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Predicting Ares I Reaction Control System Performance by Utilizing Analysis Anchored with Development Test Data

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The Ares I launch vehicle is an integral part of NASA's Constellation Program, providing a foundation for a new era of space access. The Ares I is designed to lift the Orion Crew Module and will enable humans to return to the Moon as well as explore Mars.[1] The Ares I is comprised of two inline stages: a Space Shuttle-derived five-segment Solid Rocket Booster (SRB) First Stage (FS) and an Upper Stage (US) powered by a Saturn V-derived J-2X engine. A dedicated Roll Control System (RoCS) located on the connecting interstage provides roll control prior to FS separation. Induced yaw and pitch moments are handled by the SRB nozzle vectoring. The FS SRB operates for approximately two minutes after which the US separates from the vehicle and the US Reaction Control System (ReCS) continues to provide reaction control for the remainder of the mission. A representation of the Ares I launch vehicle in the stacked configuration and including the Orion Crew Exploration Vehicle (CEV) is shown in Figure 1.

Each Reaction Control System (RCS) design incorporates a Gaseous Helium (GHe) pressurization system combined with a monopropellant Hydrazine (N_2H_4) propulsion system. Both systems have two diametrically opposed thruster modules. This architecture provides one failure tolerance for function and prevention of catastrophic hazards such as inadvertent thruster firing, bulk propellant leakage, and over-pressurization. The pressurization system on the RoCS includes two ambient pressure-referenced regulators on parallel strings in order to attain the required system level single Fault Tolerant (FT) design for function while the ReCS utilizes a blow-down approach. A single

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burst disk and relief valve assembly is also included on the RoCS to ensure single failure tolerance for must-not-occur catastrophic hazards. The Reaction Control Systems are designed to support simultaneously firing multiple thrusters as required.

Trade studies, analyses, and design assessments conducted on both RCS include: propellant selection, thruster arrangement, pressurization system configuration and system component trades. Since successful completion of the Preliminary Design Review (PDR), work has progressed towards the Critical Design Review (CDR) with accomplishments made in the following areas: pressurant/propellant tanks, thruster assemblies, component configurations, thruster module designs, and waterhammer mitigation approaches.

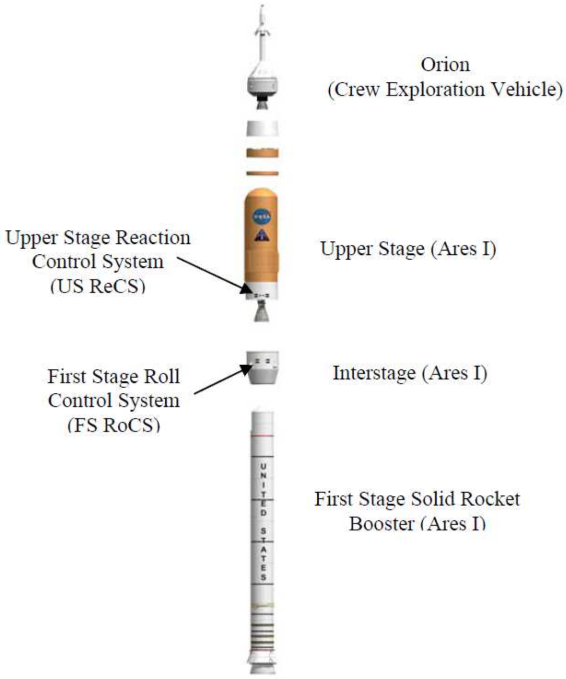

Figure 1. Schematic of the Ares I Launch Vehicle

The Constellation Program approach requires including transient system pressures in the definition of Maximum Design Pressure (MDP), which determines both proof and burst pressure levels.[2] In general, higher proof and burst pressures usually result in a heavier, more expensive system. It is therefore desirable to minimize the MDP, and the FS RoCS incorporates a few design features to help mitigate transient pressure levels. The design features include large manifold line sizes, localized propellant tanks to minimize propellant line lengths and staggered thruster valve closing times to minimize wave amplification.

System fluid analysis was performed with models created using EASY5 software to provide preliminary operating condition estimates. EASY5 is a commercial software program provided by MSC Software. EASY5 is capable of modeling and simulating multi-domain systems, systems governed by both differential and algebraic equations, as well as performing both transient and steady-state analyses. Models are primarily comprised of components provided in thermal, hydraulic, and gas dynamic libraries, but EASY5 is capable of including user generated source code as well. Models are assembled graphically using specific components such as pipes, volumes, orifices, and heat transfer components to provide an analysis approximation of the system being simulated. A sample schematic of a model used to simulate propellant fill procedures for the FS RoCS development testing is provided in Figure 2. Analyses are developed using EASY5 to predict the performance of both Reaction Control Systems. Models were created to both simulate tests performed on development testing hardware as well as provide a means to anchor the analytical methods with actual test data. Examples of currently developed models include pressurant and propellant fill/drain, waterhammer analyses, total RCS end-to-end simulations, and thermofluidic modeling including heat transfer effects. The RoCS and ReCS System Development Test Articles (SDTA) are flight-representative water flow test articles whose primary objective is to obtain fluid system performance data to evaluate integrated system level performance characteristics and verify analytical models. Data recorded during SDTA testing will increase the fidelity of fluid analysis models for the Ares I CDR and be used to identify any potential design concerns for further development of critical hardware. This testing and model anchoring is required since there is little historical precedent for large flow, pulsing systems. Figure 3 depicts the SDTA experimental setup.

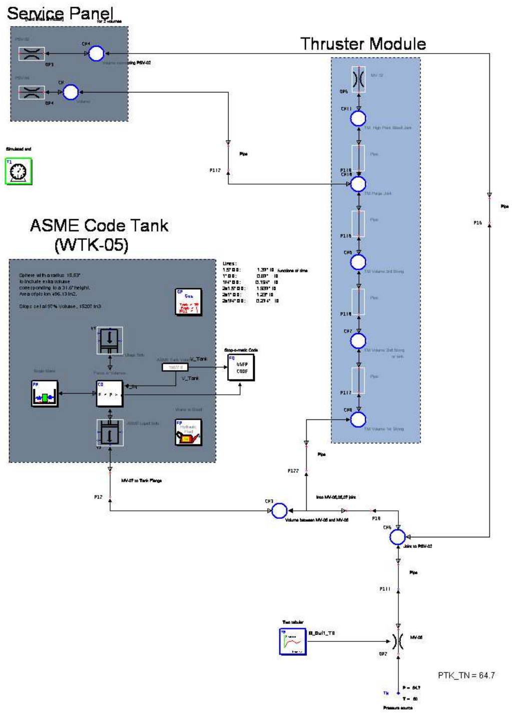

Figure 2. Schematic of the Ares I FS RoCS SDTA Fill Model

This paper provides a summary of the different types of analyses performed during the design process of the Ares I RCS. Modified analyses used for anchoring against development test data are also presented. A summary of development test data recorded during FS RoCS and US ReCS SDTA testing as well as comparisons between analytical results and test data are also presented.

Figure 3. Photo of System Development Test Article Setup.

References

[1]A. Butt, C. Popp, H. Pitts, and D. Sharp. NASA Ares I Launch Vehicle Roll and Reaction Control Systems Design Status. *45th AIAA Joint Propulsion Conference and Exhibit*, 2008.

[2]A. Butt, C. Popp, H. Pitts, and D. Sharp. NASA Ares I Launch Vehicle Roll and Reaction Control Systems Overview. *56th Joint Army, Navy, NASA, Air Force Propulsion Conference*, 2008.