N95- 70869

THE EFFECT OF INCOMPLETE FUEL-AIR MIXING ON THE LEAN BLOWOUT LIMIT, LEAN STABILITY LIMIT AND NO_x EMISSIONS IN LEAN PREMIXED GAS TURBINE COMBUSTORS

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OVERVIEW:

Gas turbine engines for both land-based and aircraft propulsion applications are facing regulations on NO_x emissions which cannot be met with current combustor technology. A number of alternative combustor strategies are being investigated which have the potential capability of achieving ultra-low NO_x emissions, including lean premixed combustors, direct injection combustors, rich burn-quick quench-lean burn combustors and catalytic combustors. The research reported in this paper addresses the effect of incomplete fuel-air mixing on the lean limit performance and the NO_x emissions characteristics of lean premixed combustors. Since in actual gas turbine combustor hardware it is impossible to achieve perfect mixing of the fuel and air, an important question is how well does the fuel and air have to be mixed to achieve acceptably low NO_x emissions? The effect of incomplete fuel-air mixing on the lean stability and lean blowout limits is also studied.

The experiments were conducted in a coaxial dump combustor at 1 atmosphere pressure. The fuel used in the tests was natural gas, where the degree of fuel-air mixing was varied by changing the fuel split between upstream and downstream fuel injection locations. Three fuel split cases were studied, i.e., 100%/0%, 50%/50% and 0%/100%, where the first percentage refers to the percentage of the fuel which was introduced at the upstream (or premixed) location.

The fuel-air distribution at the combustor inlet is quantified using two-dimensional acetone fluorescence. These measurements are made both with and without combustion. A water-cooled gas sampling probe and a chemiluminescence analyzer is used to measure the concentration of NO and NO_2 along the centerline and at the exit of the combustor.

The characteristics of the acoustic noise produced by the combustor are determined from the output of a microphone. And lastly, the flame structure is characterized using two-dimensional OH fluorescence.

RESULTS

Figure 1 is a plot of NO and NO_x concentrations measured 13" downstream of the combustor inlet versus the overall equivalence ratio for the 100%, 50% and 0% premixed cases. These results clearly show the effect of incomplete fuel-air mixing on NO_x production. At equivalence ratios below approximately 0.9, there is a significant increase in the amount of NO produced as a result of incomplete fuel-air mixing. However, for equivalence ratios near stoichiometric, incomplete mixing actually results in less NO_x production. These results are similar to those previously reported.[1-3]

There is an interesting and important relationship between flame structure and degree of fuel-air mixing illustrated by the results shown in Figure 2, which shows two-dimensional OH fluorescence images taken immediately downstream of the flameholder. Three representative images are shown for the 100%, 50% and 0% premixed cases. The field of view in each image is 35 mm by 35 mm. The flame structure for the 100% premixed case is shown to be highly reproducible. The 50% and 0% premixed cases show significant variations in flame structure; however, the images appear to repeat themselves, suggesting a periodic nature to the flame stabilization process. In addition, in the 0% premixed case, the very irregular shape of the OH images suggests that the reaction zone boundaries are confined to the local fuel-rich pockets due to the poor fuel-air mixing.

The combustion process, particularly in the incompletely mixed cases, resulted in significant combustion-generated noise, which can be related to the characteristics of the flame stability. The combustion-generated noise was recorded by a sound level meter and an A/D data acquisition system. Fourior analysis of the signals revealed their frequency content. The readings of the sound level meter were 77 dB, 105 dB, and 103 dB for 100%, 50% and 0% premixed cases, respectively. The background noise in the laboratory was around 62 dB. The frequency content of the 100% premixed case was a wide band signal with the peak located near 400 Hz. For the 50% premixed case, there was a single dominant frequency located near 375 Hz. The narrow band width indicates the noise is a pure tone. For the 0% premixed case, a frequency peak located near 400 Hz was ibserved with a slightly wider band width. Further study of the relationship between the dominant frequency of the combustion-generated noise and the periodic behavior of the flame structure is in progress.

REFERENCES

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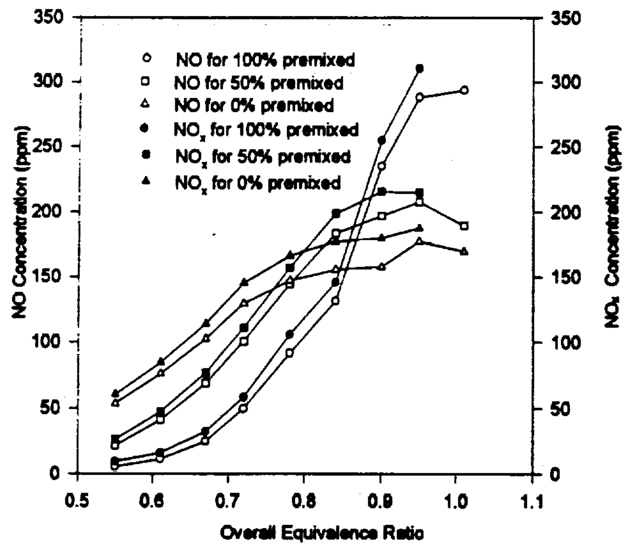
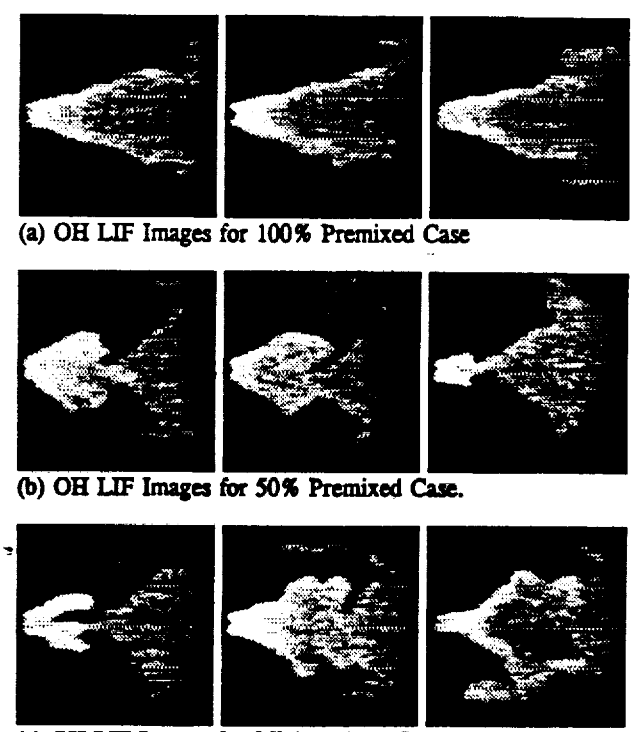


Figure 1. NO and NO_x concentrations measured 13" downstream of the combustor inlet versus overall equivalence ratio.



(a) OH LIF Images for 100% Premixed Case

(b) OH LIF Images for 50% Premixed Case.

(c) OH LIF Images for 0% Premixed Case.

Figure 2. Two-dimensional OH fluorescence images of the flame structure.