III. STATUS OF THE NASA/GENERAL ELECTRIC EXPERIMENTAL CLEAN COMBUSTOR PROGRAM - PHASE III

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The primary objectives of the NASA/General Electric Experimental Clean Combustor Program are

(1) To generate and demonstrate the technology required to design and develop advanced commercial, conventional-takeoff-and-landing (CTOL) aircraft engines with significantly lower pollutant exhaust emissions levels than those of current-technology engines

(2) To demonstrate the attainment of the target pollutant emissions reductions in tests of an advanced commercial aircraft turbofan engine

The intent of this three-phase program is to attain the target pollutant emissions reductions by developing advanced combustor designs rather than by using special engine operational techniques and/or water injection methods. The program is aimed at generating advanced combustor design technology that is primarily applicable to advanced commercial CTOL aircraft engines with high cycle pressure ratios, in the range 25 to 35. It is also intended that this technology be applicable to advanced military aircraft engines. Because the smoke emission levels of advanced commercial and military aircraft engines have already been reduced to low values, the primary focus of the program is on reducing the levels of the gaseous pollutant emissions. While this NASA/General Electric program is specifically directed toward providing advanced combustors for use in the General Electric CF6-50 engine, this technology is also intended to be generally applicable to all advanced engines with large thrust.

Phases I and II of the program have been completed and phase III is currently in progress. The key objective of phase III is to evaluate in CF6-50 engine tests the preferred combustor design concept evolved in phases I and II. To date, the phase III activities have included design and component development efforts in preparation for these CF6-50 engine tests. All preparatory efforts were completed in May 1977, and engine testing is scheduled to begin in June 1977. This report describes the phase III combustor design, the new fuel supply and control system components required to permit the use of this combustor in the CF6-50 demonstrator engine, and the development status of the demonstrator-engine combustor configuration.

CF6-50 ENGINE AND COMBUSTOR

The NASA/General Electric Experimental Clean Combustor Program has been specifically directed toward developing an advanced low-emissions combustor for use in the various models of the G.E. CF6-50 engine. The CF6-50 engine family is the higher power series of the two CF6 high-bypass-ratio turbofan engine families that have been developed by General Electric. The other series is the CF6-6 engine family. Models of the CF6-50 engines are in commercial service as the powerplants for the McDonnell Douglas DC-10 series 30 Tri-Jet long-range intercontinental aircraft, the Airbus Industrie A300B aircraft, and the Boeing 747-200 aircraft. The basic CF6-50 engine is a dual-rotor, high-bypass-ratio turbofan comprising a high-pressure compressor with variable stators; an annular combustor; a two-stage, air-cooled, high-pressure turbine; and a coaxial front fan driven by a low-pressure turbine. The CF6-50 engine is shown in figure III-1.

The CF6-50C engine model operating parameters were selected as the combustor design and test conditions. At standard-day, sea-level-static takeoff conditions, the rated thrust of the CF6-50C engine model is 222 kilonewtons, the combustor inlet air pressure is 29.8 atmospheres, and the inlet air temperature is 820 K. The high inlet temperature and pressure make the attainment of low oxides of nitrogen (NO_x) emissions levels a formidable problem. The nominal idle power setting of this engine model is 3.4 percent of takeoff thrust, which is low compared with most in-service engines. At this idle power setting the combustor inlet air temperature is only 429 K and the inlet air pressure is 2.9 atmospheres. Accordingly, the attainment of low carbon monoxide (CO) and total unburned hydrocarbon (THC) emissions levels is also a difficult problem.

The combustor configuration used in production CF6-50 engines is a high-performance design with demonstrated low exit-temperature pattern factors, low pressure loss, high combustion efficiency, and low smoke emission at all operating conditions. The key features of this combustor are its low-pressure-loss step diffuser, its carbureting swirl-cup dome design, and its short burning length. The short burning length reduces the amount of liner cooling air required, which, in turn, improves its exit-temperature pattern and profile factors. The step diffuser design provides very uniform, steady airflow distributions into the combustor.

This combustor contains 30 vortex-inducing axial swirler cups, one for each fuel nozzle. The combustor consists of four major sections that are riveted together into one unit and spot welded to prevent rivet loss: the cowl assembly, the dome, and the inner and outer liner skirts. The combustor is mounted on the cowl assembly by 30 equally spaced radial mounting pins. The inner and outer skirts each consist of a series of circumferentially stacked rings that are joined by resistance-welded and brazed joints. The liners are film cooled by air that enters each ring through closely spaced circumferential holes. Three axial planes of dilution holes on the outer skirt and five planes on the inner skirt are employed to promote additional mixing and to lower the combustor exit temperatures.

LOW-EMISSIONS COMBUSTOR DESIGN CONCEPTS

In phase I, four advanced combustor design concepts were evaluated in full-annular combustor component tests. Specifically, CF6-50 engine-size versions of NASA swirl-can-modular combustors, lean dome single-annular combustors, double-annular combustors, and radially and axially staged combustors were evaluated. The best results were obtained with the latter two design concepts.

Based on these results, the double-annular combustor and the radially and axially staged combustor designs were selected for further development in phase II. Both low-emissions combustor designs feature two discrete combustion stages; a pilot stage to provide proper combustion at low-engine-power operating conditions to yield low CO and THC emissions, and a main stage to limit NO_x emissions at high-engine-power operating conditions.

In both designs, all fuel is supplied to the pilot stage at low-engine-power operating conditions. At the higher-engine-power operating conditions, both the pilot and main stages are fueled. The two design approaches differ in the physical arrangement and design philosophy of the main combustion stage.

In phase II, the double-annular combustor was identified as the most promising concept and was selected for further development and refinement in the remaining phase II efforts. A schematic drawing and photograph of this prototype double-annular combustor are presented in figures III-2 and -3, respectively.

As is shown in figure III-2, the double-annular combustor comprises two annular primary-burning zones, in parallel, separated by a short centerbody. Thirty fuel nozzles are used in each annulus. The outer annulus is the pilot stage and is always fueled. The inner annulus is the main stage and is fueled only at higher-engine-power operating conditions. The fuel flow splits at idle and takeoff conditions are shown in figure III-2. The airflow distribution is highly biased to the main stage in order to reduce both idle and high-power emissions. The pilot-stage airflow is specifically sized to provide nearly stoichiometric fuel-air ratios and long residence times at idle power settings, thereby minimizing CO and THC emissions. At high-power operating conditions, most of the fuel is supplied to the main stage. In this stage, the combustion gas residence times are very short. Also, at high-power operating conditions, lean fuel-air ratios are maintained in both stages to minimize NO_x and smoke emissions.

Based on the phase II results, a second-generation version of this advanced combustor design, with more sophisticated and flightworthy mechanical design features, was defined for use in the CF6-50 demonstrator-engine tests of phase III. This second-generation combustor configuration was needed because the prototype configuration used in phases I and II was not suitable for use in an actual engine installation. The prototype configuration was designed only for component testing. As such, the features incorporated into this design to accommodate differential thermal growths, pressure loads, vibration loads, and mechanical assembly were not adequate to permit the use of this combustor in engine tests.

A schematic drawing and photograph of the demonstrator-engine combustor are presented in figures III-4 and -5, respectively. The aerothermal design features of this demonstrator engine combustor were patterned after those of the prototype combustor. In addition, advanced aeromechanical design features derived from other General Electric programs were incorporated into its design. Machined-ring cooling-air slots are used throughout the dome and liners for improved cooling-air effectiveness. Included in the mechanical arrangement were features for adequate differential thermal growth, assembly, and mechanical stiffness. With this design, both the pilot- and main-stage fuel nozzles can be installed through the existing fuel nozzle ports of the engine, with the combustor installed. This important design feature permits the existing engine outer casing to be used without modification. The main-stage fuel nozzles are connected to the existing CF6-50 engine fuel manifold. The pilot-stage fuel nozzles are connected to a new fuel manifold.

In table III-1, the key aerothermal design parameters of the two double-annular combustors and a current production CF6-50 combustor are compared. The combustor airflow distributions of the two advanced combustors are quite similar, as are the pilot- and main-stage velocities. Their key dimensions are also similar, although the domes of the demonstrator-engine combustor are about 20 percent higher than that of the prototype combustor. These higher domes are needed to accommodate the movements of the swirl-cup slip joints.

As is shown in table III-1, much less of the available combustor airflow is used for liner cooling in the two advanced combustors than in the current production CF6-50 combustor. This design feature was incorporated to permit more use of the available airflow as dome airflow in order to minimize primary-zone fuel-air ratios at high-power operating conditions. From the results obtained to date with the prototype combustor and on the heat transfer design studies conducted with the demonstrator-engine combustor, satisfactory liner performance is expected in the engine tests. The liner cooling airflow can be decreased because of the reduced combustion gas temperatures and associated lower flame radiation levels of the double-annular combustor. For similar reasons, the quantity of combustor airflow used for exit-temperature profile control was greatly reduced in the two advanced combustors.

FUEL FLOW CONTROL DESIGN CONCEPT

Using a double-annular combustor in the CF6-50 engine requires the proper fuel flow splits over the entire range of engine operating conditions. Accordingly, a fuel flow splitter was designed in phase II and was developed and evaluated in phase III. This splitter was designed to be added to the existing CF6-50 engine fuel control system. As is schematically shown in figure III-6, this splitter divides the total fuel flow between the pilot-stage manifold and the main-stage manifold, in the proportions required at each total fuel flow level or throttle setting. The splitter is shown in figure III-7. It is designed to provide the required fuel flow splits in the CF6-50 engine only at sea-level operating conditions. Additional features would have to be incorporated into its design to also accommodate cruise operating conditions.

One of the objectives of the phase III engine demonstration tests is to determine the optimum main-stage fuel flow cut-in point and the optimum fuel flow split between stages. Both exhaust emissions levels and engine operating characteristics, particularly the acceleration and deceleration characteristics will be determined as a function of fuel flow split. Accordingly, features have been incorporated in this fuel flow splitter to permit the remote scheduling of both cut-in and flow split after cut-in. As is schematically illustrated in figure III-6, both of these important operating parameters can be remotely adjusted from the engine test cell operating console.

OVERALL PHASE III DEVELOPMENT STATUS

In phase III, all design, hardware procurement, and component testing required in preparation for the CF6-50 demonstrator-engine tests have been completed. During May 1977, the combustor and the required new fuel control and supply systems components were installed in a CF6-50 engine. Engine testing is scheduled to start in June. In addition to an extensive series of checkout and development tests of the demonstrator-engine combustor, checkout and development testing of the fuel flow splitter, the complete new fuel supply system with its two manifolds, and a new exhaust gas sampling and traversing system for use in the demonstrator-engine tests were successfully completed.

Initial component checkout tests of the demonstrator-engine combustor showed its performance and operating characteristics to be, for the most part, virtually the same as those of the phase II prototype configuration. It also met satisfactorily all engine installation and assembly requirements. In one important performance aspect, however, its characteristics were different from those of the phase II prototype configuration - its CO and THC emissions levels were substantially higher.

After this finding, an extensive series of diagnostic and development tests of the combustor were conducted in an effort to reduce its CO and THC emissions levels at idle. Several pilot-stage modifications were defined and evaluated. Fuel spray characteristics, swirl-cup geometry, and outer-liner dilution airflow distribution were systematically varied to correct the deficiencies and to more precisely duplicate the pilot-stage design of the phase II prototype combustor. Some CO and THC emissions reductions were realized from these efforts, but levels equivalent to those of the phase II prototype combustor were not attained. It now appears that higher CO and THC emissions levels at idle must be associated with some slight differences in the pilot-stage liner and centerbody cooling airflows and in the penetration characteristics of the main-stage dilution airflow, which is introduced by holes in the inner cooling liner. The exact causes of these higher CO and THC levels can probably be identified with additional testing and subsequently corrected. However, the required corrections will involve some significant reworking of the pilot-stage dome assembly and its cooling liner assembly. It was decided to proceed with the demonstrator-engine tests without devoting more time and effort to correcting the idle emissions level deficiencies. At this stage in the development of this advanced combustor, it is more important to determine its overall performance and operating characteristics in an actual engine than to additionally delay these tests for more component testing to further reduce the idle emissions levels.

EMISSIONS CHARACTERISTICS OF DOUBLE-ANNULAR COMBUSTORS

The CO and THC emissions characteristics of the phase II prototype and phase III demonstrator-engine double-annular (D/A) combustors, as determined in full-annular component tests, are presented in figures III-8 and -9, respectively. Included for comparison are the emissions levels, as measured in both full-annular component and engine tests, of the current production CF6-50 combustor, which is a single-annular (S/A) configuration. For the current production CF6-50 combustor, the component and engine test results for CO emissions are in reasonably close agreement. Agreement is somewhat poorer for THC emissions. These comparisons suggest that the CO and THC emissions levels of the phase III demonstrator-engine combustor in the CF6-50 engine tests might be slightly lower than those attained in the component tests.

As is shown in figures III-8 and -9, respectively, the CO and THC emissions of the phase III demonstrator-engine combustor are higher than those of the phase II prototype combustor at the nominal CF6-50 engine idle power setting of 3.4 percent of takeoff power but significantly lower than those of the current production CF6-50 combustor. Also at higher idle power settings, CO and THC emissions with the demonstrator-engine combustor rapidly decrease. Thus, a CO emission level of 20 grams per kilogram of fuel burned, which is the approximate value needed at idle to meet the 1979 CO standard for class T2 engines, is attained at an idle setting of 7 percent. The needed THC level of 4 g/kg is attained at an idle setting of 5 percent.

In both figures III-8 and -9, the low-power emissions levels of the phase II prototype combustor are represented by a data point at the 3.4-percent idle power setting, since data were generally not obtained during phase II at other idle power settings. However, during phase II, emissions data were obtained at this idle power setting in several different tests of basically similar combustor configurations. The idle emissions results obtained in these phase II investigations are summarized in figures III-10 and -11. The data presented in both figures were obtained with seven test configurations at combustor inlet operating conditions equivalent to those of the engine at the 3.4-percent idle power setting. These data were obtained over a range of combustor fuel-air ratios to obtain parametric information and well-characterized curves. As is shown, at the actual fuel-air ratio (0.011) of the engine at this nominal idle power setting, CO and THC emissions indices of about 20 and 2 g/kg, respectively, were consistently obtained.

Accordingly, the CO and THC emissions levels shown in figures III-8 and -9 at the 3.4-percent idle power setting were repeatedly obtained with the phase II prototype combustor. These low CO and THC emissions levels at idle are, therefore, considered to be very representative of the levels obtainable with the double-annular combustor. Based on these well-demonstrated CO and THC emissions characteristics, it is fully believed that the pilot-stage design of the phase III demonstrator-engine combustor can, with additional component development effort, be successfully modified and adjusted to provide these same low CO and THC emissions levels.

The NO_x emissions characteristics of the phase II prototype combustor and the phase III demonstrator-engine combustor, as determined in full-annular component tests, are presented in figure III-12. As is shown, the NO_x levels of the two advanced combustor configurations are in close agreement and are significantly lower than those of the current production CF6-50 combustor. At the high-power operating conditions, NO_x emissions index reductions of 40 to 50 percent were attained with the two double-annular combustor configurations. Small reductions were also attained at the approach (30 percent of takeoff thrust) operating conditions. At idle, no reductions were attained since, at this operating condition, the operation of the double-annular combustor is essentially the same as that of a conventional single-annular combustor.

The NO_x emissions level data obtained in full-annular component and engine tests of the production CF6-50 combustor are included in figure III-12. These data are also in close agreement. In all cases, the full-annular combustor component test data, taken at the simulated high-power operating conditions, were corrected to adjust for the lower combustor operating pressures used in these tests. Standard pressure correction techniques developed at General Electric were used.

The smoke emission characteristics of the phase II prototype combustor and the phase III demonstrator-engine combustor as measured in full-annular component tests, are presented in figure III-13. The smoke levels of the two advanced combustor configurations are quite similar and are slightly lower than that of the current production CF6-50 combustor, as measured in both full-annular component and engine tests. With all three combustors, the measured smoke levels are quite low at all engine power settings. These low smoke levels are well below the visibility threshold and the applicable EPA smoke emission standard for a class T2 engine of this thrust rating.

EPAP CHARACTERISTICS OF DOUBLE-ANNULAR COMBUSTORS

The EPA parameters (EPAP's) of the two double-annular combustors and of the current production CF6-50 combustor are presented in figure III-14. Included in this figure are the 1979 EPA standards specified for class T2 engines. The EPAP's are presented as a function of the idle power setting assumed for use in the overall landing/takeoff (LTO) cycle prescribed by the EPA for determining EPAP values. For all three combustor configurations, using higher idle power settings in these EPAP determinations results in significant reductions in the CO and THC EPAP values. Smaller reductions also result in the NO_x EPAP values. For the CO and THC emissions, this strong dependence of EPAP value on idle power setting is due to the combined effects of the reduced emissions indices at idle and the increased thrust-hours as the idle power setting is increased.

For these reasons, the CO and THC EPAP's of the phase III demonstrator-engine combustor are not as low as those of the phase II prototype combustor configuration. However, the demonstrator-engine combustor EPAP's are still significantly lower than the production combustor EPAP's, especially when compared with the production combustor EPAP values based on full-annular component data. Comparisons of this kind are believed to be more valid since they are based entirely on component test data for both combustors. With the phase III demonstrator-engine combustor, the applicable CO and THC standards are met with idle power settings of about 7 and 4 percent, respectively. With the phase II prototype combustor, the applicable CO and THC standards are met even with the low idle power setting of 3.4 percent. As mentioned previously, the CO and THC EPAP's of the phase III demonstrator combustor probably can, with additional development, be reduced to EPAP's as low as those of the phase II prototype combustor.

As is shown in figure III-14, the NO_x EPAP values of the two advanced combustor configurations are essentially the same and are significiantly lower than those of the current production CF6-50 combustor. However, even with significant NO_x EPAP reductions, the applicable EPA standard is not met with the double-annular combustors when they are used in the CF6-50 engine. As described in the preceding discussion, using this advanced staged combustor in any given engine application generally reduces NO_x emissions indices by about 50 percent at the high-power operating conditions, as compared with the emissions indices obtainable with conventional-technology combustors at these operating conditions. In the approach operating mode, percentage reductions are smaller and, at idle, little or no percentage reduction is attained. Thus, percentage reductions in the resulting EPAP values are slightly smaller than those for the two high-power operating modes. Typically, NO_x EPAP reductions of about 40 percent can be realized in any given turbofan engine application.

With NO_x EPAP reductions of this order, the applicable EPA standard for NO_x emissions cannot be attained for a very high-cycle-pressure-ratio turbofan engine like the CF6-50 engine. Because of its 30:1 pressure ratio at takeoff, the NO_x EPAP of the current production CF6-50C engine model is about 7.7. Therefore, a percentage reduction of more than 60 is needed in the NO_x emission indices at all four of the prescribed modes of the EPA landing/takeoff cycle to meet the applicable standard. Reductions of this magnitude do not appear attainable with the double-annular combustor. However, for turbofan engines with lower cycle pressure ratios, of 25 or less, using a double-annular combustor would generally be expected to result in compliance with the applicable NO_x standard for class T2 engines.

CONCLUDING REMARKS

As assessment of the current development status of the double-annular combustor, based on the results of the phases II and III component development efforts, is presented in table III-2. The double-annular combustor meets most key performance and operating requirements. Considering the relatively early state of development of this advanced combustor design concept, this status is generally quite good. However, in its current form, the phase III demonstrator-engine combustor is still deficient in three key performance aspects.

First, some additional improvement is needed to meet the applicable CO and THC emissions standards with the phase III demonstrator-engine combustor at the normal engine idle power setting of 3.4 percent of takeoff thrust. However, these standards were consistently met with the phase II prototype combustor; and, therefore, these standards should also be met with the phase III demonstrator-engine combustor with additional development effort.

Second, additional reductions in its NO_x emissions levels are needed. Large further reductions in NO_x emissions levels are not, however, considered likely with the existing double-annular combustor. Thus, the development status for this performance aspect is shown in table III-2 in the major further development category. While some small further reductions in NO_x emissions levels of the phase III demonstrator-engine combustor may be attainable, the applicable NO_x emissions standard will probably not be met in the CF6-50 engine application even if these additional reductions are realized. The use of a staged combustor like the double-annular combustor in the CF6-50 engine results in significant NO_x emissions level reductions. However, because of the high (30:1) cycle pressure ratios of the CF6-50 engine family, these lower NO_x emissions levels still do meet the applicable standard. In general, based on the parametric data taken in phases II and III, using a double-annular combustor in large turbofan engines with cycle pressure ratios greater than about 25 will not result in full compliance with the applicable NO_x standard. For large turbofan engines with cycle pressure ratios less than about 25, NO_x EPAP values closely approaching the applicable standard can generally be expected when a double-annular combustor is used.

Third, further improvements are needed in the exit-temperature profile characteristics of the phase III demonstrator-engine combustor. Normally, this development task would be relatively easy; but in this advanced combustor design concept, there is very little remaining combustor airflow available for exit-temperature profile trimming.

The development status assessment presented in table III-2 is, of course, based entirely on component test results. Additional development concerns, particularly in those engine performance aspects concerned with transient operation, should be identified in the forthcoming demonstrator-engine test series. However, based on the assessments presented in table III-2, further design and development efforts are needed in order to provide a fully demonstrated combustor design concept for use in the CF6 engines in these key areas:

(1) For the combustor: Emission of CO and THC must be reduced further at idle and approach. Exit-temperature distributions must be improved. Main-stage fuel nozzle plugging must be prevented.

(2) For the fuel flow splitter: The flow splits required at cruise must be provided.

Further reductions are needed in CO and THC emissions levels at idle of the existing phase III demonstrator-engine combustor. Development efforts must also be expanded to attain lower CO emission levels in the approach mode, when both the pilot and main stages of the combustor are in operation. At present, operation of both stages of the existing phase III demonstrator-engine combustor in the approach mode results in relatively high CO emission indices and, thus, high CO EPAP values. In determining the EPAP values presented in figure III-14, pilot-stage operation only in the approach mode was assumed. From an aircraft and engine operational standpoint, staging of the combustion process at any flight condition is undesirable. Preferably, the main stage should be in operation at power settings just above ground idle and before the aircraft is airborne. To accommodate this operational need, additional features will be required in the double-annular combustor to provide lower CO emission levels in the approach mode with both the pilot and main stages in operation.

Improvements are needed in the exit-temperature distributions of the existing phase III demonstrator-engine combustor. In addition, the need is anticipated for features to prevent carbon deposition and resulting plugging within its main-stage fuel nozzles. Possible problems of this kind are anticipated since fuel nozzles are inoperative at some engine operating conditions. Without some added features, any residual fuel in the nozzles might cause plugging when the main stage is shut down. This development concern will be investigated in more detail in the forthcoming demonstrator-engine tests.

The fuel flow splitter represents still another key design and development need. The existing fuel flow splitter, which will be used in the demonstrator-engine tests, is designed only for sea-level operation. Considerable sophistication and complexity will be needed to accommodate cruise operating conditions. The design and development of a suitable device to handle the necessary fuel flow splitting functions at all ground level and cruise operating conditions of the CF6 engines is expected to be a major undertaking.

Following these design and development efforts to provide a fully developed and demonstrated prototype combustion system, we can begin to evolve versions of this system, including the necessary fuel flow control elements, for use in production CF6 engines. The major tasks involved in the design, development, and demonstration of such combustion systems for use in production CF6 engines are

(1) Design definition
(2) Component development testing
(3) Engine development testing for performance and cyclic endurance
(4) Engine flight testing
(5) Certification testing
(6) Flight service evaluation testing

Flight service evaluation tests, which cannot be started until after the engine with the new combustion system is certified, are expected to be quite extensive because of the magnitude of the combustor and engine design changes associated with using the double-annular combustor. These tests are, therefore, expected to take at least 2 years to complete. Accordingly, the total time span of these tasks will probably be 5 years or more.

Key Design Parameters of CF6-50 Combustors

	Single Annular Production	Double Annular: Phases I & II Prototype	Double Annular: Phase III Demonstrator
• Airflow Distribution, % Wc			
Primary Combustion			
Overall	48.9	74.5	76.4
Pilot Stage	—	24.5	25.8
Main Stage	—	50.0	50.6
Liner Cooling	31.7	20.7	21.6
Profile Trim	19.4	4.8	2.0
• Velocities, m/s			
Dome, Overall	12	—	—
Pilot Dome	—	11	10
Main Dome	—	29	29
• Dome Height, cm			
Overall	11.4	—	—
Pilot Stage	—	5.7	7.1
Main Stage	—	5.3	6.1
• Combustion Length, cm	34.8	32.5	32.5

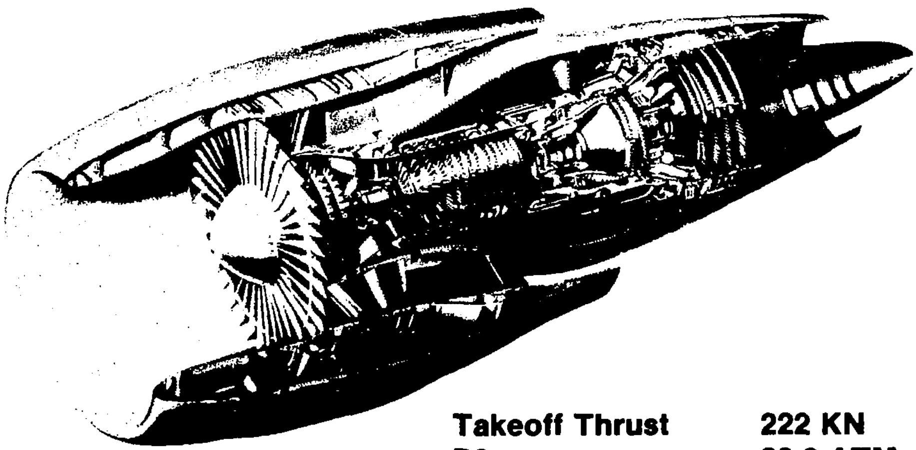
Table III-1.

Assessment of Double Annular Combustor Development Status

	Meets Requirements	Further Development Needed	Major Further Development Needed
• Emission Levels			
CO		X	
HC		X	
NOx			X
Smoke	X		
• Ground Starting	X		
• Altitude Relight	X		
• Main Stage Crossfiring	X		
• Pressure Loss	X		
• Combustion Efficiency	X		
• Exit Temperature Profile/Pattern Factor		X	
• Metal Temperature	X		
• Acoustic Resonance	X		
• Carboning	X		

Table III-2.

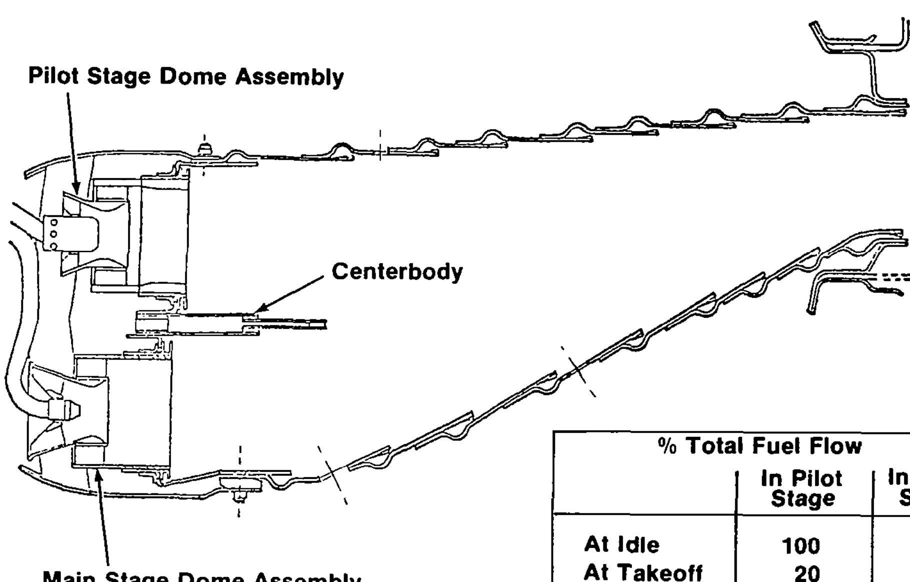
General Electric CF6-50 High Bypass Turbofan Engine



Takeoff Thrust	**222 KN**
P3	**29.8 ATM**
T3	**820 K**

Figure III-1.

Prototype Double Annular Combustor



% Total Fuel Flow	In Pilot Stage	In Main Stage
At Idle	100	0
At Takeoff	20	80

Figure III-2.

Prototype Double Annular Combustor

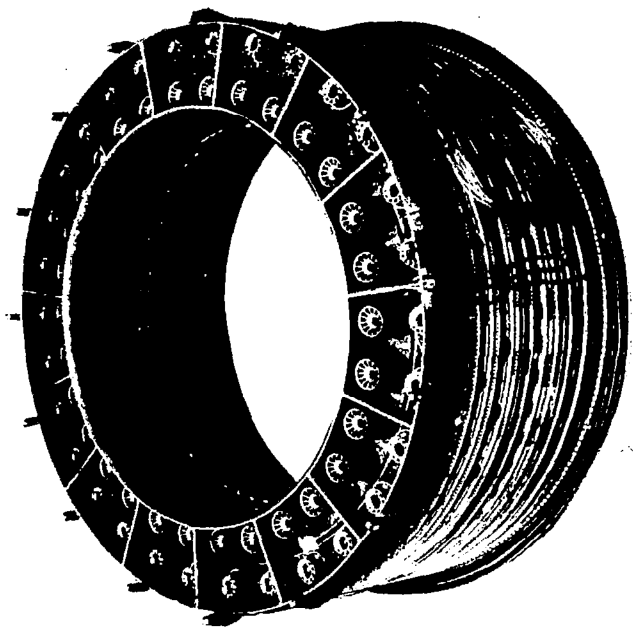


Figure III-3.

Demonstrator Double Annular Combustor

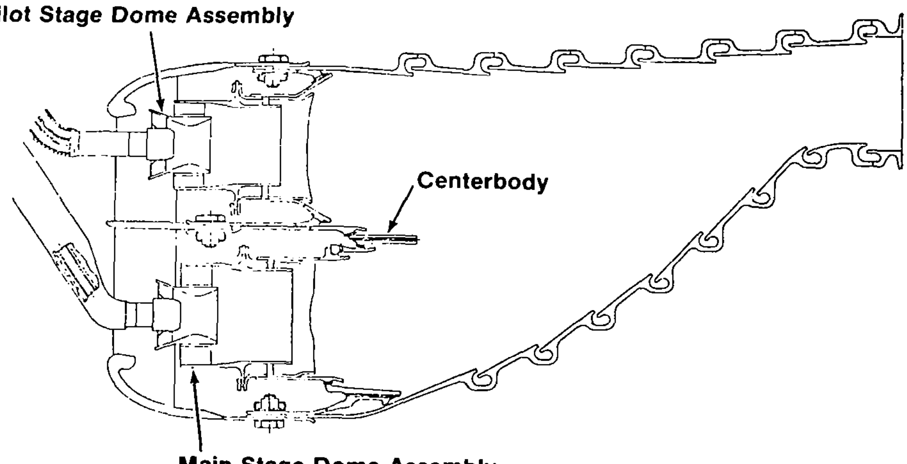


Figure III-4.

Demonstrator Double Annular Combustor

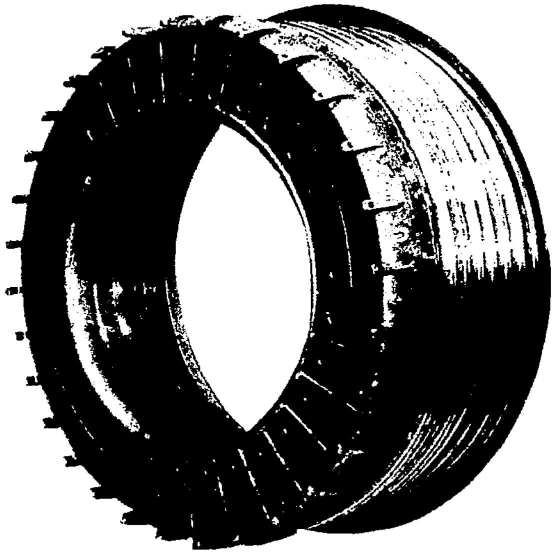


Figure III-5.

Demonstrator Engine Fuel Flow Splitter

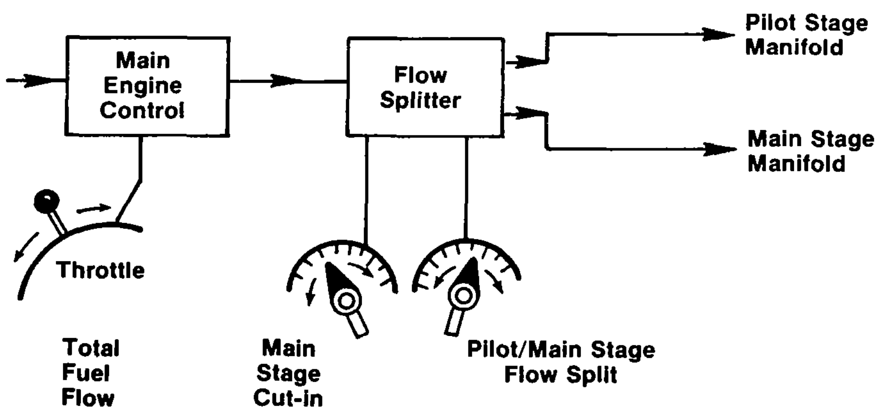


Figure III-6.

Demonstrator Engine Fuel Flow Splitter

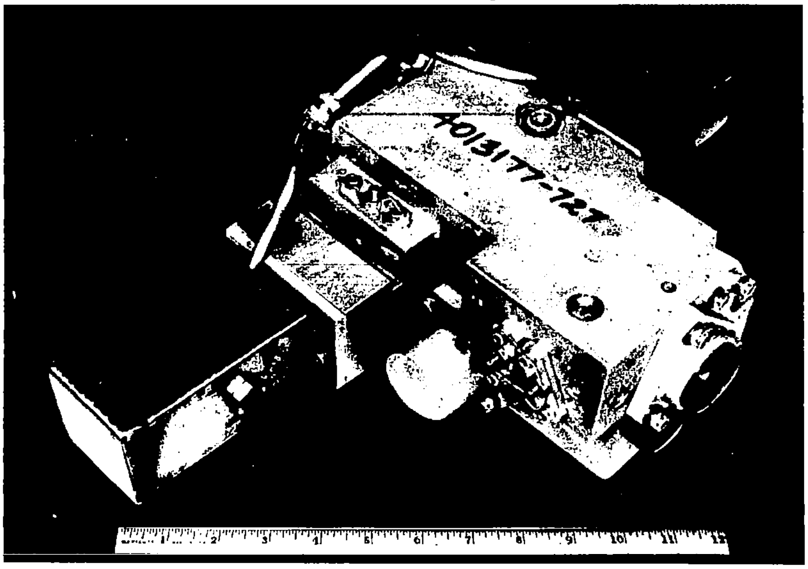


Figure III-7.

CO Emission Results/Status

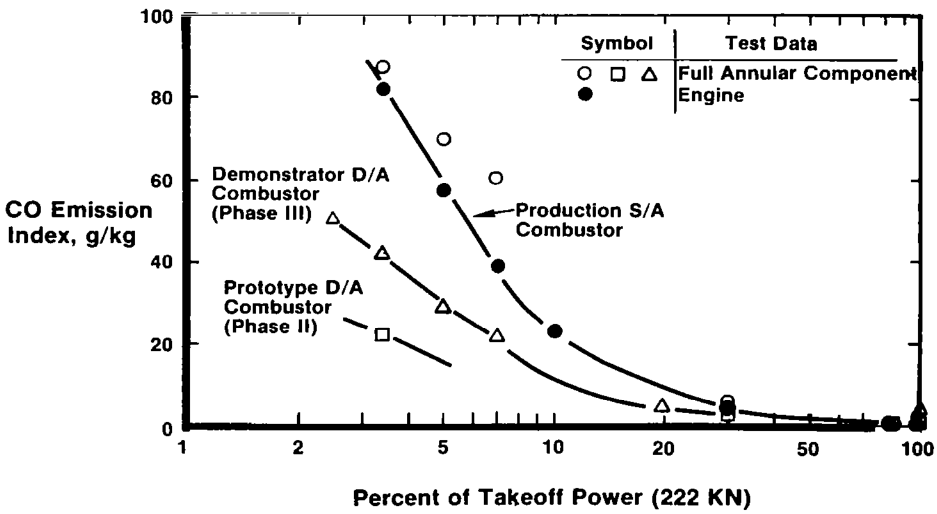


Figure III-8.

HC Emission Results/Status

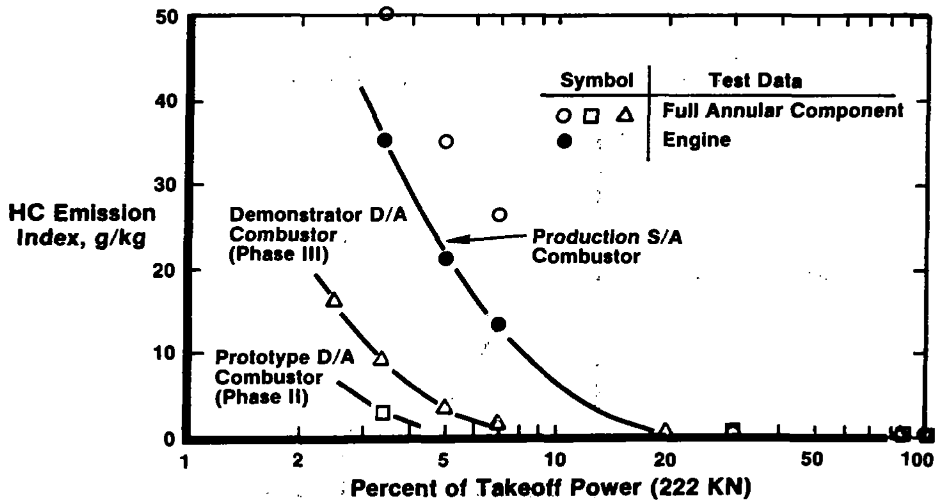


Figure III-9.

Prototype D/A Combustor — Phase II CO Emission Results at Idle

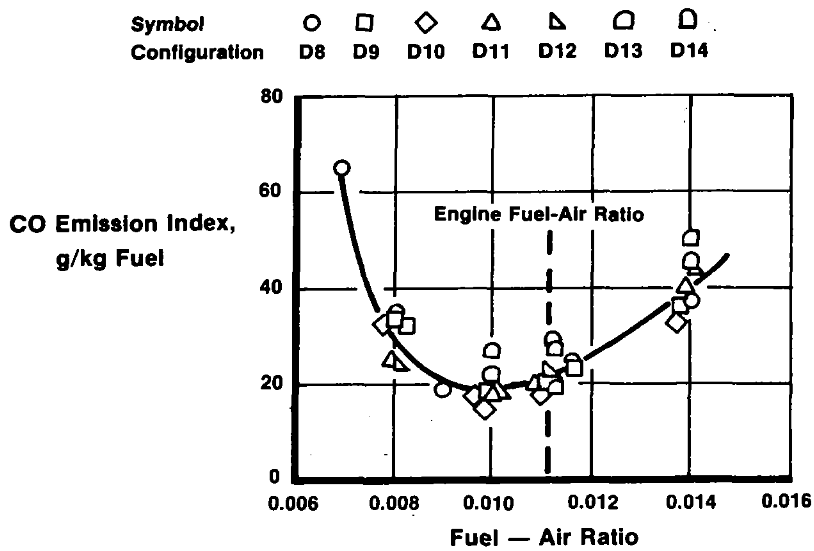


Figure III-10.

Prototype D/A Combustor — Phase II HC Emission Results at Idle

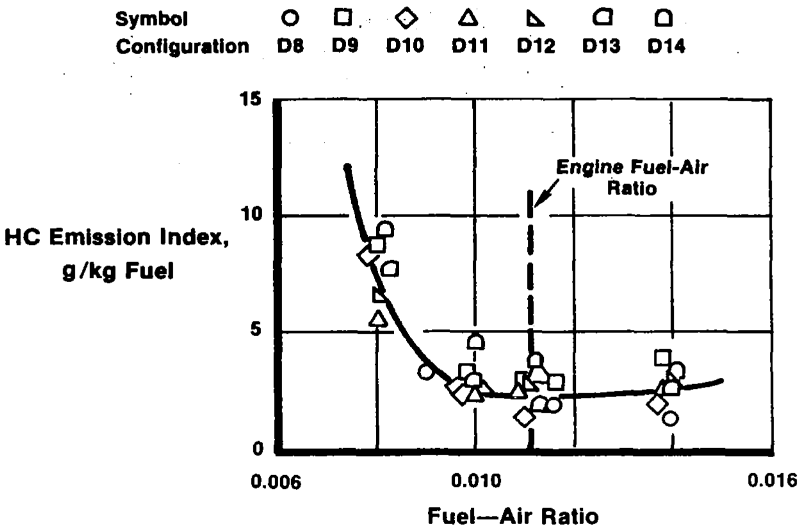


Figure III-11.

NO_X Emission Results/Status

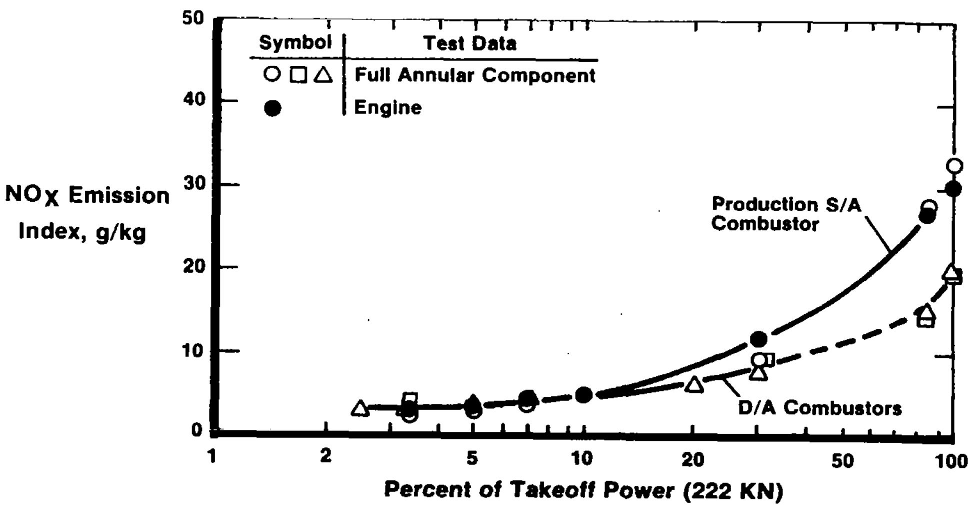


Figure III-12.

Smoke Emission Results/Status

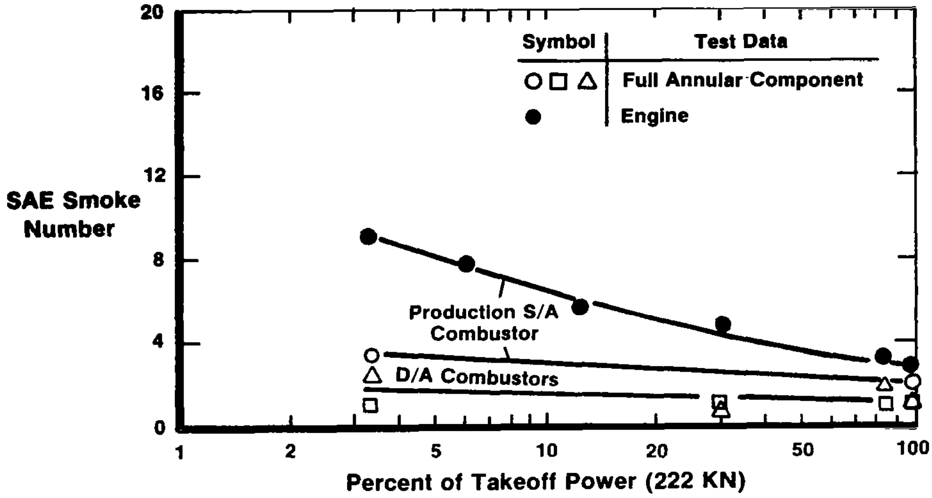


Figure III-13.

EPAP Results/Status

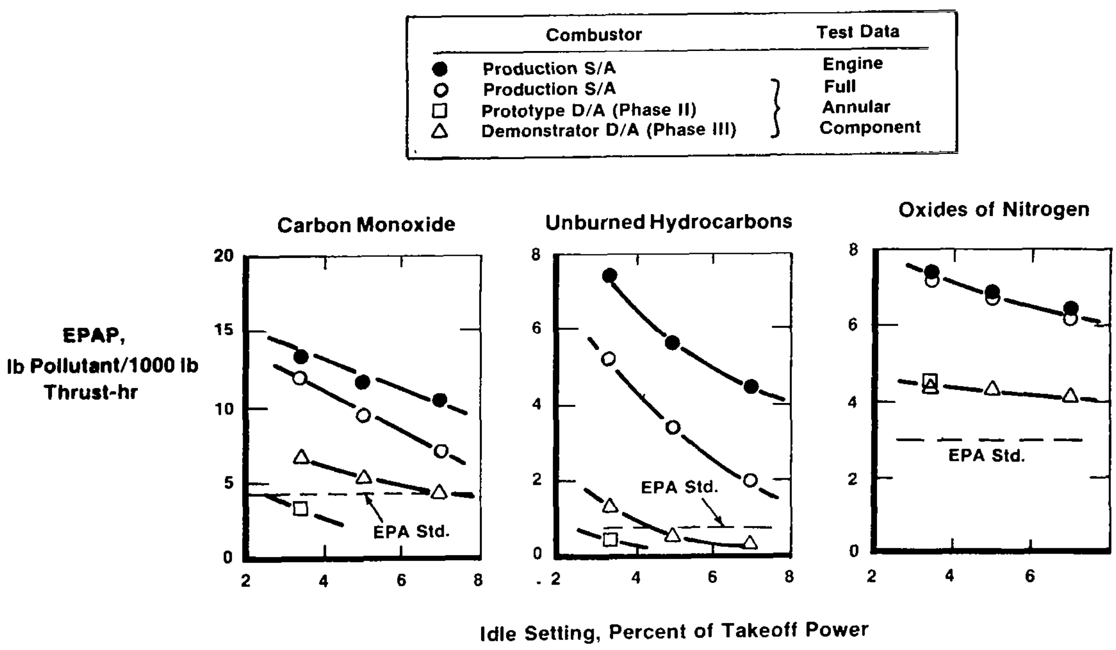


Figure III-14.