Phase I Project Summary

Firm: CFD Research Corporation
Contract Number: NNX13CM28P
Project Title: High-Fidelity Prediction of Launch Vehicle Lift-off Acoustic Environment

Identification and Significance of Innovation: Launch vehicles experience extreme acoustic loads during liftoff driven by the interaction of rocket plumes and plume-generated acoustic waves with ground structures. Currently employed predictive capabilities to model the complex turbulent plume physics are too dissipative to accurately resolve the propagation of acoustic waves throughout the launch environment. Higher fidelity liftoff acoustic analysis tools to design mitigation measures such as deluge water and launch pad geometry are critically needed to optimize launch pads for SLS and commercial launch vehicles. This STTR project will deliver breakthrough technologies to drastically improve predictive capabilities for launch vehicle lift-off acoustic environments. Hybrid RANS/LES modeling presently established in NASA production flow solvers will be used for simulation of the acoustic generation physics, and a high-order accurate unstructured discontinuous Galerkin (DG) solver developed in the same production framework will be employed to accurately propagate acoustic waves across large distances. An innovative hybrid CFD/CAA method will be developed in which the launch-induced acoustic field predicted from hybrid RANS/LES will be transmitted to a DG solver and propagated using high-order accurate schemes ideal for acoustic propagation modeling. This new paradigm enables: (1) Improved fidelity over linear methods for modeling nonlinear launch-induced acoustics; (2) Greatly reduced numerical dissipation and dispersion; and (3) Improved acoustics modeling for attenuation, reflection, and diffraction from complex geometry. The merits of the proposed approach were investigated and demonstrated in Phase I for benchmark CAA applications and plume impingement problems. In Phase II, the methodology will be refined and validated against realistic targeted applications.

Technical Objectives and Work Plan: The overall technical objective of this project is to develop a comprehensive computational fluid dynamics/computational aeroacoustics (CFD/CAA) simulation system for launch vehicle liftoff environment predictions. The developed tool will couple an existing NASA production CFD code with support for massively parallel simulations and highly-accurate numerical schemes, Loci/CHEM, with a high-order accurate discontinuous Galerkin (DG) solver developed in the same NASA production framework, Loci/THRUST. The tool will be rigorously validated against relevant acoustic benchmark problems. 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; c) development and coupling of vorticity transport method with OVERFLOW code for two-field prediction of vortex-dominated flows; and d) coupling multiphysics solvers including CFD solvers and Ffowcs Williams-Hawkings solvers, will be leveraged to minimize the risk and to reduce development cost. The Phase I objective was to demonstrate the feasibilities of adapting a coupled CFD/CAA capability for prediction and near lossless propagation of the complex acoustic physics prevalent in the SLS liftoff launch environment across large distances.

Technical Accomplishments: All technical objectives of Phase I have been accomplished by the STTR team. Development activities were conducted to create a sophisticated coupled CFD/CAA simulation capability based on a two-field Navier-Stokes/Euler paradigm. This framework is designed to provide accurate resolution of acoustic generation physics using established hybrid RANS/LES CFD methods and accurate transmission of the acoustic signal to a high-order discontinuous Galerkin (DG) CAA solver for near lossless propagation of acoustic physics throughout the entire launch environment. The developed CFD/CAA tool was verified against acoustic scattering benchmark problems and was shown to be accurate for resolving the acoustic scattering between two cylinders with up to 4th-order spatial and temporal accuracy. To support coupled CFD/CAA simulation on NASA high-performance computer (HPC) resources, all of the software under development was regularly debugged, tested, and installed on NASA HPC resources. All of these development efforts and thorough testing allowed CFDRC to successfully demonstrate the feasibility of adopting a coupled CFD/CAA simulation capability in the Loci framework using the Loci/CHEM and Loci/THRUST solvers for predicting the complex SLS liftoff acoustic environment. The demonstration of acoustic propagation in the SLS launch environment, including diffraction among multiple sources and acoustic reflection around the tower and mobile launcher (ML) provided great insight into the nonlinear acoustic physics prevalent in the launch vehicle liftoff acoustic environment in SLS.

NASA Application(s): This hybrid CFD/CAA tool will uniquely fill the technology gap at NASA centers in defining lift-off environments for on-going and new launch vehicle designs, and for the analysis of noise suppression techniques. The developed tool will provide greater confidence to NASA acoustics engineers offering accurate, quantitative acoustic loading predictions from first principle CFD/CAA simulations for specific launch vehicle configurations. The tool will also be invaluable to payload system and instrument developers, particularly for one-of-a-kind and experimental optics and telescope systems that are susceptible to acoustic effects during liftoff.

Non-NASA Commercial Applications(s): The proposed innovation offers significant advantages over aeroacoustic prediction tools currently available in industry. The hybrid RANS/LES and high-order DG modeling will provide a unique combination of robust multi-physics modeling and high-fidelity acoustic propagation physics. The proposed approach will offer a great technology advantage through its improved accuracy for acoustic propagation and its integration within a single massively parallel unified production framework (Loci). The toolset will be invaluable to current and future commercial launch service providers such as United Launch Alliance, ATK, Boeing, Space-X, Orbital Sciences, and payload system and sensitive instrument developers, particularly for one-of-a-kind DoD, NRO, and NOAA satellites. At the end of the SBIR, this technology will be readily available for analysis of micro-jet and active/passive control systems, conventional and STOVL aircraft jet acoustics, airframe and landing noise, and rotorcraft acoustic loading.

Name and Address of Principal Investigator: (Name, Organization, Street, City, State, Zip)
Robert Harris, CFD Research Corporation, 701 McMillian Way NW, Huntsville, AL 35806.

Name and Address of Offeror: (Firm, Street, City, State, Zip)
CFD Research Corporation, 701 McMillian Way NW, Huntsville, AL 35806.