Real-Time Simulation of Ares I Launch Vehicle

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The Ares Real-Time Environment for Modeling, Integration, and Simulation (ARTEMIS) has been developed for use by the Ares I launch vehicle System Integration Laboratory (SIL) at the Marshall Space Flight Center (MSFC). The primary purpose of the Ares SIL is to test the vehicle avionics hardware and software in a hardware-in-the-loop (HWIL) environment to certify that the integrated system is prepared for flight. ARTEMIS has been designed to be the real-time software backbone to stimulate all required Ares components through high-fidelity simulation.

ARTEMIS has been designed to take full advantage of the advances in underlying computational power now available to support HWIL testing. A modular real-time design relying on a fully distributed computing architecture has been achieved. Two fundamental requirements drove ARTEMIS to pursue the use of high-fidelity simulation models in a real-time environment. First, ARTEMIS must be used to test a man-rated integrated avionics hardware and software system, thus requiring a wide variety of nominal and off-nominal simulation capabilities to certify system robustness. The second driving requirement—derived from a nationwide review of current state-of-the-art HWIL facilities—was that preserving digital model fidelity significantly reduced overall vehicle lifecycle cost by reducing testing time for certification runs and increasing flight tempo through an expanded operational envelope. These two driving requirements necessitated the use of high-fidelity models throughout the ARTEMIS simulation.

The nature of the Ares mission profile imposed a variety of additional requirements on the ARTEMIS simulation. The Ares I vehicle is composed of multiple elements, including the First Stage Solid Rocket Booster (SRB), the Upper Stage powered by the J-2X engine, the Orion Crew Exploration Vehicle (CEV) which houses the crew, the Launch Abort System (LAS), and various secondary elements that separate from the vehicle. At launch, the integrated vehicle stack is composed of these stages, and throughout the mission, various elements separate from the integrated stack and tumble back towards the earth. ARTEMIS must be capable of simulating the integrated stack through the flight as well as propagating each individual element after separation. In addition, abort sequences can lead to other unique configurations of the integrated stack as the timing and sequence of the stage separations are altered.

The ARTEMIS core dynamics model has strict fidelity requirements due to the highly integrated nature of the vehicle flexible body dynamics, propellant slosh, and vehicle nozzle inertia effects combined with mass and flexible body properties that vary significantly with time during the flight. All forces that act on the vehicle during flight must be simulated, including deflected engine thrust force, spatially distributed aerodynamic forces, spatially distributed gravity forces, and reaction control jet thrust

forces. These forces are used to excite an integrated flex, slosh, and nozzle vehicle dynamics model for the integrated stack that simulates large rigid body translations and rotations along with small elastic deformations in an integrated model. Highly effective matrix math operations on a distributed, threaded high-performance simulation node allow ARTEMIS to retain up to 30 modes of flex for real-time simulation. Stage elements that separate from the stack during flight are propagated as independent rigid six degrees of freedom (6DOF) bodies.

ARTEMIS also requires high-fidelity component and subsystem models. Component models are digital simulation models of the actual avionics hardware and firmware, including the flight computer, inertial navigation system, and engine controller. The digital component models are necessary in order to simulate all required avionics component hardware faults while not risking damage to laboratory hardware. ARTEMIS must be capable of switching between the digital model and the live hardware for any component on the vehicle. Subsystem models are physics-based models of vehicle subsystems that cannot be physically tested in the laboratory. Examples of subsystem models include propellant flow through the fuel lines and engines, actuator nozzle dynamics, and engine combustion.

ARTEMIS real-time operations are maintained by the simulation's synchronization library of code, or SIL. The synchronization library is responsible for scheduling tasks at the appropriate frequency and for performing all required simulation input/output (I/O) functions. ARTEMIS will require a wide variety of I/O functionality—including MIL-STD-1553B, RS422, Gbit Ethernet, and analog signals—to properly stimulate all required avionics components.

The ARTEMIS real-time simulation hardware uses multi-core Intel x86 processors distributed throughout the SIL to allow the system to emulate actual vehicle flight cable runs. The real-time operating system (RTOS) is Concurrent's RedHawk software, a commercially available portable operating system interface (POSIX-)compliant RTOS based on Linux. This architecture allows primary software development to take place in standard Linux systems with a direct port path to RedHawk. ARTEMIS allows the same source code library to be compiled and run as either a serial non-real-time simulation on engineering desktops and laptops or in a distributed mode to support real-time test operations. This software commonality has proven to be a key factor in the ability of the software development team to meet the aggressive SIL schedule while maintaining excellent configuration control of the ARTEMIS source code.