NO_x AND CO EMISSIONS MODELS FOR GAS-FIRED, LEAN-PREMIXED COMBUSTION TURBINES

Final Report

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By

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1.0 STATUS/ACCOMPLISHMENTS FOR THE REPORTING PERIOD

Project Title: Emissions Models for LP Turbines

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Subtask 1.1: During the last period, combustion testing at METC was resumed and emissions data were taken at a range of pressures and preheat temperatures for the 8.89 cm simple disc. However, catastrophic failure of the sampling probe during testing rendering the data suspect. Attempts to redesign the probe were unsuccessful and no additional data have been taken. In the parallel effort at Hughes Associates, Inc., the STAR*CD CFD code was modified to include a five step reduced kinetics mechanism. Using this mechanism CFD predictions of flowfield, CO and NO concentrations and flame locations were obtained for an industrial, piloted-lean premixed (piloted-LP), natural gas fired, can combustor, Combustor A. This modeling proved to be valuable for evaluating both the Characteristic Time Model (CTM, Subtask 1.2) and the Chemical Reactor Model (CRM, Subtask 1.3).

Subtask1.2: The preliminary characteristic time models developed at Vanderbilt University earlier in the program for NO_x, CO and lean blowoff using data from Combustor A (95) are examined with new measurements collected in the facilities of the manufacturers with the same burner (Combustor A 96) and two other similar configurations (Combustors B and C). Most emphasis in the last portion of the work was placed on upgrading the LP NOx CTM, particularly with respect to the degree of mixedness of the burning fuel and air. Significant accomplishments under this subtask include demonstration of (1) how LP NO_x emissions under certain combustor operating conditions can appear to be independent of inlet air temperature, pressure and combustor residence time and (2) a method to determine unmixedness from fired combustor tests at engine operating temperatures and pressures.

Subtasks 1.3 and 2.2: Several significant results from the chemical reactor modeling and supporting research at the University of Washington are reported. The main topics are: (1) the present form and features of the chemical reactor model computer code, (2) results on the effects of incomplete premixing on NO_x obtained through applications of the chemical reactor model, and (3) results on NO_x formation obtained through experiments run with the high pressure jet stirred reactor operated at short residence times. Additionally, results from related research are briefly discussed, including a global mechanism for methane oxidation with NO_x formation, and NO_x yields from low-nitrogen, low sulfur fuel oils burned in the jet stirred reactor. This related research is restricted to atmospheric pressure. Also, recommendations are given for future research, including upgrades and new applications of the finite-rate mixing model (reported in Semi-Annual Reports 2 and 3) and integration of features of this model into CFD analysis of gas turbine combustors, and new applications of the high pressure jet stirred reactor to help validate chemical kinetic mechanisms used for predicting pollutant emissions of gas turbine engines.

Subtasks 1.4: The work accomplished by the California Institute of Technology has been directed to fundamental issues central to problems of combustion instabilities in a gas turbine combustor intended primarily for stationary power generation. Our purpose has been to bring to this subject experience and methods previously known in applications to liquid and solid rockets, afterburners and ramjets. However, the bulk of the effort has been concerned with the aspects of the problem particular to a gas turbine combustor. The Caltech program h as comprised four parts: numerical simulations; modeling, including initial work on representations of processes involved in NOx production; approximate analysis which will eventually incorporate results of the first two topics in a form suitable for routine use in design and development; and experiments. The last has produced the most significant accomplishment of this program, namely the first demonstration of an intrinsically nonlinear control strategy based on the existence of hystersis at the lean side of the region of instability. That result was obtained in the second half of the first (and last) year of this program.

Subtasks 2.1: Simulations, time-resolved measurements of major species (fuel, oxidizer, and products), temperature, OH, and the pollutants (NO and CO) have been obtained in a bluffbody stabilized turbulent combustor burning methane and operating in an LP mode. Combining this data with the earlier velocity measurements made at Wright Air Force Laboratories, provides a detailed map of the combustion flow-field for evaluation of engineering models of emissions. Results show that the species (except the pollutants) in the recirculation zone are in equilibrium at the local temperature. In the shear layer, simultaneous measurements of OH and reaction progress variable indicate evidence of regions of local extinction and/or distributed reaction zones. The local extinction effects decrease with downstream distance. At the centerline of the combustor exit, the fluid is at adiabatic equilibrium. The NO emissions from the LP combustor are relatively small (˜6 ppm), but the CO emissions are high (˜1500 ppm). The measurements are compared to laminar flamelet models, zonal chemical reactor models, and PSR-microstructure models. These models predict major species and temperature fairly well; however, to accurately predict the pollutants (CO and NO). The results point to the need for a better understanding of the flame structure (e.g., thin flame zone vs. distributed reaction zone) which would lead to improved combustion modeling of pollutant formation in LP combustion.