PRELIMINARY STUDIES OF COMBUSTOR SENSITIVITY TO ALTERNATIVE FUELS

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The Lewis Research Center has several in-house research programs under way to study combustion problems associated with using alternative fuels for ground power and aeropropulsion applications. The programs, which currently include individual combustor tests of tubular combustion chambers and basic flame-tube studies, will eventually include testing of rectangular sections designed to simulate large annular combustor test conditions. These programs are intended to study the effects of using alternative fuels with reduced hydrogen content, increased aromatic content, and a broad variation in fuel property characteristics. Data of special interest include flame radiation characteristics in the various combustor zones, the corresponding increase in liner temperature from increased radiant heat flux, the effect of fuel-bound nitrogen on oxides of nitrogen (NO_x) emissions, and the overall total effect of fuel variations on exhaust emissions. These data are applicable to aeropropulsion broadened-property fuels technology programs and joint NASA/Department of Energy stationary-power gas turbine programs. The in-house fuels combustion programs are described in table I. The NASA facilities used for these programs are a moderate-flow facility for high-pressure studies of tubular and simulated annular combustor sections and a limited-flow facility for basic low-pressure, flame-tube experiments.

The tubular combustor experiments were conducted with several test fuels in order to study basic alternative fuel effects by comparing the combustor sensitivity with fuel variations and with configuration modifications. A schematic of the tubular combustor test section is shown in figure 1. The test combustors were stock commercial aircraft units designated as models A and B and were obtained in 1974 and 1978, respectively. These models differed slightly in primary-zone stoichiometry and in provisions for liner cooling. The variation in average liner temperatures with increase in fuel-air ratio is shown in figure 2; the variation in SAE smoke numbers with increase in fuel-air ratio is shown in figure 3.

Data from these tubular combustor experiments have demonstrated the following characteristics:

(1) Average liner temperatures rise substantially with increases in fuel-air ratio.

(2) Combustor design modifications can significantly reduce average liner temperatures.

(3) The increase in average liner temperature due to reduced fuel hydrogen content appears to be independent of the combustor design modification.

(4) An apparent design trade-off produced a decrease in average liner temperature while causing an increase in smoke emission.

Supplemental performance data for tubular combustor model A are contained in reference 1.

Flame radiation studies were conducted with tubular combustor model B. The assembly of the combustor housing with provisions for monitoring radiant heat flux is shown in figures 4 and 5. The variation of radiant heat flux with increase in combustor pressure is shown in figure 6.

Data from tubular combustor flame radiation studies have demonstrated the following characteristics:

(1) Radiant heat flux increases with rising combustor pressure and with reductions in fuel hydrogen content.
(2) The differential increase in radiant heat flux with combustor pressure diminishes with rising combustor pressure.
(3) Average liner temperatures are relatively insensitive to increases in combustor pressure.
(4) The differential increase in average liner temperature with reductions in fuel hydrogen content diminishes with rising combustor pressure.

Supplemental spectral flame radiation data obtained with tubular combustor model B are contained in reference 2.

Studies of the conversion of fuel-bound nitrogen to NO_x emissions were conducted with a basic two-stage flame-tube combustor test section. A schematic of the test facility used for low-pressure flame-tube experiments is shown in figure 7. Gaseous propane mixed with toluene and/or pyridine was used to get various nitrogen concentrations and hydrogen-carbon ratios. The variation of percent conversion of fuel-bound nitrogen with increase in primary equivalence ratio is shown in figure 8.

Data from the flame-tube experiments have demonstrated the following characteristics:

(1) Rich-lean two-stage combustion is successful in reducing the conversion of fuel-bound nitrogen to NO_x.
(2) Optimum primary equivalence ratios are roughly 1.4 to 1.7 for fuels ranging from 9 to 18.3 percent hydrogen content.
(3) The optimum secondary equivalence ratio is about 0.5.

Supplemental data and more detailed discussion of the results from the flame-tube experiments are contained in reference 3.

REFERENCES

1. Butze, Helmut F.; and Humenik, Francis M.: Parametric Performance of a Turbojet Engine Combustor Using Jet A and a Diesel Fuel. NASA TM-79089, 1979.

2. Claus, Russell W.: Spectral Flame Radiance from a Tubular Can Combustor. NASA TP-1722, 1980.

3. Schultz, Donald F.; and Wolfbrandt, Gary: Flame Tube Parametric Studies for Control of Fuel Bound Nitrogen Using Rich-Lean Two-Stage Combustion. DOE/NASA/2593-80/15; NASA TM-81472, Apr. 1980.

TABLE I. - LEWIS IN-HOUSE PROGRAMS TO STUDY COMBUSTION PROBLEMS ASSOCIATED WITH USE OF ALTERNATIVE FUELS

PROGRAM TITLE	COMBUSTOR TYPES	FUELS (% H)
COMBUSTOR EXPERIMENTS WITH ALTERNATIVE FUELS	TUBULAR CONVENTIONAL ADVANCED SUB-COMPONENTS ANNULAR SECTION	JET A (13.9) TEST FUELS (11.0-15.3)
FLAME RADIATION STUDY	SAME AS ABOVE	JET A (13.9) TEST FUEL (12.9)
GAS TURBINE STATIONARY POWER COMBUSTION-(CRT) (NASA/DOE)	TWO-STAGE FLAME TUBE	SRC II (8.8, 11.6) PROPANE-TOLUENE-PYRIDINE (9.0, 11.3, 13.6, 15.7)
	TUBULAR	NO. 2 DIESEL (13.5) NO. 4 HEATING OIL (11.9)

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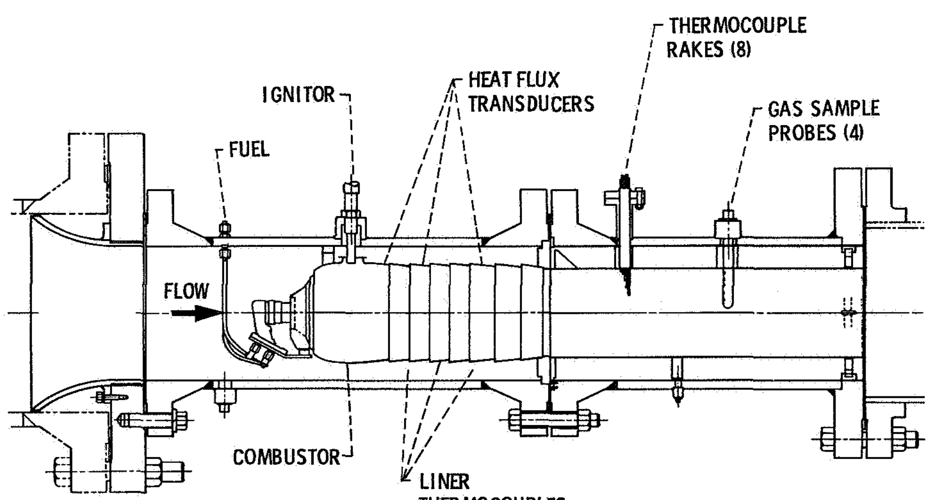

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Figure 1. - Schematic of tubular combustor installation. Nominal flow capabilities of test facility: inlet pressure, 25 atm; inlet air temperature, 870 K; inlet airflow rate, 10 kg/sec.

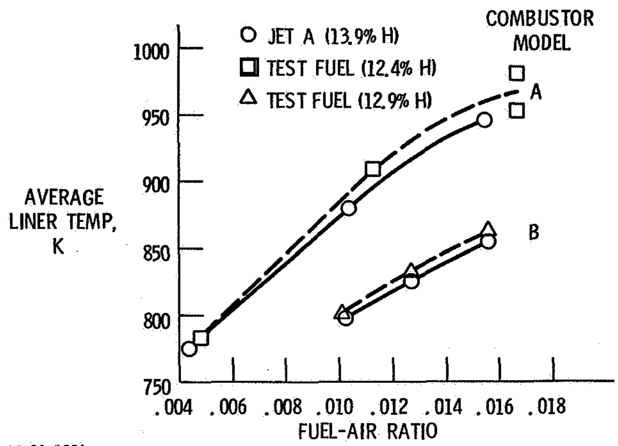

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Figure 2. - Variation of average liner temperatures with fuel-air ratio for tubular combustor models A and B using Jet A and using test fuels with reduced hydrogen content. Nominal test conditions: inlet air temperature, 700 K; inlet air pressure, 170 N/cm^2; reference velocity, 15.1 m/sec.

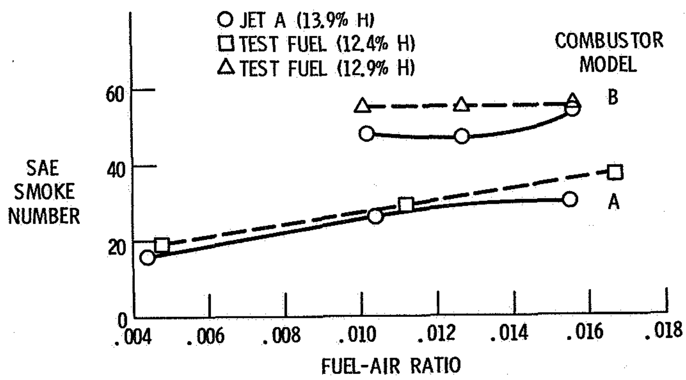

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Figure 3. - Variation of SAE smoke number with fuel-air ratio for tubular combustor models A and B using Jet A and using test fuels with reduced hydrogen content. Nominal test conditions: inlet air temperature, 700 K; inlet air pressure, 170 N/cm^2; and reference velocity, 15.1 m/sec.

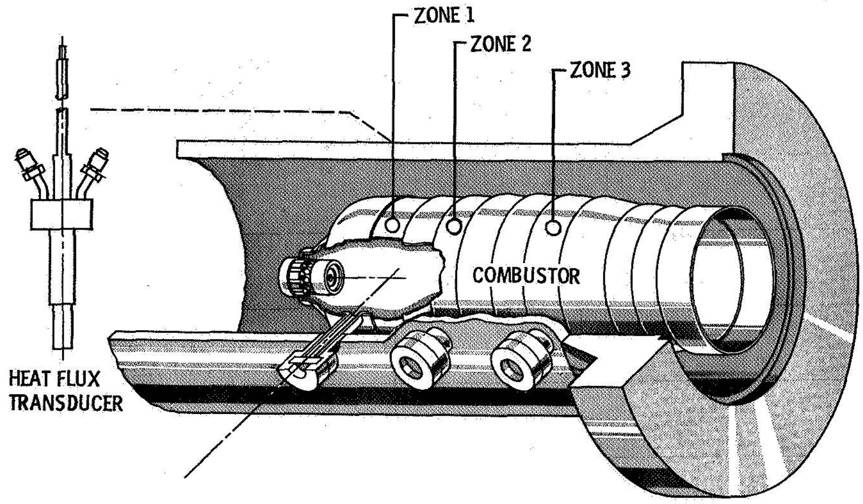

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Figure 4. - Assembly of tubular combustor for flame radiation studies. Radiant heat flux transducers installed in zones 1, 2, and 3 were thermopile type with water cooling and nitrogen purge.

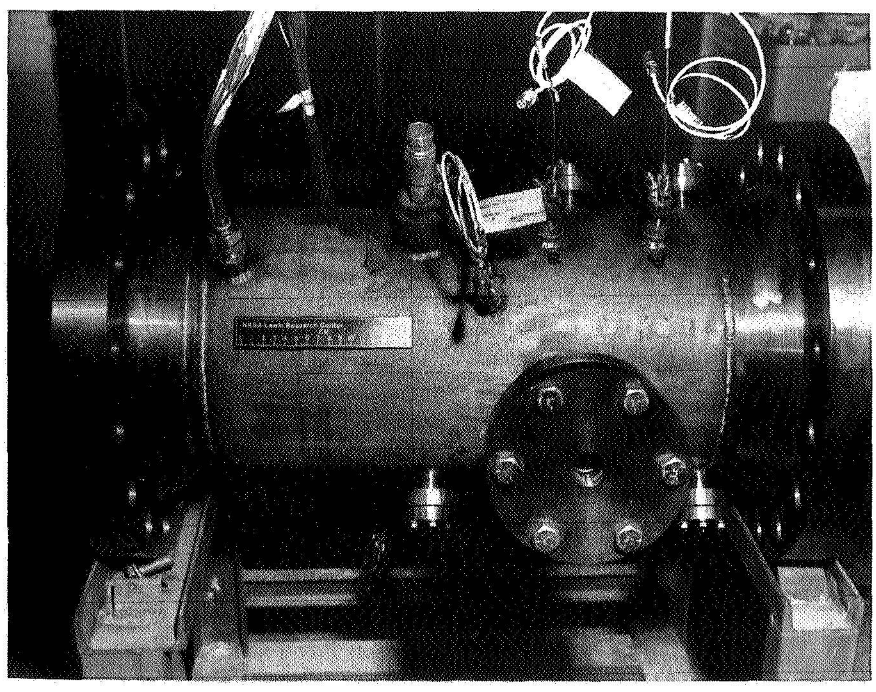

Figure 5. - Installation of radiant heat flux transducers. CS-80-1556

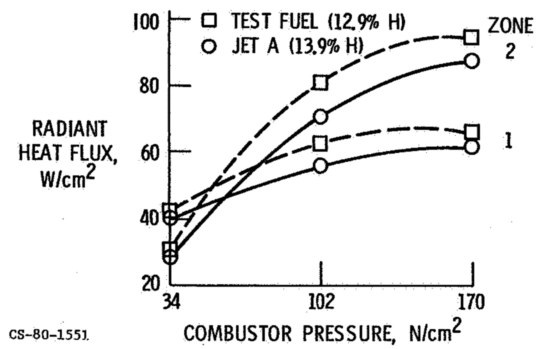

Figure 6. - Variation of radiant heat flux with increase in combustor pressure. Nominal test conditions: inlet air temperature, 700 K; fuel-air ratio, 0.0155; and reference velocity, 15.1 m/sec.

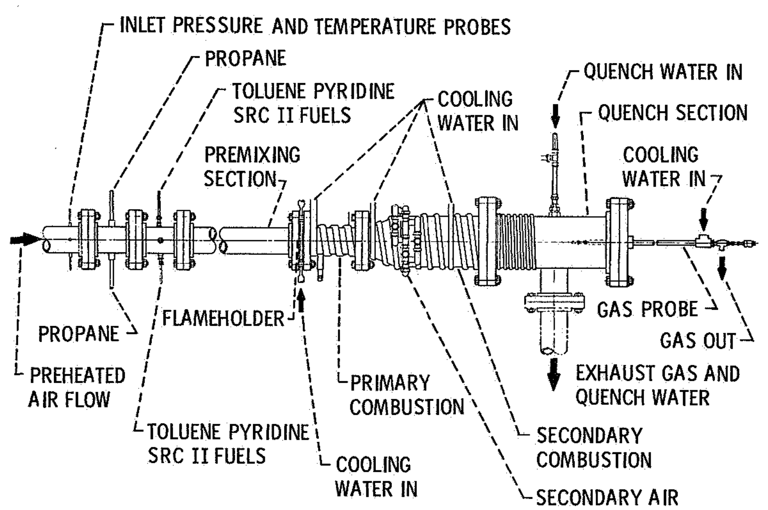

Figure 7. - Schematic of two-stage flame-tube test section. Nominal test facility capabilities; inlet pressure, 6 atm; inlet air temperature, 700 K; and inlet airflow rate, 1.4 kg/sec.

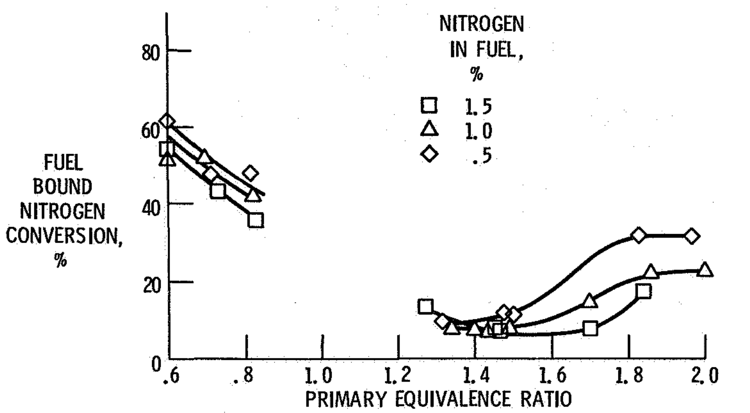

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Figure 8. - Variation of conversion of fuel-bound nitrogen with increase in primary equivalence ratio. Nominal test conditions: inlet air temperature, 672 K; inlet pressure, 48 N/cm^2. Secondary equivalence ratio was optimized at about 0.5. Test fuel was a mixture of propane, toluene, and pyridine to get 9.0 percent fuel hydrogen content and 0.5, 1.0, and 1.5 percent nitrogen in the fuel.