Project Summary

Identification and Significance of Innovation. Combustion instability is a major concern in propulsion and power generation combustion devices. It is characterized by vibrations within the combustion system, generally manifested as temporally growing pressure oscillations. The challenges that hinder the understanding and alleviation of combustion instability are primarily: 1) extremely expensive and time-consuming nature of full-scale experiments, 2) complex physics involving multiphysics aspects such as fluid dynamics, combustion, acoustics and their interactions with each other. In this project an innovative hybrid approach of combining system-level analysis tools with detailed CFD analysis is proposed to tackle the combustion instability modeling in a cost-effective and efficient manner. No such hybrid approach currently exists in the combustion instability modeling area and promises to be a ground-breaking approach for analyzing next-generation combustion systems. The innovations for this project include 1) Development of a methodology to rigorously include multi-species, finite rate kinetics into a combustion instability analysis framework. 2) Quantification multi-species, finite-rate chemical kinetics in evaluating the instability characteristics of combustion chambers, 3) Quantification of turbulence modeling in predicting possible instability modes in the combustion chamber and 4) Development of a hybrid CFD-framework which can couple with any CFD solver and provide an easy-to-use and widely applicable combustion instability analysis framework.

Technical Objectives and Work Plan. Overall Technical Objectives of this effort: Develop a hybrid CFD-analysis and systems-analysis based tool for combustion instability analysis of a wide range of combustion devices. The overall effort (Phase I and Phase II) will develop and deliver a complete suite for instability analysis of combustion devices using this hybrid methodology. The specific Phase I technical objectives included: 1)Develop specific data analysis software to analyze and post-process CFD data for use in the UCDS framework and 2) Demonstrate feasibility of the proposed approach by comparing instability predictions based on CFD simulations using a) Different reaction mechanisms (global/skeletal) to represent combustion; and b) Different turbulence models (LES/RANS).

Technical Accomplishments. All technical objectives of Phase I have been accomplished by the SBIR team. The major achievements include 1.) Development of a module to calculate the steady and unsteady chemical heat release rates in the given combustion chamber and development of a module for analyzing temporal simulation data (for e.g., temperature and heat release rate) using techniques such as Discrete (or Fast) Fourier transforms, 2) Evaluation of acoustic longitudinal modes (which are linked directly to combustion instability) of the combustion chamber based on mean temperature, pressure and other profiles obtained from CFD simulation and 3) Demonstration of the first-ever hybrid CFD-spectral analysis of the combustion chamber to identify possible unstable frequencies. It was realized that LES simulations held significantly more instability-relevant information, compared to RANS simulations. Also, for combustion instabilities, due to unsteady heat release, a skeletal mechanism containing multiple reactions (and hence, timescales) promises to be more helpful than a global mechanism (containing very few reactions and hence heat release timescales)

Potential NASA Application(s). The model developed in this SBIR project will be extremely useful in identifying the potential sources of combustion instability, and ways to suppress them. The tools developed will allow mitigation of instability problems in the design phase, eliminating expensive testing needed when combustion instabilities occur in engine testing. The methods developed under this project will have wide ranging applications at NASA, including design of propulsion devices such as solid rocket motors, liquid rocket engines and gas turbine combustors. The instability analysis methodology developed in this SBIR project can also be applied to high speed combustion devices such as ramjet and scramjet engines, as the method combines the key advantages of both sufficiently detailed CFD analysis and accurate system-level modeling paradigm.

Potential Non-NASA Application(s). The tool developed will also be useful to a number of industries, including gas turbine manufacturers for civilian energy and aviation applications. The tool will also be useful to the Air Force in the design of propulsion devices such as the engine for the Joint Strike Fighter. The software developed in this SBIR will allow cost-effective design and analysis of combustion systems. The ability to avoid combustion-driven instability and investigation of high-payoff ideas will be possible. The final product will be marketable to OEMs and designers/manufacturers of gas turbines, I.C. engines and other combustion/propulsion devices which can be affected by combustion instability