Experimental and Computational Investigations of Boundary Condition Effects on CFD Simulations of Thermo-Acoustic Instabilities

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Abstract

The goal of the proposed work is to determine the sensitivity of transient thermo-acoustic Computational Fluid Dynamics (CFD) simulations to poorly defined, or misrepresentation of prescribed acoustic boundary conditions. Time dependent experimental boundary conditions such as combustor inlets and compressor diffusers will be measured experimentally and simulated. The results of the study will lead to a methodology of measuring these experimental boundary conditions, describing them properly in a simulation, and applying them to an analysis of a realistic combustion system creating a thermo-acoustic stability testbed representative of the geometries used in the NETL combustor.

The following three specific objectives have been set for the project:

- Develop a transient Computational Fluid Dynamics (CFD) combustor model using commercial CFD and mathematics software for the purpose of investigating the impact and sensitivity of properly defined acoustic boundary conditions on the resulting CFD predictions for thermo-acoustic stability,
- Modify the dynamic combustor capabilities in an existing high-pressure, high-temperature laboratory-scale combustor in order to develop a method for rigorously measuring and describing acoustic boundary conditions that can be directly applied to transient CFD models and can be used to directly validate the CFD results,
- Use the above model and experimental results to demonstrate the effects of poor characterization of experimental acoustic boundary conditions on the thermo-acoustic results from a dynamic CFD combustion simulation.

The combustor and design features for the combustor are focused on the CFD model under development. The tractable modeling approach to exploration of combustor mechanics and design is to eliminate the upstream and downstream fluid machinery from the model while maintaining the effects those components force on the combustor model. The representation of fluid machinery upstream and downstream of the combustor is crucial to practical representation and model studies of the combustor. The approach proposed in this study is to develop models with incremental stages of complexity in the mechanics that need to be represented. This approach has a great deal of merit in that (1) it can be integrated into the experimental testbed, (2) the CFD model can be validated at several intermediate stages, where the sensitivity of modeling choices/representations can be explored and understood, (3) the approach is modular and can accommodate additional or evolving combustor design features, (4) the study can be validated by other, independent methods.

Within the context of the objectives above, the current work seeks to support the overall objectives of the University Coal Research program by education of new engineers in the field, continued improvement of the Virginia Tech Combustion Systems Dynamics Lab (CSDL) in the area of advanced fuels for use in gas turbines, and overall contribution to the field of environmentally acceptable utilization of the US coal reserves.