LEAN STABILITY AUGMENTATION STUDY

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An analytical and experimental program was conducted to investigate techniques and develop technology for improving the lean combustion limits of premixing, pre-vaporizing combustors applicable to gas turbine engine main burners. In the analytical conceptual design study, three concepts for improving lean stability limits were selected for experimental evaluation among twelve approaches considered. Concepts were selected on the basis of the potential for improving stability limits and achieving emission goals, the technological risks associated with development of practical burners employing the concepts, and the penalties to airline direct operating costs resulting from decreased combustor performance, increased engine cost, increased maintenance cost and increased engine weight associated with implementation of the concepts. Tests of flameholders embodying the selected concepts were conducted in an axi-symmetric flamtube test rig having a nominal diameter of 10.2 cm at a pressure of 10 atm and at a range of entrance temperatures simulating conditions to be encountered during stratospheric cruise. A total of sixteen test configurations were examined in which lean blowout limits, pollutant emission characteristics, and combustor performance were documented.

The use of hot gas pilots, catalyzed flameholder elements, and heat recirculation to augment lean stability limits was considered in the conceptual design study. On the basis of the results of the study, three classes of augmented flameholders were designed and tested. The first class involved the use of cavities or recesses located in the downstream face of a perforated plate flameholder—these configurations are referred to as Self-Piloting Recessed Perforated Plates. The second class involved the use of tube bundles wherein the inner diameter of the tubes and/or the reface of the tube array was treated with a platinum/rhodium catalyst. These configurations were referred to as Catalyzed Tube Flameholders. The third class of flameholders involved the direct injection of gaseous or liquid fuel into the recirculation regions formed behind V-gutter or perforated plate flameholders. This class of flameholders is referred to as Piloted Flameholders. The primary goal of the program was to achieve stable operation of the combustors at equivalence ratios as low as 0.25. It was desired that the NOx emission index be less than 1.0 g/kg at the design conditions (T0 = 600 K, $\phi = 0.6$). It was also desired that the combustor operate efficiently over a range of entrance temperatures from 600 to 800 K, a range of equivalence ratios from 0.3 to 0.6, and that the maximum emission of nitric oxides be less than that corresponding to an emission index of 3.0 g/kg.
The most promising configuration identified in this program involved the injection of pilot fuel into the base or recirculation region of a bluff-body flameholder. It was determined that with a pilot fuel flow equal to 5 percent of the total fuel flow at the design conditions, combustor blowout did not occur as fuel flow was decreased to levels corresponding to an overall equivalence ratio of 0.25. For this configuration, the NO\textsubscript{X} emission index at the design point was less than half of the design goal and, at off-design conditions, the maximum NO\textsubscript{X} emission index goal was exceeded only for the T\textsubscript{O} = 800 K, \phi = 0.6 case. At the lower entrance temperature conditions tested (T\textsubscript{O} = 700 and 600 K), the measured combustion efficiencies were unacceptably low and further effort is required to obtain the desired performance. No substantial improvement in blowout limits was achieved for the self-piloting recessed perforated plate configurations or the catalyzed tube configurations.
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NASA Lean Stability Augmentation Study

Objective: Attainment of improved lean blowout limits

Tasks:

I. Conceptual design study
II. Experimental design
III. Fabrication and installation
IV. Combustor tests
V. Final design and test
VI. Reports and records
Program Goals

Conditions:

\[ P = 10 \text{ atm} \]

\[ 600 \leq T_i \leq 800 \text{ K} \]

\[ 0.25 \leq \phi_p \leq 0.6 \]

\[ V_{\text{ref}} = 25 \text{ m/sec} \]

Emissions:

\[ \text{EI}_{\text{NOX}} < 1.0 \text{ at design; } < 3.0 \text{ overall} \]

\[ \text{EI}_{\text{CO}} < 10.0 \text{ at design} \]

\[ \text{EI}_{\text{UHC}} < 1.0 \text{ at design} \]

Performance:

\[ \eta_{\text{comb.}} \geq 0.99 \text{ for } 0.3 \leq \phi \leq 0.6 \]

\[ \Delta P/P < 0.05 \]
Bluff Body Flame Stabilization Process

Incoming mixture

Ignition point

Flame front

Recirculation zone boundary

Stagnation point

Combustion products

Bluff body

\[ \dot{q} \]

\[ M_r \]
Lean Stability Augmentation Study Test Facility

Existing facility

Inlet

Mixer / vaporizer

Electric heater

Valve

Venturi

Plenum

Combustor

Diffuser

Flame stabilizer

Fuel-injector

Instrumentation

Transition

Quench

Exhaust

Valve

Existing facility

Current effort
Fuel Injector – Airflow Nozzle

5 deg. half angle

Fuel tube port

Flow direction

19 Venturi-shaped air passages
Emission - Probe Tip Construction

Shock stabilization step

Supersonic nozzle, $A_2/A_1 = 4.7$ (M = 2.5)

Note: All dimensions in cm
Baseline Flameholder Blowout Limits

75% blockage perforated plate

\[(\Delta P/P_T)_{\text{cold}} = 2.3\%\]

\[P = 10 \text{ atm}\]

Blowout equivalence ratio, \(\phi_{bo}\)

Inlet temperature, \(T_0(K)\)

[Graph showing the relationship between blowout equivalence ratio and inlet temperature]
Variation of Blowout Flame Temperature with Inlet Temperature

Baseline configuration

$P = 10$ atm

Flame temperature, $T_f$ (K)

Inlet temperature, $T_o$ (K)

1800
1700
1600
1500
1400
500  600  700  800  900
Self-piloting Recessed Perforated Plate Flameholders

Config. No. 1
Unpiloted recess

Config. No. 2
Piloted recess

Config. No. 3
Piloted, interconnected recess

Config. No. 4
Uncooled counterbore

- Coolant passage
- 0.13 cm dia. pilot bleed hole
- 0.79 dia. x 0.64 cm deep recess
- 0.83 cm dia. perforation
- Recess interconnect groove
- 90° x 1.37 cm dia. counter-sink
Recessed Self-piloting Perforated Plate Flameholder

Thermocouples

Front view

Coolant passages

Perforation

Rear view

Recess
Lean Stability Limits
Self-Piloting Recessed Perforated Plate Series

Configuration
- Recess only
- Recess + pilot
- Interconnected recesses + pilot
- Countersink
- Final 80% blkg; deep counter bore

Blowout equivalence ratio, $\phi_{bo}$ vs Inlet temperature, $T_o$ (K)

Baseline
Self-Piloting Recessed Perforated Plate Final Design

Note: All dimensions in cm
80% blockage

19 holes

1.03 dia

1.70 dia

1.14

2.34

Section A-A