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Small Gas Turbine Combustor Primary Zone Study

R. E. Sullivan, E. R. Young, G. A. Miles, and J.R. Williams

Detroit Diesel Allison
Division of General Motors Corporation
P. O. Box 894
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Final Report for Period September 1980 through December 1982

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Cleveland, OH 44135
Under Contract NAS3-22762

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I. SUMMARY

This report documents the design, analysis, and testing of three reverse-flow annular combustor concepts resulting from NASA Contract NAS 3-22762, Small Gas Turbine Combustor Primary Zone Study. The objective of the program was to verify a design methodology using a three-dimensional (3-D) combustor primary zone (PZ) performance computer model for optimizing the design process and for gaining insight into combustor PZ performance. Three reverse-flow annular combustor concepts were used with at least five modifications made to each concept.

The Concept I reverse-flow combustor was a swirl-stabilized, double-vortex, annular combustor. The double vortex in the primary zone resulted from the combination of prechamber swirled air, a sudden expansion into the primary zone, and opposing rows of PZ air entry holes. A baseline liner and five modified versions were designed, analyzed with the 3-D computer model, fabricated, and then tested on a combustor rig. Liner modifications included a change in swirler angle; adjustments in PZ hole spacing, number of holes, and area of holes; and an increase in the porosity of the Lamilloy®* cooling material.

The Concept II reverse-flow combustor was a swirl-stabilized, double-vortex, reverse-circulation annular combustor with some film cooling in addition to the Lamilloy cooling as in Concept I. This combustor liner incorporated an upstream (reverse) film air cooling for the liner dome and forward portion of the primary zone and was subsequently used as a portion of the PZ combustion air. A baseline liner and five modified versions of this concept were also designed, analyzed, fabricated, and tested. The modifications included a change in swirler angle, increases and decreases in the PZ hole areas, and operation on only eight of the sixteen fuel nozzles.

The Concept III reverse-flow combustor was an annulus-air-aligned, single-vortex design. In this concept the PZ flame stabilization was accomplished by a single large torus created by a single-loop film cooling system and angled primary-air entry jets. Increasing the size of the PZ vortex permitted the reduction in the number of fuel nozzles from sixteen to twelve. In addition to having fewer fuel nozzles, each fuel nozzle was chuted to enhance premixing and prevaporizing of the fuel and air and to permit precise placement of the fuel in the primary zone. A baseline and eight modifications were evaluated in the program. The modifications included changes in fuel placement, changes in the PZ air between inner and outer shells, and changes to the fuel chute designs.

The major analytical effort in this program was the application of a 3-D aerodynamic combustor flow-field model to the design and test-result correlation. The model, designated MARC-I for multidimensional aerodynamic recirculation combustion--version I, is the Detroit Diesel Allison (DDA) adaptation of the 3-D recirculating (elliptic) reacting flow model developed by the Garrett Corporation for the U.S. Army Research and Technology Laboratories (AVRADCOM). MARC-I was used to analyze each of the twenty-one combustor designs. After testing of the combustor designs, the analytical and experimental data were compared to assess both qualitative and quantitative agreement.

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*Lamilloy is a registered trademark of General Motors Corporation.

In conclusion, the MARC-I three-dimensional, combustor PZ computer model proved to be a beneficial tool in combustion system design and development. Good agreement was found between analytical and experimental PZ fuel-air ratio distributions, and the three combustor concepts evaluated illustrated that the PZ stabilization can be obtained with various internal aerodynamic and fuel injection methods. As design requirements dictate unique combustor concepts, the computer model will become an increasingly more useful tool.

II. INTRODUCTION

The program discussed herein was part of an effort directed by NASA Lewis Research Center to advance the combustion technology for small gas turbine engines. This report documents the work performed under contract NAS 3-22762, Small Gas Turbine Combustor Primary Zone Study. This program evaluated design methodology and geometric approaches for obtaining the maximum performance potential of reverse-flow annular combustors. This combustor type has gained wide acceptance in small engine designs since it allows a close-coupled compressor-to-turbine shafting arrangement, resulting in a compact engine design.

The objective of this technology-generation program was to improve design methods applicable to the reverse-flow annular combustor. The program goal is to formulate an understanding of PZ aerodynamics and its relation to performance optimization. The emphasis is to improve the design process and gain insight into PZ performance through interactive analysis and test. Analytical models and test results are used to define the interaction of internal airflow patterns with fuel concentrations and burning patterns. Combustors with three distinctively different PZ flame stabilization patterns were included in this evaluation.

All performance goals for the three basic combustor designs were achieved. Despite the varied approaches for achieving flame stabilization by controlling the internal flow paths, each combustor exhibited very acceptable total performance. Gas temperature profiles, stability limits, efficiency, smoke, emissions, and metal-temperature levels were well within the range of acceptable preliminary-design standards. In addition, the effective use of the 3-D analytical aerodynamic/combustion model as a design aid was demonstrated and verified by test results. The performance predictions of the 3-D model provided the needed insight and better understanding of the PZ aerodynamics.

The baseline combustor for this investigation is a reverse-flow annular of similar size and construction to the DDA combustor used in the GMA500 engine currently under development for the U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia. The primary zone of this combustor features a conventional, double-vortex, swirl-stabilized flow pattern resulting from the interaction of swirl and PZ air jets. Two other combustor concepts were studied which have variations in the flame-stabilization swirl patterns of the primary zone. The second combustor was constructed to achieve a reverse-circulation, double-vortex pattern, while the third combustor concept exhibited a single-vortex flame-stabilization pattern.

The program elements consisted of the design process and analytical performance predictions, fabrication, and test evaluations. Test data were obtained at the intermediate plane of the PZ exit and also at the combustor exit. The test results were correlated with the analysis to validate and update design procedures. This report contains analytical and performance data from each element of the design and development process.

III. COMBUSTOR DESIGN PROCEDURE

The design process proceeds in a manner of iterative steps as illustrated in Figure 1. Once the operating conditions and performance goals are established, the type of combustor selected is often dictated from engine component arrangements. Preliminary sizing consists of aerodynamic and chemical loading considerations. Widely accepted practices used for this step are described in the Combustor Design Methods Manual by Northern Research (Ref 1). Variations of this general sizing method are usually at the discretion and preference of the designer.

The design conditions for this program were as follows:

Inlet pressure	1014 kPa (10 atm)
Inlet temperature	672 K (740°F)
Airflow	2.27 kg/s (5 lb/sec)
Temperature rise	695 K (1250°F)
Max liner metal temperature	1144 K (1600°F)
Pressure drop	4%

The final design and development of the combustor is an interactive process between the detail analytical models and feedback from test evaluations. This development phase continues until all performance objectives for the combustor are realized.

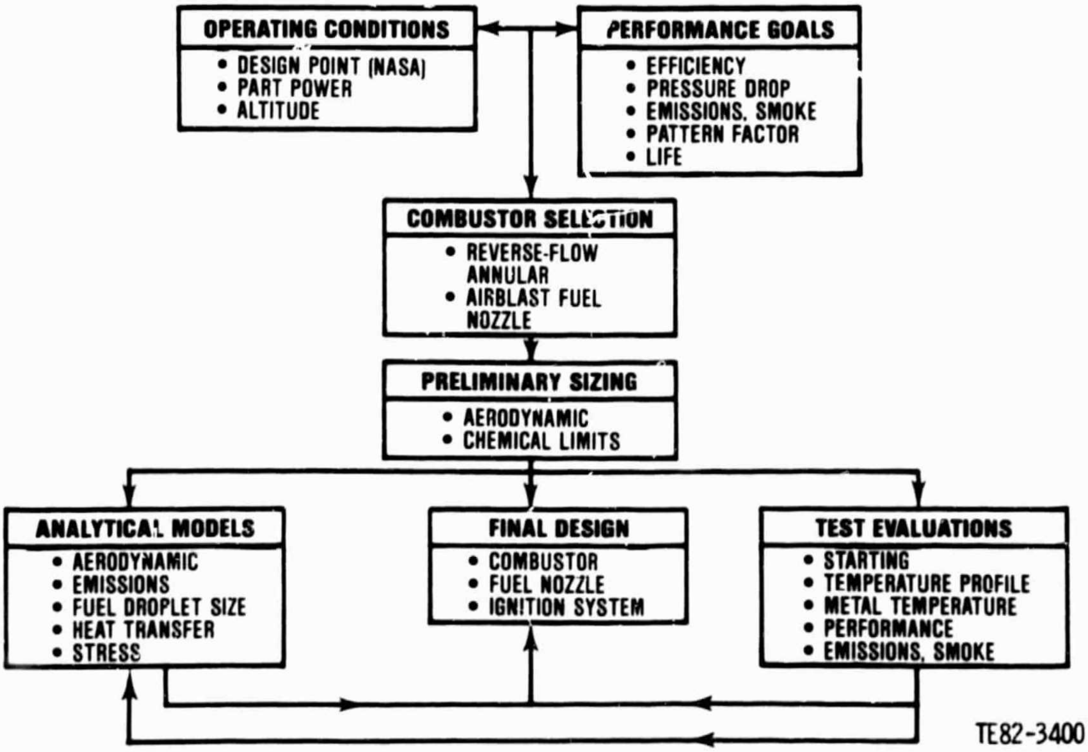

Figure 1. Flowchart for primary zone program.

The major analytical effort in this program was the application of a 3-D aerodynamic combustor flow-field model to the design and test-result correlation. The model, designated MARC-I for multidimensional aerodynamic recirculation combustion--version I, is the DDA adaptation of the 3-D recirculating (elliptic) reacting flow model developed by the Garrett Corporation for the U.S. Army Research and Technology Laboratories (AVRADCOM) (Ref 2). MARC-I is a primitive variable, finite-difference computer code that solves the Navier-Stokes equations for a three-dimensional reactive flow field. Turbulence is simulated by a two-equation K-ϵ model, and combustion following drop vaporization is determined by a two-step chemical reaction model based on Arrhenius and eddy breakup concepts. A six-flux radiation model is also incorporated.

The following variables are computed by MARC-I:

- o velocity (axial, radial, and swirl components)
- o pressure
- o enthalpy (and, derived from that, temperature and density)
- o kinetic energy of turbulence and dissipation rate
- o composition (mass fractions of fuel, O_2, N_2, CO, CO_2, and H_2O)
- o radiation flux vectors
- o fuel spray trajectory and evaporation rate

The transport equations for all dependent variables ϕ are of the following general form:

$$\text{div}\left(\rho \vec{u}\phi - \frac{\mu_{eff}}{\sigma_\phi}\text{grad}\,\phi\right) = S_\phi$$

where

ρ	is the mixture density
$\vec{u}$	is the velocity vector
μ_{eff}	is the effective turbulence
σ_ϕ	is the effective Prandtl/Schmidt number
S_ϕ	is the source term for ϕ

An iterative finite-difference solution procedure is used to solve the resulting system of nonlinear, partial-differential equations.

MARC-I has been updated to incorporate the following gas turbine combustor geometrical features:

- o prechambers
- o internal walls
- o rounded dome walls
- o axial dome swirlers
- o vertical dome slots
- o slanted liner entries
- o reverse cooling slots

In addition, an extensive plotting and restart capability has been incorporated into the program. Restart is the terminology used to describe the storage of the computer solution for a combustor design and its subsequent use to begin the solution for a similar design. This technique has significantly reduced the number of iterations required for successful numerical convergence.

By means of an IBM 370/3081 computer the MARC-I model was used to analyze each of the 21 combustor configurations tested during this program. The computer grids used for each of the three combustor concepts are listed in Table I. A complete solution for a combustor design required about 300 computer iterations. A complete solution was required for each of the three concept baseline combustor designs. Using the restart capability, the successive modified combustor revisions required only 100 iterations, thus saving significant machine time. In general, 100 iterations of a 1000-point grid required 4.7 CPU minutes of computer time. The complete solution for the Concept I baseline combustor design was 40.3 CPU minutes. The restart solution for the Concept I mod 1 combustor design was about 13.4 CPU minutes.

Table I.
MARC-I solution grids for the three primary zone combustor concepts.

	Number of grid points			
Combustor	Axial	Radial	Circumferential	Total
Concept I	17	13	13	2873
Concept II	17	17	17	4913
Concept III	27	19	15	7695

The program demonstrated the value of the MARC-I model as a useful tool to the combustor designer. The accuracy of analytical performance predictions compared to test results has not reached a level of precision desired for complete reliance on the analytical method. Combustor designs and performance attainable will still rely heavily upon the quasi-empirical correlations developed from test experience by manufacturers over the years. The analytical model, however, does exhibit the potential of effective interaction with the design process by helping to visualize the resulting aerodynamic effects of geometric variations in the combustor. Design guidance results and experimental costs are reduced when many candidate designs can be studied before committing a chosen design to hardware.

IV. COMBUSTOR DESIGNS

Full-size, reverse-flow annular combustors are being evaluated in this program. The combustors are swirl-stabilized systems established by PZ air entry ports and swirlers. A prechamber cup surrounds the fuel nozzles in the baseline combustor, where partial premixing and prevaporizing of the air and fuel occur prior to entry into the primary zone. Both axial and radial swirlers have been used to induce swirl in the prechamber zone.

Three distinctly different combustor concepts, shown in Figure 2*, were selected to provide a wide scope approach to this investigative program. Each combustor was designed with a different aerodynamic approach to the internal flow patterns that provide the fuel vaporization paths and the flame stabilization regions within the primary zone. These combustors incorporate features that address the elements of the small annular combustor that have been identified as sources of problems. Direct apprcaches to some problem areas were the application of advanced Lamilloy cooling and simplex airblast fuel nozzles as shown in Figure 3. Unique design approaches were to recycle air used for cooling back into the primary zone for combustion or to utilize air management techniques involving hole locations and swirlers to provide desired fuel-to-air distribution in the primary zones.

The fuel nozzle used for each of the combustor concepts was a simplex-airblast type composed of two subassemblies. The first subassembly was the simplex fuel atomizer shown in Figure 4. The atomizer was mounted through the outer combustor case and piloted inside the airblast swirler subassembly (see Figure 5). The airblast swirler was mounted as a floating ferrule at the front of the combustor liner prechamber. The air passing through the swirler vanes further atomized the fuel from the simplex injector and also helped generate the prechamber swirl aerodynamics. Separation of the simplex injector and the airblast swirler into subassemblies permitted the swirler portion to be a part of the combustor liner, thus simplifying the fuel injecting portion of the nozzle.

The combustor PZ concepts selected for study are identified by aerodynamic flow patterns:

Concept I	double-vortex swirl-stabilized
Concept II	double-vortex swirl-stabilized reverse-circulation
Concept III	single-vortex stabilized

For each of the three combustor concepts, a baseline configuration and five modifications were designed. These eighteen combustor versions are summarized in Table II. Subsequent paragraphs in this section will describe the design of each combustor concept baseline and the five modifications made to each combustor concept. Three additional modifications to the Concept III combustor were designed and evaluated in the contract addendum. These designs are described in Appendix A.

CONCEPT I: DOUBLE-VORTEX, SWIRL-STABILIZED COMBUSTOR

The double-vortex, swirl-stabilized combustor was selected as the Concept I combustor because it represents conventional techniques for obtaining the

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*The figures for this section appear at the end of the section.

flame stabilization pattern. The double vortex is achieved by a combination of a radial-inflow swirler and opposing rows of PZ air entry jets. Lamilloy transpiration cooling was utilized for all the walls of the combustor. The high effectiveness of this cooling technique reduces the amount of cooling air required. Also, the cooling-air entry into the primary zone is at a uniform temperature level and eliminates flame quenching normally associated with films in close proximity to the walls.

Table II.
Combustor configuration summary.

Combustor	Version	Description
Concept I	Baseline	45 deg prechamber swirler
Swirl stabilized	Mod 1	30 deg prechamber swirler
Double vortex	Mod 2	30 deg swirler, close PZ hole spacing
	Mod 3	Double number of PZ holes
	Mod 4	Reduced-area PZ holes
	Mod 5	Increased Lamilloy cooling airflow
Concept II	Baseline	30 deg axial swirler
Swirl stabilized	Mod 1	45 deg axial swirler
Double vortex	Mod 2	45 deg swirler, 50% more PZ hole area
Reverse cooling flow	Mod 3	100% more PZ hole area
	Mod 4	Original PZ hole area, 8 fuel nozzles
	Mod 5	All PZ air at active fuel nozzles
Concept III	Baseline	Fuel tubes radially out
Annulus air aligned	Mod 1	Fuel tubes circumferential clockwise
Single vortex	Mod 2	Fuel tubes circumferential counterclockwise
	Mod 3	Fuel tubes out, increased outer PZ air, decreased inner PZ air
	Mod 4	All outer PZ air
	Mod 5	All inner PZ air

Baseline Combustor

A dimensional sketch of the Concept I baseline combustor can be seen in Figure 6. The baseline combustor has 16 fuel injectors resulting in a 1.4 circumference/height spacing. These fuel nozzles are a combination simplex-airblast type. The basic nozzle consists of a simple shell encasing a filter, spin chamber. and single-orifice tip exit. An air swirler, separately attached to the combustor dome, surrounds the external nozzle casing. The combined parts form the components of an airblast nozzle which utilizes high-velocity air passing through the swirler to improve fuel atomization. The Concept I baseline combustor has 32 primary air-addition holes (2 per nozzle) through the inner liner shell plus 32 primary holes (2 per nozzle) through the outer shell. There are no intermediate zone (IZ) holes. Like the primary holes, there are 32 dilution zone (DZ) air-addition holes through the inner shell and 32 through the outer shell. All remaining air enters through the Lamilloy cooling surfaces. A summary of the air distributions for the Concept I baseline and all five of the Concept I liner mods is presented in Table III.

Table III.
Concept I combustor design summary.

	Concept I					
	Base	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5
Axial swirler blade angle	45 deg	30 deg	30 deg	30 deg	30 deg	30 deg
Number fuel nozzles	16	16	16	16	16	16
Outer shell						
PZ holes						
Number holes/nozzle	2	2	2	4	4	2
Spacing* Pair 1	0.250	0.250	0.083	0.083	0.083	0.250
Pair 2	---	---	---	0.250	0.250	---
Area, %	6.9	7.1	7.1	12.5	7.2	7.0
Number IZ holes/nozzle	0	0	0	0	0	0
Number DZ holes/nozzle	2	2	2	2	2	2
Inner shell						
PZ holes						
Number holes/nozzle	2	2	2	4	4	2
Spacing* Pair 1	0.250	0.250	0.083	0.083	0.083	0.250
Pair 2	---	---	---	0.250	0.250	---
Area, %	5.9	6.0	6.0	10.7	6.1	6.0
Number IZ holes/nozzle	0	0	0	0	0	0
Number DZ holes/nozzle	2	2	2	2	2	2
Total effective area, mm^2	3425.9	3341.4	3341.4	3780.1	3345.3	3368.7
%	100.00	97.53	97.53	110.34	97.65	98.33
Lamilloy porosity, C_d	0.0053	0.0053	0.0053	0.0053	0.0053	0.0057
Liner areas, %						
Dome swirlers	14.4	12.3	12.3	10.9	12.3	12.2
PZ holes total	12.8	13.1	13.1	23.2	13.3	13.0
IZ holes total	0	0	0	0	0	0
DZ holes total	39.6	40.6	40.6	35.9	40.6	40.2
Cooling total	33.0	34.0	34.0	30.1	33.9	34.6
PZ equivalence ratio at 100% power	0.944	0.998	0.998	0.780	0.992	1.005

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*Spacing = angle of hole from nozzle centerline/angle between nozzles

The Concept I baseline combustor, as well as all of the other combustors, was analyzed with the three-dimensional combustor model described in Section III. For each combustor configuration the 3-D model generated plots of fuel-air ratio in the primary zone at various radial planes so that the interaction of the fuel spray and the combustion air could be observed. Typical of these theoretical investigations are fuel-air plots, shown in Figures 7 through 9.

Figure 7 is a prediction of the circumferential average fuel-air ratios for the Concept I baseline combustor for a one-fuel-nozzle centered liner sector (the fuel nozzle is centered at 11.25 deg) in a radial plane located 54.6 mm downstream of the fuel-nozzle exit. This plane corresponds to the location of the PZ gas-sampling probe used in the experimental portion of the program. For the combustor operating at the 80% power condition, the average fuel-air ratio varied from 0.021 to 0.074 in each fuel-nozzle sector. Predicted fuel-air ratios for each of the experimental probes are given in Figure 8. These curves illustrate the fuel-air ratio variation across the liner annulus at each of three circumferential positions. Figure 9 shows a fuel-air ratio map of the entire 22.5 deg sector surrounding each fuel nozzle. The view direction for this map is downstream. This type of plot clearly reveals the high and low concentrations of the fuel in the primary zone of the Concept I baseline combustor. The axial position of the plane depicted in Figure 9 is plane of the experimental PZ gas-sampling probe. The predicted contours show that the baseline combustor should have four fuel-air peaks spaced around the fuel-nozzle centerline. If a series of fuel-air contour maps at different axial planes were stacked together, the result would be Figure 10. In this representation of the baseline annulus sector the map from Figure 9 is the plane identified as 54.6 mm downstream. For reference, the prechamber exit is the 13.1 mm location plane, the primary holes are located at the 35.6 mm plane, and the dilution holes are located at 68.8 mm or about halfway between the planes 54.6 mm and 76.2 mm shown. In this type of presentation, the effects of the prechamber swirl, the primary holes, and the dilution holes on the fuel spray can all be traced as the fuel spray passes down the combustor liner.

In a similar manner the gas temperatures and the local combustion efficiencies can be traced through the combustor liner, as illustrated by Figures 11 and 12.

An internal aerodynamic analysis of the liner flow fields was also performed for the first 76.2 mm downstream of the fuel nozzle tip. Figure 13 shows a series of radial planes at 12.7, 17.8, 35.6, and 48.3 mm downstream of the fuel nozzle. Physically these planes correspond to the prechamber flow just prior to the exit, the PZ flow just inside the primary zone, the flow in the plane of the PZ air entry holes, and the PZ flow downstream of the primary holes. Figure 14 is a similar set of velocity plots but in the axial plane of the baseline liner. With the fuel nozzle located at 11.25 deg, a series of velocity plots are presented at circumferential locations of 0, 0.1667, 0.5, and 0.8333 of the half angle spacing between the fuel nozzles.

Mod 1 Combustor

The first modification to the baseline Concept I combustor was the change in the blade angle of the axial swirler surrounding the fuel nozzle from 45 deg of turning to 60 deg of turning or an angle of 30 deg. There were no other changes made to the combustor. Figure 15 shows the fuel-air ratio map in the radial plane of the PZ gas-sample probes for the mod 1 combustor liner. Comparison of this map with the baseline map in Figure 9 shows no change in the distribution of fuel-air in this plane. A look at the liner internal velocities in the axial plane of the fuel nozzle (see Figure 16) does show a change with the increase in swirl number. The velocity map now shows a definite reverse flow region upstream from the plane of the PZ holes to the exit of the prechamber. This reverse flow region is, however, either too small or too weak to have any effect on the PZ combustor performance.

Mod 2 Combustor

The second modification to the Concept I baseline combustor was to move the PZ holes in the inner and outer shells closer to the centerline of the fuel nozzle. The 30 deg swirler from Concept I, mod 1, was retained. Thus there were no changes made other than the moving of the primary holes.

The average circumferential fuel-air ratio for this mod is shown in Figure 17. It shows a definite depression of the fuel-air ratio profile near the axis of the fuel nozzle as compared to the profile in the Concept I baseline design in Figure 7. The sector fuel-air ratio map for this configuration in Figure 18 also shows the evening of the fuel-air pattern. The fuel-air peaks were reduced thus indicating a potential reduction of NO_x and smoke which result from the high-temperature fuel-rich pockets in the primary zone.

Velocity diagrams for Concept I, mod 2, simply show the movement of the air jets toward the fuel nozzle in the axial plane. The radial plane velocities shown in Figure 19 would indicate that all of the flow would be directed toward the center and then would flow circumferentially away from the fuel nozzle. The recirculation seen in Figure 13c for the baseline combustor design would not be present.

Mod 3 Combustor

The third modification to the Concept I baseline combustor was to utilize all of the primary zone holes from mods 1 and 2. This increase in primary zone holes was intended to further smooth the fuel-air ratio distribution in the primary zone. This smoothing process is evident in Figure 20, where the fuel-air ratio average varied only between 0.031 to 0.049. It is clear in Figure 21 that the rich pockets in the primary zone have been substantially reduced.

The velocity diagram in the radial plane given in Figure 22 shows that the majority of the flow in this zone is toward the center of the annulus with the recirculation occurring between the fuel nozzles.

Mod 4 Combustor

The fourth modification to the Concept I baseline combustor was to utilize all of the primary zone holes from mods 1 and 2, but to reduce the flow area of the holes to be equivalent with the baseline flow. There was concern that the large holes in mod 3 were overpenetrating and would thus be detrimental to the performance in the primary zone. The circumferential-average, fuel-air ratio pattern, as seen in Figure 23, is between the baseline pattern, which was high in the middle of the sector, and the mod 3 pattern, which was low in the middle of the sector. The radial-plane, fuel-air ratio profiles in Figure 24 also show that the fuel is reasonably uniform but somewhat concentrated in line with the fuel nozzles.

The radial-plane velocity profiles in Figure 25 indicate more mixing in line with the fuel nozzle due to the air jets penetrating less toward the center of the annulus.

Mod 5 Combustor

The fifth modification to the Concept I baseline combustor was to replace the PZ Lamilloy with a more porous, higher flowing Lamilloy to further improve the durability of the combustor in the primary zone. The swirler and PZ hole pattern were returned to the configuration of Concept I, mod 1. Aerodynamics analysis of this combustor modification did not show any effect in the internal flow field. This is due to the fact that the Lamilloy flow was increased only 7.5%. The low flow of Lamilloy and its very shallow air penetration beyond the liner wall contribute to the lack of effect on the flow pattern.

Design Summary

A summary of the radial-plane fuel-air ratio patterns for each of the Concept I combustors is shown in Figure 26. It is clear from inspection of these profiles that the change in axial swirler (mod 1) and the change in Lamilloy porosity (mod 5) had negligible influences on the internal distributions. Changing the PZ air-injection hole sizes and/or location does make predictable changes to the internal flow distributions. Coupling of these changes in the primary zone with their effects on combustor internal and exit performance is an area that will be discussed in the results portion of this report.

CONCEPT II: DOUBLE-VORTEX, SWIRL-STABILIZED, REVERSE-CIRCULATION COMBUSTOR

The double-vortex, swirl-stabilized reverse-circulation combustor was selected as the Concept II combustor because the PZ aerodynamics appears to be well suited for small gas turbine combustors having problems with fuel impingement on the PZ walls or with quenching in a cooling film near the walls. In the reverse-flow design, the PZ cooling-air film is directed upstream and intermixes with the combustion air by entering the reaction zone from behind the fuel spray. This cooling-air regeneration leaves no path of escape for the quenched products of combustion without passing through the more favorable hot reaction zone. Lamilloy transpiration cooling was utilized for all of the remaining walls of the combustor. The high effectiveness of Lamilloy reduces the amount of cooling air required for the rest of the combustor liner.

Baseline Combustor

A dimensional sketch of the Concept II baseline combustor can be seen in Figure 27. The baseline combustor has 16 fuel injectors resulting in a 1.4 circumference/height spacing. These fuel nozzles are a combination simplex-airblast type and were the same nozzles used with the Concept I combustor. The Concept II baseline combustor has 16 primary air-addition holes (1 per nozzle) through the inner liner shell plus 16 primary holes (1 per nozzle) through the outer shell. Each of the holes is located on the centerline of a fuel nozzle. The air enters through formed air bushings. There are 32 intermediate zone holes (2 per nozzle) through the inner shell and 32 holes (2 per nozzle) through the outer shell. Similarly, there are 32 dilution air-addition holes through the inner shell and 32 through the outer shell. All remaining air enters through the PZ reverse film cooling slots, the fuel nozzle swirler, or the Lamilloy cooling surfaces. A summary of the air distributions for the Concept II baseline and all five of the Concept II liner mods is presented in Table IV.

Table IV.
Concept II combustor design summary.

	Concept II					
	Base	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5
Axial swirler blade angle	30 deg	45 deg	45 deg	45 deg	45 deg	45 deg
Number fuel nozzles	16	16	16	16	8	8
Outer shell						
PZ holes						
Number holes/active nozzle	1	1	1	1	1	3
Area, %	3.6	3.5	5.0	6.5	6.5	6.7
Number IZ holes/active nozzle	2	2	2	2	2	2
Number DZ holes/active nozzle	2	2	2	2	2	2
Inner shell						
PZ holes						
Number holes/active nozzle	1	1	1	1	1	3
Area, %	3.0	3.0	4.3	5.5	5.5	5.7
Number IZ holes/active nozzle	2	2	2	2	2	2
Number DZ holes/active nozzle	2	2	2	2	2	2
Total effective area, mm^2	3333.1	3417.6	3526.0	3633.7	3633.7	3653.8
%	100.00	102.54	105.79	109.02	109.02	109.62
Lamilloy porosity, C_d	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053
Liner areas, %						
Dome swirlers	6.0	8.4	8.1	7.9	7.9	7.8
PZ holes total	6.6	6.5	9.3	12.0	12.0	12.4
IZ holes total	6.6	6.5	6.3	6.1	6.1	6.0
DZ holes total	40.7	39.7	38.5	37.3	37.4	37.1
Cooling total	39.9	39.0	37.8	36.8	36.8	36.5
PZ equivalence ratio at 100% power	1.121	1.041	0.969	0.903	1.452*	0.900

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*Based on effective air for each active fuel nozzle

The Concept II baseline combustor, as well as all of the other combustors, was analyzed with the three-dimensional combustor model described in Section III. For each combustor configuration the 3-D model generated plots of fuel-air ratio in the primary zone at various radial planes so that the interaction of the fuel spray and the combustion air could be observed. Typical of these theoretical investigations are fuel-air plots as shown in Figures 28 through 30. Figure 28 is a prediction of the circumferential average fuel-air ratios for the Concept II baseline combustor for a single nozzle centered liner sector (the fuel nozzle is centered at 11.25 deg) in a radial plane located 54.6 mm downstream of the fuel-nozzle exit. This plane corresponds to the location of the PZ gas-sampling probe used in the experimental portion of the program. For the combustor operating at the 80% power condition, the average fuel-air ratio varied from 0.032 to 0.082 in each fuel-nozzle sector. Predicted fuel-air ratios for each of the experimental probes are given in Figure 29. These curves illustrate the fuel-air ratio variation across the liner annulus at each of three circumferential positions. Figure 30 shows a fuel-air ratio map of the entire 22.5 deg sector surrounding each fuel nozzle. The viewing direction for this map is downstream. Figure 30 clearly shows a single, high concentration of the fuel near the PZ inner wall of the Concept II baseline combustor. The axial position of the plane depicted in Figure 30 is the plane of the experimental gas-sampling probes. The predicted contours show that the baseline combustor should have only one fuel-air peak, which is quite different than what was predicted for the Concept I baseline combustor in Figure 9. A series of fuel-air contour maps at different axial planes stacked together results in the composite in Figure 31. In this representation of the baseline annulus sector the map from Figure 30 is the plane identified as 51 mm downstream. For reference, the prechamber exit is the 0.25 mm location plane, the primary holes are located at the 22.9 mm plane, the intermediate holes are located at the 40.6 mm plane, and the dilution holes are located at 71.1 mm or about halfway between the 63.5 mm and 76.2 mm planes shown. In this type of presentation, the effects of the prechamber swirl, the reverse-flow cooling air, the primary holes, the intermediate holes, and the dilution holes on the fuel spray can all be traced as the fuel spray passes down the combustor liner.

In a similar manner the gas temperatures and the local combustion efficiencies can be traced through the combustor liner as illustrated by Figures 32 and 33.

An internal aerodynamic analysis of the liner flow fields was also performed for the first 100 mm downstream of the fuel nozzle tip. Figure 34 shows a series of radial planes at 3.8, 6.4, 22.9, and 40.6 mm downstream of the fuel nozzle. Physically these planes correspond to the flow at the exit of the prechamber, the flow in the plane of the reverse cooling air exit, the flow in the plane of the PZ air-entry holes, and the flow in the plane of the intermediate holes. Figure 35 is a similar set of velocity plots but in the axial plane of the baseline liner. With the fuel nozzle located at 11.25 deg, a series of velocity plots are presented at circumferential locations of 0, 0.244, 0.5, and 0.889 of the half angle spacing between the fuel nozzles.

Mod 1 Combustor

The first modification to the Concept II baseline combustor was to reduce the amount of turning in the axial swirler surrounding the fuel nozzle from 60 deg of turning to 45 deg of turning. There were no other changes made to the combustor. Figure 36 shows the effect of the mechanical change on the circumferential average fuel-air ratio distribution. Comparison with the Concept II baseline distribution (Figure 28) shows that the fuel-air ratio peak would be expected to decrease from 0.082 to about 0.072. Figure 37 shows the fuel-air ratio map in the radial plane of the PZ gas-sample probes. Comparison of this map with the baseline map in Figure 30 shows almost no change in the distribution of fuel-air in that plane.

Mod 2 Combustor

The second modification to the Concept II baseline combustor was to increase the hole area of the primary holes by 50%. The 45 deg swirler from Concept II, mod 1, was retained. There were no changes made other than increasing the size of the primary holes.

The average circumferential fuel-air ratio for this mod is shown in Figure 38 and predicts a slight decrease in the fuel-air ratio peak near the axis of the fuel nozzle when compared to the profiles in both Concept II baseline and mod 1 designs. The sector fuel-air ratio map for this configuration in Figure 39 also shows a smoothing of the fuel-air pattern. The fuel-air peaks were reduced thus indicating a potential reduction of NO_x and smoke which result from the high-temperature fuel-rich pockets in the primary zone.

Comparison of the baseline and the mod 1 predicted internal velocity diagrams did not reveal any meaningful differences between the two designs.

Mod 3 Combustor

The third modification to the Concept II baseline combustor was to further increase the areas of the PZ holes by 100% when compared to the Concept II baseline combustor. This increase in PZ hole area was intended to further smooth the fuel-air ratio distribution in the primary zone. This smoothing process is evident in Figure 40, where the fuel-air ratio peak should be reduced to 0.055. It is clear in Figure 41 that the rich pockets in the primary zone have been substantially reduced.

Comparison of the mod 1 and the mod 2 predicted internal velocity diagrams did not reveal any meaningful differences between the two designs. The mod 2 design showed slightly higher velocities in the region of the primary holes, due to the increased flow, but no significant changes to the flow patterns.

Mod 4 Combustor

The fourth modification to the Concept II baseline combustor was to operate the mod 3 design by supplying fuel only to every other nozzle for a total of eight fuel nozzles. Using only eight equally spaced fuel nozzles produced a doubling of the annulus circumference/height spacing to 2.8. Increasing the circumference/height spacing would have significant advantages in simplifying annular combustors, especially the small annulars which now require small fuel nozzles that are susceptible to contamination and clogging. The predicted circumferential average fuel-air ratio distribution for the mod 4 design is shown in Figure 42 for adjacent fueled and unfueled sectors. Without any change in the combustor liner hole patterns there are alternate sectors of high and low fuel-air ratios corresponding with the fueled and unfueled nozzles. The sector fuel-air ratio map for this design is given in Figure 43. The high and low fuel-air regions are especially evident.

Mod 5 Combustor

The fifth modification to the Concept II baseline combustor was to close the PZ holes in the regions of the unfueled nozzles and add that area to the primary zones of the fueled nozzles. For each closed hole two plane flush holes were added behind the existing primary hole at equal distances from the fuel-nozzle centerline. The intention of this design change was to even out the fuel-air ratio distribution between the fueled and the unfueled nozzles.

Design Summary

A summary of the radial-plane fuel-air ratio patterns for each of the Concept II combustors is shown in Figure 44. Decreasing the swirl number at the fuel nozzle and then increasing the quantity of primary zone air in the baseline through mod 3 designs did not change the overall aerodynamic pattern in the liner annulus but tended to steadily suppress the high fuel-air ratio regions while raising the low regions. Changing to eight fuel nozzles in mod 4 produced a very nonuniform fuel-air ratio pattern, but moving all of the PZ air toward the operating fuel nozzles should have improved the fuel-air distribution.

CONCEPT III: SINGLE-VORTEX, ANNULUS-AIR-ALIGNED COMBUSTOR

The single-vortex, annulus-air-aligned combustor was selected as the Concept III combustor because this concept departs from the dual-vortex, conventional flame-stabilization designs by establishing a large single torus in the primary zone. The single-loop film cooling around the primary zone complements the internal annulus flow created by the PZ air jets. One major feature of this design is the widening of the fuel nozzle spacing to reduce the number of fuel injectors from the sixteen used in Concepts I and II to only twelve. The fuel nozzles are of an airblast atomization type feeding a positionable premixing fuel chute. This chute allows for fuel placement into designated sections of the PZ annulus. As in Concept II the primary zone is cooled by a continuously sweeping film of cooling air which, like the Concept II design, flows upstream along the outer surface of the primary zone, inward around the dome, and finally downstream along the inner surface of the primary zone. Lamilloy transpiration cooling was utilized for all of the remaining walls of the combustor as was done in each of the other concepts.

The five modifications to the Concept III combustor were chosen to demonstrate dramatic changes for analytical and experimental verification. Therefore successive modifications to the Concept III combustor were major and not intended to progress toward an optimum design configuration.

Baseline Combustor

A dimensional sketch of the Concept III baseline combustor can be seen in Figure 45. The baseline combustor has 12 fuel injectors resulting in a 1.9 circumference/height spacing compared to a 1.4 spacing in Concepts I and II. These fuel nozzles are a combination simplex-airblast type and were the same nozzles used with the Concept I combustor. Each fuel nozzle feeds into an L-shaped premixing fuel chute which can be rotated to any 360 deg position for placing the fuel in a desired location in the PZ annulus. These chutes act as premixers and, to some degree, as prevaporizers. The Concept III baseline combustor has 24 primary air-addition holes (2 per nozzle) through the liner inner shell plus 24 primary holes (2 per nozzle) through the outer shell. Each of the holes is located 7.5 deg off the centerline of a fuel nozzle. The air enters through formed air bushings inclined to the annulus centerline to form the single torus flow pattern. There are no intermediate zone holes in this combustor concept. The dilution zone of this combustor concept is the same as for Concepts I and II. Therefore, there are 32 dilution air-addition holes through the inner shell and 32 through the outer shell giving a nonsymmetric pattern of dilution holes relative to the number of fuel nozzles. There are eight dilution holes on each shell for every three fuel nozzles making a ratio of 2.67 shell dilution holes for each fuel nozzle. All remaining air enters through the PZ film cooling slots, the fuel nozzle swirler, or the Lamilloy cooling surfaces. A summary of the air distributions for the Concept III baseline and all five of the Concept III liner mods is presented in Table V.

Table V.
Concept III combustor design summary.

	Concept III					
	Base	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5
Axial swirler blade angle	45 deg	45 deg	45 deg	45 deg	45 deg	45 deg
Fuel nozzles						
Number nozzles	12	12	12	12	12	12
Exit chute						
Direction	Radial	Circumf	Circumf	Radial	Radial	Radial
Rotation	Out	CW	CCW	Out	Out	Out
Outer shell						
Number PZ holes/nozzle	2	2	2	2	2	0
Area, %	5.2	5.2	5.2	7.5	9.8	0
Number IZ holes/nozzle	0	0	0	0	0	0
Number DZ holes/active nozzle	2.67	2.67	2.67	2.67	2.67	2.67
Inner shell						
Number PZ holes/nozzle	2	2	2	2	0	2
Area, %	4.5	4.5	4.5	2.3	0	9.8
Number IZ holes/nozzle	0	0	0	0	0	0
Number DZ holes/nozzle	2.67	2.67	2.67	2.67	2.67	2.67
Total effective area, mm^2	3431.0	3431.0	3431.0	3434.0	3434.2	3434.2
%	100.00	100.00	100.00	100.09	100.09	100.09
Lamilloy porosity, C_d	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053
Liner areas, %						
Dome swirlers	6.2	6.2	6.2	6.2	6.2	6.2
Dome cooling gaps	16.6	16.6	16.6	16.6	16.6	16.6
PZ holes total	9.7	9.7	9.7	9.7	9.7	9.7
IZ holes total	0	0	0	0	0	0
DZ holes total	39.5	39.5	39.5	39.5	39.5	39.5
Cooling total	44.5	44.5	44.5	44.5	44.5	44.5
PZ equivalence ratio at 100% power	1.016	1.016	1.016	1.012	1.012	1.012

The Concept III baseline primary zone was also analyzed with the three-dimensional combustor model described in Section II. For each PZ configuration the 3-D model generated plots of fuel-air ratio in the primary zone at various radial planes so that the interaction of the fuel spray and the combustion air could be observed. Typical of these theoretical investigations are fuel-air plots as shown in Figures 46 through 48. Figure 46 is a prediction of the circumferential average fuel-air ratios for the Concept III baseline primary zone for a single nozzle centered liner sector (the fuel nozzle is centered at 15 deg) in a radial plane located 63 mm downstream of the fuel-nozzle exit. This plane corresponds to the location of the PZ gas-sampling probe used in the experimental portion of the program. For the combustor operating at the 80% power condition, the average fuel-air ratio varied from 0.025 to 0.063 in each fuel-nozzle sector. Predicted fuel-air ratios for each of the experimental probes are given in Figure 47. These curves illustrate the fuel-air ratio variation across the liner annulus at each of three circumferential positions. Figure 48 shows a fuel-air ratio map of the entire 30 deg sector surrounding each fuel nozzle. The viewing direction for this map is downstream. Figure 48 clearly shows the high concentration of the fuel near the PZ outer wall of the Concept III baseline combustor and the very low levels of fuel concentration along the nozzle centerline. A series of fuel-air contour maps at different axial planes stacked together results in the composite in Figure 49. In this representation of the baseline annulus sector the map from Figure 48 is the plane identified as 63 mm downstream. In this type of presentation the effects of each of the air addition points on the fuel spray can all be traced as the fuel spray passes down the combustor liner.

In a similar manner the gas temperatures and the local combustion efficiencies can be traced through the combustor liner as illustrated by Figures 50 and 51.

An internal aerodynamic analysis of the liner flow fields was also performed for the first 100 mm downstream of the fuel nozzle tip. Figure 52 shows a series of radial planes at 13.0, 18.8, 25.4, and 53.2 mm downstream of the liner dome. Physically these planes correspond to the flow upstream of the fuel chute exit, the flow at the leading edge of the fuel chute, the flow at the exit of the fuel chute, and the flow just upstream of the experimental probes. Figure 53 is a similar set of velocity plots but in the axial plane of the baseline liner. With the fuel nozzle located at 15 deg, a series of velocity plots is presented at circumferential locations of between the fuel nozzle and the primary holes, through the primary holes, and outside the primary holes near the edge of the sector.

Mod 1 Combustor

The first modification to the Concept III baseline combustor was to rotate the fuel chutes so that the fuel exited in a clockwise circumferential direction around the PZ annulus. There were no other changes made to the combustor. Figure 54 shows the effect of this mechanical change on the direction of the fuel exiting from the chute. In the plane of the instrumentation probes, the fuel is predicted to be quite concentrated in a region of the annulus about halfway between the fuel nozzles.

Mod 2 Combustor

The second modification to the Concept III baseline combustor was to rotate the fuel chutes so that the fuel now exited in a counterclockwise circumferential direction around the PZ annulus. There were no other changes made to the combustor. The fuel-air map in Figure 55 shows the effect of this mechanical change to the direction of the fuel exiting from the chute. In the plane of the instrumentation probes, the fuel is again predicted to be quite concentrated in a region of the annulus about halfway between the fuel nozzles.

Mod 3 Combustor

The third modification to the Concept III baseline combustor was to return the fuel chutes to the radially out position of the baseline combustor and to increase by 50% the amount of air entering through the inner shell primary holes. The sector fuel-air ratio map for this modification is shown in Figure 56. Comparison of this map with the fuel-air ratio map predicted for the baseline configuration shows that there should be very little difference in these two designs. There were no discernible differences between the predicted velocity diagrams of the two designs.

Mod 4 Combustor

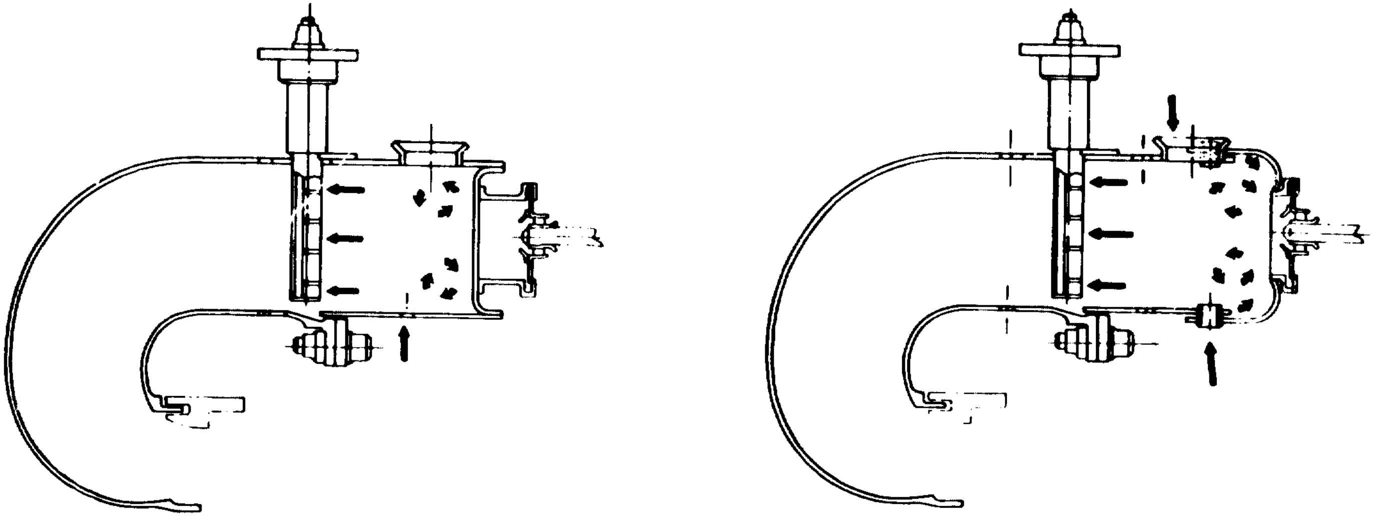
The fourth modification to the Concept III baseline combustor was to close off the inner shell PZ air in the mod 3 design and to add all of that air to the outer shell primary holes. The fuel chute remained in the radially outward position. The sector fuel-air ratio map for this configuration is shown in Figure 57. Comparison with the baseline and the mod 3 fuel-air maps shows only a minor effect of the additional outer shell PZ air on the fuel-air distribution.

Mod 5 Combustor

The fifth modification to the Concept III baseline combustor was to close off the outer shell PZ air in the mod 3 design and to add that air to the inner shell primary holes. The fuel chute remained in the radially outward position. The sector fuel-air ratio map for this configuration is shown in Figure 58. Comparison with the baseline, the mod 3, and the mod 4 configuration fuel-air maps shows that the annulus has become more fuel lean near the inner shell, where all of the primary air was added.

Design Summary

A summary of the radial-plane fuel-air ratio patterns for each of the Concept III combustors is shown in Figure 59. The 3-D model predicted major changes to the fuel-air ratio distributions when the fuel chutes were rotated and the fuel entered the primary zone in different directions. As shown, the model predicts that the fuel will not mix well in the primary zone leaving a rich region near the outer shell wall (baseline, mods 3-5) or producing rich cores which may pass through the primary zone altogether. Mods 3-5 attempted to reduce the fuel-air ratio gradient from the inner shell wall to the outer shell wall by adjusting the balance between the PZ air added through the inner and outer shell walls. The intent of the Concept III combustor designs was to produce internal aerodynamic changes of sufficient magnitudes that the 3-D model results and the experimental test results could be compared to assess the prediction accuracy of the model.

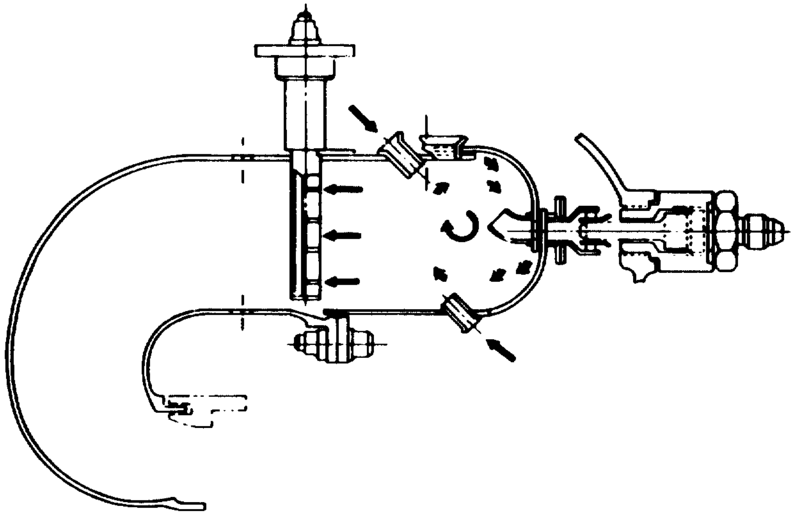


Concept I

Concept II

Double-vortex, swirl-stabilized

Double-vortex, swirl stabilized, reverse circulation



Concept III

Single-vortex, annulus-air-aligned

Figure 2. Combustor concepts.

TE83-1310

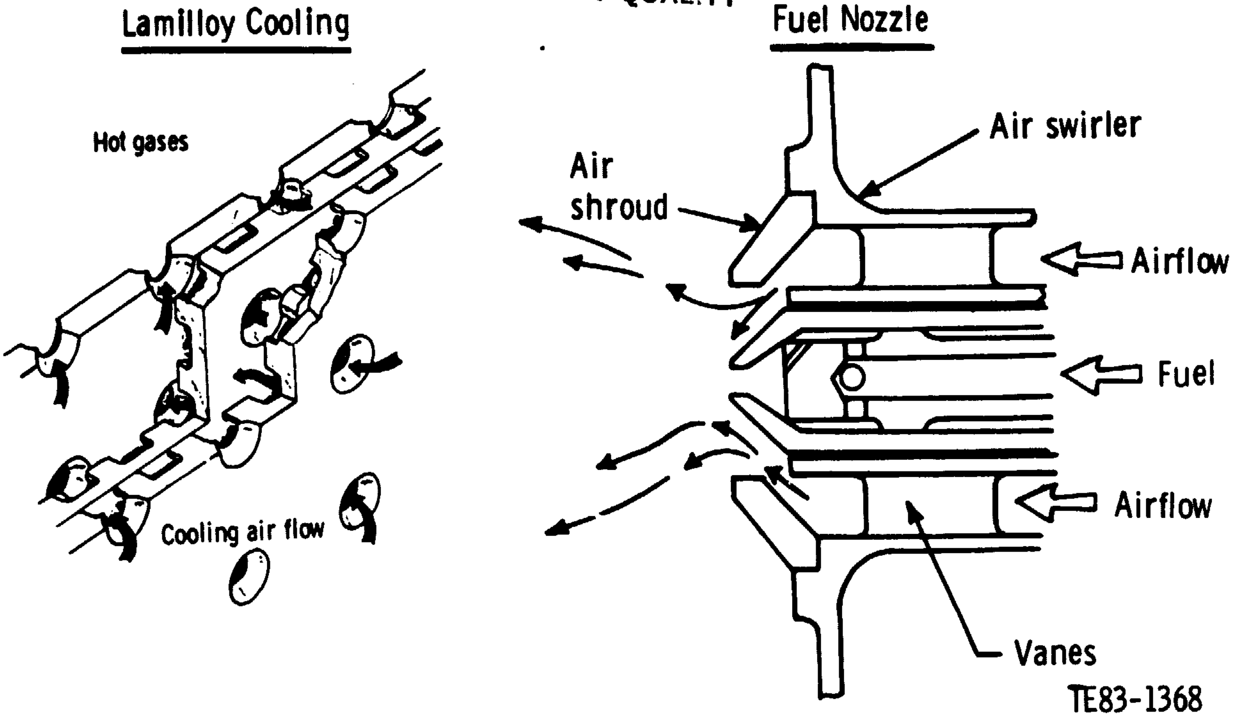
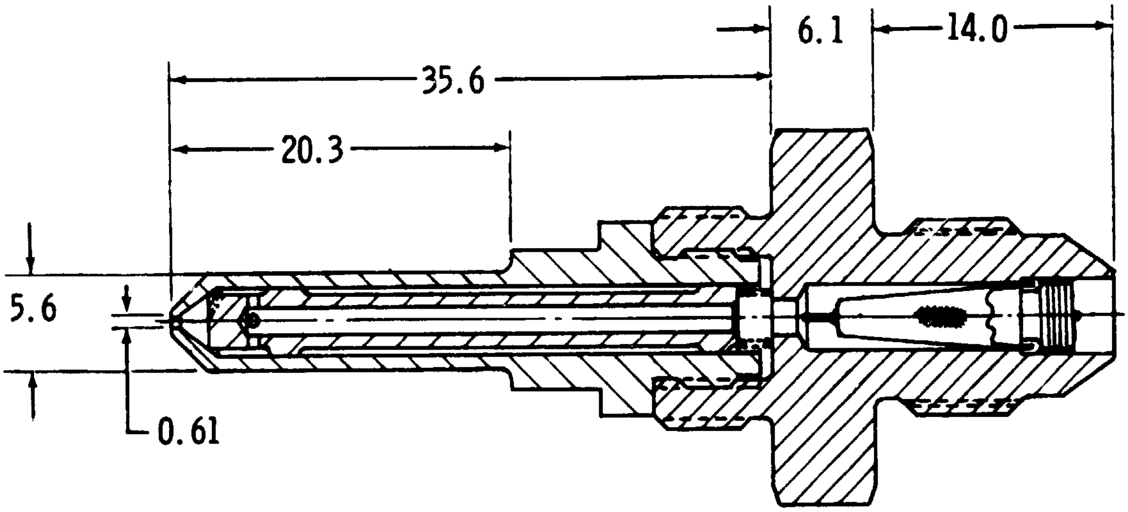


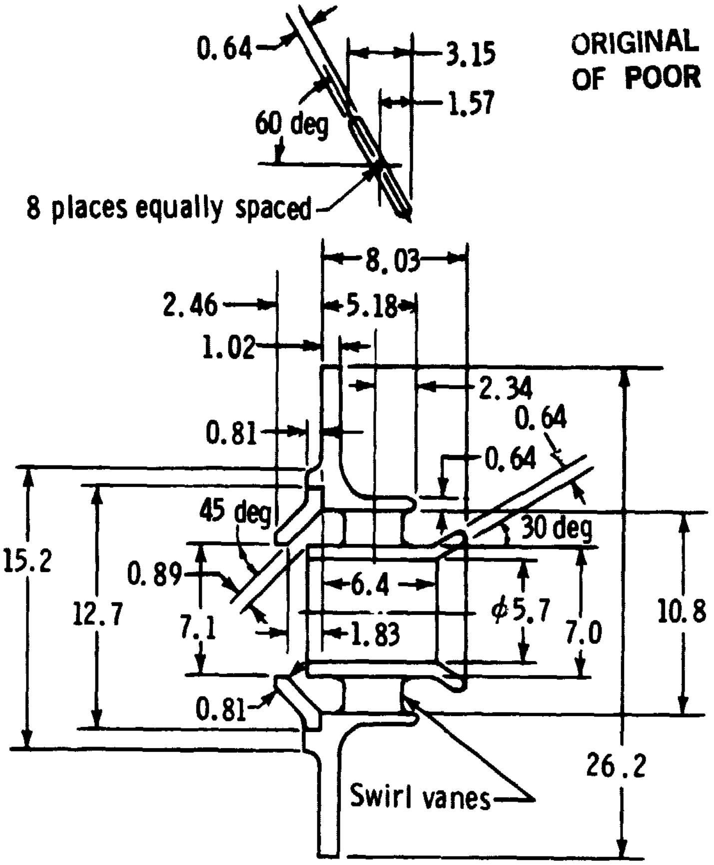
Figure 3. Lamilloy cooling and fuel nozzle features.



Note: Dimensions are in millimeters

TE83-1311

Figure 4. Fuel nozzle simplex fuel atomizer details.



Note: Dimensions are in millimeters

TE83-1312

Figure 5. Fuel nozzle airblast swirler details.

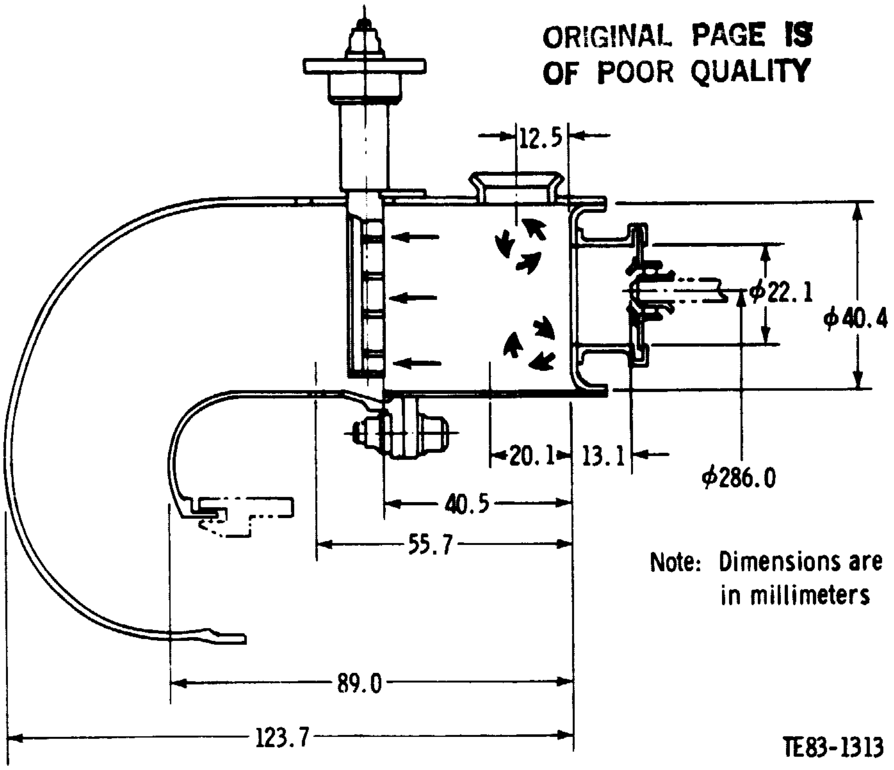


Figure 6. Dimensional cross section of Concept I, baseline, combustor.

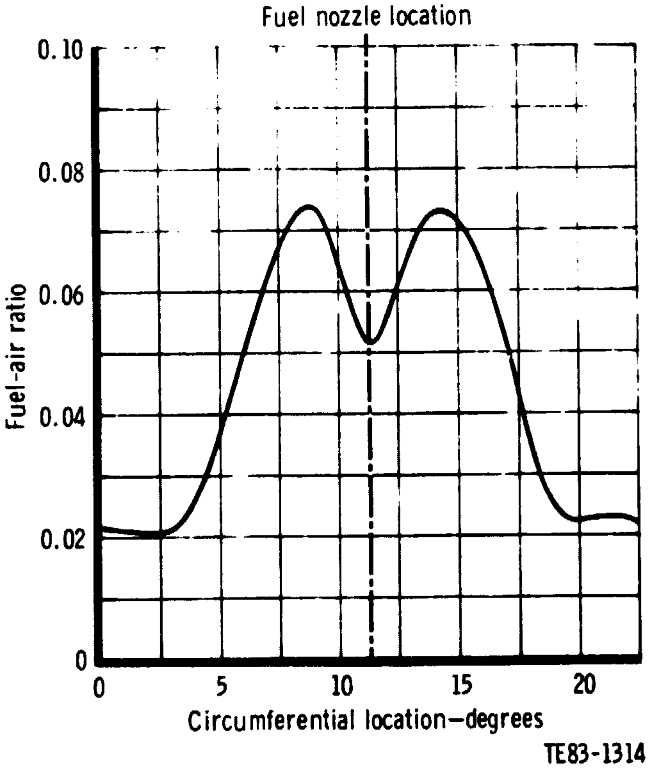


Figure 7. Predicted average primary zone fuel-air ratio
(Concept I, baseline--80% power).

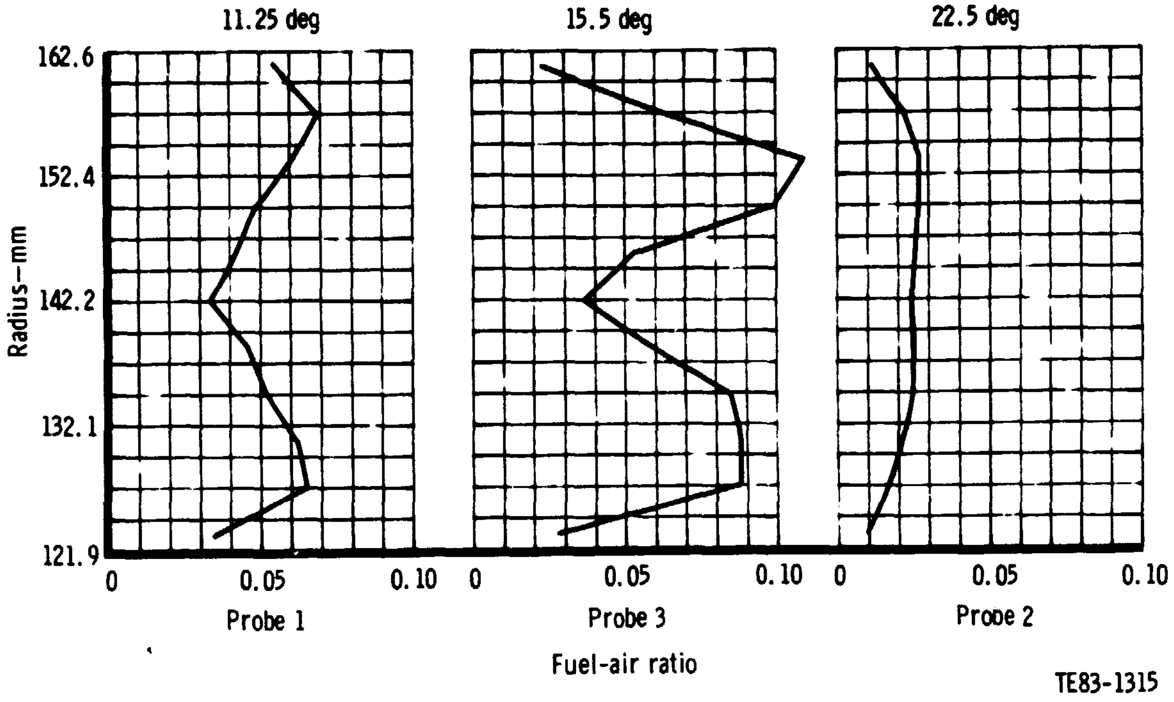


Figure 8. Predicted radial primary zone fuel-air ratio (Concept I, baseline--80% power).

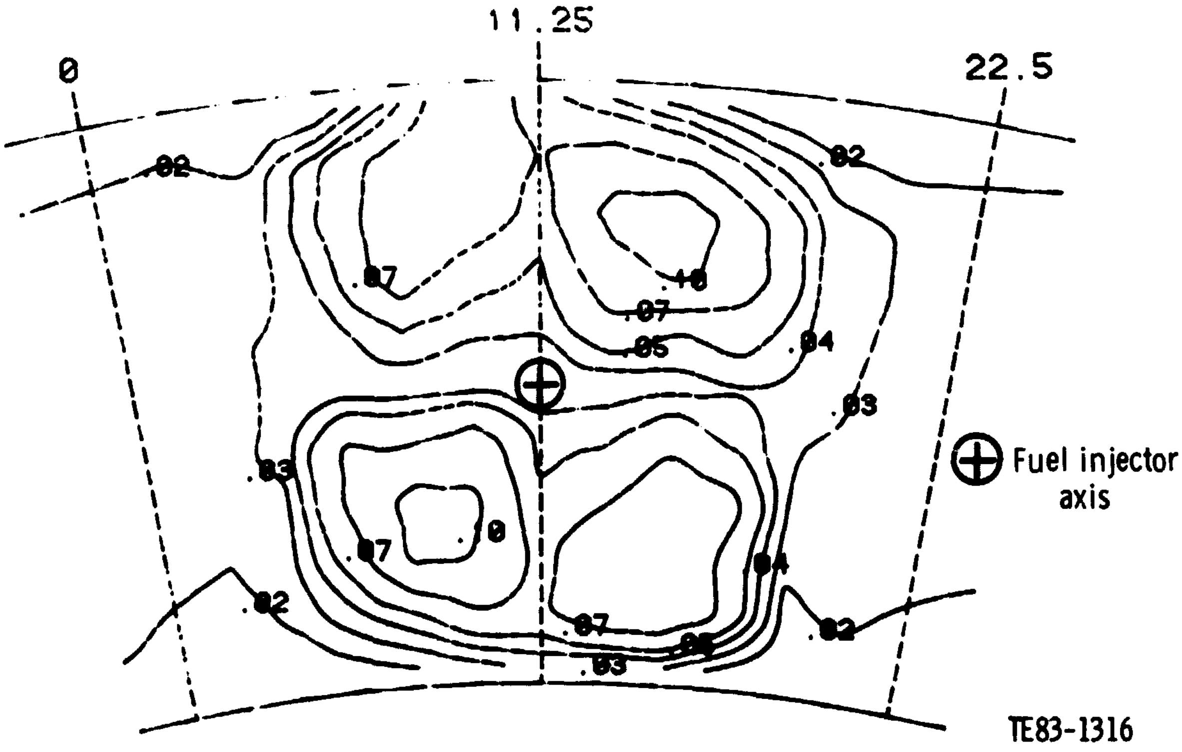


Figure 9. Predicted primary zone fuel-air ratio contours (Concept I, baseline--80% power).

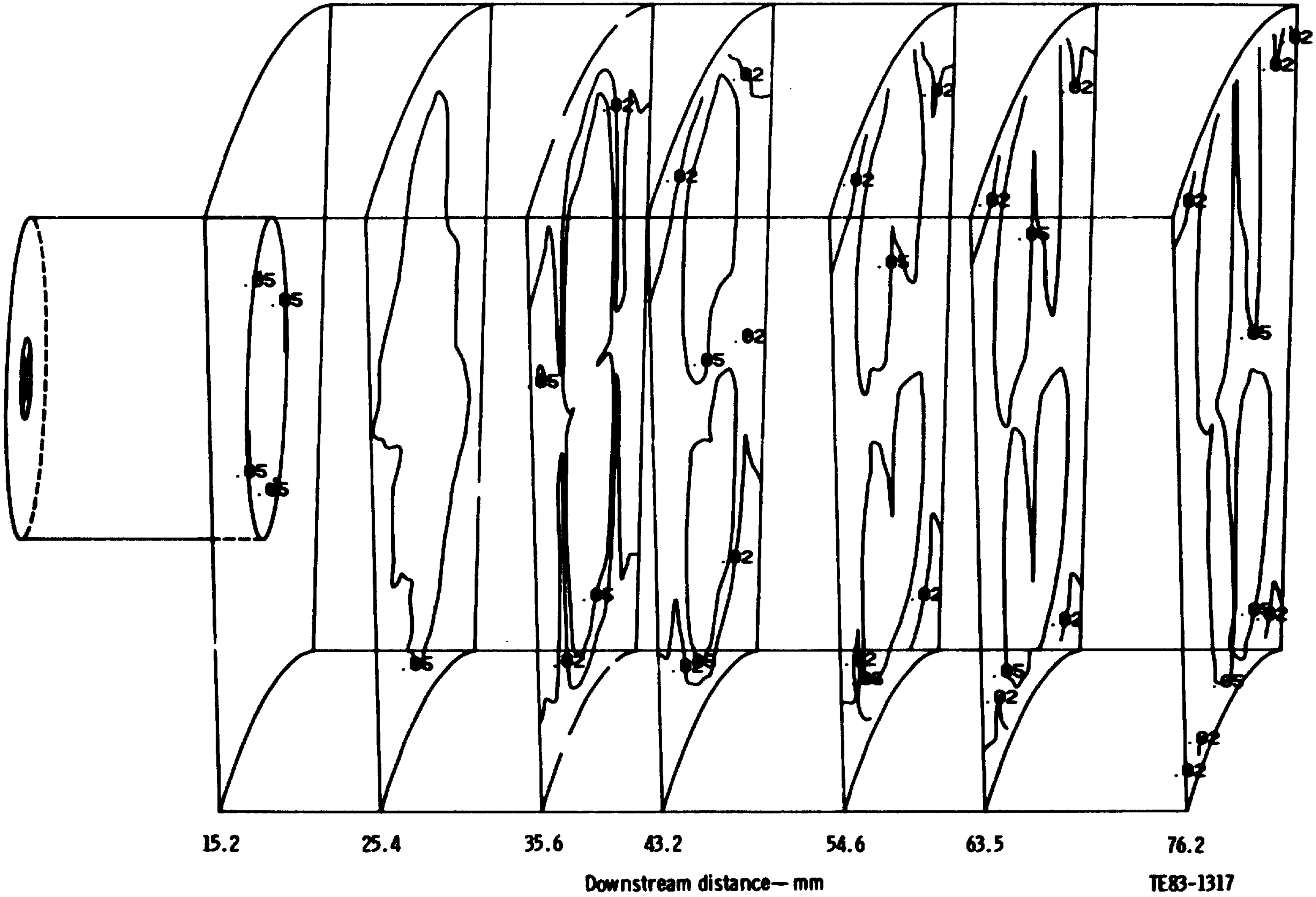


Figure 10. Predicted primary zone fuel-air contours
(Concept I, baseline--100% power).

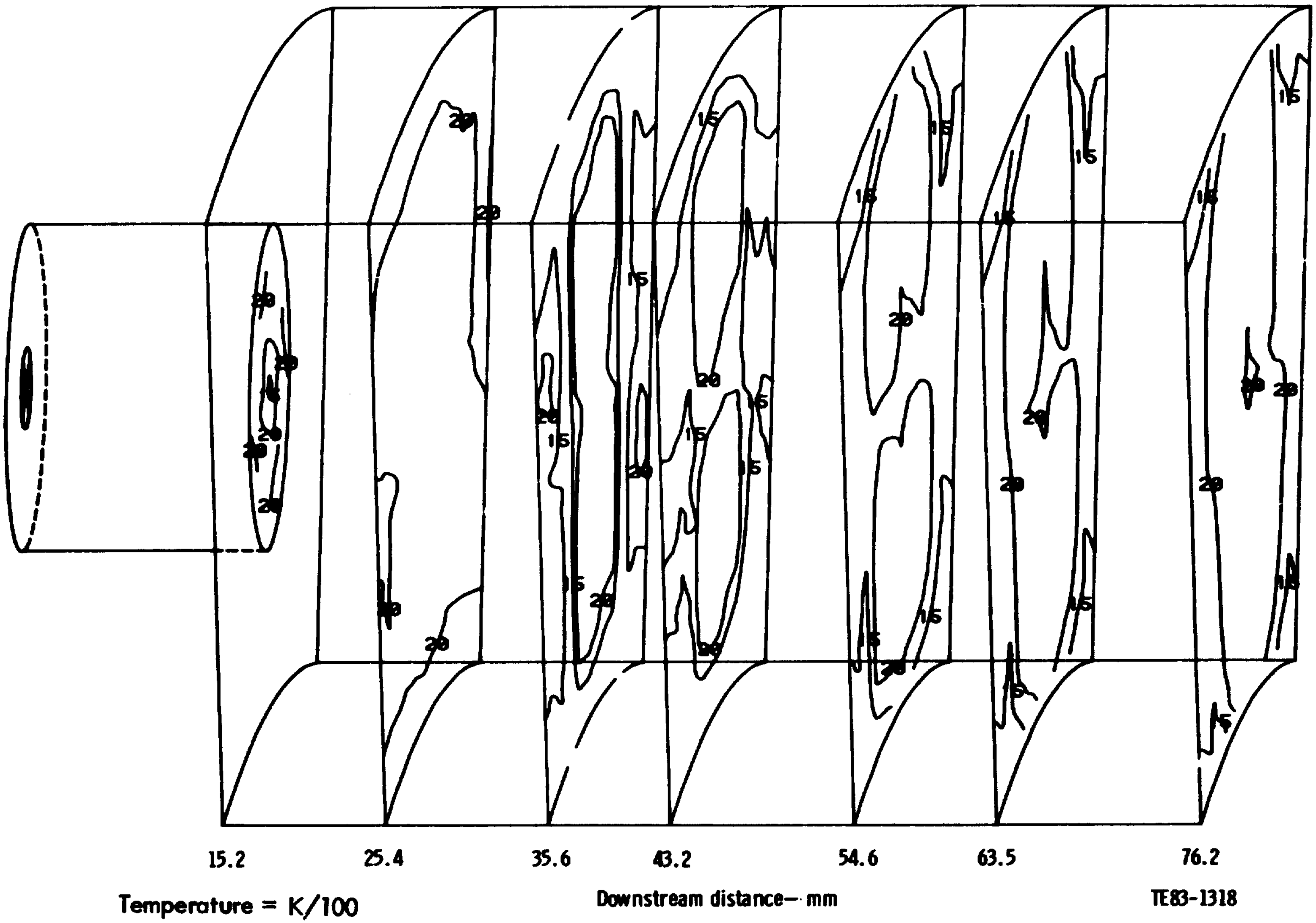


Figure 11. Predicted primary zone gas temperature contours (Concept I, baseline--100% power).

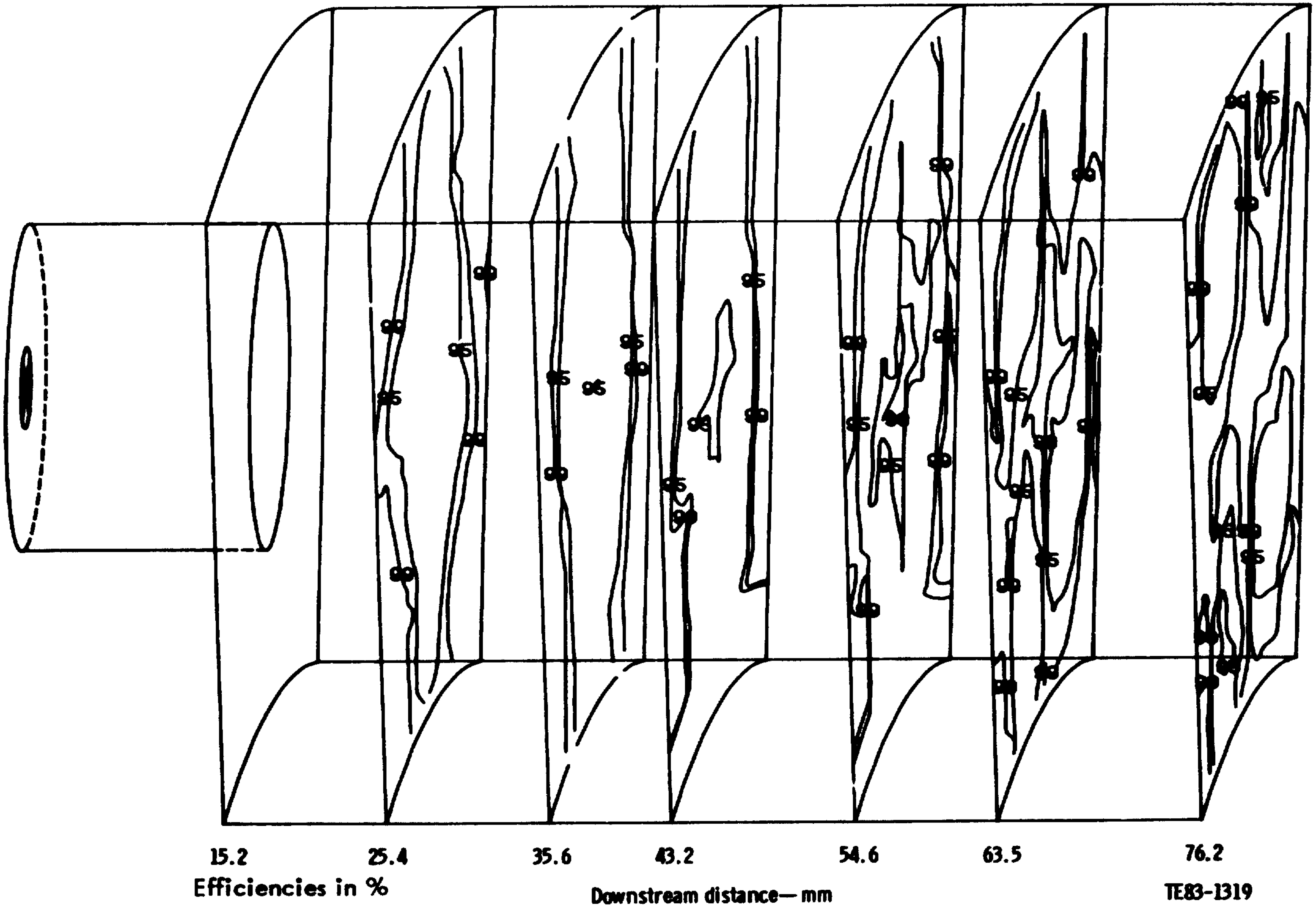
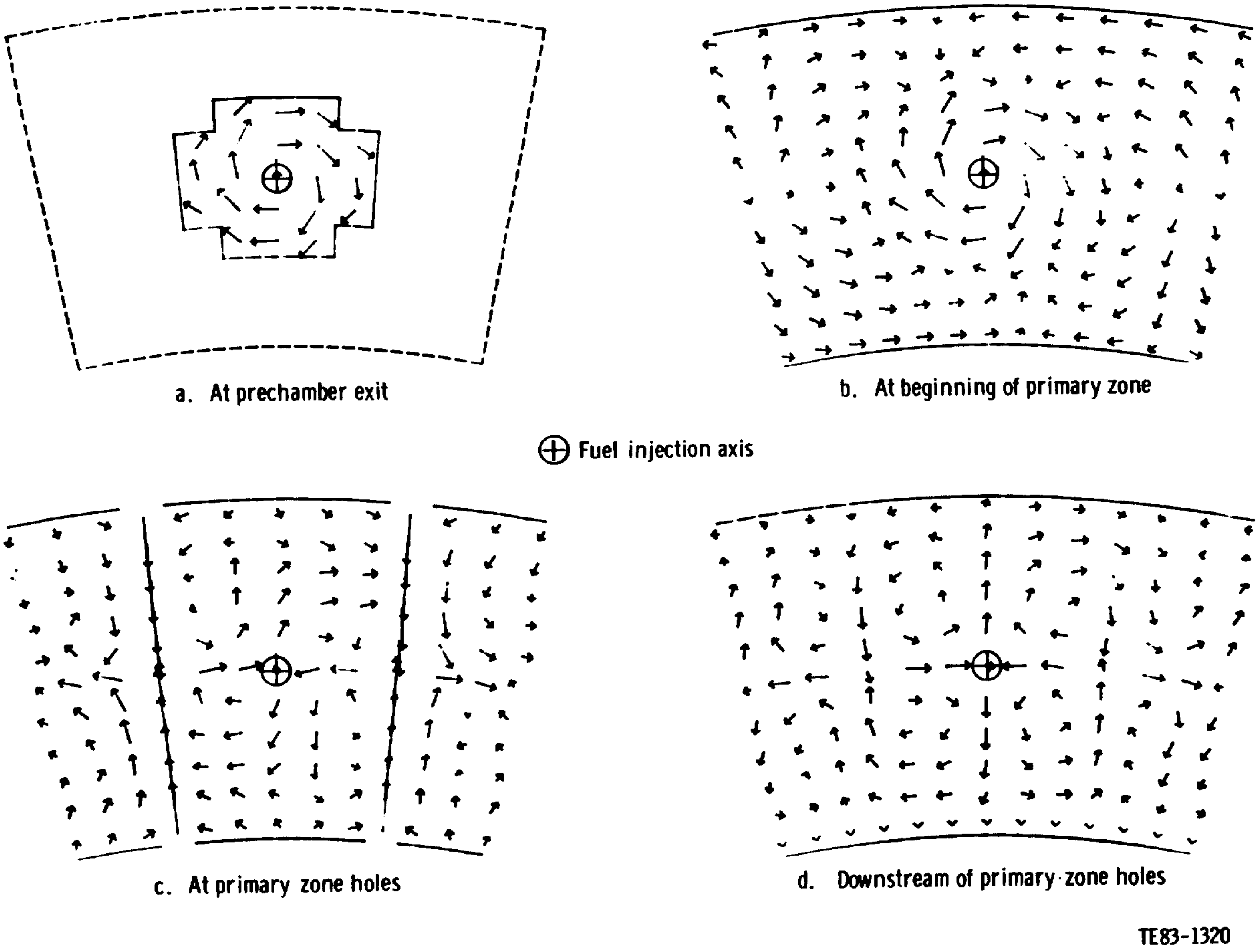


Figure 12. Predicted primary zone combustion efficiency contours (Concept I, baseline--100% power).



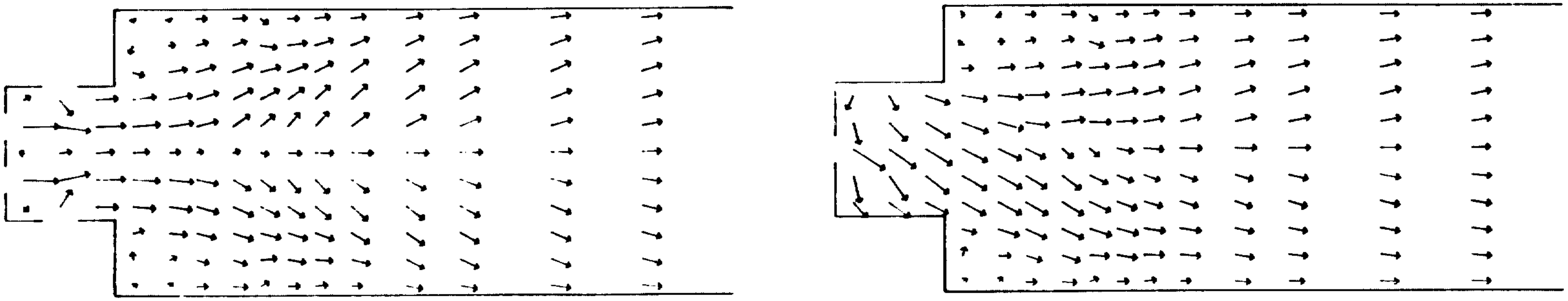
a. At prechamber exit

b. At beginning of primary zone

c. At primary zone holes

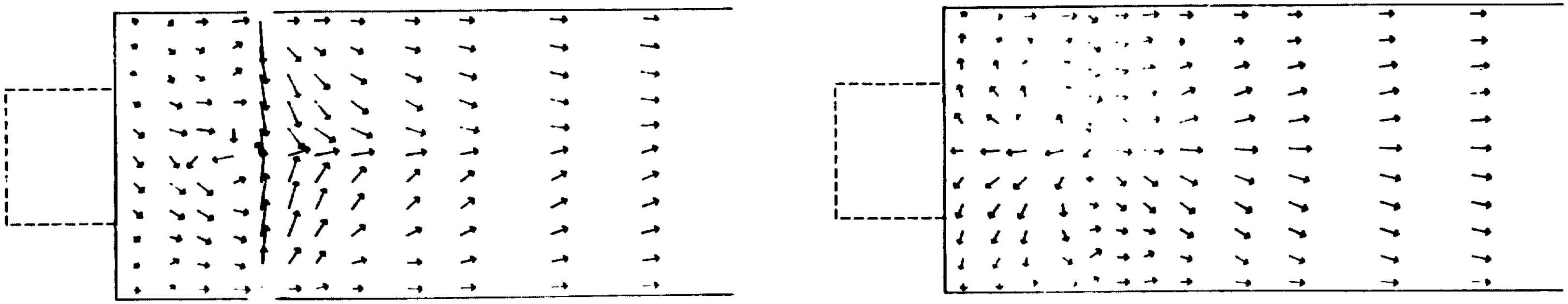
d. Downstream of primary-zone holes

Figure 13. Concept I, baseline, radial plane velocity diagrams.



a. Through fuel nozzle (liner centerline)

b. Through plane between fuel nozzle and primary zone holes



c. Through primary zone holes

d. Outside primary zone holes

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Figure 14. Concept I, baseline, axial plane velocity diagrams.

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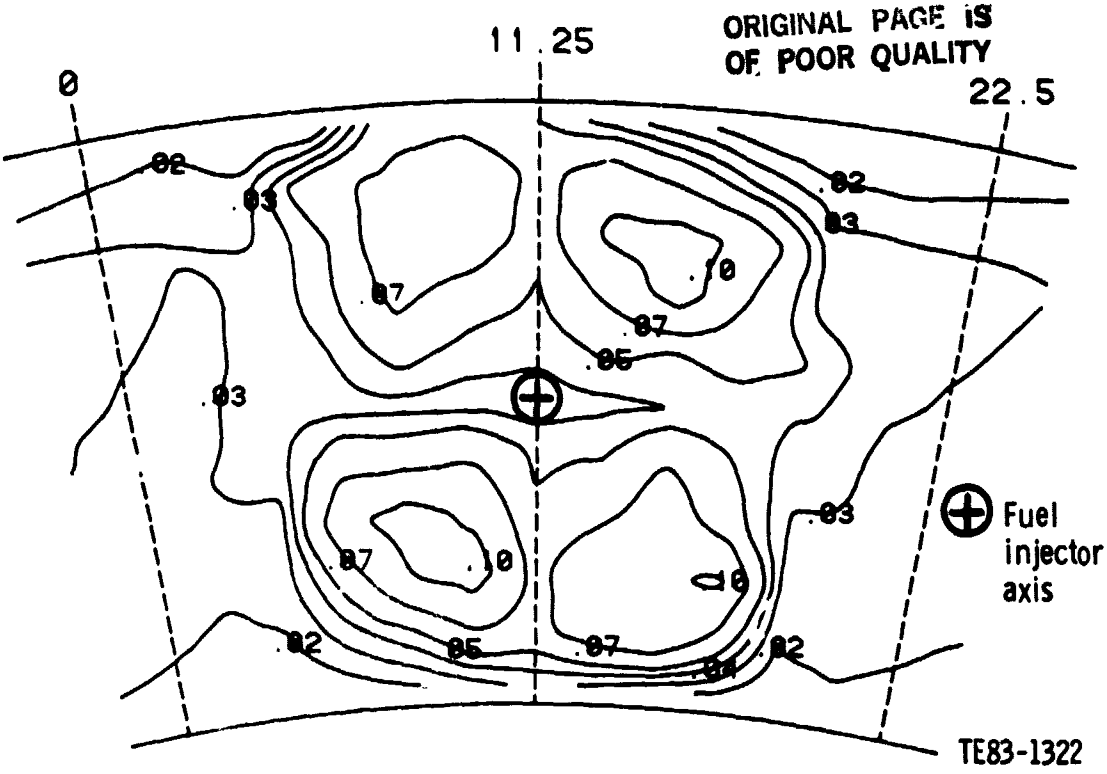


Figure 15. Predicted primary zone fuel-air ratio contours (Concept I, mod 1--80% power).

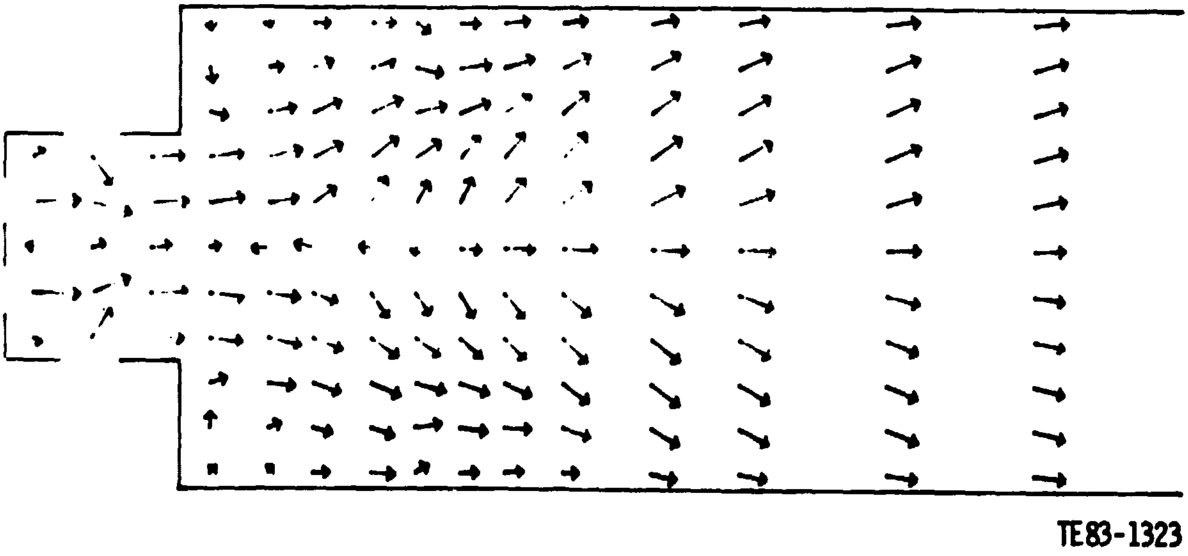
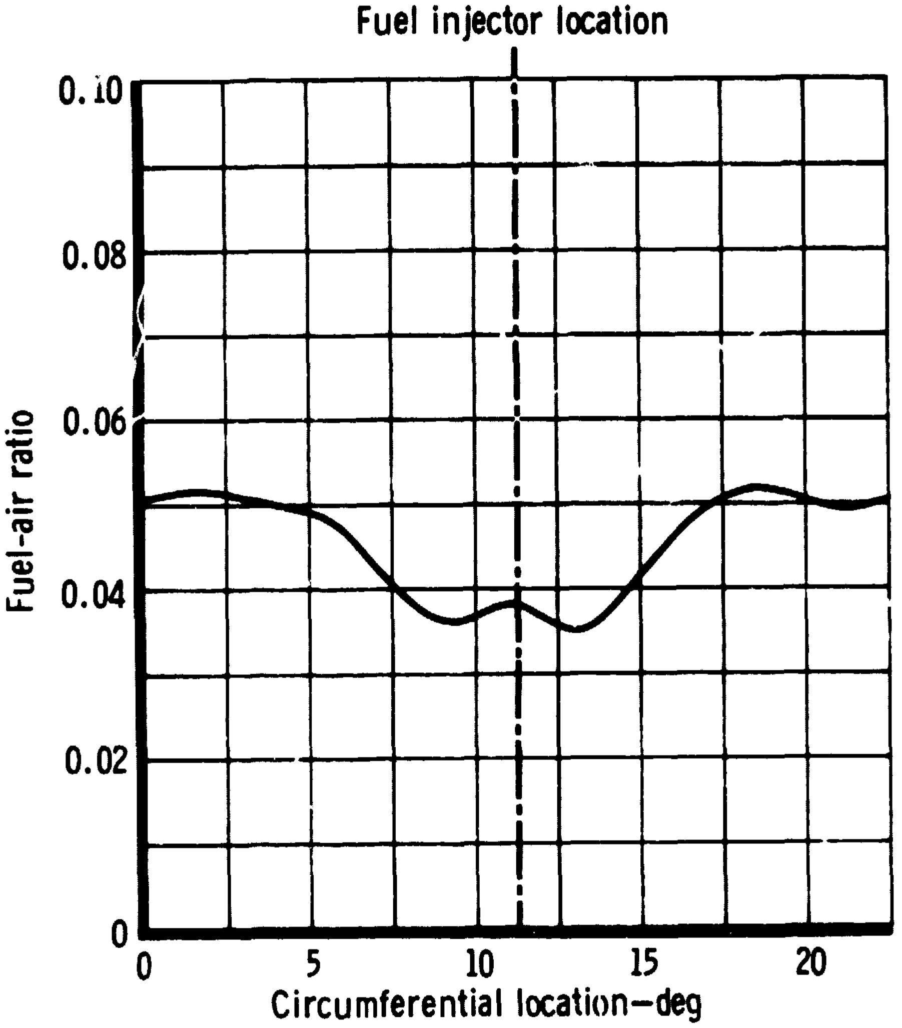


Figure 16. Concept I, mod 1, combustor internal axial velocities prediction (in plane of fuel injector).



TE83-1324

Figure 17. Predicted average primary zone fuel-air ratio (Concept I, mod 2--80% power).

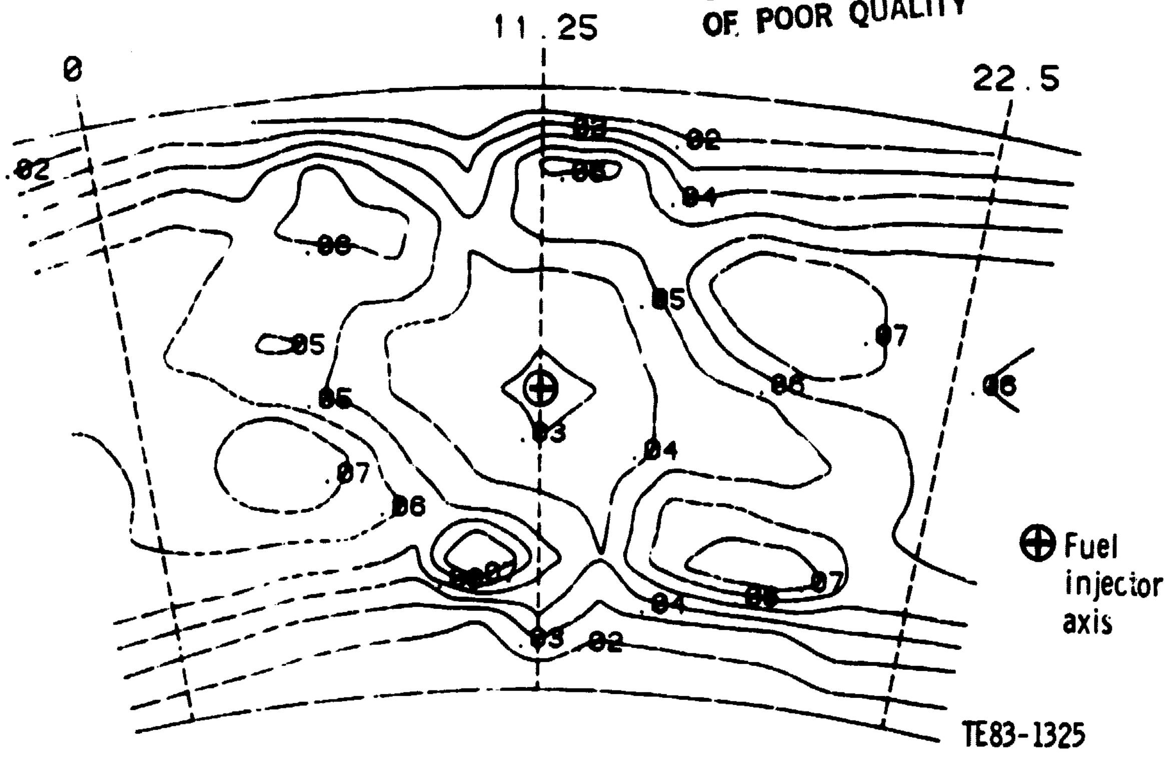


Figure 18. Predicted primary zone fuel-air ratio contours (Concept I, mod 2--80% power).

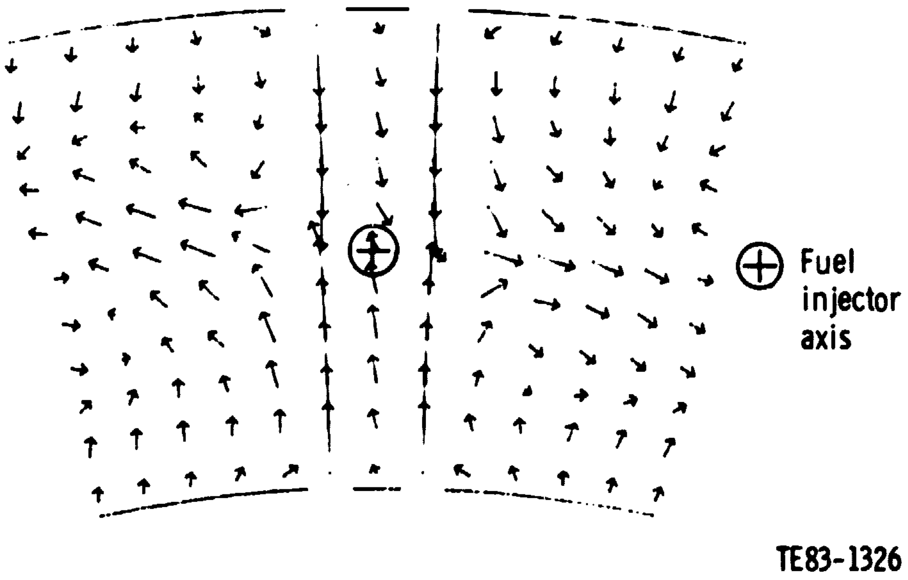


Figure 19. Concept I, mod 2, combustor primary zone internal radial velocities prediction.

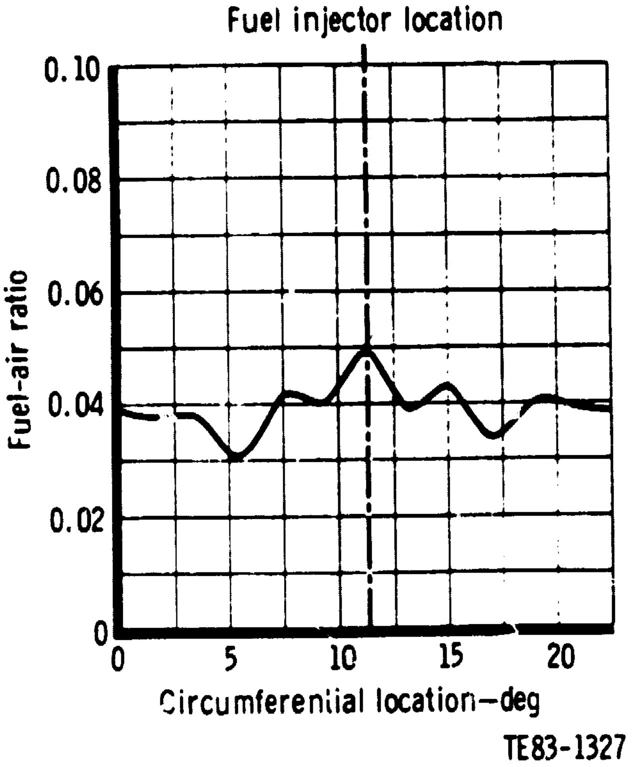


Figure 20. Predicted average primary zone fuel-air ratio (Concept I, mod 3--80% power).

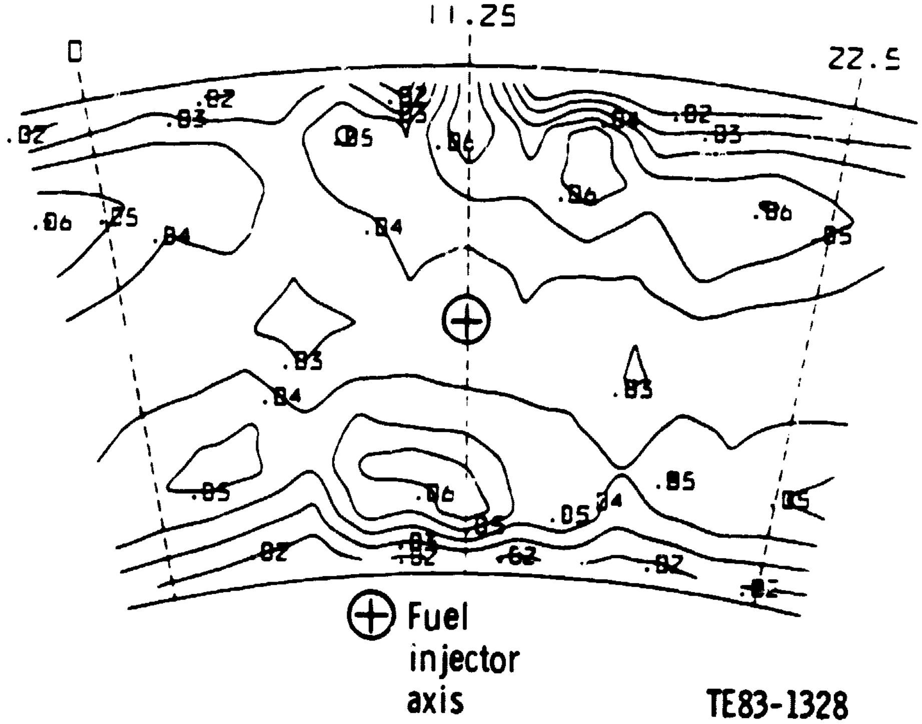


Figure 21. Predicted primary zone fuel-air ratio contours (Concept I, mod 3--80% power).

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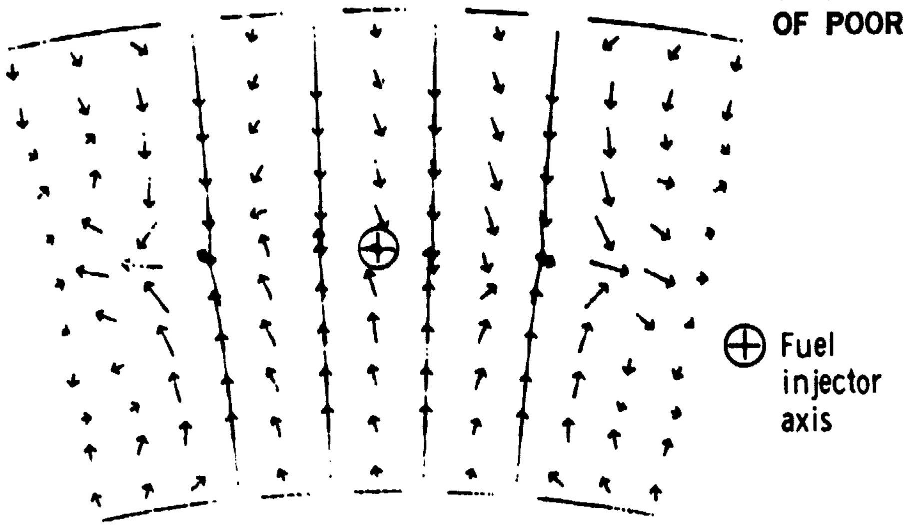

Figure 22. Concept I, mod 3, combustor primary zone internal radial velocities prediction.

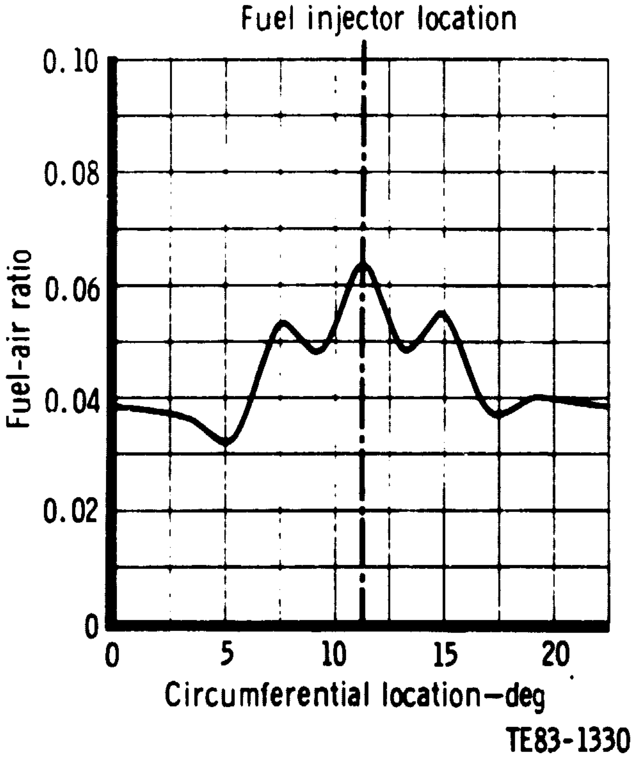

Figure 23. Predicted average primary zone fuel-air ratio (Concept I, mod 4--80% power).

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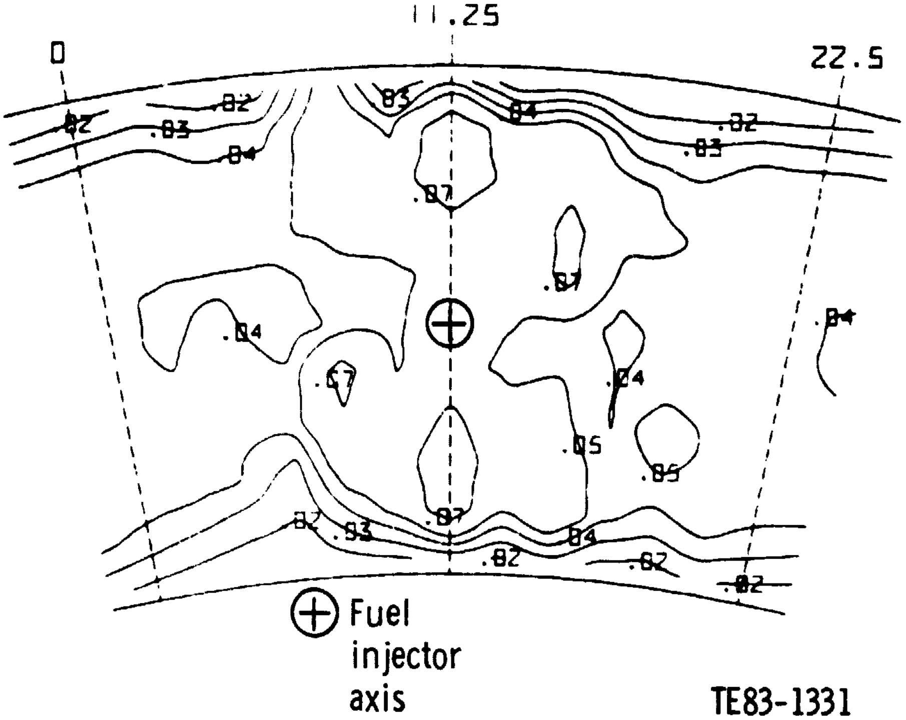


Figure 24. Predicted primary zone fuel-air ratio contours (Concept I, mod 4--80% power).

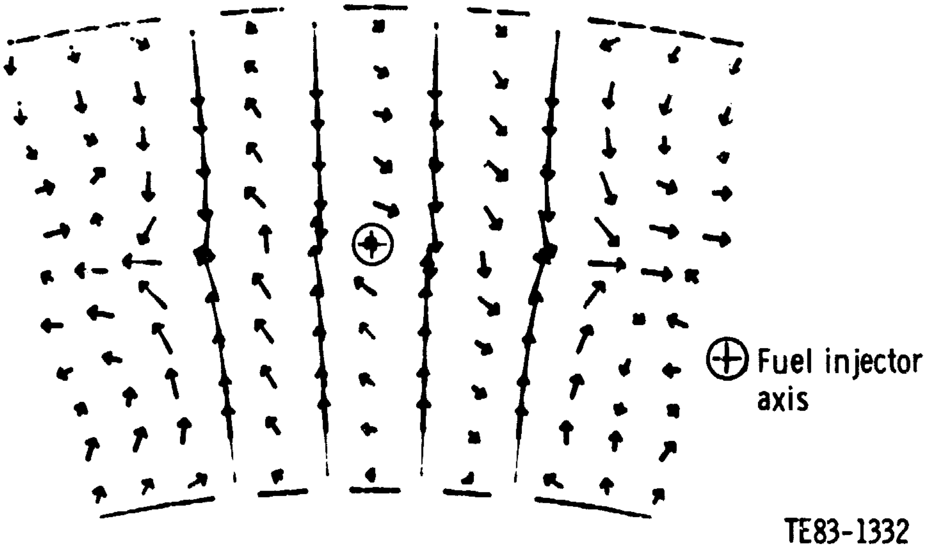


Figure 25. Concept I, mod 4, combustor primary zone internal radial velocities prediction.

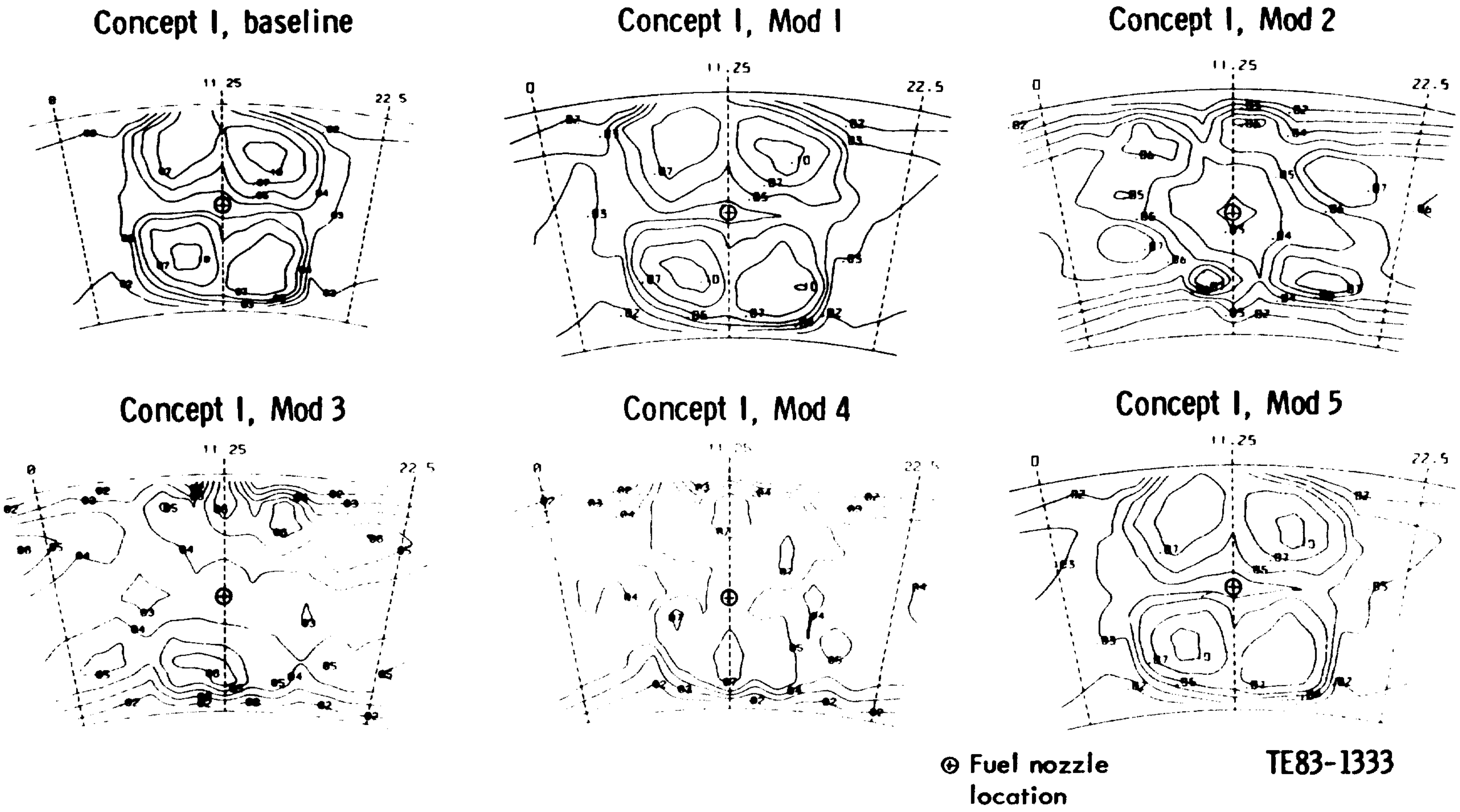


Figure 26. Comparison of Concept I fuel-air ratio contours for the baseline and five design mods.

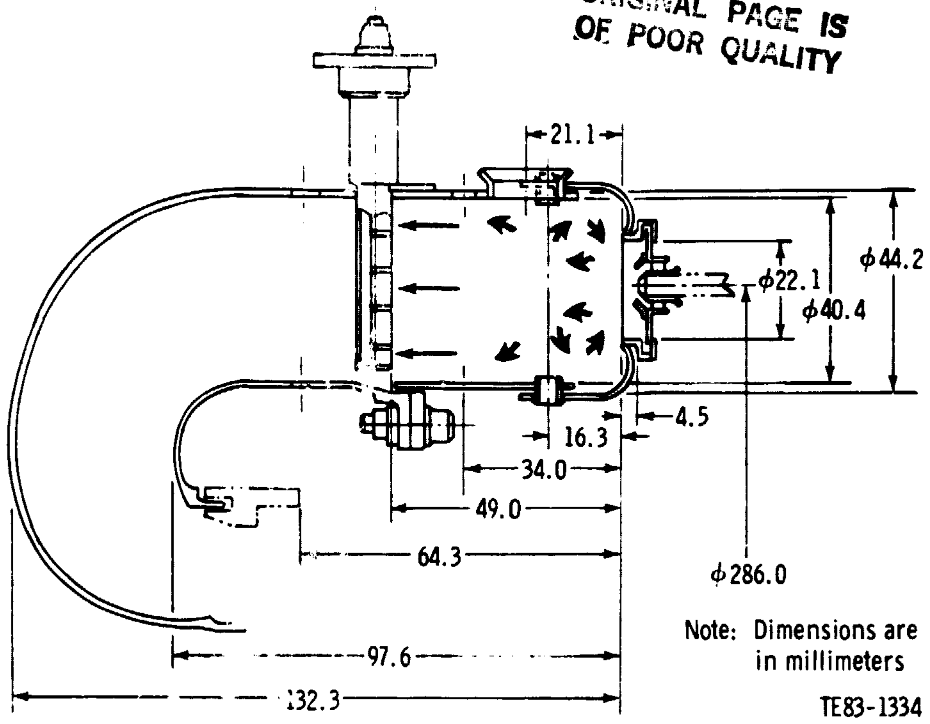


Figure 27. Dimensional cross section of Concept II, baseline, combustor.

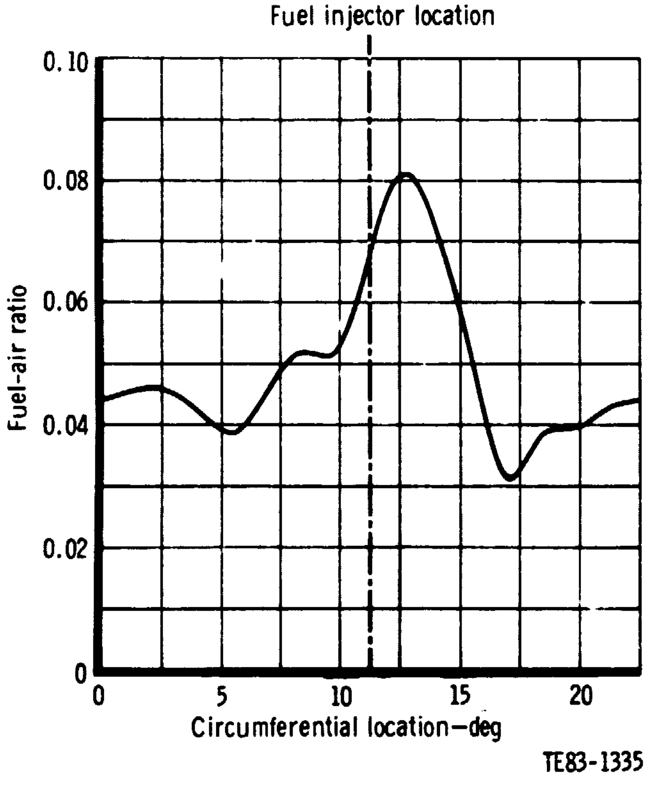


Figure 28. Predicted average primary zone fuel-air ratio (Concept II, baseline--80% power).

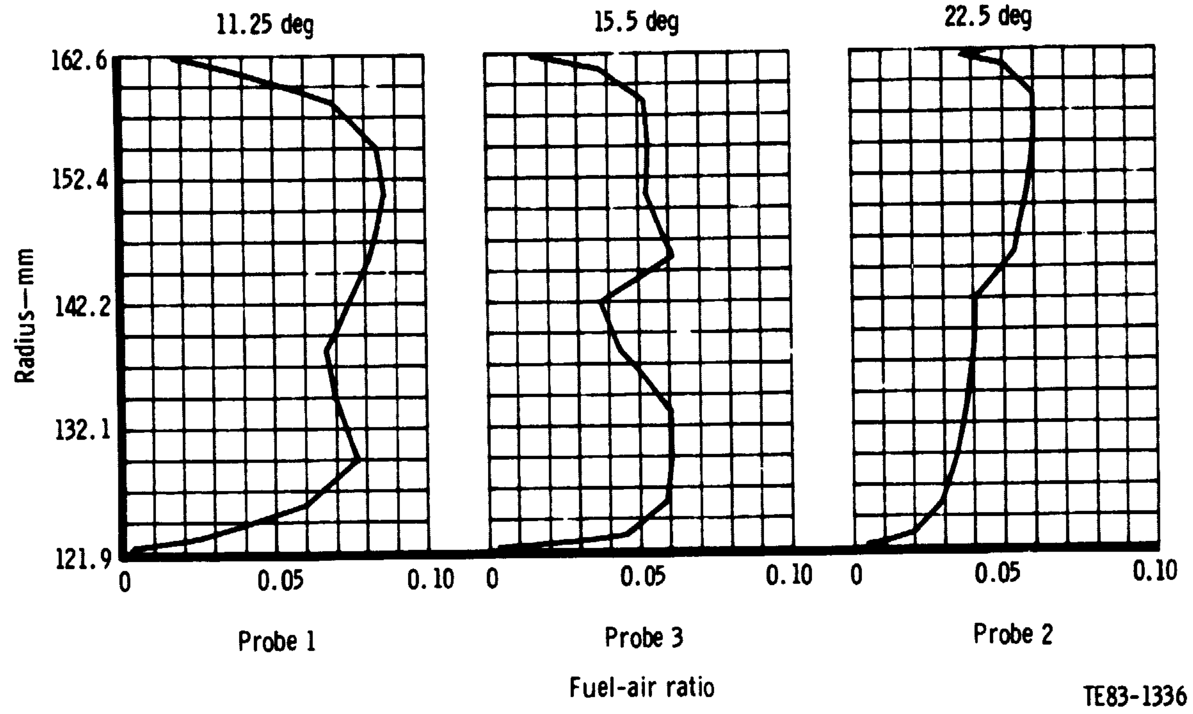


Figure 29. Predicted primary zone fuel-air ratio (Concept II, baseline--80% power).

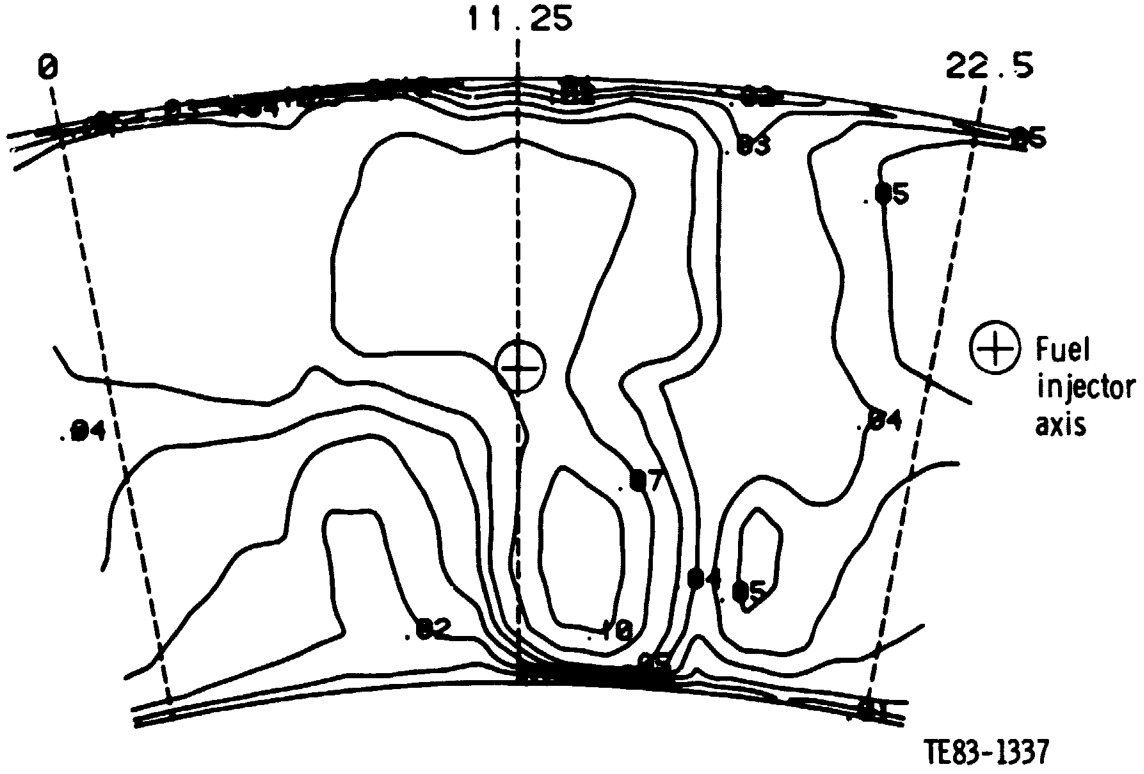


Figure 30. Predicted primary zone fuel-air ratio contours (Concept II, baseline--80% power).

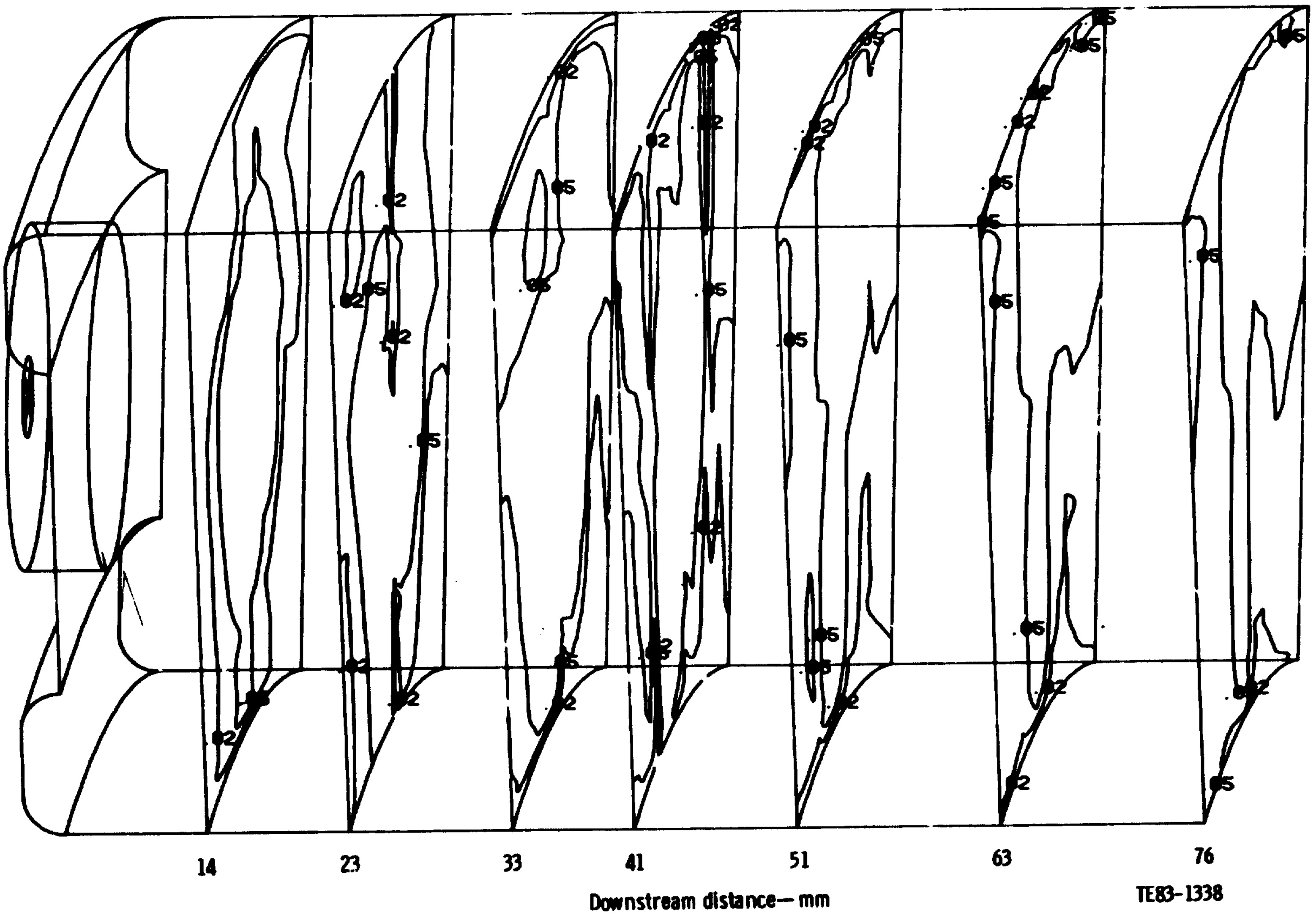


Figure 31. Predicted primary zone fuel-air ratio contours (Concept II, baseline--80% power).

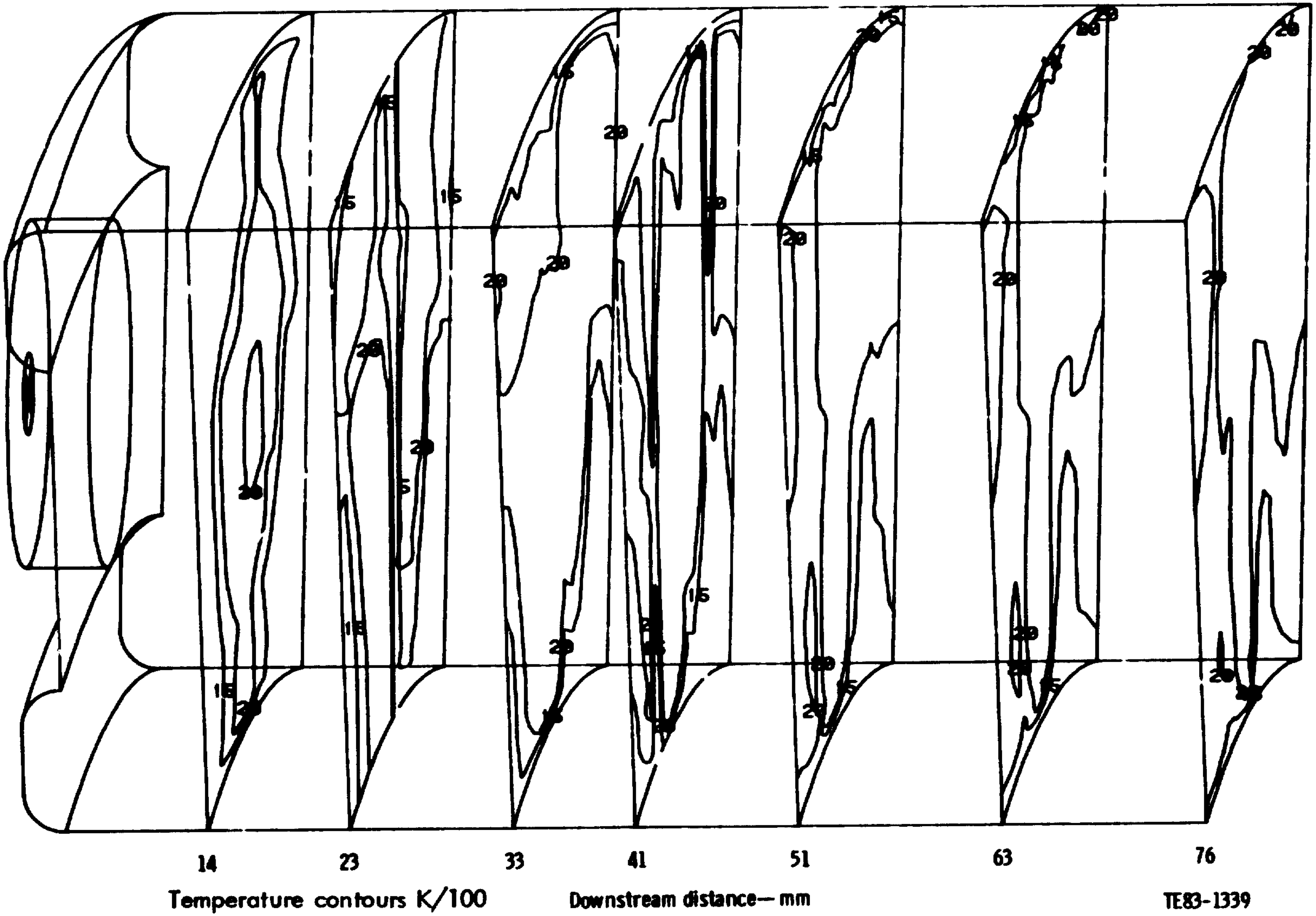


Figure 32. Predicted primary zone gas temperature contours (Concept II, baseline--80% power).

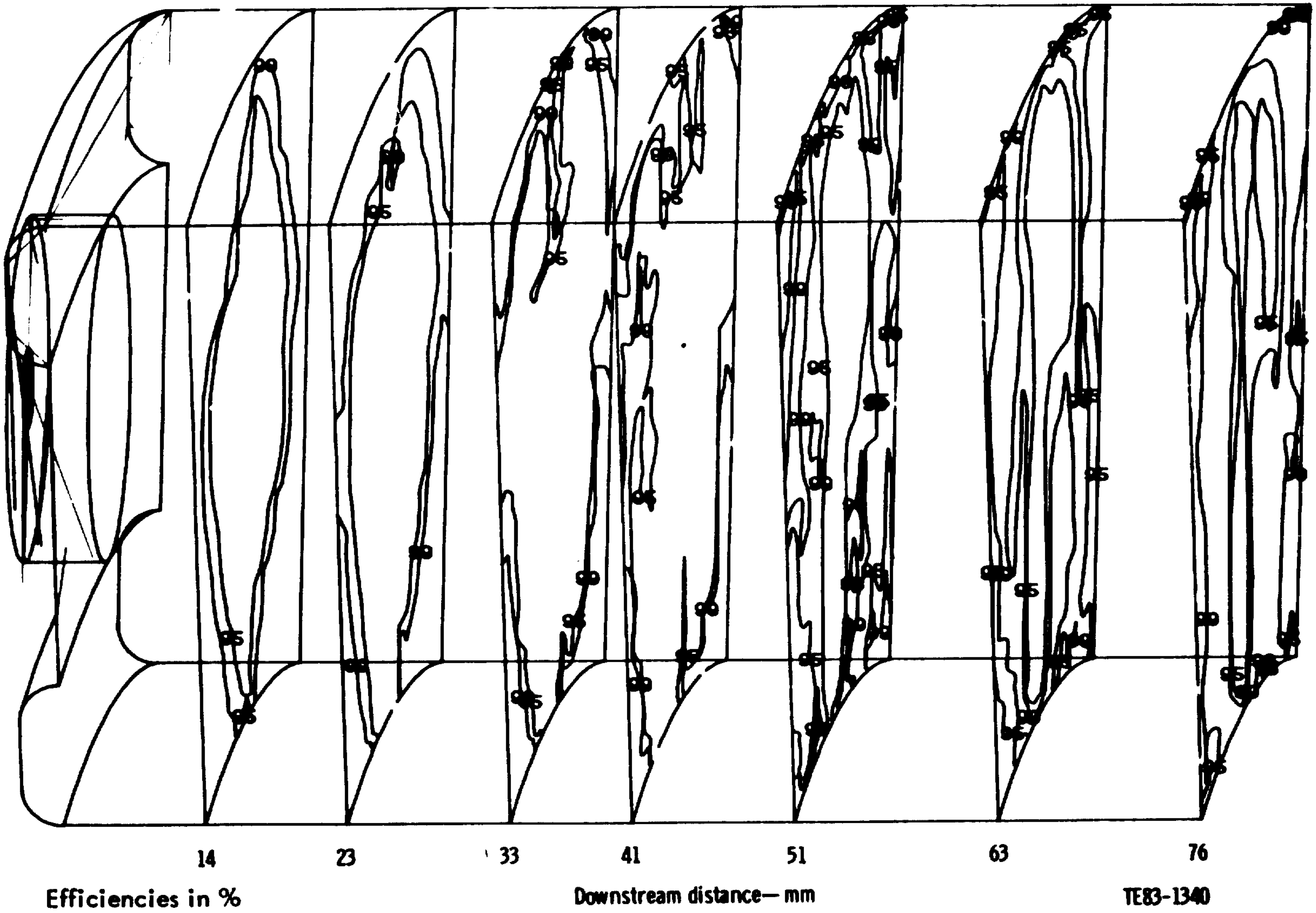
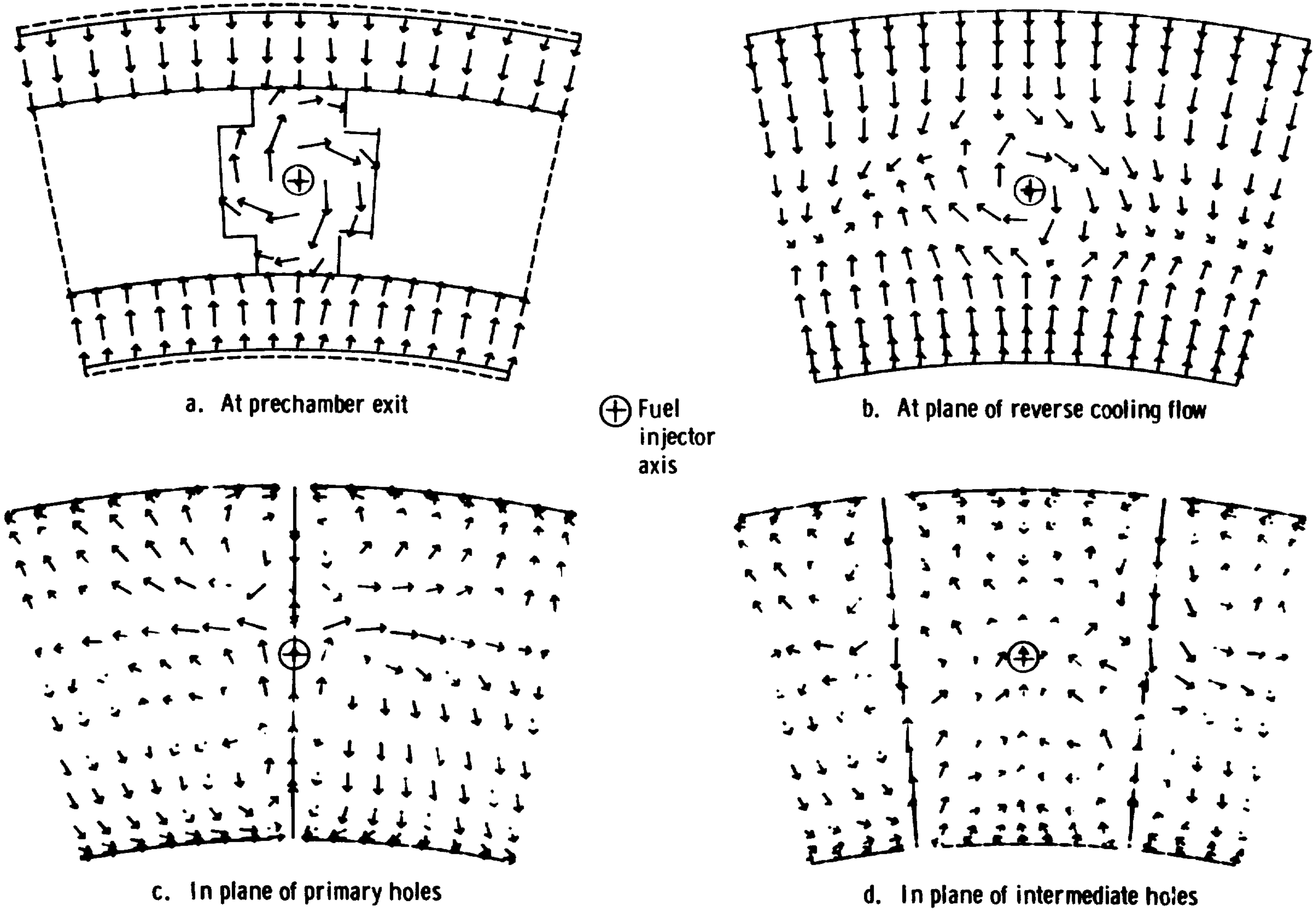


Figure 33. Predicted primary zone combustion efficiency contours (Concept II, baseline--80% power).



a. At prechamber exit

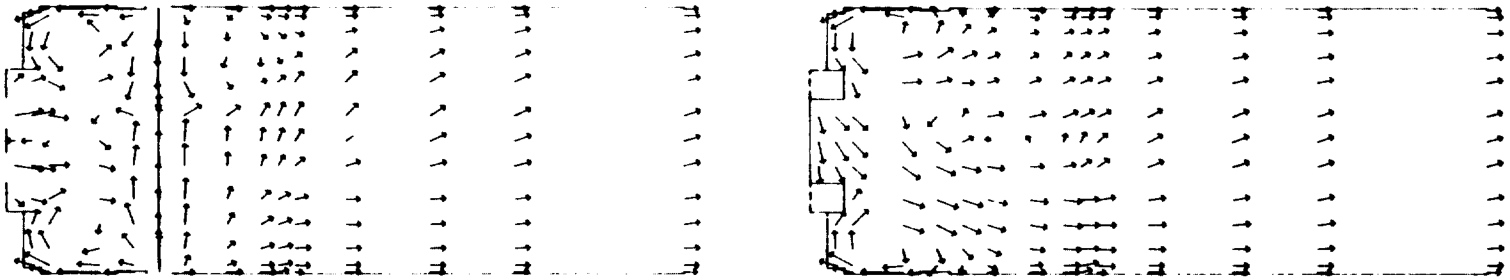
b. At plane of reverse cooling flow

c. In plane of primary holes

d. In plane of intermediate holes

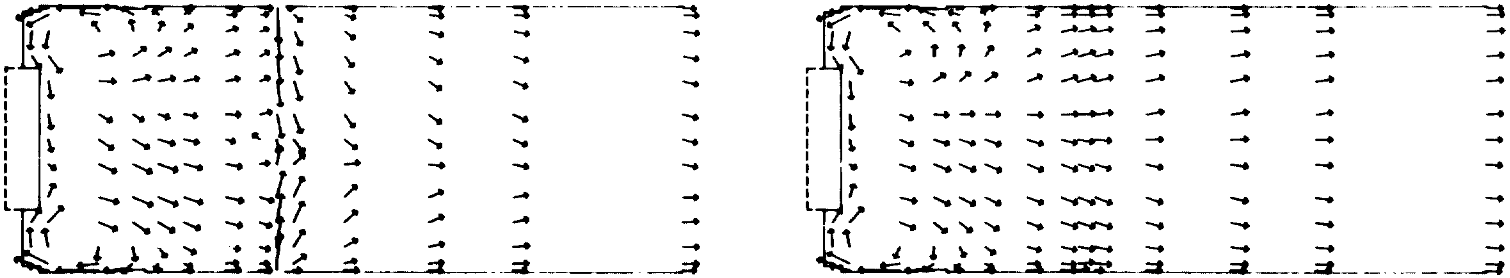
TE83-1341

Figure 34. Concept II, baseline, combustor--radial plane velocity diagrams.



a. Through fuel nozzle (liner centerline)

b. Through plane between fuel nozzle and intermediate holes



c. Through intermediate zone holes

d. Through plane midway between fuel nozzles

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Figure 35. Concept II, baseline, combustor--axial plane velocity diagrams.

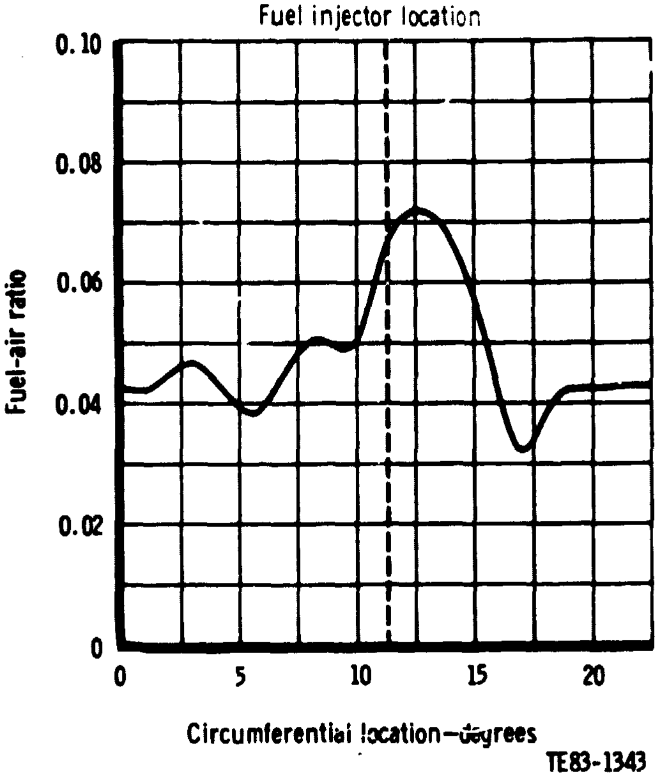

Figure 36. Predicted average primary zone fuel-air ratio (Concept II, mod 1--80% power).

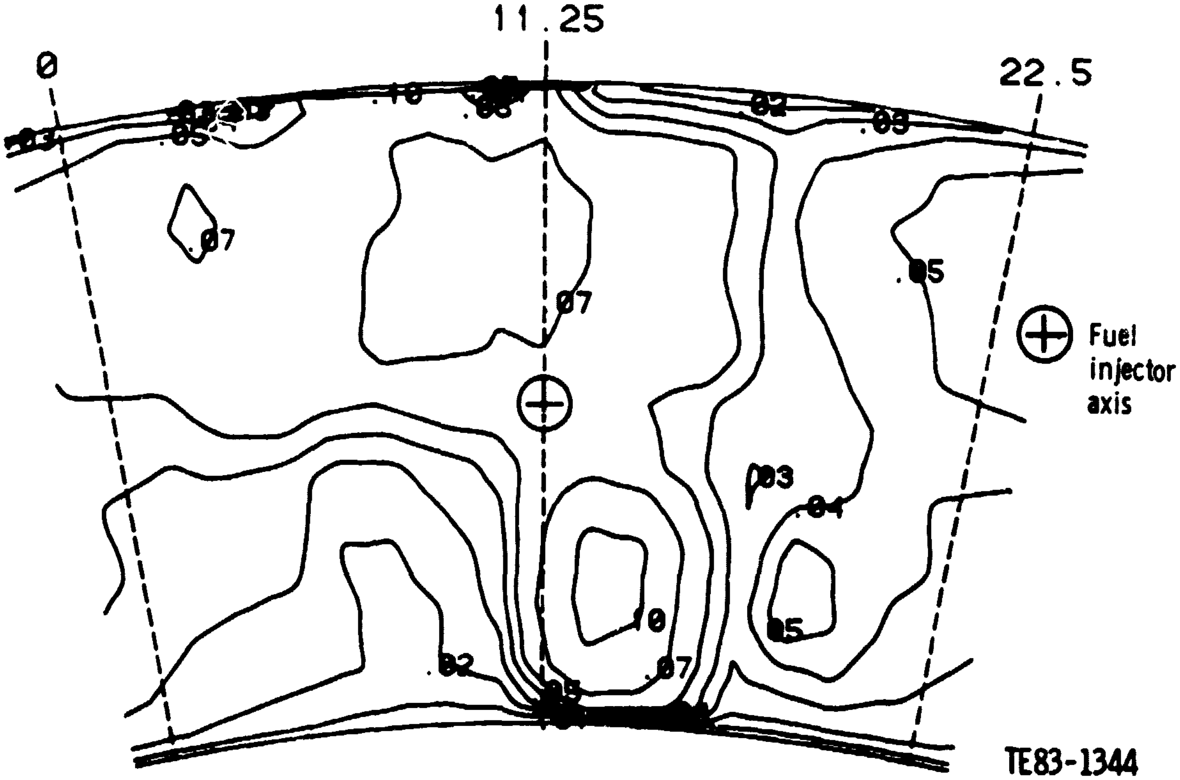

Figure 37. Predicted primary zone fuel-air ratio contours (Concept II, mod 1--80% power).

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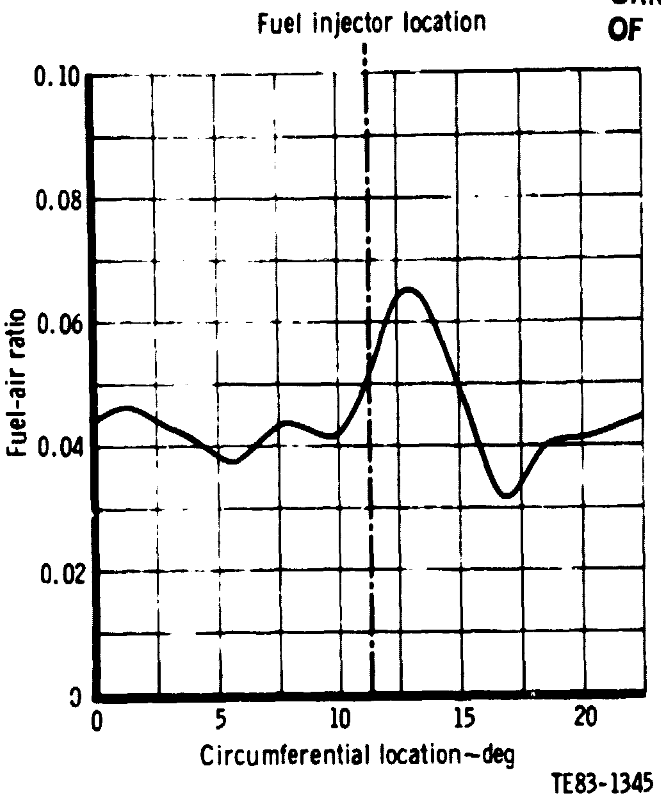

Figure 38. Predicted average primary zone fuel-air ratio (Concept II, mod 2--80% power).

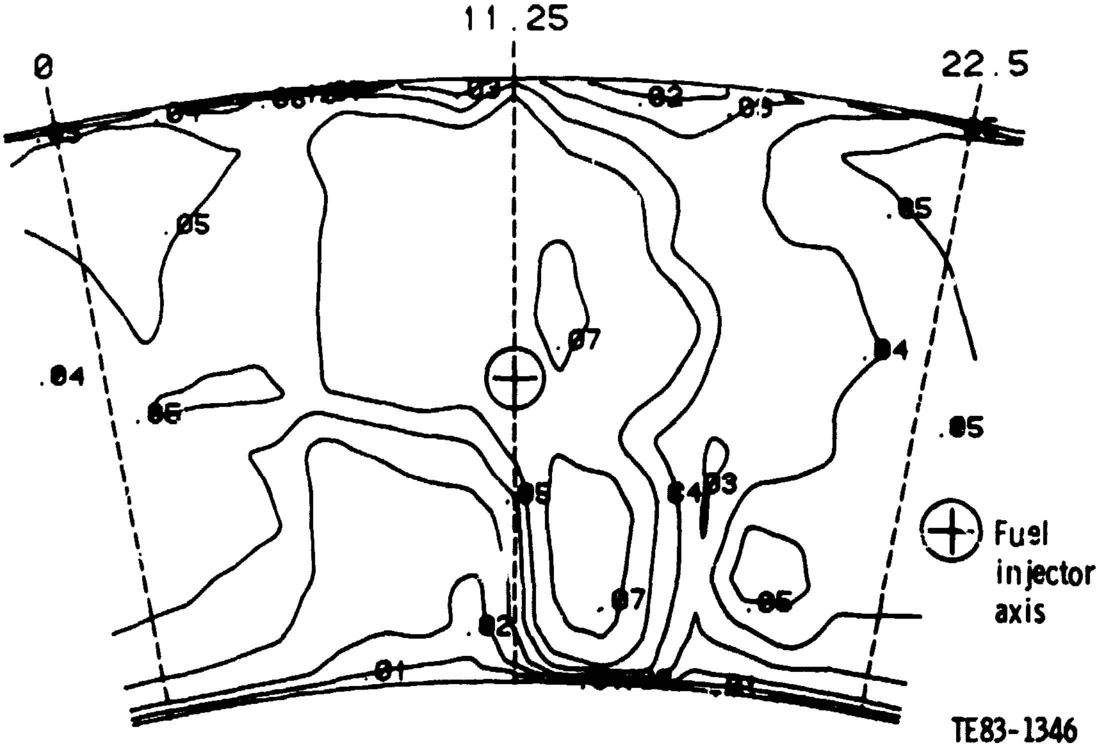

Figure 39. Predicted primary zone fuel-air ratio contours (Concept II, mod 2--80% power).

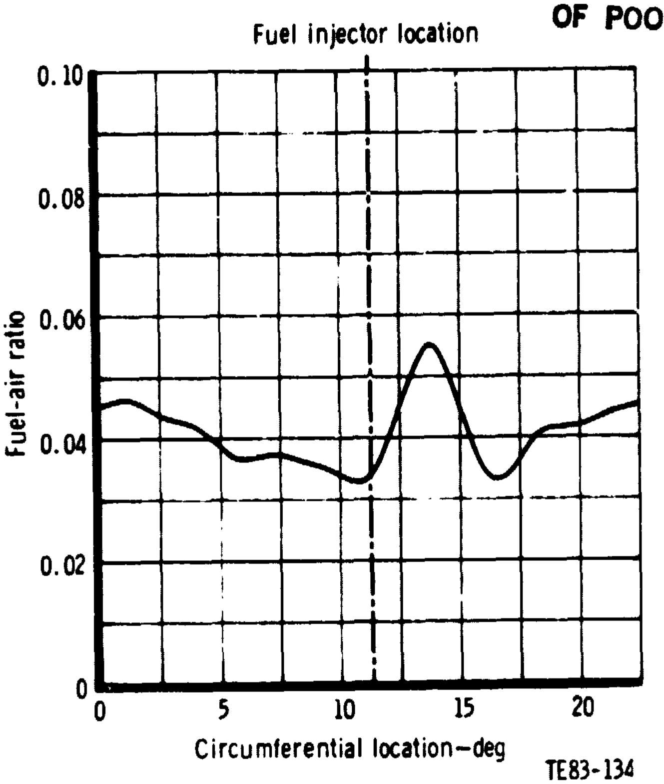

Figure 40. Predicted average primary zone fuel-air ratio (Concept II, mod 3--80% power).

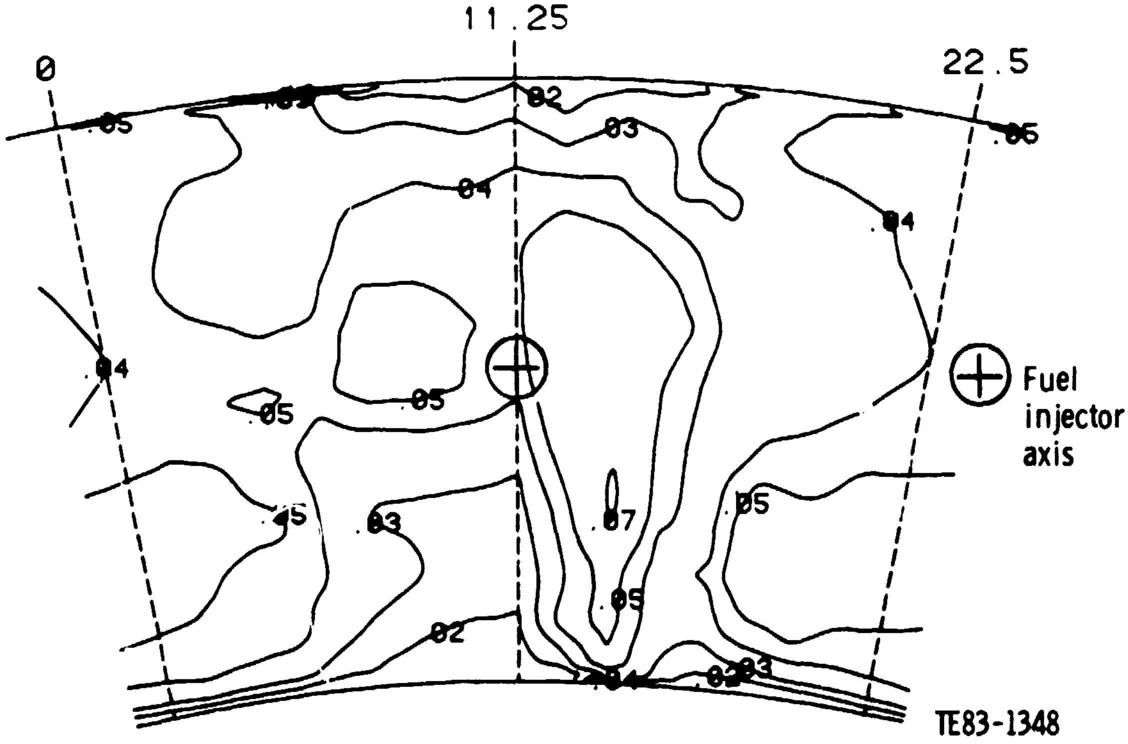

Figure 41. Predicted primary zone fuel-air ratio contours (Concept II, mod 3--80% power).

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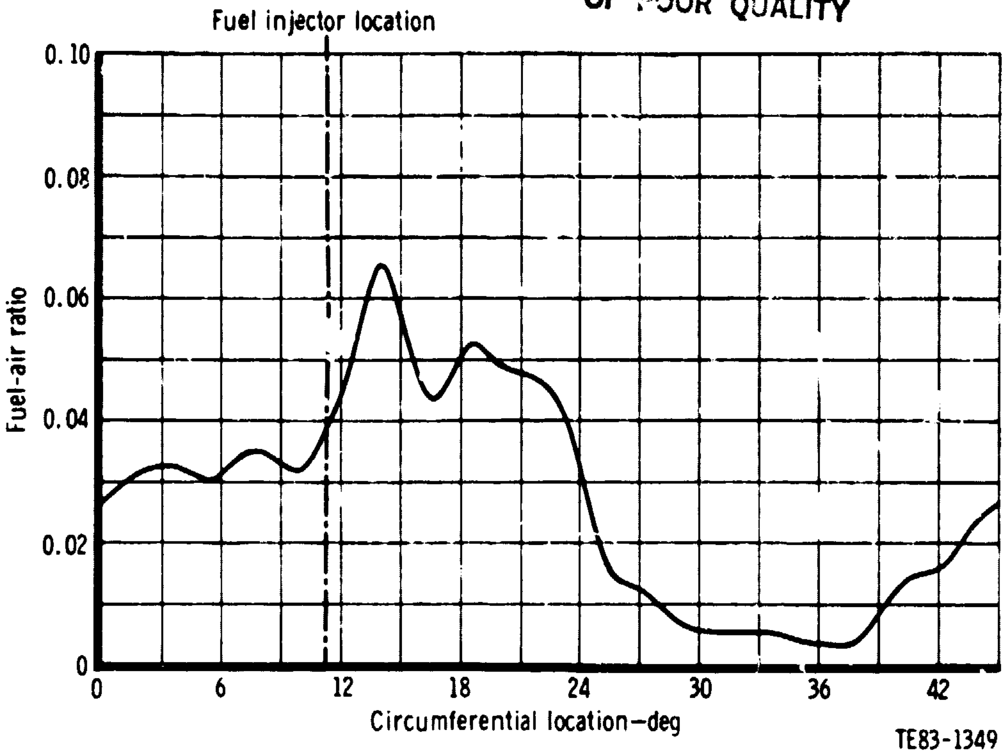


Figure 42. Predicted average primary zone fuel-air ratio (Concept II, mod 4--idle power).

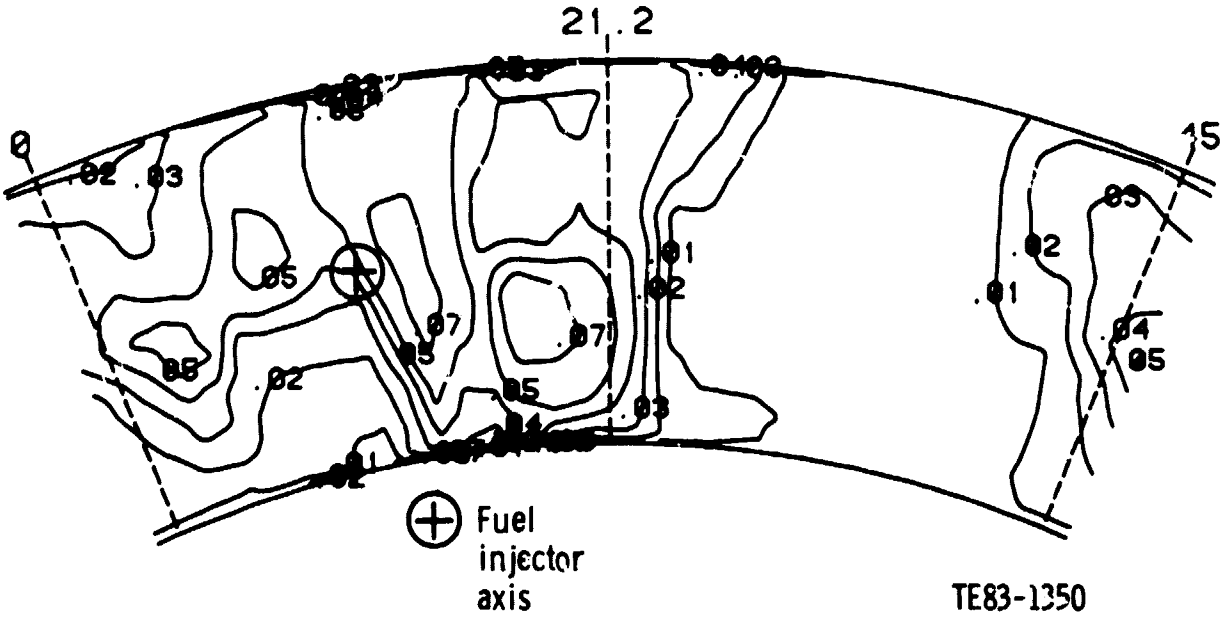
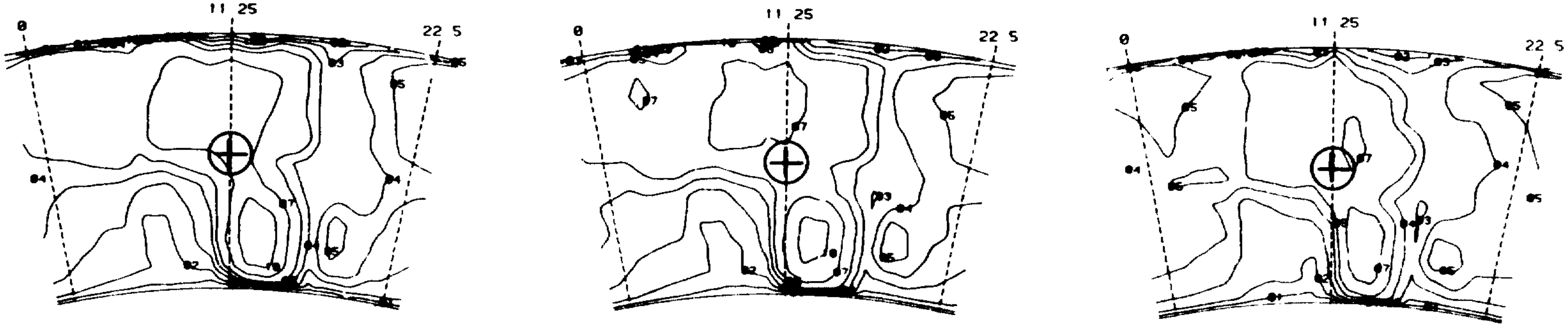


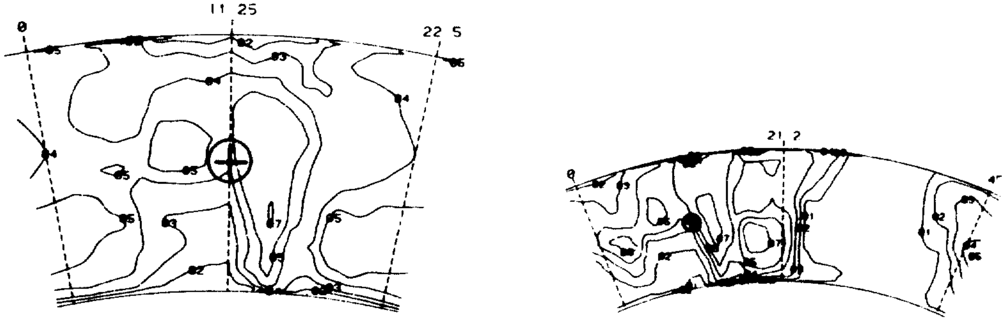
Figure 43. Predicted primary zone fuel-air ratio contours (Concept II, mod 4--idle power).



a. Concept II, baseline

b. Concept II, Mod 1

c. Concept II, Mod 2



⊕ Fuel injector axis

d. Concept II, Mod 3

e. Concept II, Mod 4

TE83-1351

Figure 44. Comparison of Concept II fuel-air ratio contours for the baseline and four design mods.

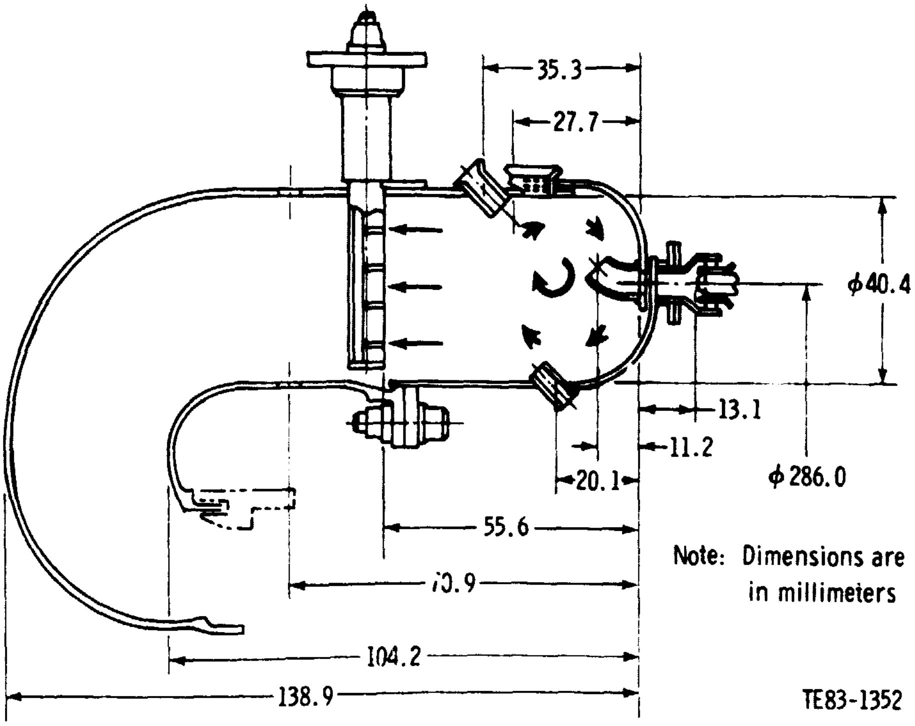


Figure 45. Dimensional cross section of Concept III, baseline, combustor.

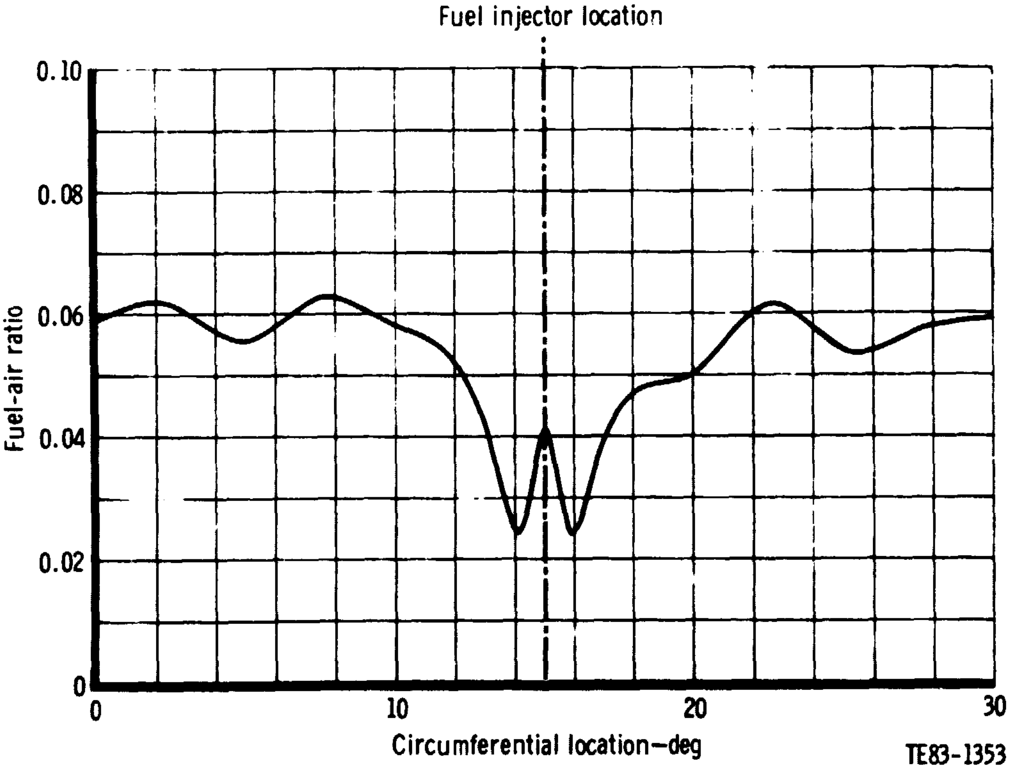


Figure 46. Predicted average primary zone fuel-air ratio (Concept III, baseline--80% power).

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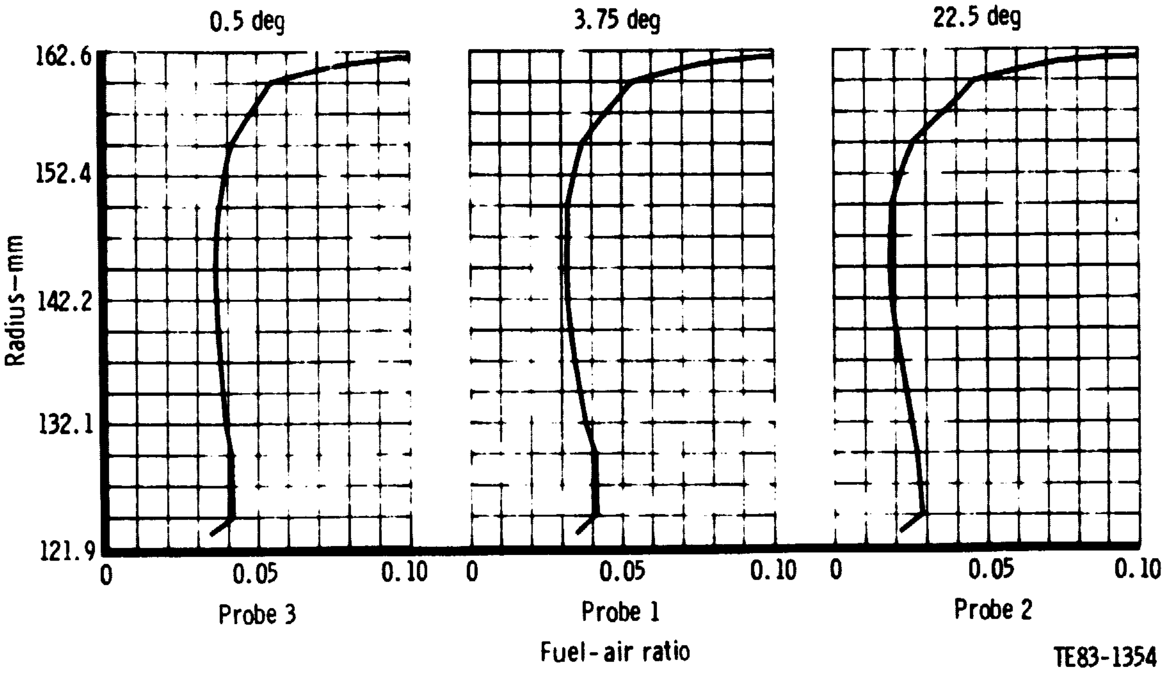


Figure 47. Predicted radial primary zone fuel-air ratio (Concept III, baseline--80% power).

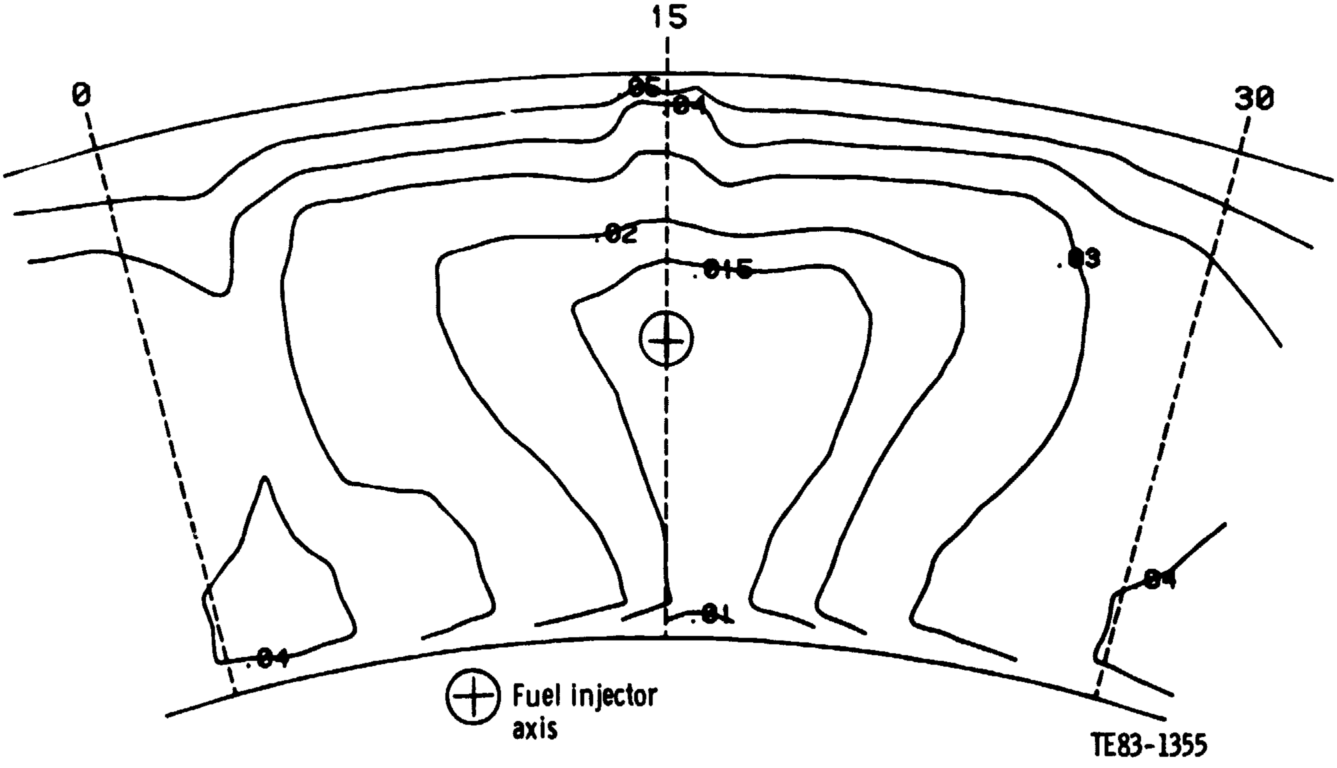


Figure 48. Predicted primary zone fuel-air ratio contours (Concept III, baseline--80% power).

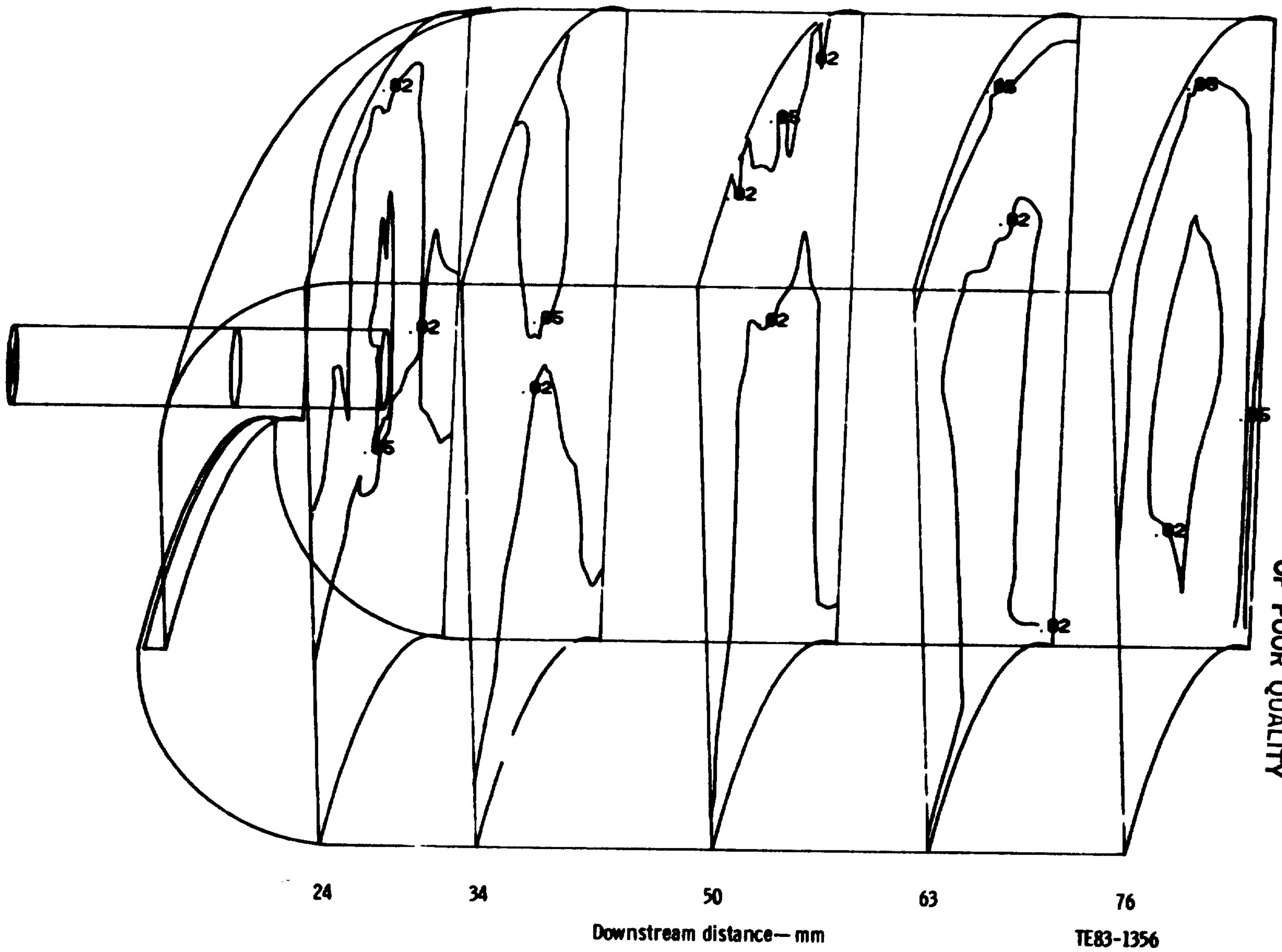


Figure 49. Predicted primary zone fuel-air ratio contours (Concept III, baseline--80% power).

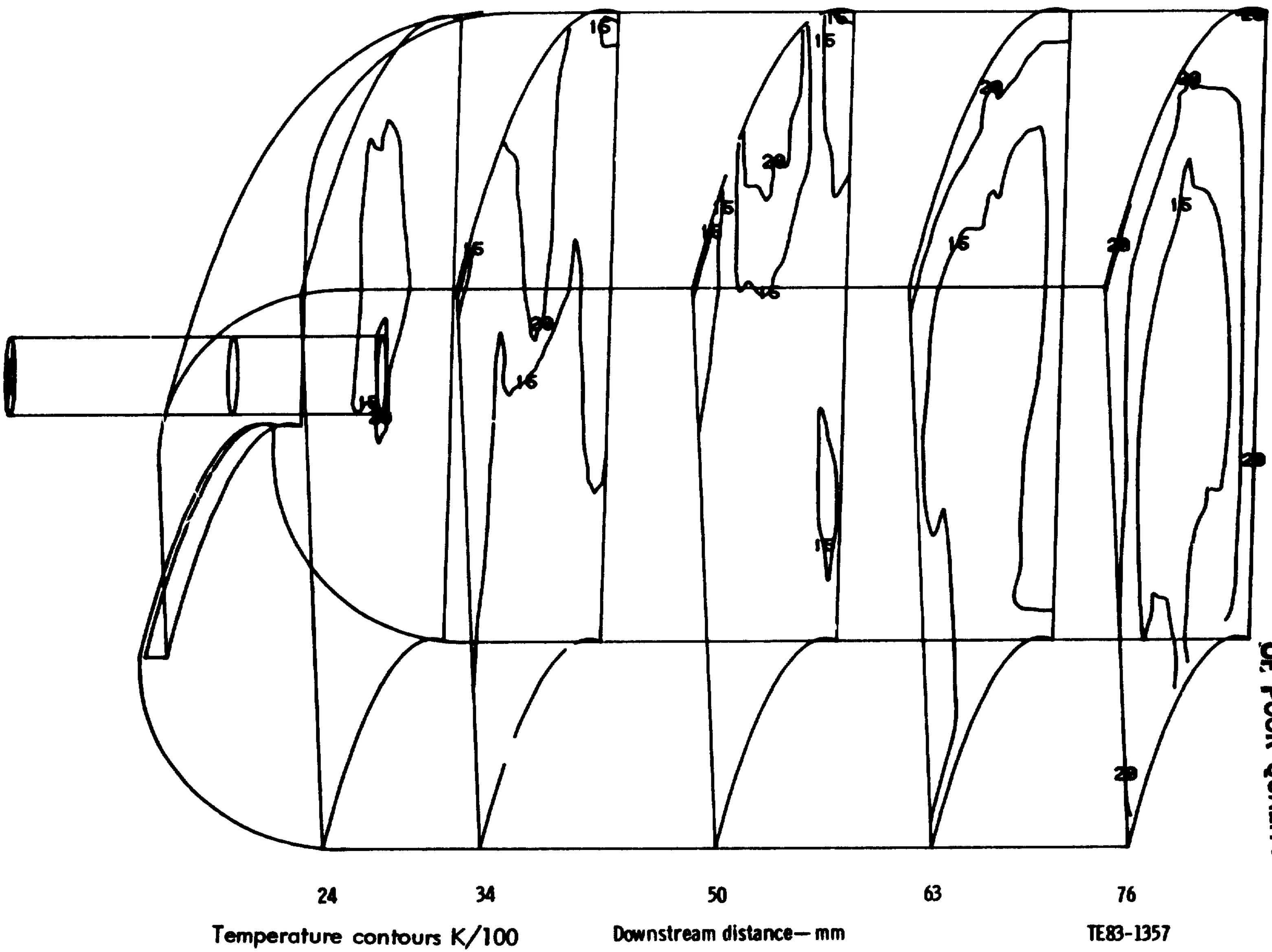


Figure 50. Predicted primary zone gas temperature contours (Concept III, baseline--80% power).

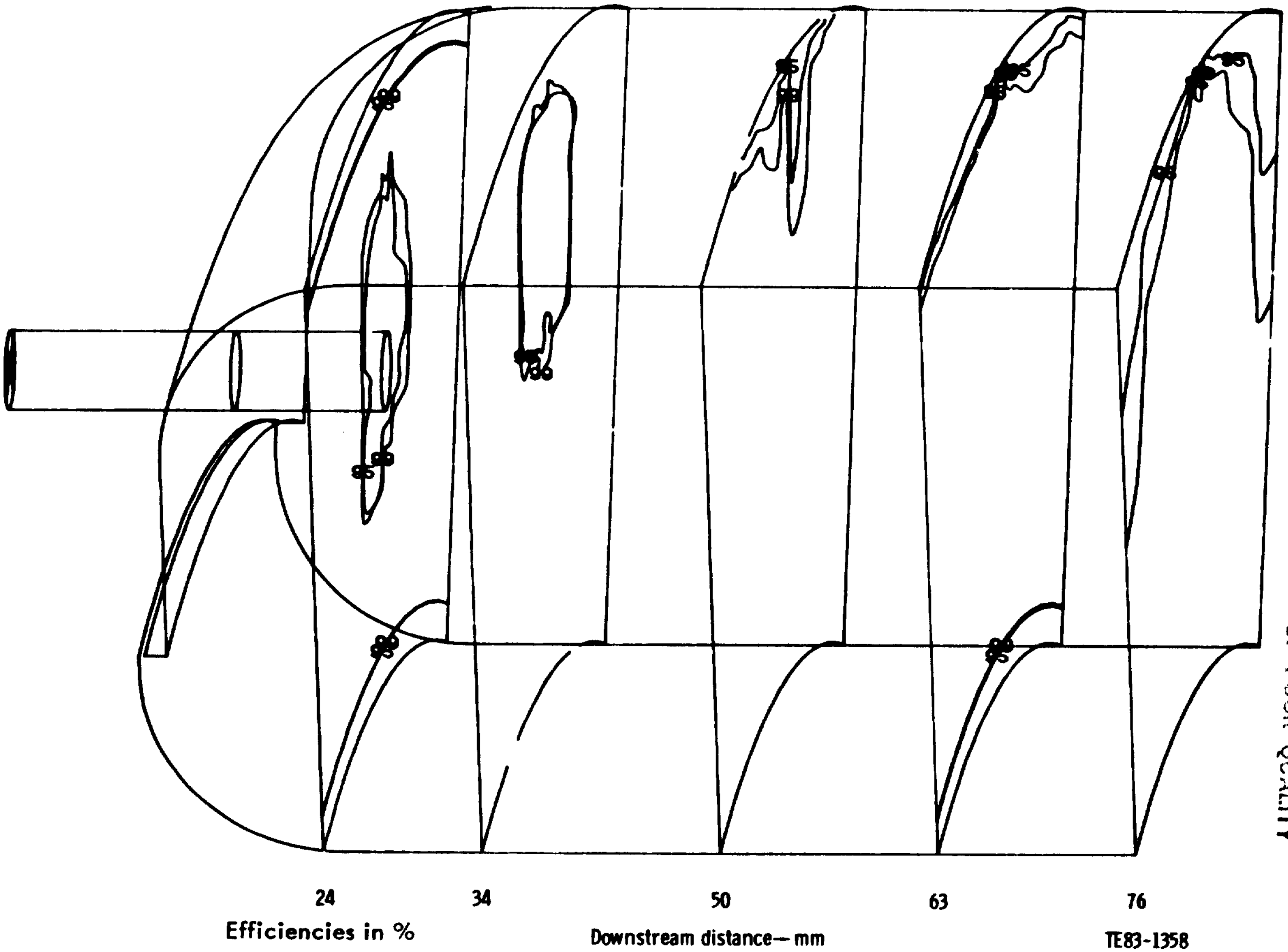
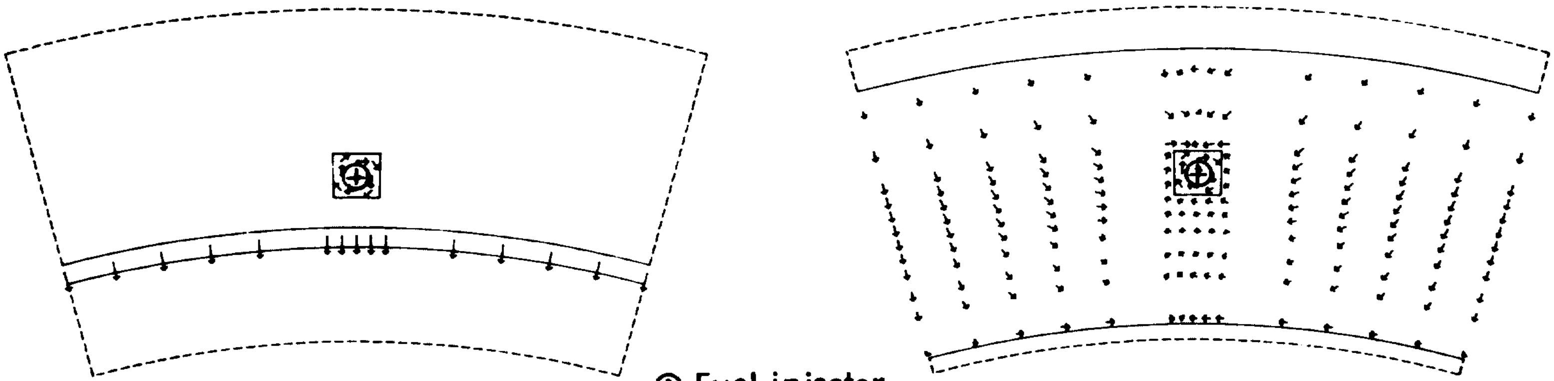


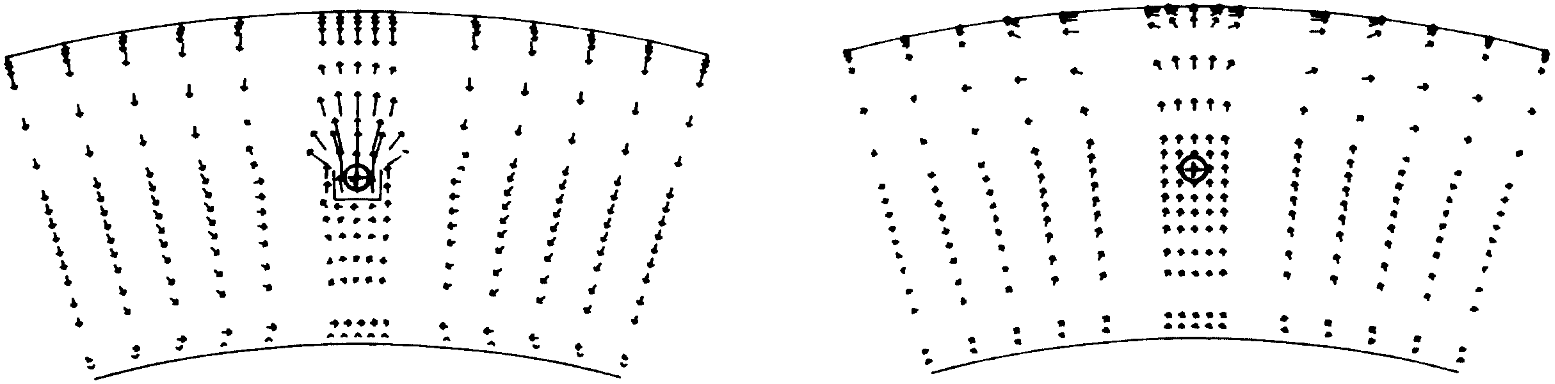
Figure 51. Predicted primary zone combustion efficiency contours (Concept III, baseline--80% power).



a. At dome film-cooling entry

⊕ Fuel injector axis

b. Along fuel-air chute

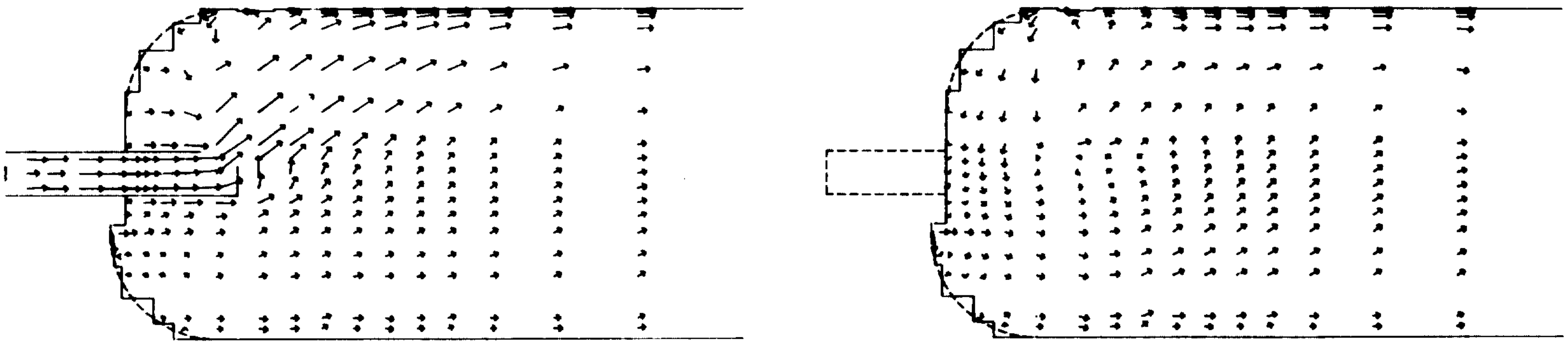


c. At fuel exit points of fuel-air chute

d. At plane downstream of primary air bushings

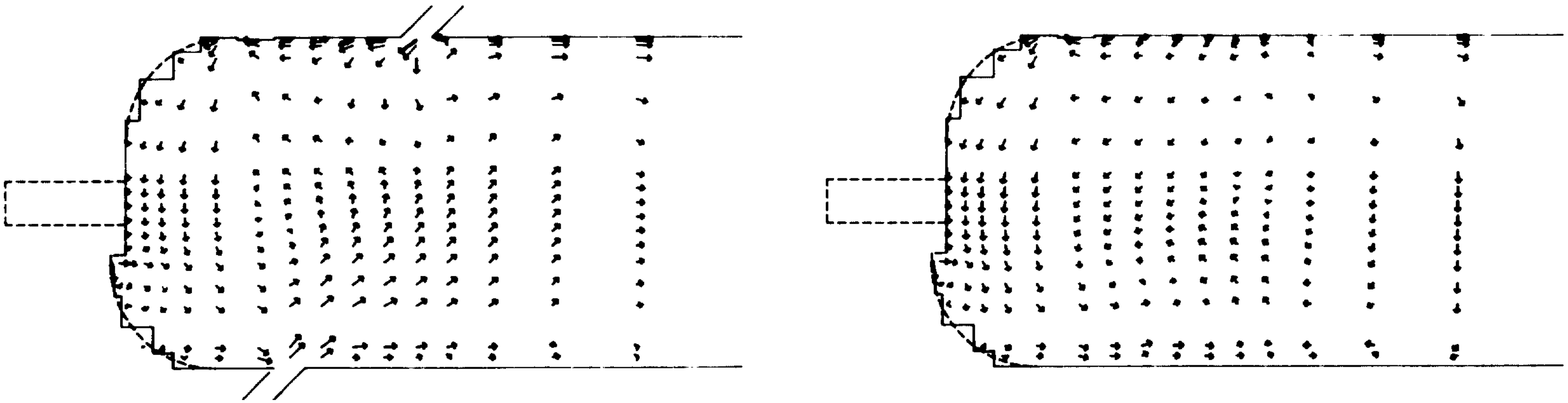
TE83-1359

Figure 52. Concept III, baseline, radial plane velocity diagrams.



a. Through fuel injector (centerline)

b. Between fuel nozzle and primary-air chutes



c. Through primary-air chutes

d. Outside primary-air chutes

TE83-1360

Figure 53. Concept III, baseline, axial plane velocity diagrams.

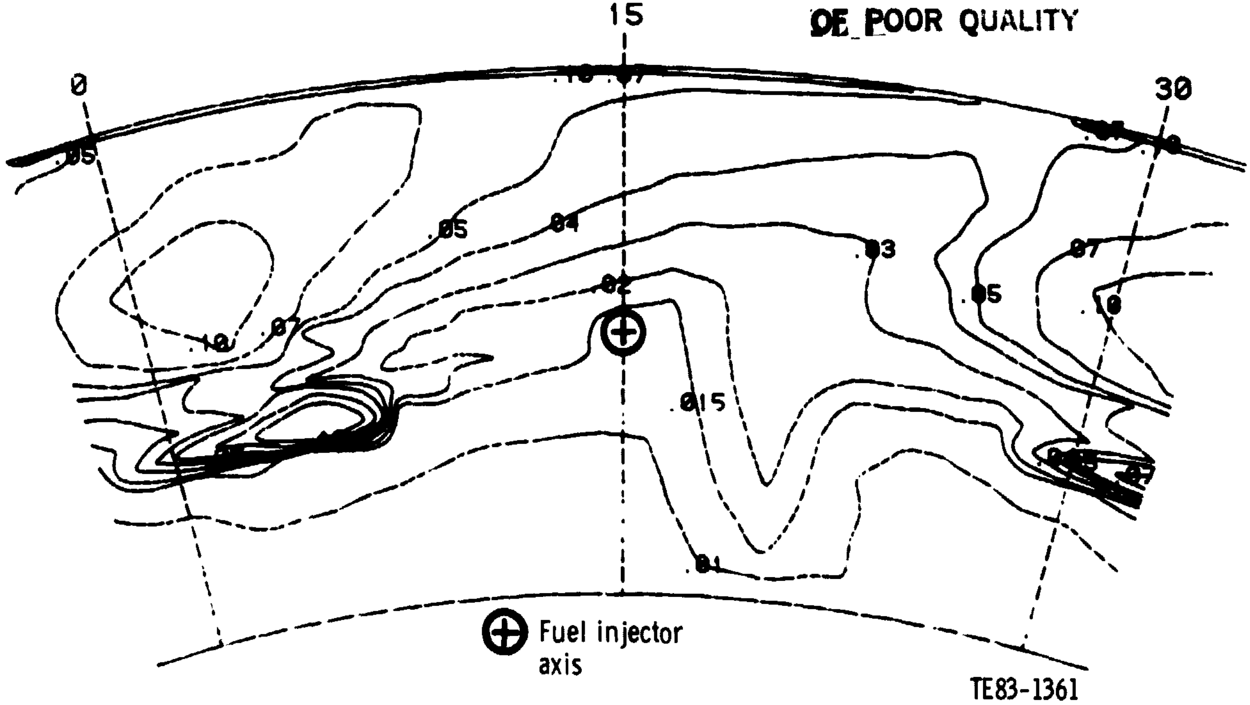


Figure 54. Predicted primary zone fuel-air ratio contours (Concept III, mod 1--80% power).

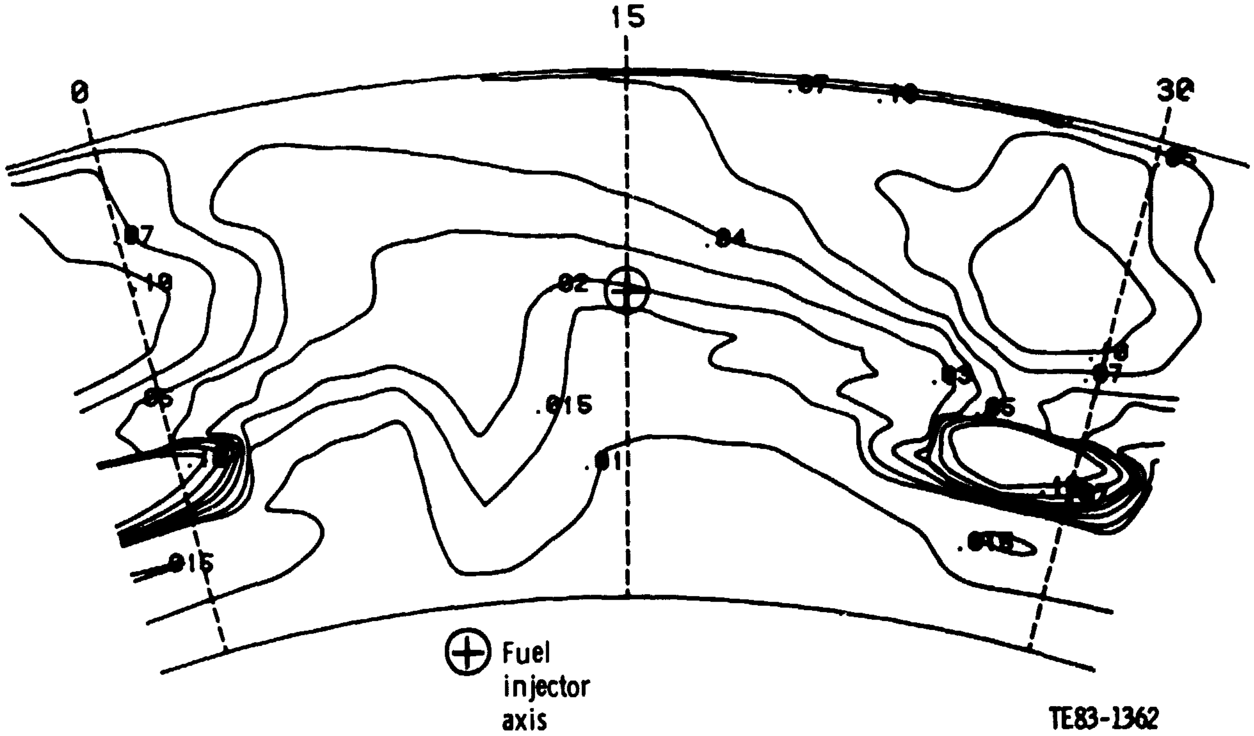


Figure 55. Predicted primary zone fuel-air ratio contours (Concept III, mod 2--80% power).

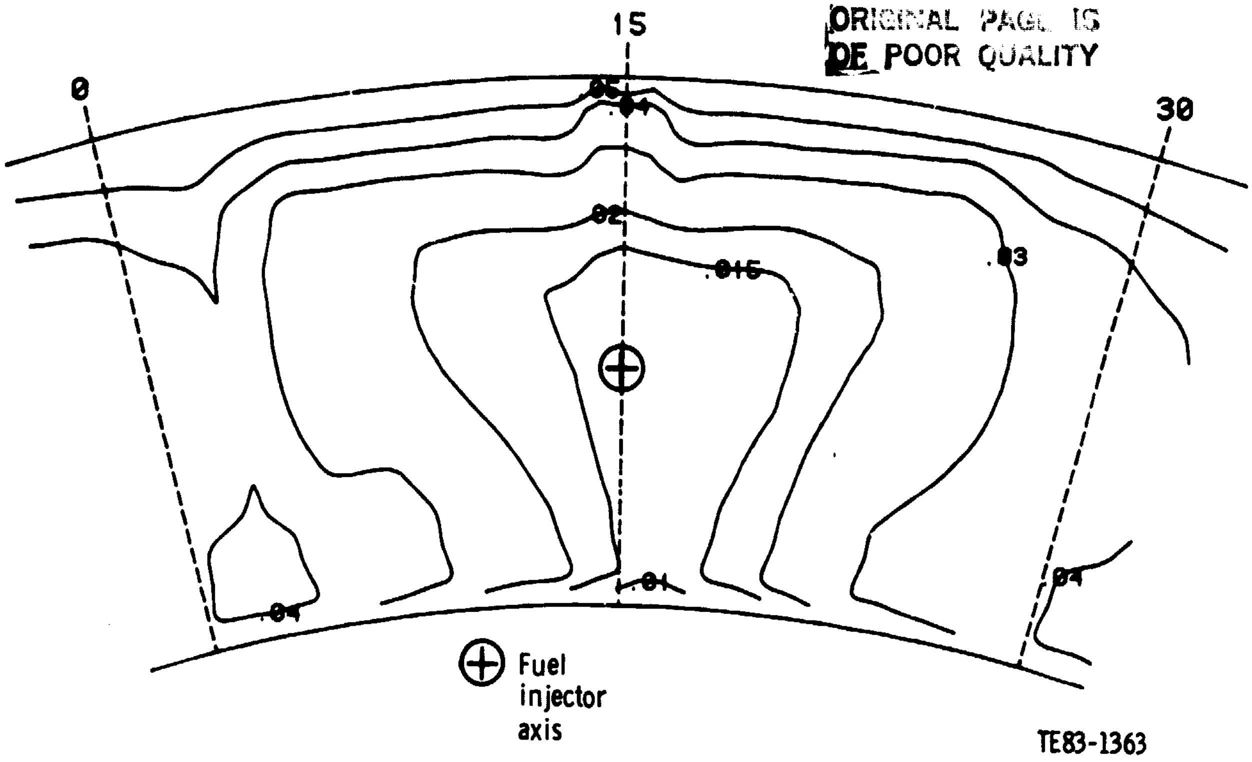


Figure 56. Predicted primary zone fuel-air ratio contours (Concept III, mod 3--80% power).

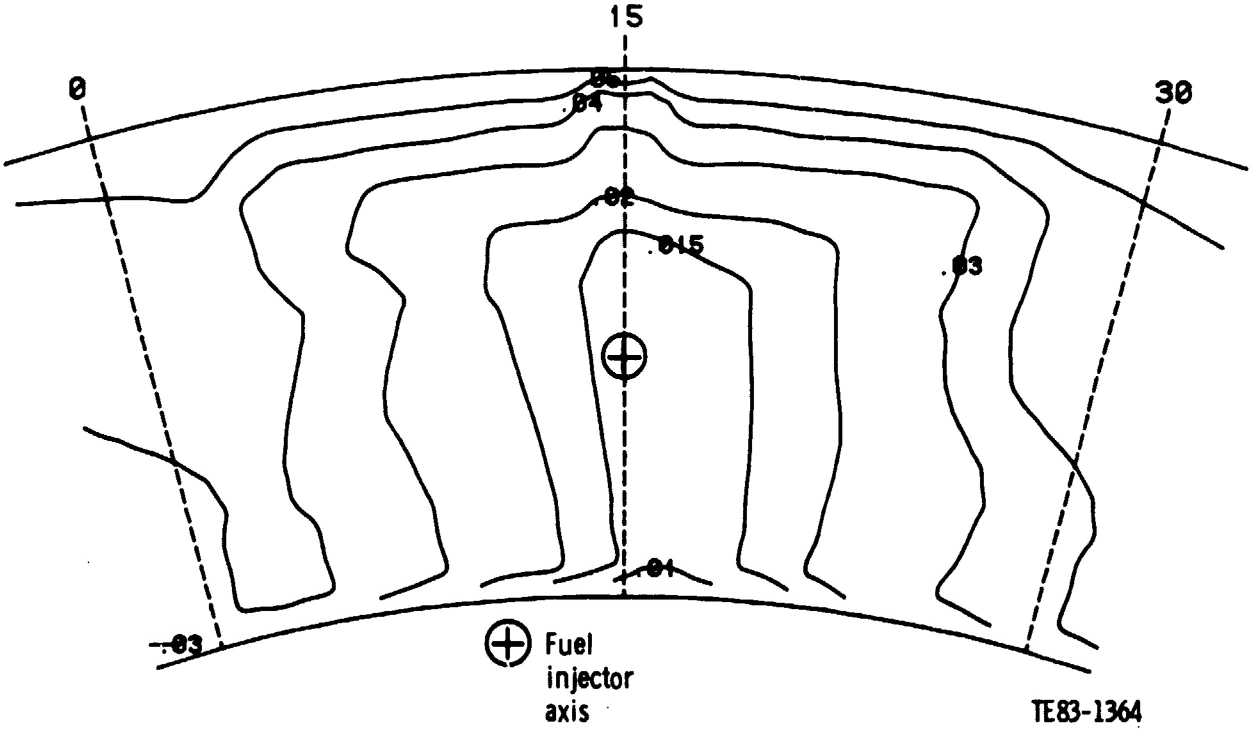


Figure 57. Predicted primary zone fuel-air ratio contours (Concept III, mod 4--80% power).

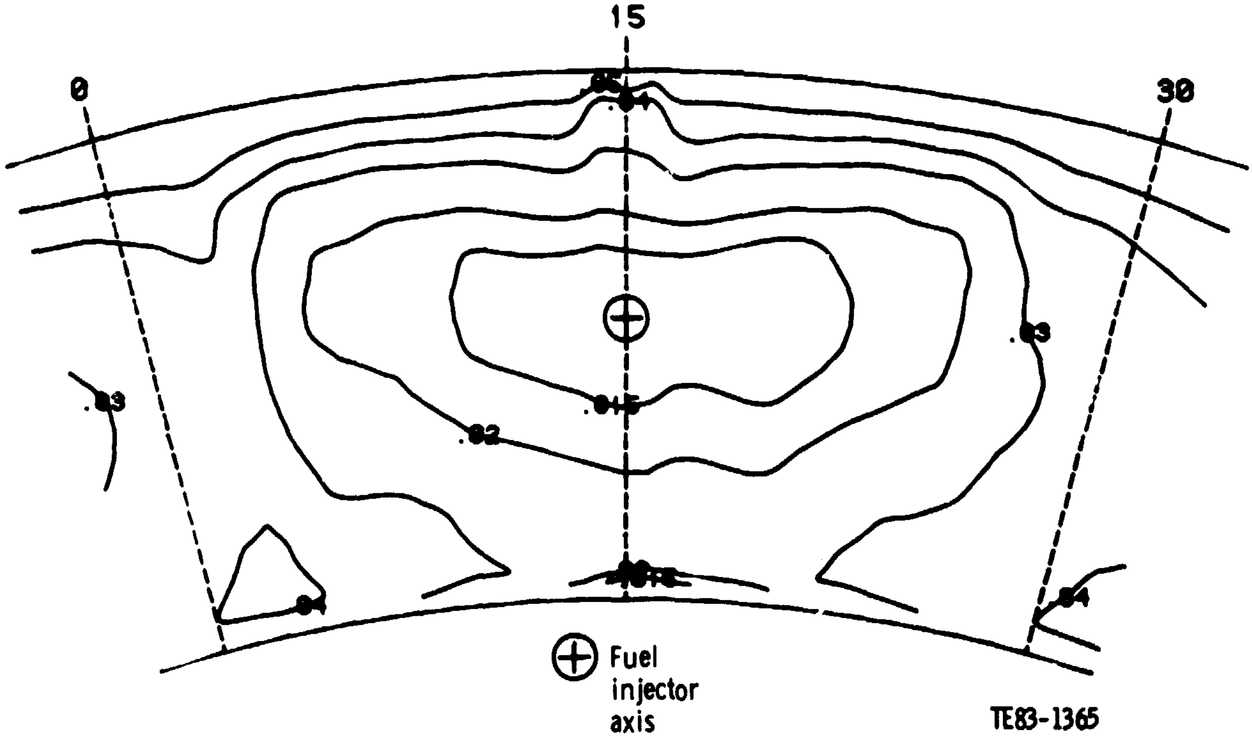
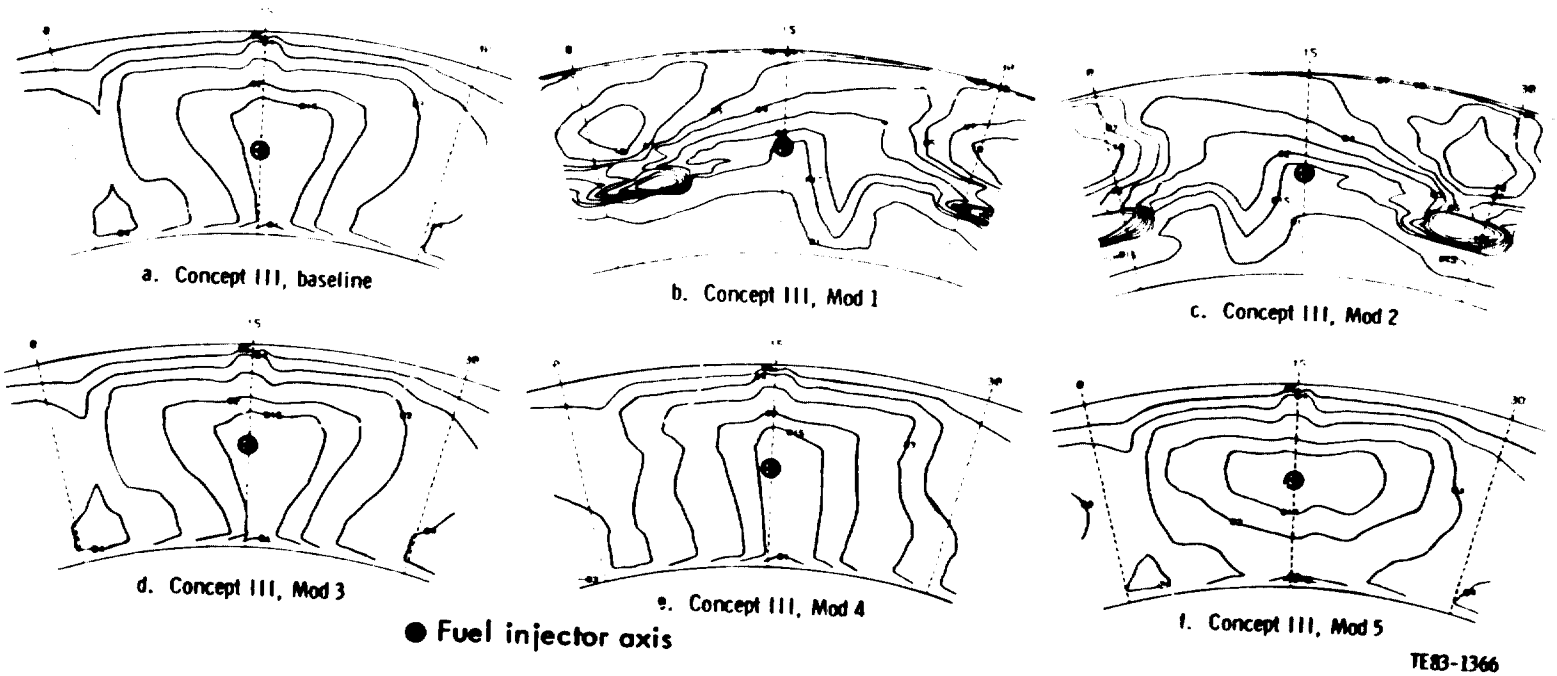


Figure 58. Predicted primary zone fuel-air ratio contours (Concept III, mod 5--80% power).



a. Concept III, baseline

b. Concept III, Mod 1

c. Concept III, Mod 2

d. Concept III, Mod 3

e. Concept III, Mod 4

f. Concept III, Mod 5

● Fuel injector axis

Figure 59. Summary of Concept III fuel-air ratio contours at the plane of primary zone probes.

V. TEST RIG AND INSTRUMENTATION

COMBUSTOR TEST RIG

The GMA500 component test rig was utilized for the performance testing of these small annular gas turbine primary zones. This rig shown in Figure 60* features a rotating temperature and gas sampling probe.

A cross section of the combustor rig is shown in Figure 61. The engine flow path is simulated from the compressor diffuser to the inlet of the gasifier turbine. All parts surrounding the combustor are actual engine hardware. The primary zone sections have provision for attachment to a flanged dilution zone and a reverse-flow annular transition section, permitting test evaluations of complete combustors.

Detailed instrumentation provides overall performance measurements at the exit of the combustor, and gas sampling probes are used for determining conditions in the primary zone.

In the exit plane of the combustor, the instrumentation consists of temperature rakes and pressure and gas sampling probes as shown in Figure 62. A good survey of overall combustion performance is provided since the instrumentation is capable of traversing through the entire 360 deg annulus. Probes and rakes also survey radial positions, four depths for each of two thermocouple arms, three depths for the gas sampling probe, and four depths for the pressure measurement.

Primary zone gas sampling is conducted with three or four water-cooled probes circumferentially located at different positions relative to the fuel nozzle in order to provide representative samples. Figure 63 shows the relative position of the PZ gas-sampling probes when testing both the 12 and 16 fuel nozzle systems. The water-cooled primary zone probes are located immediately upstream of the dilution holes. A photograph of the probe is shown in Figure 64 with a cross section in Figure 65.

GAS ANALYSIS SYSTEM

The NASA PZ gas analysis system consisted of PZ sample probes, a rotating exhaust probe, stainless-steel heated sample lines and sample manifold, a gas analyzer train, and a smoke sampling system. The four sample probes were inserted into the primary zone of each combustor in separate planes arranged so as to provide good coverage in the circumferential direction relative to fuel nozzle location. Concepts I and II used 16 fuel nozzles while Concept III used only 12 nozzles. The fourth probe (No. 4, Figure 63) was added soon after the start of work on Concept III to provide data on the nozzle centerline of Concept III. Table VI is a listing of the number of primary zone probes surveyed for each of the test conditions.

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*The figures for this section appear at the end of the section.

Table VI.
Primary zone probes used in each test configuration.

	Concept I	Concept II	Concept III
Baseline	3	3	3
Mod 1	3	3	3
Mod 2	3	3	4
Mod 3	3	4	4
Mod 4	4	4	4
Mod 5	4	4	4

A tube was routed from each port to separate fittings on the external support plate of the probe. Four heated sample lines carried the samples from each port to four solenoid valves that were manifolded at their exits. The valves for each probe could be actuated singly to obtain a port sample or simultaneously for a rake sample. The PZ rakes were water cooled.

The exhaust sample probe was also water cooled and consisted of a 6 mm (0.25 in.), stainless-steel, multihole tube mounted so that it could rotate to any circumferential location in the exhaust stream. The exhaust sample line was also heated and brought the sample gas from the exhaust probe to a solenoid valve whose exit formed part of the sample manifold. Thus with four PZ sample probes of four ports each and the exhaust sample, the completed sample array was able to deliver 17 separate samples.

The resultant sample manifold had a static-pressure tap, reverse purge capability, and two sample-line exits. The static-pressure tap was used to monitor the sample-line pressure. Reverse purging of the separate sample lines was performed frequently to ensure adaquate sample flow. The purge system was simply a nitrogen tank with a high-pressure regulator connected to the sample manifold through a length of high-pressure hose. The nitrogen tank was located in the control room so that it could be used without having to go into the test cell during the run.

Of the two, heated, 6 mm sample lines, one led to the gas analyzer train in the test cell. A schematic of the analyzer train is given in Figure 66. Measured species were carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), unburned hydrocarbons (UHC), and total oxides of nitrogen (NO_x). Although not shown, inlet water vapor was measured and used in the chemistry calculations. Analyzer outputs were read directly by the data acquisition system.

Data acquisition consisted of a performance run and two types of gas-analysis sampling. Each data run required one reading, each with its own reading number. To take each type of data, the exhaust probe actuator was preset to stop a certain number of times around the combustor annulus; then data were taken when the probe was at rest and steady state was achieved. Once the reading was begun, the probe could be stopped at any of its preset increments and remain at the position for as long as needed. In automatic mode the probe would reach a position, take the required data, and immediately continue on to the next position. Continuous on-line rig conditions were also monitored.

To take a performance-run reading, the probe actuator was set to pause at 10 deg steps. Temperature, pressure, and flow conditions were taken and then the probe continued to the next position. This process repeated until all 36 data points were taken, in which case the probe automatically returned in the reverse rotation to its starting position. All computed data were printed on the line printer. Raw data could be stored on floppy disk and cassette tapes if desired and were controlled by proper input commands during program initialization.

The second type of data taken was either one of the gas-analysis readings, which, at the option of the operator, could be either an exhaust survey or a PZ-rake survey. Usually the exhaust sample was taken first and then the four PZ-rake surveys were taken beginning with rake number one. The same sequence of steps was taken for probe actuation except that the probe was stopped after each reading to allow the manual input of the analyzer ranges from the keyboard console. Also the probe stopped at each 45 deg step giving eight samples per exhaust survey. An average exhaust reading was calculated and these values were used in the fuel-air ratio and efficiency computations. To take the chemistry samples, the analyzers were zero checked with an inert purge gas flowing through them. These were zeroed on the concentration range on which the sample would be read to give maximum but less than full-scale voltage output for each species. The analyzers were then switched to sample mode and the exhaust solenoid valve switched on. At each sample stop of the probe, a settling time of at least 90 sec was required to allow steady flow to all analyzers. Smoke measurements were taken at 0 and 180 deg of probe travel after the completion of the exhaust survey. The smoke procedure is described later. A typical exhaust survey printout is given in Table VII.

For the primary zone probe chemistry survey, the probe was set to stop in 90-deg steps for four performance data readings and gas samples. At the first stop; port one chemistry was sampled; then port two at 180 deg; and so on. An example of the PZ chemistry printout is shown in Table VIII. A smoke sample was taken after the on-line reading by actuating all four solenoid valves of the probe being sampled.

The smoke sample reached the sampling system through the second 6 mm heated line that exited the sample manifold from the side opposite the chemistry line. To take either an exhaust or a manifolded PZ smoke sample, the gas analyzers are taken off sample and the appropriate solenoid valves opened to the smoke analyzer. Four samples of different volumes of gas are withdrawn and measured for a smoke number according to the SAE ARP 1179A procedure (Ref 3). See Figure 67 for a schematic of the smoke sample system.

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Table VII.
Exhaust gas sample survey.

```
    DETROIT DIESEL ALLISON DIVISION COMBUSTION RESEARCH LABORATORY - ROOM 8137
           NASA PRIMARY ZONE STUDY - COMBUSTOR RIG EXPERIMENTAL RESULTS
             RIG BUILDUP  14   TEST SERIES -A     TEST DATE: 04/03/82

                    NASA PRIMARY ZONE STUDY--CONCEPT III, MOD. 2
      FUEL TUBES ROTATED TO TANGENT POSITION--CCW LOOKING AT DOME FROM FRONT.

                              ********************
                              *READING NUMBER 221*
                              *TIME OF DAY:  1338*
                              ********************

  ***************  EXPERIMENTAL BURNER OPERATING CONDITIONS  ***************
  BURNER AIR FLOW          4.587 LB/SEC     BURNER INLET  TEMP       625. DEG F
  BURNER INLET PRESSURE  131.4 PSIA         BURNER OUTLET TEMP      1923. DEG F
  FLOW FACTOR - F1      1.1499              AVG TEMPERATURE RISE    1297. DEG F
  BOT T-MAX/T-AVG       1.2191              PATTERN FACTOR          .3247
  BOT HOT SPOT (#3@ 90)  2344.              SKIN HOT SPOT,#,10      1490. DEG F
  BURNER SYSTEM DELTA-P  10.85 "HG          BURNER SYSTEM LOSS       4.06 % DP/P
  OUTER CASE    DELTA-P   3.71 "HG          OUTER CASE    LOSS       1.39 % DP/P
  BURNER PRIMARY ZONE DP  -.02 "HG          PRIMARY ZONE LOSS        -.01 % DP/P
  OVERALL F/A RATIO     .01957              FUEL FLOW RATE          323.2 LB/HR
  FUEL INLET TEMP          73. DEG F        FUEL INLET PRESSURE     511.9 PSIA
  FUEL F/M TEMP            76. DEF F        FUEL F/M PRESSURE       798.8 PSIA
  CALCULATED ACD VALUE   5.199              FUEL NOZZLE FLOW NO.    16.45
  *************************************************************************


            EXHAUST DUCT CHEMISTRY RESULTS FROM THE ROTATING PROBE

PROBE      O2     CO2     H2O      CO      CHX    CL NOX    ND  NO    ND NO2
ANGLE      %      %      GR/LB     PPM     PPM      PPM      PPM       PPM

 225     13.9   5.15      6.3     39.3     1.3    137.7    148.4        .1
 270     14.5   4.55      6.3     31.0      .9    128.5    139.4        .1
 315     14.4   4.61      6.2     34.6      .8    121.2    134.7        .1
 360     15.3   3.92      6.2     41.2      .8    110.8    120.8        .1
  45     14.6   4.38      6.2     51.7      .8    107.4    122.7        .1
  90     12.0   6.10      6.2     59.8     1.0    160.0    172.7        .1
 135     14.6   4.47      6.2     36.7      .6    117.7    132.5        .1
 180     14.2   4.77      6.3     29.9      .6    124.2    142.4        .1
-----------------------------------------------------------------------------
AVERAGE: 14.2   4.74      6.2     40.5      .8    125.9    139.2        .1

EMISSIONS INDEX - GM/KG FUEL:     1.73     .06     8.80     9.26       .0!

*****************************************************************************

                 AVERAGE OF CHEMISTRY CALCULATIONS FOR EACH SAMPLE
                   OVERALL FUEL/AIR RATIO     =  .01957 METERED
                   CALCULATED FUEL/AIR RATIO  =  .02328 W/O  O2
                                              =  .02258 WITH O2
                   COMBUSTION EFFICIENCY      =   99.91 %
                   CALCULATED O2              =   13.55 %
                   SAMPLE MOLECULAR WEIGHT    =   28.93
                   SAMPLE MOLE SUM            =   1.01049
                   F/A RATIO DEVIATION        =   18.93 % W/O  O2
                                              =   15.36 % WITH O2
```

Table VIII.
Primary zone gas sample survey.

```
    DETROIT DIESEL ALLISON DIVISION COMBUSTION RESEARCH LABORATORY - ROOM 81
          NASA PRIMARY ZONE STUDY - COMBUSTOR RIG EXPERIMENTAL RESULTS
            RIG BUILDUP  14   TEST SERIES -A     TEST DATE: 04/03/82

                  NASA PRIMARY ZONE STUDY--CONCEPT III, MOD. 2
     FUEL TUBES ROTATED TO TANGENT POSITION--CCW LOOKING AT DOME FROM FRONT.

                              ********************
                              *READING NUMBER 222*
                              *TIME OF DAY:  1422*
                              ********************

 ***************  EXPERIMENTAL BURNER OPERATING CONDITIONS  ***************
 BURNER AIR FLOW          4.573 LB/SEC      BURNER INLET  TEMP        610. DEG F
 BURNER INLET PRESSURE  130.8 PSIA          BURNER OUTLET TEMP       1954. DEG F
 FLOW FACTOR - F1        1.1433             AVG TEMPERATURE RISE     1344. DEG F
 BOT T-MAX/T-AVG         1.1944             PATTERN FACTOR           .2826
 BOT HOT SPOT (#3@ 90)  2334.               SKIN HOT SPOT,#,10       1476. DEG F
 BURNER SYSTEM DELTA-P  10.88 "HG           BURNER SYSTEM LOSS        4.09 % DP/P
 OUTER CASE    DELTA-P   3.65 "HG           OUTER CASE    LOSS        1.37 % DP/P
 BURNER PRIMARY ZONE DP  -.03 "HG           PRIMARY ZONE LOSS         -.01 % DP/P
 OVERALL F/A RATIO      .01965              FUEL FLOW RATE           323.4 LB/HR
 FUEL INLET TEMP           78. DEG F        FUEL INLET PRESSURE      514.4 PSIA
 FUEL F/M TEMP             81. DEF F        FUEL F/M PRESSURE        837.2 PSIA
 CALCULATED ACD VALUE    5.151              FUEL NOZZLE FLOW NO.     16.40
 *************************************************************************

   PRIMARY ZONE CHEMISTRY RESULTS FROM RAKE NO. 1, SEQUENTIAL PORT SAMPLING

 PORT      O2     CO2     H2O       CO       CHX     CL NOX    ND  NO    ND NO2
NUMBER     %       %     GR/LB     PPM       PPM      PPM       PPM       PPM

   1       7.7   9.04     6.7    2332.5     54.3     190.4     180.0       .1

   2       7.9   8.97     6.7     490.1      2.0     225.9     208.1       .1

   3      10.2   7.48     6.7     319.8       .9     173.0     174.9       .1

   4      13.8   4.95     6.7     115.9      1.3     101.2     113.9       .1
-------------------------------------------------------------------------------
AVERAGE:   9.9   7.61     6.7     814.6     14.6     172.6     184.2       .1

EMISSIONS INDEX - GM/KG FUEL:     21.39      .60      7.44      7.33      .00

*******************************************************************************

                        CHEMISTRY CALCULATIONS FOR EACH PORT

RAKE NO. 1            PORT NO.:      1         2         3         4      AVERAGE
CALCULATED F/A RATIO W/O  O2:    .04669    .04520    .03735    .02436    .03832
CALCULATED F/A RATIO WITH O2:    .04386    .04267    .03544    .02367    .03644
   COMBUSTION EFFICIENCY - %:     98.63     99.70     99.76     99.85     99.42
          CALCULATED O2 - %:      6.38      6.73      9.13     13.21      8.86
   SAMPLE MOLECULAR WEIGHTS:     28.88     28.91     28.92     28.93     28.91
            SAMPLE MOLE SUM:     1.010     1.010     1.010     1.011     1.010
```

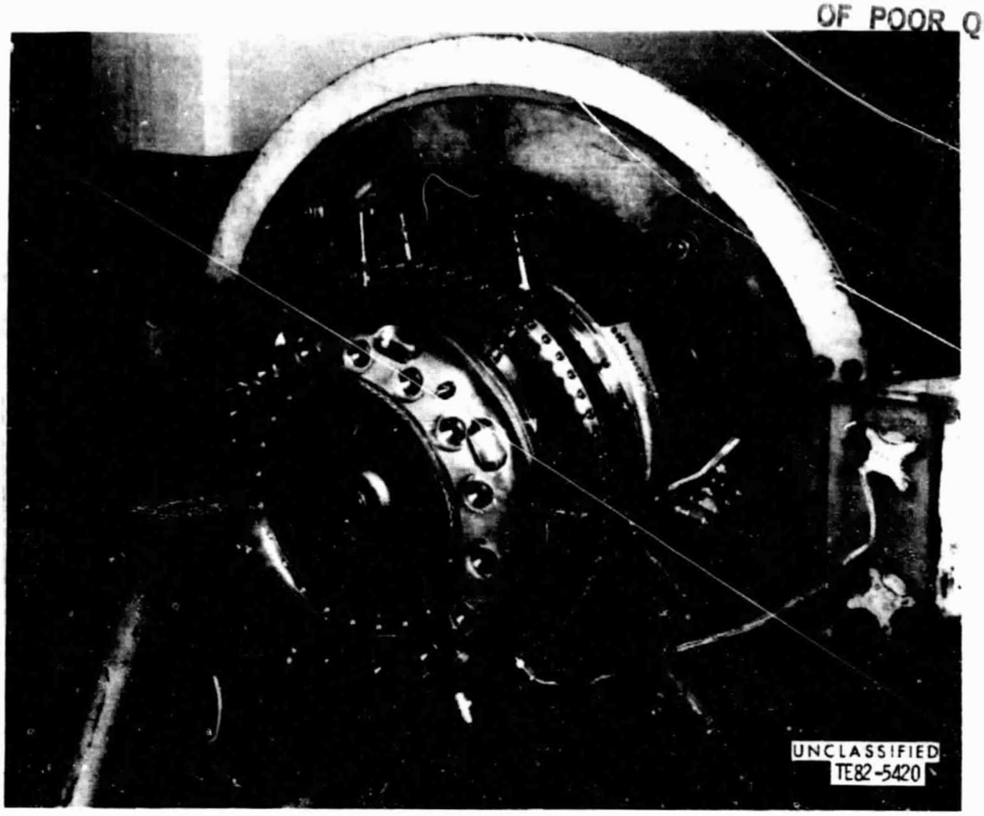

Figure 60. Combustor rig with rotating probe.

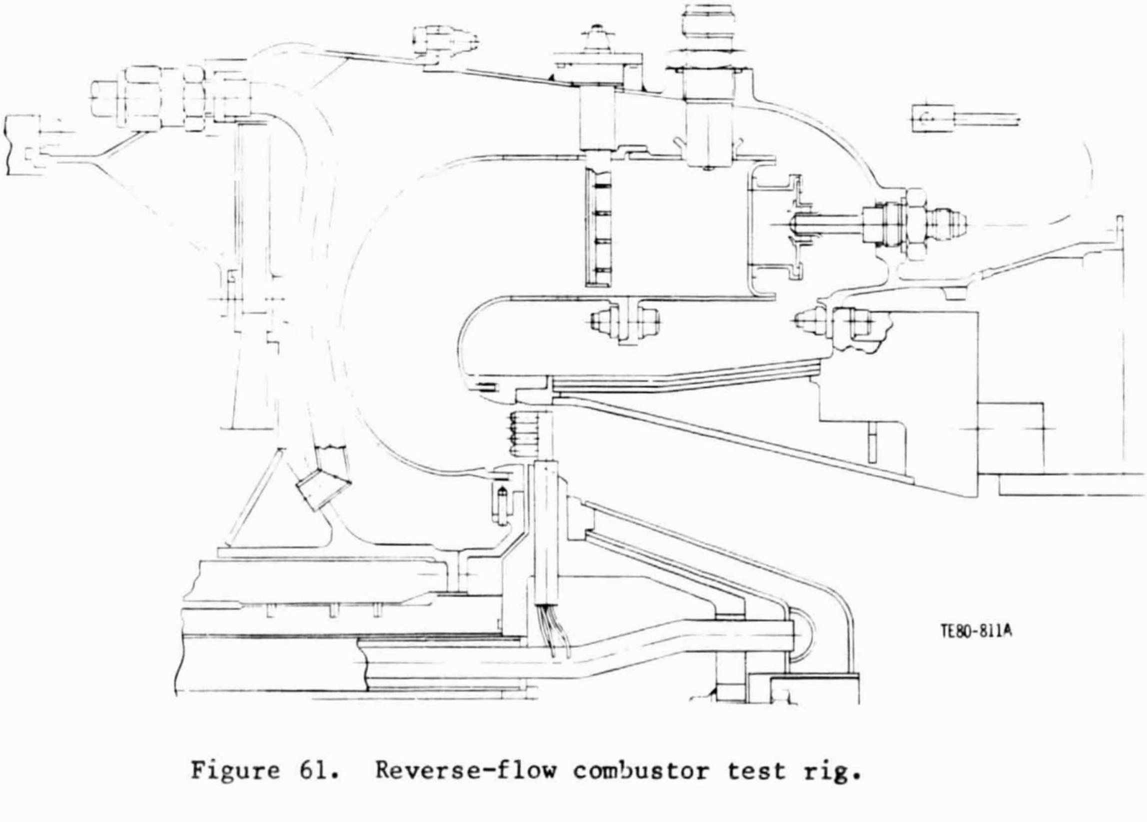

Figure 61. Reverse-flow combustor test rig.

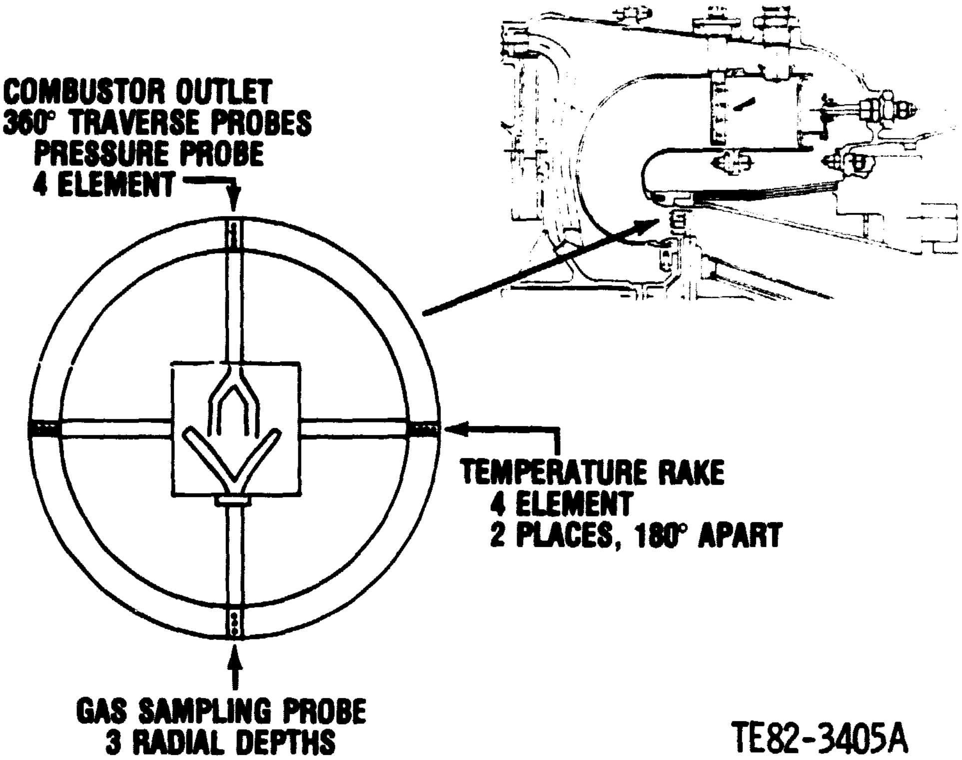

Figure 62. Combustor exit instrumentation.

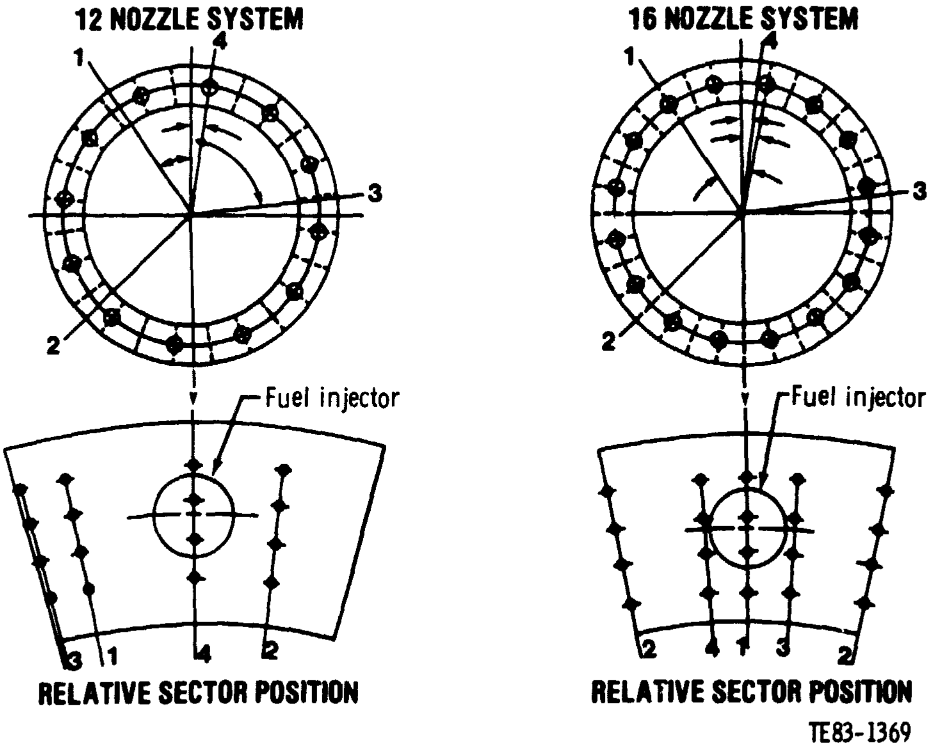

Figure 63. Primary zone probe locations.

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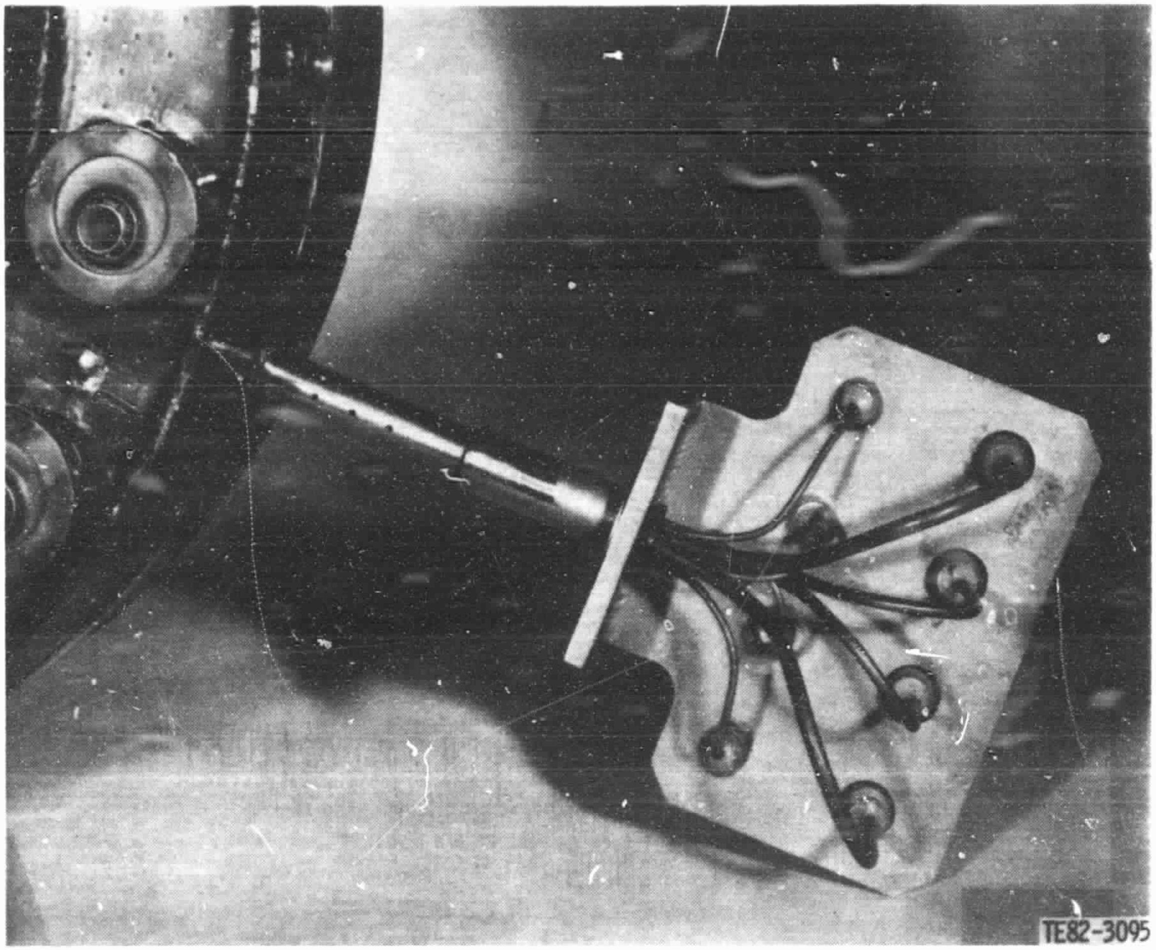

Figure 64. Photograph of primary zone gas sampling probe.

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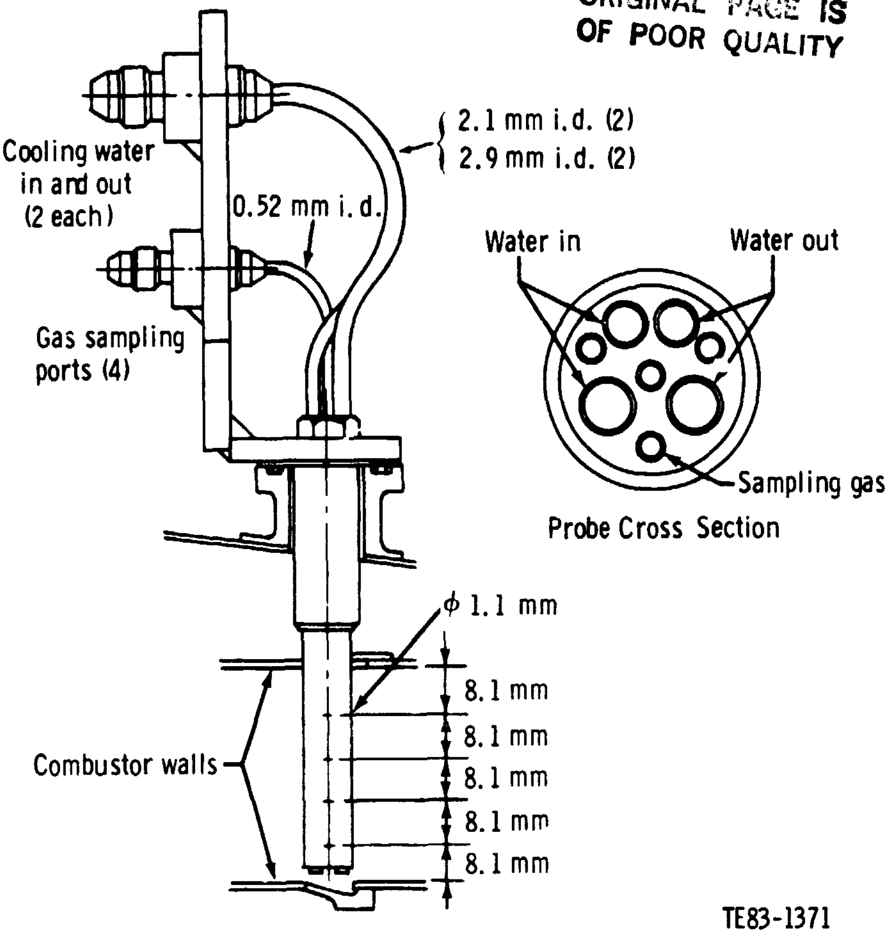

Figure 65. Primary zone gas sampling probe.

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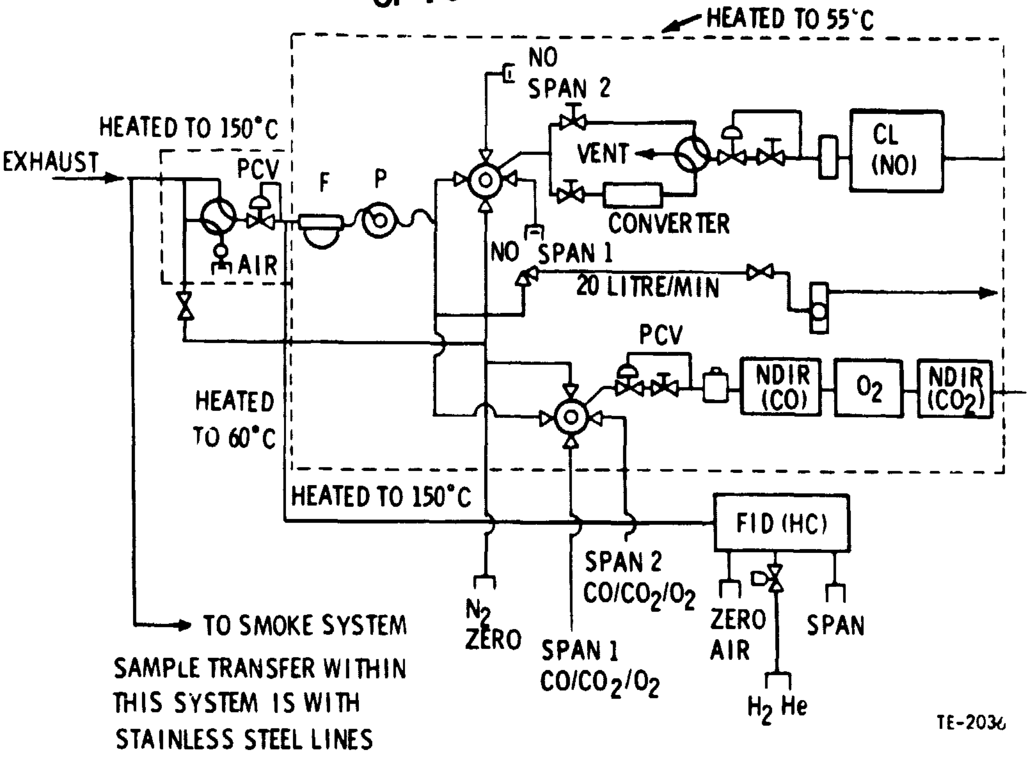

Figure 66. Emission instrument system arrangement (EPA aircraft system).

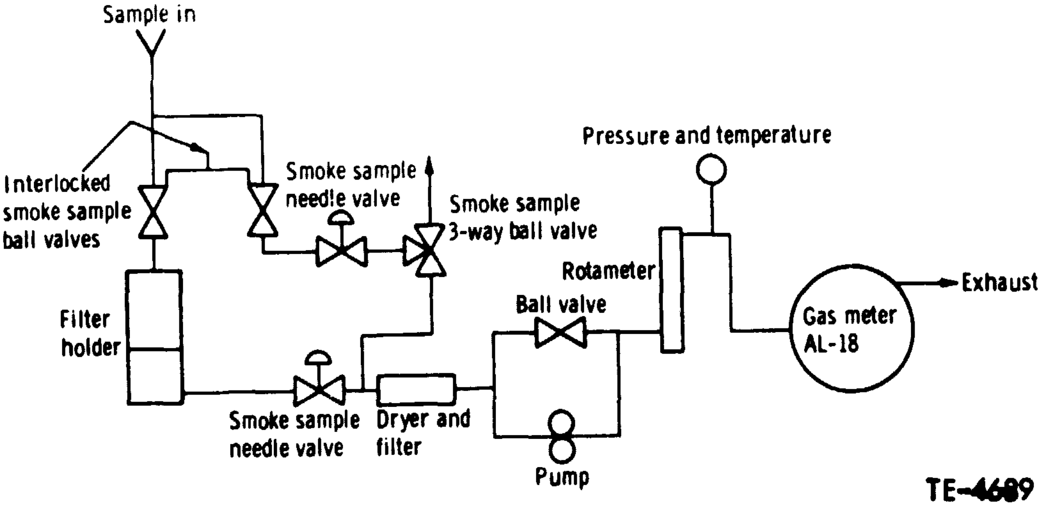

Figure 67. Smoke sampling system schematic.

VI. EXPERIMENTAL AND THEORETICAL RESULTS

This section describes the component test conditions and procedures, test results, and PZ performance predictions. The test plan was structured to provide a systematic test investigation of three distinctive primary zone concepts and the modifications necessary to correlate test results with analytical performance predictions. The test evaluation extended over a typical range of engine operating conditions and included the following performance data: outlet gas-temperature profile, pressure drop, combustion efficiency, exhaust and PZ emissions (CO, UHC, NO_x, and smoke), metal temperature indications (thermocouple or thermal paint), and blow-out limits. All testing was conducted using JP-4 fuel.

TEST CONDITIONS

The design conditions used in the evaluation tests of these primary zones and modifications are representative of the design point and part load points associated with this size combustor. The range of operating conditions tested is shown in Table IX. In addition to these conditions, other test conditions were evaluated to explore the effects of loading.

Table IX.
Combustor operating conditions.

Power (%)	Airflow (kg/s)	T_{in} (K)	T_{out} (K)	P_{in} (MPa)	F/A
100	2.27	672	1367	1.01	0.0196
80	2.09	594	1294	0.90	0.0195
50	1.68	556	1144	0.69	0.0158
Idle	1.04	456	867	0.38	0.0104
100 alt*	1.18	639	1367	0.54	0.0204

---

*This altitude condition is simulated at 6096 m elevation.

The test evaluation of the three primary-zone concepts and five modifications each required a total of 108.5 burning hours. This test time was divided among the three concepts as follows: Concept I--47.5 hr, Concept II--36.5 hr, and Concept III--24.5 hr. This testing can be categorized as follows:

- stability limits
- performance and emissions
- metal temperature determination

STABILITY LIMITS

This testing consisted of evaluating each combustor configuration's ability to sustain combustion at low fuel flows at the various test operating conditions. With the combustor airflow, inlet temperature, and inlet pressure maintained and the desired test condition and flame stabilized, the following procedure was used: Fuel flow was reduced in discrete steps until flame-out occurred and the flame did not respond to increased fuel flow.

PERFORMANCE AND EMISSIONS

Performance and emission tests consisted of measuring parameters at both the exhaust station and the PZ sampling station. The following parameters were determined at the steady-state operating conditions listed in Table IX:

- emissions of unburned hydrocarbons, carbon monoxide, carbon dioxide, oxygen, oxides of nitrogen, and smoke
- pressure loss
- combustor outlet gas-temperature profile

The instrumentation and data acquisition/reduction system is automated such that these data were obtained in a minimal time period after test conditions stabilized. The description of this instrumentation is covered in Section V and the data acquisition system is covered in Appendix A.

METAL TEMPERATURE DETERMINATION

Test evaluation of the adequacy of the Lamilloy wall cooling and film-cooled combustor walls was determined by both temperature-sensitive paint and thermocouples attached to the outer wall. Type TP-5 paint was applied to each baseline configuration by spraying both internal and external surfaces of the combustor. When applied, this paint has a purple color. After the combustor is run the paint changes to various shades as a function of surface temperature. The colors for various temperature ranges for TP-5 paint are listed in Table X.

Table X.
TP-5 paint temperature ranges.

Color	Std. ref code	Temperature (K)
Blue (purple)	-	Below 793
Pale blue-gray	N	793-1133
Dark blue-gray	T	1133-1233
Blue	P	1233-1262
Midnight blue	G	1262-1293
Matt black	M	1293-1323
Black glaze	Y	1323-1344
Dark blue glaze	R	Above 1344

To obtain a good thermal paint evaluation, ignition is achieved after combustor inlet conditions (100% power) are attained. Fuel flow is maintained at the design value for 10-15 min to thermally "set" the paint.

CONCEPT I BASELINE EXPERIMENTAL RESULTS

The Concept I combustor has a conventional, swirl-stabilized, double-vortex primary zone. Figure 68* is a photograph of Concept I. The Concept I baseline test scope consisted of thermal paint evaluation at the 100% power condition,

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*The figures for this section appear at the end of the section.

combustor exhaust data at all power conditions, and primary zone emission data at idle and 100% power conditions. Also a cold-flow pressure-loss performance was obtained. Table XI presents the measured data for Concept I baseline. Figure 69 presents the wall temperature and thermal paint results. The photos, taken after a run at 100% power conditions, indicate that the maximum Lamilloy wall temperatures occurred in the range of 1133-1233 K on the outside surface of the liner and 1262-1283 K on the inside surface. In addition to the thermal paint temperature evaluation, eighteen C-A thermocouples were attached to the liner outer surface and monitored during all tests. Combustor durability experience has previously been based on thermocouple measurements, the placement of which was intended to read the high metal temperature regions on the combustor liner. During the thermal paint test, the highest metal temperature read by the thermocouples was 954 K. The design goal on this measurement basis was 1144 K.

The overall combustor performance, consisting of combustor outlet pattern, pressure loss, and exhaust smoke, is presented in Figure 70. The circumferential pattern factor of 0.128 at 100% power condition is a good uniform pattern. Exhaust smoke (SAE smoke number) was far below the visible limit. Exhaust emission data and efficiency are shown in Figure 71.

Primary zone emissions data were obtained at idle and 100% power test conditions utilizing the three fixed-position probes. The following constituents were measured: O_2, CO_2, H_2O, CO UHC, NO_x, NO_2, and smoke. Figure 72 presents the primary zone fuel-air ratio, efficiency, and smoke data vs power condition. Figure 73 presents the 100% power data in a sector interpretation. The fuel nozzle is located at the 11.25 deg position.

CONCEPT I BASELINE COMBUSTOR PZ PERFORMANCE ANALYTICAL PREDICTION/TEST DATA COMPARISON

Analytical predictions of the primary zone performance were developed utilizing the 3-D model described in Section III. These predicted values are compared to the measured values obtained from the primary zone gas-sampling probes during the combustor tests. Both the analytical prediction and the test data values will be compared on the same figures for fuel-air ratio, oxides of nitrogen, carbon monoxide, carbon dioxide, and unburned hydrocarbons. The fuel-air ratio distribution in the plane of primary zone sampling probes are considered to be the most meaningful from a model verification standpoint. Figure 74 presents the comparison of the predicted and measured fuel-air ratio values for idle-power condition. As can be seen from these data, the probes have four elements each. Considering that each of these probes is located in a different sector of the PZ annulus and influenced by separate fuel nozzles, the similarity of the analytical and measured data is quite good.

CONCEPT I MODIFICATIONS AND EXPERIMENTAL RESULTS

In order to explore the capability of the primary zone analytical-prediction model and compare with actual test results, five primary zone modifications were analytically modeled and rig tested. These five modifications consisted of the following:

Mod 1: Axial swirlers in the prechamber changed from 45 deg to 30 deg (29.6% reduction in swirler area)

Mod 2: Mod 1 with primary holes relocated closer to fuel nozzle centerline (from 5.6 deg to 1.9 deg)

Mod 3: Mod 1 with double the number of primary holes and double the hole area (8 holes per fuel nozzle)

Mod 4: Mod 1 with 8 primary holes/nozzle but diameters reduced to equal baseline hole area

Mod 5: Mod 1 with new higher flow Lamilloy (7.5% increase) in combustor primary zone walls

Table XII presents a summary of the measured data for Concept I, mods 1 through 5.

The highlights of this summary are as follows:

- Mod 1, with the 30 deg swirlers, had little effect upon PZ or exhaust performance. There was a measured reduction in PZ smoke from an SAE smoke number of 55 to 32
- Mod 2, with the close PZ hole spacing, increased exhaust pattern factor and PZ smoke, decreased PZ efficiency, increased PZ fuel-air ratio, and increased carbon monoxide
- Mod 3, with twice as many primary holes (and a corresponding increase in primary area), had a 9.5% reduction in measured PZ fuel-air ratio and decreased PZ smoke and carbon monoxide
- Mod 4, with twice the number of primary holes and no change in total primary zone hole area, had an increase in measured PZ fuel-air ratio and NO_x and a reduction in PZ smoke and carbon monoxide

CONCEPT I COMBUSTOR MODIFICATIONS PZ PERFORMANCE ANALYTICAL PREDICTION/TEST DATA COMPARISON

The analytical predictions of the primary zone performance were used in determining the primary zone modifications that were fabricated and tested. It is therefore important to compare these predicted values with the primary zone test results. This comparison is restricted to fuel-air ratio values in the axial plane of the primary zone gas-sampling probes and mainly at the 80% power condition. The bases for making this comparison are overall average value and sector presentation of fuel-air isopleth.

The overall average value of the analytically predicted fuel-air ratio at the PZ probe location is compared to the measured average value (based on 3 or 4 probes) in Table XIII. Considering the limited instrumentation and the stage of development of the analytical model, these values are in reasonable agreement. Measured data for mod 5 were considered to be inaccurate and are not included in this table.

Figure 75 presents a contour plot comparison of the fuel-air ratios of the analytically predicted and measured values. There is considerable similarity for most of the configurations evaluated. Modifications 4 and 5 were tested

Concept

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air r
								Lean blowout
91	Idle	Exhaust chemistry	4.49	744	587			
92	Idle	PZ sequential rake 1	4.49	753	591			
95	Idle	PZ sequential rake 2	4.43	747	596			
96	Idle	PZ sequential rake 3	4.43	748	597			
97	Idle	PZ manifold rake 1	4.58	742	594		7	
98	Idle	PZ manifold rake 2	4.56	759	597		0	
99	Idle	PZ manifold rake 3	4.59	757	594		0	
100	Idle	PZ manifold rake 3	4.52	756	598			
101	Idle	Exhaust chemistry	4.54	769	599			
102	Idle	No chemistry	4.49	789	604	0.155		
103	100%	Exhaust chemistry	3.75	1016	859		0	
104	100%	No chemistry	3.74	999	858			
105	100%	PZ manifold rake 1	3.69	1014	861		92	
106	100%	PZ manifold rake 2	3.74	999	857		36	
107	100%	PZ manifold rake 3	3.73	998	858		36	
108	Alt	Exhaust chemistry	3.69	1078	876			
109	Alt	No chemistry	3.67	1083	879	0.187		
110	80%	Exhaust chemistry	3.60	933	778		5	
111	80%	No chemistry	3.55	941	782	0.150		
112	50%	Exhaust chemistry	3.85	854	711		0	
113	50%	No chemistry	3.82	851	717	0.178		
114	100%	No chemistry	3.60	954	887	0.162		
115	100%	No chemistry	3.60	945	881	0.156		

Table XI.
Concept I, baseline, test data summary.

Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2, %	Efficiency, %	Emission indices		
			Lean blowout	Chemical			CO	CH_x	NO_x
587				0.0108	2.19	98.76	36.1	4.2	1.1
591				0.0226	4.53	99.00	40.8	0.5	4.0
596				0.0121	2.44	98.88	38.2	2.5	1.1
597				0.0200	4.08	99.68	12.2	0.3	2.7
594		7		0.0233	4.62	98.60	59.2	0.3	2.9
597		0		0.0120	2.40	98.21	57.8	4.9	0.6
594		0		0.0177	3.61	99.57	17.1	0.3	2.3
598				0.0184	3.76	99.66	13.7	0.1	2.5
599				0.0103	2.10	98.90	35.4	2.9	1.5
604	0.155								
859		0		0.0222	4.54	99.91	1.1	0.0	11.9
858									
861		92		0.0436	8.07	96.05	120.6	12.3	6.8
857		36		0.0202	4.12	99.77	8.0	0.1	8.2
858		36		0.0399	7.93	99.51	19.1	0.1	9.2
876				0.0232	4.73	99.92	1.4	0.0	8.1
879	0.187								
778		5		0.0211	4.30	99.91	1.5	0.1	9.8
782	0.150								
711		0		0.0163	3.34	99.89	3.2	0.0	6.4
717	0.178								
887	0.162								
881	0.156								

2 FOLDOUT FRAME

Concept I,

Concept 1, Mod 1

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rat Lean blowout	 Ch
165	Idle	No chemistry	4.51	729	596	0.191		0.0032	
166	Idle	Exhaust chemistry	4.38	718	606				0
167	Idle	PZ sequential rake 1	4.38	716	605		0		0
168	Idle	PZ sequential rake 2	4.57	719	601		0		0
169	Idle	PZ sequential rake 3	4.21	727	594		0		0
170	80%	No chemistry	3.55	870	736	0.147		0.0018	
171	80%	Exhaust chemistry	3.64	874	740		0		0
172	80%	PZ sequential rake 1	3.49	892	744		77		0
173	80%	PZ sequential rake 2	3.49	860	736		24		0
174	80%	PZ sequential rake 3	3.55	855	738		82		0
175	100%	No chemistry	3.49	956	846	0.133			
176	100%	PZ sequential rake 1	3.53	970	848		56		0
177	100%	PZ sequential rake 2	3.44	972	854		16		[illegible]
178	100%	PZ sequential rake 3	3.43	995	852		23		0

Concept 1, Mod 2

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rat Lean blowout	 Ch
189	Idle	No chemistry	4.15	721	611	0.128		0.0040	
191	Idle	Exhaust chemistry	4.06	704	597		0		0
192	Idle	PZ sequential rake 1	4.09	704	592		0		0
193	Idle	PZ sequential rake 2	4.09	700	591		0		0
194	Idle	PZ sequential rake 3	4.10	680	586		0		0
195	80%	No chemistry	3.56	908	791	0.174			
196	80%	Exhaust chemistry	3.54	904	791		0		0
197	80%	PZ sequential rake 1	3.57	899	791		51		0
198	80%	PZ sequential rake 2	3.46	897	780		100		0
199	80%	PZ sequential rake 3	3.57	923	774		91		0
201	100%	No chemistry	3.63	959	872	0.200			
202	100%	Exhaust chemistry	3.60	956	868		16		0
203	80%	No chemistry	3.57	928	808	0.193			
205	80%	PZ sequential rake 1	3.45	891	791		70		0
206	80%	PZ sequential rake 2	3.44	912	783		93		0
207	80%	PZ sequential rake 2	3.57	922	784		85	0.0020	0

Table XII.
Concept I, mods 1-5, test data summary.

Concept 1, Mod 1

Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio Lean blowout	Fuel-air ratio Chemical	CO_2, %	Efficiency, %	Emission indices CO	Emission indices CH_x	Emission indices NO_x
596	0.191		0.0032						
606				0.0108	2.21	99.26	25.6	1.5	3.2
605		0		0.0189	3.81	99.23	29.5	0.9	2.3
601		0		0.0156	3.09	98.08	57.1	6.3	1.3
594		0		0.0222	4.51	99.76	8.7	0.3	3.6
736	0.147		0.0018						
740		0		0.0216	4.42	99.91	1.7	0.1	8.4
744		77		0.0403	7.81	98.40	61.3	1.7	6.9
736		24		0.0287	5.81	99.82	5.8	0.1	5.6
738		82		0.0526	9.99	98.10	79.5	0.5	7.7
846	0.133								
848		56		0.0355	7.03	99.18	30.0	0.9	9.3
854		16		0.0299	6.04	99.71	9.7	0.2	9.6
852		23		0.0457	9.[illegible]	99.46	20.5	0.1	11.2

Concept 1, Mod 2

Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio Lean blowout	Fuel-air ratio Chemical	CO_2, %	Efficiency, %	Emission indices CO	Emission indices CH_x	Emission indices NO_x
611	0.128		0.0040						
597		0		0.0116	2.36	99.01	30.5	3.0	2.6
592		0		0.0167	3.36	98.95	34.1	2.8	2.6
591		0		0.0136	2.73	98.58	38.9	5.4	2.4
586		0		0.0257	5.15	99.34	24.3	1.0	3.0
791	0.174								
791		0		0.0228	4.65	99.92	1.4	0.0	8.1
791		51		0.0484	9.36	98.74	51.4	0.5	7.1
780		100		0.0470	7.70	87.31	167.0	93.6	5.0
774		91		0.0508	9.40	96.74	122.9	4.4	6.9
872	0.200								
868		16		0.0239	4.87	99.91	0.9	0.1	13.0
808	0.193								
791		70		0.0484	9.16	97.78	90.9	1.0	10.3
783		93		0.0423	7.21	89.82	158.9	68.9	6.7
784		85	0.0020	0.0609	11.01	96.31	150.9	2.0	8.7

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Concept 1, Mod 3

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air Lean blowout
214	80%	No chemistry	3.23			0.199		0.0012
215	80%	Exhaust chemistry	3.45				12	
216	80%	PZ sequential rake 1	3.34				48	
217	80%	PZ sequential rake 2	3.29				12	
218	80%	PZ sequential rake 3	3.42				37	
219	100%	No chemistry	3.37			0.243		0.0016

Concept 1, Mod 4

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air Lean blowout
236	80%	No chemistry	3.59			0.154		0.0015
237	80%	Exhaust chemistry	3.64				4	
238	80%	PZ sequential rake 1	3.52				36	
239	80%	PZ sequential rake 2	3.44				8	
240	80%	PZ sequential rake 3	3.60				23	
241	80%	PZ sequential rake 4	3.54				25	
242	100%	No chemistry	3.79			0.184	0	0.0016

Concept 1, Mod 5

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air Lean blowout
286	80%	No chemistry	4.19			0.215		0.0020
287	80%	Exhaust chemistry	4.30				11	
288	80%	PZ sequential rake 1	4.25				45	
289	80%	PZ sequential rake 2	4.27				28	
290	80%	PZ sequential rake 3	4.24				27	
291	80%	PZ sequential rake 4	4.23				14	
292	80%	No chemistry	5.73			0.214	5	
293	100%	No chemistry	4.14			0.168	5	0.0020

Table XII. (cont)

Concept 1, Mod 3

K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio Lean blowout	Fuel-air ratio Chemical	CO_2, %	Efficiency, %	Emission indices CO	Emission indices CH_x	Emission indices NO_x
		0.199		0.0012						
			12		0.0214	4.38	99.94	0.9	0.0	9.9
			48		0.0326	6.54	99.65	13.4	0.1	7.4
			12		0.0298	6.03	99.93	1.4	0.0	7.4
			37		0.0487	9.38	98.55	60.0	0.5	8.5
		0.243		0.0016						

Concept 1, Mod 4

K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio Lean blowout	Fuel-air ratio Chemical	CO_2, %	Efficiency, %	Emission indices CO	Emission indices CH_x	Emission indices NO_x
		0.154		0.0015						
			4		0.0218	4.46	99.92	1.3	0.0	11.4
			36		0.0480	9.28	98.62	57.4	0.3	8.7
			8		0.0337	6.79	99.84	4.9	0.0	9.3
			23		0.0500	9.77	99.16	34.6	0.1	9.1
			25		0.0288	5.80	99.68	12.4	0.1	7.9
		0.184	0	0.0016						

Concept 1, Mod 5

K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio Lean blowout	Fuel-air ratio Chemical	CO_2, %	Efficiency, %	Emission indices CO	Emission indices CH_x	Emission indices NO_x
		0.215		0.0020						
			11		0.0215	4.39	99.90	1.6	0.3	9.1
			45		0.0234	4.72	99.52	19.5	0.1	5.5
			28		0.0170	3.47	99.44	4.4	4.6	5.1
			27		0.0306	6.17	99.73	9.9	0.1	6.8
			14		0.0256	5.17	99.53	17.6	0.4	6.6
		0.214	5							
		0.168	5	0.0020						

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Table XIII.
Fuel-air ratios--Concept I.

Mod	Test condition	Fuel-air ratio Predicted	 Measured	Percent difference
Baseline	100%	0.0474	0.0346	+37
1	80%	0.0508	0.0474	+7.2
2	80%	0.0511	0.0488	+4.7
3	80%	0.0428	0.0370	+15.7
4	80%	0.0489	0.0401	+21.9

with the fourth primary zone probe installed. This additional probe improves the sector interpretation, as can be seen in Figure 75.

CONCEPT II BASELINE EXPERIMENTAL RESULTS

The Concept II combustor has a double-vortex swirl-stabilized reverse-circulation primary zone. Figure 76 is a photograph of Concept II.

The Concept II baseline test scope consisted of a thermal paint evaluation at 100% power condition and combustor exhaust data at 100%, 80%, 50%, idle, and 100% altitude test conditions. Primary zone emission data were obtained at 90% and idle power conditions. Table XIV presents the measured data for the Concept II baseline. Figure 77 presents the wall temperature and thermal paint results. As can be seen from these photos, the outside wall temperature was 1133-1232 K maximum in the dome area close to the fuel nozzle locations and 1293-1323 K on the inner wall.

Exhaust temperature pattern and profile are presented in Figure 78. The circumferential pattern factor of 0.216 at 100% is an acceptable value. The radial gradient of 36 K indicates a relatively uniform profile. The radial gradient is defined as the difference between the maximum and the minimum radial average temperatures.

Combustor exhaust emission indices for CO, UHC, and NO_x and their corresponding combustion efficiencies over the power range are presented in Figure 79. These levels are similar to values obtained with Concept I baseline.

Primary zone emission data, which include CO, UHC, NO_x, and smoke, were obtained at idle and 80% power conditions. The average fuel-air ratio, combustion efficiency, and primary zone smoke versus power condition curves are presented in Figure 80. Figure 81 presents combustion efficiency, CO, and NO_x data at 80% power condition in a sector interpretation. The fuel nozzle is located at 11.25 deg position. The average, measured, primary zone combustion efficiency of 99.47% indicates a high degree of completed reactions at this plane. The zone between fuel nozzles was slightly depressed in efficiency.

CONCEPT II BASELINE COMBUSTOR PZ PERFORMANCE ANALYTICAL PREDICTION/TEST DATA COMPARISON

The analytical prediction of the PZ performance for the Concept II baseline design indicates a high fuel-air ratio in the area of the fuel nozzle at 80% power condition. The hub area is predicted to have a very high fuel-air ratio (above 0.10).

The test results at 80% power simulations gave a uniform fuel-air ratio profile except in the center of the passage between fuel nozzles. These data are presented in Figure 82. This does not represent a good correlation between model prediction and test data.

Figure 83 is this same measured data as compared to a circumferential average and a radial prediction in the plane of the PZ probes. From this presentation it is evident that the measured values did not correlate well with the predicted values for probes 1 and 2.

CONCEPT II MODIFICATIONS AND EXPERIMENTAL RESULTS

The Concept II combustor primary zone section was modified into a total of five configurations. These modifications to this swirl-stabilized, double-vortex reverse-circulation concept consisted of evaluating a reduction in primary zone equivalence ratios (ϕ_{PZ}) and an increase in fuel injector spacing. These modifications consisted of the following:

Mod 1: Axial swirlers in prechamber changed from 30 deg to 45 deg (42% increase in swirler flow ares), $\phi_{PZ} = 1.041$

Mod 2: Mod 1 with primary hole area increased 50%, $\phi_{PZ} = 0.969$

Mod 3: Mod 1 with primary hole area increased 100%, $\phi_{PZ} = 0.903$

Mod 4: Mod 3 with one half of the fuel injectors inoperative (8 injectors operative); this gave a fuel spacing ratio L/h = 2.8

Mod 5: Mod 3 with primary air relocated in sector of active fuel injectors (8 injectors operative per mod 4)

Table XV presents a summary of the measured data for Concept II, mods 1 through 5.

The highlights of this summary are as follows:

- All combustors, as well as the baseline configuration, exhibited a high combustion efficiency at the primary zone station.
- The measured maximum wall temperature increased with the increase in primary hole area.
- The testing with only eight fuel nozzles operational was limited to idle evaluation because of the high values of pattern factor. Pattern factor was much improved with the primary-air redistribution close to active fuel nozzles (0.54 to 0.36)
- Exhaust smoke was far below the visible area (SAE Smoke No. = 5).

CONCEPT II COMBUSTOR MODIFICATIONS PZ PERFORMANCE ANALYTICAL PREDICTION/TEST DATA COMPARISON

Analytical predictions of the primary zone performance were made for mods 1 through 4 of Concept II. A problem in matching the aerodynamic changes to the

Concep

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air Lean blowout
116	100%	No chemistry	3.63	968	873	0.216		
117	100%	No chemistry	3.52	994	866	0.220		
124	Idle	No chemistry	3.66	705	563	0.175		
125	Idle	Exhaust chemistry	3.63	707	567			
126	Idle	PZ sequential rake 1	3.64	718	569		6	
127	Idle	PZ sequential rake 2	3.67	731	571		10	
128	Idle	PZ sequential rake 3	3.63	729	569		0	
129	Idle	Exhaust chemistry	3.70	730	570			
130	Idle	No chemistry	3.72	734	569	0.169		
133	Alt	Exhaust chemistry	3.45	1039	881			
134	Alt	No chemistry	3.38	1031	873	0.203		
135	Alt	Exhaust chemistry	3.35	1028	869			
136	50%	Exhaust chemistry	3.52	859	719			
137	50%	No chemistry	3.51	856	714	0.237		
138	80%	No chemistry	3.67	962	821	0.354		
139	80%	Exhaust chemistry	3.63	968	824			
140	80%	PZ sequential rake 1	3.60	934	809		34	
141	80%	PZ sequential rake 2	3.53	921	798		61	
142	80%	PZ sequential rake 2	3.47	922	797		66	
143	80%	PZ sequential rake 3	3.63	922	797		0	
144	80%	PZ sequential rake 3	3.61	931	804			

Table XIV.
Concept II, baseline, test data summary.

Avg	Pattern	Smoke,	Fuel-air ratio		CO_2,	Efficiency,	Emission indices		
skin, K	factor	SAE No.	Lean blowout	Chemical	%	%	CO	CH_x	NO_x
873	0.216								
866	0.220								
563	0.175								
567				0.0097	1.95	98.26	40.8	8.3	1.9
569		6		0.0139	2.79	98.53	38.4	6.1	2.9
571		10		0.0201	3.98	97.87	44.3	11.7	2.5
569		0		0.0129	2.51	95.93	71.4	25.6	0.8
570				0.0096	1.94	98.42	39.4	7.0	1.2
569	0.169								
881				0.0176	3.60	99.89	1.6	0.2	13.6
873	0.203								
869				0.0212	4.33	99.91	1.5	0.1	10.7
719				0.0162	3.32	99.91	2.1	0.1	8.4
714	0.237								
821	0.354								
824				0.0205	4.19	99.92	1.2	0.0	10.8
809		34		0.0345	6.91	99.73	9.8	0.1	8.8
798		61		0.0462	8.79		88.5	0.3	
797		66		0.0343	6.80	99.20	31.3	0.4	10.1
797		0		0.0266	5.36	99.62	13.4	0.4	8.4
804				0.0244	4.96	99.90	2.4	0.1	7.7

Concept II

Concept II, Mod 1

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air r Lean blowout
179	Idle	No chemistry	3.41	716	585	0.172		0.0050
180	80%	No chemistry	3.29	901	800	0.274		0.0040
181	80%	Exhaust chemistry	3.26	901	806		0	
183	80%	PZ sequential rake 1	3.29	906	799		7	
184	80%	PZ sequential rake 2	3.23	903	796		16	
185	80%	PZ sequential rake 3	3.36	904	798		21	
186	100%	No chemistry	3.57	973	880	0.216	21	
187	100%	Exhaust chemistry	3.59	973	880		5	0.0025

Concept II, Mod 2

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air r Lean blowout
208	80%	No chemistry	3.57	1011	843	0.237		0.0020
209	80%	Exhaust chemistry	3.46	1003	843		8	
210	80%	PZ sequential rake 1	3.51	987	838		27	
211	80%	PZ sequential rake 2	3.41	987	838		33	
212	80%	PZ sequential rake 3	3.44	978	835		29	
213	100%	No chemistry	3.69	1063	930	0.238		0.0015

Concept II, Mod 3

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air r Lean blowout
227	Idle	No chemistry	3.56			0.197		0.0050
228	Idle	Exhaust chemistry	3.57				0	
229	80%	No chemistry	3.51			0.180		0.0020
230	80%	Exhaust chemistry	3.25				0	
231	80%	PZ sequential rake 1	3.29				55	
232	80%	PZ sequential rake 2	3.24				27	
233	80%	PZ sequential rake 3	3.26				8	
234	80%	PZ sequential rake 4	3.22				29	
235	100%	No chemistry	3.35			0.198		0.0017
243	Idle	No chemistry	3.32			0.665		0.0060
244	Idle	No chemistry	3.18			0.156		
245	Idle	No chemistry	3.46			0.530		
246	Idle	No chemistry	3.38			0.569		0.0065
247	Idle	No chemistry	3.80			0.267		
248	Idle	PZ sequential rake 1	3.86					
249	Idle	PZ sequential rake 2	3.82					
250	Idle	PZ sequential rake 3	3.79					
251	Idle	PZ sequential rake 4	3.84					

Table XV.
Concept II, mods 1-5, test data summary.

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Concept II, Mod 1

	Avg	Pattern	Smoke,	Fuel-air ratio		CO_2,	Efficiency,	Emission indices		
K	skin, K	factor	SAE No.	Lean blowout	Chemical	%	%	CO	CH_x	NO_x
	585	0.172		0.0050						
	800	0.274		0.0040						
	806		0		0.0217	4.42	99.90	1.5	0.1	11.4
	799		7		0.0372	7.46	99.79	7.4	0.0	8.4
	796		16		0.0270	5.43	99.49	20.0	0.1	10.5
	798		21		0.0322	6.47	99.70	10.9	0.0	10.3
	880	0.216	21							
	880		5	0.0025	0.0209	4.27	99.90	1.1	0.0	15.6

Concept II, Mod 2

	Avg	Pattern	Smoke,	Fuel-air ratio		CO_2,	Efficiency,	Emission indices		
K	skin, K	factor	SAE No.	Lean blowout	Chemical	%	%	CO	CH_x	NO_x
	843	0.237		0.0020						
	843		8		0.0212	4.33	99.92	1.2	0.1	10.7
	838		27		0.0282	5.70	99.74	9.4	0.1	8.5
	838		33		0.0371	7.33	99.13	35.6	0.2	9.7
	835		29		0.0280	5.66	99.71	10.0	0.1	10.6
	930	0.238		0.0015						

Concept II, Mod 3

	Avg	Pattern	Smoke,	Fuel-air ratio		CO_2,	Efficiency,	Emission indices		
K	skin, K	factor	SAE No.	Lean blowout	Chemical	%	%	CO	CH_x	NO_x
		0.197		0.0050						
			0		0.0109	2.02	92.70	121.3	47.8	2.1
		0.180		0.0020						
			0		0.0219	4.46	99.88	1.2	0.4	12.0
			55		0.0323	6.42	99.15	33.3	0.5	9.7
			27		0.0251	5.07	99.57	15.1	0.3	11.7
			[illegible]		0.0336	6.77	99.81	5.0	0.4	9.4
			29		0.0270	5.42	99.30	26.2	0.6	9.6
		0.198		0.0017						
		0.665		0.0060						
		0.156								
		0.530								
		0.569		0.0065						
		0.267								
					0.0222	4.34	97.19	62.2	14.7	2.4
					0.0254	5.00	97.67	51.6	12.1	2.3
					0.0199	3.99	98.85	35.5	3.5	2.7
					0.0272	5.25	96.68	73.7	17.3	2.2

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Concept II, Mod 4

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air Lean blowout
252	Idle	No chemistry	3.26			0.539		0.0038
253	Idle	No chemistry	3.67			0.504		
254	Idle	Exhaust chemistry	3.58				0	
255	Idle	Exhaust chemistry	3.65				0	
256	Idle	PZ sequential rake 1	3.65				8	
257	Idle	PZ sequential rake 2	3.66				69	
258	Idle	PZ sequential rake 3	3.67				0	
259	Idle	PZ sequential rake 4	3.65				18	

Concept II, Mod 5

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air Lean blowout
267	Idle	No chemistry	3.64			0.366		0.0040
268	Idle	Exhaust chemistry	3.56				0	
269	Idle	PZ sequential rake 1	3.49				0	
270	Idle	PZ sequential rake 2	3.49				0	
271	Idle	PZ sequential rake 3	3.47				0	
272	Idle	PZ sequential rake 4	3.44				0	
273	Idle	No chemistry	3.91			0.348		
274	Idle	Exhaust chemistry	3.76				0	
275	Idle	PZ sequential rake 1	3.67				3	
276	Idle	PZ sequential rake 2	3.64				22	
277	Idle	PZ sequential rake 3	3.80				0	
278	Idle	PZ sequential rake 4	3.78				0	

Table XV. (cont)

Concept II, Mod 4

Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2, %	Efficiency, %	Emission indices		
			Lean blowout	Chemical			CO	CH_x	NO_x
	0.539		0.0038						
	0.504								
		0		0.0120	2.42	98.28	38.1	8.8	4.1
		0		0.0152	3.06	98.60	29.0	7.6	4.2
		8		0.0284	5.56	97.75	46.5	12.4	3.7
		69		0.0374	7.08	97.11	102.0	5.6	4.8
		0		0.0120	2.43	98.84	29.0	5.1	4.3
		18		0.0359	6.31	92.43	179.9	36.4	2.4

Concept II, Mod 5

Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2, %	Efficiency, %	Emission indices		
			Lean blowout	Chemical			CO	CH_x	NO_x
	0.366		0.0040						
		0		0.0105	2.07	97.00	52.2	19.1	2.7
		0		0.0138	2.69	96.22	67.3	23.7	2.6
		0		0.0190	3.76	97.52	46.5	14.9	3.3
		0		0.0102	2.03	97.81	40.9	13.2	2.8
		0		0.0106	2.08	96.39	61.4	23.3	2.2
	0.348								
		0		0.0126	2.54	98.67	32.2	6.2	3.1
		3		0.0232	4.57	98.06	59.4	6.1	2.5
		22		0.0388	7.50	98.07	70.4	3.3	3.4
		0		0.0131	2.66	99.02	24.7	4.3	3.1
		0		0.0180	3.55	97.78	61.7	8.5	2.0

analytical model prevented the prediction for mod 5. Again the fuel-air ratio data is compared to the predicted values. This comparison is shown in Figure 84. It can be seen that from these contour plots that rig data do not agree with the predictions either in shape or level.

The absolute level of predicted and measured fuel-air ratios is shown in Table XVI. The measured values represent approximately 2/3 the value for the calculated value. This could be a result of inadequate sampling positions or predicted value shortcomings.

Table XVI.
Fuel-air ratios--Concept II.

Mod	Test condition	Fuel-air ratio Predicted	Fuel-air ratio Measured	Percent difference
Baseline	80%	0.0496	0.0331	+49.9
1	80%	0.0484	0.0321	+50.8
2	80%	0.0448	0.0311	+44.1
3	80%	0.0412	0.0295	+39.7
4	Idle	0.0266	0.0283	- 6.0

CONCEPT III BASELINE EXPERIMENTAL RESULTS

The Concept III combustor features a single-vortex primary zone with a 25% reduction in the number of fuel injectors (12 instead of 16). Figure 85 is a photograph of Concept III.

Concept III baseline testing consisted of the following:

- thermal paint at 100% power
- exhaust performance at 100%, 80%, 50%, and idle power
- primary zone emissions at 80% power

Table XVII presents the measured data for the Concept III baseline. Figure 86 presents the wall temperature and thermal-paint results. The Concept III configuration exhibited localized hot zones in the plane of the fuel injector. Thermal paint results indicates these areas are in the 1323-1344 K temperature range. The film cooling of the dome portion of this design appears to be inadequate for 100% power operation.

Exhaust temperature profile and pattern factor versus power plots are presented in Figure 87. The circumferential pattern factor of 0.189 at 100% power for a new primary zone concept indicates a uniform gas temperature profile. The level of pattern factor was not affected by power condition. The radial gradient of 30 K indicates a relatively uniform profile.

Combustor exhaust emission level indices for CO, UHC, and NO_x and corresponding combustion efficiency over the power range is presented in Figure 88. These levels are similar to values obtained with Concept I and II.

Primary zone emission data were obtained at 80% power condition. Figure 89 presents the combustion efficiency, carbon monoxide, and oxides of nitrogen data in a sector interpretation. The fuel nozzle is located at the 15 deg

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position. The low combustion efficiency at probe No. 2 position is substantiated by a high level of smoke at that position. Smoke level was 87 at probe No. 2 as compared to 42 and 48 for the other probes.

The predicted and measured fuel-air ratios are compared in Table XVIII. Mods 2 through 5 were evaluated with four probe positions providing a uniform location as samples. The measured values for these configurations compare very favorably with the predicted value of the overall primary zone fuel-air ratio.

CONCEPT III BASELINE COMBUSTOR PZ PERFORMANCE ANALYTICAL PREDICTION/TEST DATA COMPARISON

The analytical prediction of the primary zone performance for Concept III baseline design indicated a high radial gradient with the outer zone in excess of 0.05 fuel-air ratio and the inner zone at 0.01 fuel-air ratio. The area between fuel injectors has the higher fuel-air values. The measured data indicated fuel-air values below average between fuel nozzles and did not resemble the predicted values. These data are presented in Figures 90 and 91.

CONCEPT III MODIFICATIONS AND EXPERIMENTAL RESULTS

Concept III combustor primary zone section was modified into five distinct configurations. The modifications of this single-vortex primary zone consisted of changes to fuel entry directions and variations of inner-to-outer primary-air balance. These modifications are briefly described as follows:

Mod 1: Fuel tube exit located tangent to combustor centerline pointing clockwise viewed looking downstream

Mod 2: Mod 1 with fuel tube pointing in a counterclockwise direction

Mod 3: Fuel tube radially outward (baseline configuration), with 50% increase in outer-shell primary air and 50% reduction in inner-shell primary air

Mod 4: Mod 3 with all primary air in the outer wall

Mod 5: Mod 3 with all primary air in the inner wall

Table XIX presents a summary of the measured data for Concept III, mods 1 through 5.

The highlights of this summary are these:

- The fuel placement, whether radially out or tangent right or left had little effect upon overall performance except there was some deterioration of exhaust pattern factor for mod 2. It was also noted that the primary zone smoke was lower for mod 2.
- Lean-burn to a low fuel-air ratio value was observed for all mods.
- The attempt to put all of the primary air through the inner wall tubes produced a drastic increase in wall temperature and limited the test evaluation to the idle conditions.

Concept III,

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rati Lean blowout	 Che
118	100%	No chemistry	3.85	998	841	0.200			
119	100%	No chemistry	3.93	1021	855	0.189			
149	Idle	No chemistry	4.04	772	581	0.200		0.0030	
150	Idle	Exhaust chemistry	4.00	759	578				0.0
151	Idle	Exhaust chemistry	4.01	763	580				0.0
152	50%	No chemistry	3.53	963	704	0.210		0.0018	
153	50%	Exhaust chemistry	3.52	966	706				0.0
154	80%	No chemistry	3.35	1135	793	0.215		0.0024	
155	80%	No chemistry	3.37	1115	785	0.218			
156	80%	Exhaust chemistry	3.36	1073	771		6		0.
157	80%	PZ sequential rake 1	3.37	1053	759		48		0.
158	80%	PZ sequential rake 2	3.32	1096	773		87		0.
159	80%	PZ sequential rake 3	3.45	1122	764		42		0.0

Fuel-air

Mod	Test condition
Baseline	80%
1	80%
2	80%
3	80%
4	80%
5	Idle

Table XVII.
Concept III, baseline, test data summary.

K	Pattern factor	Smoke, SAE No.	Fuel-air ratio Lean blowout	Fuel-air ratio Chemical	CO_2, %	Efficiency, %	Emission indices CO	Emission indices CH_x	Emission indices NO_x
	0.200								
	0.189								
	0.200		0.0030						
				0.0113	2.28	98.85	32.9	4.0	3.9
				0.0114	2.32	99.07	31.5	2.1	2.8
	0.210		0.0018						
				0.0171	3.50	99.84	4.8	0.1	7.3
	0.215		0.0024						
	0.218								
		6		0.0229	4.66	99.91	1.9	0.0	9.6
		48		0.0283	5.72	99.73	9.5	0.1	9.9
		87		0.0545	7.36	72.81	126.5	256.7	2.9
		42		0.0170	[illegible]	99.42	7.5	4.0	6.8

Table XVIII.
Fuel-air ratios--Concept III.

Mod	Test condition	Fuel-air ratio Predicted	Fuel-air ratio Measured	Percent difference
Baseline	80%	0.0360	0.0333	+8.1
1	80%	0.0350	0.0446	-21.5
2	80%	0.0375	0.0339	+10.6
3	80%	0.0359	0.0355	+1.1
4	80%	0.0374	0.0382	-2.1
5	Idle	0.0205	0.0208	-1.4

Concept III,

Concept III, Mod 1

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rati	
								Lean blowout	Che
160	80%	No chemistry	3.53	933	767	0.209	0		
161	80%	Exhaust chemistry	3.42	933	763				0.
162	80%	PZ sequential rake 1	3.42	933	763		82		0.
163	80%	PZ sequential rake 2	3.46	936	765		29		0.
164	80%	PZ sequential rake 3	3.44	933	763		95		0.

Concept III, Mod 2

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rati	
								Lean blowout	Ch
220	80%	No chemistry	4.04	1071	844	0.452			
221	80%	Exhaust chemistry	4.06	1083	849		5	0.0020	0.
222	80%	PZ sequential rake 1	4.09	1076	842		28		0.
223	80%	PZ sequential rake 2	4.06	1077	843		33		0.
224	80%	PZ sequential rake 3	4.03	1079	843		35		0.
225	80%	PZ sequential rake 4	4.24	1073	841		6		0.
226	100%	No chemistry	4.11	1178	936	0.234		0.0015	

Concept III, Mod 3

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rati	
								Lean blowout	Che
260	80%	No chemistry	3.48	856	769	0.239		0.0015	
261	80%	Exhaust chemistry	3.51	848	764		7		0.
262	80%	PZ sequential rake 1	3.46	863	778		61		0.
263	80%	PZ sequential rake 2	3.74	853	768		74		0.
264	80%	PZ sequential rake 3	3.74	864	768		44		0.
265	80%	PZ sequential rake 4	3.69	875	770		74		0.
266	100%	No chemistry	3.69	1023	866	0.212		0.0012	

Table XIX.
Concept III, mods 1-5, test data summary.

Concept III, Mod 1

Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2,	Efficiency,	Emission indices		
		Lean blowout	Chemical	%	%	CO	CH_x	NO_x
0.209	0							
			0.0234	4.77	99.85	3.2	0.3	7.9
	82		0.0458	7.89	91.57	175.6	46.3	4.3
	29		0.0388	7.67	99.18	27.6	1.6	6.6
	95		0.0493	8.49	92.17	186.5	37.4	4.4

Concept III, Mod 2

Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2,	Efficiency,	Emission indices		
		Lean blowout	Chemical	%	%	CO	CH_x	NO_x
0.452								
	5	0.0020	0.0233	4.74	99.91	1.7	0.1	8.8
	28		0.0383	7.61	99.42	21.4	0.6	7.4
	33		0.0307	6.18	99.63	13.8	0.1	8.6
	35		0.0347	6.82	98.75	49.9	0.8	7.3
	6		0.0320	6.45	99.89	2.8	0.1	8.0
0.234		0.0015						

Concept III, Mod 3

Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2,	Efficiency,	Emission indices		
		Lean blowout	Chemical	%	%	CO	CH_x	NO_x
0.239		0.0015						
	7		0.0211	4.33	99.83	3.2	0.6	9.6
	61		0.0296	6.00	99.65	9.1	1.1	9.1
	74		0.0422	7.97	94.08	6.6	61.3	7.8
	44		0.0215	4.39	99.68	9.4	0.7	8.8
	74		0.0485	9.63	99.37	7.0	4.8	5.3
0.212		0.0012						

Concept III, Mod 4

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rat	
								Lean blowout	Ch
279	80%	No chemistry	3.41	887	791	0.239		0.0015	
280	80%	Exhaust chemistry	3.39	902	784		36		0
281	80%	PZ sequential rake 1	3.40	950	796		100		0
282	80%	PZ sequential rake 2	3.43	947	812		95		0
283	80%	PZ sequential rake 3	3.36	956	782		80		0
284	80%	PZ sequential rake 4	3.33	948	796		53		0
285	100%	No chemistry	3.29	978	878	0.233		0.0014	

Concept III, Mod 5

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rat	
								Lean blowout	Ch
294	---	No chemistry	3.09	1304	691	0.352		0.0025	
295	Idle	No chemistry	3.46	717	547	0.322		0.0030	
296	Idle	Exhaust chemistry	3.41	614	534				0
297	Idle	PZ sequential rake 1	3.41	616	533		60		0
298	Idle	PZ sequential rake 2	3.45	624	538		68		0
299	Idle	PZ sequential rake 3	3.39	617	532		42		0
300	Idle	PZ sequential rake 4	3.43	631	538		42		0

Table XIX. (cont)

ept III, Mod 4

tern	Smoke,	Fuel-air ratio		CO$_2$,	Efficiency,	Emission indices		
tor	SAE No.	Lean blowout	Chemical	%	%	CO	CH$_x$	NO$_x$
239		0.0015						
	36		0.0220	4.48	99.73	7.2	0.8	8.1
	100		0.0347	6.61	97.04	90.3	9.2	6.5
	95		0.0485	7.40	82.24	180.6	144.2	3.4
	80		0.0290	5.69	98.26	60.7	3.6	4.6
	53		0.0406	8.04	99.36	23.8	0.8	4.5
233		0.0014						

ept III, Mod 5

tern	Smoke,	Fuel-air ratio		CO$_2$,	Efficiency,	Emission indices		
tor	SAE No.	Lean blowout	Chemical	%	%	CO	CH$_x$	NO$_x$
352		0.0025						
322		0.0030						
			0.0119	2.37	97.16	50.9	17.7	3.0
	60		0.0283	5.34	95.38	89.9	27.1	2.7
	68		0.0250	4.73	95.83	105.0	18.7	2.7
	42		0.0141	2.71	95.53	82.4	27.3	2.7
	42		0.0158	2.96	94.05	106.1	37.3	2.2

CONCEPT III COMBUSTOR MODIFICATIONS PZ PERFORMANCE ANALYTICAL PREDICTION/TEST DATA COMPARISON

The comparison of the primary zone analytical prediction and the measured test data for fuel-air ratio in the plane of the primary zone probe for the five modification configurations is presented in Figure 92. The redirection of the fuel spray in modifications 1 and 2 produced a significant shift in the calculated fuel-air signatures. This characteristic was found in the measured data as can be seen in Figure 92, mods 1 and 2. The modifications which were designed to influence the primary air recirculation did not produce data that reflected the anaytical prediction.

COMBUSTOR CONCEPT PERFORMANCE SUMMARY

Even though this was not a combustor development program, some comparative evaluations of the combustor concepts and modifications should be made based on the physical differences among the configurations of each concept and the data resulting from the experimental testing. A summary of the test data for all eighteen combustor tests is shown in Table XX for the 80% power condition. More data were recorded at 80% than at any other condition even though all combustor mods could not be operated at that high a power condition.

The Concept I combustor designs are summarized in Table III. The performance of the baseline Concept I combustor was excellent. Metal temperatures were below 950 K, exhaust temperature profiles were uniform, and exhaust emissions were acceptable. Increasing the fuel nozzle swirler swirl number from 0.84 to 1.45 by increasing the turning angle of the air from 45 deg to 60 deg produced performance improvements. Both maximum and average metal temperatures were reduced. Exhaust CO and UHC remained nearly the same with NO_x and smoke number decreasing. Changes in primary zone hole spacing (mod 2), numbers of holes (mods 3 and 4), and flow fraction (mod 3) showed no improvement over the baseline configuration or no additional improvement over mod 1. Thus for Concept I, the best configuration from an overall performance standpoint was the mod 1 design with the increased fuel nozzle swirl number.

The Concept II combustor designs are summarized in Table IV. The performance of the baseline Concept II combustor was good, but not as good as the Concept I combustors. Metal temperatures were below 975 K, exhaust pattern factor at 0.35 was poor, and the exhaust emissions showed a hotter reaction zone with lower CO and UHC but higher NO_x. The Concept II, mod 1, combustor changed to the lower swirl number fuel nozzle swirler used in the Concept I baseline combustor and showed an increase in exhaust emissions, especially NO_x. Metal temperature and exit temperature profile were reduced as well as primary zone CO, UHC, and smoke. Primary zone NO_x increased. Mods 2 and 3 progressively increased the flow area of the primary holes by 50% and 100% respectively. Temperature pattern improved for these two mods when compared to mod 1. Mod 2 showed lower exhaust CO, UHC, and NO_x but an increase in smoke. In the primary zone, CO, UHC, and smoke increased but NO_x decreased slightly. Both metal temperature and exit temperature profile increased. Mod 2 performance appears equally variable. The final two designs, mods 4 and 5, used only 8 fuel nozzles instead of 16. These combustors at a nozzle spacing-to-annulus height ratio of 2.8 produced very high exit temperature profiles and thus were limited to idle operating conditions. The best overall performance was probably the Concept II, mod 3, design which demonstrated a low exit temperature profile and slightly higher exhaust, UHC, and NO_x. Exhaust smoke and primary zone CO, UHC, and smoke were approximately equal in all Concept II designs.

The Concept III single vortex combustor designs are summarized in Table V. The performance of the baseline Concept III combustor was quite good considering that this was the initial design of the general concept. Except for the 1073 K maximum measured metal temperature, all of the combustor performance parameters were more than satisfactory. The exit temperature profile was very uniform having a pattern factor of 0.215. The exhaust emissions were only slightly higher than the Concept I baseline emissions. The primary zone emissions showed very high levels of CO, UHC, and smoke, but these levels were not observed in the exhaust gas samples. Concept III, mods 1 and 2, rotated the fuel nozzle chutes 90 deg clockwise and counterclockwise, respectively. The clockwise rotation in mod 1 showed considerably better performance than the mod 2 rotation. The mod 2 design produced high average and maximum metal temperatures as well as an unacceptably high exit temperature profile. Compared to the Concept III baseline combustor, the mod 1 design demonstrated lower metal temperatures, exhaust NO_x, and exhaust smoke, but higher exit temperature profiles, exhaust CO, and exhaust UHC. Concept III, mods 3 and 4, progressively moved primary zone injection air from the inner shell to the outer shell. The mod 3 design which had half the inner shell primary zone injection air transferred to the outer shell gave better performance than the mod 4 and better than the baseline designs; metal temperatures were lower, the exit temperature profile was the most uniform, exhaust NO_x and smoke were low, and exhaust CO and UHC were acceptable. Primary zone emissions also were as low as for most designs Concept III, mod 5, moved all of the primary zone air to the inner shell, but high metal temperatures restricted operation to idle conditions. Thus for the single vortex design, baseline and mod 2 produced the best overall performance.

Table XX.
Combustor performance summary at 80% power conditions.

Combustor		P/P	Metal temp (K)		Exit temp profile		LBO	Primary Zone Emissions				
Concept	Mod	(%)	Avg	Max	Tm/Ta	Pat Fact	F/A	CO (ppm)	UHC (ppm)	No$_x$ (ppm)	SN	Eff. (%)
I	Base	3.60	778	933	1.100	0.160	---	---	---	---		---
	1	3.64	740	874	1.100	0.147	0.0018	555	26	29	0	99.02
	2	3.54	789	904	1.119	0.174	---	5414	964	185	81	94.26
	3	3.45	---	---	1.136	0.199	0.0012	1117	5	176	32	99.38
	4	3.64	---	---	1.105	0.154	0.0015	1234	3	213	23	99.32
	5	4.30	---	---	1.144	0.215	0.0020	323	16	91	28	99.55
II	Base	3.63	824	968	1.235	0.354	---	1151	5	162	32	99.61
	1	3.26	806	901	1.186	0.274	0.0040	388	1	189	15	99.66
	2	3.46	843	1003	1.160	0.237	0.0020	620	3	182	30	99.52
	3	3.25	---	---	1.122	0.180	0.0020	584	8	181	30	99.46
	4	---	---	---	---	---	---	---	---	---	--	---
	5	---	---	---	---	---	---	---	---	---	--	---
III	Base	3.36	771	1073	1.144	0.215	0.0024	2347	2873	112	59	99.65
	1	3.42	763	933	1.143	0.209	---	5981	837	134	69	94.31
	2	4.06	849	1083	1.304	0.452	0.0020	764	9	161	25	99.42
	3	3.51	764	848	1.162	0.238	0.0015	270	449	157	63	98.20
	4	3.39	784	902	1.162	0.239	0.0015	3592	1155	106	82	94.23
	5	---	---	---	---	---	---	---	---	---	--	---

ower conditions.

Zone Emissions			Combustor Exit Emissions				
No_x (ppm)	SN	Eff. (%)	CO (ppm)	UHC (ppm)	NO_x (ppm)	SN	Eff. (%)
---		---	32	1.6	127	5	99.91
29	0	99.02	37	0.9	112	0	99.91
185	81	94.26	33	0.4	113	0	99.92
176	32	99.38	19	0.1	131	12	99.94
213	23	99.32	28	0.5	153	4	99.92
91	28	99.55	34	4.0	120	11	99.90
162	32	99.61	26	0.2	136	0	99.92
189	15	99.66	32	2.0	151	0	99.90
182	30	99.52	27	0.8	140	8	99.92
181	30	99.46	26	5.9	162	0	99.88
---	--	---	---	---	---	---	---
---	--	---	---	---	---	---	---
112	59	99.65	43	0.7	135	6	99.91
134	69	94.31	76	5.2	114	0	99.85
161	25	99.42	41	0.8	126	5	99.91
157	63	98.20	67	8.1	125	7	99.83
106	82	94.23	160	10.9	109	36	99.73
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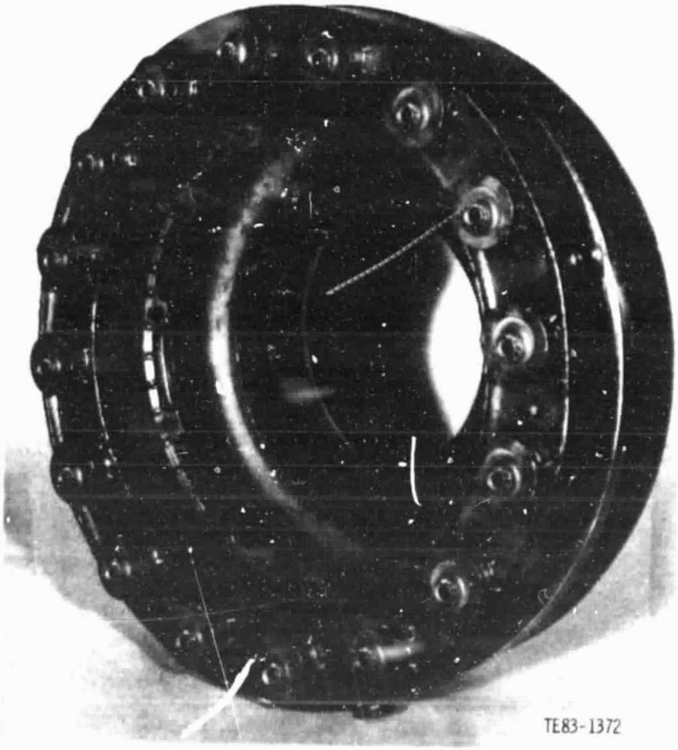

Figure 68. Concept I conventional, swirl-stabilized, double-vortex annular combustor.

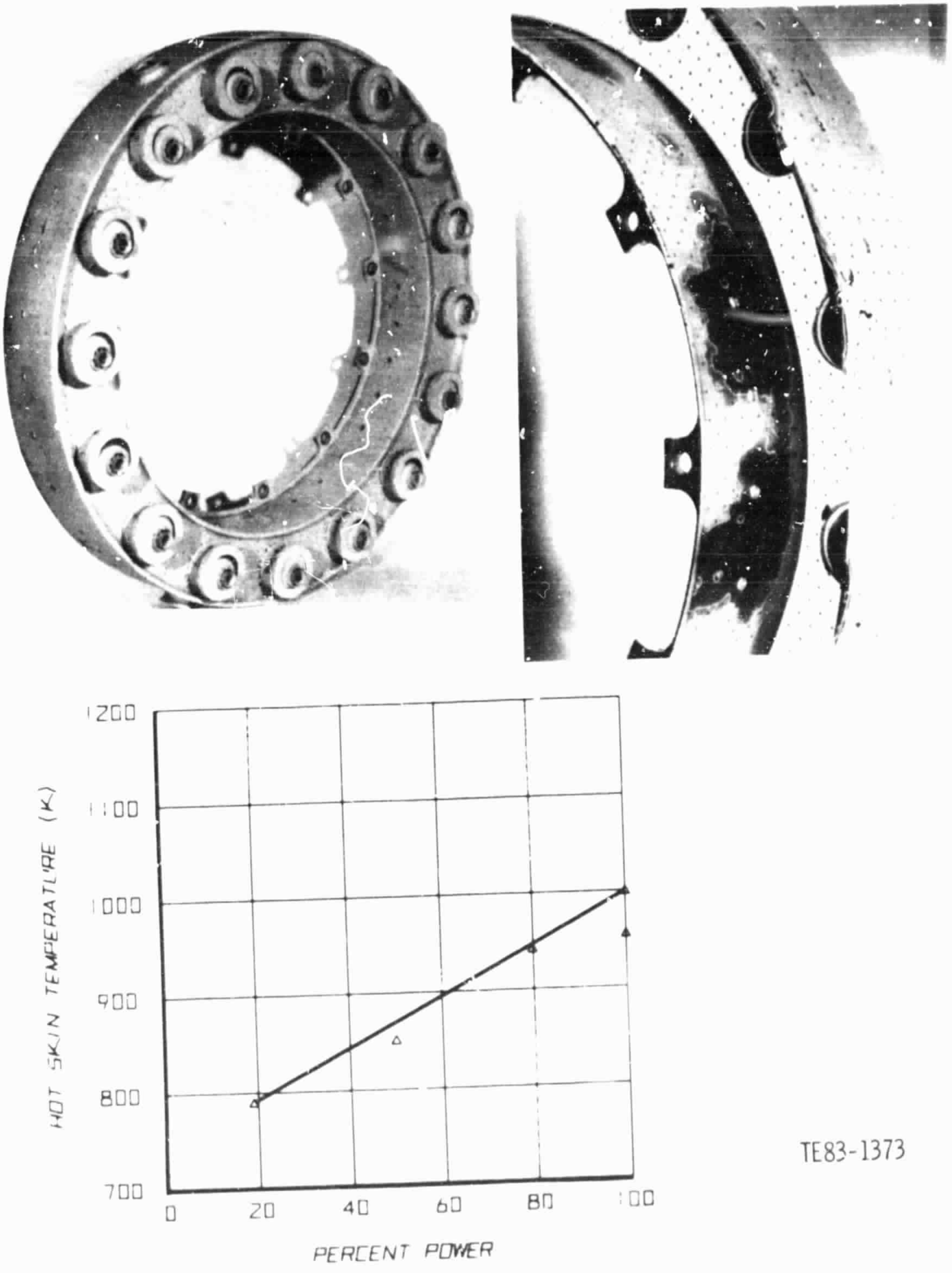

Figure 69. Concept I, baseline, wall temperature and thermal paint results.

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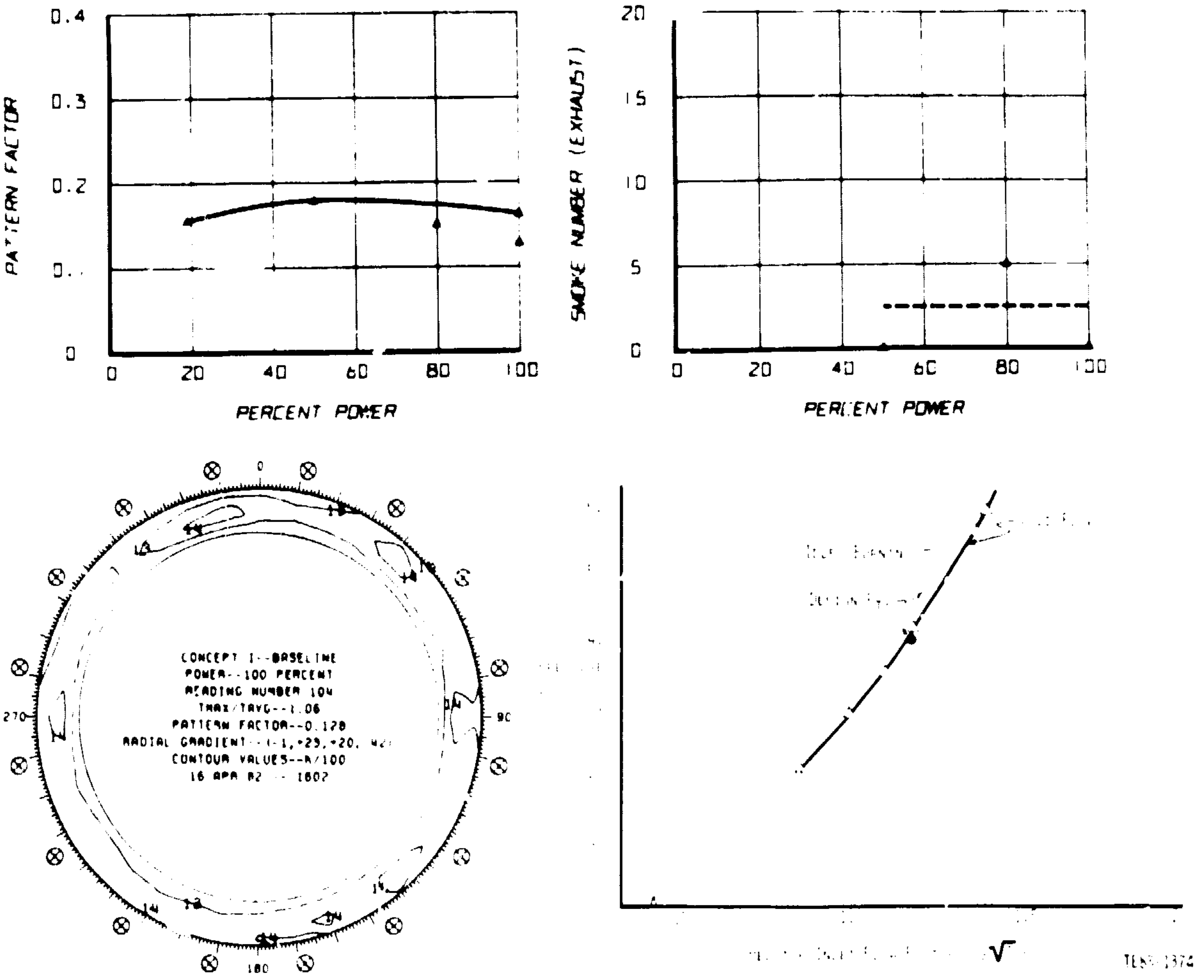

Figure 70. Concept I, baseline, overall combustor performance.

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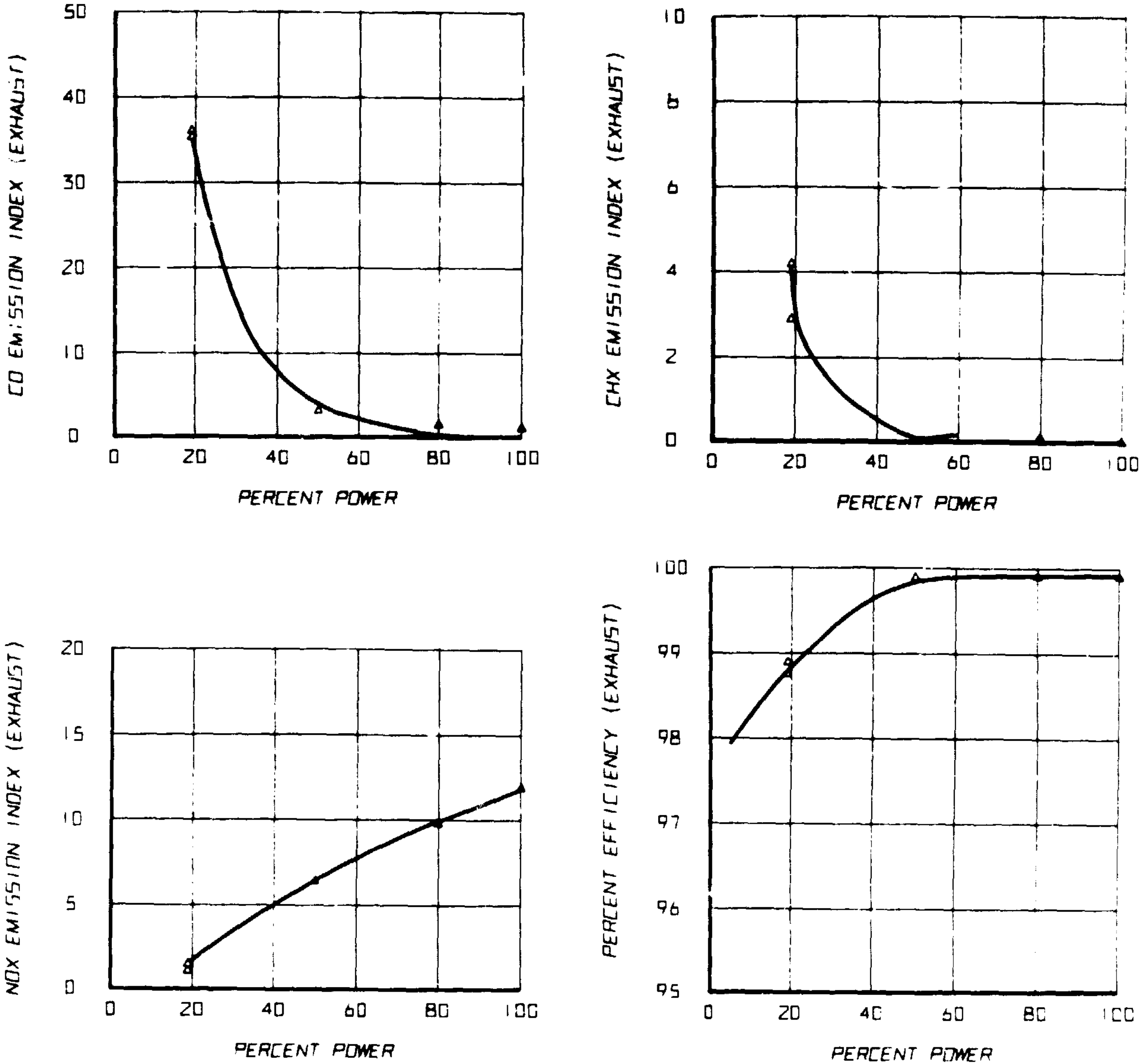

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Figure 71. Concept I, baseline, combustor exhaust emission and efficiency.

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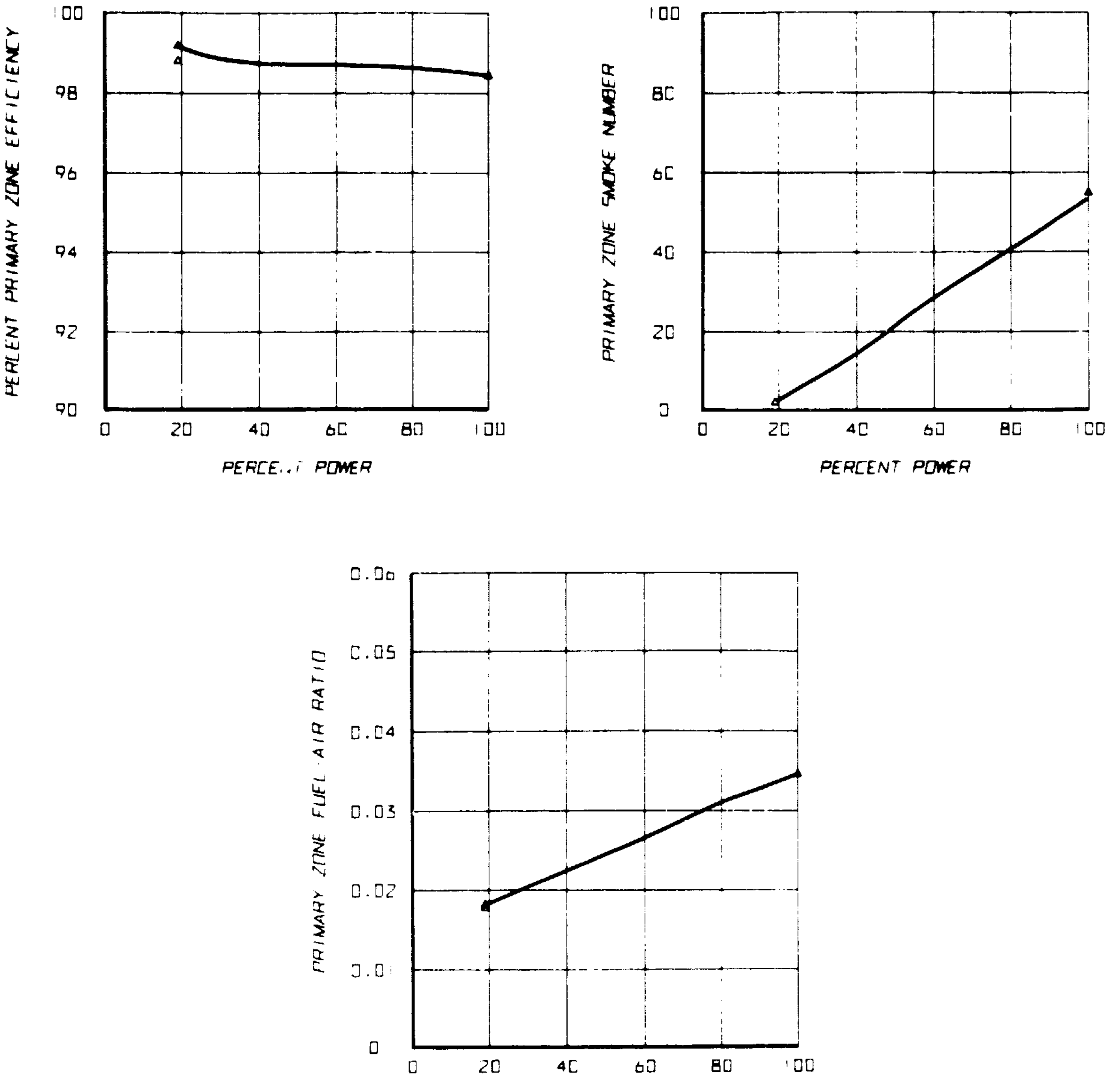
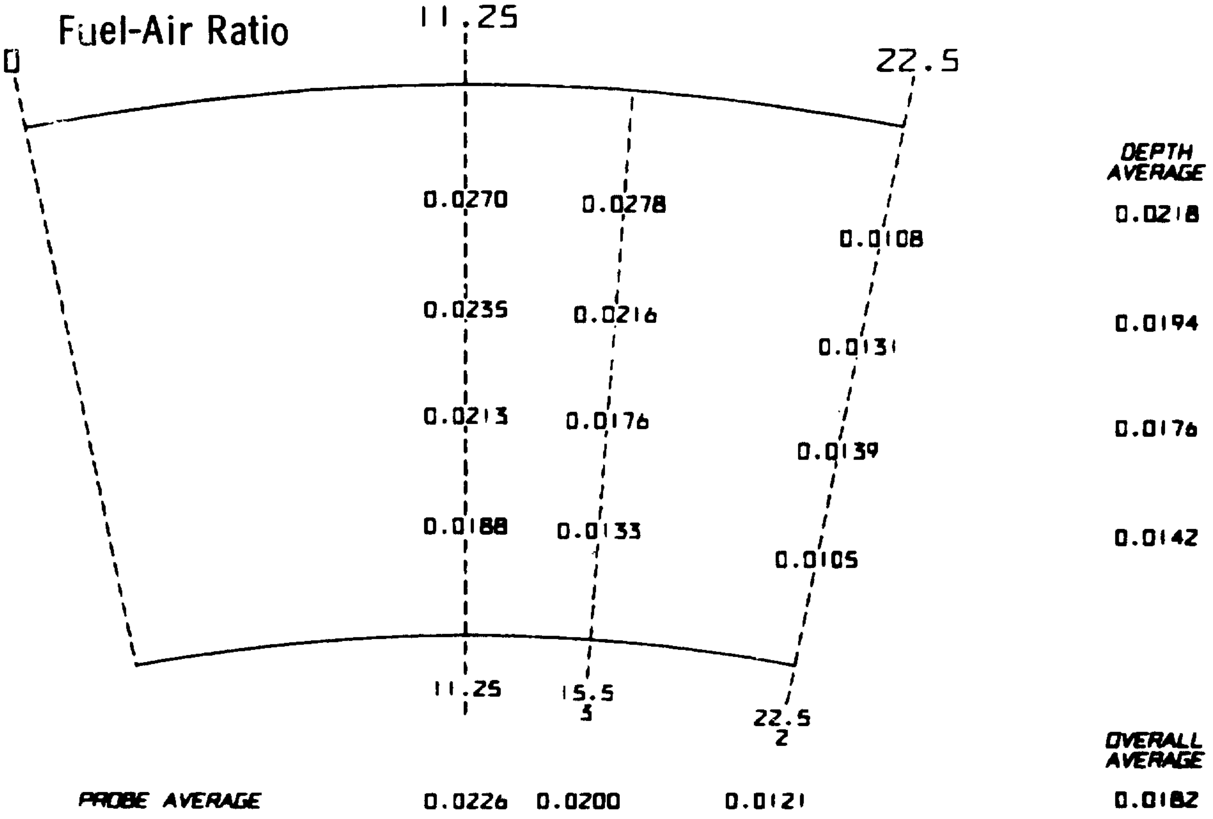
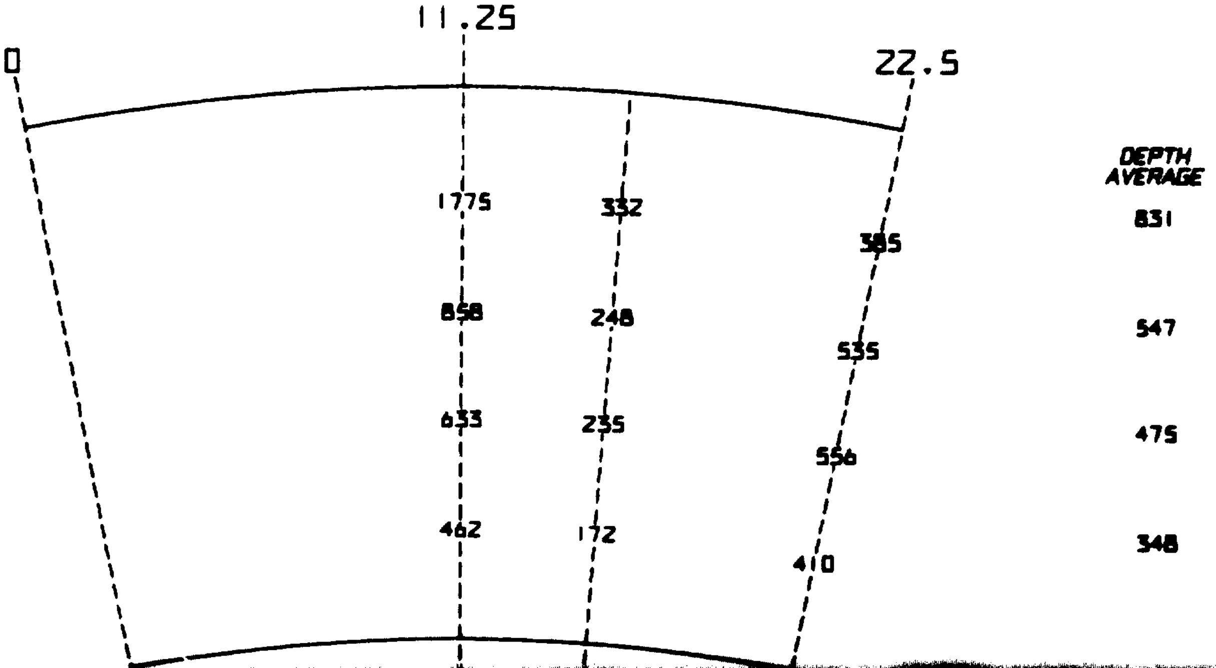


TE83-1376

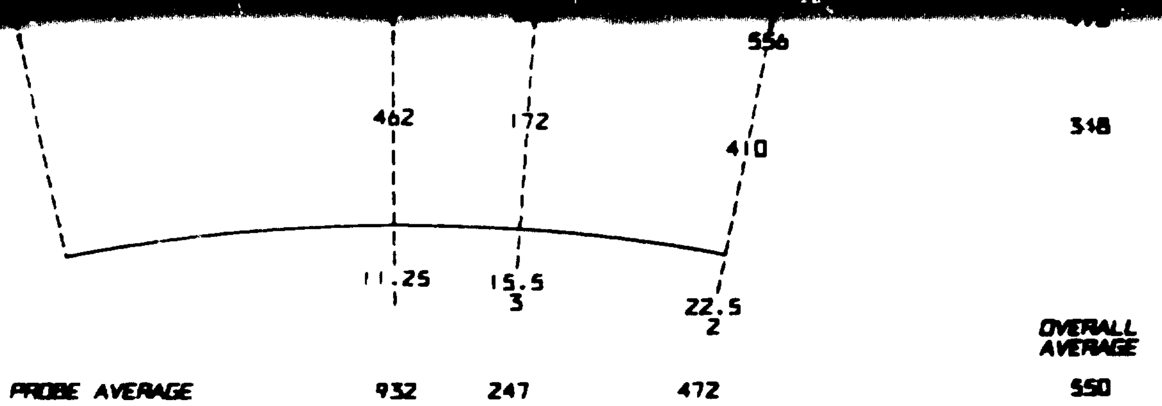
Figure 72. Concept I, baseline, combustor primary zone performance.



Fuel-Air Ratio



Carbon Monoxide—PPM



Oxides of Nitrogen—PPM

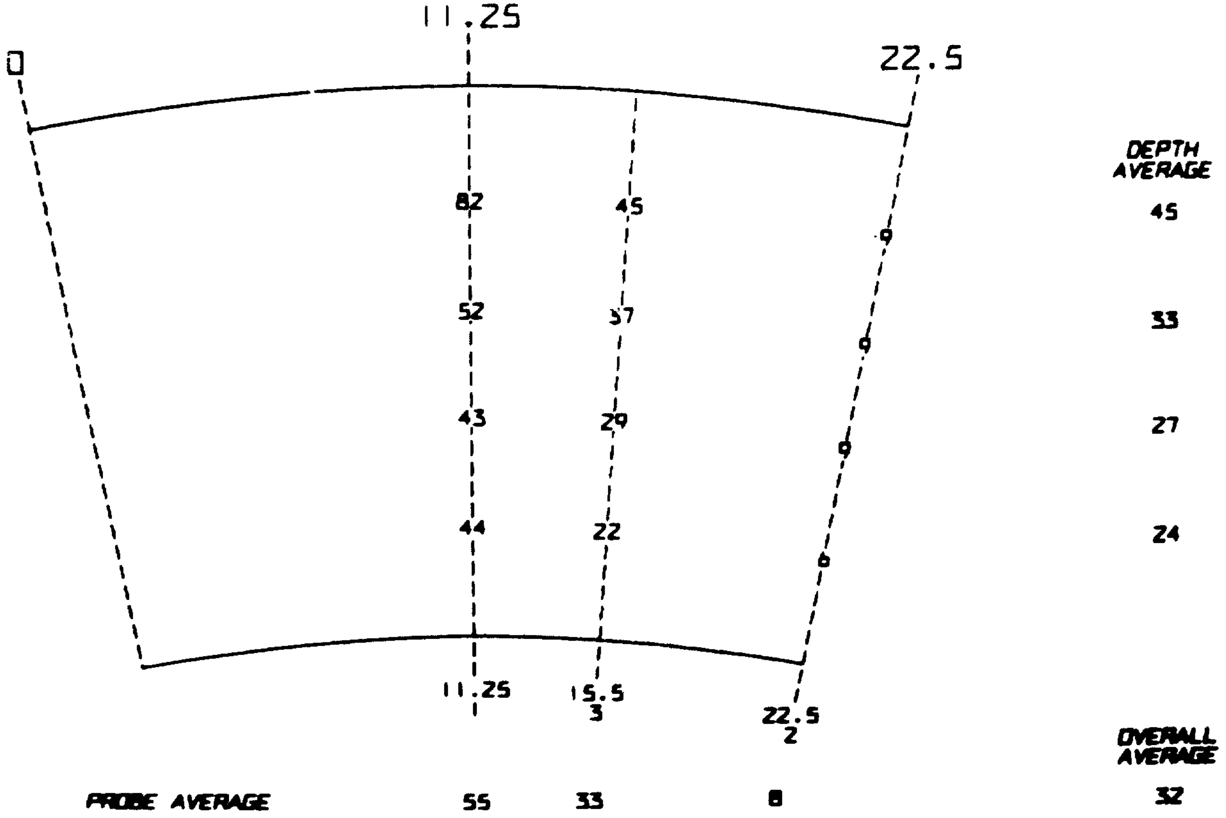


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Figure 73. Concept I, baseline, primary zone sector emissions.

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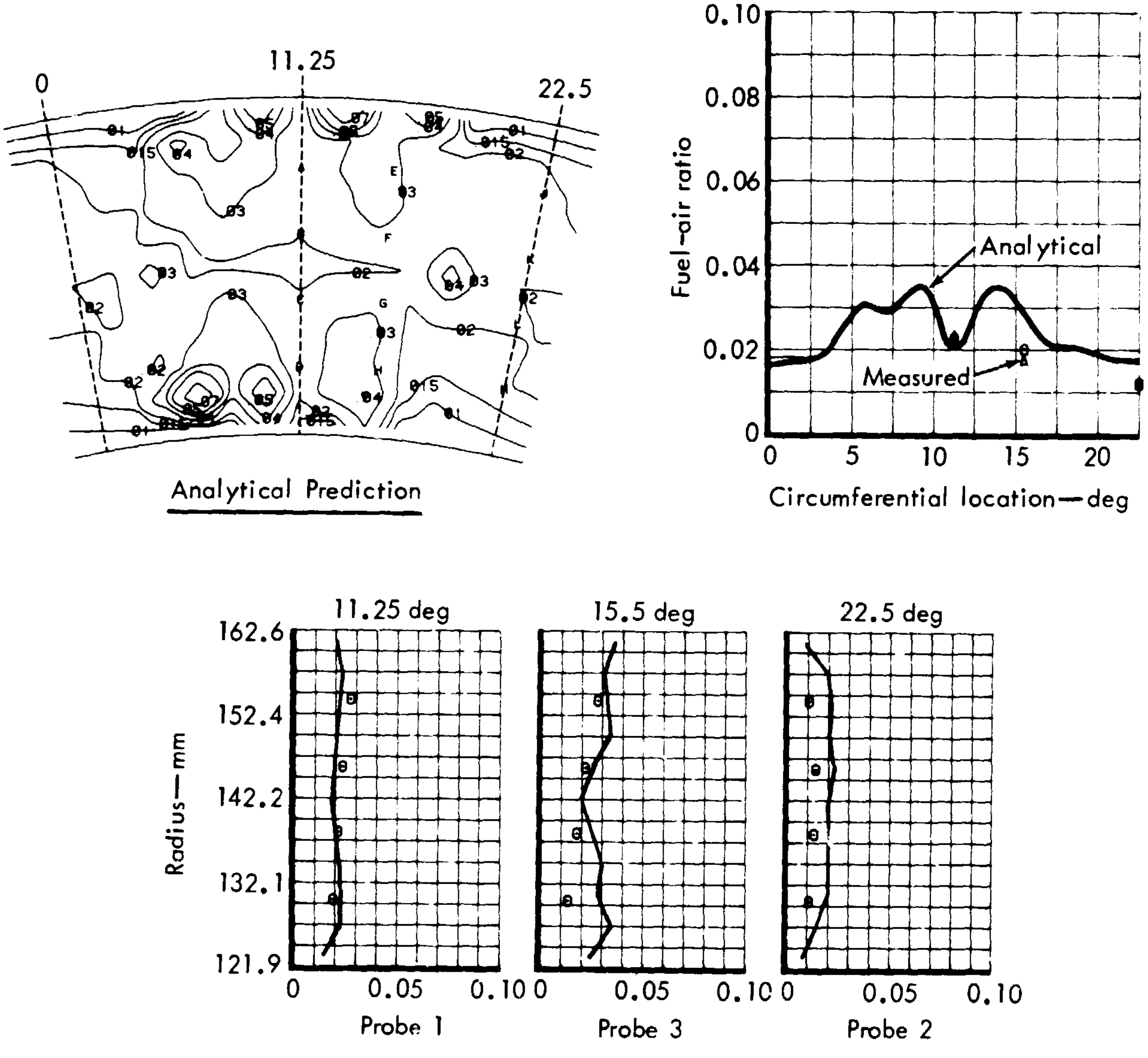
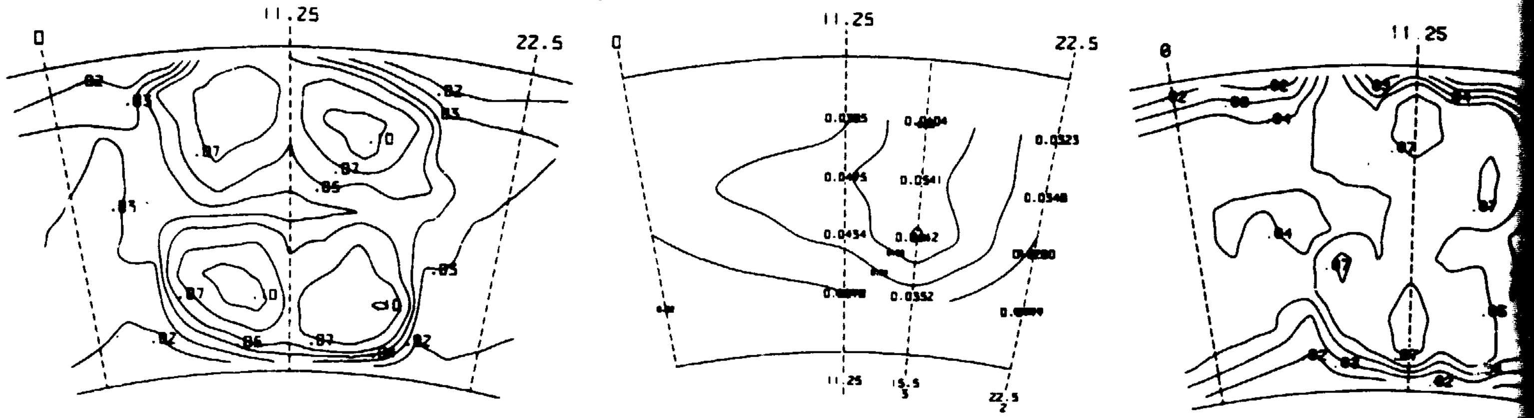


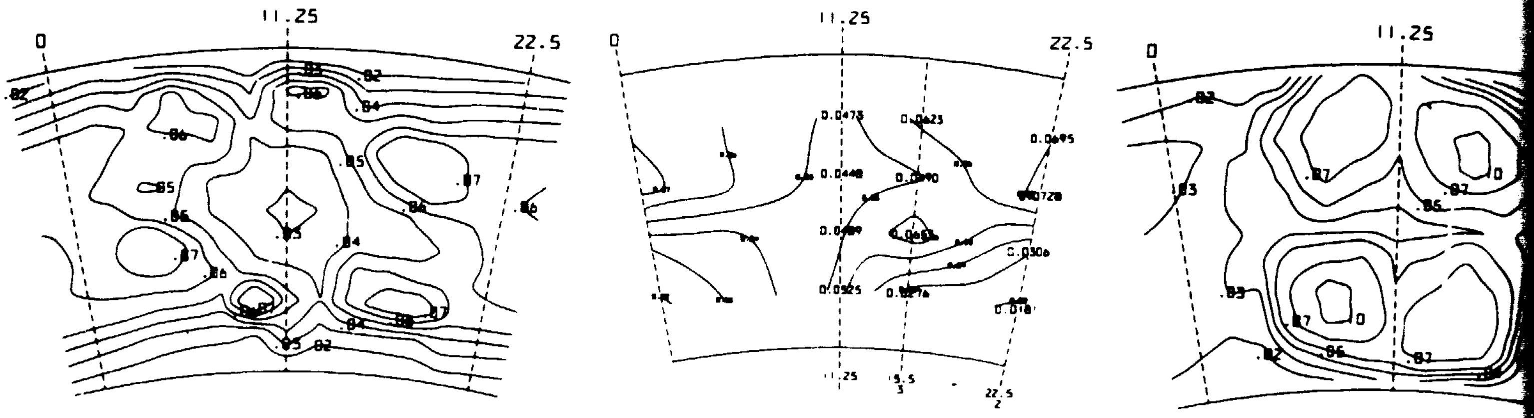
Figure 74. Concept I, baseline, idle-power comparison of analytical prediction and measured primary zone fuel-air ratio.

Analytical Prediction   Measured Values   Analytical Pred

Concept I, Mod 1



Concept I, Mod 2



Concept I, Mod 3

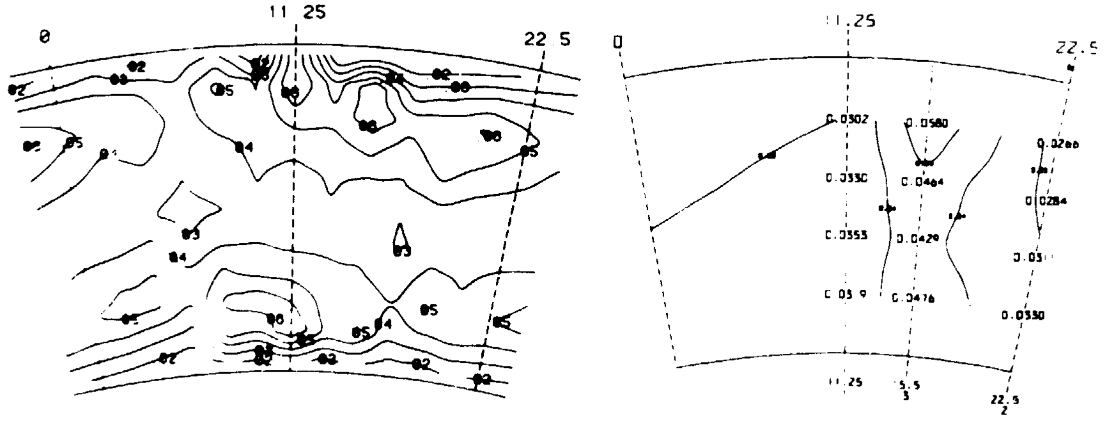
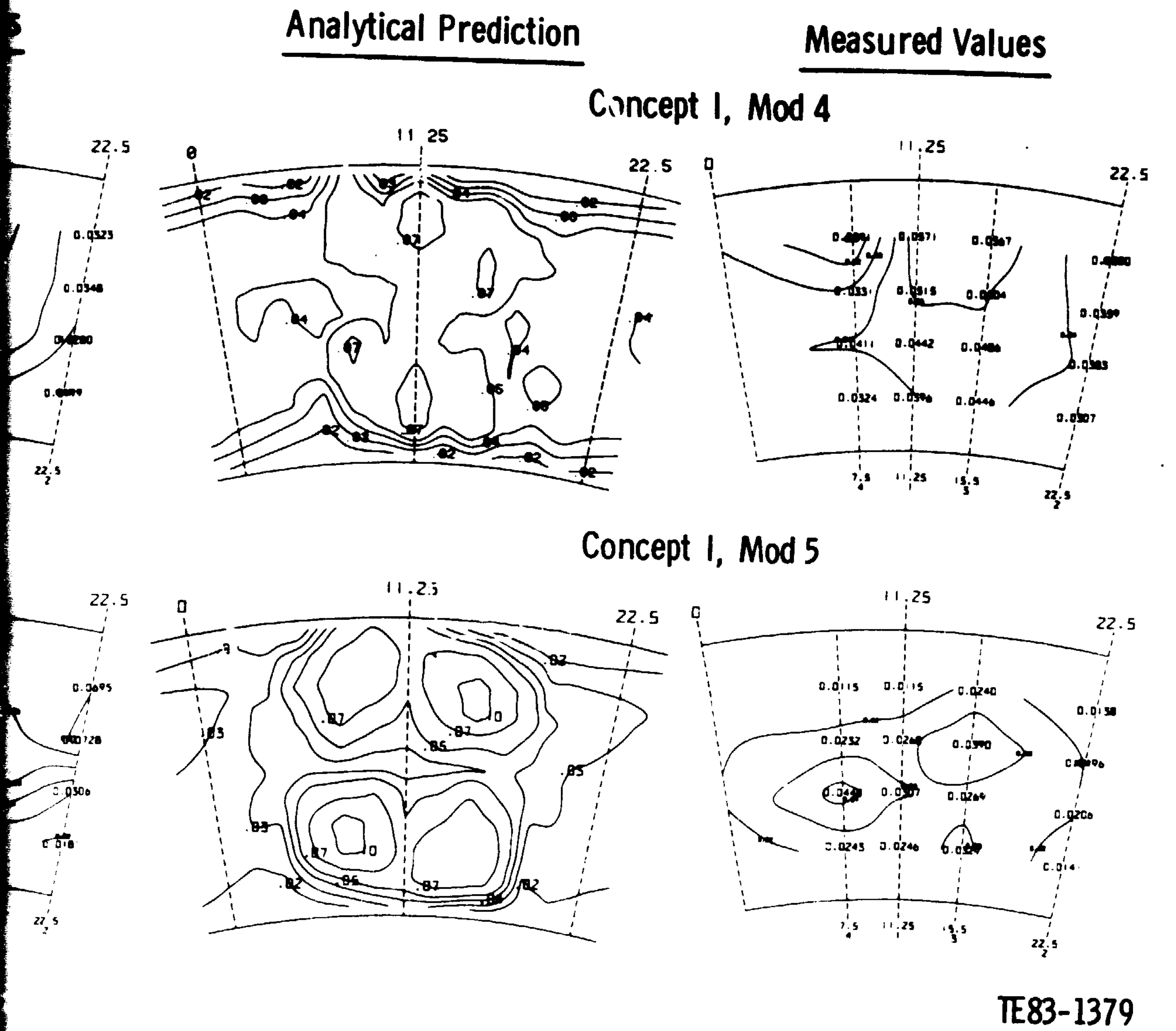


Figure 75. Comparison o
fuel-air



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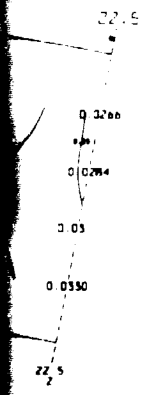


Figure 75. Comparison of analytical prediction and measured primary zone fuel-air ratio (Concept I mods--80% power).

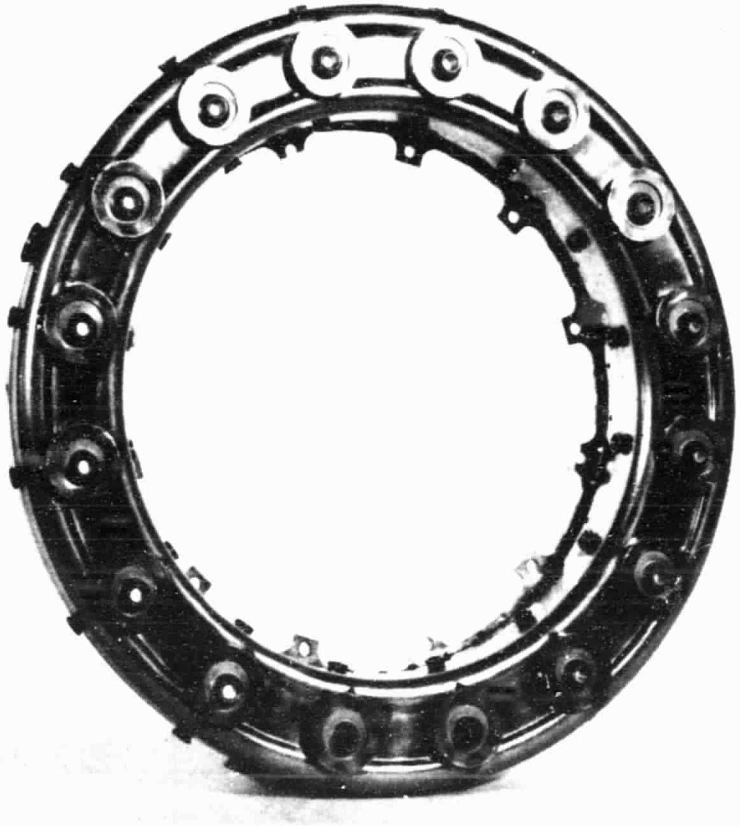
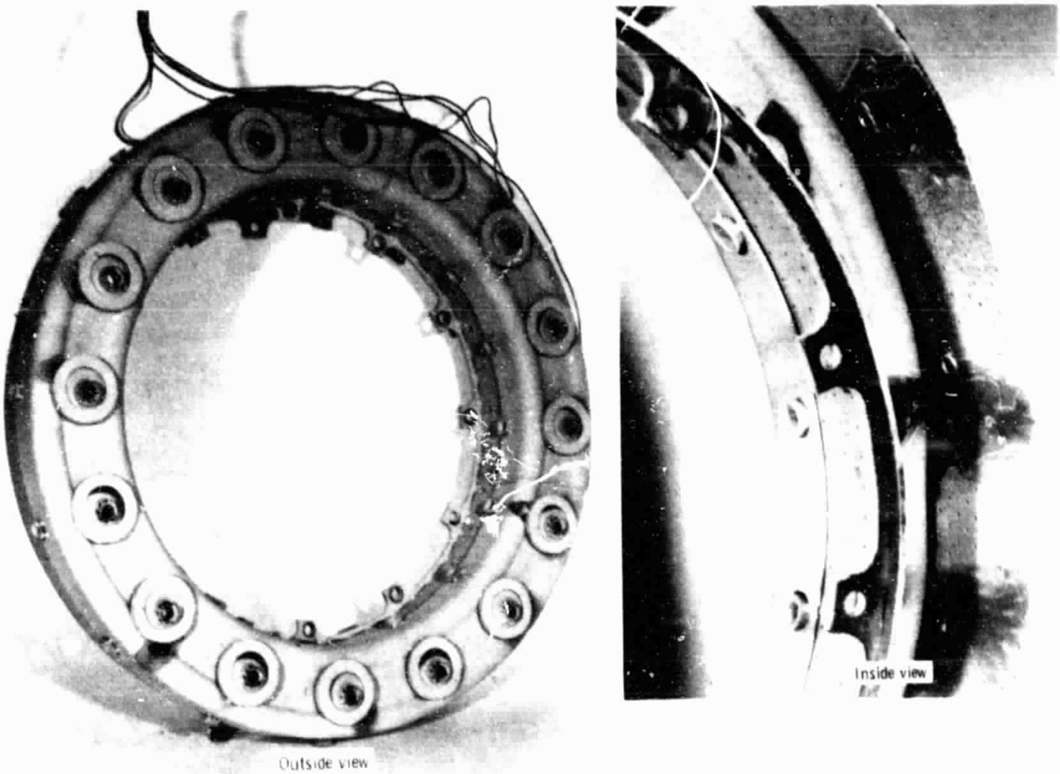

TE83-1380

Figure 76. Concept II, baseline, combustor photograph.



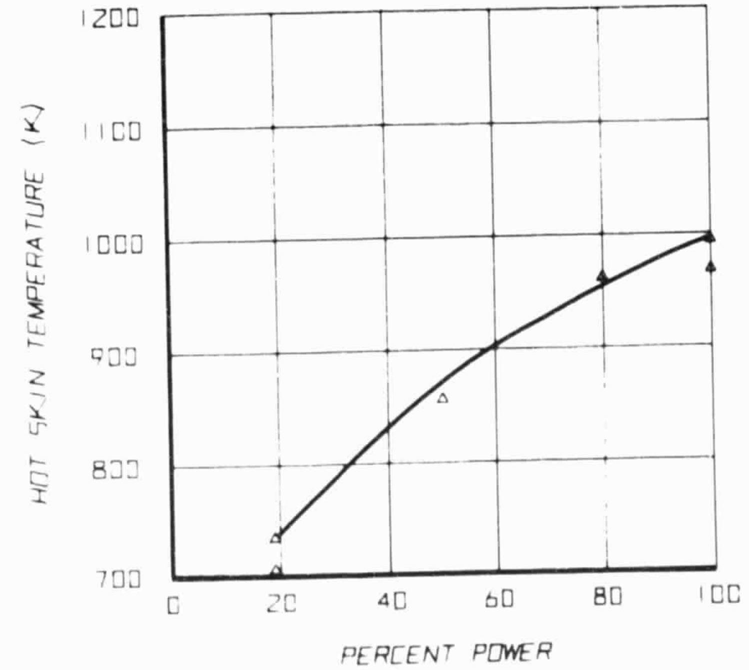


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Figure 77. Concept II, baseline, wall temperature and thermal paint results.

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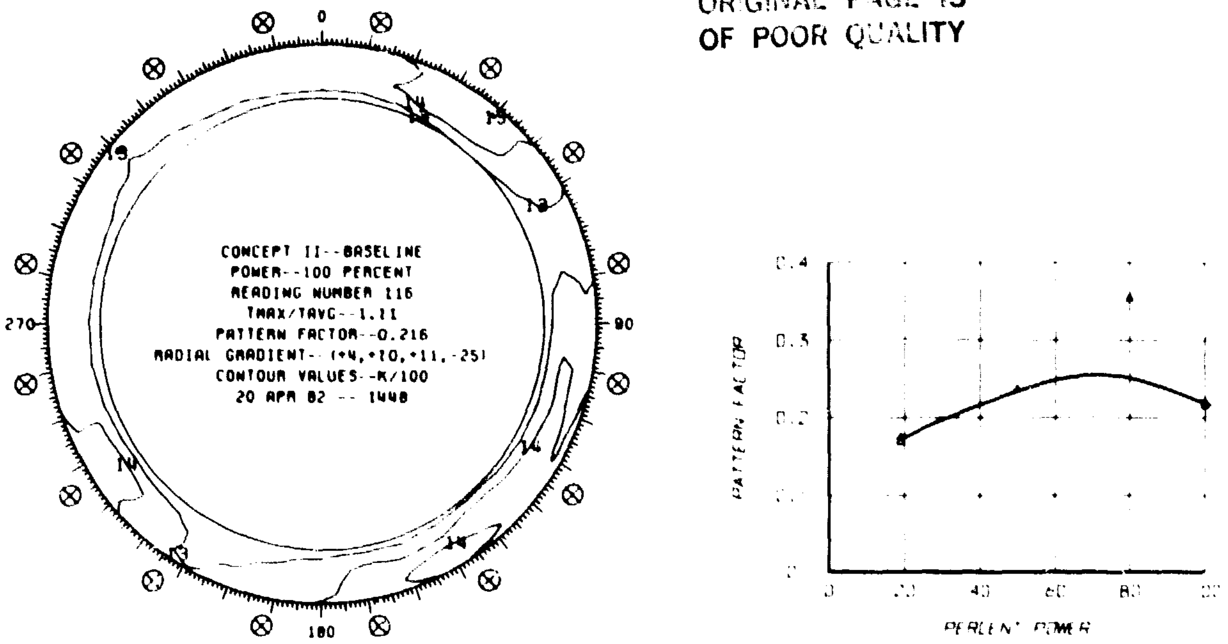

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Figure 78. Concept II, baseline, exhaust temperature pattern.

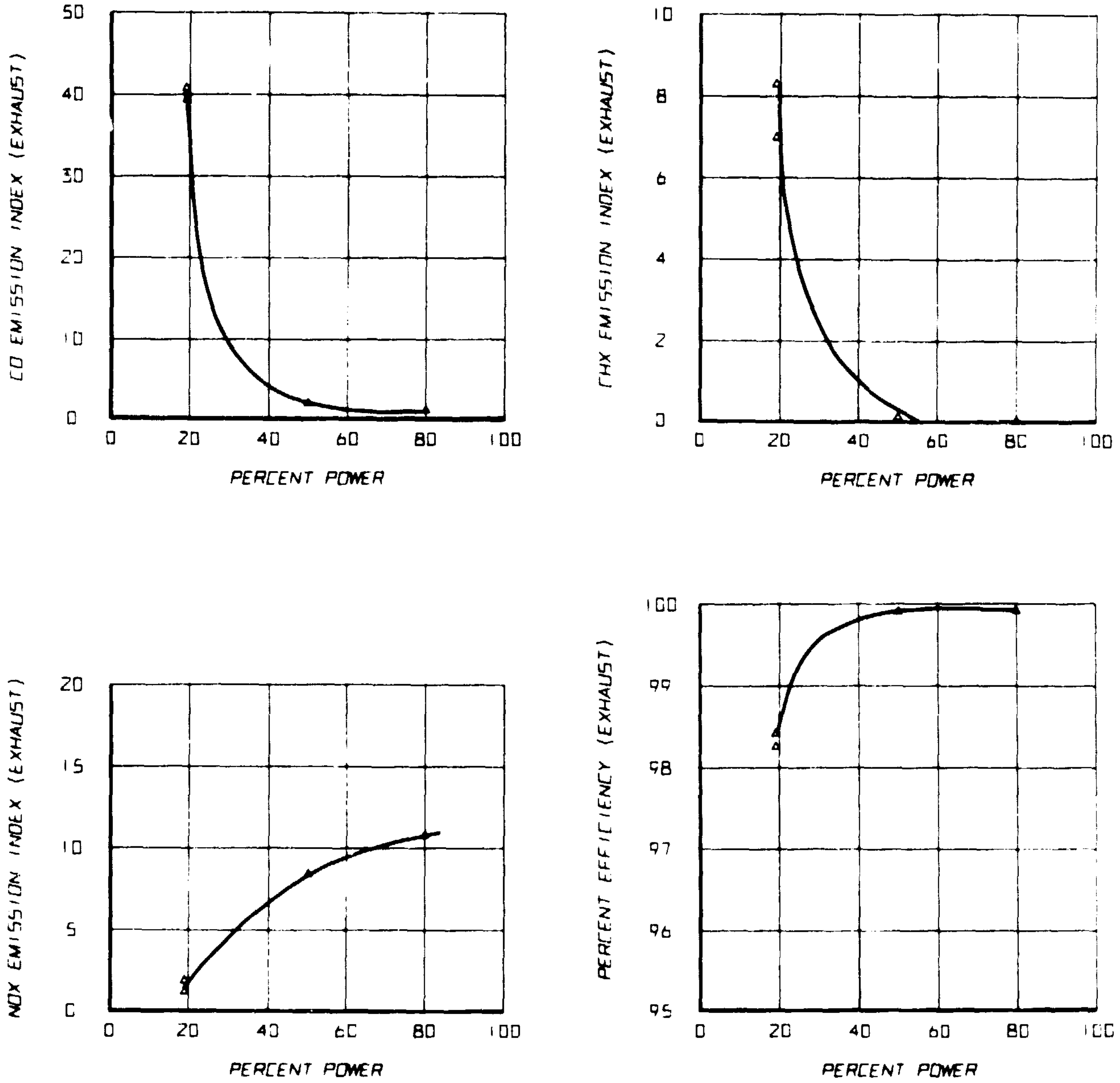

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Figure 79. Concept II, baseline, combustor exhaust emissions.

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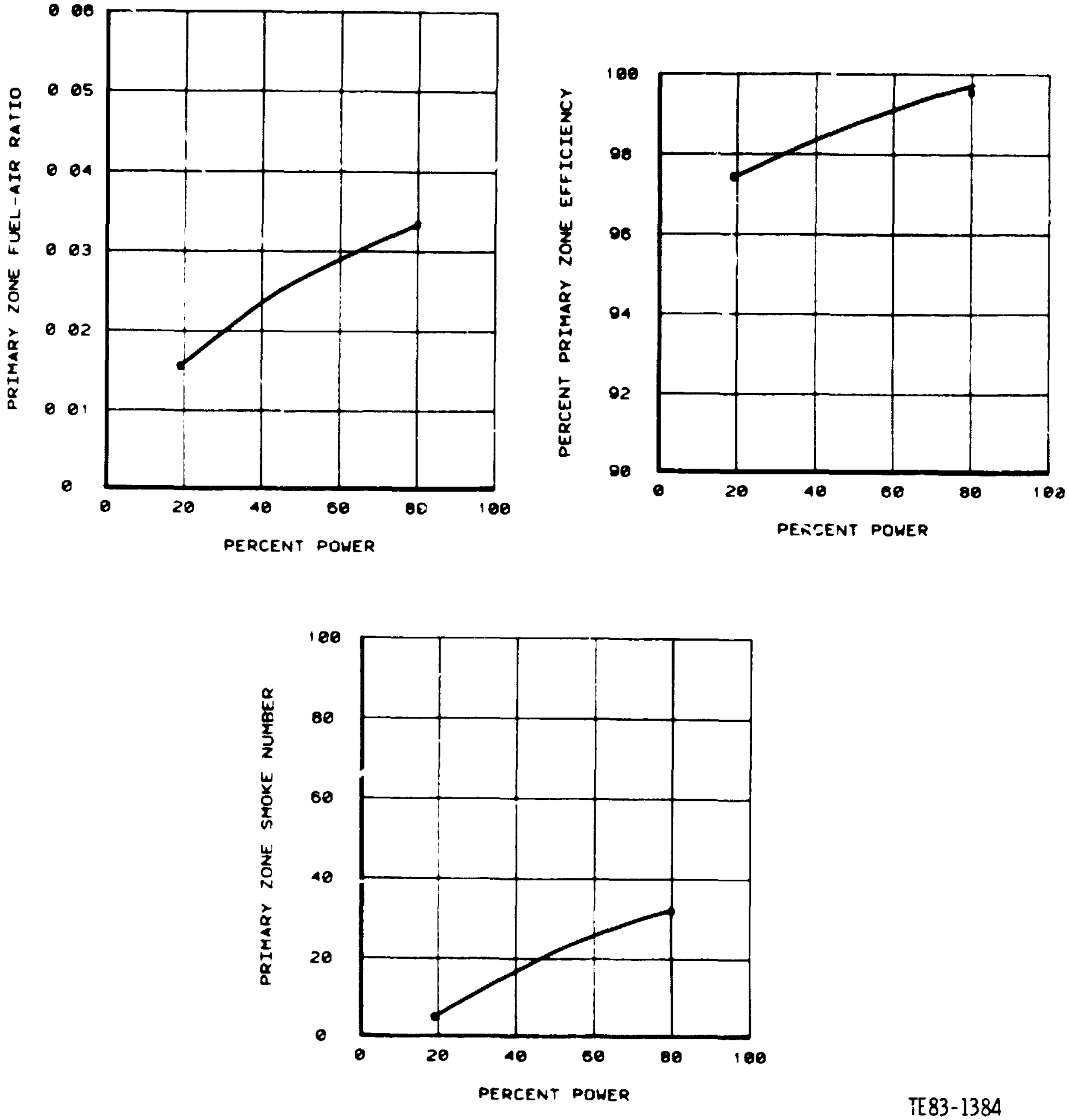

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Figure 80. Concept II, baseline, primary zone performance.

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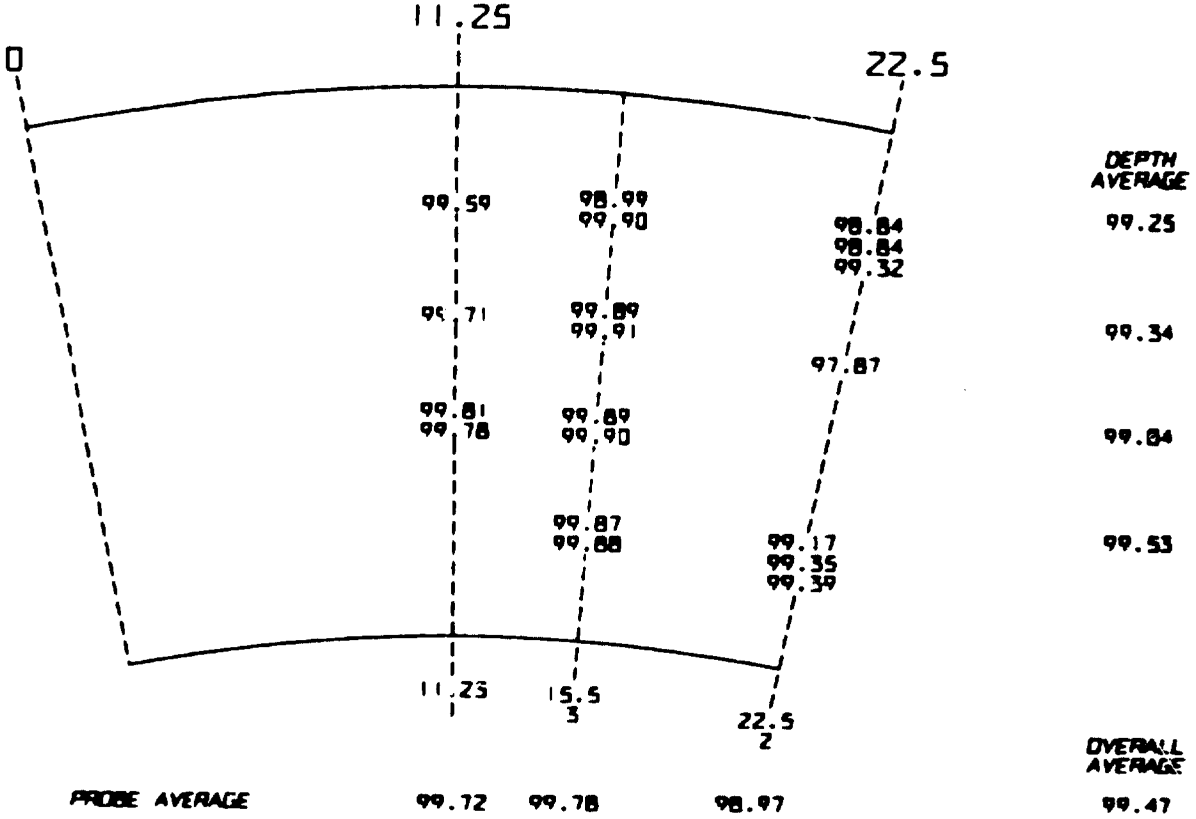
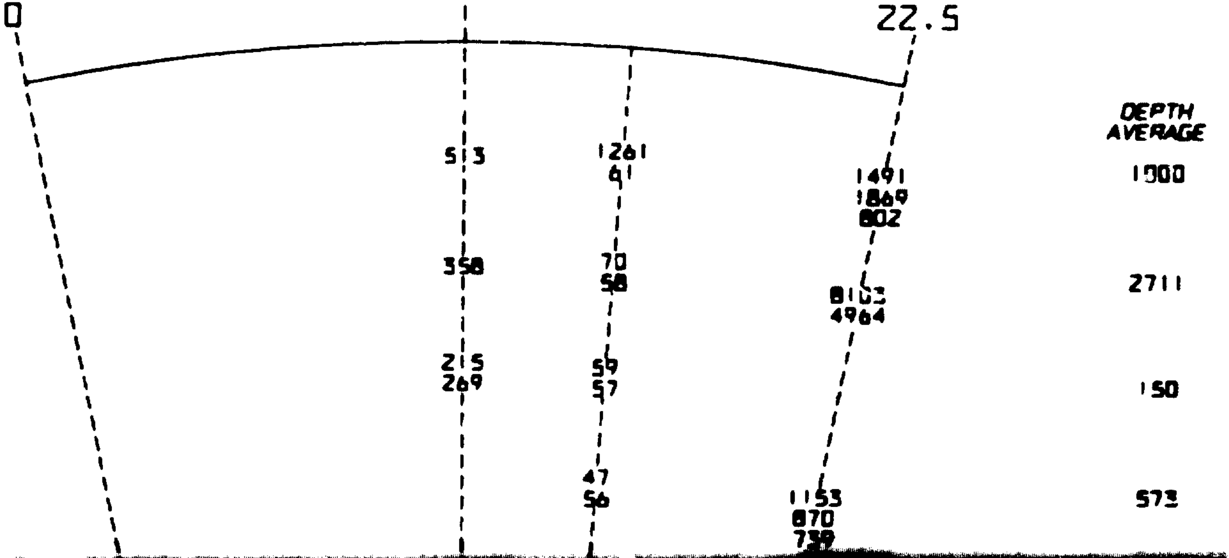
Combustion Efficiency—%



Carbon Monoxide—PPM



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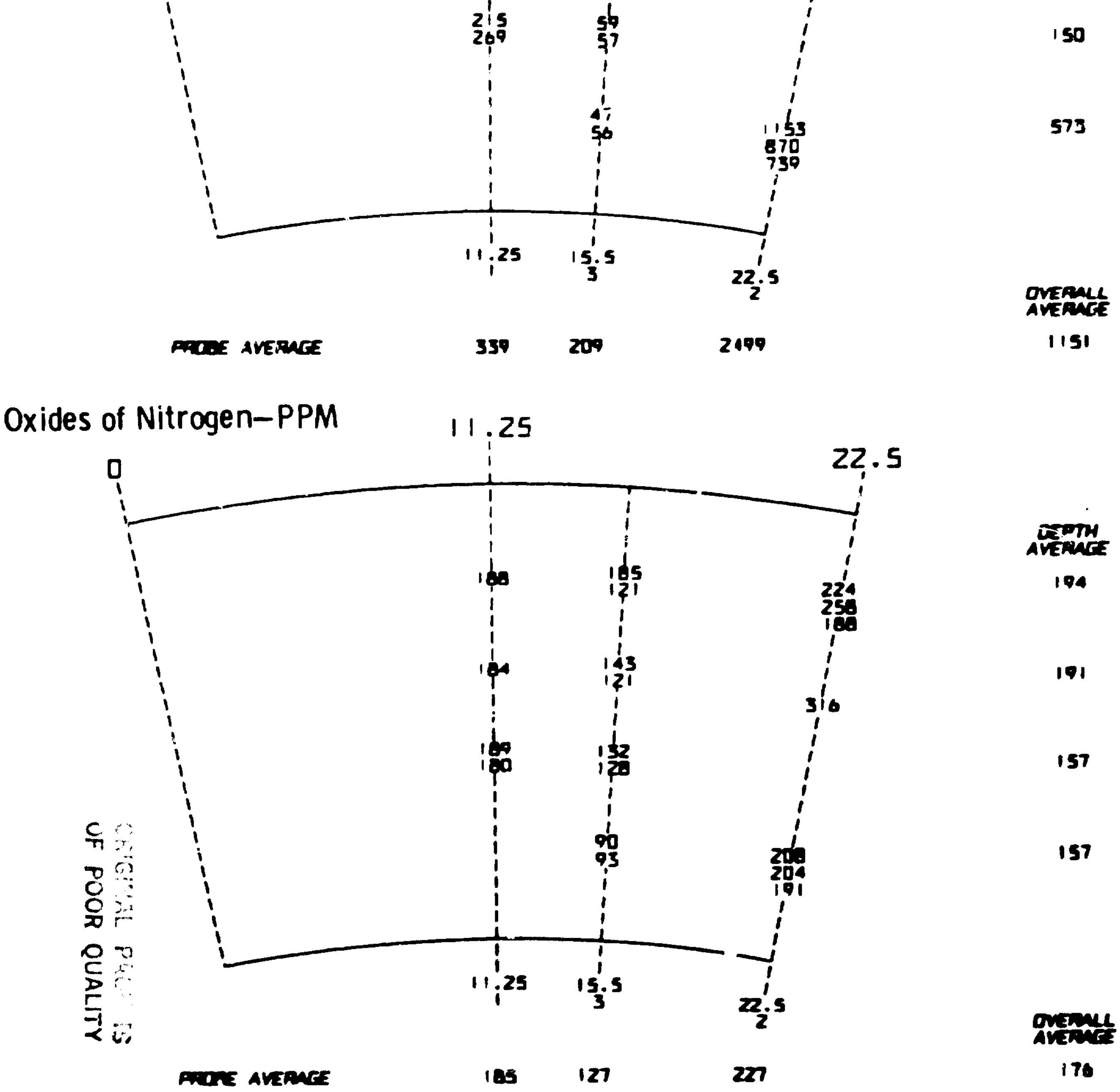

Oxides of Nitrogen—PPM

TE83-1385

Figure 81. Concept II, baseline, primary zone emissions and combustion efficiency.

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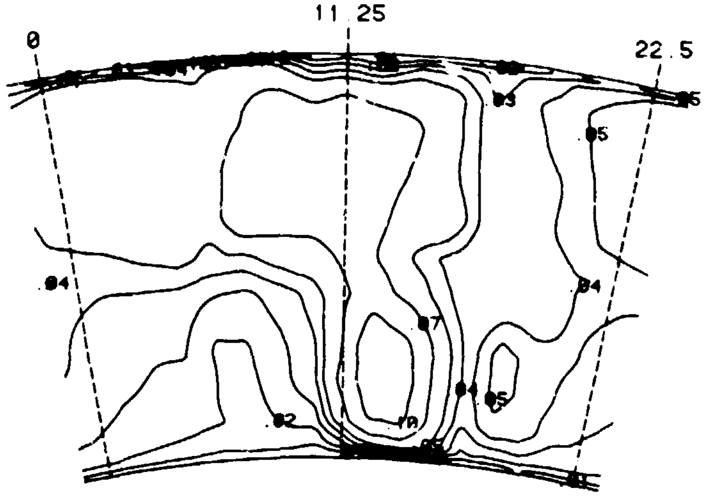
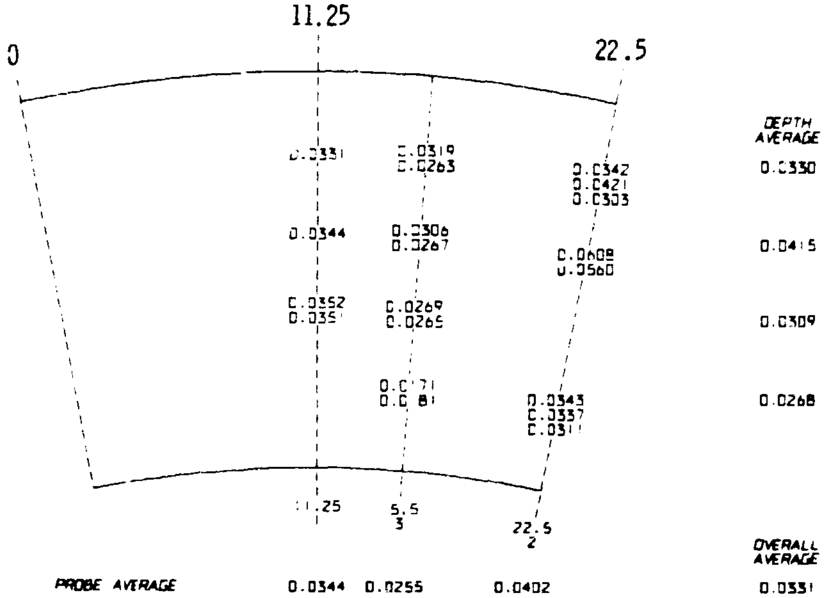


3-D Modeling Results



Test Results

TE83-1386

Figure 82. Comparison of analytical prediction and measured value of primary zone fuel-air ratio (Concept II, baseline--80% power).

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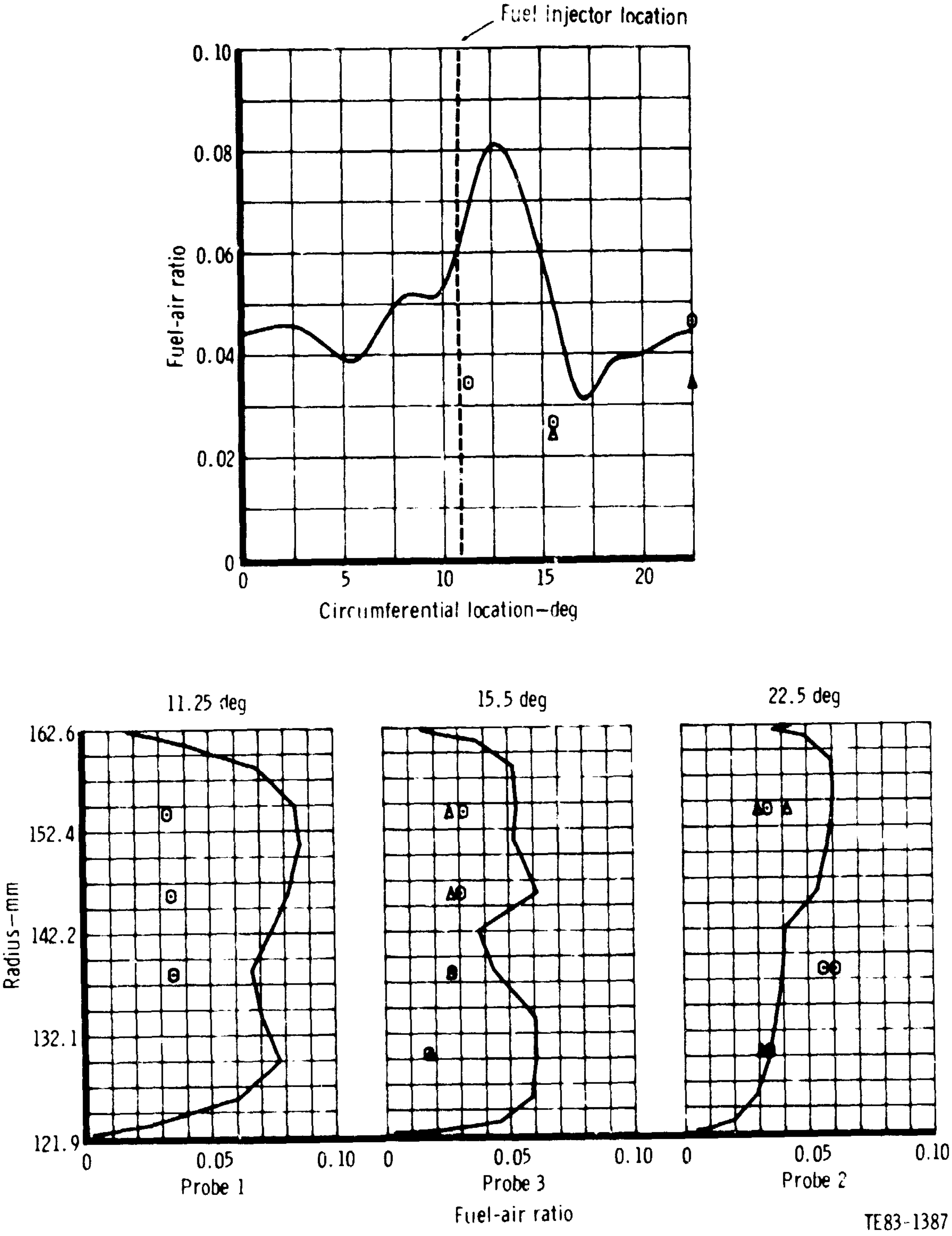
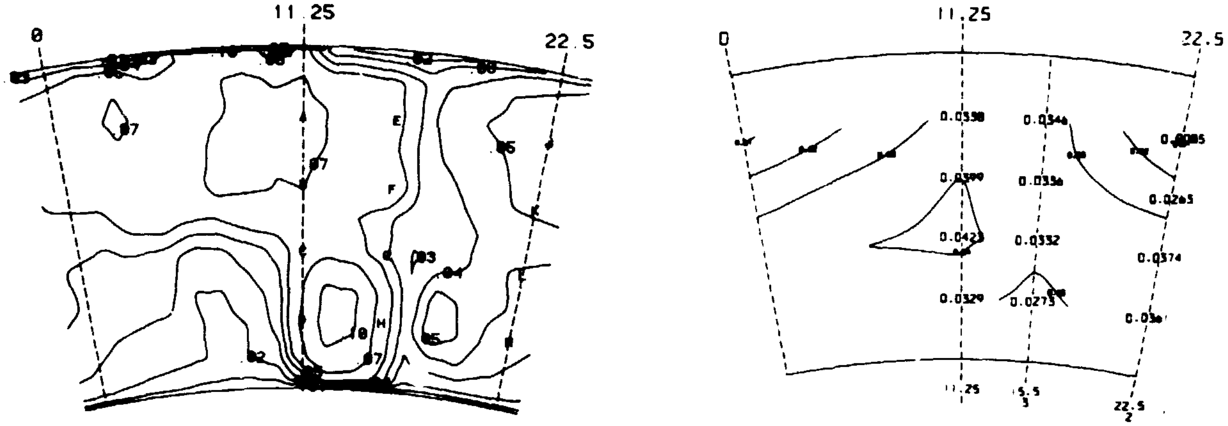
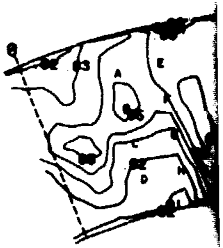


Figure 83. Concept II, baseline, analytical prediction and measured fuel-air ratios (80% power).

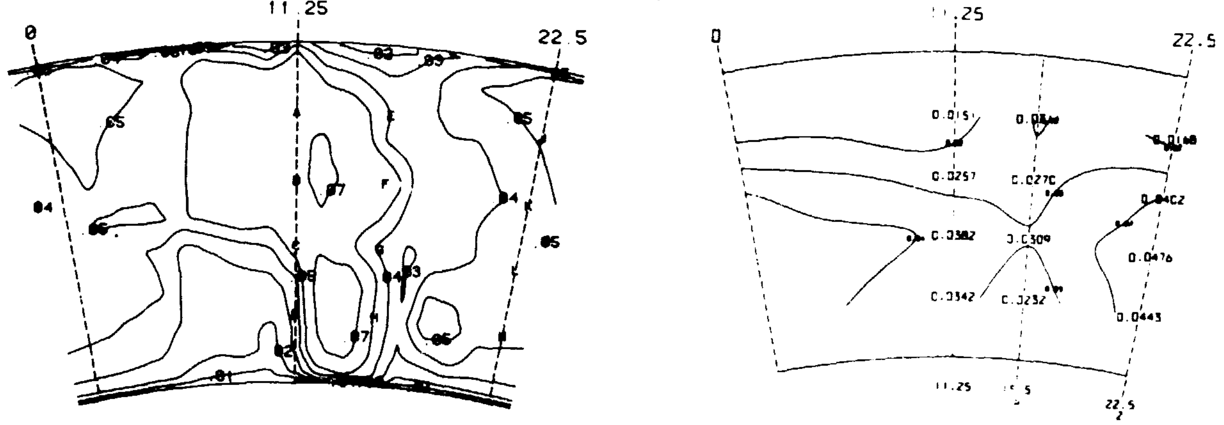
Analytical Prediction **Measured Values** **Anal**

Concept II, Mod 1





Concept II, Mod 2



Concept II, Mod 3

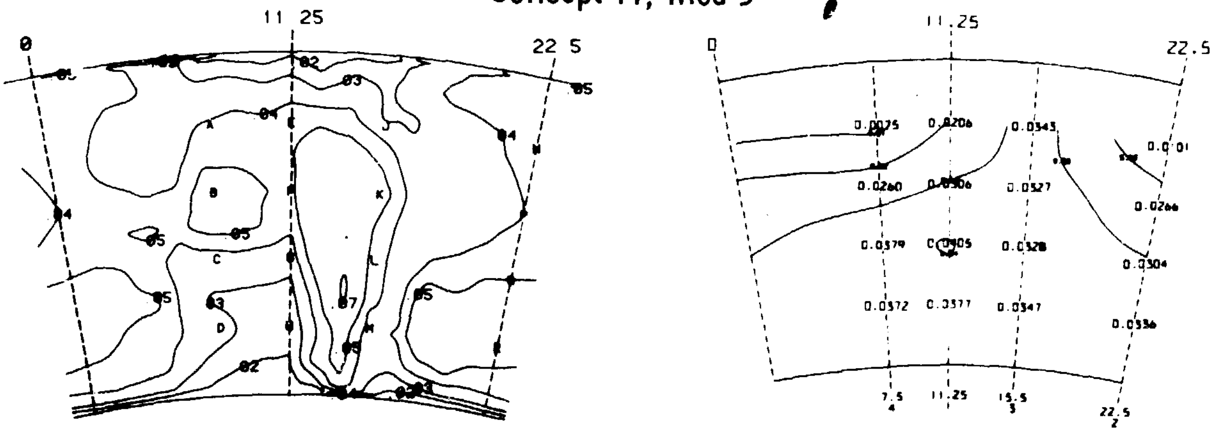


Figure 84. (
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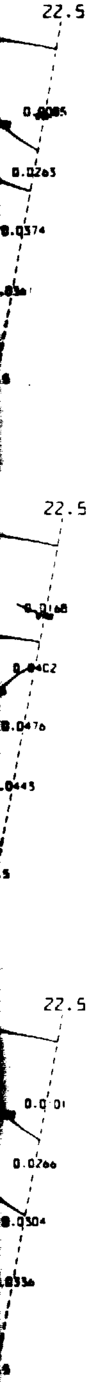

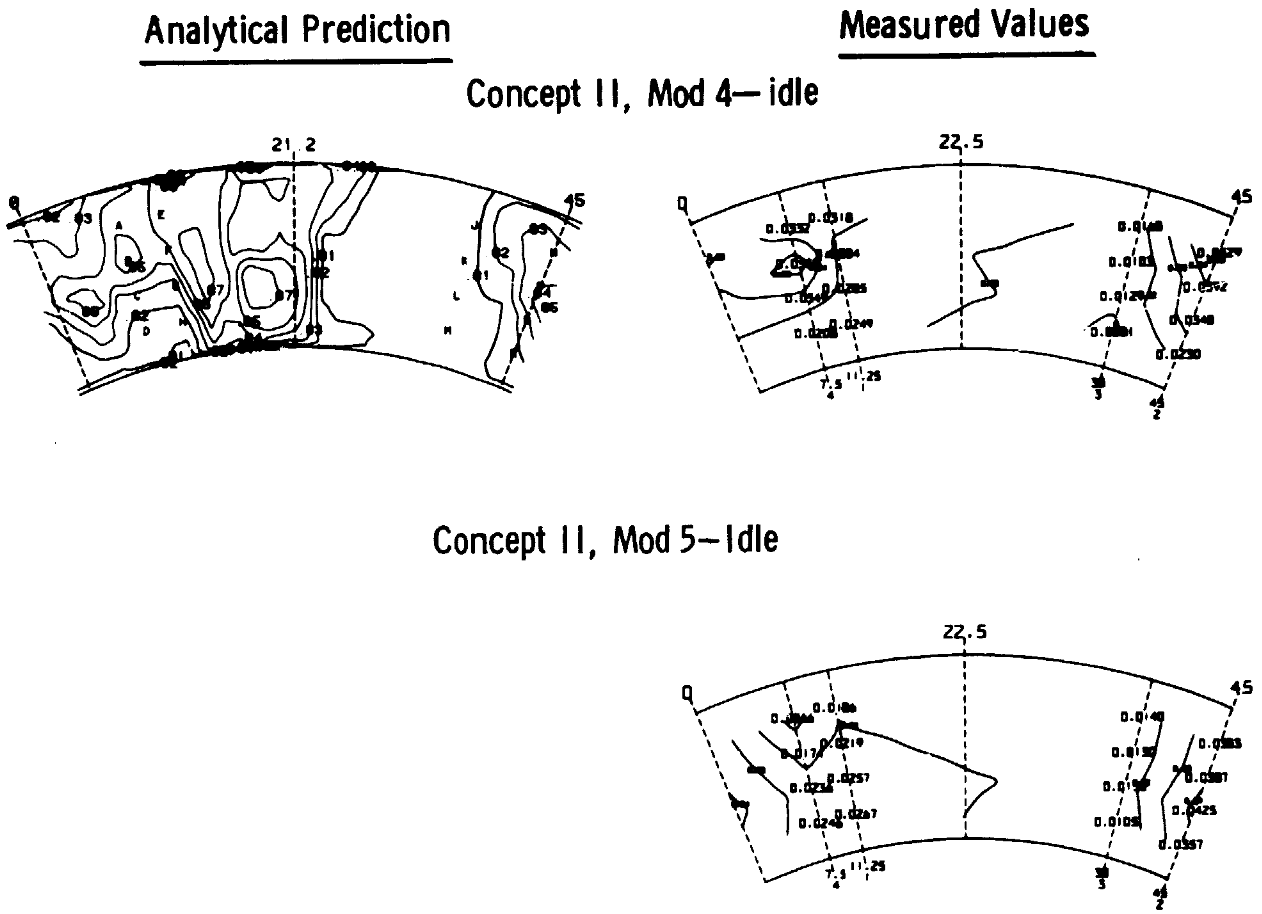

Analytical Prediction

Measured Values

Concept II, Mod 4— idle

Concept II, Mod 5—Idle

TE83-1388

Figure 84. Comparison of analytical prediction and measured values of primary zone fuel-air ratio (Concept II mods--80% power).

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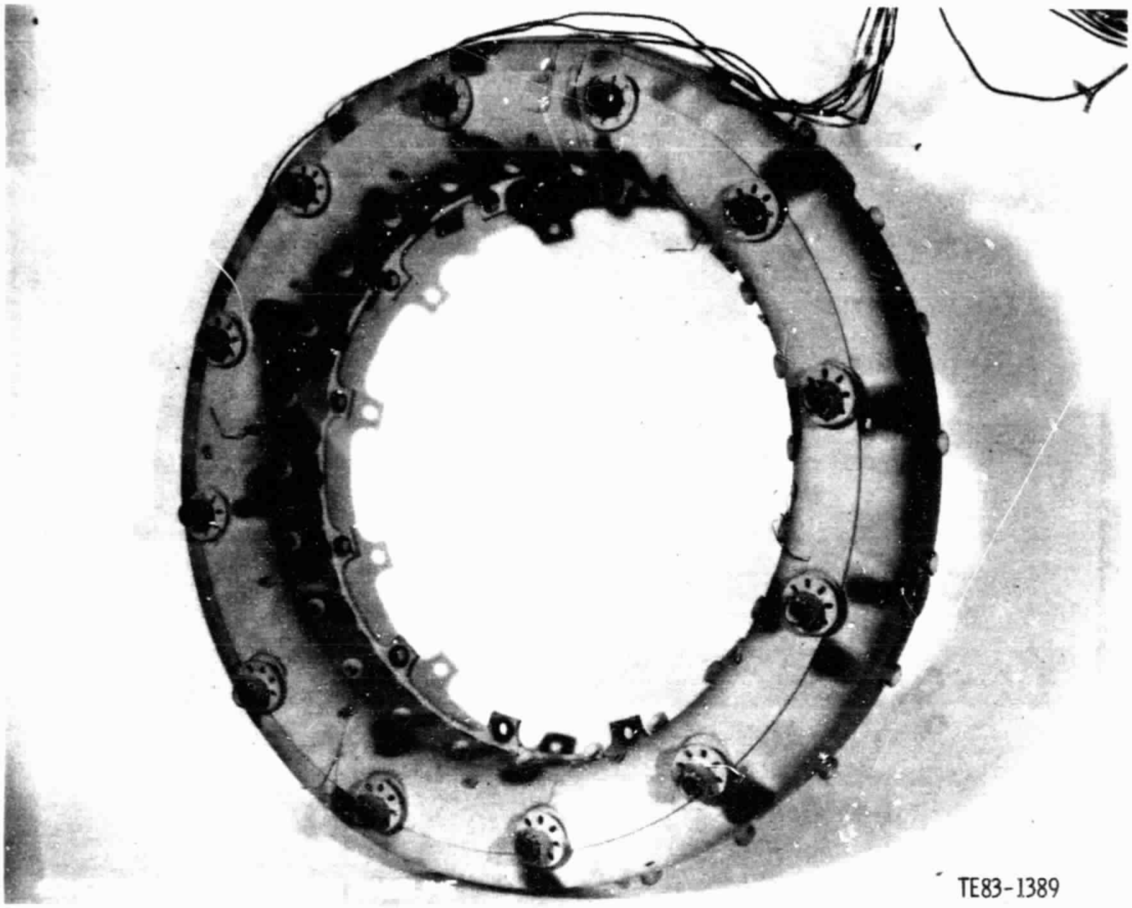

TE83-1389

Figure 85. Concept III, baseline, combustor photograph.

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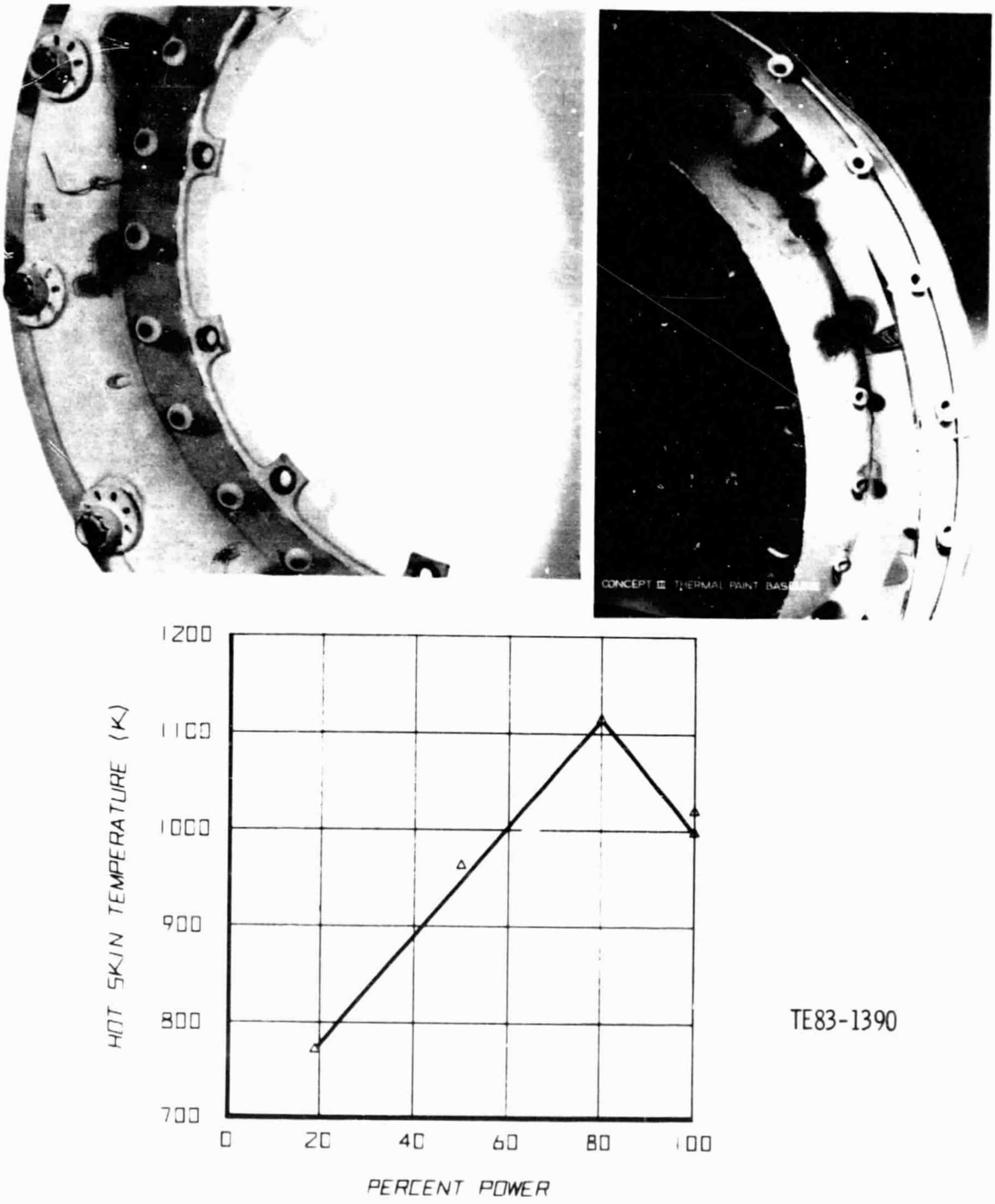

Figure 86. Concept III, baseline, wall temperature and thermal paint results.

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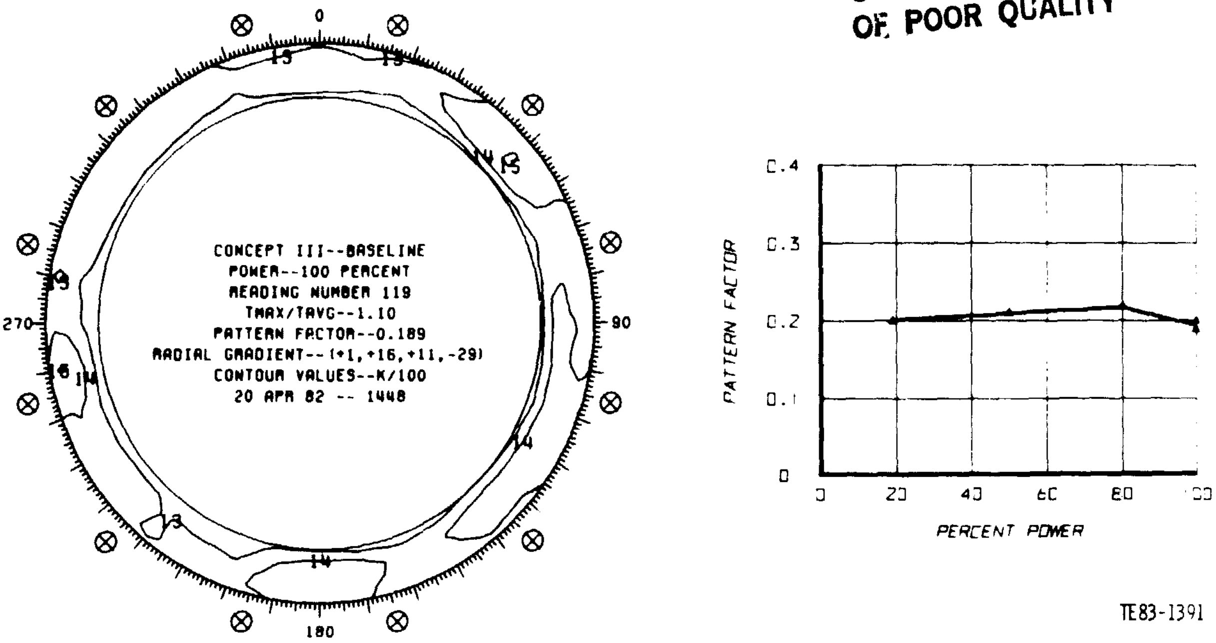


TE83-1391

Figure 87. Exhaust temperature patterns for Concept III, baseline.

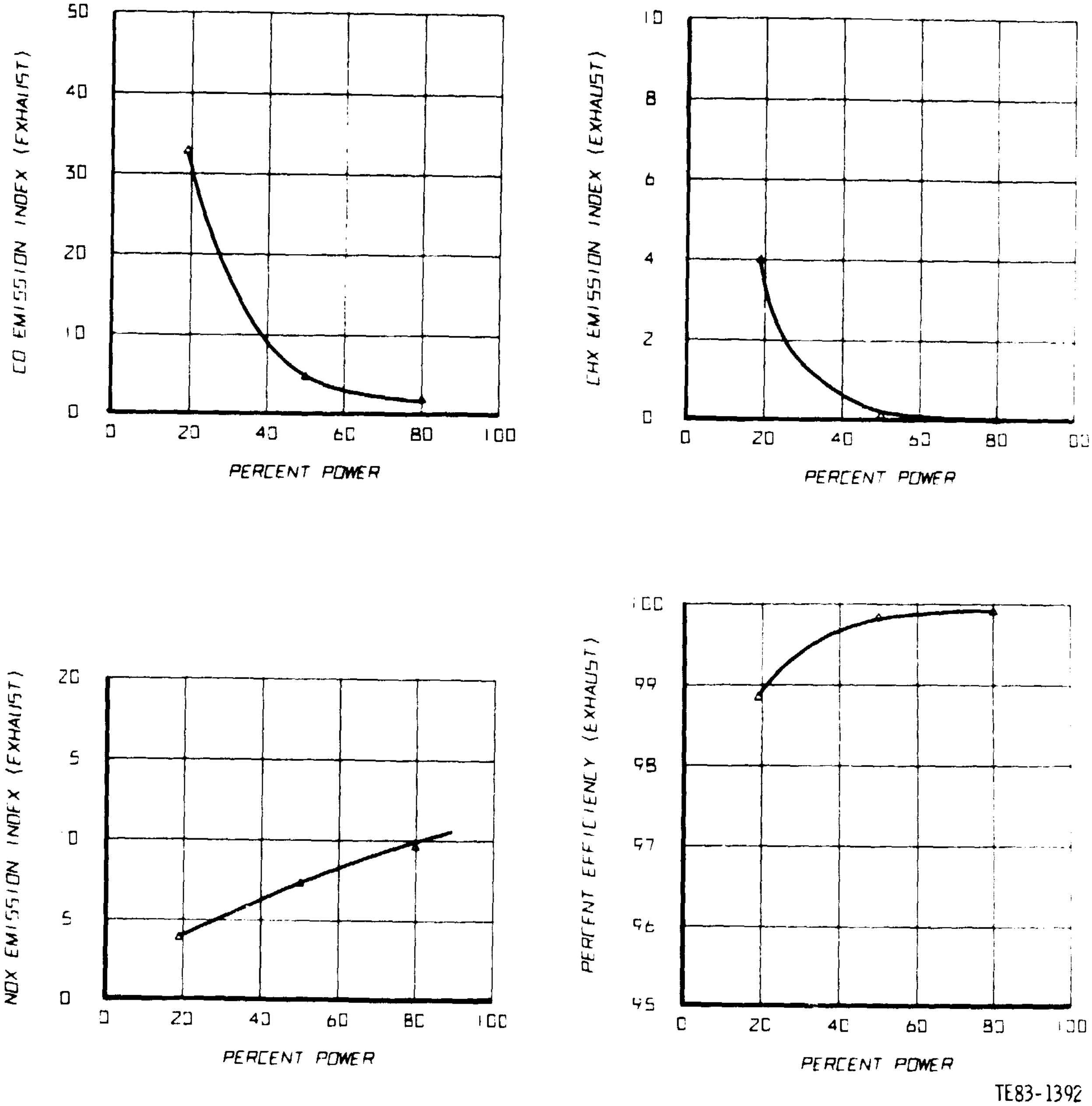
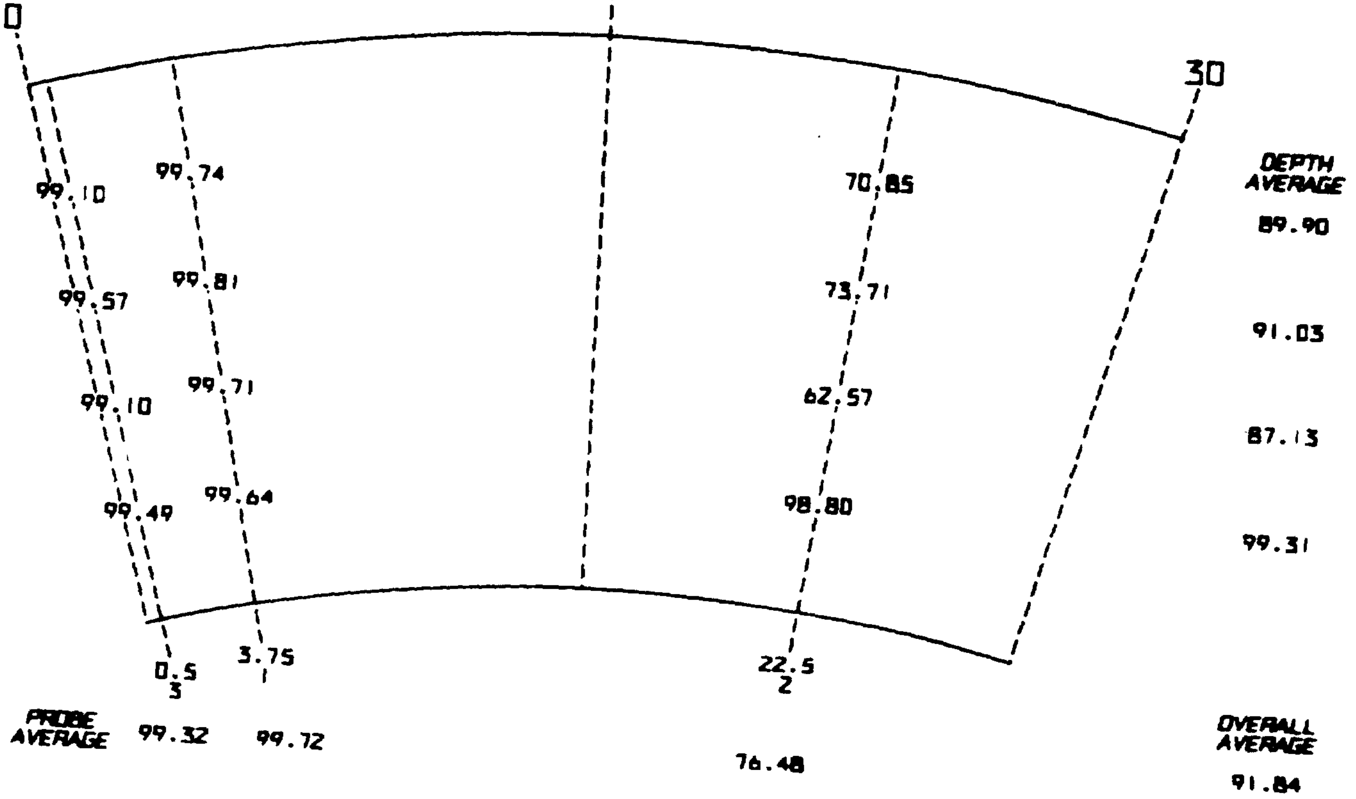
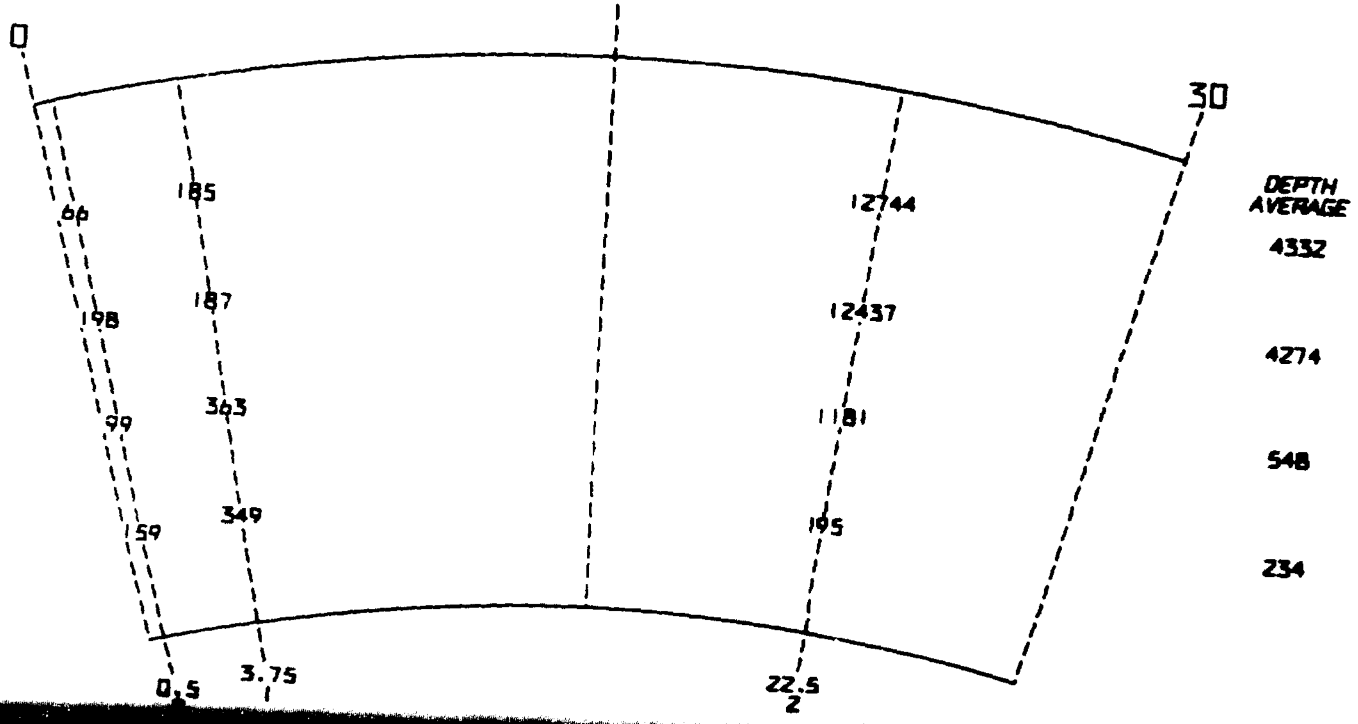


Figure 88. Combustor exhaust emission Concept III, baseline.

Combustion Efficiency—%



Carbon Monoxide—PPM



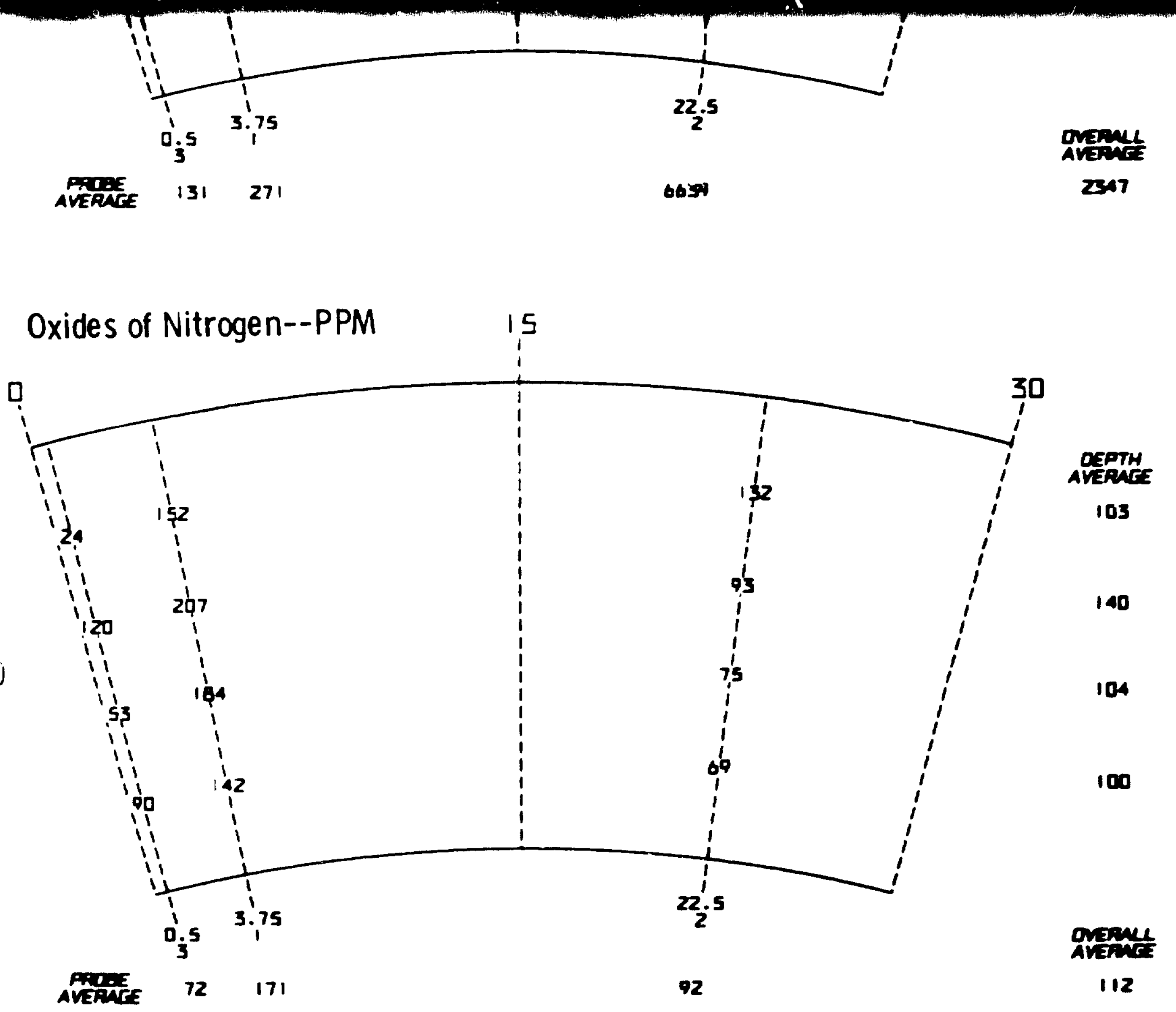


Figure 89. Primary zone sector emissions (Concept III, baseline).

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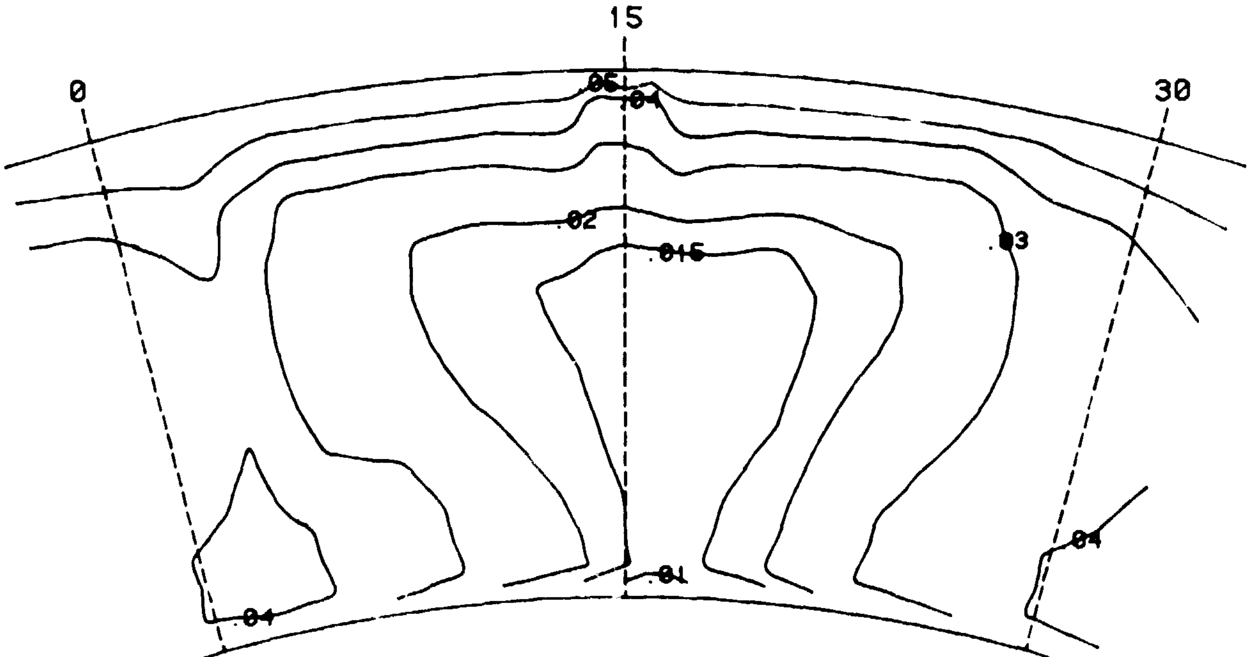
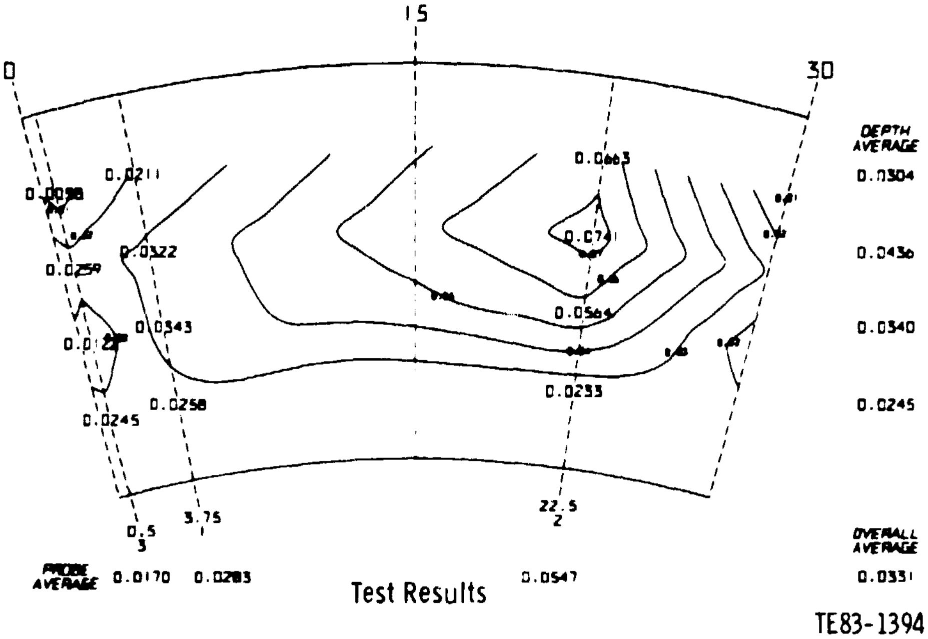
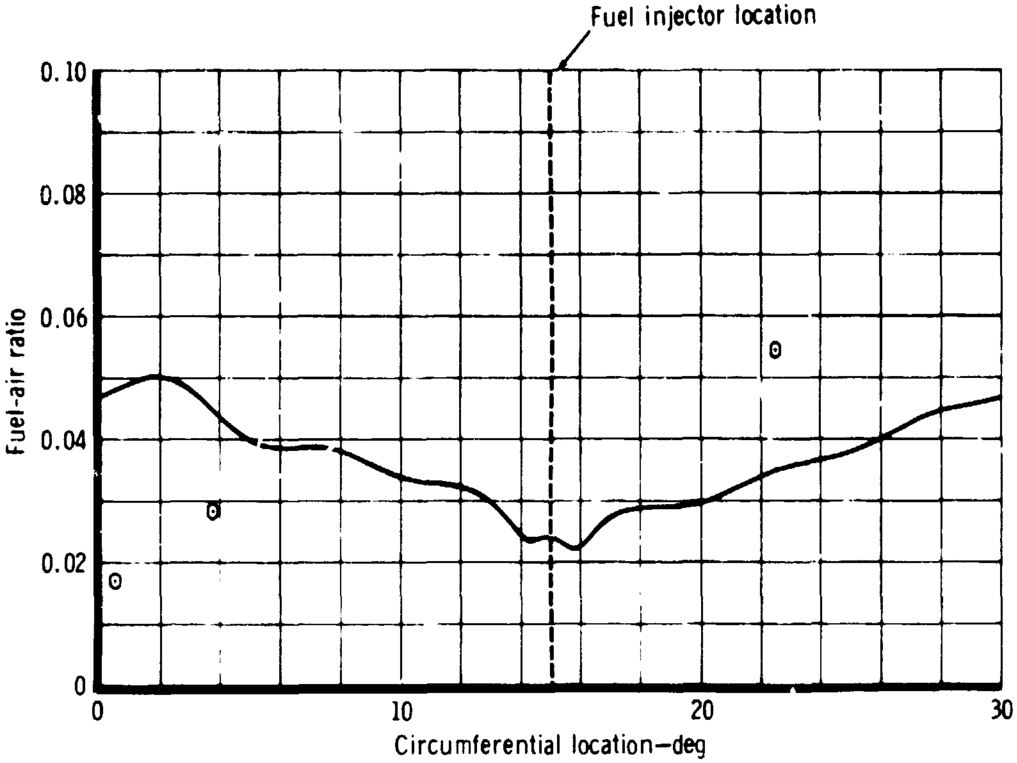


3-D Modeling Predictions



Test Results

Figure 90. Comparison of analytical prediction and measured primary zone fuel-air ratio (Concept III, baseline--80% power).



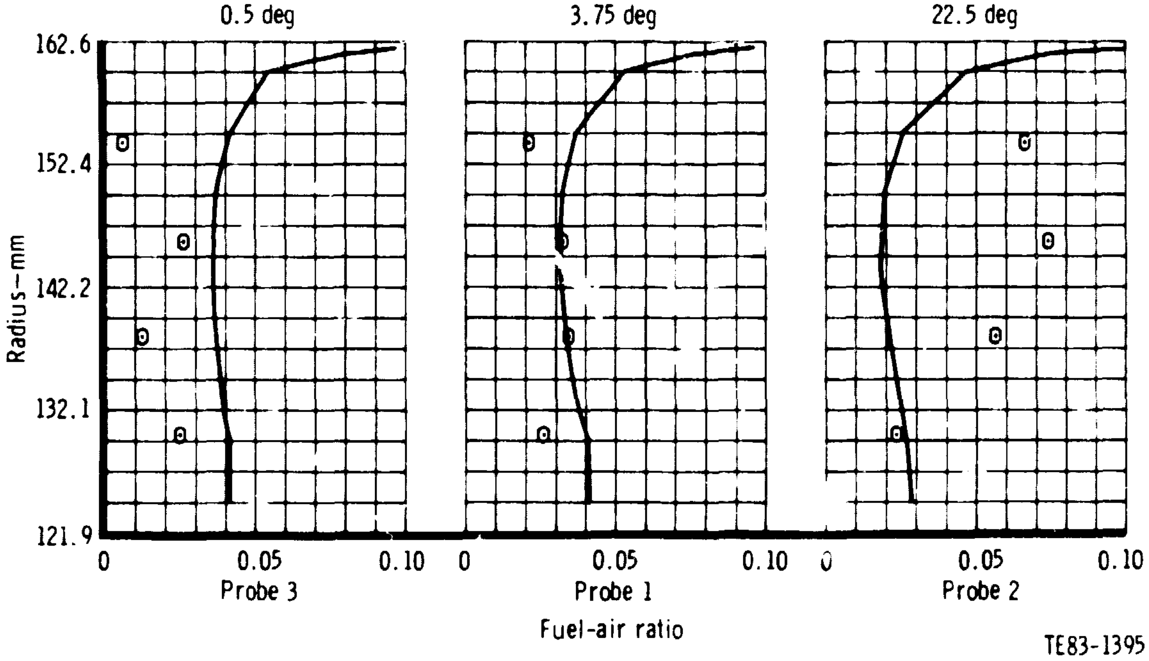
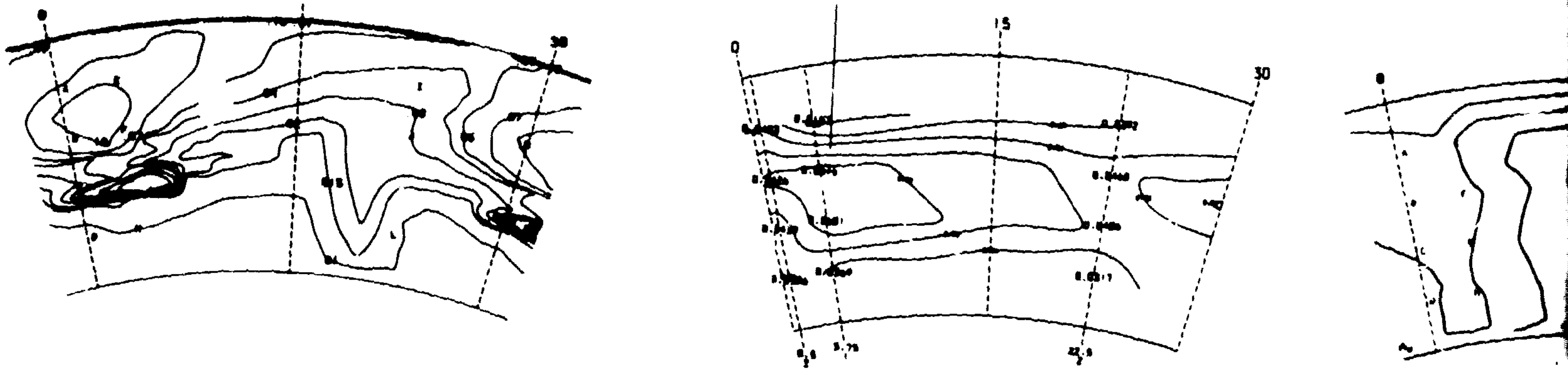


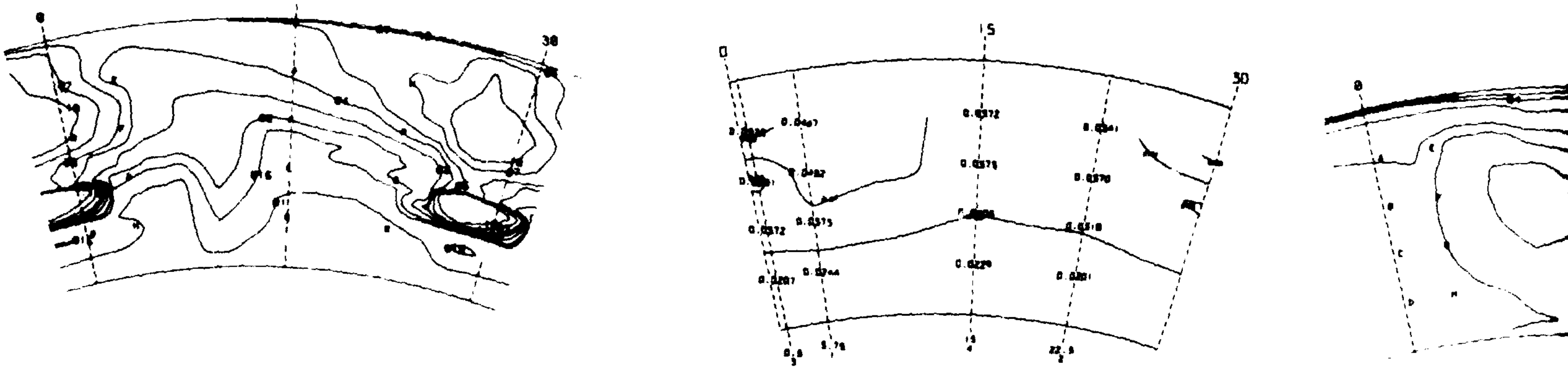
Figure 91. Comparison of analytical prediction and measured primary zone fuel-air ratio (Concept III, baseline--80% power).

Analytical Prediction **Measured Values** **Anal**

Concept III, Mod 1



Concept III, Mod 2



Concept III, Mod 3

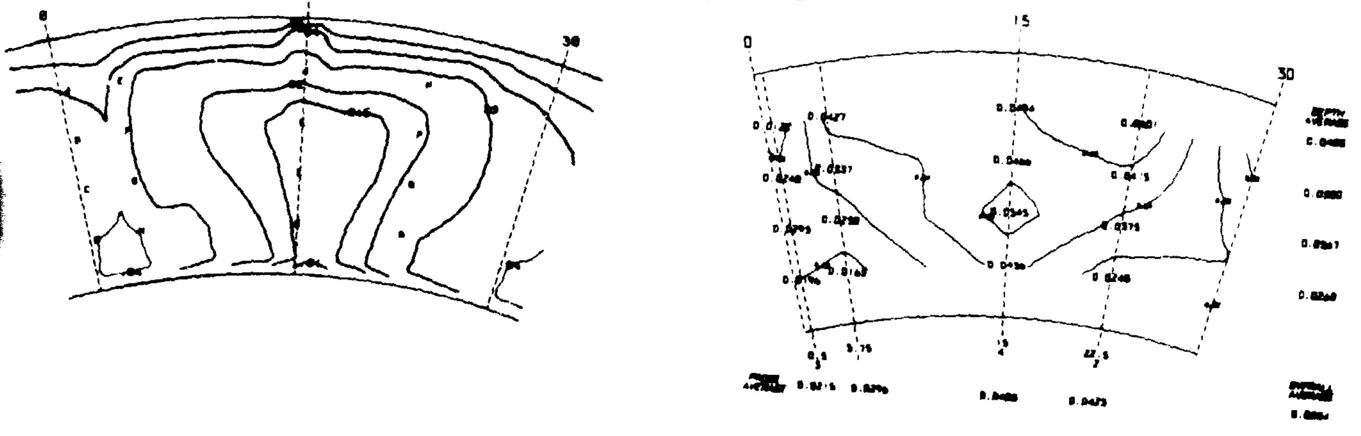
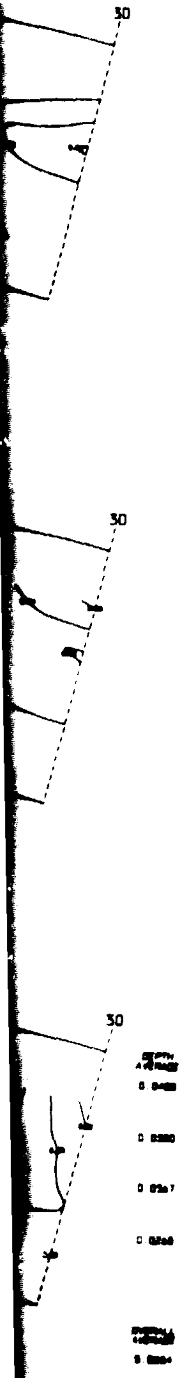


Figure 92.



Analytical Prediction **Measured Values**

Concept III, Mod 4

Concept III, Mod 5

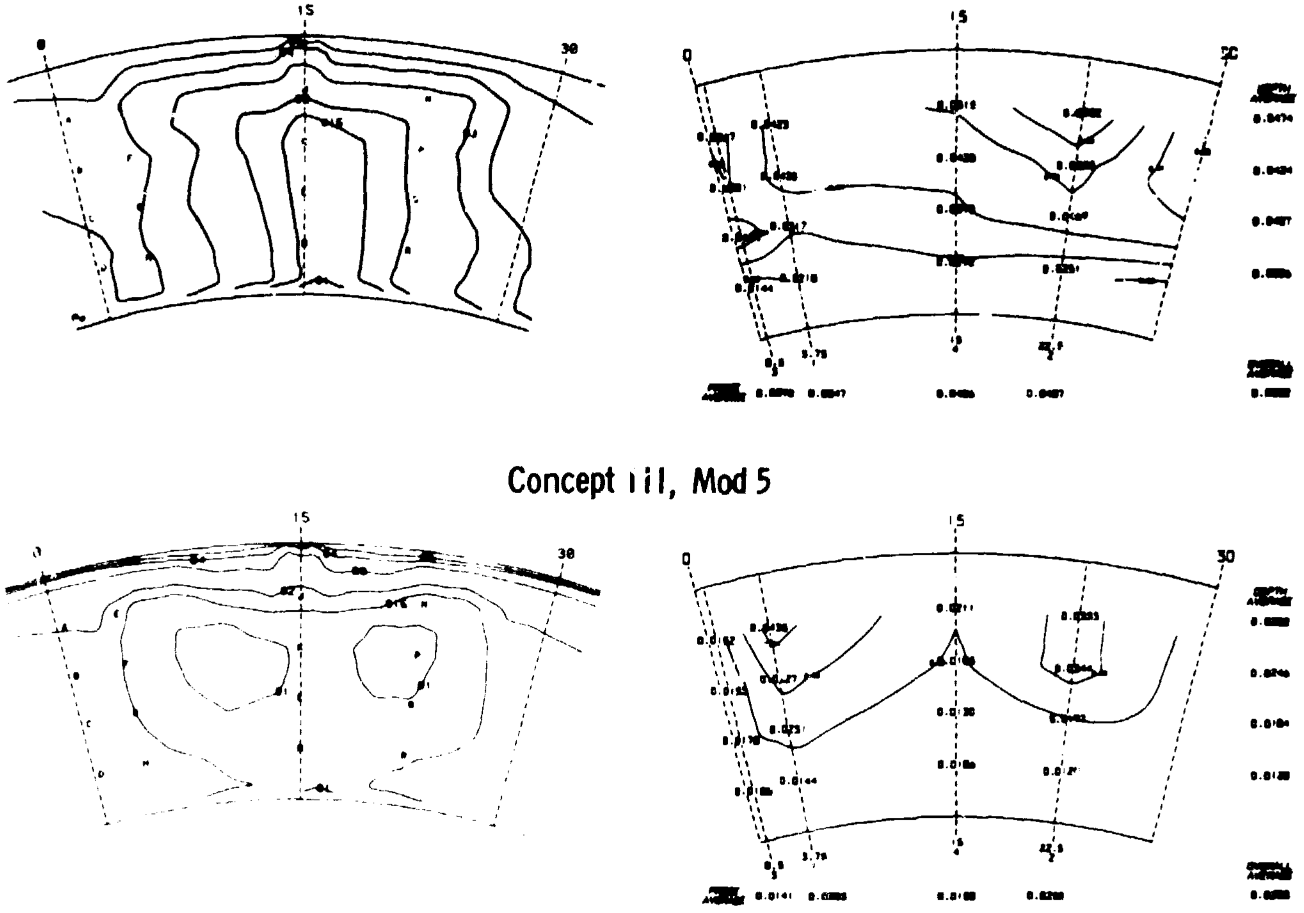


Figure 92. Comparison of analytical prediction and measured primary zone fuel-air ratio (Concept III mods).

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VII. CONCLUSIONS

Three small gas-turbine annular-combustor concepts and five modifications of each were designed, fabricated, and tested for the purpose of formulating an understanding of primary zone aerodynamics and improving the design methodology of reverse-flow annular combustors.

These combustor concepts were designed with the following features:

- o Concept I double-vortex, swirl-stabilized, primary zone
- o Concept II double-vortex, swirl-stabilized, reverse-circulation primary zone
- o Concept III single-vortex primary zone

The MARC-I three-dimensional aerodynamic combustor flow-field model was modified to adapt to the distinctive features of these three primary zone concepts. The combustor geometric features incorporated in this model include the following:

- o prechambers
- o internal walls
- o rounded dome walls
- o axial dome swirlers
- o vertical dome slots
- o slanted liner entries
- o reverse cooling slots

From the analytical modeling and testing of the eighteen combustor configurations the following conclusions can be drawn:

- o The analytical model as modified and updated has provided a useful tool in designing and analyzing test results from this program.

- o The primary zone gas sampling probes, designed and fabricated for this study, were satisfactory in all aspects. Utilizing these probes, CO, CO_2, NO_x, and UHC and smoke emissions were obtained for all combustor configurations.

- o The three primary zone concepts, designed with the aid of the analytical model, demonstrated excellent performance in the following areas:

  - o exhaust temperature pattern
  - o low exhaust smoke
  - o cool liner walls
  - o high combustion efficiency
  - o wide combustion limits

- o The correlation of primary zone predicted with the measured fuel-air ratio contours demonstrated the usefulness of the analytical model as an aid to the combustion designer.

- o Additional model development is needed to define completely new designs having geometric features that depart from conventional internal flow patterns.

STATUS OF 3-D COMBUSTION MODEL

Several factors are believed to be responsible for those cases when the correlation between the analytical model and actual fuel-air measurements was less than satisfactory. First the experimental measurements were made at discrete probe locations while the analytical model computed values across the entire combustor cross section. In addition, some simplifying boundary condition assumptions undoubtedly affected the analytical results. For example, Lamilloy air was assumed to enter as cooling slot air parallel to the walls. Beyond these items the three-dimensional combustion model has been found to be deficient in several phiso-chemical areas. These deficiencies are not due to numerical techniques but rather to real deficiencies in the submodels used to describe physical and chemical phenomena. These areas in which deficiencies occur are the following:

1. Prechambers on annular section

   Up to the present time all reacting 3-D codes treat the prechamber as part of the annular combustor and attempt to analyze the flow field within this circular can with the coordinates used for the annular sector. Since the coordinates for the entire combustor originate at the centerline of the sector, the circular prechamber is approximated by a polygon. Detailed analysis comparing prechambers analyzed by body-centered coordinates and those analyzed by fine-grid sector coordinates reveals some discrepancies. The correct computation of angular momentum from both axial and, if present, radial air swirlers incorporated in prechambers is extremely sensitive to the coordinate system describing the boundary condition of the prechamber. Deviations from true circular boundary conditions introduce steps such as those resulting from a multisided polygon. A portion of the circulating flow impinges on these steps and creates an overpressure which propagates toward the center of the circulating flow. The net effect of this overpressure is to reduce the angular momentum to a level much lower than that which could be caused by the action of viscous forces within a circular can.

   The approach to rectify any possible discrepancy that may disturb the actual flow-field computation is to integrate a body-centered circular coordinate system describing the prechamber can with that describing the body-centered coordinates of the sector.

2. Droplet fuel spray heating. Vaporization and drag, and subsequent micro-mixing and chemically kinetic limited combustion of the fuel vapor

   The latest published versions of 3-D models contain at best an initial spray size distribution subprogram. Usually this takes the form of the Rosin-Rammler distribution, a correlation which is generally considered to be adequate. However, subsequent droplet dynamics are treated in a totally simplistic and incorrect manner. Modern well-designed gas turbine combustors are generally believed to be evaporation rate limited. At the high pressures, temperatures, and convective conditions involved, both chemical kinetic and mixing rates are high compared with those of spray evaporation. All present 3-D codes, including MARC-1, only partially recognize this fact. Following spray evaporation, the source term for the rate of oxidation of the fuel is determined by the minimum of the rate of fuel oxidation as controlled by chemical kinetics or eddy-breakup mixing. This latter mixing term is dependent upon the level of turbulence and fuel vapor and/or oxygen concentration. In almost all cases the rate of oxidation of the fuel must be artificially slowed by choosing the latter minimum rate method involving mixing. Detailed analysis of droplet evaporation under convection conditions indicates that the time for the droplet to evaporate is slow compared to the time for fuel vapor and air to mix in the droplet wake. Clearly, the existing 3-D models appear to be overpredicting the rate of evaporation of the spray.

During droplet heat-up to the wet bulb temperature no evaporation is allowed. As soon as the wet bulb temperature is reached, the vaporization rate is set equal to its maximum rate. But this step function approach is a gross oversimplification. Over wide ranges of operating conditions the heat-up period represents an appreciable portion of the total drop evaporation time. This is especially true for high gas pressures and temperatures where all but the smallest droplets fail to attain their wet bulb temperature and, hence, their maximum steady-state evaporation rate during their lifetime.

The result of the existing droplet evaporation model is to considerably overpredict the evaporation rate. The effects of this overprediction propagate throughout the entire solution domain. The droplet diameter and, hence, droplet mass are underpredicted, with the consequence that the droplet trajectory is not proper evaluated. This affects the calculated distribution of fuel-air ratio, temperature, chemical kinetics, and species concentration. The error is tempered somewhat in all present models by the artificial reduction of the apparent evaporation rate through the use of the mixing model. But, while overall performance and pattern factor predictions may be only slightly changed, local primary zone temperature profiles and chemical kinetics can be substantially affected.

As a consequence of these effects, detailed droplet dynamic models are being evaluated in a separate NASA program (Analytical Fuel Property Effects--Small Combustor, NASA Contract NAS3-23165) and the best of these will be used to replace the existing droplet dynamics package within MARC-1. It is anticipated that incorporation of such a model will remove the need for MARC-1 to rely so heavily upon artificial techniques to properly predict the combustion rate of the fuel.

3. Fuel insertion modeling--dual orifice and airblast type injectors

The phenomena described above with regard to droplet dynamic effects on model predictions are extremely important. But replacement of the current droplet dynamic package with an improved submodel still requires precise boundary conditions regarding the initial fuel placement. Better dual orifice and airblast fuel insertion models are required in order that the improved droplet dynamics submodel can accurately predict fuel-air ratio distributions, etc. Work on such models is presently being initiated.

All of the deficiencies described in the paragraphs above are well understood, many as a result of the investigations conducted under this program. Contractual and/or IR&D effort is presently underway to eliminate these problems from MARC-1.

APPENDIX A

PRIMARY ZONE ADDENDUM PROGRAM

The single-torus primary zone combustor (Concept III) demonstrated the potential for reducing the number of fuel nozzles in a small annular combustor. Therefore this combustor concept was selected for additional evaluation in a program addendum. This design, shown in Figure 93, reduced the number of fuel nozzles from 16 to 12, which increased the spacing-to-height ratio from 1.4 to 1.8. The principle of this concept departed from the dual-vortex, conventional flame stabilization methods by establishing a larger single torus in the primary zone. Features of this design were as follows:

- torus directionally aligned with annulus airflow
- fuel entry tangential and opposed to torus
- film cooling upstream on one side and downstream on the other
- variable fuel directing tubes
- fewer fuel nozzles

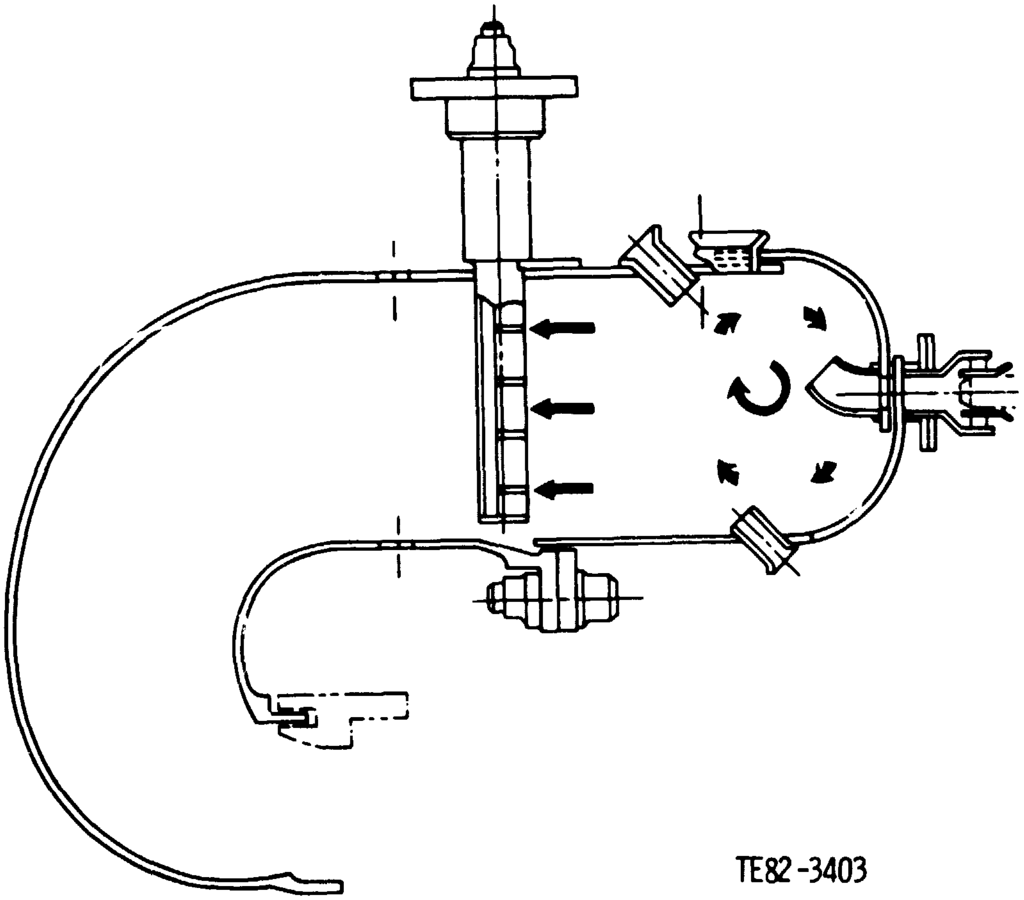


Figure 93. Concept III combustor--single torus selected for addendum to primary zone study.

The major aerodynamic feature of this design was the increased residence time in the primary zone established by the single reversal pattern. This provided the potential for improved vaporization of the fuel droplets and for more complete combustion reaction.

The three additional modifications selected for the contract addendum included two aerodynamic configurations and one fuel placement configuration. The design changes were made to provide a more uniform fuel-air mixture to avoid fuel impingement on the liner walls and to introduce the fuel at an optimum location that provided the best vaporization path for improved combustion performance.

Modifications to alter the primary zone aerodynamic flow patterns are shown in Figures 94 and 95. In Figure 94 the primary zone air bushings in the outer combustor liner were positioned circumferentially on either side of the fuel nozzle centerline, while on the inner liner wall a larger single air bushing was aligned with the fuel nozzle. The air bushing was located axially near the fuel nozzle to disperse the fuel spray into two patterns emanating from a single fuel nozzle source. The second aerodynamic modification, shown in Figure 95, was a similar concept, but the inner bushings were moved axially downstream to allow more time for the development of the fuel spray prior to introducing the jet flow. Experience has shown that care must be taken when directing air jets near the spray injection point. Combustion instability, noise, or flame quenching are possible results of early air admission. The size and jet angles used were dictated by the predictions from the MARC-1 3-D model.

The third Concept III combustion system modification involved a change to the fuel direction tubes, as shown in Figure 96. The evaluations made during the basic program demonstrated the potential for improved performance from fuel placement techniques. For this modification, the fuel directing tube was capped off and two fuel exit holes were directed in opposed circumferential directions from each fuel nozzle source. In this manner, the fuel spray gave more uniform fuel-air coverage between fuel injection points; this design also provided a means of preventing fuel from impinging on the combustor walls.

ANALYTICAL RESULTS

Concept III mods A1, A2, and A3 were analyzed with the three-dimensional combustor model described in Section III. For each modification the 3-D model generated plots of fuel-air ratio in the primary zone at various radial planes so that the interaction of the fuel spray and the combustion air could be studied. Figure 97 shows the predicted fuel-air ratio in the primary zone both on sector presentation and an average circumferential plot per fuel injector sector for all three design configurations. In all mods it was predicted that the inner wall primary air jets would produce a low fuel-air ratio region in its wake. Mod A3, which featured bifurcated fuel tubes, responded with high fuel concentrations on each side of the fuel injector location. While all designs of Concept III exhibit the tendency for high fuel-air ratios at the outer wall and low ratios at the inner wall, the predictions for mod A3 indicated a lower gradient than the other designs.

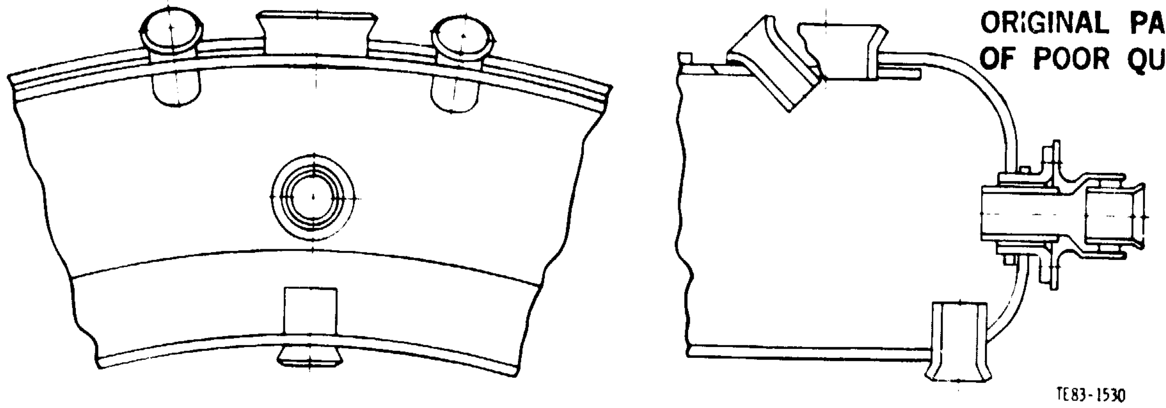


Figure 94. Concept III, mod A1, combustor (short fuel tube).

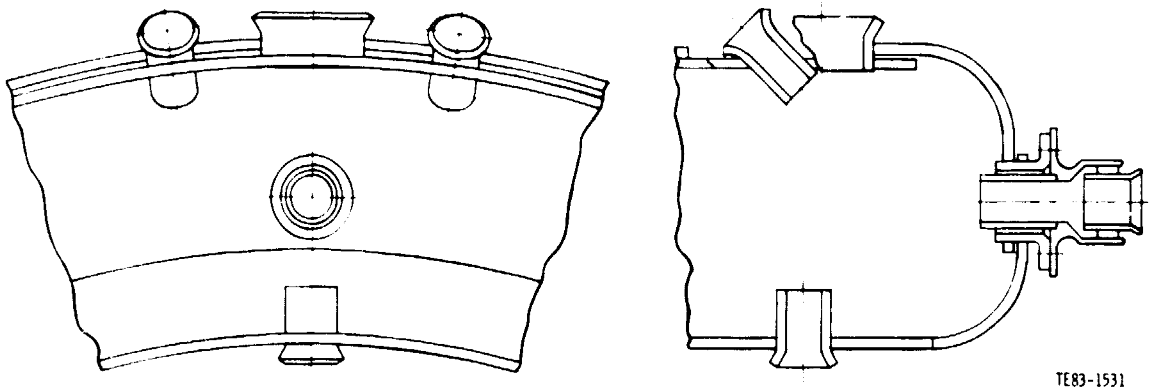


Figure 95. Concept III, mod A2, combustor.

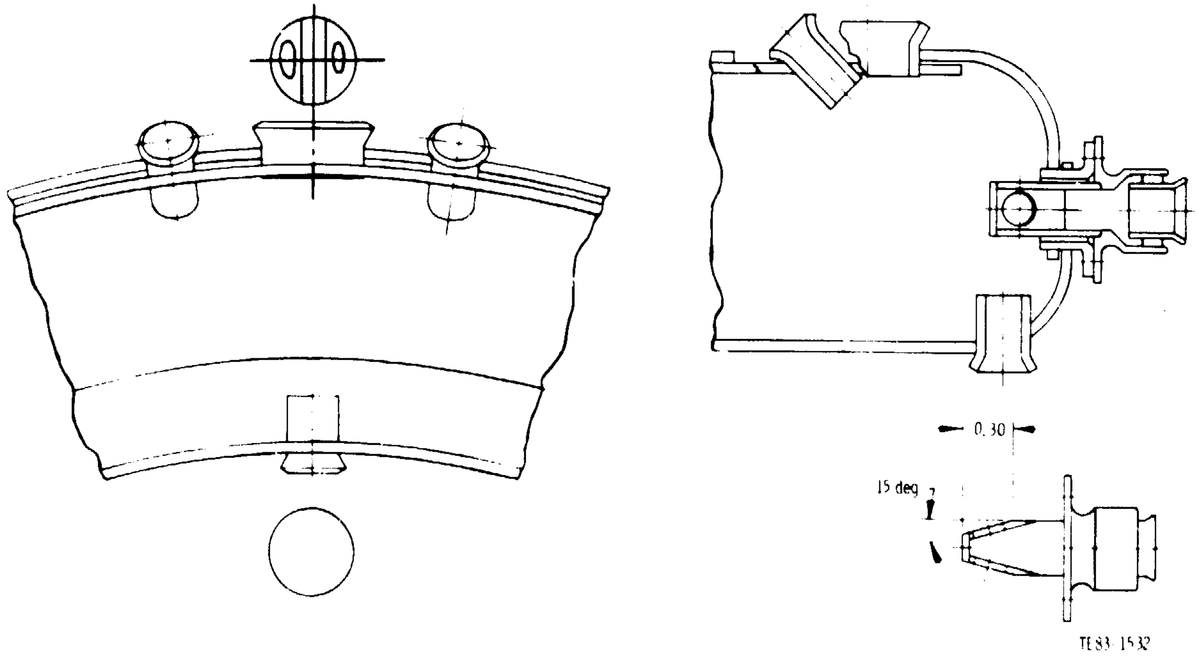
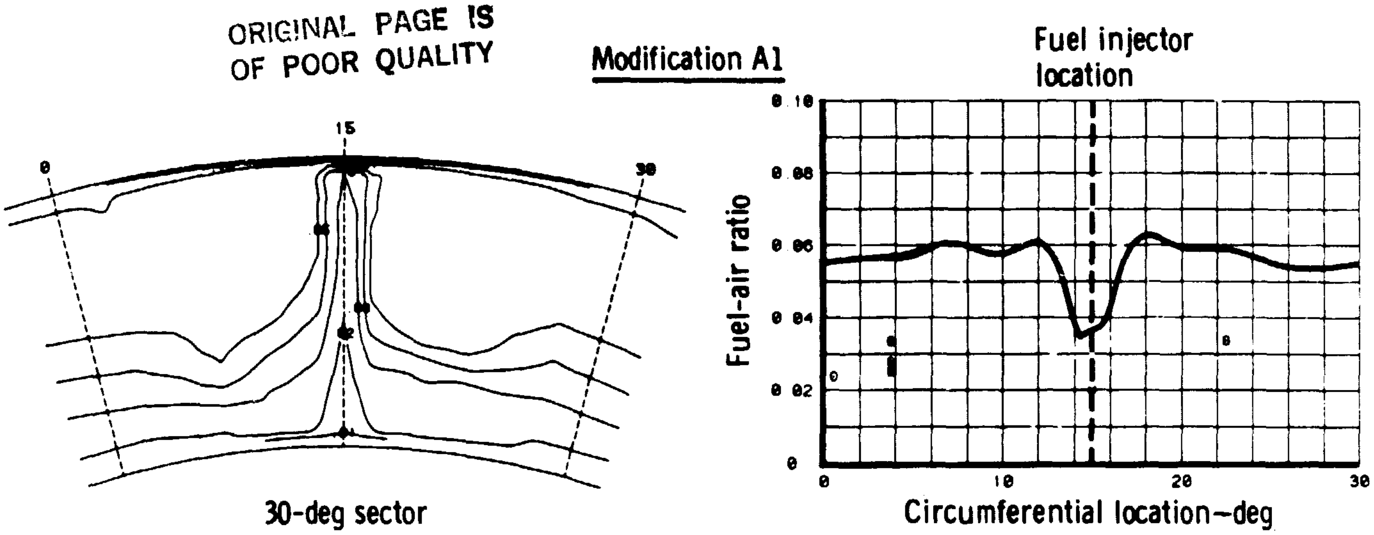
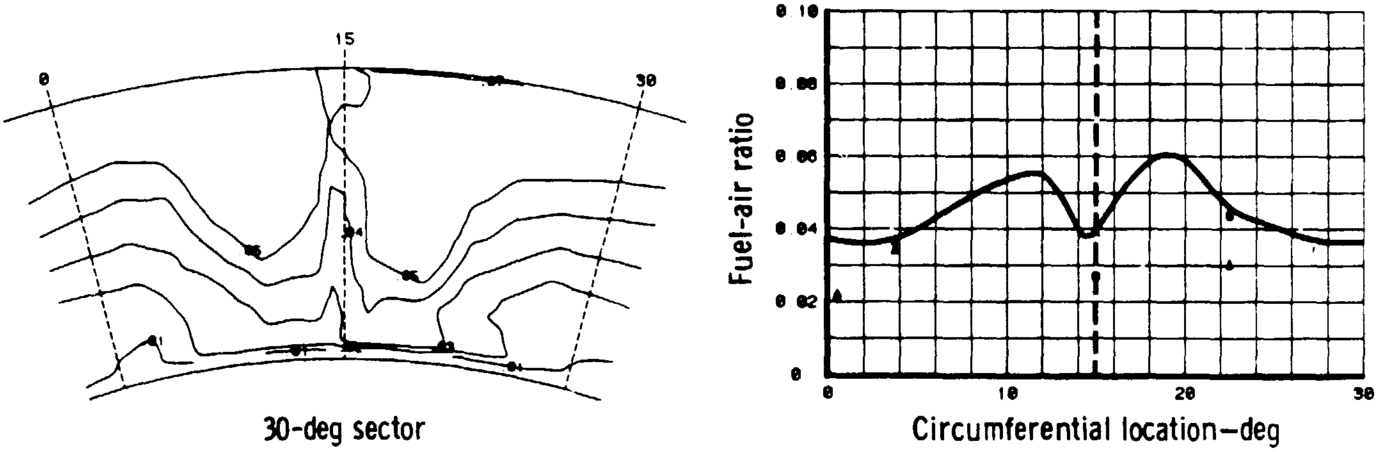


Figure 96. Concept III, mod A3, combustor with bifurcated fuel tube.

Modification A1



Modification A2



Modification A3

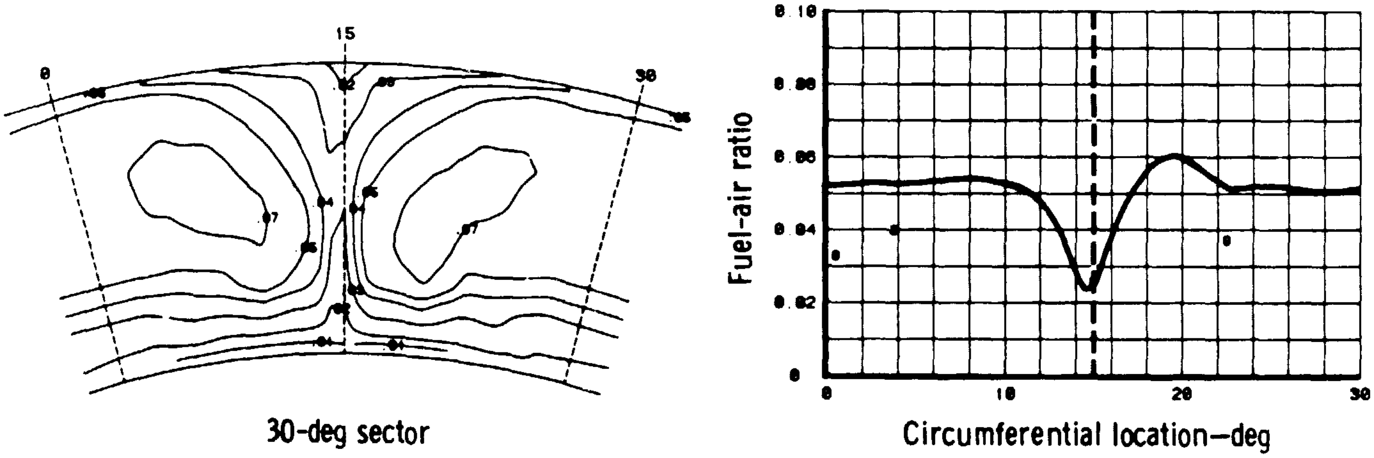


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Figure 97. Predicted primary fuel-air contours.

EXPERIMENTAL RESULTS

Experimental testing of the addendum configuration consisted of the following:

- exhaust performance at 100%, 80%, and idle power
- primary zone emissions at 80% power

Table XXI summarizes the measured performance for Concept III mods A1, A2, and A3. Included in the table are both the exhaust and the primary zone data.

Exhaust temperature patterns for each of the addendum mods are shown in Figure 98. Mod A1, which features the inner primary hole in close proximity to the fuel spray, resulted in an unsatisfactory exhaust pattern factor of 0.478. The pattern improved significantly by placing the inner air jet in a more normal downstream position, as noted by the 0.294 pattern factor value of Mod A2.

The combustion efficiency measured in the combustor exhaust was 99.15% for mod A1, while mods A2 and A3 were 99.88% and 99.90% respectively. Mod A1's lower overall efficiency was due to the close proximity of the inner primary air jet, which also resulted in the poor temperature pattern.

Primary zone emission data were obtained at 80% power condition. Figure 99 is a comparison of computer code analytical prediction and measured primary zone fuel-air ratio sector contours. There was a degree of similarity between calculated and measured values for these test configurations. All mods exhibited an above average fuel-air ratio on the outer annulus area and below average values at the inner annulus area on both the calculated and predicted evaluations.

SUMMARY

The exhaust and primary zone performance values are as follows (in all mods tested the primary zone combustion efficiency was relatively high):

Mod	Performance							
	Primary zone					Exhaust		
	Eff.	Smoke	CO EI	CH_X EI	NO_X EI	Eff.	P.F.	LBO
A1	98.84%	35.0	33.8	3.7	6.8	99.15%	0.478	0.0010
A2	97.44%	49.5	54.4	13.5	7.3	99.88%	0.294	0.0008
A3	99.01%	59.0	36.8	1.2	8.5	99.90%	0.309	0.0005

In conclusion, the design, analysis, and testing of the Addendum Concept III modifications again verified the usefulness of the three-dimensional computer model in combustor design and analysis effort.

Concept III, Mod A1

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ra	
								Lean blowout	C
327	Idle	Exhaust chemistry	3.60	723	586			0.0058	[illegible]
328	Idle	No chemistry	3.60	723	584	0.244			
329	80%	No chemistry	3.43	1051	766	0.499		0.0010	
330	80%	Exhaust chemistry	3.37	1059	776				[illegible]
331	80%	PZ sequential rake 1	3.44	1074	777				[illegible]
332	80%	PZ sequential rake 1	3.43	1083	785				[illegible]
333	80%	No chemistry	3.84	1029	777	0.462			[illegible]
334	80%	PZ sequential rake 1	3.43	1042	789		40		[illegible]
335	80%	PZ sequential rake 2	3.43	1046	788		78		[illegible]
336	80%	PZ sequential rake 3	3.38	1098	797		4		[illegible]
337	80%	PZ sequential rake 4	3.39	1089	795		18		[illegible]
338	80%	No chemistry	3.41	1107	791	0.478	1		
339	80%	Exhaust chemistry	3.42	1115	792				0

Concept III, Mod A2

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rat	
								Lean blowout	Ch
340	Idle	No chemistry	3.85	698	543	0.544		0.0050	
341	Idle	Exhaust chemistry	3.81	699	547				0
348	80%	No chemistry	3.65	855	816	0.294		0.0008	
349	80%	Exhaust chemistry	3.66	834	804				0.
350	80%	PZ sequential rake 1	3.61	854	810		53		0.
351	80%	PZ sequential rake 2	3.58	832	806		37		0.
352	80%	PZ sequential rake 3	3.56	836	814		32		0.
353	80%	PZ sequential rake 4	3.53	836	802		76		0.

Concept III, Mod A3

Reading	Condition	Measurement	Pressure drop, %	Hot skin, K	Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air rat	
								Lean blowout	Ch
354	80%	No chemistry	3.40	957	870	0.309		0.0005	
355	80%	Exhaust chemistry	3.27	950	868				0.
356	80%	PZ sequential rake 4	3.25	961	876		34		0.
357	80%	PZ sequential rake 1	3.22	949	872		80		0.
358	80%	PZ sequential rake 2	3.27	945	867		74		0.
359	80%	PZ sequential rake 3	3.24	949	871		48		0.
360	100%	No chemistry	3.53	1011	945	0.333			

Table XXI.
Concept III, mods A1, A2, and A3, test data summary

Concept III, Mod A1

Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2, %	Efficiency, %	Emission indices		
			Lean blowout	Chemical			CO	CH_x	NO_x
586			0.0058	0.0117	2.19	91.64	46.3	77.2	3.2
584	0.244								
766	0.499		0.0010						
776				0.0231	4.65	99.00	21.6	5.0	9.5
777				0.0334	6.53	98.33	58.4	3.4	3.0
785				0.0252	5.05	99.02	26.8	3.6	5.8
777	0.462								
789		40		0.0278	5.52	98.58	30.8	7.2	7.5
788		78		0.0337	6.57	98.16	54.3	6.0	6.8
797		4		0.0238	4.84	99.79	6.0	0.3	6.8
795		18		0.0200	4.00	98.84	44.2	1.3	4.1
791	0.478	1							
792				0.0221	4.44	99.15	26.6	2.1	4.8

Concept III, Mod A2

Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2, %	Efficiency, %	Emission indices		
			Lean blowout	Chemical			CO	CH_x	NO_x
543	0.544		0.0050						
547				0.0103	1.80	85.78	53.81	37.6	0.3
816	0.294		0.0008						
804				0.0215	4.38	99.88	3.0	0.1	9.8
810		53		0.0346	6.75	98.23	61.1	3.6	7.1
806		37		0.0305	5.99	98.40	52.4	3.8	8.3
814		32		0.0222	4.52	99.72	9.7	0.1	9.5
802		76		0.0392	7.14	93.41	94.3	46.7	4.4

Concept III, Mod A3

Avg skin, K	Pattern factor	Smoke, SAE No.	Fuel-air ratio		CO_2, %	Efficiency, %	Emission indices		
			Lean blowout	Chemical			CO	CH_x	NO_x
870	0.309		0.0005						
868				0.0254	5.16	99.90	1.9	0.1	9.6
876		34		0.0257	5.18	99.53	16.6	0.6	7.7
872		80		0.0399	7.83	98.84	42.6	1.5	9.2
867		74		0.0372	7.28	98.68	49.0	1.7	9.2
871		48		0.0328	6.50	99.00	39.1	0.8	8.0
945	0.333								

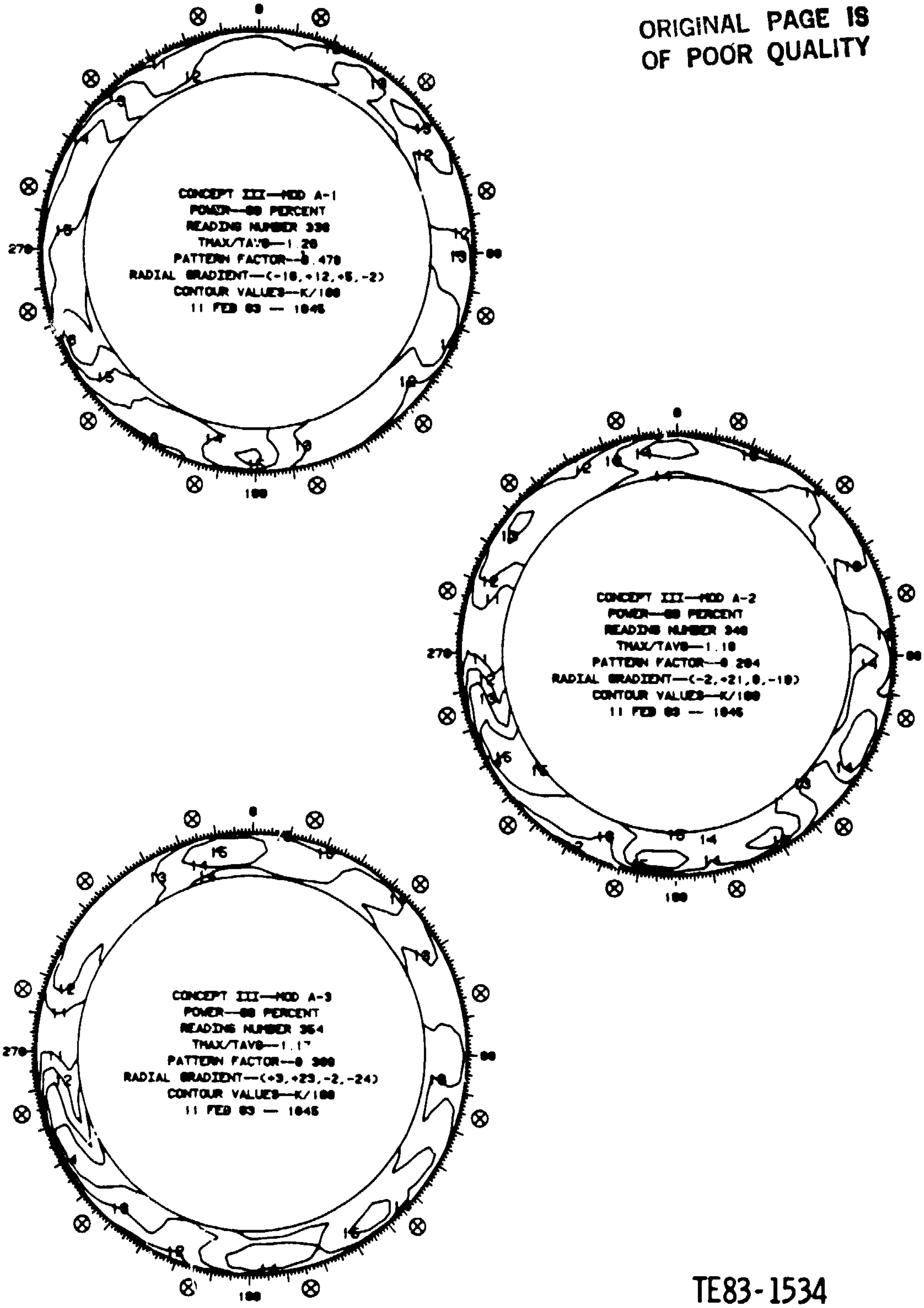

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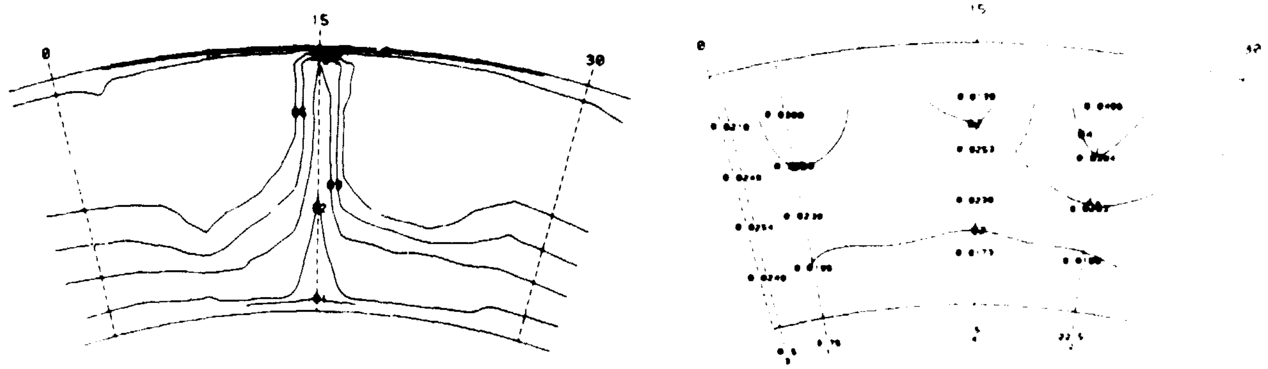
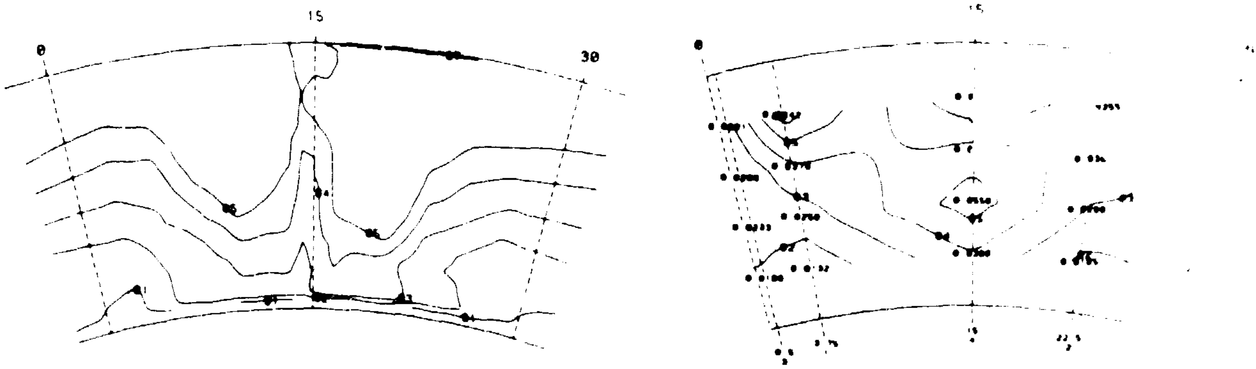
Figure 98. Comparison of combustor outlet temperature pattern at 80% power (Concept III, Addendum mods).



Concept III, Mod A1



Concept III, Mod A2

Concept III, Mod A3

TE83-1535

Figure 99. Comparison of analytical prediction and measured primary zone fuel-air ratio (Concept III, Addendum mods--80% power).

APPENDIX B

TEST DATA SUMMARY

Tabulated in this appendix are the test data for all three concepts and mods including the addendum test program. Each data grouping requires three lines of description on separate pages for summary of exhaust and primary zone data. An additional two pages are required for tabulation of primary zone probe data. This tabulation is grouped for each of the three concepts and the addendum. The comments below describe the parameters in the following tabulation.

RDG	Reading number
COND	Test condition--described in Section VI
MEASUREMENT	Defines test measurement, i.e., exhaust chemistry, primary zone chemistry (PZSEQUN RK1), and exhaust temperature pattern (no chemistry)
WA	Airflow in lb/sec
BIP	Burner inlet pressure, lb/in.^{2} abs
BIT	Average burner inlet temperature, °F
BOT	Average burner outlet temperature, °F
RISE	Temperature rise, °F
WF	Fuel flow, lb/hr
F/A	Fuel-air ratio
FLOW #	Fuel flow/(fuel flow pressure drop)$^{1/2}$
F1	Flow factor $Wa\sqrt{T}/P$
ACD	Calculated liner effective hole area based on measured pressure loss, in.^{2}
DP/P	Burner pressure loss, %
HOT SKIN	Maximum combustor metal temperature via thermocouples
AVG SKIN	Average combustor metal temperature via thermocouples
TM/TA	Exhaust maximum temperature/exhaust average temperature, °F/°F
PATRN	Exhaust pattern factor = PF = $(BOT_{max} - BOT)/(BOT - BIT)$
TIP	Tip (max radius) annulus average exhaust gas temperature, °F
TMID	Mid-tip annulus average exhaust gas temperature, °F

RMID	Mid-root annulus average exhaust gas temperature, °F
ROOT	Root (min radius) average exhaust gas temperature, °F
AT	Data location (EX = exhaust, PZ = primary zone)
SMOKE	SAE smoke number per ARP-1179
LBO F/A	Lean blowout fuel-air ratio
CHEM F/A	Gas analysis fuel-air ratio
CO2 %	Measured carbon dioxide, percent
CO PPM	Measured carbon monoxide, parts per million
CHX PPM	Measured unburned hydrocarbon (C_3 base, as C_3H_8)
NOX PPM	Total nitrogen oxides
EFF	Combustion efficiency calculated from exhaust gases, %
CO EI	Measured carbon monoxide emission index, g/kg
CHX EI	Measured unburned hydrocarbons emission index, g/kg
NOX EI	Measured oxide of nitrogen emission index, g/kg
CIRCUM LOCATION	Circumferential location, degrees from right-hand edge of sector

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PAGE 1
-- DATA LISTING FOR CONCEPT I BASELINE -- NASA PRIMARY ZONE STUDY --
                        DATE TABULATED:  9 FEB 82
                                                                            FLOW
RDG COND   MEASUREMENT      WA      BIP    BIT    BOT     RISE    WF      F/A     #

 91 IDLE  EXHAUST  CHEM   2.30    55.3   374.  1046.    672.   85.4  0.01034  30.
 92 IDLE  PZ SEQUN RK 1   2.30    55.5   380.  1052.    672.   85.4  0.01032  30.
 95 IDLE  PZ SEQUN RK 2   2.30    56.0   384.  1070.    685.   87.5  0.01059  30.
 96 IDLE  PZ SEQUN RK 3   2.29    56.1   386.  1075.    689.   87.9  0.01065  30.
 97 IDLE  PZ MFOLD RK 1   2.30    55.2   386.  1057.    670.   85.3  0.01031  30.
 98 IDLE  PZ MFOLD RK 2   2.29    55.4   387.  1064.    677.   86.3  0.01046  30.
 99 IDLE  PZ MFOLD RK 3   2.30    55.2   388.  1041.    653.   83.2  0.01006  30.
100 IDLE  PZ MFOLD RK 3   2.29    55.6   388.  1065.    677.   85.9  0.01040  30.
101 IDLE  EXHAUST  CHEM   2.29    55.6   388.  1058.    669.   84.9  0.01030  30.
102 IDLE  NO  CHEMISTRY   2.29    55.9   389.  1069.    680.   86.9  0.01055  30.
103 100%  EXHAUST  CHEM   5.03   147.4   754.  1991.   1236.  356.2  0.01968  25.
104 100%  NO  CHEMISTRY   5.02   147.6   757.  1970.   1213.  353.9  0.01957  25.
105 100%  PZ MFOLD RK 1   5.02   148.4   755.  1992.   1237.  357.1  0.01975  25.
106 100%  PZ MFOLD RK 2   5.03   147.6   752.  1991.   1238.  355.5  0.01964  24.
107 100%  PZ MFOLD RK 3   5.04   148.3   751.  1996.   1245.  356.4  0.01963  24.
108  ALT  EXHAUST  CHEM   2.62    78.2   698.  1911.   1213.  190.3  0.02018  24.
109  ALT  NO  CHEMISTRY   2.62    78.5   702.  1871.   1169.  190.3  0.02017  24.
110  80%  EXHAUST  CHEM   4.62   131.2   614.  1885.   1270.  324.6  0.01950  25.
111  80%  NO  CHEMISTRY   4.58   130.9   612.  1860.   1247.  323.1  0.01960  24.
112  50%  EXHAUST  CHEM   3.73   100.9   535.  1545.   1010.  210.2  0.01563  25.
113  50%  NO  CHEMISTRY   3.72   101.3   541.  1547.   1006.  210.6  0.01575  25.
114 100%  NO  CHEMISTRY   4.93   146.1   753.  2026.   1273.  349.2  0.01967  24.
115 100%  NO  CHEMISTRY   4.97   147.0   753.  2019.   1265.  349.2  0.01953  24.
```

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PAGE 2
-- DATA LISTING FOR CONCEPT I BASELINE -- NASA PRIMARY ZONE STUDY --
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RDG COND     FI    ACD   DP/P  HOT   AVG     TM/TA  PATRN  TIP THID RMID ROOT
                               SKIN  SKIN                   F    F    F    F
 91 IDLE  1.198  5.15  4.49  880.  596.   1.099  0.155  22.  24.   5. -51.
 92 IDLE  1.201  5.16  4.49  895.  603.   1.088  0.137  23.  24.   4. -51.
 95 IDLE  1.192  5.16  4.43  885.  612.   1.090  0.140  24.  24.   4. -54.
 96 IDLE  1.189  5.14  4.43  886.  615.   1.084  0.131  24.  25.   4. -53.
 97 IDLE  1.210  5.15  4.58  876.  609.   1.084  0.132  25.  25.   3. -52.
 98 IDLE  1.202  5.13  4.56  906.  614.   1.084  0.132  24.  25.   4. -53.
 99 IDLE  1.212  5.15  4.59  903.  609.   1.085  0.135  24.  24.   3. -51.
100 IDLE  1.202  5.15  4.52  901.  617.   1.083  0.130  24.  24.   3. -52.
101 IDLE  1.199  5.13  4.54  925.  618.   1.084  0.132  24.  25.   4. -52.
102 IDLE  1.192  5.12  4.49  960.  628.   1.099  0.155  22.  25.   6. -51.
103 100%  1.189  5.59  3.75 1368. 1087.   1.072  0.116  -7.  48.  38. -79.
104 100%  1.188  5.59  3.74 1338. 1085.   1.079  0.128  -1.  42.  37. -76.
105 100%  1.180  5.59  3.69 1366. 1090.   1.078  0.126   6.  47.  32. -85.
106 100%  1.186  5.58  3.74 1338. 1083.   1.078  0.125   7.  47.  32. -87.
107 100%  1.184  5.58  3.73 1336. 1084.   1.074  0.119   3.  48.  35. -86.
108  ALT  1.139  5.40  3.69 1480. 1117.   1.094  0.149  40.  55.  26.-122.
109  ALT  1.139  5.41  3.67 1490. 1123.   1.117  0.187  29.  48.  30.-106.
110  80%  1.155  5.54  3.60 1220.  940.   1.080  0.119   5.  37.  32. -75.
111  80%  1.145  5.54  3.55 1234.  948.   1.100  0.150  -3.  33.  36. -66.
112  50%  1.168  5.42  3.85 1078.  820.   1.081  0.123  24.  36.  18. -77.
113  50%  1.161  5.41  3.82 1071.  830.   1.116  0.178  17.  32.  21. -72.
114 100%  1.176  5.65  3.60 1258. 1137.   1.102  0.162 -25.  31.  37. -43.
115 100%  1.177  5.65  3.60 1241. 1125.   1.098  0.156 -31.  30.  38. -38.
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PAGE 3
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RDG AT SMOKE   LBO      CHEM    CO2     CO    CHX     NOX    EFF     CO    CHX   NOX
               F/A      F/A      %     PPM    PPM     PPM            EI    EI     EI
 91 EX                 0.0108  2.19   399.   29.8     7.   98.76   36.1   4.2   1.1
 92 PZ                 0.0226  4.53   932.    7.5    55.   99.00   40.8   0.5   4.0
 95 PZ                 0.0121  2.44   472.   19.3     8.   98.88   38.2   2.5   1.1
 96 PZ                 0.0200  4.08   247.    3.9    33.   99.68   12.2   0.3   2.7
 97 PZ    7.           0.0233  4.62  1392.    5.1    41.   98.60   59.2   0.3   2.9
 98 PZ    0.           0.0120  2.40   707.   38.0     5.   98.21   57.8   4.9   0.6
 99 PZ    0.           0.0177  3.61   307.    3.3    26.   99.57   17.1   0.3   2.3
100 PZ                 0.0184  3.76   257.    1.8    29.   99.66   13.7   0.1   2.5
101 EX                 0.0103  2.10   374.   19.4     9.   98.90   35.4   2.9   1.5
102
103 EX    0.           0.0222  4.54    25.    0.2   163.   99.91    1.1   0.0  11.9
104
105 PZ   92.           0.0436  8.07  5187.  335.9   179.   96.05  120.6  12.3   6.8
106 PZ   36.           0.0202  4.12   163.    0.9   102.   99.77    8.0   0.1   8.2
107 PZ   36.           0.0399  7.93   756.    1.9   222.   99.51   19.1   0.1   9.2
108 EX                 0.0232  4.73    33.    0.0   116.   99.92    1.4   0.0   8.1
109
110 EX    5.           0.0211  4.30    32.    1.6   127.   99.91    1.5   0.1   9.8
111
112 EX    0.           0.0163  3.34    53.    0.2    64.   99.89    3.2   0.0   6.4
113
114
115
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PAGE 1
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RDG COND   MEASUREMENT     WA      BIP    BIT     BOT      RISE     WF        F/A      %

165 IDLE  NO  CHEMISTRY  2.35    55.9   368.   1054.     685.   87.9   0.01038   28.
166 IDLE  EXHAUST  CHEM  2.36    56.5   370.   1080.     710.   88.3   0.01038   28.
167 IDLE  PZ SEQUN RK 1  2.37    56.6   369.   1086.     717.   88.3   0.01036   28.
168 IDLE  PZ SEQUN RK 2  2.27    53.3   368.   1079.     711.   94.7   0.01036   28.
169 IDLE  PZ SEQUN RK 3  2.27    55.4   370.   1084.     713.   85.4   0.01043   28.
170  80%  NO  CHEMISTRY  4.56   129.7   615.   1930.    1315.  323.9   0.01973   24.
171  80%  EXHAUST  CHEM  4.56   127.2   618.   1924.    1306.  321.0   0.01955   24.
172  80%  PZ SEQUN RK 1  4.50   128.3   608.   1933.    1325.  320.7   0.01979   24.
173  80%  PZ SEQUN RK 2  4.54   130.2   608.   1923.    1314.  321.0   0.01963   23.
174  80%  PZ SEQUN RK 3  4.57   129.6   609.   1928.    1319.  320.6   0.01949   23.
175 100%  NO  CHEMISTRY  4.93   146.6   756.   2065.    1309.  346.0   0.01951   24.
176 100%  PZ SEQUN RK 1  4.92   146.1   750.   2046.    1296.  345.5   0.01951   24.
177 100%  PZ SEQUN RK 2  4.90   147.2   755.   2103.    1348.  347.3   0.01969   23.
178 100%  PZ SEQUN RK 3  4.89   147.2   752.   2094.    1342.  345.8   0.01963   22.
```

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PAGE 2
-- DATA LISTING FOR CONCEPT I MOD 1 -- NASA PRIMARY ZONE STUDY --
                           DATE TABULATED:  18 FEB 82
RDG COND    F1     ACD    DP/P   HOT    AVG     TM/TA   PATRN   TIP  TMID RMID ROOT
                                 SKIN   SKIN                     F     F    F    F

165 IDLE  1.212   5.19   4.51   853.   613.   1.124   0.191   29.   34. -19. -46.
166 IDLE  1.204   5.24   4.38   833.   630.   1.072   0.110   22.   26.    5. -52.
167 IDLE  1.205   5.24   4.38   828.   629.   1.080   0.121   20.   25.    5. -51.
168 IDLE  1.227   5.23   4.57   835.   621.   1.064   0.097   20.   26.    6. -50.
169 IDLE  1.182   5.24   4.21   848.   610.   1.072   0.109   19.   27.    6. -51.
170  80%  1.153   5.57   3.55 1106.   864.   1.100   0.147    7.   37.   24. -67.
171  80%  1.177   5.62   3.64 1113.   872.   1.090   0.133   -9.   39.   31. -60.
172  80%  1.147   5.59   3.49 1145.   880.   1.071   0.104    5.   40.   24. -71.
173  80%  1.141   5.56   3.49 1088.   864.   1.106   0.155  -44.   32.   48. -38.
174  80%  1.153   5.57   3.55 1079.   868.   1.076   0.111  -42.   32.   50. -40.
175 100%  1.171   5.71   3.49 1260.  1063.   1.084   0.133   10.   37.   22. -71.
176 100%  1.172   5.68   3.53 1286.  1067.   1.039   0.062   -5.   30.   29. -55.
177 100%  1.160   5.70   3.44 1290.  1078.   1.044   0.068   -7.   27.   27. -47.
178 100%  1.157   5.69   3.43 1331.  1074.   1.045   0.070   -4.   26.   30. -52.
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PAGE 3
-- DATA LISTING FOR CONCEPT I MOD 1 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  18 FEB 82
RDG AT SMOKE  LBO      CHEM    CO2     CO    CHX    NOX    EFF    CO   CHX   NOX
              F/A      F/A      %      PPM   PPM    PPM           EI    EI    EI
165          0.0032
166 EX                0.0108  2.21    284.  10.4    22.  99.26  25.6  1.5   3.2
167 PZ    0.          0.0189  3.81    565.  10.6    27.  99.23  29.5  0.9   2.3
168 PZ    0.          0.0156  3.09    904.  63.8    12.  98.08  57.1  6.3   1.3
169 PZ    0.          0.0222  4.51    196.   4.3    49.  99.76   8.7  0.3   3.6
170          0.0018
171 EX    0.          0.0216  4.42     37.   0.9   112.  99.91   1.7  0.1   8.4
172 PZ   77.          0.0403  7.81   2448.  44.4   168.  98.40  61.3  1.7   6.9
173 PZ   24.          0.0287  5.81    166.   2.7    99.  99.82   5.8  0.1   5.6
174 PZ   82.          0.0526  9.99   4092.  15.9   240.  98.10  79.5  0.5   7.7
175
176 PZ   56.          0.0355  7.03   1060.  20.6   200.  99.18  30.0  0.9   9.3
177 PZ   16.          0.0299  6.04    290.   3.6   175.  99.71   9.7  0.2   9.6
178 PZ   23.          0.0457  9.02    926.   2.3   308.  99.46  20.5  0.1  11.2
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PAGE 1
-- DATA LISTING FOR CONCEPT I MOD 2 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  5 APR 82
                                                                                FLOW
RDG COND   MEASUREMENT       WA      BIP    BIT    BOT      RISE     WF       F/A      #

189 IDLE  NO  CHEMISTRY  2.28    55.4  373.  1070.    697.  84.6  0.01032  28.
191 IDLE  EXHAUST  CHEM  2.27    55.9  367.  1074.    706.  85.2  0.01041  28.
192 IDLE  PZ SEQUN RK 1  2.29    55.9  368.  1051.    683.  84.5  0.01026  27.
193 IDLE  PZ SEQUN RK 2  2.29    55.9  367.  1049.    682.  85.2  0.01035  27.
194 IDLE  PZ SEQUN RK 3  2.29    55.9  367.  1050.    683.  84.4  0.01026  27.
195  80%  NO  CHEMISTRY  4.59   130.6  620.  1976.   1355. 323.9  0.01958  24.
196  80%  EXHAUST  CHEM  4.59   131.6  617.  1974.   1357. 323.2  0.01955  24.
197  80%  PZ SEQUN RK 1  4.66   131.6  608.  1978.   1370. 325.5  0.01942  24.
198  80%  PZ SEQUN RK 2  4.68   133.5  602.  1995.   1393. 327.0  0.01941  24.
199  80%  PZ SEQUN RK 3  4.68   132.0  601.  1990.   1388. 327.6  0.01946  24.
201 100%  NO  CHEMISTRY  4.89   146.2  751.  2061.   1309. 345.0  0.01958  22.
202 100%  EXHAUST  CHEM  4.88   147.0  749.  2088.   1339. 342.9  0.01952  22.
203  80%  NO  CHEMISTRY  4.60   130.2  619.  1945.   1326. 323.5  0.01952  23.
205  80%  PZ SEQUN RK 1  4.57   131.1  604.  2086.   1481. 323.5  0.01967  23.
206  80%  PZ SEQUN RK 2  4.57   131.7  603.  2117.   1514. 322.2  0.01957  23.
207  80%  PZ SEQUN RK 3  4.58   128.9  600.  2095.   1494. 322.4  0.01957  23.

PAGE 2
-- DATA LISTING FOR CONCEPT I MOD 2 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  5 APR 82
RDG COND     FI    ACD   DP/P  HOT   AVG    TM/TA  PATRN   TIP  TMID RMID ROOT
                               SKIN  SKIN                   F    F    F    F
189 IDLE  1.185  5.29  4.15  837.  640.   1.084  0.128  20.   28.   3. -51.
191 IDLE  1.170  5.28  4.06  808.  618.   1.088  0.133  16.   26.   4. -47.
192 IDLE  1.177  5.30  4.09  807.  606.   1.108  0.167  18.   26.   2. -47.
193 IDLE  1.175  5.30  4.09  800.  603.   1.122  0.187  21.   27.   1. -49.
194 IDLE  1.177  5.29  4.10  764.  594.   1.116  0.179  19.   26.   3. -48.
195  80%  1.156  5.58  3.56 1175.  964.   1.119  0.174   6.   37.  24. -66.
196  80%  1.145  5.54  3.54 1168.  960.   1.110  0.160  -1.   35.  26. -60.
197  80%  1.156  5.57  3.57 1158.  964.   1.085  0.123  -8.   29.  27. -49.
198  80%  1.143  5.60  3.46 1154.  944.   1.070  0.101 -40.   27.  46. -34.
199  80%  1.154  5.56  3.57 1202.  934.   1.068  0.097  -2.   37.  26. -61.
201 100%  1.165  5.57  3.63 1266. 1109.   1.127  0.200 -10.   36.  45. -40.
202 100%  1.154  5.54  3.60 1261. 1102.   1.067  0.105 -28.   34.  37. -44.
203  80%  1.162  5.60  3.57 1211.  994.   1.131  0.193   7.   43.  27. -77.
205  80%  1.138  5.57  3.45 1143.  964.   1.036  0.051 -13.   22.  36. -46.
206  80%  1.132  5.56  3.44 1181.  950.   1.028  0.038 -12.   26.  39. -53.
207  80%  1.156  5.57  3.57 1199.  952.   1.022  0.030 -16.   23.  41. -48.
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PAGE 3
-- DATA LISTING FOR CONCEPT I MOD 2 -- NASA PRIMARY ZONE STUDY --
                            DATE TABULATED:  5 APR 82
RDG AT SMOKE  LBO     CHEM    CO2     CO    CHX     NOX    EFF    CO    CHX   NOX
              F/A     F/A      %     PPM    PPM     PPM           EI    EI    EI
189          0.0040
191 EX   0.           0.0116  2.36   363.   22.6    19.  99.01  30.5   3.0   2.6
192 PZ   0.           0.0167  3.36   578.   29.8    27.  98.95  34.1   2.8   2.6
193 PZ   0.           0.0136  2.73   538.   47.8    20.  98.58  38.9   5.4   2.4
194 PZ   0.           0.0257  5.15   628.   15.8    47.  99.34  24.3   1.0   3.0
195
196 EX   0.           0.0228  4.65    33.    0.4   113.  99.92   1.4   0.0   8.1
197 PZ  51.           0.0484  9.36  2446.   15.4   206.  98.74  51.4   0.5   7.1
198 PZ 100.           0.0470  7.70  7679.2737.4   139.  87.31 167.0 93.6   5.0
199 PZ  91.           0.0508  9.40  6116. 138.6   209.  96.74 122.9   4.4   6.9
201
202 EX  16.           0.0239  4.87    22.    1.4   190.  99.91   0.9   0.1  13.0
203
205 PZ  70.           0.0484  9.16  4319.   29.0   298.  97.78  90.9   1.0  10.3
206 PZ  93.           0.0423  7.21  6620.1827.7   169.  89.82 158.9 68.9   6.7
207 PZ  85.  0.0020   0.0609 11.01  8907.   76.5   313.  96.31 150.9   2.0   8.7
```

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PAGE 1
-- DATA LISTING FOR CONCEPT I MOD 3 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  5 APR 82
                                                                               FLOW
RDG COND   MEASUREMENT    WA     BIP    BIT    BOT     RISE    WF      F/A        %

214  80%  NO  CHEMISTRY  4.65  130.8  608.  1925.  1317. 324.6  0.01941   24.
215  80%  EXHAUST  CHEM  4.66  130.1  611.  1906.  1295. 324.6  0.01935   24.
216  80%  PZ SEQUN RK 1  4.63  131.5  608.  1940.  1332. 324.4  0.01944   24.
217  80%  PZ SEQUN RK 2  4.61  132.2  610.  1909.  1300. 324.5  0.01957   24.
218  80%  PZ SEQUN RK 3  4.64  129.9  609.  1911.  1303. 324.7  0.01944   23.
219 100%  NO  CHEMISTRY  4.98  147.0  760.  2015.  1256. 352.6  0.01966   24.
```

```
PAGE 2
-- DATA LISTING FOR CONCEPT I MOD 3 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  5 APR 82
RDG COND    FI    ACD   DP/P   HOT   AVG    TM/TA  PATRN   TIP  TMID RMID ROOT
                               SKIN  SKIN                   F     F    F    F
214  80%  1.161  5.88  3.23  117.     0.  1.136  0.199 -53.  25.  57. -30.
215  80%  1.172  5.74  3.45  116.     0.  1.116  0.171 -85.  24.  71. -10.
216  80%  1.151  5.74  3.34  118.     0.  1.052  0.076 -78.  21.  70. -13.
217  80%  1.139  5.72  3.29  121.     0.  1.065  0.095 -72.  23.  65. -15.
218  80%  1.168  5.75  3.42  120.     0.  1.079  0.116 -59.  25.  60. -25.
219 100%  1.183  5.87  3.37  134.     0.  1.152  0.243 -61.  47.  75. -60.
```

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PAGE 3
-- DATA LISTING FOR CONCEPT I MCD 3 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  5 APR 82
RDG AT SMOKE  LBC      CHEM     CO2     CO    CHX    NOX    EFF    CO   CHX   NOX
              F/A      F/A      %      PPM    PPM    PPM           EI    EI    EI
214          0.0012
215 EX  12.          0.0214  4.38    19.   0.1  131.  99.94   0.9  0.0  9.9
216 PZ  48.          0.0326  6.54   435.   1.2  147.  99.65  13.4  0.1  7.4
217 PZ  12.          0.0298  6.03    43.   0.7  134.  99.93   1.4  0.0  7.4
218 PZ  37.          0.0487  9.38  2872.  13.9  246.  98.55  60.0  0.5  8.5
219          0.0C16
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PAGE 1
-- DATA LISTING FOR CONCEPT I MOD 4 -- NASA PRIMARY ZONE STUDY --
                           DATE TABULATED:  26 MAY 82
                                                                              FLOW
RDG COND    MEASUREMENT      WA     BIP    BIT    BOT     RISE     WF       F/A      %

236  80%   NO   CHEMISTRY   4.58   131.1  613.   1928.   1315. 322.3   0.01956   23.
237  80%   EXHAUST  CHEM    4.58   131.2  611.   1940.   1328. 322.6   0.01955   23.
238  80%   PZ SEQUN RK 1    4.57   131.6  609.   1930.   1320. 322.7   0.01960   23.
239  80%   PZ SEQUN RK 2    4.56   132.8  609.   1940.   1330. 322.9   0.01967   23.
240  80%   PZ SEQUN RK 3    4.58   130.9  610.   1957.   1347. 322.3   0.01956   23.
241  80%   PZ SEQUN RK 4    4.62   132.6  609.   1932.   1323. 322.2   0.01936   23.
242 100%   NO   CHEMISTRY   4.97   146.7  748.   2076.   1328. 351.8   0.01966   22.
```

```
PAGE 2
-- DATA LISTING FOR CONCEPT I MOD 4 -- NASA PRIMARY ZONE STUDY --
                           DATE TABULATED:  26 MAY 82
RDG COND     F1     ACD    DP/P   HOT    AVG     TM/TA   PATRN   TIP  TMID RMID ROOT
                                  SKIN   SKIN                     F     F    F    F
236  80%   1.143   5.50   3.59    87.     0.    1.105   0.154 -29.   57.   58. -87.
237  80%   1.143   5.46   3.64    87.     0.    1.078   0.114 -16.   54.   47. -87.
238  80%   1.136   5.51   3.52    89.     0.    1.100   0.146 -27.   56.   49. -78.
239  80%   1.122   5.51   3.44    90.     0.    1.076   0.110 -21.   55.   49. -84.
240  80%   1.144   5.49   3.60    91.     0.    1.089   0.130  -6.   55.   42. -92.
241  80%   1.139   5.52   3.54    90.     0.    1.074   0.108  -7.   52.   43. -90.
242 100%   1.178   5.51   3.79    94.     0.    1.118   0.184   6.   60.   44.-112.
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PAGE 3
-- DATA LISTING FOR CONCEPT I MOD 4 -- NASA PRIMARY ZONE STUDY --
                           DATE TABULATED:  26 MAY 82
RDG AT  SMOKE   LBO      CHEM     CO2     CO    CHX     NOX    EFF     CO    CHX   NOX
                F/A      F/A      %      PPM    PPM     PPM            EI    EI    EI
236            0.0015
237 EX    4.            0.0218   4.46    28.    0.5   153.   99.92    1.3   0.0  11.4
238 PZ   36.            0.0480   9.28  2712.    9.1   250.   98.62   57.4   0.3   8.7
239 PZ    8.            0.0337   6.79   166.    0.6   191.   99.84    4.9   0.0   9.3
240 PZ   23.            0.0500   9.77  1700.    2.0   272.   99.16   34.6   0.1   9.1
241 PZ   25.            0.0288   5.80   357.    1.1   139.   99.68   12.4   0.1   7.9
242       0.   0.0016
```

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PAGE 1
-- DATA LISTING FOR CONCEPT I MOD 5 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  28 MAY 82
                                                                        FLOW
RDG COND   MEASUREMENT      WA     BIP    BIT    BOT     RISE    WF      F/A      %

286  80%  NO  CHEMISTRY  4.59  131.1  616.  1863.  1247. 323.4  0.01957  33.
287  80%  EXHAUST  CHEM  4.58  130.4  623.  1949.  1326. 323.6  0.01961  31.
288  80%  PZ SEQUN RK 1  4.59  131.5  604.  1924.  1320. 323.2  0.01955  29.
289  80%  PZ SEQUN RK 2  4.62  131.3  607.  1907.  1300. 323.7  0.01946  29.
290  80%  PZ SEQUN RK 3  4.57  130.5  611.  1933.  1321. 323.6  0.01966  27.
291  80%  PZ SEQUN RK 4  4.59  131.2  612.  1932.  1320. 323.3  0.01955  27.
292  80%  NO  CHEMISTRY  5.26  129.6  612.  1865.  1253. 370.2  0.01957  25.
293 100%  NO  CHEMISTRY  4.95  148.1  755.  1983.  1228. 349.3  0.01962  24.

PAGE 2
-- DATA LISTING FOR CONCEPT I MOD 5 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  28 MAY 82
RDG COND    FI     ACD    DP/P   HOT    AVG    TM/TA  PATRN   TIP  TMID RMID ROOT
                                 SKIN   SKIN                   F    F    F    F
286  80%  1.148  5.11  4.19    0.     0.   1.144  0.215   3.   31.  38.  -74.
287  80%  1.156  5.08  4.30    0.     0.   1.098  0.144   8.   37.  42.  -87.
288  80%  1.139  5.03  4.25    0.     0.   1.125  0.183  -5.   27.  47.  -71.
289  80%  1.150  5.07  4.27    0.     0.   1.124  0.182  -0.   30.  45.  -74.
290  80%  1.147  5.07  4.24    0.     0.   1.134  0.196   3.   34.  46.  -82.
291  80%  1.147  5.08  4.23    0.     0.   1.120  0.175   1.   30.  45.  -75.
292  80%  1.327  5.05  5.73    0.     0.   1.144  0.214   4.   36.  44.  -85.
293 100%  1.164  5.21  4.14    C.     0.   1.104  0.168   6.   38.  49.  -94.

PAGE 3
-- DATA LISTING FOR CONCEPT I MOD 5 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  28 MAY 82
RDG AT SMOKE   LBC      CHEM    CO2     CO    CHX    NOX    EFF     CO   CHX   NOX
               F/A      F/A     %      PPM    PPM    PPM            EI   EI    EI
286           0.0020
287 EX  11.           0.0215  4.39     34.    4.0   120.   99.90    1.6  0.3  9.1
288 PZ  45.           0.0234  4.72    459.    2.2    79.   99.52   19.5  0.1  5.5
289 PZ  28.           0.0170  3.47     76.   50.8    53.   99.44    4.4  4.6  5.1
290 PZ  27.           0.0306  6.17    305.    2.6   127.   99.73    9.9  0.1  6.8
291 PZ  14.           0.0256  5.17    453.    6.6   104.   99.53   17.6  0.4  6.6
292      5.
293      5.   0.0020
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1 JUNE 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT I
                                  CIRCUM    (-------AVERAGE RAKE VALUES-------)
RDG COND  CONCEPT MOD    RAKE  LOCATION  F/A      EFF    CO2     CO     NOX  SMOKE
                                                  %      %       PPM    PPM
 92 IDLE     I    BASLNE  1     11.25   0.0226  99.00   4.53    932.    55.
 95 IDLE     I    BASLNE  2     22.50   0.0121  98.88   2.44    472.     8.
 96 IDLE     I    BASLNE  3     15.50   0.0200  99.68   4.08    247.    33.
 97 IDLE     I    BASLNE  1     11.25   0.0233  98.60   4.62   1392.    41.  7.
 98 IDLE     I    BASLNE  2     22.50   0.0120  98.21   2.40    707.     5.  0.
 99 IDLE     I    BASLNE  3     15.50   0.0177  99.57   3.61    307.    26.  0.
100 IDLE     I    BASLNE  3     15.50   0.0184  99.66   3.76    257.    29.
105 100%     I    BASLNE  1     11.25   0.0436  96.05   8.07   5187.   179. 92.
106 100%     I    BASLNE  2     22.50   0.0202  99.77   4.12    163.   102. 36.
107 100%     I    BASLNE  3     15.50   0.0399  99.51   7.93    756.   222. 36.
167 IDLE     I      1     1     11.25   0.0189  99.23   3.81    565.    27.  0.
168 IDLE     I      1     2     22.50   0.0156  98.08   3.09    904.    12.  0.
169 IDLE     I      1     3     15.50   0.0222  99.76   4.51    196.    49.  0.
172  80%     I      1     1     11.25   0.0403  98.40   7.81   2448.   168. 77.
173  80%     I      1     2     22.50   0.0287  99.82   5.81    166.    99. 24.
174  80%     I      1     3     15.50   0.0526  98.10   9.99   4092.   240. 82.
176 100%     I      1     1     11.25   0.0355  99.18   7.03   1060.   200. 56.
177 100%     I      1     2     22.50   0.0299  99.71   6.04    290.   175. 16.
178 100%     I      1     3     15.50   0.0457  99.46   9.02    926.   308. 23.
192 IDLE     I      2     1     11.25   0.0167  98.95   3.36    578.    27.  0.
193 IDLE     I      2     2     22.50   0.0136  98.58   2.73    538.    20.  0.
194 IDLE     I      2     3     15.50   0.0257  99.34   5.15    628.    47.  0.
197  80%     I      2     1     11.25   0.0468  98.74   9.36   2446.   206. 51.
198  80%     I      2     2     22.50   0.0470  87.31   7.70   7679.   139.100.
199  80%     I      2     3     15.50   0.0508  96.74   9.40   6116.   209. 91.
205  80%     I      2     1     11.25   0.0484  97.78   9.16   4319.   298. 70.
206  80%     I      2     2     22.50   0.0423  89.82   7.21   6620.   169. 93.
207  80%     I      2     3     15.50   0.0609  96.31  11.01   8907.   313. 85.
216  80%     I      3     1     11.25   0.0326  99.65   6.54    435.   147. 48.
217  80%     I      3     2     22.50   0.0298  99.93   6.03     43.   134. 12.
218  80%     I      3     3     15.50   0.0487  98.55   9.38   2872.   246. 37.
238  80%     I      4     1     11.25   0.0480  98.62   9.28   2712.   250. 36.
239  80%     I      4     2     22.50   0.0337  99.84   6.79    166.   191.  8.
240  80%     I      4     3     15.50   0.0500  99.16   9.77   1700.   272. 23.
241  80%     I      4     4      7.50   0.0288  99.68   5.80    357.   139. 25.
288  80%     I      5     1     11.25   0.0234  99.52   4.72    459.    79. 45.
289  80%     I      5     2     22.50   0.0170  99.44   3.47     76.    53. 28.
290  80%     I      5     3     15.50   0.0306  99.73   6.17    305.   127. 27.
291  80%     I      5     4      7.50   0.0256  99.53   5.17    453.   104. 14.
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    PAGE 2
 1 JUNE 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT I

                                      RADIAL   (----INDIVIDUAL PORT VALUES---)
 RDG COND CONCEPT MOD RAKE PORT LOCATION   F/A      EFF      CO2      CO     NOX
                                                     %        %       PPM    PPM
   92 IDLE     I  BASLNE  1
                                1    6.07  0.0270   98.45    5.31   1775.    82.
                                2    5.75  0.0235   99.12    4.70    858.    52.
                                3    5.44  0.0213   99.25    4.29    633.    43.
                                4    5.12  0.0188   99.35    3.81    462.    44.
   95 IDLE     I  BASLNE  2
                                4    5.12  0.0105   98.81    2.13    410.     6.
*PORTS CONNECTED BACKWARDS      3    5.44  0.0139   98.87    2.80    556.     9.
                                2    5.75  0.0131   98.64    2.65    535.     9.
                                1    6.07  0.0108   99.02    2.19    385.     9.
   96 IDLE     I  BASLNE  3
                                1    6.07  0.0278   99.69    5.61    332.    45.
                                2    5.75  0.0216   99.71    4.39    248.    37.
                                3    5.44  0.0176   99.67    3.59    235.    29.
                                4    5.12  0.0133   99.62    2.71    172.    22.
   97 IDLE     I  BASLNE  1  MANIFOLDED
   98 IDLE     I  BASLNE  2  MANIFOLDED
   99 IDLE     I  BASLNE  3  MANIFOLDED
  100 IDLE     I  BASLNE  3  MANIFOLDED
  105 100%     I  BASLNE  1  MANIFOLDED
  106 100%     I  BASLNE  2  MANIFOLDED
  107 100%     I  BASLNE  3  MANIFOLDED
  167 IDLE     I       1  1
                                1    6.07  0.0224   99.17    4.50    797.    40.
                                2    5.75  0.0200   99.05    4.03    645.    25.
                                3    5.44  0.0173   99.22    3.50    538.    23.
                                4    5.12  0.0158   99.54    3.22    279.    21.
  168 IDLE     I       1  2
                                1    6.07  0.0132   96.78    2.56   1297.    12.
                                2    5.75  0.0201   98.89    4.03    778.    20.
                                3    5.44  0.0169   98.22    3.35    893.    12.
                                4    5.12  0.0121   97.99    2.41    648.     6.
  169 IDLE     I       1  3
                                1    6.07  0.0271   99.84    5.50    161.    50.
                                2    5.75  0.0212   99.59    4.30    304.    50.
                                3    5.44  0.0271   99.79    5.47    222.    63.
                                4    5.12  0.0135   99.79    2.78     99.    33.
  172  80%     I       1
                                1    6.07  0.0385   97.13    7.28   4259.   142.
                                2    5.75  0.0495   97.81    9.39   3942.   207.
                                3    5.44  0.0434   99.29    8.55   1238.   201.
                                4    5.12  0.0298   99.68    6.00    352.   122.
  173  80%     I       1  2
                                1    6.07  0.0323   99.83    6.50    176.   136.
                                2    5.75  0.0348   99.77    7.00    279.   143.
                                3    5.44  0.0280   99.86    5.67    118.    98.
                                4    5.12  0.0199   99.85    4.07     90.    18.
  174  80%     I       1  3
                                1    6.07  0.0604   97.89   11.33   5133.   267.
                                2    5.75  0.0541   99.00   10.48   2175.   262.
                                3    5.44  0.0612   96.53   11.09   8671.   274.
                                4    5.12  0.0352   99.70    7.06    391.   157.
  176 100%     I       1  1
                                1    6.07  0.0408   97.80    7.81   3549.   186.
                                2    5.75  0.0405   99.57    8.06    637.   237.
                                3    5.44  0.0349   99.84    7.03    139.   232.
                                4    5.12  0.0257   99.83    5.23    113.   145.
  177 100%     I       1  2
                                1    6.07  0.0321   99.86    6.48    114.   191.
                                2    5.75  0.0377   99.59    7.52    550.   224.
                                3    5.44  0.0301   99.62    6.05    410.   171.
                                4    5.12  0.0201   99.83    4.10     87.   116.
  178 100%     I       1  3
                                1    6.07  0.0510   99.60   10.05    727.   356.
                                2    5.75  0.0402   99.67    8.02    449.   257.
                                3    5.44  0.0552   99.06   10.69   2067.   348.
                                4    5.12  0.0366   99.64    7.33    460.   269.
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1 JUNE 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT I

RDG	COND	CONCEPT	MOD	RAKE	PORT	RADIAL LOCATION	F/A	EFF %	CO2 %	CO PPM	NOX PPM
192	IDLE	I	2	1	1	6.07	0.0164	98.74	3.29	620.	27.
					2	5.75	0.0154	98.64	3.08	660.	24.
					3	5.44	0.0174	98.95	3.50	628.	28.
					4	5.12	0.0176	99.40	3.57	405.	29.
193	IDLE	I	2	2	1	6.07	0.0157	98.89	3.15	567.	23.
					2	5.75	0.0162	98.54	3.24	697.	23.
					3	5.44	0.0130	98.58	2.62	488.	20.
					4	5.12	0.0094	98.14	1.89	401.	15.
194	IDLE	I	2	3	1	6.07	0.0358	99.64	7.15	484.	70.
					2	5.75	0.0237	99.17	4.74	841.	41.
					3	5.44	0.0294	99.34	5.88	685.	54.
					4	5.12	0.0141	98.88	2.84	500.	23.
197	80%	I	2	1	1	6.07	0.0473	98.08	9.03	3547.	176.
					2	5.75	0.0448	99.32	8.81	1231.	199.
					3	5.44	0.0489	99.14	9.55	1713.	215.
					4	5.12	0.0525	98.47	10.06	3292.	232.
198	80%	I	2	2	1	6.07	0.0695	85.38	10.66	14047.	166.
					2	5.75	0.0728	80.83	10.41	15262.	185.
					3	5.44	0.0306	98.72	6.04	1225.	135.
					4	5.12	0.0181	99.56	3.68	180.	68.
199	80%	I	2	3	1	6.07	0.0623	96.55	11.34	7982.	242.
					2	5.75	0.0490	97.74	9.30	3745.	231.
					3	5.44	0.0653	95.18	11.43	12376.	247.
					4	5.12	0.0276	98.95	5.52	363.	117.
205	80%	I	2	1	1	6.32	0.0408	98.98	8.00	1676.	207.
					2	6.00	0.0477	97.28	8.95	5155.	259.
					3	5.69	0.0438	99.08	8.59	1641.	263.
					4	5.37	0.0614	96.42	11.11	8606.	461.
206	80%	I	2	2	1	6.32	0.0564	77.53	7.77	13532.	119.
					2	6.00	0.0584	91.69	9.78	12753.	233.
					3	5.69	0.0311	99.84	6.28	62.	190.
					4	5.37	0.0247	99.79	5.01	133.	135.
207	80%	I	2	3	1	6.32	0.0597	96.07	10.73	9261.	181.
					2	6.00	0.0604	96.02	11.65	7747.	428.
					3	5.69	0.0625	95.24	10.99	11471.	287.
					4	5.37	0.0612	97.13	11.26	7150.	359.
216	80%	I	3	1	1	6.07	0.0302	99.25	6.02	915.	149.
					2	5.75	0.0330	99.68	6.62	407.	153.
					3	5.44	0.0353	99.75	7.09	325.	149.
					4	5.12	0.0319	99.90	6.44	93.	136.
217	80%	I	3	2	1	6.07	0.0266	99.93	5.41	38.	130.
					2	5.75	0.0284	99.92	5.76	48.	136.
					3	5.44	0.0311	99.93	6.29	45.	131.
					4	5.12	0.0330	99.93	6.66	61.	139.
218	80%	I	3	3	1	6.07	0.0580	95.77	10.36	9984.	255.
					2	5.75	0.0464	99.74	9.20	441.	244.
					3	5.44	0.0429	99.59	8.52	680.	214.
					4	5.12	0.0476	99.77	9.43	383.	273.
238	80%	I	4	1	1	6.07	0.0571	97.16	10.56	6614.	274.
					2	5.75	0.0515	98.38	9.96	3450.	251.
					3	5.44	0.0442	99.73	8.78	437.	247.
					4	5.12	0.0396	99.75	7.92	347.	227.
239	80%	I	4	2	1	6.07	0.0300	99.90	6.07	76.	172.
					2	5.75	0.0359	99.91	7.23	80.	199.
					3	5.44	0.0383	99.86	7.68	169.	213.
					4	5.12	0.0307	99.70	6.19	338.	179.

PAGE 2 CONTINUED

1 JUNE 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT I

RDG	COND	CONCEPT	MOD	RAKE	PORT	RADIAL LOCATION	(----INDIVIDUAL PORT VALUES---)				
							F/A	EFF %	CO2 %	CO PPM	NOX PPM
240	80%	I	4	3							
					1	6.07	0.0567	98.33	10.78	3906.	294.
					2	5.75	0.0504	99.56	9.92	850.	276.
					3	5.44	0.0486	99.26	9.51	1458.	249.
					4	5.12	0.0446	99.65	8.85	588.	269.
241	80%	I	4	4							
					1	6.07	0.0091	99.03	1.84	373.	47.
					2	5.75	0.0331	99.66	6.64	441.	127
					3	5.44	0.0411	99.74	8.21	377.	224
					4	5.12	0.0324	99.79	6.53	240.	158.
288	80%	I	5	1							
					1	6.07	0.0115	98.55	2.31	725.	35.
					2	5.75	0.0268	99.24	5.36	835.	93.
					3	5.44	0.0307	99.83	6.21	188.	101.
					4	5.12	0.0246	99.89	5.01	88.	86.
289	80%	I	5	2							
					1	6.07	0.0138	98.47	2.80	64.	46.
					2	5.75	0.0196	99.63	4.00	60.	64.
					3	5.44	0.0206	99.73	4.20	92.	61.
					4	5.12	0.0141	99.70	2.89	89.	41.
290	80%	I	5	3							
					1	6.07	0.0240	99.52	4.84	461.	88.
					2	5.75	0.0390	99.75	7.81	359.	171.
					3	5.44	0.0269	99.73	5.44	257.	113.
					4	5.12	0.0327	99.86	6.61	142.	134.
291	80%	I	5	4							
					1	6.07	0.0115	98.88	2.32	500.	46.
					2	5.75	0.0232	99.50	4.68	440.	93.
					3	5.44	0.0440	99.57	8.74	726.	172.
					4	5.12	0.0243	99.80	4.94	144.	104.

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PAGE 1

-- DATA LISTING FOR CONCEPT II BASELINE -- NASA PRIMARY ZONE STUDY --

DATE TABULATED: 9 FEB 82

RDG	COND	MEASUREMENT	WA	BIP	BIT	BOT	RISE	WF	F/A	FLOW #
116	100%	NO CHEMISTRY	4.94	145.1	752.	1981.	1230.	345.6	0.01943	25.
117	100%	NO CHEMISTRY	4.94	147.0	751.	1998.	1247.	349.4	0.01965	26.
124	IDLE	NO CHEMISTRY	2.27	54.7	367.	1041.	675.	85.5	0.01045	29.
125	IDLE	EXHAUST CHEM	2.27	55.6	370.	1056.	687.	86.4	0.01056	29.
126	IDLE	PZ SEQUN RK 1	2.28	55.2	370.	1060.	690.	85.8	0.01047	29.
127	IDLE	PZ SEQUN RK 2	2.26	55.2	370.	1050.	680.	85.1	0.01046	29.
128	IDLE	PZ SEQUN RK 3	2.28	55.6	368.	1039.	670.	86.5	0.01055	29.
129	IDLE	EXHAUST CHEM	2.29	55.3	368.	1054.	685.	85.1	0.01033	29.
130	IDLE	NO CHEMISTRY	2.29	55.0	357.	1029.	662.	84.2	0.01021	29.
133	ALT	EXHAUST CHEM	2.60	78.2	696.	1896.	1199.	189.9	0.02028	25.
134	ALT	NO CHEMISTRY	2.61	78.6	684.	1852.	1168.	190.1	0.02023	25.
135	ALT	EXHAUST CHEM	2.60	78.9	682.	1878.	1196.	189.3	0.02025	25.
136	50%	EXHAUST CHEM	3.66	99.0	545.	1557.	1012.	207.1	0.01570	26.
137	50%	NO CHEMISTRY	3.67	98.6	538.	1530.	992.	205.6	0.01557	26.
138	80%	NO CHEMISTRY	4.57	129.6	614.	1829.	1215.	321.7	0.01958	25.
139	80%	EXHAUST CHEM	4.57	130.0	615.	1872.	1257.	321.3	0.01955	25.
140	80%	PZ SEQUN RK 1	4.56	129.8	606.	1750.	1144.	321.2	0.01956	25.
141	80%	PZ SEQUN RK 2	4.56	130.5	606.	1752.	1146.	321.3	0.01956	25.
142	80%	PZ SEQUN RK 2	4.54	131.4	606.	1755.	1150.	321.0	0.01963	25.
143	80%	PZ SEQUN RK 3	4.55	128.6	604.	1747.	1143.	320.8	0.01959	25.
144	80%	PZ SEQUN RK 3	4.56	129.0	603.	1737.	1134.	321.3	0.01958	25.

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PAGE 2
-- DATA LISTING FOR CONCEPT II BASELINE -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  9 FEB 82
RDG COND    F1    ACD   DP/P  HOT   AVG     TM/TA  PATRN  TIP  TMID RMID ROOT
                              SKIN  SKIN                   F    F    F    F

116 100%  1.186  5.67  3.63 1283. 1111.   1.134  0.216   7.  18.  21. -44.
117 100%  1.169  5.67  3.52 1330. 1098.   1.137  0.220   6.  19.  20. -45.
124 IDLE  1.196  5.69  3.66  809.  553.   1.113  0.175  20.  24.   5. -49.
125 IDLE  1.177  5.63  3.63  812.  561.   1.110  0.170  19.  22.   4. -43.
126 IDLE  1.187  5.67  3.64  832.  565.   1.106  0.162  21.  22.   2. -45.
127 IDLE  1.178  5.60  3.67  855.  567.   1.115  0.178  18.  21.   4. -43.
128 IDLE  1.179  5.63  3.63  853.  565.   1.060  0.093  22.  22.   2. -45.
129 IDLE  1.190  5.64  3.70  854.  566.   1.094  0.145  20.  21.   3. -43.
130 IDLE  1.198  5.65  3.72  852.  565.   1.109  0.169  20.  23.   4. -47.
133  ALT  1.131  5.55  3.45 1411. 1126.   1.122  0.193  29.  32.  18. -78.
134  ALT  1.123  5.56  3.38 1395. 1111.   1.131  0.208  25.  36.  21. -82.
135  ALT  1.113  5.53  3.35 1391. 1105.   1.132  0.208  27.  31.  17. -76.
136  50%  1.173  5.70  3.52 1086.  834.   1.142  0.218  24.  29.   9. -62.
137  50%  1.175  5.71  3.51 1081.  826.   1.154  0.237  19.  30.  13. -61.
138  80%  1.155  5.49  3.67 1272. 1018.   1.235  0.354  14.  30.  12. -56.
139  80%  1.151  5.50  3.63 1282. 1023.   1.170  0.254  18.  28.   8. -54.
140  80%  1.148  5.51  3.60 1222.  997.   1.026  0.039  -7.  10.  25. -27.
141  80%  1.141  5.53  3.53 1197.  977.   1.030  0.045  -6.  11.  25. -28.
142  80%  1.128  5.51  3.47 1199.  975.   1.025  0.039  -5.  12.  23. -29.
143  80%  1.154  5.52  3.63 1199.  974.   1.037  0.056  -6.  14.  20. -27.
144  80%  1.151  5.51  3.61 1215.  988.   1.042  0.064  -9.   8.  30. -27.
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PAGE 3
-- DATA LISTING FOR CONCEPT II BASELINE -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  9 FEB 82
RDG AT SMOKE LBO     CHEM   CO2     CO   CHX   NOX   EFF      CO   CHX   NOX
             F/A     F/A     %     PPM   PPM   PPM            EI    EI    EI
116
117
124
125 EX              0.0097  1.95   406.  52.8  12.   98.26   40.8   8.3  1.9
126 PZ    6.        0.0139  2.79   543.  54.5  25.   98.53   38.4   6.1  2.9
127 PZ   10.        0.0201  3.98   903. 151.2  30.   97.87   44.3  11.7  2.5
128 PZ    0.        0.0129  2.51   942. 215.1   6.   95.93   71.4  25.6  0.8
129 EX              0.0096  1.94   389.  43.7   7.   98.42   39.4   7.0  1.2
130
133 EX              0.0176  3.60    28.   1.8 148.   99.89    1.6   0.2 13.6
134
135 EX              0.0212  4.33    32.   0.9 139.   99.91    1.5   0.1 10.7
136 EX              0.0162  3.32    35.   0.6  84.   99.91    2.1   0.1  8.4
137
138
139 EX              0.0205  4.19    26.   0.2 136.   99.92    1.2   0.0 10.8
140 PZ   34.        0.0345  6.91   339.   1.8 185.   99.73    9.8   0.1  8.8
141 PZ   61.        0.0462  8.79  3927.   7.1*************   88.5   0.3*****
142 PZ   66.        0.0343  6.80  1070.   8.9 210.   99.20   31.3   0.4 10.1
143 PZ    0.        0.0266  5.36   359.   6.7 137.   99.62   13.4   0.4  8.4
144 PZ              0.0244  4.96    58.   1.6 116.   99.90    2.4   0.1  7.7
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PAGE 1
-- DATA LISTING FOR CONCEPT II MOD 1 -- NASA PRIMARY ZONE STUDY --
                          DATE TABULATED:  2 MAR 82
                                                                         FLOW
RDG COND   MEASUREMENT    WA     BIP    BIT    BOT    RISE    WF      F/A     %

179 IDLE  NO  CHEMISTRY  2.35   56.4   360.   1044.   684.  87.5  0.01035  28.
180  80%  NO  CHEMISTRY  4.58  130.8   611.   1897.  1286. 322.2  0.01952  23.
181  80%  EXHAUST  CHEM  4.58  131.4   612.   1931.  1319. 322.8  0.01959  23.
183  80%  PZ SEQUN RK 1  4.60  131.1   609.   1852.  1243. 322.1  0.01946  23.
184  80%  PZ SEQUN RK 2  4.61  132.7   608.   1846.  1238. 320.7  0.01935  23.
185  80%  PZ SEQUN RK 3  4.60  130.0   610.   1862.  1252. 322.0  0.01946  23.
186 100%  NO  CHEMISTRY  4.92  145.3   753.   2007.  1254. 344.3  0.01943  23.
187 100%  EXHAUST  CHEM  4.93  146.0   750.   2013.  1263. 343.6  0.01935  23.

PAGE 2
-- DATA LISTING FOR CONCEPT II MOD 1 -- NASA PRIMARY ZONE STUDY --
                          DATE TABULATED:  2 MAR 82
RDG COND    F1     ACD   DP/P  HOT   AVG    TM/TA  PATRN   TIP  TMID RMID ROOT
                               SKIN  SKIN                   F     F    F    F
179 IDLE  1.191   5.87   3.41  828.   593.  1.113  0.172   11.   23.   9. -42.
180  80%  1.147   5.76   3.29 1161.   980.  1.186  0.274   -5.   18.  16. -29.
181  80%  1.141   5.75   3.26 1162.   991.  1.140  0.204   -4.   15.  11. -23.
183  80%  1.147   5.75   3.29 1171.   978.  1.035  0.052  -11.   10.   9.  -8.
184  80%  1.134   5.75   3.23 1165.   972.  1.064  0.095   -9.   13.   5.  -5.
185  80%  1.156   5.74   3.36 1167.   976.  1.068  0.101   -7.   14.   4.  -6.
186 100%  1.180   5.69   3.57 1292.  1124.  1.135  0.216    4.   26.  -7. -21.
187 100%  1.175   5.65   3.59 1292.  1123.  1.079  0.126   -3.   17.  -3. -14.

PAGE 3
-- DATA LISTING FOR CONCEPT II MOD 1 -- NASA PRIMARY ZONE STUDY --
                          DATE TABULATED:  2 MAR 82
RDG AT SMOKE  LBC      CHEM     CO2     CO    CHX    NOX    EFF     CO  CHX  NOX
              F/A      F/A      %      PPM    PPM    PPM            EI   EI   EI
179          0.0050
180          0.0040
181 EX   0.           0.0217  4.42    32.    2.0   151.   99.90   1.5  0.1 11.4
183 PZ   7.           0.0372  7.46   272.    0.2   190.   99.79   7.4  0.0  8.4
184 PZ  16.           0.0270  5.43   542.    1.2   174.   99.49  20.0  0.1 10.5
185 PZ  21.           0.0322  6.47   351.    0.9   202.   99.70  10.9  0.0 10.3
186     21.
187 EX   5.  0.0025   0.0209  4.27    23.    0.1   201.   99.90   1.1  0.0 15.6
```

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PAGE 1
-- DATA LISTING FOR CONCEPT II MOD 2 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  5 APR 82
                                                                  FLOW
RDG COND   MEASUREMENT    WA     BIP   BIT    BOT    RISE    WF     F/A     #

208  80%  NO  CHEMISTRY  4.64  130.3  610.  1869.  1259. 325.5  0.01947  23.
209  80%  EXHAUST  CHEM  4.64  132.0  609.  1890.  1281. 325.4  0.01947  23.
210  80%  PZ SEQUN RK 1  4.66  130.8  605.  1873.  1268. 325.5  0.01938  23.
211  80%  PZ SEQUN RK 2  4.65  131.6  603.  1880.  1277. 325.7  0.01947  23.
212  80%  PZ SEQUN RK 3  4.66  130.9  601.  1854.  1253. 324.9  0.01938  23.
213 100%  NO  CHEMISTRY  5.00  145.9  757.  2004.  1247. 352.5  0.01960  23.
```

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PAGE 2
-- DATA LISTING FOR CONCEPT II MOD 2 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  5 APR 82
RDG COND    FI    ACD   DP/P  HOT   AVG    TM/TA  PATRN  TIP THID RMID ROOT
                             SKIN  SKIN                   F    F    F    F
208  80%  1.165  5.62  3.57 1360. 1058.  1.160  0.237  -5.  22.  35. -52.
209  80%  1.150  5.63  3.46 1345. 1057.  1.143  0.210   3.  25.  32. -59.
210  80%  1.164  5.66  3.51 1317. 1049.  1.140  0.207   4.  25.  33. -60.
211  80%  1.151  5.67  3.41 1317. 1050.  1.142  0.209   3.  27.  35. -65.
212  80%  1.158  5.68  3.44 1300. 1043.  1.148  0.219   3.  26.  35. -62.
213 100%  1.194  5.66  3.69 1453. 1214.  1.148  0.238   4.  28.  36. -68.
```

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PAGE 3
-- DATA LISTING FOR CONCEPT II MOD 2 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  5 APR 82
RDG AT SMOKE  LBC     CHEM    CO2    CO   CHX   NOX   EFF    CO   CHX  NOX
              F/A     F/A     %     PPM   PPM   PPM          EI    EI   EI
208          0.0020
209 EX   8.          0.0212  4.33   27.   0.8  140.  99.92   1.2  0.1 10.7
210 PZ  27.          0.0282  5.70  265.   1.0  147.  99.74   9.4  0.1  8.5
211 PZ  33.          0.0371  7.33 1313.   4.8  218.  99.13  35.6  0.2  9.7
212 PZ  29.          0.0280  5.66  282.   2.0  182.  99.71  10.0  0.1 10.6
213          0.0015
```

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PAGE 1

-- DATA LISTING FOR CONCEPT II MOD 3 -- NASA PRIMARY ZONE STUDY --

DATE TABULATED: 26 MAY 82

RDG	COND	MEASUREMENT	WA	BIP	BIT	BOT	RISE	WF	F/A	FLOW #
227	IDLE	NO CHEMISTRY	2.33	55.3	381.	1030.	649.	87.4	0.01041	26.
228	IDLE	EXHAUST CHEM	2.32	54.6	369.	1027.	659.	87.6	0.01047	26.
229	80%	NO CHEMISTRY	4.53	130.4	615.	1902.	1287.	317.4	0.01944	23.
230	80%	EXHAUST CHEM	4.50	129.3	621.	1920.	1299.	317.2	0.01960	23.
231	80%	PZ SEQUN RK 1	4.49	129.0	624.	1895.	1270.	317.4	0.01962	23.
232	80%	PZ SEQUN RK 2	4.48	130.2	624.	1915.	1292.	318.9	0.01976	23.
233	80%	PZ SEQUN RK 3	4.55	130.1	609.	1865.	1257.	324.5	0.01980	23.
234	80%	PZ SEQUN RK 4	4.59	130.9	607.	1868.	1261.	321.4	0.01944	23.
235	100%	NO CHEMISTRY	4.98	147.8	755.	1974.	1219.	352.4	0.01965	23.
243	IDLE	NO CHEMISTRY	2.29	55.3	383.	874.	491.	85.2	0.01036	25.
244	IDLE	NO CHEMISTRY	2.24	58.7	408.	1366.	958.	117.9	0.01459	25.
245	IDLE	NO CHEMISTRY	2.28	55.2	399.	940.	541.	85.7	0.01043	25.
246	IDLE	NO CHEMISTRY	2.28	55.8	372.	868.	496.	84.9	0.01035	27.
247	IDLE	NO CHEMISTRY	2.32	55.1	384.	1151.	767.	103.8	0.01242	26.
248	IDLE	PZ SEQUN RK 1	2.32	54.7	380.	977.	597.	103.7	0.01242	26.
249	IDLE	PZ SEQUN RK 2	2.32	55.0	383.	1042.	659.	103.9	0.01242	26.
250	IDLE	PZ SEQUN RK 3	2.32	55.5	385.	1071.	685.	103.9	0.01246	26.
251	IDLE	PZ SEQUN RK 4	2.32	55.7	385.	1136.	751.	104.5	0.01252	26.

PAGE 2

-- DATA LISTING FOR CONCEPT II MOD 3 -- NASA PRIMARY ZONE STUDY --

DATE TABULATED: 26 MAY 82

RDG	COND	F1	ACD	DP/P	HOT SKIN	AVG SKIN	TM/TA	PATRN	TIP F	TMID F	RMID F	ROOT F
227	IDLE	1.224	5.91	3.56	72.	0.	1.124	0.197	12.	21.	15.	-47.
228	IDLE	1.225	5.91	3.57	76.	0.	1.153	0.238	17.	25.	13.	-54.
229	80%	1.139	5.54	3.51	83.	0.	1.122	0.180	-9.	15.	26.	-32.
230	80%	1.143	5.78	3.25	85.	0.	1.102	0.150	25.	45.	32.	-101.
231	80%	1.147	5.75	3.29	89.	0.	1.050	0.075	14.	37.	35.	-87.
232	80%	1.133	5.73	3.24	90.	0.	1.049	0.073	19.	41.	34.	-94.
233	80%	1.144	5.77	3.26	92.	0.	1.055	0.082	23.	44.	34.	-101.
234	80%	1.146	5.81	3.22	94.	0.	1.053	0.078	22.	48.	36.	-104.
235	100%	1.175	5.84	3.35	99.	0.	1.122	0.198	21.	43.	37.	-102.
243	IDLE	1.200	5.99	3.32	75.	0.	1.374	0.666	5.	15.	16.	-35.
244	IDLE	1.126	5.75	3.18	82.	0.	1.109	0.156	0.	17.	24.	-43.
245	IDLE	1.212	5.93	3.46	84.	0.	1.305	0.530	-0.	12.	16.	-28.
246	IDLE	1.176	5.82	3.38	90.	0.	1.326	0.569	-1.	7.	12.	-18.
247	IDLE	1.224	5.72	3.80	91.	0.	1.178	0.257	-1.	12.	20.	-31.
248	IDLE	1.230	5.70	3.86	93.	0.	1.205	0.336	8.	10.	11.	-28.
249	IDLE	1.226	5.71	3.82	95.	0.	1.184	0.291	12.	14.	11.	-37.
250	IDLE	1.215	5.68	3.79	96.	0.	1.100	0.156	10.	13.	10.	-34.
251	IDLE	1.212	5.63	3.84	94.	0.	1.185	0.280	13.	19.	10.	-43.

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PAGE 3
-- DATA LISTING FOR CONCEPT II MOD 3 -- NASA PRIMARY ZONE STUDY --
                                DATE TABULATED:  26 MAY 82
RDG AT SMOKE  LBO      CHEM    CO2     CO    CHX     NOX    EFF     CO   CHX   NOX
              F/A      F/A      %     PPM    PPM     PPM            EI    EI    EI
227          0.0050
228 EX   0.            0.0109  2.02  1356.  340.3    14.   92.70 121.3  47.8   2.1
229          0.0020
230 EX   0.            0.0219  4.46    26.    5.9   162.   99.88   1.2   0.4  12.0
231 PZ  55.            0.0323  6.42  1074.   10.1   191.   99.15  33.3   0.5   9.7
232 PZ  27.            0.0251  5.07   382.    5.4   180.   99.57  15.1   0.3  11.7
233 PZ   8.            0.0336  6.77   169.    8.5   193.   99.81   5.0   0.4   9.4
234 PZ  29.            0.0270  5.42   711.   10.1   159.   99.30  26.2   0.6   9.6
235          0.0017
243          0.0060
244
245
246          0.0065
247
248 PZ                 0.0222  4.34  1390.  209.4    32.   97.19  62.2  14.7   2.4
249 PZ                 0.0254  5.00  1320.  197.4    36.   97.67  51.6  12.1   2.3
250 PZ                 0.0199  3.99   712.   45.1    33.   98.85  35.5   3.5   2.7
251 PZ                 0.0272  5.25  2012.  301.0    36.   96.68  73.7  17.3   2.2
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PAGE 1
-- DATA LISTING FOR CONCEPT II MOD 4 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  26 MAY 82
                                                                              FLOW
RDG COND   MEASUREMENT     WA      BIP    BIT    BOT     RISE    WF      F/A      %

252 IDLE  NO  CHEMISTRY  2.32     56.3   377.   1022.    644.   86.2  0.01031   13.
253 IDLE  NO  CHEMISTRY  2.33     55.9   400.   1215.    815.  105.3  0.01257   13.
254 IDLE  EXHAUST  CHEM  2.30     54.8   376.   1126.    750.   86.7  0.01045   13.
255 IDLE  EXHAUST  CHEM  2.32     54.9   374.   1305.    931.  104.7  0.01253   13.
256 IDLE  PZ SEQUN RK 1  2.31     54.7   373.   1209.    836.  103.9  0.01251   13.
257 IDLE  PZ SEQUN RK 2  2.30     54.6   376.   1211.    835.  104.2  0.01261   13.
258 IDLE  PZ SEQUN RK 3  2.35     55.3   375.   1197.    822.  104.3  0.01236   13.
259 IDLE  PZ SEQUN RK 4  2.33     55.2   374.   1198.    825.  104.4  0.01243   13.

PAGE 2
-- DATA LISTING FOR CONCEPT II MOD 4 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  26 MAY 82
RDG COND      FI     ACD    DP/P   HOT    AVG     TM/TA   PATRN   TIP  TMID RMID ROOT
                                   SKIN   SKIN                     F     F    F    F

252 IDLE   1.194   6.02   3.26     0.     0.   1.340   0.539   20.   32.   19. -70.
253 IDLE   1.220   5.80   3.67     0.     0.   1.338   0.504   18.   31.   21. -72.
254 IDLE   1.215   5.85   3.58     0.     0.   1.263   0.395   32.   39.   13. -83.
255 IDLE   1.220   5.82   3.65     0.     0.   1.244   0.342   38.   48.   17.-103.
256 IDLE   1.218   5.81   3.65     0.     0.   1.169   0.244   33.   38.   13. -83.
257 IDLE   1.216   5.78   3.66     0.     0.   1.168   0.244   34.   38.   14. -86.
258 IDLE   1.224   5.82   3.67     0.     0.   1.165   0.239   34.   39.   12. -84.
259 IDLE   1.220   5.81   3.65     0.     0.   1.181   0.263   34.   39.   13. -85.

PAGE 3
-- DATA L7STING FOR CONCEPT II MOD 4 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  26 MAY 82
RDG AT  SMOKE  LBO        CHEM     CO2      CO     CHX      NOX    EFF     CO    CHX   NOX
               F/A        F/A      %       PPM     PPM      PPM            EI     EI    EI

252          0.0038
253
254 EX   0.             0.0120   2.42    468.   68.9     30.   98.28   38.1   8.8   4.1
255 EX   0.             0.0152   3.06    449.   74.5     40.   98.60   29.0   7.6   4.2
256 PZ   8.             0.0284   5.56   1325.  224.6     63.   97.75   46.5  12.4   3.7
257 PZ  69.             0.0374   7.08   3788.  133.4    108.   97.11  102.0   5.6   4.8
258 PZ   0.             0.0120   2.43    355.   39.6     32.   98.84   29.0   5.1   4.3
259 PZ  18.             0.0359   6.31   6413.  826.8     51.   92.43  179.9  36.4   2.4
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PAGE 1
-- DATA LISTING FOR CONCEPT II MOD 5 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  28 MAY 82
                                                                          FLOW
RDG COND    MEASUREMENT     WA     BIP   BIT    BOT    RISE    WF      F/A     %

267 IDLE  NO  CHEMISTRY   2.31    55.8  364.  1050.   686.  86.3  0.01037  13.
268 IDLE  EXHAUST  CHEM   2.31    56.1  362.  1028.   665.  86.0  0.01036  13.
269 IDLE  PZ SEQUN RK 1   2.31    56.2  354.   950.   595.  86.0  0.01037  12.
270 IDLE  PZ SEQUN RK 2   2.31    56.2  350.   950.   600.  86.3  0.01040  12.
271 IDLE  PZ SEQUN RK 3   2.30    56.1  349.   955.   606.  86.1  0.01039  12.
272 IDLE  PZ SEQUN RK 4   2.30    56.3  345.   945.   600.  86.2  0.01040  12.
273 IDLE  NO  CHEMISTRY   2.31    54.6  364.  1200.   836. 104.1  0.01250  12.
274 IDLE  EXHAUST  CHEM   2.32    55.5  361.  1176.   815. 104.2  0.01250  12.
275 IDLE  PZ SEQUN RK 1   2.32    56.0  353.  1070.   718. 104.2  0.01248  12.
276 IDLE  PZ SEQUN RK 2   2.33    56.1  348.  1050.   702. 104.0  0.01239  12.
277 IDLE  PZ SEQUN RK 3   2.35    55.2  344.  1048.   704. 105.2  0.01243  12.
278 IDLE  PZ SEQUN RK 4   2.33    55.0  342.  1053.   711. 105.5  0.01258  12.


PAGE 2
-- DATA LISTING FOR CONCEPT II MOD 5 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  28 MAY 82
RDG COND      FI     ACD   DP/P   HOT    AVG     TM/TA   PATRN  TIP TMID RMID ROOT
                                  SKIN   SKIN                    F    F    F    F

267 IDLE   1.190   5.68  3.64    0.      0.   1.240   0.366   5.  16.  14. -36.
268 IDLE   1.178   5.68  3.56    0.      0.   1.137   0.212  15.  20.   6. -43.
269 IDLE   1.172   5.71  3.49    0.      0.   1.145   0.231  12.  16.   6. -35.
270 IDLE   1.169   5.69  3.49    0.      0.   1.150   0.238  12.  16.   7. -33.
271 IDLE   1.166   5.70  3.47    0.      0.   1.170   0.269  14.  16.   5. -35.
272 IDLE   1.161   5.69  3.44    0.      0.   1.152   0.240  16.  18.   3. -37.
273 IDLE   1.217   5.61  3.91    0.      0.   1.242   0.348   8.  21.  17. -47.
274 IDLE   1.196   5.62  3.76    0.      0.   1.200   0.289  22.  29.   8. -59.
275 IDLE   1.182   5.62  3.67    0.      0.   1.092   0.137  18.  21.   5. -44.
276 IDLE   1.181   5.63  3.64    0.      0.   1.082   0.123  18.  22.   6. -47.
277 IDLE   1.207   5.64  3.80    0.      0.   1.128   0.190  19.  20.   7. -47.
278 IDLE   1.200   5.62  3.78    0.      0.   1.110   0.162  20.  24.   6. -50.
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PAGE 3
-- DATA LISTING FOR CONCEPT II MOD 5 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  28 MAY 82
RDG AT SMOKE  LBO      CHEM     CO2     CO    CHX     NOX    EFF     CO   CHX   NOX
              F/A      F/A       %     PPM    PPM     PPM             EI    EI    EI
267          0.0040
268 EX   0.           0.0105   2.07    558.  129.8    18.   97.00   52.2  19.1  2.7
269 PZ   0.           0.0138   2.69    944.  211.8    22.   96.22   67.3  23.7  2.6
270 PZ   0.           0.0190   3.76    895.  182.9    39.   97.52   46.5  14.9  3.3
271 PZ   0.           0.0102   2.03    424.   87.5    18.   97.81   40.9  13.2  2.8
272 PZ   0.           0.0106   2.08    666.  161.1    15.   96.39   61.4  23.3  2.2
273
274 EX   0.           0.0126   2.54    412.   50.6    24.   98.67   32.2   6.2  3.1
275 PZ   3.           0.0232   4.57   1389.   90.9    36.   98.06   59.4   6.1  2.5
276 PZ  22.           0.0388   7.50   2708.   80.9    79.   98.07   70.4   3.3  3.4
277 PZ   0.           0.0131   2.66    331.   36.4    25.   99.02   24.7   4.3  3.1
278 PZ   0.           0.0180   3.55   1125.   98.6    22.   97.78   61.7   8.5  2.0
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1 JUNE 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT II

						(-------AVERAGE RAKE VALUES-------)					
RDG	COND	CONCEPT	MOD	RAKE	CIRCUM LOCATION	F/A	EFF %	CO2 %	CO PPM	NOX PPM	SMOKE
126	IDLE	II	BASLNE	1	11.25	0.0139	98.53	2.79	54[illegible].	25.	6.
127	IDLE	II	BASLNE	2	22.50	0.0201	97.87	3.98	903.	30.	10.
128	IDLE	II	BASLNE	3	15.50	0.0129	95.93	2.51	942.	6.	0.
140	80%	II	BASLNE	1	11.25	0.0345	99.73	6.91	339.	185.	34.
141	80%	II	BASLNE	2	22.50	0.0462	*******	8.79	3927.	******	61.
142	80%	II	BASLNE	2	22.50	0.0343	99.20	6.80	1070.	210.	66.
143	80%	II	BASLNE	3	15.50	0.0266	99.62	5.36	359.	137.	0.
144	80%	II	BASLNE	3	15.50	0.0244	99.90	4.96	58.	116.	
183	80%	II	1	1	11.25	0.0372	99.79	7.46	272.	190.	7.
184	80%	II	1	2	22.50	0.0270	99.49	5.43	542.	174.	16.
185	80%	II	1	3	15.50	0.0322	99.70	6.47	351.	202.	21.
210	80%	II	2	1	11.25	0.0282	99.74	5.70	265.	147.	27.
211	80%	II	2	2	22.50	0.0371	99.13	7.33	1313.	218.	33.
212	80%	II	2	3	15.50	0.0280	99.71	5.66	282.	182.	29.
231	80%	II	3	1	11.25	0.0323	99.15	6.42	1074.	191.	55.
232	80%	II	3	2	22.50	0.0251	99.57	5.07	382.	180.	27.
233	80%	II	3	3	15.50	0.0336	99.81	6.77	169.	193.	8.
234	80%	II	3	4	7.50	0.0270	99.30	5.42	711.	159.	29.
248	IDLE	II	3	1	11.25	0.0222	97.19	4.34	1390.	32.	
249	IDLE	II	3	2	22.50	0.0254	97.67	5.00	1320.	36.	
250	IDLE	II	3	3	15.50	0.0199	98.85	3.99	712.	33.	
251	IDLE	II	3	4	7.50	0.0272	96.68	5.25	2012.	36.	
256	IDLE	II	4	1	11.25	0.0284	97.75	5.56	1325.	63.	8.
257	IDLE	II	4	2	45.00	0.0374	97.11	7.08	3788.	108.	69.
258	IDLE	II	4	3	38.00	0.0120	98.84	2.43	355.	32.	0.
259	IDLE	II	4	4	7.50	0.0359	92.43	6.31	6413.	51.	18.
269	IDLE	II	5	1	11.25	0.0138	96.22	2.69	944.	22.	0.
270	IDLE	II	5	2	45.00	0.0190	97.52	3.76	895.	39.	0.
271	IDLE	II	5	3	38.00	0.0102	97.81	2.03	424.	18.	0.
272	IDLE	II	5	4	7.50	0.0106	96.39	2.08	666.	15.	0.
275	IDLE	II	5	1	11.25	0.0232	98.06	4.57	1389.	36.	3.
276	IDLE	II	5	2	45.00	0.0388	98.07	7.50	2708.	79.	22.
277	IDLE	II	5	3	38.00	0.0131	99.02	2.66	331.	25.	0.
278	IDLE	II	5	4	7.50	0.0180	97.78	3.55	1125.	22.	0.

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   PAGE 2
 1 JUNE 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT II
                                       RADIAL  (----INDIVIDUAL PORT VALUES---)
 RDG COND CONCEPT MOD RAKE PORT LOCATION  F/A     EFF      CO2      CO     NOX
                                                    %        %      PPM    PPM
 126 IDLE    II  BASLNE  1
                              1   6.07   0.0112   98.79   2.26    399.    26.
                              2   5.75   0.0150   98.61   3.01    566.    29.
                              3   5.44   0.0173   98.31   3.45    739.    26.
                              4   3.12   0.0121   98.50   2.43    469.    18.
 127 IDLE    II  BASLNE  2
                              4   5.12   0.0180   98.69   3.61    533.    22.
*PORTS CONNECTED BACKWARDS    3   5.44   0.0196   98.44   3.90    909.    18.
                              2   5.75   0.0269   97.31   5.24   1429.    46.
                              1   6.07   0.0161   97.36   3.17    741.    36.
 128 IDLE    II  BASLNE  3
                              1   6.07   0.0110   92.07   2.03   1230.     4.
                              2   5.75   0.0132   96.79   2.58    896.     6.
                              3   5.44   0.0151   96.24   2.93   1068.     5.
                              4   5.12   0.0125   98.06   2.49    576.    10.
 140  80%    II  BASLNE  1
                              1   6.07   0.0331   99.59   6.63    513.   188.
*SOME PORTS PLUGGED           2   5.75   0.0344   99.71   6.90    358.   184.
                              3   5.44   0.0352   99.81   7.08    215.   189.
                              3   5.44   0.0351   99.78   7.05    269.   180.
 141  80%    II  BASLNE  2
                              4   5.12   0.0343   99.17   6.80   1153.   208.
*PORTS BACKWARDS & PLUGGED    3   5.75   0.0608******* 11.09   8103.******
                              3   5.75   0.0560   97.87  10.53   4964.   316.
                              1   6.07   0.0342   98.84   6.73   14[illegible].   224.
 142  80%    II  BASLNE  2
                              4   5.12   0.0337   99.35   6.70    870.   204.
*PORTS BACKWARDS & PLUGGED    4   5.12   0.0311   99.39   6.23    739.   191.
                              1   6.07   0.0421   98.84   8.23   1869.   258.
                              1   6.07   0.0303   99.32   6.06    802.   188.
 143  80%    II  BASLNE  3
                              1   6.07   0.0319   98.99   6.31   1261.   185.
                              2   5.75   0.0306   99.89   6.18     70.   143.
                              3   5.44   0.0269   99.89   5.45     59.   132.
                              4   5.12   0.0171   99.87   3.51     47.    90.
 144  80%    II  BASLNE  3
                              1   6.07   0.0263   99.90   5.34     61.   121.
                              2   5.75   0.0267   99.91   5.31     58.   121.
                              3   5.44   0.0265   99.90   5.37     57.   126.
                              4   5.12   0.0181   99.88   3.71     56.    93.
 183  80%    II       1  1
                              1   6.07   0.0338   99.79   6.80    259.   186.
                              2   5.75   0.0399   99.85   7.99    177.   248.
                              3   5.44   0.0423   99.75   8.43    363.   114.
                              4   5.12   0.0329   99.75   6.61    291.   211.
 184  80%    II       1  2
                              1   6.07   0.0085   99.00   1.72    355.    55.
                              2   5.75   0.0263   99.48   5.30    552.   160.
                              3   5.44   0.0374   99.50   7.46    728.   239.
                              4   5.12   0.0361   99.61   7.22    534.   241.
 185  80%    II       1  3
                              1   6.07   0.0346   99.56   6.91    589.   222.
                              2   5.75   0.0336   99.79   6.76    239.   207.
                              3   5.44   0.0332   99.68   6.68    394.   203.
                              4   5.12   0.0273   99.80   5.53    182.   176.
 210  80%    II       2  1
                              1   6.07   0.0151   99.88   3.11     55.    75.
                              2   5.75   0.0257   99.85   5.22    128.   117.
                              3   5.44   0.0382   99.65   7.62    504.   193.
                              4   5.12   0.0342   99.70   6.86    373.   201.
 211  80%    II       2  2
                              1   6.07   0.0168   98.66   3.36    955.   105.
                              2   5.75   0.0402   98.73   7.86   2073.   236.
                              3   5.44   0.0476   99.10   9.31   1729.   282.
                              4   5.12   0.0443   99.69   8.79    495.   247.
 212  80%    II       2  3
                              1   6.07   0.0311   99.48   6.23    594.   221.
                              2   5.75   0.0270   99.90   5.49     64.   176.
                              3   5.44   0.0309   99.64   6.21    416.   193.
                              4   5.12   0.0232   99.90   4.73     53.   138.
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1 JUNE 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT II

						RADIAL	(----INDIVIDUAL PORT VALUES---)				
RDG	COND	CONCEPT	MOD	RAKE	PORT	LOCATION	F/A	EFF %	CO2 %	CO PPM	NOX PPM
231	80%	II	3	1							
					1	6.07	0.0206	99.82	4.21	116.	117.
					2	5.75	0.0306	99.67	6.16	375.	172.
					3	5.44	0.0405	99.03	7.97	1559.	245.
					4	5.12	0.0377	98.48	7.34	2247.	231.
232	80%	II	3	2							
					1	6.07	0.0101	99.12	2.05	360.	76.
					2	5.75	0.0266	99.39	5.34	612.	194.
					3	5.44	0.0304	99.67	6.13	327.	229.
					4	5.12	0.0336	99.76	6.75	230.	222.
233	80%	II	3	3							
					1	6.07	0.0343	99.80	6.89	222.	209.
					2	5.75	0.0327	99.90	6.60	81.	179.
					3	5.44	0.0328	99.74	6.62	99.	187.
					4	5.12	0.0347	99.78	6.97	273.	196.
234	80%	II	3	4							
					1	6.07	0.0075	97.29	1.47	824.	35.
					2	5.75	0.0260	99.15	5.20	876.	128.
					3	5.44	0.0379	99.39	7.53	837.	229.
					4	5.12	0.0372	99.74	7.46	306.	244.
248	IDLE	II	3	1							
					1	6.07	0.0201	95.23	3.83	1706.	28.
					2	5.75	0.0210	97.73	4.14	1268.	29.
					3	5.44	0.0239	97.46	4.68	1458.	36.
					4	5.12	0.0237	98.10	4.69	1129.	36.
249	IDLE	II	3	2							
					1	6.07	0.0302	99.10	6.04	781.	57.
					2	5.75	0.0256	98.97	5.12	827.	37.
					3	5.44	0.0242	97.27	4.73	1580.	29.
					4	5.12	0.0217	94.61	4.09	2092.	21.
250	IDLE	II	3	3							
					1	6.07	0.0209	99.11	4.21	575.	36.
					2	5.75	0.0214	99.04	4.31	682.	36.
					3	5.44	0.0209	98.97	4.20	705.	34.
					4	5.12	0.0163	98.11	3.24	888.	26.
251	IDLE	II	3	4							
					1	6.07	0.0267	94.85	4.99	3072.	32.
					2	5.75	0.0321	97.29	6.23	2003.	50.
					3	5.44	0.0264	97.15	5.13	1743.	35.
					4	5.12	0.0237	97.40	4.65	1230.	28.
256	IDLE	II	4	1							
					1	6.07	0.0318	98.46	6.25	1494.	69.
					2	5.75	0.0284	98.74	5.63	979.	65.
					3	5.44	0.0285	98.13	5.61	1185.	64.
					4	5.12	0.0249	95.30	4.75	1641.	55.
257	IDLE	II	4	2							
					1	6.07	0.0529	94.98	9.39	9703.	152.
					2	5.75	0.0392	97.84	7.53	3096.	121.
					3	5.44	0.0348	98.74	6.85	1432.	98.
					4	5.12	0.0230	98.16	4.56	922.	60.
258	IDLE	II	4	3							
					1	6.07	0.0168	99.06	3.41	414.	51.
					2	5.75	0.0103	98.47	2.07	354.	26.
					3	5.44	0.0129	99.04	2.61	341.	32.
					4	5.12	0.0081	98.52	1.63	311.	20.
259	IDLE	II	4	4							
					1	6.07	0.0332	86.16	5.17	10519.	31.
					2	5.75	0.0555	91.30	9.34	11261.	81.
					3	5.44	0.0349	97.14	6.68	2606.	66.
					4	5.12	0.0208	97.13	4.07	1265.	37.
269	IDLE	II	5	1							
					1	6.07	0.0110	94.76	2.12	860.	16.
					2	5.75	0.0130	96.19	2.52	924.	18.
					3	5.44	0.0149	97.91	2.97	805.	26.
					4	5.12	0.0162	95.67	3.13	1188.	29.
270	IDLE	II	5	2							
					1	6.07	0.0152	96.35	2.97	901.	28.
					2	5.75	0.0188	98.08	3.76	693.	37.
					3	5.44	0.0210	99.02	4.23	554.	48.
					4	5.12	0.0211	96.36	4.09	1431.	42.

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1 JUNE 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT II

RDG	COND	CONCEPT	MOD	RAKE	PORT	RADIAL LOCATION	(----INDIVIDUAL PORT VALUES---) F/A	EFF %	CO2 %	CO PPM	NOX PPM
271	IDLE	II	5	3							
					1	6.07	0.0093	97.04	1.84	434.	17.
					2	5.75	0.0100	97.13	1.99	487.	17.
					3	5.44	0.0109	98.40	2.20	397.	18.
					4	5.12	0.0104	98.51	2.11	379.	18.
272	IDLE	II	5	4							
					1	6.07	0.0076	94.71	1.46	540.	8.
					2	5.75	0.0091	95.53	1.78	611.	12.
					3	5.44	0.0120	97.26	2.38	657.	19.
					4	5.12	0.0138	97.14	2.72	857.	19.
275	IDLE	II	5	1							
					1	6.07	0.0186	96.83	3.61	1404.	29.
					2	5.75	0.0219	97.97	4.32	1348.	32.
					3	5.44	0.0257	98.47	5.07	1384.	40.
					4	5.12	0.0267	98.60	5.28	1418.	43.
275	IDLE	II	5	2							
					1	6.07	0.0383	97.25	7.32	3191.	71.
					2	5.75	0.0387	98.98	7.62	1528.	78.
					3	5.44	0.0425	98.69	8.27	2255.	90.
					4	5.12	0.0357	97.22	6.79	3857.	74.
277	IDLE	II	5	3							
					1	6.07	0.0140	98.51	2.83	446.	29.
					2	5.75	0.0130	99.26	2.64	289.	24.
					3	5.44	0.0150	99.21	3.06	326.	28.
					4	5.12	0.0105	99.12	2.13	262.	19.
278	IDLE	II	5	4							
					1	6.07	0.0066	96.23	1.30	463.	10.
					2	5.75	0.0174	98.27	3.45	973.	13.
					3	5.44	0.0236	97.76	4.64	1558.	31.
					4	5.12	0.0246	97.88	4.82	1606.	33.

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PAGE 1
-- DATA LISTING FOR CONCEPT III BASELINE -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  9 FEB 82
                                                                          FLOW
RDG COND    MEASUREMENT      WA     BIP    BIT    BOT    RISE     WF      F/A    F

118 100%  NO   CHEMISTRY   5.03   148.6   747.   2005.  1258. 355.3  0.01960  19.
119 100%  NO   CHEMISTRY   5.03   147.6   751.   2018.  1267. 355.0  0.01959  19.
149 IDLE  NO   CHEMISTRY   2.25    54.0   359.   1033.   673.  82.8  0.01021  20.
150 IDLE  EXHAUST  CHEM    2.25    53.8   355.   1059.   704.  82.6  0.01019  20.
151 IDLE  EXHAUST  CHEM    2.24    53.8   358.   1071.   713.  83.4  0.01035  20.
152  50%  NO   CHEMISTRY   3.72   100.3   544.   1590.  1046. 208.5  0.01557  18.
153  50%  EXHAUST  CHEM    3.72   100.6   540.   1593.  1054. 208.5  0.01557  18.
154  80%  NO   CHEMISTRY   4.61   131.2   624.   1896.  1273. 323.7  0.01949  18.
155  80%  NO   CHEMISTRY   4.62   130.6   612.   1892.  1280. 322.6  0.01938  18.
156  80%  EXHAUST  CHEM    4.62   131.0   610.   1967.  1357. 323.5  0.01946  18.
157  80%  PZ SEQUN RK 1    4.62   130.8   609.   1988.  1379. 322.9  0.01941  17.
158  80%  PZ SEQUN RK 2    4.64   131.4   607.   2016.  1409. 322.7  0.01930  17.
159  80%  PZ SEQUN RK 3    4.63   129.3   604.   1997.  1393. 323.2  0.01941  17.
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PAGE 2
-- DATA LISTING FOR CONCEPT III BASELINE -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  9 FEB 82
RDG COND    F1     ACD    DP/P  HOT   AVG     TM/TA   PATRN   TIP  TMID  RMID  ROOT
                                SKIN  SKIN                     F     F     F     F
118 100%   1.177   5.46   3.85 1337. 1054.    1.126   0.200    7.   30.   19.  -56.
119 100%   1.188   5.46   3.93 1377. 1079.    1.119   0.189    3.   29.   21.  -51.
149 IDLE   1.195   5.41   4.04  930.  585.    1.130   0.200    9.   19.    9.  -38.
150 IDLE   1.193   5.43   4.00  906.  581.    1.109   0.164   14.   21.    6.  -43.
151 IDLE   1.190   5.41   4.01  913.  584.    1.100   0.150   17.   24.   10.  -51.
152  50%   1.175   5.69   3.53 1274.  807.    1.138   0.210    6.   27.   18.  -51.
153  50%   1.169   5.67   3.52 1279.  811.    1.114   0.172   12.  -31.   37.  -17.
154  80%   1.157   5.76   3.35 1583.  968.    1.144   0.215   -0.   34.   27.  -59.
155  80%   1.159   5.75   3.37 1547.  953.    1.148   0.218   -2.   33.   27.  -60.
156  80%   1.153   5.73   3.36 1471.  928.    1.103   0.150    1.   34.   26.  -59.
157  80%   1.154   5.73   3.37 1435.  906.    1.079   0.114   -2.   41.   27.  -64.
158  80%   1.154   5.77   3.[illegible]2 1512.  932.    1.051   0.073    5.   40.   25.  -71.
159  80%   1.167   5.72   3.45 1559.  915.    1.085   0.122   11.   47.   23.  -81.
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PAGE 3
-- DATA LISTING FOR CONCEPT III BASELINE -- NASA PRIMARY ZONE STUDY --
                          DATE TABULATED:  9 FEB 82
RDG AT SMOKE   LBO      CHEM    CO2     CO    CHX     NOX    EFF     CO    CHX    NOX
               F/A      F/A      %     PPM    PPM     PPM            EI     EI     EI

118

119

149           0.0030

150 EX                 0.0113  2.28   379.   29.3    27.   98.85   32.9   4.0   3.9

151 EX                 0.0114  2.32   368.   15.5    20.   99.07   31.5   2.1   2.8

152           0.0018

153 EX                 0.0171  3.50    84.    1.4    77.   99.84    4.8   0.1   7.3

154           0.0024

155

156 EX   6.            0.0229  4.66    43.    0.7   135.   99.91    1.9   0.0   9.6

157 PZ  48.            0.0283  5.72   271.    1.6   171.   99.73    9.5   0.1   9.9

158 PZ  87.            0.0545  7.36  6639.8573.9    92.   72.81  126.5256.7   2.9

159 PZ  42.            0.0170  3.47   130.   44.4    72.   99.42    7.5   4.0   6.8
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PAGE 1
-- DATA LISTING FOR CONCEPT III MOD 1 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  22 FEB 82
                                                                          FLOW
RDG COND   MEASUREMENT     WA     BIP    BIT    BOT     RISE     WF       F/A    %

160  80%  NO  CHEMISTRY  4.62  130.7  615.  1945.  1330. 324.2  0.01949  19.
161  80%  EXHAUST  CHEM  4.63  132.8  611.  1978.  1367. 322.7  0.01937  18.
162  80%  PZ SEQUN RK 1  4.58  131.3  603.  1918.  1315. 323.9  0.01965  18.
163  80%  PZ SEQUN RK 2  4.59  129.8  603.  1934.  1331. 324.2  0.01962  18.
164  80%  PZ SEQUN RK 3  4.59  130.2  602.  1903.  1301. 323.0  0.01955  18.
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PAGE 2
-- DATA LISTING FOR CONCEPT III MOD 1 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  22 FEB 82
RDG COND    FI    ACD   DP/P  HOT   AVG    TM/TA  PATRN  TIP THID RMID ROOT
                              SKIN  SKIN                  F    F    F    F
160  80%  1.159  5.62  3.53 1219.  921.  1.143  0.209 -13.  35.  31. -52.
161  80%  1.140  5.61  3.42 1219.  913.  1.132  0.191 -25.  32.  37. -45.
162  80%  1.137  5.60  3.42 1219.  913.  1.065  0.094 -36.  30.  43. -38.
163  80%  1.153  5.64  3.46 1225.  917.  1.070  0.102 -26.  31.  37. -43.
164  80%  1.148  5.64  3.44 1220.  913.  1.056  0.082 -63.  27.  57. -22.
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PAGE 3
-- DATA LISTING FOR CONCEPT III MOD 1 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  22 FEB 82
RDG AT SMOKE  LBO      CHEM    CO2     CO    CHX    NOX   EFF    CO    CHX   NOX
              F/A      F/A     %      PPM    PPM    PPM          EI    EI    EI
160      0.
161 EX                0.0234  4.77    76.    5.2  114.  99.85   3.2  0.3   7.9
162 PZ  82.           0.0458  7.89  7893.1325.5  117.  91.57 175.6 46.3   4.3
163 PZ  29.           0.0388  7.67  1064.  39.6  156.  99.18  27.6  1.6   6.6
164 PZ  95.           0.0493  8.49  8986.1147.0  130.  92.17 186.5 37.4   4.4
```

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PAGE 1
-- DATA LISTING FOR CONCEPT III MOD 2 -- NASA PRIMARY ZONE STUDY --
                               DATE TABULATED:  9 AUG 82
                                                                               FLOW
RDG COND   MEASUREMENT      WA     BIP    BIT    BOT     RISE    WF      F/A      #

220  80%  NO  CHEMISTRY   4.59   130.5   621.   1895.   1275. 323.3  0.01958  17.
221  80%  EXHAUST  CHEM   4.59   131.4   625.   1924.   1299. 323.2  0.01957  16.
222  80%  PZ SEQUN RK 1   4.57   130.8   610.   1950.   1340. 323.4  0.01965  16.
223  80%  PZ SEQUN RK 2   4.58   131.3   610.   1952.   1342. 323.2  0.01959  16.
224  80%  PZ SEQUN RK 3   4.58   131.6   610.   1941.   1331. 322.8  0.01958  16.
225  80%  PZ SEQUN RK 4   4.60   129.1   609.   1940.   1332. 323.0  0.01952  16.
226 100%  NO  CHEMISTRY   4.97   147.1   753.   2023.   1270. 352.1  0.01969  16.


PAGE 2
-- DATA LISTING FOR CONCEPT III MOD 2 -- NASA PRIMARY ZONE STUDY --
                               DATE TABULATED:  9 AUG 82
RDG COND    FI     ACD    DP/P  HO    [illegible]  TM/TA  PATRN  TIP  TMID RMID ROOT
                                SKIN                               F    F    F    F

220  80%  1.155   5.23   4.04 1467. [illegible]  1.304  0.452 -43.  40.  66. -62.
221  80%  1.150   5.20   4.06 1490. [illegible]  1.218  0.323 -40.  39.  67. -65.
222  80%  1.143   5.15   4.09 1476. 1055.   1.197  0.287 -19.  55.  52. -88.
223  80%  1.142   5.16   4.06 1478. 1057.   1.201  0.292 -12.  60.  50. -99.
224  80%  1.138   5.16   4.03 1482. 1058.   1.186  0.271 -18.  56.  52. -90.
225  80%  1.163   5.15   4.24 1471. 1053.   1.183  0.266 -17.  61.  52. -95.
226 100%  1.176   5.29   4.11 1660. 1228.   1.147  0.234 -56.  39.  73. -55.


PAGE 3
-- DATA LISTING FOR CONCEPT III MOD 2 -- NASA PRIMARY ZONE STUDY --
                               DATE TABULATED:  9 AUG 82
RDG AT SMOKE  LBO      CHEM     CO2     CO    CHX     NOX    EFF     CO   CHX   NOX
              F/A      F/A      %      PPM    PPM     PPM            EI    EI    EI

220
221 EX   5.  0.0020   0.0233   4.74     41.    0.8   126.   99.91   1.7   0.1   8.8
222 PZ  28.           0.0383   7.61    815.   14.6   173.   99.42  21.4   0.6   7.4
223 PZ  33.           0.0307   6.18    426.    2.8   161.   99.63  13.8   0.1   8.6
224 PZ  35.           0.0347   6.82   1727.   18.1   153.   98.75  49.9   0.8   7.3
225 PZ   6.           0.0320   6.45     89.    1.6   156.   99.89   2.8   0.1   8.0
226          0.0015
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PAGE 1
-- DATA LISTING FOR CONCEPT III MOD 3 -- NASA PRIMARY ZONE STUDY --
                           DATE TABULATED:  26 MAY 82
                                                                      FLOW
RDG COND   MEASUREMENT    WA     BIP    BIT    BOT    RISE    WF     F/A     #

260  80%  NO  CHEMISTRY  4.55  130.4  612.  1915.  1303. 322.4  0.01968  17.
261  80%  EXHAUST  CHEM  4.57  131.2  610.  1923.  1313. 322.6  0.01962  17.
262  80%  PZ SEQUN RK 1  4.61  132.7  602.  1950.  1348. 323.5  0.01949  17.
263  80%  PZ SEQUN RK 2  4.61  128.5  598.  1936.  1337. 323.2  0.01947  17.
264  80%  PZ SEQUN RK 3  4.62  128.7  597.  1915.  1318. 323.6  0.01947  17.
265  80%  PZ SEQUN RK 4  4.57  128.2  597.  1967.  1370. 323.6  0.01969  17.
266 100%  NO  CHEMISTRY  5.03  146.9  755.  2017.  1263. 352.9  0.01949  17.


PAGE 2
-- DATA LISTING FOR CONCEPT III MOD 3 -- NASA PRIMARY ZONE STUDY --
                           DATE TABULATED:  26 MAY 82
RDG COND    FI    ACD   DP/P  HOT   AVG   TM/TA  PATRN  TIP THID RMID ROOT
                              SKIN  SKIN               F    F    F    F
260  80%  1.142  5.58  3.48 1080.  924.  1.162  0.238  12.  45.  37. -94.
261  80%  1.139  5.53  3.51 1066.  915.  1.080  0.118  15.  48.  32. -97.
262  80%  1.133  5.54  3.46 1098.  940.  1.071  0.103  44.  63.  18.-125.
263  80%  1.167  5.50  3.74 1076.  923.  1.067  0.096  43.  62.  17.-124.
264  80%  1.167  5.50  3.74 1095.  923.  1.078  0.113  38.  59.  20.-117.
265  80%  1.157  5.49  3.69 1115.  926.  1.049  0.070  48.  64.  20.-133.
266 100%  1.193  5.65  3.69 1382. 1099.  1.132  0.212   1.  51.  46. -97.


PAGE 3
-- DATA LISTING FOR CONCEPT III MOD 3 -- NASA PRIMARY ZONE STUDY --
                           DATE TABULATED:  26 MAY 82
RDG AT  SMOKE  LBO      CHEM    CO2    CO   CHX    NOX    EFF    CO   CHX  NOX
               F/A      F/A     %     PPM   PPM    PPM           EI    EI   EI
260           0.0015
261 EX   7.            0.0211  4.33   67.    8.1  125.  99.83   3.2  0.6  9.6
262 PZ  61.            0.0296  6.00  270.   21.2  164.  99.65   9.1  1.1  5.1
263 PZ  74.            0.0422  7.97  274.1620.4  197.  94.08   6.6 61.3  7.8
264 PZ  44.            0.0215  4.39  203.    9.8  116.  99.68   9.4  0.7  8.8
265 PZ  74.            0.0485  9.63  331. 145.8  153.  99.37   7.0  4.8  5.3
266           0.0012
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PAGE 1
-- DATA LISTING FOR CONCEPT III MOD 4 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  26 MAY 82
                                                                          FLOW
RDG COND   MEASUREMENT     WA     BIP    BIT    BOT    RISE    WF      F/A      #

279  80%  NO  CHEMISTRY   4.58   131.3  616.   1912.  1296. 323.1  0.01961   17.
280  80%  EXHAUST  CHEM   4.58   131.3  608.   1962.  1354. 323.9  0.01964   17.
281  80%  PZ SEQUN RK 1   4.57   131.3  609.   1941.  1332. 322.7  0.01960   17.
282  80%  PZ SEQUN RK 2   4.63   130.4  605.   1958.  1353. 322.1  0.01933   29.
283  80%  PZ SEQUN RK 3   4.61   131.9  605.   1942.  1337. 322.2  0.01940   39.
284  80%  PZ SEQUN RK 4   4.58   131.1  607.   1942.  1335. 323.2  0.01960   32.
285 100%  NO  CHEMISTRY   4.97   147.6  752.   2041.  1288. 352.0  0.01966    0.


PAGE 2
-- DATA LISTING FOR CONCEPT III MOD 4 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  26 MAY 82
RDG COND     FI     ACD    DP/P  HOT    AVG    TM/TA  PATRN  TIP  TMID  RMID  ROOT
                                 SKIN   SKIN                  F     F     F     F
279  80%   1.143   5.64   3.41 1136.   964.   1.162  0.239 -19.   43.   44.  -69.
280  80%   1.140   5.63   3.39 1164.   952.   1.102  0.147  -5.   46.   42.  -83.
281  80%   1.138   5.62   3.40 1250.   972.   1.073  0.106 -15.   45.   47.  -77.
282  80%   1.159   5.70   3.43 1245.  1002.   1.121  0.175 -23.   48.   53.  -76.
283  80%   1.142   5.68   3.36 1260.   947.   1.088  0.127 -20.   53.   53.  -86.
284  80%   1.142   5.70   3.33 1247.   973.   1.046  0.067 -31.   43.   56.  -70.
285 100%   1.173   5.89   3.29 1301.  1121.   1.147  0.233 -11.   51.   50.  -90.


PAGE 3
-- DATA LISTING FOR CONCEPT III MOD 4 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  26 MAY 82
RD  ST SMOKE  LBO     CHEM    CO2     CO    CHX     NOX    EFF     CO    CHX   NOX
              F/A     F/A      %     PPM    PPM     PPM            EI     EI    EI
279          0.0015
280 EX  36.          0.0220  4.43   160.   10.9   109.   99.73    7.2   0.8   8.1
281 PZ 100.          0.0347  6.61  3119.  201.2   136.   97.04   90.3   9.2   6.5
282 PZ  95.          0.0485  7.40  8525.4331.0    98.   82.24  180.6144.2   3.4
283 PZ  80.          0.0290  5.69  1765.   65.7    81.   98.26   60.7   3.6   4.6
284 PZ  53.          0.0406  8.04   957.   21.2   110.   99.36   23.8   0.8   4.5
285          0.0014
```

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PAGE 1
-- DATA LISTING FOR CONCEPT III MOD 5 -- NASA PRIMARY ZONE STUDY --
                                DATE TABULATED:  14 JULY 82
                                                                                FLOW
RDG COND    MEASUREMENT     WA     BIP    BIT     BOT     RISE     WF       F/A      #

294 ----   NO  CHEMISTRY  4.30   116.7  489.    993.    504.  110.6  0.00715   20.
295 IDLE   NO  CHEMISTRY  2.29    54.9  285.   1031.    747.   85.9  0.01041   21.
296 IDLE   EXHAUST  CHEM  2.28    55.1  286.   1079.    793.   85.7  0.01044   21.
297 IDLE   PZ SEQUN RK 1  2.28    55.2  284.   1005.    721.   85.7  0.01042   21.
298 IDLE   PZ SEQUN RK 2  2.29    55.4  288.    998.    710.   85.7  0.01042   21.
299 IDLE   PZ SEQUN RK 3  2.29    55.6  286.    985.    699.   85.9  0.01044   21.
300 IDLE   PZ SEQUN RK 4  2.30    55.6  283.    989.    706.   85.8  0.01037   21.
```

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PAGE 2
-- DATA LISTING FOR CONCEPT III MOD 5 -- NASA PRIMARY ZONE STUDY --
                                DATE TABULATED:  14 JULY 82
RDG COND     FI    ACD    DP/P   HOT    AVG    TM/TA   PATRN   TIP  TMID  RMID  ROOT
                                 SKIN   SKIN                    F     F     F     F
294 ----   1.134  5.88   3.09  1888.   783.   1.179   0.353    2.   24.   -7.  -21.
295 IDLE   1.139  5.58   3.46   831.   525.   1.233   0.322   -5.   14.    2.   -9.
296 IDLE   1.130  5.57   3.41   646.   502.   1.112   0.153   -9.   11.    2.   -4.
297 IDLE   1.129  5.57   3.41   648.   500.   1.139   0.194    0.   18.    0.  -18.
298 IDLE   1.128  5.53   3.45   663.   509.   1.146   0.205   -3.   16.    2.  -14.
299 IDLE   1.122  5.55   3.39   650.   497.   1.163   0.230   -6.   11.    0.   -5.
300 IDLE   1.127  5.54   3.43   675.   509.   1.155   0.217   -6.   11.    0.   -6.
```

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PAGE 3
-- DATA LISTING FOR CONCEPT III MOD 5 -- NASA PRIMARY ZONE STUDY --
                                DATE TABULATED:  14 JULY 82
RDG AT SMOKE   LBO       CHEM     CO2     CO     CHX      NOX     EFF     CO    CHX    NOX
               F/A       F/A      %      PPM     PPM      PPM             EI     EI     EI
294           0.0025
295           0.0030
296 EX                  0.0119   2.37    621.  136.9     22.   97.16   50.9  17.7   3.0
297 PZ   60.            0.0283   5.34   2551.  485.4     47.   95.38   89.9  27.1   2.7
298 PZ   68.            0.0250   4.73   2639.  298.3     41.   95.83  105.0  18.7   2.7
299 PZ   42.            0.0141   2.71   1179.  248.9     23.   95.53   82.4  27.3   2.7
300 PZ   42.            0.0158   2.96   1701.  380.3     22.   94.05  106.1  37.3   2.2
```

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9 AUG 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT III
                                  CIRCUM    (-------AVERAGE RAKE VALUES-------)
RDG COND CONCEPT MOD RAKE LOCATION   F/A     EFF     CO2    CO     NOX  SMOKE
                                              %       %     PPM    PPM
157  80%   III  BASLNE  1     3.75  0.0283  99.73   5.72   271.   171. 48.
158  80%   III  BASLNE  2    22.50  0.0545  72.81   7.36  6639.    92. 87.
159  80%   III  BASLNE  3     0.50  0.0170  99.42   3.47   130.    72. 42.
162  80%   III     1    1     3.75  0.0458  91.57   7.89  7893.   117. 82.
163  80%   III     1    2    22.50  0.0388  99.18   7.67  1064.   156. 29.
164  80%   III     1    3     0.50  0.0493  92.17   8.49  8986.   130. 95.
222  80%   III     2    1     3.75  0.0383  99.42   7.61   815.   173. 28.
223  80%   III     2    2    22.50  0.0307  99.63   6.18   426.   161. 33.
224  80%   III     2    3     0.50  0.0347  98.75   6.82  1727.   153. 35.
225  80%   III     2    4    15.00  0.0320  99.89   6.45    89.   156.  6.
262  80%   III     3    1     3.75  0.0296  99.65   6.00   270.   164. 61.
263  80%   III     3    2    22.50  0.0422  94.08   7.97   274.   197. 74.
264  80%   III     3    3     0.50  0.0215  99.68   4.39   203.   116. 44.
265  80%   III     3    4    15.00  0.0485  99.37   9.63   331.   153. 74.
281  80%   III     4    1     3.75  0.0347  97.04   6.61  3119.   136.100.
282  90%   III     4    2    22.50  0.0485  82.24   7.40  8525.    98. 95.
283  80%   III     4    3     0.50  0.0290  98.26   5.69  1765.    81. 80.
284  80%   III     4    4    15.00  0.0406  99.36   8.04   957.   110. 53.
297 IDLE   III     5    1     3.75  0.0283  95.38   5.34  2551.    47. 60.
298 IDLE   III     5    2    22.50  0.0250  95.83   4.73  2639.    41. 68.
299 IDLE   III     5    3     0.50  0.0141  95.53   2.71  1179.    23. 42.
300 IDLE   III     5    4    15.00  0.0158  94.05   2.96  1701.    22. 42.
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   PAGE  2
9 AUG 82 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT III
                                       RADIAL  (----INDIVIDUAL PORT VALUES---)
RDG CONO CONCEPT MOD RAKE PORT LOCATION  F/A      EFF      CO2     CO     NOX
                                                   %        %     PPM     PPM
157  80%   III  BASLNE  1
                             1   6.07   0.0211   99.74    4.29    185.   152.
                             2   5.75   0.0322   99.81    6.49    187.   207.
                             3   5.44   0.0343   99.71    6.89    363.   184.
                             4   5.12   0.0258   99.64    5.21    349.   142.
158  80%   III  BASLNE  2
                             1   6.07   0.0663   70.85    8.30  12744.   132.
                             2   5.75   0.0741   73.71    9.70  12437.    93.
                             3   5.44   0.0564   62.57    6.76   1181.    75.
                             4   5.12   0.0233   98.80    4.69    195.    69.
159  80%   III  PASLNE  3
                             1   6.07   0.0058   99.10    1.18     66.    24.
                             2   5.75   0.0259   99.57    5.24    198.   120.
                             3   5.44   0.0122   99.10    2.50     99.    53.
                             4   5.12   0.0245   99.49    4.97    159.    90.
162  80%   III       1  1
                             1   6.07   0.0157   98.53    3.14    895.    62.
                             2   5.75   0.06[illegible]9   89.26   10.43  13987.   154.
                             3   5.44   0.0681   89.04   10.97  13606.   129.
                             4   5.12   0.0369   96.94    7.02   3084.   123.
163  80%   III       1  2
                             1   6.07   0.0292   99.69    5.89    293.   127.
                             2   5.75   0.0460   99.05    9.01   1400.   182.
                             3   5.44   0.0486   98.90    9.45   1903.   192.
                             4   5.12   0.0317   99.32    6.33    659.   121.
164  80%   III       1  3
                             1   6.07   0.0403   97.46    7.64   4169.   135.
                             2   5.75   0.0626   88.55   10.04  13449.   140.
                             3   5.44   0.0439   94.67    7.87   7397.   122.
                             4   5.12   0.0506   90.10    8.40  10929.   125.
222  80%   III       2  1
                             1   6.07   0.0467   98.63    9.04   2333.   190.
                             2   5.75   0.0452   99.70    8.97    490.   226.
                             3   5.44   0.0373   99.76    7.48    320.   173.
                             4   5.12   0.0244   99.85    4.95    116.   101.
223  80%   III       2  2
                             1   6.07   0.0341   99.68    6.84    412.   180.
                             2   5.75   0.0370   99.43    7.37    815.   200.
                             3   5.44   0.0318   99.67    6.40    380.   164.
                             4   5.12   0.0201   99.84    4.10     97.   101.
224  80%   III       2  3
                             1   6.07   0.0535   97.69   10.06   4832.   227.
                             2   5.75   0.0281   99.66    5.67    344.   125.
                             3   5.44   0.0372   98.93    7.32   1637.   166.
                             4   5.12   0.0207   99.83    4.23     95.    94.
225  80%   III       2  4
                             1   6.07   0.0372   99.90    7.47     94.   192.
                             2   5.75   0.0373   99.90    7.50     89.   177.
                             3   5.44   0.0305   99.90    6.18     77.   138.
                             4   5.12   0.0229   99.85    4.67     95.   117.
262  80%   III       3  1
                             1   6.07   0.0427   99.65    8.55    319.   240.
                             2   5.75   0.0337   99.60    6.81    308.   187.
                             3   5.44   0.0258   99.69    5.25    266.   134.
                             4   5.12   0.0165   99.65    3.40    186.    93.
263  80%   III       3  2
                             1   6.07   0.0601   85.10   10.02    338.   225.
                             2   5.75   0.0473   97.71    9.26    329.   251.
                             3   5.44   0.0375   99.71    7.55    271.   202.
                             4   5.12   0.0248   99.78    5.06    158.   111.
264  80%   III       3  3
                             1   6.07   0.0122   99.74    2.52     59.    70.
                             2   5.75   0.0248   99.71    5.06    234.   135.
                             3   5.44   0.0295   99.69    5.99    245.   149.
                             4   5.12   0.0196   99.60    4.00    234.   107.
265  80%   III       3  4
                             1   6.07   0.0494   99.18    9.77    335.   130.
                             2   5.75   0.0466   99.17    9.25    333.    64.
                             3   5.44   0.0545   99.45   10.77    330.   234.
                             4   5.12   0.0436   99.69    8.73    326.   182.
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   PAGE 2 CONTINUED
 9 AUG 82 --TABULATION OF DATA FROM PRIMARY ZONE PROBES -- CONCEPT III
                                      RADIAL   (----INDIVIDUAL PORT VALUES---)
RDG COND CONCEPT MOD RAKE PORT LOCATION   F/A     EFF      CO2     CO     NOX
                                                   %        %      PPM    PPM
281  80%   III     4    1
                          1     6.07    0.0423   97.66    8.07   3548.   170.
                          2     5.75    0.0433   94.86    7.82   6675.   146.
                          3     5.44    0.0317   98.28    6.21   1649.   139.
                          4     5.12    0.0218   98.30    4.35    602.    88.
282  80%   III     4    2
                          1     6.07    0.0702   56.05    6.10  23998.    43.
                          2     5.75    0.0535   94.03    9.57   6652.   168.
                          3     5.44    0.0469   97.10    8.91   2964.   122.
                          4     5.12    0.0251   98.38    5.01    484.    59.
283  80%   III     4    3
                          1     6.07    0.0267   98.12    5.25   1336.    87.
                          2     5.75    0.0301   98.60    5.94   1453.    76.
                          3     5.44    0.0454   97.90    8.65   3796.   123.
                          4     5.12    0.0144   98.88    2.90    473.    38.
284  80%   III     4    4
                          1     6.07    0.0515   99.10   10.03   1759.   149.
                          2     5.75    0.0428   99.39    8.47    953.   122.
                          3     5.44    0.0390   99.50    7.77    678.   101.
                          4     5.12    0.0292   99.56    5.87    439.    69.
297 IDLE   III     5    1
                          1     6.07    0.0435   98.55    8.44   2520.    81.
                          2     5.75    0.0327   98.20    6.37   2383.    61.
                          3     5.44    0.0231   92.59    4.21   2917.    31.
                          4     5.12    0.0144   84.15    2.36   2382.    15.
298 IDLE   III     5    2
                          1     6.07    0.0333   97.60    6.44   2391.    61.
                          2     5.75    0.0344   96.99    6.54   3607.    59.
                          3     5.44    0.0197   93.77    3.64   2524.    28.
                          4     5.12    0.0129   91.43    2.32   2032.    15.
299 IDLE   III     5    3
                          1     6.07    0.0152   98.11    3.02    818.    29.
                          2     5.75    0.0133   94.86    2.53   1282.    22.
                          3     5.44    0.0178   96.66    3.46   1311.    27.
                          4     5.12    0.0100   90.56    1.81   1306.    14.
300 IDLE   III     5    4
                          1     6.07    0.0211   96.81    4.10   1341.    34.
                          2     5.75    0.0185   93.42    3.44   2001.    22.
                          3     5.44    0.0130   92.08    2.38   1842.    16.
                          4     5.12    0.0106   92.15    1.94   1618.    13.
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PAGE 1
-- DATA LISTING FOR CONCEPT III MOD A-1 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  23 NOV 82
                                                                              FLOW
RDG COND   MEASUREMENT      WA     BIP    BIT     BOT     RISE     WF      F/A      %

327 IDLE  EXHAUST  CHEM   2.35    57.8   370.   1069.     699.   86.8  0.01026   23.
328 IDLE  NO  CHEMISTRY   2.36    57.7   370.   1039.     669.   86.2  0.01016   23.
329  80%  NO  CHEMISTRY   4.58   130.0   602.   1953.    1352.  326.9  0.01982   21.
330  80%  EXHAUST  CHEM   4.58   130.7   611.   1996.    1385.  325.4  0.01972   21.
331  80%  PZ SEQUN RK 1   4.59   129.4   603.   2026.    1423.  322.7  0.01955   19.
332  80%  PZ SEQUN RK 1   4.60   131.0   615.   2051.    1436.  323.2  0.01952   19.
333  80%  NO  CHEMISTRY   4.58   124.2   617.   1925.    1307.  321.9  0.01954   21.
334  80%  PZ SEQUN RK 1   4.56   129.6   614.   2034.    1420.  321.9  0.01960   21.
335  80%  PZ SEQUN RK 2   4.56   129.6   612.   2014.    1401.  320.3  0.01951   21.
336  80%  PZ SEQUN RK 3   4.55   130.1   613.   2007.    1394.  322.1  0.01965   21.
337  80%  PZ SEQUN RK 4   4.54   130.2   612.   2050.    1438.  320.9  0.01962   21.
338  80%  NO  CHEMISTRY   4.56   129.2   612.   1943.    1331.  320.7  0.01956   21.
339  80%  EXHAUST  CHEM   4.56   130.0   607.   1967.    1359.  320.1  0.01952   21.


PAGE 2
-- DATA LISTING FOR CONCEPT III MOD A-1 -- NASA PRIMARY ZONE STUDY --
                         DATE TABULATED:  23 NOV 82
RDG COND    F1    ACD   DP/P  HOT   AVG    TM/TA  PATRN  TIP THID RMID ROOT
                              SKIN  SKIN                  F    F    F    F

327 IDLE  1.172  5.62  3.60  842.  594.   1.132  0.202 -10.  11.   4.  -6.
328 IDLE  1.177  5.65  3.60  842.  592.   1.157  0.244  -8.  11.   4.  -6.
329  80%  1.148  5.65  3.43 1432.  919.   1.345  0.499 -27.  21.  10.  -3.
330  80%  1.148  5.69  3.37 1447.  936.   1.200  0.288 -25.  27.   9. -13.
331  80%  1.156  5.68  3.44 1473.  938.   1.134  0.191 -19.  35.  10. -26.
332  80%  1.151  5.67  3.43 1490.  953.   1.121  0.173 -12.  42.   7. -38.
333  80%  1.209  5.62  3.84 1393.  939.   1.314  0.462 -29.  19.  10.  -2.
334  80%  1.154  5.67  3.43 1415.  960.   1.130  0.186 -10.  39.   6. -36.
335  80%  1.153  5.66  3.43 1422.  958.   1.135  0.195 -15.  39.   8. -33.
336  80%  1.146  5.68  3.38 1516.  974.   1.163  0.235 -13.  37.   8. -31.
337  80%  1.143  5.65  3.39 1500.  971.   1.136  0.194 -11.  41.   5. -35.
338  80%  1.154  5.69  3.41 1533.  964.   1.327  0.478 -29.  23.  10.  -5.
339  80%  1.145  5.64  3.42 1547.  966.   1.170  0.246 -19.  24.   6. -13.
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-- DATA LISTING FOR CONCEPT III MOD A-1 -- NASA PRIMARY ZONE STUDY --

DATE TABULATED: 23 NOV 82

RDG	AT	SMOKE	LBO F/A	CHEM F/A	CO2 %	CO PPM	CHX PPM	NOX PPM	EFF	CO EI	CHX EI	NOX EI
327	EX		0.0058	0.0117	2.29	554.	5[illegible].3	23.	91.64	46.3	77.2	3.2
328												
329			0.0010									
330	EX			0.0231	4.65	504.	73.6	135.	99.00	21.6	5.0	9.5
331	PZ			0.0334	6.53	1949.	72.6	60.	98.33	58.4	3.4	3.0
332	PZ			0.0252	5.05	681.	57.6	89.	99.02	26.8	3.6	5.8
333												
334	PZ	40.		0.0278	5.52	861.	127.2	128.	98.58	30.8	7.2	7.5
335	PZ	78.		0.0337	6.57	1824.	128.1	139.	98.16	54.3	6.0	6.8
336	PZ	4.		0.0238	4.84	145.	5.1	129.	99.79	6.0	0.3	8.8
337	PZ	18.		0.0200	4.00	896.	16.7	51.	98.84	44.2	1.3	4.1
338		1.										
339	EX			0.0221	4.44	593.	30.4	65.	99.15	26.6	2.1	4.8

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PAGE 1
-- DATA LISTING FOR CONCEPT III MOD A-2 -- NASA PRIMARY ZONE STUDY --
                       DATE TABULATED:  3 JAN 83
                                                                         FLOW
RDG COND   MEASUREMENT    WA     BIP    BIT    BOT    RISE    WF     F/A      #

340 IDLE  NO  CHEMISTRY  2.28   54.4  367.   902.   536.   83.2  0.01015  36.
341 IDLE  EXHAUST  CHEM  2.27   54.7  373.   946.   574.   83.4  0.01021  35.
342  80%  NO  CHEMISTRY  4.58  130.7  611.  1953.  1342. 324.8  0.01970  27.
343  80%  EXHAUST  CHEM  4.55  130.4  609.  2019.  1409. 324.4  0.01981  27.
344  80%  PZ SEQUN RK 1  4.58  130.0  610.  2012.  1402. 322.3  0.01957  27.
345  80%  PZ SEQUN RK 2  4.57  131.1  606.  2033.  1427. 322.2  0.01959  27.
346  80%  PZ SEQUN RK 3  4.56  129.2  610.  2043.  1433. 320.6  0.01952  27.
347  80%  PZ SEQUN RK 4  4.56  129.8  610.  2054.  1443. 324.0  0.01972  27.
348  80%  NO  CHEMISTRY  4.58  127.5  610.  1940.  1329. 323.4  0.01963  17.
349  80%  EXHAUST  CHEM  4.58  126.8  614.  1945.  1331. 320.0  0.01943  17.
350  80%  PZ SEQUN RK 1  4.58  127.5  612.  1953.  1341. 320.9  0.01948  17.
351  80%  PZ SEQUN RK 2  4.57  128.1  611.  1987.  1376. 322.0  0.01955  17.
352  80%  PZ SEQUN RK 3  4.57  128.1  612.  1980.  1368. 322.0  0.01959  17.
353  80%  PZ SEQUN RK 4  4.58  128.6  611.  1958.  1347. 319.9  0.01940  17.
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PAGE 2
-- DATA LISTING FOR CONCEPT III MOD A-2 -- NASA PRIMARY ZONE STUDY --
                       DATE TABULATED:  3 JAN 83
RDG COND    FI     ACD   DP/P   HOT    AVG    TM/TA  PATRN   TIP  TMID  RMID  ROOT
                               SKIN   SKIN                   F     F     F     F
340 IDLE  1.203   5.58   3.85   796.   517.   1.323  0.544   -0.   13.   -0.  -12.
341 IDLE  1.196   5.58   3.81   799.   524.   1.264  0.436    2.   16.   -1.  -16.
342  80%  1.147   6.04   2.99  1271.   951.   1.212  0.309  -68.    9.   27.   33.
343  80%  1.141   5.99   3.00  1289.   955.   1.212  0.304  -75.   13.   29.   31.
344  80%  1.151   6.05   3.00  1271.   950.   1.110  0.158  -76.   17.   29.   30.
345  80%  1.138   6.05   2.94  1244.   939.   1.128  0.183  -72.   22.   27.   21.
346  80%  1.155   6.06   3.01  1233.   944.   1.111  0.159  -72.   23.   28.   20.
347  80%  1.150   6.06   2.99  1240.   948.   1.105  0.150  -69.   26.   29.   15.
348  80%  1.174   5.60   3.65  1079.  1009.   1.202  0.294   -4.   38.    0.  -35.
349  80%  1.182   5.62   3.66  1042.   988.   1.216  0.316  -16.   29.    4.  -18.
350  80%  1.175   5.63   3.61  1077.   998.   1.180  0.262    8.   52.   -5.  -53.
351  80%  1.169   5.63   3.58  1037.   990.   1.251  0.362   14.   58.   -8.  -64.
352  80%  1.166   5.63   3.55  1044.  1005.   1.231  0.334   10.   57.   -8.  -60.
353  80%  1.166   5.65   3.53  1044.   963.   1.186  0.270    2.   49.   -3.  -49.
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PAGE 3
-- DATA LISTING FOR CONCEPT III MOD A-2 -- NASA PRIMARY ZONE STUDY --
                              DATE TABULATED:  3 JAN 83
RDG AT SMOKE  LBO      CHEM    CO2    CO    CHX    NOX    EFF     CO   CHX   NOX
              F/A      F/A     %     PPM    PPM    PPM            EI    EI    EI
340          0.0050
341 EX                0.0103  1.80   567.  922.3    2.   85.78  53.8137.6   0.3
342
343 EX       0.0004   0.0230  4.67   194.   12.4  156.   99.68   8.4   9.8  11.0
344 PZ  79.           0.0368  7.11  2443.  134.0  190.   97.89  66.8   5.8   8.5
345 PZ  74.           0.0438  8.30  4147.   59.1  287.   97.55  95.9   2.1  10.9
346 PZ  29.           0.0211  4.31    89.    5.1  170.   99.81   4.2   0.4  13.1
347 PZ  33.           0.0270  5.38  1015.   36.6  127.   98.91  37.3   2.1   7.7
348          0.0008
349 EX                0.0215  4.38    65.    0.8  130.   99.88   3.0   0.1   9.8
350 PZ  53.           0.0346  6.75  2109.   79.9  149.   98.23  61.1   3.6   7.1
351 PZ  37.           0.0305  5.99  1598.   74.6  154.   98.40  52.4   3.8   8.3
352 PZ  32.           0.0222  4.52   210.    2.0  129.   99.72   9.7   0.1   9.5
353 PZ  76.           0.0392  7.14  3660.1153.5  104.   93.41  94.3  46.7   4.4
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C-3

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PAGE 1
-- DATA LISTING FOR CONCEPT III MOD A-3 -- NASA PRIMARY ZONE STUDY --
                                DATE TABULATED:  3 JAN 83
                                                                                FLOW
RDG COND    MEASUREMENT     WA     BIP    BIT    BOT     RISE     WF       F/A     %

354  80%  NO  CHEMISTRY  4.61   129.2  615.   1937.   1322. 322.4   0.01942  17.
355  80%  EXHAUST  CHEM  4.61   131.8  614.   1976.   1362. 322.3   0.01942  17.
356  80%  PZ SEQUN RK 4  4.60   131.6  617.   1925.   1309. 322.9   0.01950  17.
357  80%  PZ SEQUN RK 1  4.58   131.6  614.   1921.   1306. 320.7   0.01944  17.
358  80%  PZ SEQUN RK 2  4.62   131.5  613.   1907.   1294. 322.9   0.01940  17.
359  80%  PZ SEQUN RK 3  4.62   132.3  613.   1909.   1297. 322.4   0.01938  17.
360 100%  NO  CHEMISTRY  4.97   143.3  746.   2067.   1321. 352.0   0.01967  17.


PAGE 2
-- DATA LISTING FOR CONCEPT III MOD A-3 -- NASA PRIMARY ZONE STUDY --
                                DATE TABULATED:  3 JAN 83
RDG COND     F1    ACD    DP/P   HOT   AVG    TH[illegible]  PATRN   TIP  TMID  RMID  ROOT
                                 SKIN  SKIN                     F     F     F     F
354  80%   1.171  5.78   3.40 1263. 1106.   1.211   0.309    6.   42.   -4.  -44.
355  80%   1.146  5.77   3.27 1250. 1103.   1.158   0.229   10.   42.   -6.  -47.
356  80%   1.147  5.79   3.25 1269. 1116.   1.[illegible]   0.227   30.   52.  -15.  -66.
357  80%   1.141  5.80   3.22 1249. 1110.   1.176   0.259   28.   51.  -14.  -65.
358  80%   1.152  5.80   3.27 1241. 1101.   1.145   0.214   33.   52.  -16.  -68.
359  80%   1.144  5.79   3.24 1249. 1107.   1.149   0.220   32.   53.  -15.  -67.
360 100%   1.204  5.84   3.53 1360. 1241.   1.213   0.333    4.   43.   -4.  -45.


PAGE 3
-- DATA LISTING FOR CONCEPT III MOD A-3 -- NASA PRIMARY ZONE STUDY --
                                DATE TABULATED:  3 JAN 83
RDG AT SMOKE  LBO       CHEM     CO2     CO     CHX    NOX    EFF     CO    CHX   NOX
              F/A       F/A      %      PPM    PPM    PPM            EI    EI    EI
354          0.0005
355 EX                 0.0254   5.16    49.    1.9   149.   99.90   1.9   0.1   9.6
356 PZ  34.            0.0257   5.18   428.    9.4   122.   99.53  16.6   0.6   7.7
357 PZ  80.            0.0399   7.83  1689.   38.7   221.   98.84  42.6   1.5   9.2
358 PZ  74.            0.0372   7.28  1810.   39.8   208.   98.68  49.0   1.7   9.2
359 PZ  48.            0.0328   6.50  1284.   16.1   159.   99.00  39.1   0.8   8.0
360
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3 JAN 83 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- ADDENDUM

					CIRCUM	(-------AVERAGE RAKE VALUES-------)					
RDG	COND	CONCEPT	MOD	RAKE	LOCATION	F/A	EFF	CO2	CO	NOX	SMOKE
331	80%	III	A-1	1	3.75	0.0334	98.33	6.53	1949.	60.	
332	80%	III	A-1	1	3.75	0.0252	99.02	5.05	681.	89.	
334	80%	III	A-1	1	3.75	0.0278	98.58	5.52	861.	128.	40.
335	80%	III	A-1	2	22.50	0.0337	98.16	6.57	1824.	139.	78.
336	80%	III	A-1	3	0.50	0.0238	99.79	4.84	145.	129.	4.
337	80%	III	A-1	4	15.00	0.0200	98.84	4.00	896.	51.	18.
344	80%	III	A-2	1	3.75	0.0368	97.89	7.11	2443.	190.	79.
345	80%	III	A-2	2	22.50	0.0438	97.55	8.30	4147.	287.	74.
346	80%	III	A-2	3	0.50	0.0211	99.81	4.31	89.	170.	29.
347	80%	III	A-2	4	15.00	0.0270	98.91	5.38	1015.	127.	33.
350	80%	III	A-2	1	3.75	0.0346	98.23	6.75	2109.	149.	53.
351	80%	III	A-2	2	22.50	0.0305	98.40	5.99	1598.	154.	37.
352	80%	III	A-2	3	0.50	0.0222	99.72	4.52	218.	129.	32.
353	80%	III	A-2	4	15.00	0.0392	93.41	7.14	3660.	104.	76.
356	80%	III	A-3	4	15.00	0.0257	99.53	5.18	428.	122.	34.
357	80%	III	A-3	1	3.75	0.0399	98.84	7.83	1689.	221.	80.
358	80%	III	A-3	2	22.50	0.0372	98.68	7.28	1810.	208.	74.
359	80%	III	A-3	3	0.50	0.0328	99.00	6.50	1284.	159.	48.

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3 JAN 83 -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- ADDENDUM

RDG	COND	CONCEPT	MOD	RAKE	PORT	RADIAL LOCATION	(----INDIVIDUAL PORT VALUES---) F/A	EFF %	CO2 %	CO PPM	NOX PPM
331	80%	III	A-1	1	1	6.07	0.0474	98.16	9.06	3535.	31.
					2	5.75	0.0302	99.27	6.03	602.	36.
					3	5.44	0.0413	98.34	7.98	2911.	133.
					4	5.12	0.0155	96.96	3.06	551.	41.
332	80%	III	A-1	1	1	6.07	0.0390	98.77	7.62	1996.	105.
					2	5.75	0.0237	99.86	4.81	95.	106.
					3	5.44	0.0231	99.87	4.71	80.	105.
					4	5.12	0.0155	97.09	3.06	552.	41.
334	80%	III	A-1	1	1	6.07	0.0380	98.95	7.46	1615.	126.
					2	5.75	0.0300	99.32	6.01	656.	165.
					3	5.44	0.0238	98.82	4.77	268.	133.
					4	5.12	0.0196	96.48	3.85	605.	88.
335	80%	III	A-1	2	1	6.07	0.0486	97.50	9.15	4865.	129.
					2	5.75	0.0394	99.21	7.78	1152.	129.
					3	5.44	0.0293	99.18	5.86	680.	162.
					4	5.12	0.0180	95.98	3.51	600.	137.
336	80%	III	A-1	3	1	6.07	0.0210	99.69	4.28	220.	116.
					2	5.75	0.0249	99.83	5.05	114.	135.
					3	5.44	0.0254	99.81	5.15	126.	136.
					4	5.12	0.0240	99.81	4.87	119.	129.
337	80%	III	A-1	4	1	6.07	0.0139	98.45	2.77	921.	32.
					2	5.75	0.0253	98.85	5.03	1199.	67.
					3	5.44	0.0236	99.08	4.73	834.	53.
					4	5.12	0.0173	98.81	3.47	630.	52.
344	80%	III	A-2	1	1	6.07	0.C272	98.53	5.36	1621.	149.
					2	5.75	0.0428	95.87	7.93	4744.	206.
					3	5.44	0.0451	98.49	8.73	2538.	240.
					4	5.12	0.0322	99.15	6.40	870.	165.
345	80%	III	A-2	2	1	6.07	0.0417	98.49	8.09	2530.	330.
					2	5.75	0.0628	95.71	11.18	10184.	415.
					3	5.44	0.0467	97.93	8.90	3781.	263.
					4	5.12	0.0248	99.77	5.03	94.	143.
346	80%	III	A-2	3	1	6.07	0.0259	99.72	5.24	298.	191.
					2	5.75	0.0203	99.90	4.16	32.	165.
					3	5.44	0.0240	99.80	4.89	40.	198.
					4	5.12	0.0143	99.86	2.93	36.	126.
347	80%	III	A-2	4	1	6.07	0.0277	99.74	5.60	258.	134.
					2	5.75	0.0372	98.73	7.27	1866.	170.
					3	5.44	0.0271	98.44	5.34	1512.	121.
					4	5.12	0.0164	98.68	3.30	425.	84.
350	80%	III	A-2	1	1	6.07	0.0642	96.52	11.71	7369.	201.
					2	5.75	0.0376	99.47	7.49	747.	201.
					3	5.44	0.0250	99.76	5.08	210.	135.
					4	5.12	0.0132	99.78	2.72	108.	60.
351	80%	III	A-2	2	1	6.07	0.0355	95.77	6.59	4723.	131.
					2	5.75	0.0384	99.06	7.57	1368.	203.
					3	5.44	0.0298	99.76	6.02	223.	179.
					4	5.12	0.0185	99.86	3.79	61.	102.
352	80%	III	A-2	3	1	6.07	0.C261	99.33	5.23	720.	123.
					2	5.75	0.0206	99.90	4.25	42.	132.
					3	5.44	0.0233	99.86	4.76	70.	145.
					4	5.12	0.0188	99.90	3.85	40.	118.
353	80%	III	A-2	4	1	6.07	0.0201	99.33	4.06	553.	64.
					2	5.75	0.0430	98.93	8.42	1787.	141.
					3	5.44	0.0558	86.36	8.99	8226.	92.
					4	5.12	0.0388	94.08	7.09	4074.	118.

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   PAGE 2 CONTINUED
3 JAN 83  -- TABULATION OF DATA FROM PRIMARY ZONE PROBES -- ADDENDUM

                                   RADIAL   (----INDIVIDUAL PORT VALUES---)
RDG COND CONCEPT MOD RAKE PORT LOCATION   F/A      EFF     CO2      CO     NOX
                                                    %       %       PPM    PPM
356  80%  III    A-3   4
                        1      6.07    0.0086   99.77    1.77     62.    34.
                        2      5.75    0.0238   99.73    4.63    186.   113.
                        3      5.44    0.0392   99.42    7.78    785.   213.
                        4      5.12    0.0317   99.45    6.34    682.   126.
357  80%  III    A-3   1
                        1      6.07    0.0598   98.15   11.32   3902.   324.
                        2      5.75    0.0468   98.91    9.11   1863.   279.
                        3      5.44    0.0343   99.48    6.85    672.   185.
                        4      5.12    0.0198   99.56    4.03    317.    97.
358  80%  III    A-3   2
                        1      6.07    0.0219   99.65    4.45    290.   148.
                        2      5.75    0.0397   99.20    7.84   1254.   240.
                        3      5.44    0.0556   97.71   10.48   4438.   285.
                        4      5.12    0.0320   98.99    6.33   1259.   159.
359  80%  III    A-3   3
                        1      6.07    0.0314   99.54    6.29    562.   169.
                        2      5.75    0.0335   98.82    6.60   1542.   155.
                        3      5.44    0.0379   98.78    7.43   1800.   175.
                        4      5.12    0.0287   98.89    5.68   1233.   138.
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