Phase I Project Summary

Firm: CFD Research Corporation
Contract Number: NNX12CG35P
Project Title: A Multi-disciplinary Tool for Space Launch Systems Propulsion Analysis

Identification and Significance of Innovation: Space Launch System architecture involves nonlinear interaction between flow and multiple structures that dominate the performance characteristics of the launch vehicle and could lead to catastrophic failures if not properly understood. Coupling between thrust oscillations in the solid rocket motor (SRM) first stage and vibration modes in the launch vehicle are identified as major risk factors in the development of launch vehicles. The frequency of pressure pulses in multi-segment SRM is close to the natural frequency of second longitudinal vibration mode of the complete launch vehicle. This creates the risk of a "pogo stick" resonant vibration, which leads to the concerns that the vibration could make it difficult for the astronaut to perform their tasks, including reading their flight displays. Flexible inhibitors have been used in Space Shuttle Reusable Solid Rocket Motor to control the burning of propellant. However, the vortices generated by the presence of obstacles such as flexible inhibitors has been identified as the driving acoustic and combustion instability sources that can lead to thrust oscillation from the SRM. An accurate predictive capability of pressure oscillation features considering all the important driving physics including fluid structure interaction with the flexible inhibitors in the SRM is crucial in the development of NASA's new Space Launch System (SLS).

Technical Objectives and Work Plan: The overall technical objective of this project is to develop a comprehensive, fully coupled, high-fidelity, user-friendly simulation tool for fluid structure interaction analysis of various SLS propulsion applications including solid rocket motors thrust oscillations. The developed tool will couple an existing NASA production CFD code with highly accurate numerical schemes and massive parallel capabilities, Loci/CHEM, with a Finite Element nonlinear large deformation structural solver, CoBi, to solve fluid-structure interaction from first-principles. The conjugate heat transfer can be solved in CoBi to form a comprehensive fluid-thermal-structure analysis environment. The tool will be rigorously validated against coupled as well as decoupled problems (fluid and structure individually). Previous experiences of the proposing team in a) development and application of multi-physics commercial software CFD-ACE+ and CFD-FASTRAN, b) development and integration of different modules into Loci suite codes: Loci/CHEM and Loci/STREAM; and c) coupling multiphysics solvers including CFD solver and Computational Structure Dynamics (CSD) solvers, will be leveraged to minimize the risk and to reduce development cost. The Phase I objective is to demonstrate the feasibilities of adapting the fully coupled FSI software for predicting the complex flow and structural behaviors during the operation of solid rocket motor.

Technical Accomplishments: All technical objectives of Phase I have been accomplished by the SBIR team. Development activities were conducted to create a sophisticated user friendly, multiple interface, sub iteration level tightly coupled FSI co-simulation framework tool based on MDICE API & socket based communication. This framework synchronizes the applications, coordinates communication, and provides spatial and temporal mapping at the domain interfaces between solid and fluid. Initial efforts were also made to develop an FSI interface without MDICE using direct Loci CHEM API to a shared library version of CoBi FEM. The developed FSI tool was validated against coupled as well as decoupled problems (fluid and structure individually. To support multidisciplinary simulation on NASA high-performance computer (HPC) resources, all of the software under development was regularly delivered, installed, and tested on NASA HPC resources. All these development efforts and thorough testing allowed CFDRC to successfully demonstrate the feasibility of adopting a tightly-coupled FSI simulation capability in the Loci/CHEM code for use in predicting the complex flow and structural behaviors during operation of solid rocket motors on 1000 processors on the NASA Supercomputing grid. The demonstration of flexible inhibitor interactions with vortical flow inside an SRM-like chamber provided great insight into the physics of nonlinear FSI leading to thrust oscillations in SRMs.

NASA Application(s): This tool will find a large number of applications in the NASA launch vehicles propulsion systems including: (a) Prediction of self-generated dynamics of fluid delivery pipes with deformable bellows; (b) Modeling of water troughs during water suppression system interactions with Ignition Over Pressure (IOP) for accurate prediction of acoustic launch environment of SLS; (c) Modeling of liquid damping devices such as LOX damper performance; (d) Liquid propellant tank breathing due to liquid interaction with the flexible tank shell; (e) Fluid-structure interaction in nuclear thermal rockets; (f) Modeling of fluid-thermal-structural coupling of rocket

engine nozzles; (g) Investigation of fluid-induced vibration of J-2X turbine and inducer blades; and (h) Design of new generation POGO accumulators with bellows separating liquid and gas phases.

Non-NASA Commercial Application(s): Aerospace engineers will be able to utilize the proposed technology to analyze early designs thereby reducing the dependence on expensive wind tunnel/water tunnel and flight tests. Benefits will be achieved in the final performance, and enhanced structural integrity, prolonged structural life, and improved safety of aerospace vehicles. Direct applications of the technology include analysis of dynamic loads problems for aerospace vehicles, such as buffet, flutter, buzz, and control reversal; and noise, vibrations, and buffet suppression of rotorcraft and commercial air vehicles. General applications include FSI problems such as vortex-blade interaction of rotorcraft, trailing vortex dynamics of commercial aircraft, heat exchanger vibration, strumming of cables and offshore pipelines, galloping of towers and masts, and fatigue of panels.

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