NASA/GENERAL ELECTRIC BROAD-SPECIFICATION FUELS

COMBUSTION TECHNOLOGY PROGRAM - PHASE I

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The use of broad-specification fuels in aircraft turbine engine combustion systems presents several design problems. In general, levels of exhaust pollutant emissions increase and the combustor performance and durability requirements become more difficult to meet as the fuel specifications are relaxed. Fuel hydrogen content will be lower than in presently used fuels, causing increased visible smoke output, increased carbon deposition on fuel nozzles and combustor liners, increased NO_X emissions, and increased flame luminosity, resulting in increased radiant heat transfer and shorter life. Fuel volatility will be lower and viscosity will be higher than in presently used fuels. This will result in more difficult cold start and altitude relight and greater difficulty in achieving satisfactory emissions levels at low power conditions. Thermal stability may be poorer than in presently used fuels, causing fuel system deposits and fuel injector plugging.

Design approaches to counteract the effects of decreased fuel hydrogen content include the use of short combustors with improved liner cooling techniques. Improved combustor dome and swirler designs eliminate carbon deposition and improve primary zone mixing, thereby decreasing smoke formation and flame luminosity and minimizing repetitive hot streaks which can reduce liner life. In advanced designs, smoke, NO_X and flame luminosity can all be reduced by providing for lean combustion at high power operating conditions. Effects of increased viscosity and reduced volatility can be reduced by the use of improved dome, fuel injector and swirler designs to improve fuel atomization and mixing at lightoff and low power operating conditions, and by providing low velocities and near-stoichiometric mixtures in the combustor primary zone at low power operating conditions. Fuel thermal stability effects can be reduced by reducing fuel manifold temperatures and by using more effective thermal insulation in fuel system components.

In Phase I of the NASA/General Electric Broad-Specification Fuels Technology program, three different combustor design concepts will be evaluated for their ability to use broad-specification fuels while meeting several specific emissions, performance, and durability goals. These combustor concepts cover a range from those having limited complexity and relatively low technical risk to those having high potential for achieving all of the program goals at the expense of increased technical risk.

The concept with the least complexity is the basic CF6-80 combustor. This advanced single-annular combustor is a direct derivative of the successful CF6-50 combustor design. Compared to the CF6-50 design, the CF6-80 combustor length has been reduced by 8 cm, counterrotating dome swirlers are used rather than the corotating design, and the liner film cooling slots are a newly developed rolled-ring design that features improved film cooling effectiveness and maximum resistance to film slot closure.

The second concept is a parallel-staged double-annular design similar to that used in the NASA/GE Experimental Clean Combustor and E^3 programs. At lightoff and low power operating conditions, all of the fuel is burned in the pilot stage, which is designed to provide low velocity, near-stoichiometric primary combustion. At high power conditions, both the pilot and main stages are fueled, but most of the fuel is injected into the main stage dome. This dome is designed to provide lean combustion and short residence times to reduce NO_x and smoke formation, thereby reducing flame luminosity effects.

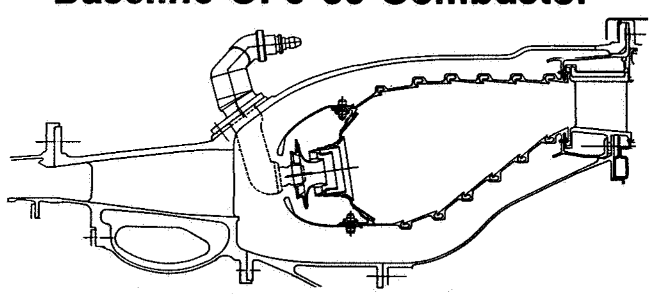
The third concept is an advanced, short single-annular combustor which employs variable geometry swirlers to provide optimum flow rates and stoichiometries in the dome region at the various operating conditions. At lightoff and low power conditions, the swirlers are closed down to reduce the combustor velocity to provide near-stoichiometric primary zone mixtures. At high power conditions, the swirlers are opened to provide lean, high velocity combustion.

The combustor test program will consist of screening tests of a baseline configuration and approximately five modifications of each combustor concept. About six additional refinement tests will then be conducted to improve the performance of selected combustor configurations and to more completely document combustor operating characteristics and fuel properties effects. All testing will be conducted using a full-scale CF6-80 sector test rig which is designed to operate at the full sea-level-takeoff pressure and temperature conditions of the CF6-80 engine.

Combustor Design Considerations

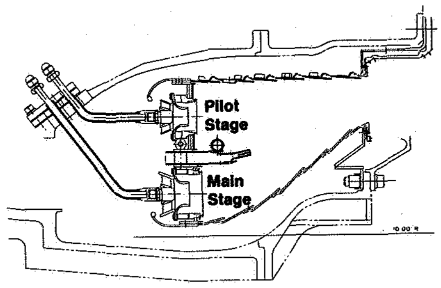
Fuel Property Change	Problems	Approach
• Reduced Hydrogen Content/Higher Aromatics	• Increased Flame Luminosity (Increased Liner Temperatures)	• Lean-Well Mixed Combustion at High Power
	• Increased Smoke	• Short Combustor-Reduced Liner Cooling Requirements
	• Increased NOx	
	• Increased Carboning	• Improved Dome/Swirler Designs
• Increased Viscosity/ Reduced Volatility	• Increased Ground Start/Relight Difficulty	• Rich-Low Velocity Combustion at Low Power
	• Increased Low Power Emissions (CO & HC)	• Improved Dome/Swirler Designs
• Reduced Thermal Stability	• Fuel Valve & Nozzle Fouling	• Increase Fuel System Insulation

Baseline CF6-80 Combustor



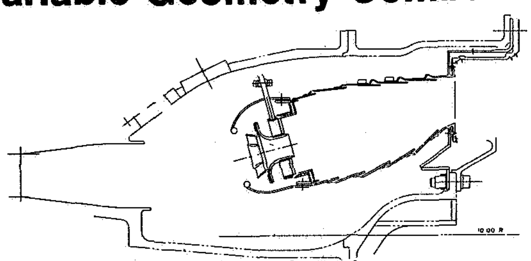
- Short Single Annular Combustor Design
- Counterrotating Dome Swirlers
- Advanced Liner Cooling Slot Design
- Short Prediffuser

Double Annular Combustor



- Short Double Annular Combustor Design
- Low Velocity Pilot Stage — Near Stoichiometric Primary Zone Combustion at Idle
- High Velocity Main Stage — Lean Primary Zone Combustion at High Power
- Centerbody Dilution for Improved Mixing
- Utilizes NASA/GE E^3 Swirler Components

Variable Geometry Combustor



- Very Short Single Annular Design
- Dome Swirler Closed for Low Power Operation
  - Low Velocity
  - Rich Primary Zone Combustion
  - Increased Pressure Drop
- Dome Swirler Open for High Power Operation
  - High Velocity
  - Lean Primary Zone Combustion
  - Short Residence Time

Combustor Design Parameters

	Baseline CF6-80	Double Annular Pilot	Double Annular Main	Variable Geometry
Low Power (Idle)				
Dome Reference Velocity, m/s	8.3	6.6	—	5.7
Dome Swirler Equivalence Ratio	0.73	1.1	—	1.0
High Power (Takeoff)				
Dome Reference Velocity, m/s	11.3	9.0	28.6	19.3
Dome Overall Equivalence Ratio	0.88	0.63	0.63	0.60
Combustor Length, cm	27.7	22.1	22.1	20.8

Planned Test Program

Scope:

- Screening Tests on Six Configurations of Each Concept (18 Tests Total). 60 Percent of Engine Pressure.
- Refinement Tests on Two Most Promising Concepts (6 Tests Total). Some Tests at Full Engine Pressure.

Test Vehicle: CF6-80 High Pressure (Up to 3.5 MPa) Five Cup (60-Degree) Sector Combustor Test Rig.

Test Facility: Test Cell A3 — Evendale.