AIAA 79-1322R

Emission Characteristics of a Combustor Burning Simulated Partial-Oxidation Product Gas

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Abstract

A TWO-STAGE gas turbine combustor concept based upon a very fuel-rich partial-oxidation stage is being explored for broadening the combustion margin between ultralow emissions and the lean stability limit. Combustion and emission results are presented for a series of experiments where a simulated partial-oxidation product gas was used in a premix combustor operated with inlet air state conditions typical of cruise power for high-performance aviation engines (1.2 MPa and 728 K). Ultralow NO_x, CO, and HC emissions and an extended lean burning limit (relative to single-stage baseline operation) were achieved simultaneously.

Contents

Description of Experiments

The premix combustor shown in Fig. 1 was used for all of the experiments. The cylindrical combustion chamber, inlet/flameholder assembly, gas sample probe, and sonic exhaust nozzle are water-cooled. In order to reduce the effects of cooled walls on emissions and blowout limits, the cooling system is designed to maintain a relatively high (~810 K) gas-side wall temperature. Premixing is accomplished in the uncooled mixing duct where the externally prepared fuel gas, finely atomized jet fuel (under some operating modes), and air are combined. The flow area of the mixing duct and of the passage around the flameholder centerbody provides a space velocity of about 140 m/s and a premix residence time of about 1.6 ms. Neither flashback nor autoignition were encountered throughout the experiments. On-line analysis of the emission species was accomplished using chemiluminescence, FID, and NDIR instruments for NO_x, HC, and CO, respectively.

The simulated product gas contained 2.05% H_2, 31.66% CO, and 66.29% N_2 by mass. This mixture is nearly equivalent to the thermochemical equilibrium product of a JP5/air reaction for an equivalence ratio of 2.83, which theoretically yields the greatest mass of H_2 (hence, greatest combustion enhancement) per unit mass of JP5 stock without producing smoke. The adiabatic temperature of the actual product gas is about 1422 K, but the simulant fuel gas was not heated prior to injection. A partial compensation for that thermal deficiency and an estimate of the dependency of emission levels and lean blowout (LBO) on the reactant premix temperature (TM) was obtained by overheating the inlet air (TA) for several runs.

The experiments were conducted with standard inlet air conditions of 1.2 MPa and 728 K, except for runs with the air overheated to 825 K. Three modes of combustor operation were investigated: 1) JP5 only, a baseline single-stage operating condition; 2) fuel gas only, a limit mode where processing all fuel through a precombustion stage was simulated; and 3) three levels of precombustion stage

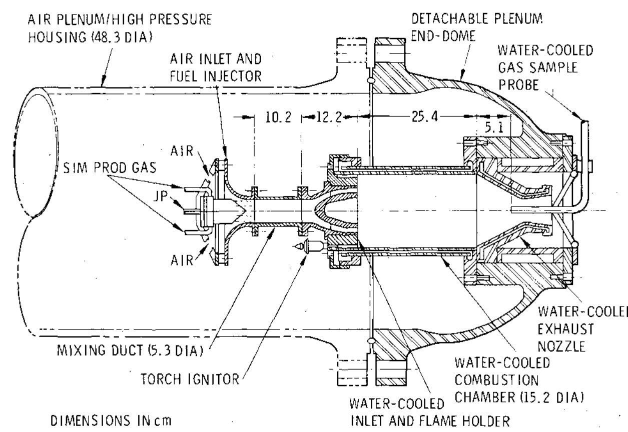

Fig. 1 Schematic of research combustor installed in burner housing.

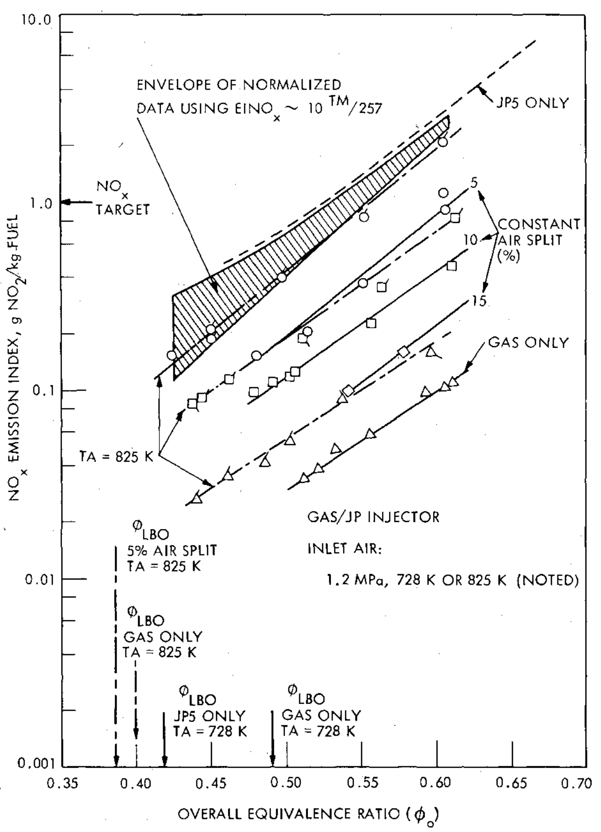

Fig. 2 NO_x emissions for various simulated precombustion-stage throughput levels, cruise power conditions.

Presented as Paper 79-1322 at the AIAA/SAE/ASME 15th Joint Propulsion Conference, Las Vegas, Nev., June 18-20, 1979; submitted July 10, 1979; synoptic received May 19, 1980. Full paper available from AIAA Library, 555 West 57th Street, New York, N.Y. 10019. Price: Microfiche, $3.00. **Remittance must accompany order.**

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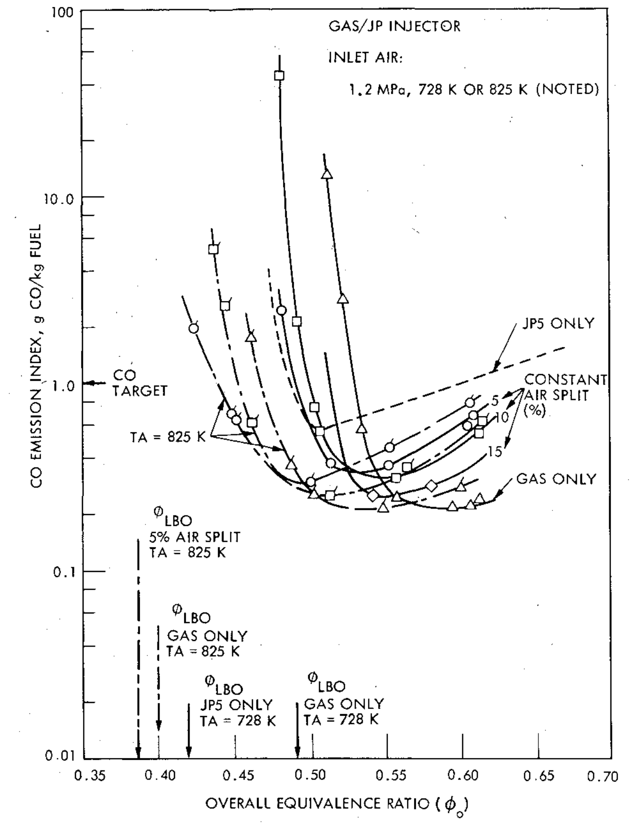

Fig. 3 CO emissions for various simulated precombustion-stage throughput levels, cruise power condition.

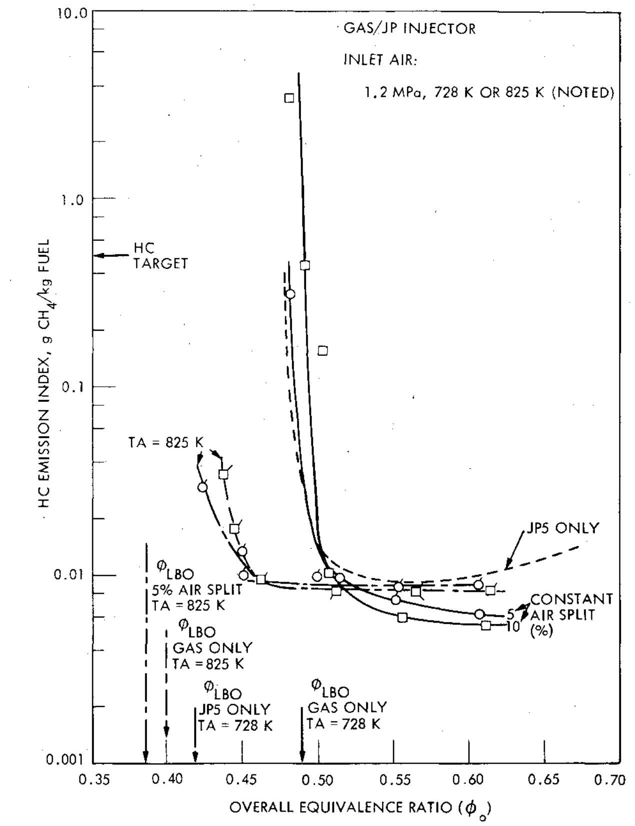

Fig. 4 HC emissions for various simulated precombustion-stage throughput levels, cruise power condition.

throughput, where intermediate levels of fuel processing were simulated. For modes 2 and 3, the reactant flows were controlled and the results are presented as if the fuel gas were produced by a precombustion stage exhausting into the entrance of the mixing duct. The intermediate throughput levels are designated as 5, 10, or 15% air split, the fraction of total combustion air ideally required to process about 25, 50, and 75% of the total fuel, respectively, at the 2.83 equivalence ratio.

Results and Discussion

The NO_x, CO, and HC emission results from the fuel-gas experiments are summarized as a function of overall equivalence ratio (ϕ_0) in Figs. 2-4, respectively, where they can be compared to the baseline emissions with JP5 only. The emission index values adopted as ultralow targets for these experiments are also shown.

When the combustor was operated with the fuel gas and the standard TA, NO_x (Fig. 2) was lowered from the baseline operation because of the reduction of mixture temperature and hence combustion temperature. In order to establish a normalization factor for this temperature effect, the NO_x results from fuel-gas-only runs with overheated air were used to estimate the temperature dependency. The form of the normalization factor was suggested in Ref. 1 and by the essentially parallel trend lines for NO_x with hot and cold mixture as shown by the two lowest trend lines in Fig. 2. The temperature dependency derived was $EINO_x \sim 10^x$ where x is TM/257 with TM in kelvins.

The result of extrapolating the measured NO_x data from the experimental TM to the theoretical TM for all of the fuel-gas runs is shown by the cross-hatched envelope in Fig. 2. Although the necessity for the extrapolation may lessen the accuracy of these results, two considerations are believed to lend credence to the position of the envelope below the JP5 baseline curve. The first is the enhanced premixing effectiveness associated with the use of the gaseous fuel and the second is the complete absence of nitrogen intermediates in the fuel gas because it was not produced chemically.

Perusal of the low ϕ_0 portions of Figs. 3 and 4 shows that the CO and HC emission trends as well as LBO were also affected by the premix temperature. With the cold TM obtained with the standard TA, the onset of rapid increase of CO and HC emissions (indicating approach to LBO) and ϕ_{LBO} actually worsened (moved to richer ϕ_0) relative to the baseline trend. However when TM was increased toward its theoretical value, those emission trends and ϕ_{LBO} were improved markedly relative to the baseline data. These improved lean burning characteristics are a central argument for the two-stage concept.

At higher ϕ_0, a small but consistent increase in CO and HC emissions was observed for the fuel-gas runs when TA was increased (Figs. 3 and 4). A rational explanation for this apparently contradictory trend has yet to be found.

Conclusions

Ultralow levels of NO_x, CO, and HC emissions can be achieved simultaneously in a single-stage premix combustor, but very little combustion margin remains. The results with the simulated product gas show that use of a very fuel-rich precombustion stage to precondition a large portion of the fuel, combined with effective premixing before final combustion, would significantly improve the margin of combustion while maintaining ultralow emission levels.

Acknowledgment

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS7-100.

References

[1] Roffe, G., "Effect of Inlet Temperature and Pressure on Emissions from a Premixing Gas Turbine Primary Zone Combustor," NASA CR-2740, Sept. 1976.