5	105.5

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 7/ 7/71

ENGINE NUMBER - P-668816 ☐

ENGINE TYPE - JT3D

TEST STAND - P- 68

BURNER CONFIGURATION - B/M

FUEL - JP4

	POINT NUMBER	1	2	3	4	5
E	TIME	14:29:17	14:42:57	14:43: 4	14:53:14	15:11:34
X	F/A	0.00971	0.00864	0.00846	0.00907	0.01028
H	WF(LB/HR)	1017.0	1266.0	1501.0	3197.0	4659.0
A	HIGH ROTOR SPEED(RPM)	5495.	6440.	7025.	8510.	9020.
U	THRUST(LBS)	840.	1350.	1850.	5870.	8900.
S	TT2(DEG F)	85.0	87.0	87.0	87.0	87.0
T						
	N2(%V BY DIFFERENCE)	79.67	79.66	79.56	78.61	78.61
	O2(%V)	17.54	17.40	17.41	17.88	17.48
	H2O(%V) CALCULATED	1.32	1.42	1.48	1.73	2.12
		13.0	13.3	15.1	38.0	51.9
	NO2(PPMV)	4.0	5.3	5.1	10.0	2.9
C	NO(PPMV)	9.0	8.0	10.0	28.0	49.0
O	NOX(LB/LB FUEL AS NO2)	.00147	.0024	.0028	.0066	.0080
N	NOX(LB/HR AS NO2)	1.2	3.1	4.2	21.2	37.3
S						
T	CO2(%V)	1.28	1.41	1.48	1.77	2.18
I	CO2(LB/LB FUEL)	1.997	2.470	2.657	2.964	3.214
T	CO2(LB/HR)	2031.	3127.	3988.	9475.	14975.
U						
E	CO(PPMV)	867.6	645.6	455.7	93.5	41.5
N	CO(LB/LB FUEL)	0.0863	0.0721	0.0520	0.0100	0.0039
T	CO(LB/HR)	87.7	91.3	78.1	31.8	18.1
S						
	THC(PPMV AS CH4)	1055.8	459.8	222.0	14.3	2.0
	THC(LB/LB FUEL)	0.0600	0.0294	0.0145	0.0009	0.0001
	THC(LB/HR)	61.0	37.2	21.7	2.8	0.5

* ALL DATA REPORTED WET *

```
                                                                      PAGE     2 OF 2

  GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

  ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

  DATE OF TEST   7/ 7/71

  ENGINE NUMBER           - P-668816  ☐

  ENGINE TYPE             - JT3D

  TEST STAND              - P-  68

  BURNER CONFIGURATION - B/M

  FUEL                    - JP4

     POINT NUMBER                        6            7            8            9
E    TIME                         15:18:23     15:28:50     15:40:52     15:51:22
X    F/A                           0.01113      0.01200      0.01292      0.01432
H    WF(LB/HR)                      5636.0       6705.0       7924.0       9450.0
A    HIGH ROTOR SPEED(RPM)           9260.        9475.        9695.       10000.
U    THRUST(LBS)                    10740.       12570.       14450.       16400.
S    TT2(DEG F)                       87.0         87.0         86.0         87.0
T
     N2(%V BY DIFFERENCE)            78.09        78.01        77.91        77.64
     O2(%V)                          17.23        16.93        16.60        16.14
     H2O(%V) CALCULATED               2.31         2.50         2.72         3.08
                                      66.4         82.3        115.1        147.4
     NO2(PPMV)                         5.4          6.3         17.1          8.4
C    NO(PPMV)                         61.0         76.0         98.0        139.0
C    NOX(LB/LB FUEL AS NO2)          .0094        .0109        .0141        .0163
N    NOX(LB/HR AS NO2)                53.3         72.9        111.7        154.3
S
T    CO2(%V)                          2.37         2.56         2.77         3.13
I    CO2(LB/LB FUEL)                 3.225        3.231        3.257        3.318
T    CO2(LB/HR)                     18173.       21662.       25805.       31356.
U
E    CO(PPMV)                         27.2         19.7         14.3         10.7
N    CO(LB/LB FUEL)                 0.0024       0.0016       0.0011       0.0007
T    CO(LB/HR)                        13.3         10.6          8.5          6.8
S
     THC(PPMV AS CH4)                  5.7          9.3          5.6          4.5
     THC(LB/LB FUEL)                0.0003       0.0004       0.0002       0.0002
     THC(LB/HR)                        1.6          2.9          1.9          1.7


                      *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 7/21/71

ENGINE NUMBER - P-668817 ∇

ENGINE TYPE - JT3D

TEST STAND - P- 68

BURNER CONFIGURATION -

FUEL - JP4

	POINT NUMBER	1	2	3	4	5
E	TIME	9:30:12	9:42:12	10:29:40	13:13:55	13:21:33
X	F/A(STA 7 UNCORR)	0.00911	0.00839	0.00791	0.01017	0.01103
H	WF(LB/HR)	1080.0	2875.0	950.0	4745.0	5835.0
A	HIGH ROTOR SPEED(RPM)	5440.	8260.	5535.	8995.	9230.
U	THRUST(LBS)	850.	5200.	880.	8980.	10990.
S	TT2(DEG F)	68.0	69.0	71.0	78.0	78.0
T						
	N2(%V BY DIFFERENCE)	78.91	79.46	80.15	78.29	78.21
	O2(%V)	18.19	17.23	16.89	17.78	17.50
	H2O(%V CALCULATED)	1.35	1.63	1.39	1.93	2.11
		7.2	26.2	9.2	45.9	56.6
	NO2(PPMV)	3.1	8.0	5.6	9.3	9.1
C	NO(PPMV)	4.1	18.2	3.6	36.6	47.5
O	NOX(LB/LB FUEL AS NO2)	0.0013	0.0050	0.0019	0.0072	0.0081
N	NOX(LB/HR AS NO2)	1.4	14.3	1.7	34.0	47.5
S						
T	CO2(%V)	1.31	1.66	1.35	1.98	2.17
I	CO2(LB/LB FUEL)	2.181	3.010	2.592	2.958	2.981
T	CO2(LB/HR)	2356.	8655.	2462.	14036.	17397.
U						
E	CO(PPMV)	396.9	143.8	864.8	55.2	35.3
N	CO(LB/LB FUEL)	0.0951	0.0166	0.1056	0.0052	0.0031
T	CO(LB/HR)	102.7	47.6	100.3	24.9	13.0
S						
	THC(PPMV AS CH4)	1425.6	34.5	1293.8	4.4	1.9
	THC(LB/LB FUEL)	0.0863	0.0023	0.0902	0.0002	0.0001
	THC(LB/HR)	93.2	6.5	85.7	1.1	0.6

* ALL DATA REPORTED WET *

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/21/71

ENGINE NUMBER            - P-669817  ▽

ENGINE TYPE              - JT3D

TEST STAND               - P-  68

BURNER CONFIGURATION -

FUEL                     - JP4

   POINT NUMBER                        6          7          8
E  TIME                        13:40:51   13:53: 3   14:13:50
X  F/A(STA 7 UNCORR)            0.01177    0.01275    0.01432
H  WF(LB/HR)                     6885.0     8050.0     9320.0
A  HIGH ROTOR SPEED(RPM)          9450.      9660.      9930.
U  THRUST(LBS)                   12760.     14580.     16500.
S  TT2(DEG F)                      79.0       79.0       79.0
T
   N2(%V BY DIFFERENCE)           77.86      78.06      78.01
   O2(%V)                         17.18      16.92      16.40
   H2O(%V CALCULATED)              2.45       2.48       2.76
                                   72.9       89.6      128.8
   NO2(PPMV)                       11.3        9.3       10.1
C  NO(PPMV)                        61.5       80.3      118.7
O  NOX(LB/LB FUEL AS NO2)        0.0098     0.0111     0.0143
N  NOX(LB/HR AS NO2)               67.6       89.7      140.1
S
T  CO2(%V)                         2.51       2.53       2.81
I  CO2(LB/LB FUEL)                3.232      3.014      2.981
T  CO2(LB/HR)                    22249.     24259.     29274.
U
E  CO(PPMV)                        24.3       17.4       12.6
N  CO(LB/LB FUEL)                0.0020     0.0013     0.0009
T  CO(LB/HR)                       13.7       10.6        8.3
S
   THC(PPMV AS CH4)                 1.4        2.1        4.7
   THC(LB/LB FUEL)               0.0001     0.0001     0.0002
   THC(LB/HR)                       0.4        0.7        1.8

              *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/22/71

ENGINE NUMBER              - P-669797 /O

ENGINE TYPE                - JT3D

TEST STAND                 - P-  68

BURNER CONFIGURATION -

FUEL                       - JP4

  POINT NUMBER                       2          3          4          5          6
E TIME                        17: 1:26   17:51:36   18: 3:32   18:19:54   18:32: 2
X F/A(STA 7 UNCORR)            0.00760    0.01091    0.01172    0.01261    0.01417
H WF(LB/HR)                      915.0     5770.0     6910.0     8050.0     9720.0
A HIGH ROTOR SPEED(RPM)          5445.      9210.      9440.      9640.      9940.
U THRUST(LBS)                     840.     10800.     12700.     14600.     16500.
S TT2(DEG F)                      82.0       80.0       79.0       77.0       77.0
T
  N2(%V BY DIFFERENCE)           78.06      78.30      78.12      77.91      77.77
  O2(%V)                         19.04      17.28      16.93      16.64      16.01
  H2O(%V CALCULATED)              1.36       2.18       2.45       2.69       3.08
                                   4.8       57.7       73.9       89.8      122.8
  NO2(PPMV)                        0.0        6.6        6.2        5.3        4.3
C NO(PPMV)                         4.8       51.1       67.7       84.5      119.5
O NOX(LB/LB FUEL AS NO2)        0.0010     0.0034     0.0100     0.0113     0.0137
N NOX(LB/HR AS NO2)                0.9       48.4       69.1       91.0      133.6
S
T CO2(%V)                         1.32       2.23       2.50       2.75       3.13
I CO2(LB/LB FUEL)                2.639      3.103      3.237      3.304      3.351
T CO2(LB/HR)                     2415.     17907.     22370.     26593.     32573.
U
E CO(PPMV)                       887.1       31.2       20.7       14.8       10.9
N CO(LB/LB FUEL)                0.1127     0.0028     0.0017     0.0011     0.0007
T CO(LB/HR)                      103.1       15.9       11.8        9.1        7.2
S
  THC(PPMV AS CH4)              1241.2        4.1        4.0        3.5        3.4
  THC(LB/LB FUEL)               0.0901     0.0002     0.0002     0.0002     0.0001
  THC(LB/HR)                      82.4        1.2        1.3        1.3        1.3

                 *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/22/71

ENGINE NUMBER            - P-669797

ENGINE TYPE              - JT3D

TEST STAND               - P-  68

BURNER CONFIGURATION -

FUEL                     - JP4

   POINT NUMBER                        7
E  TIME                         18:39:20
X  F/A(STA 7 UNCORR)             0.01003
H  WF(LB/HR)                      4715.0
A  HIGH ROTOR SPEED(RPM)           3985.
U  THRUST(LBS)                     8900.
S  TT2(DEG F)                       77.0
T
   N2(%V BY DIFFERENCE)            78.72
   O2(%V)                          17.15
   H2O(%V CALCULATED)               2.03
                                    46.2
   NO2(PPMV)                         6.5
C  NO(PPMV)                         39.7
O  NOX(LB/LB FUEL AS NO2)         0.0073
N  NOX(LB/HR AS NO2)                34.5
S
T  CO2(%V)                          2.08
I  CO2(LB/LB FUEL)                 3.148
T  CO2(LB/HR)                     14844.
U
E  CO(PPMV)                         49.9
N  CO(LB/LB FUEL)                 0.0048
T  CO(LB/HR)                        22.6
S
   THC(PPMV AS CH4)                  6.2
   THC(LB/LB FUEL)                0.0003
   THC(LB/HR)                        1.6

              *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 7/23/71

ENGINE NUMBER - P-663815 /0

ENGINE TYPE - JT3D

TEST STAND - P- 68

BURNER CONFIGURATION -

FUEL - JP4

	POINT NUMBER	2	3	14	5	6
E	TIME	10:42:21	11:19:55	11:26:19	11:38:35	13:52:52
X	F/A(STA 7 UNCORR)	0.00760	0.01008	0.01095	0.01168	0.01366
H	WF(LB/HR)	915.0	4765.0	5770.0	6630.0	8120.0
A	HIGH ROTOR SPEED(RPM)	5465.	8995.	9230.	9455.	9690.
U	THRUST(LBS)	850.	8970.	10760.	12670.	14600.
S	TT2(DEG F)	76.0	79.0	79.0	80.0	81.0
T						
	N2(%V BY DIFFERENCE)	78.87	78.93	78.79	78.54	78.29
	O2(%V)	18.17	17.02	16.83	16.73	16.50
	H2O(%V CALCULATED)	1.39	2.00	2.16	2.33	2.57
		6.7	47.7	10.6	74.1	89.7
	NO2(PPMV)	5.0	10.5	10.6	10.6	6.3
C	NO(PPMV)	1.7	37.2	0.0	63.5	83.4
O	NOX(LB/LB FUEL AS NO2)	0.0014	0.0075	0.0015	0.0101	0.0104
N	NOX(LB/HR AS NO2)	1.3	35.8	8.8	68.7	84.6
S						
T	CO2(%V)	1.35	2.05	2.21	2.39	2.63
I	CO2(LB/LB FUEL)	2.691	3.083	3.064	3.100	2.919
T	CO2(LB/HR)	2462.	14693.	17682.	21171.	23700.
U						
E	CO(PPMV)	915.8	56.3	36.0	24.4	16.6
N	CO(LB/LB FUEL)	0.1163	0.0054	0.0032	0.0020	0.0012
T	CO(LB/HR)	106.5	25.7	18.3	13.8	9.5
S						
	THC(PPMV AS CH4)	1354.2	5.0	4.6	3.1	2.7
	THC(LB/LB FUEL)	0.0983	0.0003	0.0002	0.0001	0.0001
	THC(LB/HR)	90.0	1.3	1.3	1.0	0.9

* ALL DATA REPORTED WET *

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/23/71

ENGINE NUMBER          - P-663815

ENGINE TYPE            - JT3D

TEST STAND             - P- 68

BURNER CONFIGURATION -

FUEL                   - JP4

    POINT NUMBER                    17
E   TIME                      12: 6:38
X   F/A(STA 7 UNCORR)          0.01414
H   WF(LB/HR)                   9700.0
A   HIGH ROTOR SPEED(RPM)        9980.
U   THRUST(LBS)                 13140.
S   TT2(DEG F)                    82.0
T
    N2(%V BY DIFFERENCE)         78.29
    O2(%V)                       15.98
    H2O(%V CALCULATED)            2.84
                                  4.7
    NO2(PPMV)                      4.7
C   NO(PPMV)                       0.0
O   NOX(LB/LB FUEL AS NO2)      0.0005
N   NOX(LB/HR AS NO2)              5.1
S
T   CO2(%V)                       2.89
I   CO2(LB/LB FUEL)              3.103
T   CO2(LB/HR)                  30097.
U
E   CO(PPMV)                      12.5
N   CO(LB/LB FUEL)              0.0009
T   CO(LB/HR)                      8.3
S
    THC(PPMV AS CH4)              14.6
    THC(LB/LB FUEL)             0.0006
    THC(LB/HR)                     5.5

            *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/18/71

ENGINE NUMBER           - P-668821

ENGINE TYPE             - JT3D

TEST STAND              - P-  68

BURNER CONFIGURATION -  B/M

FUEL                    - JP4


   POINT NUMBER                   1          3          4          5          6
E  TIME                    17:51:40   18:43:46   18:50:21   19: 8:41   19:18: 0
X  F/A(STA 7 UNCORR)        0.00870    0.01029    0.01092    0.01180    0.01280
H  WF(LB/HR)                 2791.0     4634.0     5559.0     6667.0     7845.0
A  HIGH ROTOR SPEED(RPM)      8315.      9015.      9240.      9460.      9680.
U  THRUST(LBS)                5000.      8850.     10700.     12600.     14500.
S  TT2(DEG F)                  86.0       85.0       84.0       84.0       84.0
T
   N2(%V BY DIFFERENCE)       79.28      78.58      78.45      78.17      77.92
   O2(%V)                     17.31      17.35      17.13      16.86      16.56
   H2O(%V CALCULATED)          1.68       2.00       2.17       2.45       2.73

   NO2(PPMV)                    3.0        7.8        6.9        4.8        6.4
C  NO(PPMV)                    22.6       40.9       52.3       66.4       88.2
O  NOX(LB/LB FUEL AS NO2)    0.0047     0.0075     0.0086     0.0096     0.0117
N  NOX(LB/HR AS NO2)           13.0       34.8       47.8       63.8       92.0
S
T  CO2(%V)                     1.72       2.06       2.23       2.51       2.79
I  CO2(LB/LB FUEL)            2.998      3.032      3.096      3.227      3.303
T  CO2(LB/HR)                 8368.     14052.     17212.     21514.     25910.
U
E  CO(PPMV)                   110.6       48.5       32.4       21.6       15.6
N  CO(LB/LB FUEL)            0.0123     0.0046     0.0029     0.0018     0.0012
T  CO(LB/HR)                   34.3       21.1       15.9       11.8        9.2
S
   THC(PPMV AS CH4)             0.0        0.0        0.0        0.0        0.0
   THC(LB/LB FUEL)          0.0        0.0        0.0        0.0        0.0
   THC(LB/HR)                   0.0        0.0        0.0        0.0        0.0


              *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/18/71

ENGINE NUMBER          - P-663821

ENGINE TYPE            - JT3D

TEST STAND             - P-  68

BURNER CONFIGURATION -  B/M

FUEL                   - JP4

    POINT NUMBER                      7
E   TIME                       19:23:47
X   F/A(STA 7 UNCORR)           0.01420
H   WF(LB/HR)                    9408.0
A   HIGH ROTOR SPEED(RPM)         9975.
U   THRUST(LBS)                  16400.
S   TT2(DEG F)                     83.0
T
    N2(%V BY DIFFERENCE)          77.63
    O2(%V)                        16.17
    H2O(%V CALCULATED)             3.07

    NO2(PPMV)                       4.7
C   NO(PPMV)                      121.6
O   NOX(LB/LB FUEL AS NO2)       0.0141
N   NOX(LB/HR AS NO2)             132.7
S
T   CO2(%V)                        3.12
I   CO2(LB/LB FUEL)               3.337
T   CO2(LB/HR)                   31390.
U
E   CO(PPMV)                       11.7
N   CO(LB/LB FUEL)               0.0008
T   CO(LB/HR)                       7.5
S
    THC(PPMV AS CH4)                0.0
    THC(LB/LB FUEL)             0.0
    THC(LB/HR)                      0.0

              *  ALL DATA REPORTED WET  *
```

```
                                                                        PAGE      1

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/19/71

ENGINE NUMBER            - P-668820

ENGINE TYPE              - JT3D

TEST STAND               - P-  68

BURNER CONFIGURATION -    B/M

FUEL                     - JP4

  POINT NUMBER                       1          2          3          4          5
E TIME                        12: 8:55   10:29:55   12:59:10   11: 8:27   13:20:31
X F/A(STA 7 UNCORR)            0.00831    0.00895    0.00997    0.01082    0.01171
H WF(LB/HR)                     2736.0      938.0     4574.0     5606.0     6747.0
A HIGH ROTOR SPEED(RPM)          8245.      5480.      8960.      9190.      9420.
U THRUST(LBS)                    5000.       840.      8900.     10800.     12750.
S TT2(DEG F)                      74.0       75.0       77.0       77.0       77.0
T
  N2(%V BY DIFFERENCE)           78.16      79.76      78.22      78.46      78.60
  O2(%V)                         18.25      17.52      17.45      17.17      16.82
  H2O(%V CALCULATED)              1.76       1.31       2.14       2.16       2.26

  NO2(PPMV)                       13.4        4.9        3.2        2.9        0.4
C NO(PPMV)                        18.4        4.6       36.3       40.8       60.1
O NOX(LB/LB FUEL AS NO2)        0.0061     0.0017     0.0063     0.0064     0.0082
N NOX(LB/HR AS NO2)               16.6        1.6       28.7       35.9       55.3
S
T CO2(%V)                         1.80       1.27       2.19       2.21       2.32
I CO2(LB/LB FUEL)                3.288      2.149      3.327      3.097      3.001
T CO2(LB/HR)                     8997.      2016.     15220.     17361.     20248.
U
E CO(PPMV)                       155.7      908.6       60.1       38.8       20.7
N CO(LB/LB FUEL)                0.0181     0.0980     0.0058     0.0035     0.0017
T CO(LB/HR)                       49.5       91.9       26.6       19.4       11.5
S
  THC(PPMV AS CH4)                19.2      532.2        3.5        1.9        0.2
  THC(LB/LB FUEL)               0.0013     0.0328     0.0002     0.0001     0.0000
  THC(LB/HR)                       3.5       30.8        0.9        0.6        0.1


                    *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3673)

DATE OF TEST   8/19/71

ENGINE NUMBER          - P-668820

ENGINE TYPE            - JT3D

TEST STAND             - P-  68

BURNER CONFIGURATION -  B/M

FUEL                   - JP4

   POINT NUMBER                   6          7
E  TIME                    11:31:26   11:40:27
X  F/A(STA 7 UNCORR)        0.01263    0.01405
H  WF(LB/HR)                 7882.0     9397.0
A  HIGH ROTOR SPEED(RPM)      9650.      9930.
U  THRUST(LBS)               14600.     16400.
S  TT2(DEG F)                  78.0       79.0
T
   N2(%V BY DIFFERENCE)       79.04      79.24
   O2(%V)                     15.50      15.10
   H2O(%V CALCULATED)          2.69       2.80

   NO2(PPMV)                    1.4        0.6
C  NO(PPMV)                    73.7      112.1
O  NOX(LB/LB FUEL AS NO2)    0.0094     0.0127
N  NOX(LB/HR AS NO2)           74.3      119.5
S
T  CO2(%V)                     2.75       2.85
I  CO2(LB/LB FUEL)            3.303      3.078
T  CO2(LB/HR)                26031.     28921.
U
E  CO(PPMV)                    17.4        9.1
N  CO(LB/LB FUEL)            0.0013     0.0006
T  CO(LB/HR)                   10.5        5.9
S
   THC(PPMV AS CH4)             3.8        3.2
   THC(LB/LB FUEL)           0.0002     0.0001
   THC(LB/HR)                   1.3        1.2

             *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 8/20/71

ENGINE NUMBER - P-668822

ENGINE TYPE - JT3D

TEST STAND - P- 68

BURNER CONFIGURATION - B/M

FUEL - JP4

	POINT NUMBER	1	2	3	4	5
EXHAUST	TIME	10: 0: 1	12:29:12	11: 0:42	11:12:41	13:23:35
	F/A(STA 7 UNCORR)	0.00839	0.00819	0.01002	0.01054	0.01190
	WF(LB/HR)	2772.0	951.0	4526.0	5612.0	6703.0
	HIGH ROTOR SPEED(RPM)	8225.	5480.	8950.	9180.	9420.
	THRUST(LBS)	5020.	840.	8770.	10720.	12600.
	TT2(DEG F)	76.0	76.0	80.0	80.0	80.0
	N2(%V BY DIFFERENCE)	79.05	79.31	79.51	80.08	79.47
	O2(%V)	17.79	17.80	16.88	15.57	15.18
	H2O(%V CALCULATED)	1.56	1.41	1.78	2.15	2.64
CONSTITUENTS	NO2(PPMV)	8.5	1.5	0.7	6.4	5.8
	NO(PPMV)	17.6	5.3	35.0	50.5	59.3
	NOX(LB/LB FUEL AS NO2)	0.0049	0.0013	0.0056	0.0086	0.0087
	NOX(LB/HR AS NO2)	13.7	1.2	25.6	48.1	58.6
	CO2(%V)	1.59	1.37	1.82	2.20	2.70
	CO2(LB/LB FUEL)	2.878	2.533	2.763	3.167	3.468
	CO2(LB/HR)	7978.	2409.	12507.	17774.	23249.
	CO(PPMV)	149.2	908.5	60.4	37.0	21.0
	CO(LB/LB FUEL)	0.0172	0.1071	0.0058	0.0034	0.0017
	CO(LB/HR)	47.6	101.9	26.3	19.0	11.5
	THC(PPMV AS CH4)	19.1	244.9	8.1	2.9	2.1
	THC(LB/LB FUEL)	0.0013	0.0165	0.0004	0.0002	0.0001
	THC(LB/HR)	3.5	15.7	2.0	0.9	0.6

* ALL DATA REPORTED WET *

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/20/71

ENGINE NUMBER          - P-663822

ENGINE TYPE            - JT3D

TEST STAND             - P-  68

BURNER CONFIGURATION -  B/M

FUEL                   - JP4

   POINT NUMBER                   6           7
E  TIME                      11:33: 2    11:53:45
X  F/A(STA 7 UNCORR)          0.01285     0.01435
H  WF(LB/HR)                  7912.0      9499.0
A  HIGH ROTOR SPEED(RPM)      9655.       9925.
U  THRUST(LBS)               14500.      17492.
S  TT2(DEG F)                   81.0        82.0
T
   N2(%V BY DIFFERENCE)        78.67       78.06
   O2(%V)                      15.53       15.32
   H2O(%V CALCULATED)           2.87        3.28

   NO2(PPMV)                    5.5         5.1
C  NO(PPMV)                    76.9       109.5
O  NOX(LB/LB FUEL AS NO2)    0.0102      0.0127
N  NOX(LB/HR AS NO2)           80.5       120.4
S
T  CO2(%V)                      2.93        3.33
I  CO2(LB/LB FUEL)              3.454       3.516
T  CO2(LB/HR)                27331.      33399.
U
E  CO(PPMV)                    17.4        13.6
N  CO(LB/LB FUEL)             0.0013      0.0009
T  CO(LB/HR)                   10.3         8.7
S
   THC(PPMV AS CH4)             5.4         5.8
   THC(LB/LB FUEL)            0.0002      0.0002
   THC(LB/HR)                   1.8         2.1

              *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 9/ 2/71

ENGINE NUMBER - P-669798

ENGINE TYPE - JT3D

TEST STAND - P- 68

BURNER CONFIGURATION - B/M

FUEL - JP4

	POINT NUMBER	1	2	3	4	5
EXHAUST	TIME	13:37: 8	14: 0: 4	14:12:21	14:22: 0	14:40:51
	F/A(STA 7 UNCORR)	0.00837	0.00994	0.01069	0.01153	0.01255
	WF(LB/HR)	1010.0	4750.0	5740.0	6850.0	8080.0
	HIGH ROTOR SPEED(RPM)	5460.	8985.	9220.	9435.	9670.
	THRUST(LBS)	750.	9000.	10850.	12750.	14650.
	TT2(DEG F)	76.0	76.0	76.0	76.0	76.0
	N2(%V BY DIFFERENCE)	78.79	78.72	78.60	78.56	78.32
	O2(%V)	18.26	17.27	17.04	16.75	16.36
	H2O(%V CALCULATED)	1.38	1.98	2.15	2.31	2.63
CONSTITUENTS	NO2(PPMV)	6.1	9.4	8.6	8.4	9.7
	NO(PPMV)	3.9	37.8	50.1	67.3	90.7
	NOX(LB/LB FUEL AS NO2)	0.0019	0.0075	0.0087	0.0104	0.0127
	NOX(LB/HR AS NO2)	1.9	35.8	50.0	71.3	102.5
	CO2(%V)	1.34	2.03	2.20	2.36	2.68
	CO2(LB/LB FUEL)	2.424	3.093	3.123	3.111	3.245
	CO2(LB/HR)	2449.	14694.	17924.	21307.	26224.
	CO(PPMV)	894.4	56.6	36.5	25.4	20.0
	CO(LB/LB FUEL)	0.1032	0.0055	0.0033	0.0021	0.0015
	CO(LB/HR)	104.2	26.1	18.9	14.5	12.4
	THC(PPMV AS CH4)	1407.0	7.0	2.9	1.1	2.1
	THC(LB/LB FUEL)	0.0927	0.0004	0.0001	0.0001	0.0001
	THC(LB/HR)	93.7	1.8	0.8	0.3	0.8

* ALL DATA REPORTED WET *

```
                                                    PAGE      2 OF 2

 GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

 ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

 DATE OF TEST   9/ 2/71

 ENGINE NUMBER          - P-669798

 ENGINE TYPE            - JT3D

 TEST STAND             - P-  68

 BURNER CONFIGURATION -  B/M

 FUEL                   - JP4

    POINT NUMBER                  6
E   TIME                   14:52:25
X   F/A(STA 7 UNCORR)       0.01404
H   WF(LB/HR)                9680.0
A   HIGH ROTOR SPEED(RPM)     9960.
U   THRUST(LBS)              16525.
S   TT2(DEG F)                 76.0
T
    N2(%V BY DIFFERENCE)      78.09
    O2(%V)                    15.84
    H2O(%V CALCULATED)         3.00

    NO2(PPMV)                   8.6
C   NO(PPMV)                  128.2
O   NOX(LB/LB FUEL AS NO2)   0.0155
N   NOX(LB/HR AS NO2)         149.6
S
T   CO2(%V)                    3.05
I   CO2(LB/LB FUEL)           3.298
T   CO2(LB/HR)               31923.
U
E   CO(PPMV)                   15.8
N   CO(LB/LB FUEL)           0.0011
T   CO(LB/HR)                  10.5
S
    THC(PPMV AS CH4)            2.8
    THC(LB/LB FUEL)          0.0001
    THC(LB/HR)                  1.1


                * ALL DATA REPORTED WET *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 9/ 7/71

ENGINE NUMBER - P-669799

ENGINE TYPE - JT3D

TEST STAND - P- 68

BURNER CONFIGURATION -

FUEL - JP4C

	POINT NUMBER	1	2	3	4	5
EXHAUST	TIME	12: 9: 4	12:11:41	12:23:40	12:38:50	12:59: 0
	F/A(STA 7 UNCORR)	0.00988	0.01171	0.01152	0.01245	0.01405
	WF(LB/HR)	4561.0	5522.0	6631.0	7811.0	9414.0
	HIGH ROTOR SPEED(RPM)	8965.	9190.	9420.	9650.	9970.
	THRUST(LBS)	8930.	10740.	12700.	14600.	16500.
	TT2(DEG F)	71.0	72.0	72.0	72.0	73.0
	N2(%V BY DIFFERENCE)	78.94	78.76	78.61	78.50	79.18
	O2(%V)	16.99	16.80	16.54	16.19	15.23
	H2O(%V CALCULATED)	2.00	2.19	2.39	2.62	2.76
	NO2(PPMV)	7.4	7.5	6.2	1.8	2.7
CONSTITUENTS	NO(PPMV)	37.2	47.8	61.2	79.3	114.3
	NOX(LB/LB FUEL AS NO2)	0.0072	0.0075	0.0093	0.0103	0.0132
	NOX(LB/HR AS NO2)	32.6	41.3	61.5	80.6	124.3
	CO2(%V)	2.05	2.24	2.45	2.68	2.82
	CO2(LB/LB FUEL)	3.154	2.905	3.226	3.264	3.041
	CO2(LB/HR)	14383.	16041.	21389.	25493.	28627.
	CO(PPMV)	60.2	39.5	26.5	18.5	10.2
	CO(LB/LB FUEL)	0.0059	0.0033	0.0022	0.0014	0.0007
	CO(LB/HR)	26.8	18.0	14.7	11.2	6.6
	THC(PPMV AS CH4)	7.2	4.9	2.6	1.9	0.9
	THC(LB/LB FUEL)	0.0004	0.0002	0.0001	0.0001	0.0000
	THC(LB/HR)	1.8	1.3	0.8	0.7	0.3

* ALL DATA REPORTED WET *

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST   6/23/71

ENGINE NUMBER          - X-370-47

ENGINE TYPE            - JT8D

TEST STAND             - X-  53

BURNER CONFIGURATION -  4C9-H

FUEL                   - JP4C

   POINT NUMBER                      1          2          3          4          5
E  TIME                       10: 9:56   10:23:17   10:32:20   10:43:47   11: 2:35
X  F/A                         0.00870    0.00970    0.01097    0.01341    0.01520
H  WF(LB/HR)                     950.0     1519.0     3453.0     5644.0     7563.0
A  HIGH ROTOR SPEED(RPM)         6515.      8160.      9935.     10720.     11180.
U  THRUST(LBS)                    850.      1875.      6040.      9970.     13050.
S
T
   N2(%V BY DIFFERENCE)          78.87      78.86      78.81      78.70      78.96
   O2(%V)                        18.93      18.57      18.03      17.22      16.45
   H2O(%V) CALCULATED             1.07       1.26       1.55       2.01       2.26

   NO2(PPMV)                       3.4        5.0        5.5        5.8        8.3
C  NO(PPMV)                        9.2       15.4       39.3       86.9      139.7
O  NOX(LB/LB FUEL AS NO2)       0.0023     0.0033     0.0065     0.0110     0.0154
N  NOX(LB/HR AS NO2)               2.2        5.1       22.4       61.9      116.8
S
T  CO2(%V)                        1.09       1.30       1.60       2.06       2.31
I  CO2(LB/LB FUEL)               1.904      2.028      2.208      2.333      2.307
T  CO2(LB/HR)                    1808.      3081.      7626.     13165.     17444.
U
E  CO(PPMV)                      229.2      114.5       42.6       18.3       43.9
N  CO(LB/LB FUEL)               0.0254     0.0114     0.0037     0.0013     0.0028
T  CO(LB/HR)                      24.2       17.3       12.9        7.4       21.1
S
   THC(PPMV AS CH4)               84.8       23.6        6.2        7.1        4.4
   THC(LB/LB FUEL)              0.0054     0.0013     0.0003     0.0003     0.0002
   THC(LB/HR)                      5.1        2.0        1.1        1.7        1.2

               *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/23/71

ENGINE NUMBER - X-370-47

ENGINE TYPE - JT8D

TEST STAND - X- 53

BURNER CONFIGURATION - 409-H

FUEL - JP4C

	POINT NUMBER	6	7	8	9	10
E	TIME	11:11:15	11:20:21	11:30:10	11:38:47	11:50:40
X	F/A	0.01681	0.01469	0.01071	0.01051	0.00914
H	WF(LB/HR)	9375.0	6826.0	3982.0	2927.0	1155.0
A	HIGH ROTOR SPEED(RPM)	11590.	11055.	10185.	9655.	7400.
U	THRUST(LBS)	15520.	12060.	6950.	5010.	1350.
S						
T						
	N2(%V BY DIFFERENCE)	78.47	79.12	79.70	79.76	80.10
	O2(%V)	16.29	16.64	17.26	17.67	18.01
	H2O(%V) CALCULATED	2.58	2.09	1.49	1.26	0.93
	NO2(PPMV)	10.5	8.3	7.5	8.2	7.1
C	NO(PPMV)	209.3	119.2	49.1	29.8	10.2
O	NOX(LB/LB FUEL AS NO2)	0.0207	0.0138	0.0084	0.0057	0.0030
N	NOX(LB/HR AS NO2)	194.5	94.0	33.4	16.8	3.5
S						
T	CO2(%V)	2.64	2.14	1.53	1.29	0.95
I	CO2(LB/LB FUEL)	2.380	2.207	2.170	1.857	1.574
T	CO2(LB/HR)	22314.	15067.	8639.	5435.	1818.
U						
E	CO(PPMV)	35.8	49.3	59.6	116.7	142.2
N	CO(LB/LB FUEL)	0.0021	0.0032	.0054	.0107	0.0150
T	CO(LB/HR)	19.3	22.1	21.4	31.4	17.4
S						
	THC(PPMV AS CH4)	4.2	4.5	6.5	9.5	35.1
	THC(LB/LB FUEL)	0.0001	0.0002	0.0003	0.0005	0.0021
	THC(LB/HR)	1.3	1.1	1.3	1.5	2.5

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/23/71

ENGINE NUMBER - X-37C-47

ENGINE TYPE - JT8D

TEST STAND - X- 53

BURNER CONFIGURATION - 409-H

FUEL - JP4C

	POINT NUMBER	11	12	13	14	15
E	TIME	13:41:57	13:53:13	14: 9:51	14:51:53	15: 8:11
X	F/A	0.00904	0.00953	0.01117	0.01365	0.01554
H	WF(LB/HR)	966.0	1488.0	3503.0	5622.0	7556.0
A	HIGH ROTOR SPEED(RPM)	6685.	8130.	10005.	10800.	11255.
U	THRUST(LBS)	850.	1800.	6065.	9950.	13050.
S						
T						
	N2(%V BY DIFFERENCE)	78.92	78.82	78.55	77.83	77.58
	O2(%V)	18.88	18.65	18.18	17.70	17.15
	H2O(%V) CALCULATED	1.08	1.24	1.61	2.20	2.60
	NO2(PPMV)	4.5	7.1	8.2	7.4	9.4
C	NO(PPMV)	7.0	14.9	44.0	96.4	163.3
C	NOX(LB/LB FUEL AS NO2)	0.0020	0.0037	0.0074	0.0121	0.0176
N	NOX(LB/HR AS NO2)	1.9	5.5	26.0	67.8	133.2
S						
T	CO2(%V)	1.09	1.28	1.64	2.26	2.66
I	CO2(LB/LB FUEL)	1.838	2.033	2.234	2.507	2.594
T	CO2(LB/HR)	1775.	3026.	7824.	14097.	19601.
U						
E	CO(PPMV)	211.3	105.8	68.4	16.3	10.6
N	CO(LB/LB FUEL)	0.0226	0.0107	.0059	0.0012	0.0007
I	CO(LB/HR)	21.8	16.0	20.7	6.5	5.0
S						
	THC(PPMV AS CH4)	68.5	17.9	7.8	8.3	7.0
	THC(LB/LB FUEL)	0.0042	0.0010	0.0004	0.0003	0.0002
	THC(LB/HR)	4.0	1.5	1.4	1.9	1.9

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/23/71

ENGINE NUMBER - X-37C-47

ENGINE TYPE - JT8D

TEST STAND - X- 53

BURNER CONFIGURATION - 4CS-H

FUEL - JP4C

	POINT NUMBER	16	17	18	19	20
E	TIME	15:13: 6	15:23:41	15:30:54	15:54:39	16:13:45
X	F/A	0.01735	0.01494	0.01179	0.01046	0.00915
H	WF(LB/HR)	9593.0	6933.0	3985.0	2917.0	1188.0
A	HIGH ROTOR SPEED(RPM)	11685.	11120.	10240.	9716.	7547.
U	THRUST(LBS)	15520.	12060.	6950.	5010.	1350.
S						
T						
	N2(%V BY DIFFERENCE)	77.27	77.66	78.61	78.49	78.12
	O2(%V)	16.61	17.36	18.09	18.63	19.62
	H2O(%V) CALCULATED	3.02	2.45	1.62	1.41	1.11
	NO2(PPMV)	13.1	10.0	8.6	10.1	8.2
C	NO(PPMV)	241.6	142.9	53.8	34.1	14.5
O	NOX(LB/LB FUEL AS NO2)	0.0233	0.0162	0.0084	0.0067	0.0039
N	NOX(LB/HR AS NO2)	223.4	112.5	33.5	19.5	4.7
S						
T	CO2(%V)	3.07	2.51	1.67	1.46	1.14
I	CO2(LB/LB FUEL)	2.684	2.546	2.148	2.112	1.898
T	CO2(LB/HR)	25751.	17655.	8558.	6161.	2255.
U						
E	CO(PPMV)	8.6	11.7	27.5	49.2	132.0
N	CO(LB/LB FUEL)	0.0005	0.0008	0.0022	0.0045	.0140
T	CO(LB/HR)	4.6	5.2	9.0	13.2	16.6
S						
	THC(PPMV AS CH4)	6.3	6.2	7.2	9.1	28.8
	THC(LB/LB FUEL)	0.0002	0.0002	0.0003	0.0005	0.0017
	THC(LB/HR)	1.9	1.6	1.3	1.4	2.1

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/23/71

ENGINE NUMBER - X-370-47

ENGINE TYPE - JT8D

TEST STAND - X- 53

BURNER CONFIGURATION - 409-H

FUEL - JP5

	POINT NUMBER	21	22	23	24	25
E	TIME	18: 2:52	18 :21:56	18:33:26	18:52:32	19: 9: 6
X	F/A	0.00908	0.00991	0.01124	0.01392	0.01564
H	WF(LB/HR)	970.0	1539.0	3486.0	5779.0	7657.0
A	HIGH ROTOR SPEED(RPM)	6680.	8194.	9973.	10772.	11207.
U	THRUST(LBS)	850.	1850.	6000.	10000.	13000.
S						
T						
	N2(%V BY DIFFERENCE)	78.38	77.97	77.79	77.35	77.08
	O2(%V)	19.20	19.21	18.76	17.80	17.10
	H2O(%V) CALCULATED	1.18	1.38	1.69	2.39	2.88
	NO2(PPMV)	7.8	7.0	7.4	7.3	9.1
C	NO(PPMV)	6.1	12.4	35.8	84.3	144.3
O	NOX(LB/LB FUEL AS NO2)	0.0024	0.0031	0.0061	0.0104	0.0156
N	NOX(LB/HR AS NO2)	2.3	4.8	21.3	60.3	119.2
S						
T	CO2(%V)	1.20	1.42	1.74	2.44	2.93
I	CO2(LB/LB FUEL)	2.003	2.171	2.352	2.663	2.844
T	CO2(LB/HR)	1943.	3342.	8200.	15392.	21774.
U						
E	CO(PPMV)	285.6	125.6	46.9	19.6	12.2
N	CO(LB/LB FUEL)	0.0304	0.0122	0.0040	0.0014	0.0008
T	CO(LB/HR)	29.5	18.8	14.1	7.8	5.7
S						
	THC(PPMV AS CH4)	60.1	24.6	8.5	5.3	4.0
	THC(LB/LB FUEL)	0.0037	0.0014	0.0004	0.0002	0.0001
	THC(LB/HR)	3.5	2.1	1.4	1.2	1.1

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/23/71

ENGINE NUMBER - X-370-47

ENGINE TYPE - JT8D

TEST STAND - X- 53

BURNER CONFIGURATION - 409-H

FUEL - JP5

	POINT NUMBER	26	27	28	29	30
E	TIME	19:16: 9	19:30:34	19:33:13	19:49:43	20: 8: 1
X	F/A	0.01732	0.01503	0.01183	0.01062	0.00927
H	WF(LB/HR)	9651.0	6986.0	4013.0	2981.0	1136.0
A	HIGH ROTOR SPEED(RPM)	11627.	11056.	10182.	9677.	7252.
U	THRUST(LBS)	15550.	12000.	6950.	2960.	1235.
S						
T						
	N2(%V BY DIFFERENCE)	76.81	77.26	78.21	78.40	78.66
	O2(%V)	16.49	17.20	18.07	18.52	18.90
	H2O(%V) CALCULATED	3.32	2.74	1.82	1.51	1.19
	NO2(PPMV)	11.8	9.0	7.7	8.8	6.0
C	NO(PPMV)	225.9	120.6	54.0	28.0	9.0
O	NOX(LB/LB FUEL AS NO2)	0.0218	0.0137	.0083	.0055	.0026
N	NOX(LB/HR AS NO2)	210.2	95.5	33.2	16.6	2.9
S						
T	CO2(%V)	3.36	2.79	1.88	1.56	1.23
I	CO2(LB/LB FUEL)	2.946	2.816	2.406	2.222	2.011
T	CO2(LB/HR)	28430.	19676.	9654.	6625.	2285.
U						
E	CO(PPMV)	9.5	14.0	37.7	62.4	178.0
N	CO(LB/LB FUEL)	0.0005	0.0009	0.0031	0.0057	.0186
T	CO(LB/HR)	5.1	6.3	12.3	16.9	20.9
S						
	THC(PPMV AS CH4)	3.9	3.6	5.7	9.0	52.5
	THC(LB/LB FUEL)	0.0001	0.0001	0.0003	0.0005	0.0031
	THC(LB/HR)	1.2	0.9	1.1	1.4	3.5

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 6/24/71

ENGINE NUMBER - X-370-47

ENGINE TYPE - JT8D

TEST STAND - X- 53

BURNER CONFIGURATION - 4Q9-H

FUEL - JP5

	POINT NUMBER	31	32	33	34
E	TIME	9:52:10	11:22:46	13:19:50	14:33:43
X	F/A	0.01054	0.01656	0.01467	0.01073
H	WF(LB/HR)	2982.0	8792.0	7463.0	1390.0
A	HIGH ROTOR SPEED(RPM)	9670.	11415.	11225.	7595.
U	THRUST(LBS)	5010.	14500.	12700.	1350.
S					
T					
	N2(%V BY DIFFERENCE)	74.86	77.95	77.73	79.95
	O2(%V)	18.06	16.61	16.55	18.87
	H2O(%V) CALCULATED	3.52	2.68	2.83	0.58
	NO2(PPMV)	6.1	9.5	7.5	10.6
C	NO(PPMV)	25.6	178.9	147.1	7.9
O	NOX(LB/LB FUEL AS NO2)	0.0048	0.0180	0.0167	0.0027
N	NOX(LB/HR AS NO2)	14.2	158.7	124.8	3.8
S					
T	CO2(%V)	1.51	2.74	2.88	1.22
I	CO2(LB/LB FUEL)	2.175	2.508	2.979	1.72
T	CO2(LB/HR)	6490.	22054.	22230.	2390.
U					
E	CO(PPMV)	59.9	10.3	13.2	151.4
N	CO(LB/LB FUEL)	0.0055	0.0006	0.0009	0.0136
T	CO(LB/HR)	16.4	5.3	6.5	18.9
S					
	THC(PPMV AS CH4)	9.4	5.8	5.9	7.1
	THC(LB/LB FUEL)	0.0005	0.0002	0.0002	0.0004
	THC(LB/HR)	1.5	1.7	1.7	0.5

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST 7/ 9/71

ENGINE NUMBER - P-674552

ENGINE TYPE - JT8D

TEST STAND - P- 67

BURNER CONFIGURATION -

FUEL - JP4C

	POINT NUMBER	1	2	3	4	5
E	TIME	13:20: 2	13:28: 0	13:33:46	13:45:48	13:50:22
X	F/A	0.00930	0.00920	0.00998	0.01120	0.01220
H	WF(LB/HR)	1122.0	890.0	1427.0	2884.0	5090.0
A	HIGH ROTOR SPEED(RPM)	7325.	6420.	8060.	9930.	10900.
U	THRUST(LBS)	1100.	680.	1600.	5000.	9050.
S	TT2(DEG F)	96.0	96.0	96.0	96.0	96.0
T						
	N2(%V BY DIFFERENCE)	78.71	78.75	78.72	78.55	78.22
	O2(%V)	19.02	18.94	18.81	18.44	17.63
	H2O(%V) CALCULATED	1.11	1.13	1.21	1.48	2.04
	NO2(PPMV)	3.0	5.1	3.4	5.6	5.2
C	NO(PPMV)	10.7	8.5	13.6	32.6	80.0
O	NOX(LB/LB FUEL AS NO2)	0.0023	0.0023	0.0027	0.0054	0.0111
N	NOX(LB/HR AS NO2)	2.6	2.1	3.8	15.6	56.4
S						
T	CO2(%V)	1.14	1.14	1.25	1.53	2.09
I	CO2(LB/LB FUEL)	1.856	1.887	1.895	2.069	2.605
T	CO2(LB/HR)	2082.	1680.	2704.	5967.	13261.
U						
E	CO(PPMV)	156.4	277.3	110.8	47.3	17.9
N	CO(LB/LB FUEL)	0.0162	0.0291	0.0107	0.0041	0.0014
T	CO(LB/HR)	18.2	25.9	15.3	11.8	7.2
S						
	THC(PPMV AS CH4)	35.4	115.6	19.1	5.3	0.3
	THC(LB/LB FUEL)	0.0021	0.0069	0.0011	0.0003	0.0000
	THC(LB/HR)	2.4	6.2	1.5	0.8	0.1

* ALL DATA REPORTED WET *

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST  70/91/71

ENGINE NUMBER             - P-674552

ENGINE TYPE               - JT8D

TEST STAND                - P-  67

BURNER CONFIGURATION -

FUEL                      - 0 NOT PROPER CODE


   POINT NUMBER                     6          7          83
E  TIME                      14:10:34   14:41:15   15: 7: 9
X  F/A                        0.01320    0.01410    0.01510
H  WF(LB/HR)                   5865.0     6677.0     7815.0
A  HIGH ROTOR SPEED(RPM)       11125.     11340.     11590.
U  THRUST(LBS)                 10350.     11550.     13100.
S  TT2(DEG F)                    96.0       97.0       97.0
T
   N2(%V BY DIFFERENCE)         78.23      78.37      78.51
   O2(%V)                       17.35      17.05      16.56
   H2O(%V) CALCULATED            2.18       2.26       2.43

   NO2(PPMV)                      5.9        7.9        7.5
C  NO(PPMV)                      99.4      116.9      159.1
O  NOX(LB/LB FUEL AS NO2)      0.0127     0.0140     0.0175
N  NOX(LB/HR AS NO2)             74.2       93.8      136.8
S
T  CO2(%V)                       2.23       2.31       2.48
I  CO2(LB/LB FUEL)              2.567      2.487      2.495
T  CO2(LB/HR)                  15055.     16606.     19495.
U
E  CO(PPMV)                      14.1       12.9       10.5
N  CO(LB/LB FUEL)              0.0010     0.0009     0.0007
T  CO(LB/HR)                      6.1        5.9        5.2
S
   THC(PPMV AS CH4)               0.2        4.3        2.7
   THC(LB/LB FUEL)             0.0000     0.0002     0.0001
   THC(LB/HR)                     0.0        1.1        0.8


                  *  ALL DATA REPORTED WET  *
```

1

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST    7/12/71

ENGINE NUMBER          - P-676215

ENGINE TYPE            - JT8D

TEST STAND             - P-  67

BURNER CONFIGURATION -

FUEL                   - JP4

   POINT NUMBER                     1          2          3          4          8
E  TIME                      10:33:11   10:40:41   10:58:21   11:21:50   12:22:53
X  F/A                        0.00950    0.01010    0.00870    0.01120    0.01240
H  WF(LB/HR)                   1293.0     1596.0      945.0     2930.0     5465.0
A  HIGH ROTOR SPEED(RPM)        7545.      9160.      6640.      9740.     10770.
U  THRUST(LBS)                  1350.      1870.       850.      5070.      9550.
S  TT2(DEG F)                    72.0       74.0       74.0       76.0       76.0
T
   N2(%V BY DIFFERENCE)         78.47      78.46      78.56      78.63      78.26
   O2(%V)                       19.27      19.09      19.25      18.35      17.29
   H2O(%V) CALCULATED            1.11       1.20       1.07       1.48       2.19

   NO2(PPMV)                      5.1        6.4        5.8        7.5        7.6
C  NO(PPMV)                      12.6       15.5        5.1       33.4       95.8
O  NOX(LB/LB FUEL AS NO2)      0.0030     0.0034     0.0020     0.0058     0.0132
N  NOX(LB/HR AS NO2)              3.8        5.5        1.9       17.0       72.3
S
T  CO2(%V)                       1.14       1.23       1.09       1.53       2.25
I  CO2(LB/LB FUEL)              1.814      1.854      1.901      2.070      2.753
T  CO2(LB/HR)                   2345.      2960.      1796.      6065.     15046.
U
E  CO(PPMV)                     136.8      110.3      214.4       46.3       15.6
N  CO(LB/LB FUEL)              0.0139     0.0105     0.0238     0.0040     0.0012
T  CO(LB/HR)                     18.0       16.8       22.5       11.7        6.6
S
   THC(PPMV AS CH4)              31.6       12.4       74.6        4.9        1.2
   THC(LB/LB FUEL)             0.0018     0.0007     0.0047     0.0002     0.0001
   THC(LB/HR)                     2.4        1.1        4.5        0.7        0.3


                    *  ALL DATA REPORTED WET  *
```

1

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST   7/12/71

ENGINE NUMBER             - P-676215

ENGINE TYPE               - JT8D

TEST STAND                - P-  67

BURNER CONFIGURATION -

FUEL                      - JP4

   POINT NUMBER                        9           10           11           12
E  TIME                         12:39:37     12:54:48     13:10:56     13:31:17
X  F/A                           0.01350      0.01420      0.01500      0.01560
H  WF(LB/HR)                      6275.0       6950.0       7930.0       8640.0
A  HIGH ROTOR SPEED(RPM)          10990.       11155.       11370.       11545.
U  THRUST(LBS)                    10920.       12000.       13360.       14330.
S  TT2(DEG F)                       76.0         77.0         76.0         77.0
T
   N2(%V BY DIFFERENCE)            78.30        78.27        78.11        77.47
   O2(%V)                          16.93        16.71        16.58        16.99
   H2O(%V) CALCULATED               2.35         2.47         2.62         2.73

   NO2(PPMV)                         8.5         10.0         11.9         15.6
C  NO(PPMV)                        118.8        142.4        175.1        198.3
O  NOX(LB/LB FUEL AS NO2)         0.0150       0.0170       0.0198       0.0218
N  NOX(LB/HR AS NO2)                93.8        118.3        156.8        188.0
S
T  CO2(%V)                          2.41         2.53         2.68         2.79
I  CO2(LB/LB FUEL)                 2.707        2.702        2.708        2.709
T  CO2(LB/HR)                     16987.       18776.       21472.       23409.
U
E  CO(PPMV)                         13.7         12.0         10.5          9.9
N  CO(LB/LB FUEL)                 0.0010       0.0008       0.0007       0.0006
T  CO(LB/HR)                         6.1          5.7          5.4          5.3
S
   THC(PPMV AS CH4)                  0.7          0.5          1.4          1.7
   THC(LB/LB FUEL)                0.0000       0.0000       0.0001       0.0001
   THC(LB/HR)                        0.2          0.1          0.4          0.5


               *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST   7/14/71

ENGINE NUMBER        - P-665705

ENGINE TYPE          - JT8D

TEST STAND           - P-  67

BURNER CONFIGURATION -

FUEL                 - JP4C


   POINT NUMBER                 1          2          3          4          6
E  TIME                  11:19:13   11:24:59   11:39:32   11:42:21   12:52:57
X  F/A                    0.00890    0.00910    0.00930    0.00930    0.01230
H  WF(LB/HR)                879.0     1189.0     1487.0     2861.0     5340.0
A  HIGH ROTOR SPEED(RPM)    6360.      7515.      8130.      9830.     10860.
U  THRUST(LBS)               690.      1250.      1740.      5000.      9470.
S  TT2(DEG F)                77.0       77.0       77.0       77.0       78.0
T
   N2(%V BY DIFFERENCE)     79.06      79.08      78.51      78.18      78.32
   O2(%V)                   19.07      18.97      19.25      19.01      17.53
   H2O(%V) CALCULATED        0.92       0.95       1.10       1.38       2.05

   NO2(PPMV)                  1.0        2.2        2.0        4.6        4.6
C  NO(PPMV)                   5.6        6.9       10.9       29.3       78.3
O  NOX(LB/LB FUEL AS NO2)  0.0012     0.0016     0.0021     0.0058     0.0107
N  NOX(LB/HR AS NO2)          1.0        1.9        3.1       16.6       57.1
S
T  CO2(%V)                   0.93       0.98       1.13       1.42       2.10
I  CO2(LB/LB FUEL)          1.587      1.627      1.748      2.323      2.591
T  CO2(LB/HR)               1395.      1934.      2600.      6645.     13836.
U
E  CO(PPMV)                 215.3      119.5      100.6       43.8       17.3
N  CO(LB/LB FUEL)          0.0234     0.0127     0.0099     0.0045     0.0014
T  CO(LB/HR)                 20.5       15.1       14.7       13.0        7.2
S
   THC(PPMV AS CH4)          81.3       30.7       16.1        4.1        1.5
   THC(LB/LB FUEL)         0.0050     0.0019     0.0009     0.0002     0.0001
   THC(LB/HR)                 4.4        2.2        1.3        0.7        0.4


                    *  ALL DATA REPORTED WET  *
```

```
                                                                      PAGE   2

  GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

  ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

  DATE OF TEST    7/14/71

  ENGINE NUMBER            - P-665705

  ENGINE TYPE              - JT8D

  TEST STAND               - P-  67

  BURNER CONFIGURATION -

  FUEL                     - JP4C

     POINT NUMBER                        7           8           9
 E   TIME                         13: 3: 0    13:21:52    13:39:51
 X   F/A                           0.01310     0.01380     0.01510
 H   WF(LB/HR)                      6040.0      6700.0      8120.0
 A   HIGH ROTOR SPEED(RPM)          11060.      11230.      11560.
 U   THRUST(LBS)                    10700.      11720.      13660.
 S   TT2(DEG F)                       79.0        79.0        80.0
 T
     N2(%V BY DIFFERENCE)            78.35       78.35       78.14
     O2(%V)                          17.23       17.01       16.62
     H2O(%V) CALCULATED               2.17        2.28        2.59

     NO2(PPMV)                         5.8         3.9         7.3
 C   NO(PPMV)                         96.6       118.3       170.2
 O   NOX(LB/LB FUEL AS NO2)         0.0124      0.0141      0.0186
 N   NOX(LB/HR AS NO2)                74.9        94.2       151.4
 S
 T   CO2(%V)                          2.23        2.34        2.64
 I   CO2(LB/LB FUEL)                 2.583       2.573       2.655
 T   CO2(LB/HR)                     15600.      17237.      21559.
 U
 E   CO(PPMV)                         14.3        12.7        10.3
 N   CO(LB/LB FUEL)                 0.0011      0.0009      0.0007
 T   CO(LB/HR)                         6.4         5.9         5.3
 S
     THC(PPMV AS CH4)                  1.1         1.7         1.8
     THC(LB/LB FUEL)                0.0000      0.0001      0.0001
     THC(LB/HR)                        0.3         0.5         0.5


                    *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST   7/15/71

ENGINE NUMBER            - P-665706

ENGINE TYPE              - JT8D

TEST STAND               - P-  67

BURNER CONFIGURATION -

FUEL                     - JP4

   POINT NUMBER                  1          2          3          4          7
E  TIME                    9:21:16    9:33:10    9:43:20    9:50:44   11: 1:40
X  F/A                     0.00864    0.00902    0.00968    0.00919    0.01297
H  WF(LB/HR)                 872.0     1179.0     1481.0     2869.0     6065.0
A  HIGH ROTOR SPEED(RPM)     6340.      7405.      8060.      9770.     11035.
U  THRUST(LBS)                720.      1220.      1720.      5000.     10800.
S  TT2(DEG F)                 70.0       70.0       71.0       71.0       76.0
T
   N2(%V BY DIFFERENCE)      78.23      78.26      78.27      78.07      78.07
   O2(%V)                    19.82      19.76      19.60      19.02      17.46
   H2O(%V) CALCULATED         0.95       0.97       1.04       1.43       2.20

   NO2(PPMV)                   3.8        4.5        3.0        7.2        7.8
C  NO(PPMV)                    3.2        5.8        8.7       28.8       99.7
O  NOX(LB/LB FUEL AS NO2)   0.0013     0.0018     0.0019     0.0062     0.0131
N  NOX(LB/HR AS NO2)           1.1        2.1        2.8       17.8       79.7
S
T  CO2(%V)                    0.97       0.99       1.07       1.48       2.26
I  CO2(LB/LB FUEL)           1.693      1.668      1.684      2.437      2.641
T  CO2(LB/HR)                1481.      1967.      2493.      6992.     16016.
U
E  CO(PPMV)                  216.7      118.3       93.4       46.8       14.5
N  CO(LB/LB FUEL)           0.0242     0.0127     0.0093     0.0049     0.0011
T  CO(LB/HR)                  21.1       14.9       13.8       14.1        6.5
S
   THC(PPMV AS CH4)           75.3       14.2        3.7        6.5        2.0
   THC(LB/LB FUEL)          0.0048     0.0009     0.0002     0.0004     0.0001
   THC(LB/HR)                  4.2        1.0        0.3        1.1        0.5

                     *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST   7/15/71

ENGINE NUMBER          - P-665706

ENGINE TYPE            - JT8D

TEST STAND             - P-  67

BURNER CONFIGURATION -

FUEL                   - JP4


   POINT NUMBER                      8            9            6
E  TIME                       11:13:13     11:29:44     11:40:23
X  F/A                         0.01360      0.01470      0.01200
H  WF(LB/HR)                    6780.0       8010.0       5275.0
A  HIGH ROTOR SPEED(RPM)        11175.       11500.       10840.
U  THRUST(LBS)                  11850.       13600.        9540.
S  TT2(DEG F)                     74.0         75.0         76.0
T
   N2(%V BY DIFFERENCE)          78.11        78.00        78.45
   O2(%V)                        17.20        16.78        17.51
   H2O(%V) CALCULATED             2.31         2.58         1.99

   NO2(PPMV)                       8.3          8.1          8.2
C  NO(PPMV)                      120.0        165.3         85.9
O  NOX(LB/LB FUEL AS NO2)       0.0150       0.0187       0.0124
N  NOX(LB/HR AS NO2)             101.5        149.8         65.6
S
T  CO2(%V)                        2.37         2.63         2.04
I  CO2(LB/LB FUEL)               2.644        2.717        2.583
T  CO2(LB/HR)                   17925.       21764.       13623.
U
E  CO(PPMV)                       12.5         10.8         17.0
N  CO(LB/LB FUEL)               0.0009       0.0007       0.0014
T  CO(LB/HR)                       6.0          5.7          7.2
S
   THC(PPMV AS CH4)                5.8          6.7          3.9
   THC(LB/LB FUEL)              0.0002       0.0003       0.0002
   THC(LB/HR)                      1.6          2.0          0.9


               *  ALL DATA REPORTED WET  *
```

```
                                                                        PAGE      1

   GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

   ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

   DATE OF TEST   7/16/71

   ENGINE NUMBER          - P-665708

   ENGINE TYPE            - JT8D

   TEST STAND             - P-  67

   BURNER CONFIGURATION -

   FUEL                   - JP4

     POINT NUMBER                         1           2           3           4           5
 E   TIME                          31:28:42    31:42:53    12:18:11    12:32: 1    12:43:56
 X   F/A                            0.00940     0.00850     0.01240     0.01330     0.01410
 H   WF(LB/HR)                       2911.0       899.0      5340.0      6106.0      6875.0
 A   HIGH ROTOR SPEED(RPM)            9900.       6675.      10935.      11140.      11340.
 U   THRUST(LBS)                      5100.        740.       9500.      10750.      11950.
 S   TT2(DEG F)                        80.0        83.0        84.0        84.0        84.0
 T
     N2(%V BY DIFFERENCE)             78.75       79.69       79.31       79.24       79.06
     O2(%V)                           18.38       18.39       16.51       16.26       16.09
     H2O(%V) CALCULATED                1.41        0.94        2.05        2.22        2.39

     NO2(PPMV)                          6.1         4.7         7.8         8.8         9.7
 C   NO(PPMV)                          30.9         7.2        85.3       105.9       131.8
 O   NOX(LB/LB FUEL AS NO2)          0.0062      0.0022      0.0119      0.0137      0.0159
 N   NOX(LB/HR AS NO2)                 18.2         2.0        63.6        83.5       109.4
 S
 T   CO2(%V)                           1.46        0.95        2.11        2.27        2.45
 I   CO2(LB/LB FUEL)                  2.350       1.700       2.579       2.591       2.633
 T   CO2(LB/HR)                       6840.       1529.      13770.      15821.      18102.
 U
 E   CO(PPMV)                          44.8       227.7        17.4        13.8        12.0
 N   CO(LB/LB FUEL)                  0.0046      0.0259      0.0014      0.0010      0.0008
 T   CO(LB/HR)                         13.4        23.3         7.2         6.1         5.6
 S
     THC(PPMV AS CH4)                   6.0       102.1         3.3         4.6         3.2
     THC(LB/LB FUEL)                 0.0004      0.0066      0.0001      0.0002      0.0001
     THC(LB/HR)                         1.0         6.0         0.8         1.2         0.9


                         *  ALL DATA REPORTED WET  *
```

1

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-7764)

DATE OF TEST   7/16/71

ENGINE NUMBER   - P-665708

ENGINE TYPE   - JT8D

TEST STAND   - P- 67

BURNER CONFIGURATION -

FUEL   - JP4

```
   POINT NUMBER                       6
E  TIME                       13: 1:30
X  F/A                         0.01520
H  WF(LB/HR)                    8130.0
A  HIGH ROTOR SPEED(RPM)        11635.
U  THRUST(LBS)                  13650.
S  TT2(DEG F)                     84.0
T
   N2(%V BY DIFFERENCE)          78.91
   O2(%V)                        15.64
   H2O(%V) CALCULATED             2.69

   NO2(PPMV)                      10.4
C  NO(PPMV)                      174.5
O  NOX(LB/LB FUEL AS NO2)       0.0193
N  NOX(LB/HR AS NO2)             156.9
S
T  CO2(%V)                        2.74
I  CO2(LB/LB FUEL)               2.739
T  CO2(LB/HR)                   22267.
U
E  CO(PPMV)                       10.3
N  CO(LB/LB FUEL)               0.0007
T  CO(LB/HR)                       5.3
S
   THC(PPMV AS CH4)                1.9
   THC(LB/LB FUEL)              0.0001
   THC(LB/HR)                      0.6
```

* ALL DATA REPORTED WET *

```
                                                                          PAGE      1

   GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

   ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

   DATE OF TEST   7/20/71

   ENGINE NUMBER          - P-665709

   ENGINE TYPE            - JT8D

   TEST STAND             - P-   67

   BURNER CONFIGURATION -

   FUEL                   - JP4

      POINT NUMBER                      1            1            4            5            6
 E    TIME                       11:33:37     11:41: 1     12:43:53     12:58:50     13:11:31
 X    F/A                         0.00880      0.00950      0.01210      0.01300      0.01360
 H    WF(LB/HR)                     908.0       2843.0       5250.0       6035.0       6675.0
 A    HIGH ROTOR SPEED(RPM)         6620.        9790.       10810.       11030.       11205.
 U    THRUST(LBS)                    810.        5000.        9450.       10770.       11850.
 S    TT2(DEG F)                     72.0         73.0         74.0         74.0         76.0
 T
      N2(%V BY DIFFERENCE)          79.23        79.46        79.67        79.82        79.70
      O2(%V)                        18.86        17.74        16.18        15.77        15.43
      H2O(%V) CALCULATED             0.93         1.37         2.04         2.17         2.40

      NO2(PPMV)                       4.5          9.9         10.8          9.8          9.1
 C    NO(PPMV)                        5.8         29.8         78.6         98.2        120.5
 O    NOX(LB/LB FUEL AS NO2)       0.0019       0.0066       0.0117       0.0132       0.0151
 N    NOX(LB/HR AS NO2)               1.7         18.8         61.5         79.5        100.9
 S
 T    CO2(%V)                        0.95         1.42         2.10         2.23         2.46
 I    CO2(LB/LB FUEL)               1.639        2.261        2.629        2.600        2.742
 T    CO2(LB/HR)                    1488.        6427.       13804.       15689.       18305.
 U
 E    CO(PPMV)                      184.3         47.1         17.5         14.6         12.6
 N    CO(LB/LB FUEL)               0.0202       0.0048       0.0014       0.0011       0.0009
 T    CO(LB/HR)                      18.4         13.6          7.3          6.5          6.0
 S
      THC(PPMV AS CH4)               64.2          4.8          3.6          0.5          1.3
      THC(LB/LB FUEL)              0.0040       0.0003       0.0002       0.0000       0.0001
      THC(LB/HR)                      3.7          0.8          0.9          0.1          0.3


                        *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 7/20/71

ENGINE NUMBER - P-665709

ENGINE TYPE - JT8D

TEST STAND - P- 67

BURNER CONFIGURATION -

FUEL - JP4

	POINT NUMBER	7	8
E	TIME	13:28:27	13:50:40
X	F/A	0.01480	0.00880
H	WF(LB/HR)	8000.0	908.0
A	HIGH ROTOR SPEED(RPM)	11525.	6530.
U	THRUST(LBS)	13600.	780.
S	TT2(DEG F)	77.0	77.0
T			
	N2(%V BY DIFFERENCE)	79.78	81.72
	O2(%V)	14.89	16.27
	H2O(%V) CALCULATED	2.63	0.98
	NO2(PPMV)	10.8	6.7
C	NO(PPMV)	168.3	5.1
O	NOX(LB/LB FUEL AS NO2)	0.0192	0.0021
N	NOX(LB/HR AS NO2)	153.6	1.9
S			
T	CO2(%V)	2.68	1.00
I	CO2(LB/LB FUEL)	2.750	1.717
T	CO2(LB/HR)	21998.	1559.
U			
E	CO(PPMV)	10.6	197.2
N	CO(LB/LB FUEL)	0.0007	0.0216
T	CO(LB/HR)	5.5	19.6
S			
	THC(PPMV AS CH4)	2.0	64.5
	THC(LB/LB FUEL)	0.0001	0.0040
	THC(LB/HR)	0.6	3.7

* ALL DATA REPORTED WET *

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/21/71

ENGINE NUMBER          - P-674550

ENGINE TYPE            - JT8D

TEST STAND             - P-  67

BURNER CONFIGURATION -

FUEL                   - JP4

   POINT NUMBER                     1          2          3          4          5
E  TIME                      16:43:27   16:58:20   17:38:43   17:53:15   18: 6: 9
X  F/A(STA 7 UNCORR)          0.00960    0.01490    0.01210    0.01290    0.01360
H  WF(LB/HR)                   2833.0     8195.0     5360.0     6150.0     6865.0
A  HIGH ROTOR SPEED(RPM)        9860.     11650.     10945.     11150.     11330.
U  THRUST(LBS)                  5000.     13830.      9550.     10920.     12000.
S  TT2(DEG F)                    81.0       80.0       81.0       81.0       81.0
T
   N2(%V BY DIFFERENCE)         78.60      77.97      78.49      78.17      78.08
   O2(%V)                       18.71      16.88      17.54      17.24      17.01
   H2O(%V CALCULATED)            1.32       2.54       1.96       2.26       2.42

   NO2(PPMV)                      6.8        8.6        7.3        7.7        8.9
C  NO(PPMV)                      32.0      167.0       87.2      105.1      123.7
O  NOX(LB/LB FUEL AS NO2)      0.0064     0.0187     0.0124     0.0139     0.0155
N  NOX(LB/HR AS NO2)             18.1      153.2       66.4       85.3      106.2
S
T  CO2(%V)                       1.36       2.59       2.01       2.32       2.47
I  CO2(LB/LB FUEL)              2.151      2.642      2.520      2.727      2.759
T  CO2(LB/HR)                   6093.     21653.     13508.     16773.     18941.
U
E  CO(PPMV)                      40.0       11.0       16.6       14.1       12.7
N  CO(LB/LB FUEL)              0.0040     0.0007     0.0013     0.0011     0.0009
T  CO(LB/HR)                     11.4        5.8        7.1        6.5        6.2
S
   THC(PPMV AS CH4)               4.4        1.8        3.5        1.3        1.2
   THC(LB/LB FUEL)             0.0003     0.0001     0.0002     0.0001     0.0001
   THC(LB/HR)                     0.7        0.6        0.8        0.3        0.3

               *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/21/71

ENGINE NUMBER           - P-674550

ENGINE TYPE             - JT8D

TEST STAND              - P-   67

BURNER CONFIGURATION -

FUEL                    - JP4


   POINT NUMBER                     6            7
E  TIME                      18:13:25     18:31:41
X  F/A(STA 7 UNCORR)          0.01165      0.00860
H  WF(LB/HR)                   8195.0        912.0
A  HIGH ROTOR SPEED(RPM)       11650.        6540.
U  THRUST(LBS)                 13800.         800.
S  TT2(DEG F)                    81.0         81.0
T
   N2(%V BY DIFFERENCE)         77.96        79.38
   O2(%V)                       16.63        18.86
   H2O(%V CALCULATED)            2.67         0.86

   NO2(PPMV)                      9.7          5.4
C  NO(PPMV)                     162.3          2.4
O  NOX(LB/LB FUEL AS NO2)      0.0234       0.0014
N  NOX(LB/HR AS NO2)            191.9          1.3
S
T  CO2(%V)                       2.72         0.87
I  CO2(LB/LB FUEL)              3.545        1.540
T  CO2(LB/HR)                  29049.        1404.
U
E  CO(PPMV)                      11.0        220.3
N  CO(LB/LB FUEL)              0.0009       0.0247
T  CO(LB/HR)                      7.5         22.6
S
   THC(PPMV AS CH4)               4.6         86.9
   THC(LB/LB FUEL)             0.0002       0.0056
   THC(LB/HR)                     1.8          5.1


              *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/19/71

ENGINE NUMBER          - P-666987

ENGINE TYPE            - JT8D

TEST STAND             - P-  67

BURNER CONFIGURATION -    10

FUEL                   - JP4

   POINT NUMBER                        1          2          3          4          5
E  TIME                         17:13:14   10: 1:32   18:11: 7   18:22:40   10:30:54
X  F/A(STA 7 UNCORR)             0.00959    0.01234    0.01333    0.01395    0.01509
H  WF(LB/HR)                      2929.0     5375.0     6190.0     6860.0     8195.0
A  HIGH ROTOR SPEED(RPM)           9880.     10910.     11125.     11294.     11590.
U  THRUST(LBS)                     5040.      9520.     10850.     11950.     13750.
S  TT2(DEG F)                       84.0       82.0       82.0       81.0       80.0
T
   N2(%V BY DIFFERENCE)            78.43      78.35      78.20      78.23      78.05
   O2(%V)                          18.26      16.93      16.67      16.43      16.07
   H2O(%V CALCULATED)               1.63       2.32       2.53       2.64       2.90

   NO2(PPMV)                         6.5        9.1        9.1        9.1        9.4
C  NO(PPMV)                          0.0       85.9      105.2      124.1      166.0
O  NOX(LB/LB FUEL AS NO2)         0.0011     0.0122     0.0136     0.0151     0.0184
N  NOX(LB/HR AS NO2)                 3.2       65.6       84.2      103.9      151.1
S
T  CO2(%V)                          1.68       2.38       2.58       2.69       2.95
I  CO2(LB/LB FUEL)                 2.652      2.927      2.941      2.928      2.971
T  CO2(LB/HR)                      7767.     15733.     18205.     20087.     24347.
U
E  CO(PPMV)                         49.3       18.5       15.0       13.2       10.7
N  CO(LB/LB FUEL)                 0.0050     0.0014     0.0011     0.0009     0.0007
T  CO(LB/HR)                        14.5        7.8        6.7        6.2        5.6
S
   THC(PPMV AS CH4)                  5.9        3.3        3.2        3.5        4.5
   THC(LB/LB FUEL)                0.0003     0.0001     0.0001     0.0001     0.0002
   THC(LB/HR)                        1.0        0.8        0.8        1.0        1.4

                     * ALL DATA REPORTED WET *
```

```
                                                              PAGE    2

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/19/71

ENGINE NUMBER            - P-666987

ENGINE TYPE              - JT8D

TEST STAND               - P-  67

BURNER CONFIGURATION -    B/M

FUEL                     - JP4

   POINT NUMBER                    6
E  TIME                     18:45:29
X  F/A(STA 7 UNCORR)         0.00846
H  WF(LB/HR)                   911.0
A  HIGH ROTOR SPEED(RPM)       6680.
U  THRUST(LBS)                  840.
S  TT2(DEG F)                   80.0
T
   N2(%V BY DIFFERENCE)        79.60
   O2(%V)                      18.54
   H2O(%V CALCULATED)           0.91

   NO2(PPMV)                     2.3
C  NO(PPMV)                      6.8
O  NOX(LB/LB FUEL AS NO2)     0.0017
N  NOX(LB/HR AS NO2)             1.6
S
T  CO2(%V)                      0.92
I  CO2(LB/LB FUEL)             1.657
T  CO2(LB/HR)                  1510.
U
E  CO(PPMV)                    195.2
N  CO(LB/LB FUEL)             0.0223
T  CO(LB/HR)                    20.3
S
   THC(PPMV AS CH4)             31.1
   THC(LB/LB FUEL)            0.0020
   THC(LB/HR)                    1.8

            *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/20/71

ENGINE NUMBER             - P-666988

ENGINE TYPE               - JT8D

TEST STAND                - P-  67

BURNER CONFIGURATION -  B/M

FUEL                      - JP4

   POINT NUMBER                   1          3          4          5          6
E  TIME                    13:59:54   14:38:44   17:14:18   15:31:50   15:41:22
X  F/A(STA 7 UNCORR)        0.00989    0.00343    0.01237    0.01319    0.01406
H  WF(LB/HR)                 2932.0      910.0     5280.0     5990.0     6860.0
A  HIGH ROTOR SPEED(RPM)      9920.      6745.     10925.     11120.     11330.
U  THRUST(LBS)                5050.       890.      9350.     10550.     11900.
S  TT2(DEG F)                  87.0       86.0       88.0       88.0       87.0
T
   N2(%V BY DIFFERENCE)       78.29      79.77      78.22      78.18      78.11
   O2(%V)                     18.40      18.09      17.07      16.78      16.47
   H2O(%V CALCULATED)          1.63       1.05       2.32       2.48       2.67

   NO2(PPMV)                    9.5        5.3        9.7        9.9       11.9
C  NO(PPMV)                    34.6        0.2       85.7      102.6      127.4
O  NOX(LB/LB FUEL AS NO2)    0.0071     0.0010     0.0122     0.0135     0.0157
N  NOX(LB/HR AS NO2)           20.7        0.9       64.6       81.1      107.8
S
T  CO2(%V)                     1.68       1.07       2.38       2.54       2.73
I  CO2(LB/LB FUEL)            2.572      1.921      2.918      2.919      2.943
T  CO2(LB/HR)                 7542.      1748.     15407.     17484.     20188.
U
E  CO(PPMV)                    41.9      189.2       17.4       14.7       12.7
N  CO(LB/LB FUEL)            0.0041     0.0217     0.0014     0.0011     0.0009
T  CO(LB/HR)                   12.0       19.7        7.2        6.5        6.0
S
   THC(PPMV AS CH4)             5.9       29.6        4.9        3.2        3.3
   THC(LB/LB FUEL)           0.0003     0.0019     0.0002     0.0001     0.0001
   THC(LB/HR)                   1.0        1.8        1.2        0.8        0.9

             *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/20/71

ENGINE NUMBER          - P-666988

ENGINE TYPE            - JT8D

TEST STAND             - P-  67

BURNER CONFIGURATION -   10

FUEL                   - JP4

   POINT NUMBER                     7
E  TIME                      16: 1:22
X  F/A(STA 7 UNCORR)          0.01517
H  WF(LB/HR)                   8110.0
A  HIGH ROTOR SPEED(RPM)       11640.
U  THRUST(LBS)                 13550.
S  TT2(DEG F)                    87.0
T
   N2(%V BY DIFFERENCE)         77.56
   O2(%V)                       16.06
   H2O(%V CALCULATED)            3.15

   NO2(PPMV)                     13.3
C  NO(PPMV)                     165.7
O  NOX(LB/LB FUEL AS NO2)      0.0187
N  NOX(LB/HR AS NO2)            151.8
S
T  CO2(%V)                       3.20
I  CO2(LB/LB FUEL)              3.204
T  CO2(LB/HR)                  25986.
U
E  CO(PPMV)                      10.6
N  CO(LB/LB FUEL)              0.0007
T  CO(LB/HR)                      5.4
S
   THC(PPMV AS CH4)               5.0
   THC(LB/LB FUEL)             0.0002
   THC(LB/HR)                     1.5

              *  ALL DATA REPORTED WET  *
```

1

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/ 7/71

ENGINE NUMBER          - X-495-14

ENGINE TYPE            - JT9D

TEST STAND             - X-    7

BURNER CONFIGURATION -    10

FUEL                   - JP4C


   POINT NUMBER                    1          2          3          4          5
E  TIME                     21:21: 1   21:38:41   21:48: 1   22: 1:12   22:13:11
X  F/A(STA 7 UNCORR)         0.00860    0.00910    0.01140    0.01680    0.01820
H  WF(LB/HR)                  1732.0     2071.0     4246.0    11879.0    14183.0
A  HIGH ROTOR SPEED(RPM)       4956.      5330.      6386.      7252.      7394.
U  THRUST(LBS)                 2948.      4028.     10167.     31208.     36753.
S  TT2(DEG F)                   81.6       80.3       79.4       78.4       78.2
T
   N2(%V BY DIFFERENCE)        78.27      78.15      77.86      77.24      77.12
   O2(%V)                      19.48      18.45      17.68      16.04      15.61
   H2O(%V CALCULATED)           1.58       1.67       2.19       3.32       3.60

   NO2(PPMV)                     4.5        8.1        9.0       12.5       16.2
C  NO(PPMV)                      9.3       12.0       41.7      226.0      319.4
O  NOX(LB/LB FUEL AS NO2)     0.0025     0.0035     0.0071     0.0225     0.0293
N  NOX(LB/HR AS NO2)             4.3        7.3       30.0      267.5      415.7
S
T  CO2(%V)                      1.59       1.68       2.24       3.37       3.64
I  CO2(LB/LB FUEL)             2.736      2.804      2.985      3.043      3.033
T  CO2(LB/HR)                  4739.      5808.     12675.     36149.     43018.
U
E  CO(PPMV)                    488.0      361.5       84.2       12.2       11.0
N  CO(LB/LB FUEL)             0.0535     0.0384     0.0071     0.0007     0.0006
T  CO(LB/HR)                    92.7       79.4       30.3        8.3        8.3
S
   THC(PPMV AS CH4)            243.0       68.9       14.7        6.3        5.8
   THC(LB/LB FUEL)            0.0152      .0042     0.0007     0.0002     0.0002
   THC(LB/HR)                   26.4        8.7        3.0        2.5        2.5


                 *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/ 7/71

ENGINE NUMBER          - X-495-14

ENGINE TYPE            - JT9D

TEST STAND             - X-   7

BURNER CONFIGURATION -

FUEL                   - JP4C

    POINT NUMBER                      6          7          8          9         10
F   TIME                      22:22: 5   22:32:41   22:43:20   22:50:55   23: 3:15
X   F/A(STA 7 UNCORR)          0.01940    0.01680    0.01530    0.01010    0.00840
H   WF(LB/HR)                  16052.0    12588.0     8420.0     3250.0     1882.0
A   HIGH ROTOR SPEED(RPM)        7556.      7288.      7168.      6048.      5151.
U   THRUST(LBS)                 40970.     33044.     20780.      7538.      3413.
S   TT2(DEG F)                    76.9       76.6       76.6       76.4       76.3
T
    N2(%V BY DIFFERENCE)         77.09      77.49      77.84      78.66      78.74
    O2(%V)                       15.22      15.76      16.19      17.60      18.07
    H2O(%V CALCULATED)            3.81       3.34       2.95       1.84       1.56

    NO2(PPMV)                     21.6       14.5       10.6       12.4       11.2
C   NO(PPMV)                     404.1      251.7      141.1       26.8        6.9
O   NOX(LB/LB FUEL AS NO2)      0.0348     0.0251     0.0157     0.0062     0.0034
N   NOX(LB/HR AS NO2)            558.7      316.4      132.5       20.0        6.4
S
T   CO2(%V)                       3.84       3.38       3.00       1.88       1.57
I   CO2(LB/LB FUEL)              3.004      3.056      2.977      2.826      2.827
T   CO2(LB/HR)                  48213.     38467.     25064.      9185.      5321.
U
E   CO(PPMV)                      11.6       11.2       17.7      150.6      423.2
N   CO(LB/LB FUEL)              0.0006     0.0006     0.0011     0.0144     0.0486
T   CO(LB/HR)                      9.2        8.1        9.4       46.8       91.5
S
    THC(PPMV AS CH4)               7.6        6.3        6.8       34.1      184.3
    THC(LB/LB FUEL)             0.0002     0.0002     0.0002     0.0019     0.0121
    THC(LB/HR)                     3.5        2.6        2.1        6.1       22.8

              *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/ 0/ 1

ENGINE NUMBER          - X-495-14

ENGINE TYPE            - JT9D

TEST STAND             - X-   7

BURNER CONFIGURATION -

FUEL                   - 0 NOT PROPER CODE


  POINT NUMBER                    11         12         13         14         15
E TIME                      10:50: 1   10:59:23   13:12:30   13:33:13   13:40:17
X F/A(STA 7 UNCORR)          0.00980    0.01000    0.01350    0.01910    0.02100
H WF(LB/HR)                   1749.0     2102.0     4846.0    12469.0    15218.0
A HIGH ROTOR SPEED(RPM)        4977.      5370.      6622.      7420.      7580.
U THRUST(LBS)                  2742.      3764.     11040.     30841.     37004.
S TT2(DEG F)                    85.2       79.9       81.7       84.8       82.3
T
  N2(%V BY DIFFERENCE)         78.08      77.93      77.63      76.58      76.55
  O2(%V)                       18.59      18.65      17.55      16.02      15.40
  H2O(%V CALCULATED)            1.57       1.65       2.38       3.67       3.99

  NO2(PPMV)                      8.2       10.7        8.7       17.3       24.0
C NO(PPMV)                       7.5       10.8        0.0      278.6      411.1
O NOX(LB/LB FUEL AS NO2)      0.0025     0.0034     0.0010     0.0246     0.0329
N NOX(LB/HR AS NO2)              4.4        7.2        5.0      306.4      500.1
S
T CO2(%V)                       1.58       1.66       2.43       3.70       4.01
I CO2(LB/LB FUEL)              2.441      2.524      2.736      2.942      2.900
T CO2(LB/HR)                   4269.      5305.     13260.     36686.     44135.
U
E CO(PPMV)                    1069.8      751.7       55.8       10.6        9.7
N CO(LB/LB FUEL)              0.1053     0.0725     0.0040     0.0005     0.0004
T CO(LB/HR)                    184.3      152.6       19.4        6.7        6.8
S
  THC(PPMV AS CH4)             233.0      127.5        7.7        2.1        4.5
  THC(LB/LB FUEL)             0.0131     0.0070     0.0003     0.0001     0.0001
  THC(LB/HR)                    22.9       14.8        1.5        0.8        1.8


                  *   ALL DATA REPOPTED WET   *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/ 8/71

ENGINE NUMBER          - X-495-14

ENGINE TYPE            - JT9D

TEST STAND             - X-   7

BURNER CONFIGURATION -    10

FUEL                   - JP4C

   POINT NUMBER                   16          17          18          19          20
E  TIME                       11:51: 0    12: 3:51    12:12:56    12:25:39    12:38:32
X  F/A(STA 7 UNCORR)           0.02020     0.02020     0.01630     0.01160     0.00990
H  WF(LB/HR)                   14128.0     13834.0      8618.0      3397.0      1960.0
A  HIGH ROTOR SPEED(RPM)         7503.       7485.       7108.       6178.       5272.
U  THRUST(LBS)                  34530.      33946.      21482.       7306.       3323.
S  TT2(DEG F)                     82.0        81.9        84.5        84.0        84.6
T
   N2(%V BY DIFFERENCE)          76.80       76.87       77.71       78.47       78.62
   O2(%V)                        15.48       15.56       16.39       17.44       18.00
   H2O(%V CALCULATED)             3.82        3.75        2.92        2.01        1.66

   NO2(PPMV)                      21.3        20.2        10.7        13.6        13.3
C  NO(PPMV)                      344.5       322.1       136.5        28.5         6.9
O  NOX(LB/LB FUEL AS NO2)       0.0287      0.0269      0.0143      0.0058      0.0032
N  NOX(LB/HR AS NO2)             405.8       371.8       123.4        19.6         6.3
S
T  CO2(%V)                        3.86        3.78        2.97        2.05        1.67
I  CO2(LB/LB FUEL)               2.896       2.843       2.764       2.688       2.562
T  CO2(LB/HR)                   40912.      39325.      23819.       9130.       5021.
U
E  CO(PPMV)                        9.5         9.7        15.9       116.8       369.4
N  CO(LB/LB FUEL)               0.0005      0.0005      0.0009      0.0097      0.0360
T  CO(LB/HR)                       6.4         6.4         8.1        33.0        70.6
S
   THC(PPMV AS CH4)                9.7         9.6         5.7        21.9       141.1
   THC(LB/LB FUEL)              0.0003      0.0003      0.0002      0.0010      0.0079
   THC(LB/HR)                      3.7         3.6         1.7         3.5        15.4




                  *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   8/71/25

ENGINE NUMBER           - X-495-14

ENGINE TYPE             - JT9D

TEST STAND              - X-   7

BURNER CONFIGURATION -      7

FUEL                    - 0 NOT PROPER CODE

    POINT NUMBER                   21          22          23          24          25
E   TIME                     17:11:36    17:23:44    17:30:56    17:52:11    17:59:31
X   F/A(STA 7 UNCORR)         0.00900     0.00937     0.01280     0.01780     0.01930
H   WF(LB/HR)                  1700.0      2063.0      4930.0     12778.0     15004.0
A   HIGH ROTOR SPEED(RPM)       4898.       5310.       6642.       7381.       7564.
U   THRUST(LBS)                 2482.       3493.      10968.      31280.      36151.
S   TT2(DEG F)                   89.4        90.5        90.4        88.7        89.6
T
    N2(%V BY DIFFERENCE)        78.76       78.76       78.33       77.60       77.33
    O2(%V)                      17.58       17.55       16.73       15.24       14.65
    H2O(%V CALCULATED)           1.79        1.81        2.44        3.54        3.97

    NO2(PPMV)                    11.1        15.3        13.0        17.5        25.2
C   NO(PPMV)                      9.6        13.8        62.4       314.1       465.4
O   NOX(LB/LB FUEL AS NO2)     0.0036      0.0049      0.0093      0.0296      0.0403
N   NOX(LB/HR AS NO2)             6.2        10.2        46.1       377.7       605.1
S
T   CO2(%V)                      1.90        1.83        2.49        3.58        4.00
I   CO2(LB/LB FUEL)             3.036       2.968       2.949       3.055       3.146
T   CO2(LB/HR)                  5161.       6122.      14537.      39040.      47202.
U
E   CO(PPMV)                    468.1       340.5        73.0         9.9         9.8
N   CO(LB/LB FUEL)             0.0502      0.0351      0.0055       .0005       .0005
T   CO(LB/HR)                    85.4        72.4        27.1         6.9         7.4
S
    THC(PPMV AS CH4)            240.6       132.8         9.5         2.2         0.9
    THC(LB/LB FUEL)            0.0147      0.0078      0.0004      0.0001      0.0000
    THC(LB/HR)                   25.1        16.1         2.0         0.9         0.4


                    *   ALL DATA REPORTED WET   *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST  70/07/13

ENGINE NUMBER          - X-495-14

ENGINE TYPE            - JT9D

TEST STAND             - X-   7

BURNER CONFIGURATION -

FUEL                   - 0 NOT PROPER CODE

    POINT NUMBER                  26         27         28         29         30
E   TIME                    18:28:21   18:30:37   18:40:23   18:53: 0   23: 3:24
X   F/A(STA 7 UNCORR)        0.01840    0.01490    0.01080    0.00910    0.01200
H   WF(LB/HR)                13610.0     8540.0     3504.0     1871.0     4925.0
A   HIGH ROTOR SPEED(RPM)      7433.      7050.      6185.      5119.      6538.
U   THRUST(LBS)               33051.     21006.      7297.      2951.     10962.
S   TT2(DEG F)                  89.3       88.3       88.0       87.9       87.5
T
    N2(%V BY DIFFERENCE)       77.67      78.37      78.88      78.97      78.11
    O2(%V)                     14.84      15.93      16.90      17.31      16.86
    H2O(%V CALCULATED)          3.71       2.81       2.08       1.78       2.48

    NO2(PPMV)                   20.3       11.9       15.9       13.5        8.3
C   NO(PPMV)                   367.6      142.4       41.6       17.1       50.9
O   NOX(LB/LB FUEL AS NO2)    0.0334     0.0164     0.0084     0.0053     0.0078
N   NOX(LB/HR AS NO2)          455.0      140.2       29.6       10.0       38.5
S
T   CO2(%V)                     3.75       2.87       2.12       1.80       2.53
I   CO2(LB/LB FUEL)            3.088      2.920      2.981      2.996      3.202
T   CO2(LB/HR)                42030.     24938.     10446.      5606.     15772.
U
E   CO(PPMV)                    10.0       22.4      136.0      832.3       69.3
N   CO(LB/LB FUEL)            0.0005     0.0014     0.0122     0.0883     0.0056
T   CO(LB/HR)                    7.1       12.4       42.6      165.2       27.4
S
    THC(PPMV AS CH4)             2.3        2.5       26.0      173.9        5.4
    THC(LB/LB FUEL)           0.0001     0.0001     0.0013     0.0105     0.0002
    THC(LB/HR)                   1.0        0.8        4.6       19.7        1.2

                  *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   0/10/97   _ _

ENGINE NUMBER            - X-495-14

ENGINE TYPE              - JT12

TEST STAND               - X-5000

BURNER CONFIGURATION     - 7000

FUEL                     - JP4C

   POINT NUMBER                31          32          33
E  TIME                     1:14:58     3:10:11     4:33:15
X  F/A(STA 7 UNCORR)        0.01700     0.01780     0.00390
H  WF(LB/HR)                12255.0     13540.0      1827.0
A  HIGH ROTOR SPEED(RPM)      5095.       7302.       4970.
U  THRUST(LBS)               30560.      33733.       2909.
S  TT2(DEG F)                  71.1        69.5        70.2
T
   N2(%V BY DIFFERENCE)       77.35       77.20       74.36
   O2(%V)                     15.47       15.21       18.16
   H2O(%V CALCULATED)          3.56        3.76        1.67

   NO2(PPMV)                   13.8         0.4         0.5
C  NO(PPMV)                   224.4       268.7         7.8
O  NOX(LB/LB FUEL AS NO2)    0.0222      0.0239      0.0014
N  NOX(LB/HR AS NO2)          272.3       324.8 8       2.7
S
T  CO2(%V)                     3.60        3.80        1.62
I  CO2(LB/LB FUEL)            3.213       3.237        2.76
T  CO2(LB/HR)                39370.      43833.       5045.
U
E  CO(PPMV)                    11.1        10.7        555.
N  CO(LB/LB FUEL)            0.0006      0.0006      0.0602
T  CO(LB/HR)                    7.7         7.9       110.0
S
   THC(PPMV AS CH4)             4.0         2.5       333.8
   THC(LB/LB FUEL)           0.0001      0.0001      0.0210
   THC(LB/HR)                   1.6         1.1        38.4


              *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/28/71

ENGINE NUMBER          - P-685605 ▽

ENGINE TYPE            - JT9D

TEST STAND             - P-   3

BURNER CONFIGURATION -    B/M

FUEL                   - JP4

   POINT NUMBER                        1          2          34          4          5
E  TIME                         10:29:26   10:43:43   12:53:56   11: 1:47   13: 8:15
X  F/A(SIA 7 UNCORR)             0.00837    0.00837    0.00837    0.01930    0.01842
H  WF(LB/HR)                      1719.0     1884.0     2010.0    16571.0    15604.0
A  HIGH ROTOR SPEED(RPM)           4925.      5116.      5238.      7322.      7288.
U  THRUST(LBS)                     3373.      3954.      4368.     45955.     43794.
S  TT2(DEG F)                       72.8       73.5       74.6       74.9       75.0
T
   N2(%V BY DIFFERENCE)            76.71      78.19      78.64      77.75      78.10
   O2(%V)                          19.89      18.43      17.95      15.24      15.17
   H2O(%V CALCULATED)               1.66       1.65       1.67       3.46       3.32

   NO2(PPMV)                         0.0        0.0        3.6       19.3       19.8
C  NO(PPMV)                         15.9       16.1       15.8      376.0      369.3
O  NOX(LB/LB FUEL AS NO2)         0.0030     0.0031     0.0037     0.0325     0.0335
N  NOX(LB/HR AS NO2)                 5.2        5.8        7.4      538.5      522.8
S
T  CO2(%V)                          1.67       1.67       1.69       3.50       3.37
I  CO2(LB/LB FUEL)                 3.026      3.025      3.059      2.755      2.775
T  CO2(LB/HR)                      5201.      5699.      6148.     45657.     43308.
U
E  CO(PPMV)                        454.1      377.9      308.8        7.5        4.3
N  CO(LB/LB FUEL)                 0.0524     0.0436     0.0356     0.0004     0.0002
T  CO(LB/HR)                        90.0       82.1       71.6        6.2        3.5
S
   THC(PPMV AS CH4)                180.7      122.8       85.2        5.9        2.9
   THC(LB/LB FUEL)                0.0119     0.0081     0.0056     0.0002     0.0001
   THC(LB/HR)                       20.5       15.3       11.3        2.8        1.4

                     * ALL DATA REPORTED WET *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 7/28/ 0

ENGINE NUMBER - P-685605 ▽

ENGINE TYPE - JT9D

TEST STAND - P- 3

BURNER CONFIGURATION - ~~B~~ B/M

FUEL - 0 ~~NOT PROPER CODE~~ JP4

```
    POINT NUMBER                     61          7          8          9         10
E   TIME                       13:10:57   11:22:27   11:29:27   11:32:43   11:43: 4
X   F/A(STA 7 UNCORR)           0.01842    0.01758    0.01758    0.01674    0.01674
H   WF(LB/HR)                   15031.0    14356.0    13846.0    13132.0    12588.0
A   HIGH ROTOR SPEED(RPM)         7268.      7235.      7210.      7165.      7133.
U   THRUST(LBS)                  42510.✓    40841.✓    39597.✓    37742.✓    36453.✓
S   TT2(DEG F)                     75.2       75.4       75.5       77.1       76.6
T
    N2(%V BY DIFFERENCE)          77.95      78.28      78.48      78.63      78.89
    O2(%V)                        14.91      14.73      14.62      14.57      14.51
    H2O(%V CALCULATED)             3.53       3.45       3.41       3.36       3.26

    NO2(PPMV)                      19.6       18.9       16.2       15.6       37.9
C   NO(PPMV)                      324.7      314.5      290.8      262.6      242.2
O   NOX(LB/LB FUEL AS NO2)       0.0296     0.0301     0.0277     0.0264     0.0265
N   NOX(LB/HR AS NO2)             447.1      431.9      383.5      346.1      334.1
S
T   CO2(%V)                        3.58       3.50       3.45       3.41       3.31
I   CO2(LB/LB FUEL)               2.946      3.019      2.981      3.098      2.997
T   CO2(LB/HR)                   44431.     43339.     41280.     40553.     37729.
U
E   CO(PPMV)                        3.1        4.0        6.5        6.1       23.2
N   CO(LB/LB FUEL)               0.0002     0.0002     0.0004     0.0004     0.0013
T   CO(LB/HR)                       2.4        3.1        5.0        4.6       16.9
S
    THC(PPMV AS CH4)                5.6        4.8        4.2        4.3        0.0
    THC(LB/LB FUEL)              0.0002     0.0002     0.0001     0.0001     0.0
    THC(LB/HR)                      2.5        2.2        1.8        1.9        0.0
```

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 7/28/71

ENGINE NUMBER - P-585605 ∇

ENGINE TYPE - JT9D

TEST STAND - P- 3

BURNER CONFIGURATION - ⇌ B/M

FUEL - 0 ~~NOT PROPER CODE~~ JP4

	POINT NUMBER	11A	12A	13A	14A	15A
E	TIME	11:50: 1	11:59:22	12: 1:36	12:12:26	12:18:11
X	F/A(STA 7 UNCORR)	0.01591	0.01591	0.01507	0.01507	0.01507
H	WF(LB/HR)	11910.0	11492.0	10896.0	10291.0	9789.0
A	HIGH ROTOR SPEED(RPM)	7089.	7061.	7026.	6980.	6938.
U	THRUST(LBS)	34632. ✓	33976. ✓	32108. ✓	30445. ✓	29146. ✓
S	TT2(DEG F)	77.6	76.5	76.2	77.2	77.0
T						
	N2(%V BY DIFFERENCE)	79.14	79.35	79.44	79.52	79.65
	O2(%V)	14.48	14.51	14.55	14.58	14.62
	H2O(%V CALCULATED)	3.15	3.03	2.97	2.90	2.82
	NO2(PPMV)	27.5	19.0	26.5	24.7	25.2
C	NO(PPMV)	221.3	201.6	184.5	414.0	368.0
O	NOX(LB/LB FUEL AS NO2)	0.0248	0.0220	0.0222	0.0462	0.0414
N	NOX(LB/HR AS NO2)	295.5	252.7	242.0	475.2	405.0
S						
T	CO2(%V)	3.20	3.08	3.02	2.95	2.87
I	CO2(LB/LB FUEL)	3.051	2.939	3.037	2.968	2.890
T	CO2(LB/HR)	36342.	33779.	33096.	30544.	28293.
U						
E	CO(PPMV)	22.6	27.9	27.3	29.2	31.5
N	CO(LB/LB FUEL)	0.0014	0.0017	0.0018	0.0019	0.0020
T	CO(LB/HR)	16.3	19.5	19.1	19.2	19.7
S						
	THC(PPMV AS CH4)	0.5	1.6	2.7	25.7	20.2
	THC(LB/LB FUEL)	0.0000	0.0001	0.0001	0.0009	0.0007
	THC(LB/HR)	0.2	0.6	1.1	9.7	7.2

* ALL DATA REPORTED WET *

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST    7/28/71

ENGINE NUMBER          - P-685602 ☐

ENGINE TYPE            - JT9D

TEST STAND             - P-    3

BURNER CONFIGURATION -    10

FUEL                   - JP4

    POINT NUMBER                         1           2           3           4           5
E   TIME                          16: 1:36    16:11:11    16:18:53    16:21:33    16:34:58
X   F/A(STA 7 UNCORR)              0.01930     0.01842     0.01753     0.01674     0.01507
H   WF(LB/HR)                      16549.0     14921.0     13827.0     12307.0     10347.0
A   HIGH ROTOR SPEED(RPM)            7330.       7264.       7203.       7110.       6983.
U   THRUST(LBS)                     45787.      42070.      39345.      35544.      30448.
S   TT2(DEG F)                        80.0        80.0        80.0        81.0        80.0
T
    N2(%V BY DIFFERENCE)             77.37       77.72       77.87       78.18       78.44
    O2(%V)                           14.78       14.83       14.98       15.13       15.42
    H2O(%V CALCULATED)                3.89        3.68        3.53        3.31        3.05

    NO2(PPMV)                         26.4        23.8        19.7        16.7        13.3
C   NO(PPMV)                         442.7       377.9       319.9       256.1         0.0
O   NOX(LB/LB FUEL AS NO2)          0.0336      0.0346      0.0306      0.0258      0.0015
N   NOX(LB/HR AS NO2)                638.0       516.1       423.7       318.1        15.0
S
T   CO2(%V)                           3.92        3.72        3.57        3.35        3.10
I   CO2(LB/LB FUEL)                  3.080       3.065       3.085       3.040       3.118
T   CO2(LB/HR)                      50973.      45736.      42658.      37414.      32263.
U
E   CO(PPMV)                           7.3         6.5         6.1         5.7         6.4
N   CO(LB/LB FUEL)                  0.0004      0.0003      0.0003      0.0003      0.0004
T   CO(LB/HR)                          6.0         5.1         4.7         4.1         4.2
S
    THC(PPMV AS CH4)                   8.9        18.1        13.3         9.5         7.4
    THC(LB/LB FUEL)                 0.0003      0.0005      0.0004      0.0003      0.0003
    THC(LB/HR)                         4.2         9.1         5.8         3.8         2.8


                  *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/28/71

ENGINE NUMBER          - P-685602 ☐

ENGINE TYPE            - JT9D

TEST STAND             - P-   3

BURNER CONFIGURATION -

FUEL                   - JP4

   POINT NUMBER                      6          7          8
E  TIME                       16:42:31   16:42: 6   16:51:26
X  F/A(STA 7 UNCORR)           0.00837    0.00837    0.00837
H  WF(LB/HR)                    1595.0     1797.0     1926.0
A  HIGH ROTOR SPEED(RPM)         4895.      5060.      5177.
U  THRUST(LBS)                   3077.      3570.      4009.
S  TT2(DEG F)                     80.0       80.0       80.0
T
   N2(%V BY DIFFERENCE)          79.45      79.43      79.40
   O2(%V)                        17.30      17.27      17.23
   H2O(%V CALCULATED)             1.59       1.61       1.65

   NO2(PPMV)                      15.0       16.3       17.1
C  NO(PPMV)                       10.4       11.5       12.6
O  NOX(LB/LB FUEL AS NO2)       0.0048     0.0053     0.0056
N  NOX(LB/HR AS NO2)               7.7        9.5       10.9
S
T  CO2(%V)                        1.60       1.63       1.67
I  CO2(LB/LB FUEL)               2.896      2.957      3.031
T  CO2(LB/HR)                    4620.      5314.      5838.
U
E  CO(PPMV)                      410.6      351.2      314.6
N  CO(LB/LB FUEL)               0.0473     0.0405     0.0363
T  CO(LB/HR)                      75.5       72.8       69.9
S
   THC(PPMV AS CH4)              152.6      114.7       92.8
   THC(LB/LB FUEL)              0.0101     0.0076     0.0051
   THC(LB/HR)                     16.0       13.6       11.8


            *  ALL DATA REPORTED WET  *
```

```
GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST   7/29/71

ENGINE NUMBER            - P-663 71     O

ENGINE TYPE              - JT9D

TEST STAND               - P-   3

BURNER CONFIGURATION -     10

FUEL                     - JP4

   POINT NUMBER                  10          2          3          4          5
E  TIME                    13:10:16   13:23:51   13:33:32   13:50:17   13:53:11
X  F/A(STA 7 UNCORR)        0.00878    0.00790    0.00790    0.01844    0.01490
H  WF(LB/HR)                 1555.0     1707.0     1811.0    15364.0    10998.0
A  HIGH ROTOR SPEED(RPM)      4765.      4983.      5108.      7403.      7169.
U  THRUST(LBS)                2626.      3205.      3595.     43656.     32599.
S  TT2(DEG F)                  79.7       81.9       81.4       80.9       81.7
T
   N2(%V BY DIFFERENCE)       78.86      78.98      79.13      77.48      78.11
   O2(%V)                     17.55      17.49      17.30      14.59      15.11
   H2O(%V CALCULATED)          1.75       1.73       1.74       3.94       3.35

   NO2(PPMV)                    7.2       10.6       12.9       17.3       16.7
C  NO(PPMV)                     9.6        9.1        8.8      265.6      209.1
O  NOX(LB/LB FUEL AS NO2)    0.0030     0.0040     0.0044     0.0243     0.0240
N  NOX(LB/HR AS NO2)            4.7        6.8        7.9      373.9      264.4
S
T  CO2(%V)                     1.74       1.73       1.75       3.97       3.40
I  CO2(LB/LB FUEL)            3.014      3.328      3.368      3.263      3.460
T  CO2(LB/HR)                 4686.      5682.      6099.     50126.     38057.
U
E  CO(PPMV)                   572.7      473.7      429.9       12.0       18.1
N  CO(LB/LB FUEL)            0.0630     0.0579     0.0525     0.0006     0.0012
T  CO(LB/HR)                   97.9       98.8       95.2        9.6       12.9
S
   THC(PPMV AS CH4)           401.9      280.1      226.5        5.2        4.1
   THC(LB/LB FUEL)           0.0253     0.0196     0.0158     0.0002     0.0002
   THC(LB/HR)                  39.3       33.4       28.6        2.4        1.7


               *  ALL DATA REPORTED WET  *
```

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST 7/29/71 O

ENGINE NUMBER - P-663 71

ENGINE TYPE - JT9D

TEST STAND - P- 3

BURNER CONFIGURATION - 10

FUEL - JP4

	POINT NUMBER	6	7	8
E	TIME	10:41:32	22: 6:19	22:17:59
X	F/A(STA 7 UNCORR)	0.01405	0.01580	0.01668
H	WF(LB/HR)	9912.0	12323.0	13712.0
A	HIGH ROTOR SPEED(RPM)	7075.	7279.	7373.
U	THRUST(LBS)	30066.	36393.	39943.
S	TT2(DEG F)	75.7	75.5	75.6
T				
	N2(%V BY DIFFERENCE)	79.16	77.98	77.96
	O2(%V)	15.26	15.40	15.05
	H2O(%V CALCULATED)	2.75	3.27	3.46
	NO2(PPMV)	6.2	14.6	15.4
C	NO(PPMV)	167.3	204.9	219.2
O	NOX(LB/LB FUEL AS NO2)	0.0196	0.0220	0.0223
N	NOX(LB/HR AS NO2)	194.2	271.6	306.0
S				
T	CO2(%V)	2.80	3.32	3.51
I	CO2(LB/LB FUEL)	3.029	3.188	3.189
T	CO2(LB/HR)	30019.	39289.	43722.
U				
E	CO(PPMV)	21.2	16.1	12.2
N	CO(LB/LB FUEL)	0.0015	0.0010	0.0007
T	CO(LB/HR)	14.5	12.1	9.7
S				
	THC(PPMV AS CH4)	2.1	0.8	1.2
	THC(LB/LB FUEL)	0.0001	0.0000	0.0000
	THC(LB/HR)	0.8	0.3	0.5

* ALL DATA REPORTED WET *

GAS TURBINE EXHAUST ANALYSIS REPORT - MEASURED

ENGINE EMISSION ANALYSIS GROUP - (PHONE 203-565-3873)

DATE OF TEST ~~59/57/16~~ 8/5/71

ENGINE NUMBER ~~X 03 41~~ P685614 O

ENGINE TYPE - JT9D-7

TEST STAND ~~X 33~~ P3

BURNER CONFIGURATION - ~~100~~ B/M

FUEL ~~0 NOT PROPER CODE~~ JP4

	POINT NUMBER	1	2	3	4	5
E	TIME	16:12:25	16:24:19	16:32:51	10:30:37	10:43:12
X	F/A(STA 7 UNCORR)	0.00860	0.01700	0.01300	0.00860	0.00860
H	WF(LB/HR)	2224.0	13464.0	16252.0	2230.0	1685.0
A	HIGH ROTOR SPEED(RPM)	5453.	7220.	7405.	5457.	4758.
U	THRUST(LBS)	5325.	39014.	45834.	5330.	3397.
S	TT2(DEG F)	76.0	74.7	74.4	75.0	74.9
T						
	N2(%V BY DIFFERENCE)	80.93	78.73	78.73	80.66	81.95
	O2(%V)	15.65	14.50	14.13	16.04	15.23
	H2O(%V CALCULATED)	1.68	3.34	3.53	1.62	1.38
	NO2(PPMV)	16.2	17.5	25.3	14.9	4.8
C	NO(PPMV)	4.9	272.3	421.1	16.1	0.3
O	NOX(LB/LB FUEL AS NO2)	0.0039	0.0270	0.0393	0.0057	0.0009
N	NOX(LB/HR AS NO2)	8.7	364.1	639.3	12.8	1.6
S						
T	CO2(%V)	1.71	3.39	3.57	1.65	1.38
I	CO2(LB/LB FUEL)	3.016	3.026	3.009	2.905	2.438
T	CO2(LB/HR)	6708.	40747.	48894.	6479.	4107.
U						
E	CO(PPMV)	256.2	3.4	3.1	271.0	425.7
N	CO(LB/LB FUEL)	0.0288	0.0002	0.0002	0.0304	0.0478
T	CO(LB/HR)	64.0	2.6	2.7	67.8	80.5
S						
	THC(PPMV AS CH4)	47.6	1.1	0.4	56.0	141.9
	THC(LB/LB FUEL)	0.0031	0.0000	0.0000	0.0036	0.0091
	THC(LB/HR)	6.8	0.5	0.2	8.0	15.3

* ALL DATA REPORTED WET *