THE ROLE OF REACTANT UNIMIXEDNESS AND TURBULENT PROPERTIES ON COMBUSTOR PERFORMANCE

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EXECUTIVE SUMMARY

AGTSR FINAL REPORT
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Project Title:
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AGTSR Subcontract No.: 94-01-SR020
Principal Investigator: Scott Samuelsen
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The focus of the program was to establish the role of reactant unmixedness and turbulent properties on the performance of premixed, natural gas-fired gas turbine combustors. Performance criteria measured included emissions of NO_x CO, and hydrocarbon species, acoustic emissions, and lean blow-out. This report presents a summary of the accomplishments realized.

Summary of Industrial Interaction

- One of the keys to the success of the UCI AGTSR program was the constant exchange of information and experience between the University and Industry. During the initial stages of the program, four industrial partners (Allison, Westinghouse, GE, and Solar Turbines) were identified and contacted with a survey of industrial goals. The UCI AGTSR program was modified based on the results of the survey. The two graduate research students associated with the project visited each industrial partner and presented the modified program for further industrial input.
- During the program, five graduate students interned at Westinghouse Corporation, General Electric, Allied Signal, Solar Turbines, and Pratt &

Whitney, respectively. These internships introduced and involved these UCI students to current state of the art work being conducted in industry.

- At a Westinghouse summer internship, one graduate research student was tasked with developing a series of swirl vanes that, when studied, would provide Westinghouse with useful data in the design of swirl vanes. These vanes were fabricated and used in the UCI AGTSR program. The data collected were provided to Westinghouse during the course of this program.
- To address instability issues discussed at the AGTSR Combustion Stability meeting, UCI provided Dr. Pandalai of GE Aircraft with complete drawings of the UCI combustion test facility so that computational fluid dynamic (CFD) predictions of acoustic instability could be performed. To further assist the project, UCI performed a series of acoustic tests in both reacting and non-reacting modes. These data were provided to Dr. Pandalai.
- From these initial acoustical tests, further interaction regarding acoustic instability occurred between UCI and Geo Richards of FETC and Tim Snyder of UTRC. Both of these industrial partners supplied pressure transducers that were incorporated into the experiments to further assess the amplitudes, modes, and frequencies of pressure fluctuation in the combustor. Each partner specified their interests and explained experiments that had been previously performed at their respective facilities. Appropriate experiments were performed and data were provided to all interested industrial partners.

Summary of Program Results

- The Program consisted of two major components:
    1) <u>Model Combustor</u>: A model combustor was designed with industry input to be suitable for optical access, amendable to CFD modeling, and amenable to Design of Experiments.
    2) <u>Combustor Experiments</u>: Parametric studies, following Design of Experiments, were completed to reveal the relationships between combustor inlet conditions and combustor performance. For those conditions yielding the most interest, detailed in-situ measurements were acquired to develop a mechanistic understanding of the cause-effect relation between inlet conditions and combustor performance.
- A third related, but independent study was also conducted:
    3) <u>Swirler Simulation Experiments</u>: An auxiliary study was conducted to systematically understand the fluid dynamics associated with swirl vanes in a turbulent flow due to the observation that swirl vanes affect both the inlet unmixedness and inlet turbulent properties.

- Model Combustor.
    - The combustor has been designed with the guidance of industry.
- Combustor Experiments.
    - The CFK results revealed that a homogeneous premixed inlet profile of fuel, while advantageous, may not be ideal. A fuel profile that is tailored by the premixer, however, can minimize NO_x emission.
    - The behavior of flow in a combustor both upstream and downstream of the swirl vanes has been studied for the first time. The results of this study have been used to develop swirl vanes that impact mixing.
    - The planar laser induced fluorescence (PLIF) results are consistent with the CFD results when fuel weighting is utilized.
    - High speed videography revealed small fuel packets that contribute to NO_x formation. Thus, NO_x appears to be formed in discrete zones.
    - The size of these packets correlate to the temporal unmixedness measurements.
    - Increases in unmixedness correspond to increases in local equivalence ratios that can lead to higher instantaneous temperatures. Therefore, NO_x production is related mainly to thermal mechanisms although it is likely that prompt and N_2O pathways are contributing as well.
    - The emission of hazardous air pollutants and ozone precursors (HAPS/OPs) was found to be dependent upon the length scale associated with mixing with a larger scale structure producing higher levels of VOCs.
    - The distribution of the fuel determines the NO_x performance. However it is fount that a substantial departure from fully premixed operation can still provide comparable NO_x performance while benefiting from an enhanced lean blow off limit.
- Swirler Simulation Experiments.
    - Smoke images obtained both upstream and downstream of the swirl vanes have revealed the structure and behavior of the vortices being shed by the vanes.
    - An array of flat plates has been used to model swirl vanes in order to determine the fluid dynamic effects of the vanes other then in the production of swirl. The results show that the cord length and thickness of the plates in a vane array effect the size of the recirculation zone about the plate and the frequency of the vortices shed from the plate.
    - The vortex shedding behavior of a single plate differs significantly from the vortex shedding behavior of a plate in an array. Therefore, a single plate cannot be used as a model for flow behavior downstream of an array of plates.

- Instability in the wake size and location downstream of the trailing edges of swirl vanes have been observed and studied. The change from one wake size to another occurs spontaneously and may influence the stability of the reaction in the combustor.