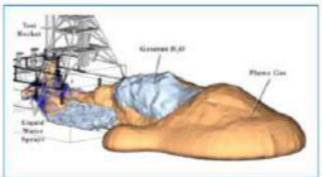
Space Exploration

Simulating Rocket Ignition and Launch Environments for NASA's Space Launch System

Overview

At liftoff, the Space Launch System's (SLS) solid rocket boosters (SRBs) will send large amplitude pressure waves into the confined space of the launch structure. These ignition overpressure (IOP) waves, which radiate throughout the launch environment, can cause damage to the launch structure, the vehicle, and the payload, and therefore must be well understood during the design process.

Project Details



Simulating both the rapid ignition process within the SRBs and the IOP phenomenon in the external launch environment is a highly complex and computationally expensive endeavor. Therefore, we decomposed the full-scale analysis into component problems that could be simulated and validated independently, then used to inform simulations of the full-scale integrated vehicle. We developed robust models using the Loci/CHEM computational fluid dynamics (CFD) software and ultimately, supported by these models, simulations of the entire vehicle were used to augment existing analysis tools and aid the SLS vehicle design process.

The first component problem examined the propagation of acoustic waves through the launch environment and established the accuracy of the simulation methods by validating them against real-world test data gained from the Ares I Scale Model Acoustics Test. The simulations tracked the propagation of acoustic waves in both dry launch pad conditions and in conditions with water-based sound suppression systems activated. Dry simulations showed excellent correlation to real-world results and provided NASA with the confidence to move forward with full-scale simulations, while wet simulations provided a new capability for sound suppression to be tailored to a specific vehicle.

For the second component problem, we performed time-accurate, fully 3D simulations of the SRB ignition transient to determine the internal dynamics of the rocket during ignition. We used a Loci/CHEM ignition module to determine the ignition conditions from the chemical kinetics of the propellant and the local heat flux at the propellant surface. When ignited, the simulated propellant "burned" using an empirical boundary condition based on propellant formulation and local pressure. Simulation results were validated through comparisons to data from motor static test firings, which showed excellent correlation. Once validated, the results were used to create a time-dependent, 3D CFD profile as an input boundary condition to further simulations for SLS launch-induced environments.

Results and Impact

Finally, using the results of the sub-scale and SRB simulations, we performed full-scale simulations of the SLS launch environment with the goal of resolving multiple uncertainties in existing IOP analysis tools developed for the Space Shuttle that could not account for differences in the SLS vehicle configuration. Several simulations indicated that the biggest difference in IOP for the SLS was due to the interaction of the plumes from the SRBs and the core stage engines. These and other findings were used to improve the IOP analysis provided to the SLS vehicle designers by removing unnecessary levels of conservatism, which could lead to increased program costs.

Role of High-End Computing Resources

The use of NASA's supercomputing resources was vital to completing this work. Our simulations used thousands of processors over periods of weeks and were typically run in groups of two or more to test model permutations. In addition, each simulation required multiple terabytes of storage, with regular processing of hundreds of individual gigabyte-scale files for visualization, postprocessing, and data analysis.

Philip Davis, NASA Marshall Space Flight Center
philip.a.davis@nasa.gov

Gabriel Putnam, NASA Marshall Space Flight Center
gabriel.c.putnam@nasa.gov

Brandon Williams, NASA Marshall Space Flight Center
brandon.williams@nasa.gov

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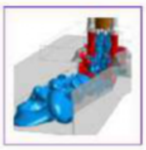

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