Small Projects Rapid Integration and Test Environment (SPRITE)

An Innovation Space for Small Projects Design, Development, Integration, and Test

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ABSTRACT

Over the past few years interest in the development and use of small satellites has rapidly gained momentum with universities, commercial, and government organizations. In a few years we may see networked clusters of dozens or even hundreds of small, cheap, easily replaceable satellites working together in place of the large, expensive and difficult-to-replace satellites now in orbit. Standards based satellite buses and deployment mechanisms, such as the CubeSat and Poly Pico-satellite Orbital Deployer (P-POD), have stimulated growth in this area. The use of small satellites is also proving to be a cost effective capability in many areas traditionally dominated by large satellites, though many challenges remain. Currently many of these small satellites undergo very little testing prior to flight. As these small satellites move from technology demonstration and student projects toward more complex operational assets, it is expected that the standards for verification and validation will increase.

1.0 SMALL PROJECTS RAPID INTEGRATION AND TEST ENVIRONMENT

Marshall Space Flight Center's (MSFC) Small Projects Rapid Integration and Test Environment (SPRITE) is a Hardware-In-The-Loop (HWIL) test facility that provides rapid development, integration, and testing capabilities for small projects (CubeSats, payloads, spacecraft, and launch vehicles). This environment focuses on efficient processes and modular design to support rapid prototyping, integration, testing and verification of small projects at an affordable cost, especially compared to larger type HWIL facilities. SPRITE also serves as a development environment or "innovation space" for rapid development of innovative concepts and provides an avenue for actual development and test of these new technologies.

The SPRITE laboratory (Figure 1) is leveraged off of MSFC's System Integration Laboratory (SIL) developed for the Space Launch System (SLS) program. The SIL enables real-time simulation of a human-rated launch vehicle's ascent flight with flight-like avionics and software. SPRITE adapts the SIL's Advanced Real-Time Environment for Modelling, Integration, and Simulation (ARTEMIS)

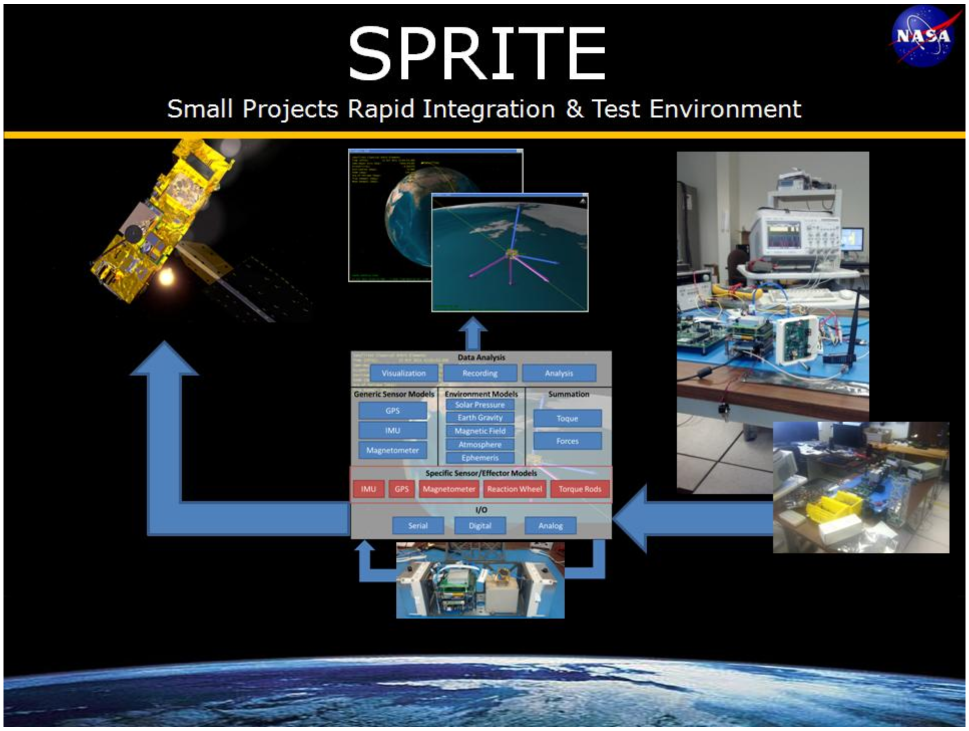

Figure 1 : SPRITE Laboratory

framework and modular design for applications on a smaller scale than the complex launch vehicles, and adapted the architecture to support rapid turn-around in all aspects of the life cycle. ARTEMIS is based on proven state-of-the-art, real-time Hardware-in-the-Loop (HWIL) simulation concepts that include the development of modular models and simulations based on real-time programming constructs, low latency communications, distributed processing, a deterministic real-time operating system (RTOS), as well as a non-intrusive data collection capability.

The ARTEMIS simulation framework is comprised five primary software components: an Executive which provides a common wrapper and framework for executables, Synchronization and Timing to control the execution and timing of executables and shared data, Input/Output (I/O) which provides interfaces to actual and simulated bus hardware, Data Recording of multiple types of interfaces (Discretes, Analog, etc.), and Models that represent a system and its elements such as, components, subsystems, vehicle dynamics (equations of motion, numerical integration, state vectors, etc.), and environment such as planet ephemeris (TOD, gravity), data & atmospheric properties, and environmental forces & torques (aero, gravity, parachutes). The modular design of ARTEMIS, coupled with the software representations of a system and its environment, provides the capability to support a full range of test configurations in support of formal Verification and Validation (V&V) activities. This approach provides the end-user/customer a simple, affordable method to minimize project risk, schedule, and budget, while maintaining high confidence of mission success and satisfying flight readiness requirements.

The SPRITE implementation of the ARTEMIS framework currently contains only rigid body dynamics. The small satellites that are intended for use will not incur substantial flexible body effects due to the size, but the ability to calculate these effects will be added later. Each model in the dynamics computation can easily be turned off to ignore the physical effects. This provides the ability for users to not only compare with simplified calculations but to see incremental effects. The incremental effects give users the ability to easily identify areas to be addressed. The integration of the states is done by Newton-Cotes based numerical integration. The Newton-Cotes integration increases with accuracy as the simulation begins and once enough information is obtained to use a sixth order integration, the integration method stays constant at that method. The user is given the ability to add Gaussian pseudo-random noise and/or a bias to sensors to enhance the reality of the simulation.

SPRITE also serves as a development environment or “innovation space” for rapid development of innovative concepts and provides an avenue for actual development and test of these new technologies. SPRITE also enables quick evaluations of COTS components for applicability to space flight applications. SPRITE has already facilitated testing of custom components and new technologies, emphasizing that the existence of this laboratory has already been used for several technology research projects. SPRITE has also been the conduit for innovative exchanges between MSFC and universities and cross-discipline technical exchanges by MSFC engineers.

MSFC is now making this capability portable (Figure 2) by containing all the simulation computers and interfaces in a single chassis the size of a medium-sized suitcase. This enables MSFC to bring the V&V environment to the customer so that the flight article doesn't have to undergo the risky transportation process or leave its clean-room environment. As interest is growing in small, responsive launchers, SPRITE provides the capability and portability to exercise the ascent vehicle's avionics through a simulated trajectory, exactly like SIL did for Ares I and performs for SLS.

1.1 Core Capabilities

SPRITE consists of a "core" capability or "plant" simulation framework (Figure 2) capable of being rapidly re-configured for any potential test article's space environments, as well as a standard set of interfaces (i.e. Mil-Std 1553, Serial, Analog, Digital, etc.). SPRITE also allows this level of interface testing of components and subsystems very early in a program, thereby reducing program risk.

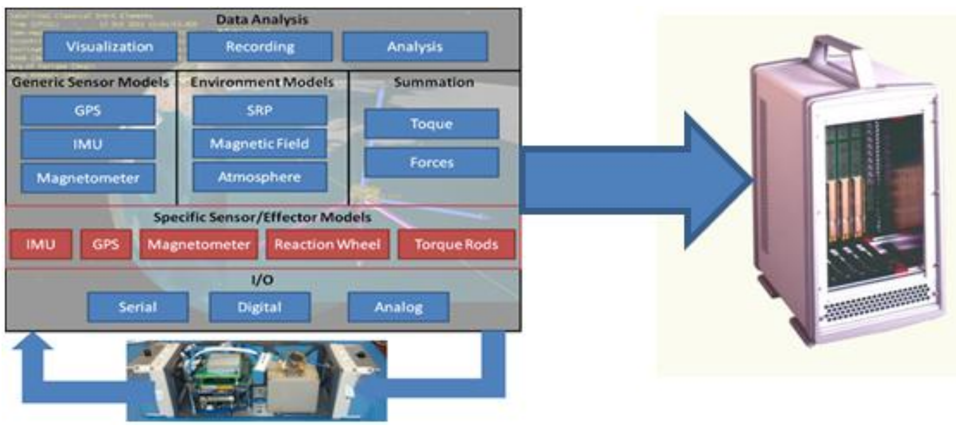

Figure 2 : SPRITE HWIL Testbed Core Components

1.2 Applications

1.2.1 Closed Loop Testing

The SPRITE HWIL Testbed (Figure 3) can be used to test spacecraft control software and avionics interfaces. The SPRITE HWIL simulation sums all of the forces and torques, either imparted by spacecraft effectors or resulting from the spacecraft's interaction with its environment, and provides simulated sensor inputs back to the unit under test to provide full closed-loop simulation. This is accomplished by intercepting commands to effectors and injecting data to sensors at the avionics interfaces.

For small spacecraft, such as CubeSats, the flight computer processors can be connected to the SPRITE real-time simulation computer, either directly or via development board interface. Simulated sensor measurements can then be fed into the flight processor. This allows the flight processor to exercise the flight software, operating on these simulated sensor inputs. The flight software and processor then outputs actuator commands back to the real-time simulation computer. The actuator commands are applied to the simulated vehicle dynamics, fed into the sensor models, and the loop starts over again. In another scenario, actual flight sensors and actuators can be included in the loop to exercise the actual hardware interfaces of those components. MSFC has succeeded in bringing this HWIL capability, previously reserved for V&V of large systems, into the realm of small systems through its portable HWIL Testbed capability.

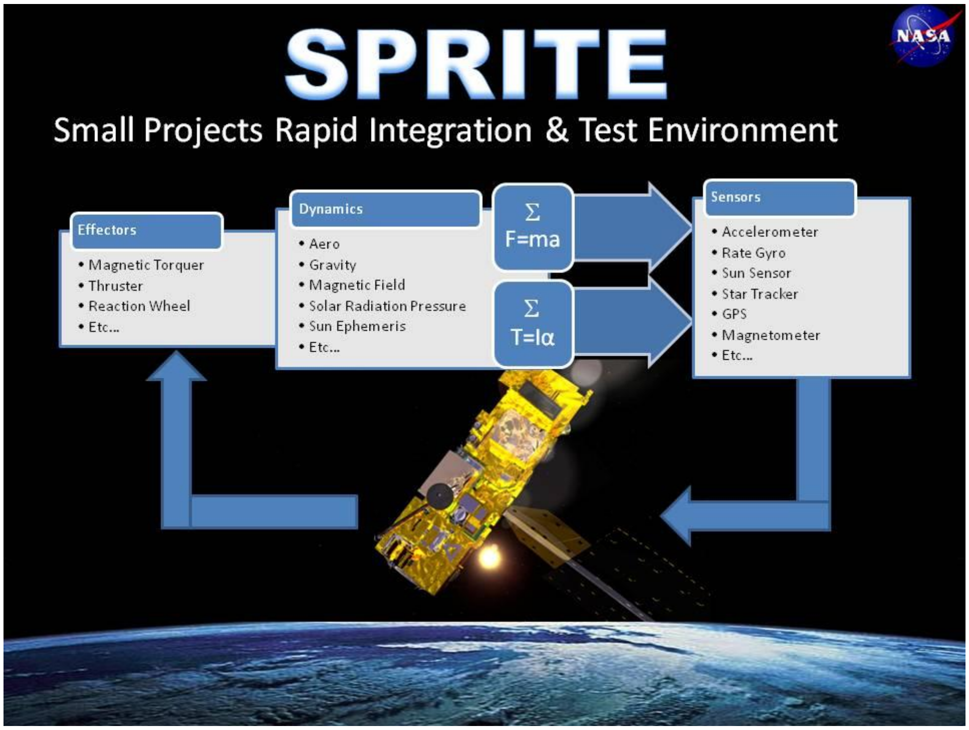

Figure 3 : SPRITE Functional Capabilities

1.2.2 Operational Check-out

SPRITE can also provide an essential service to spacecraft once they achieve operations on orbit. If anomalies occur during the mission, SPRITE has the ability to replay telemetry through the flight system within the real-time simulation. This greatly aids in troubleshooting on-orbit problems. Once the problems have been identified and solutions developed, SPRITE is again there to verify the software fixes before uploading them to the spacecraft.

1.2.3 Flight Software Development

SPRITE is conducive to a model-based approach to software development. One can develop flight code, and, with the assistance of the development board, test the prototype flight code in the real-time simulation. This way, early versions of flight software can be tested, and complex interfaces can be checked, early in the development cycle.

1.2.4 Power Management

As power management can be an issue on small CubeSats, SPRITE can help verify performance of the power system. All subsystems can be integrated together in the SPRITE lab and the simulation run while engineers monitor power draw across all subsystems. Power draw can be assessed at different points throughout the mission timeline in the real-time simulation environment as different subsystems demand varying power levels depending on what the spacecraft is required to do.

1.2.5 Guidance Navigation and Control

Navigation and attitude determination systems can be evaluated by flowing simulated data into navigation and attitude determination filters. Inexpensive IMUs can be evaluated with the filters, and interfaces quickly resolved.

1.2.5 Telemetry System Verification

SPRITE can support telemetry system testing. Telemetry archived on the CubeSat can be transmitted, via the CubeSat's own RF transmitter, to a separate receiver located in the SPRITE lab. That way, end-to-end telemetry can be checked out versus the mission timeline inside the simulation.

2.0 Innovation Space

SPRITE has served as an "innovation space" for small satellite advanced development work at MSFC. That work leveraged MSFC's cross-cutting heritage in automated rendezvous and capture (AR&C) into enhancing CubeSat capabilities for future mission architectures. Conceivable architectures include satellite servicing, orbital debris detection and removal, planetary sample return missions, and data relay and navigation architectures for lunar and planetary constellations.

In FY 2012 under the NASA Office of the Chief Technologist's (OCT) Center Innovation Fund (CIF), MSFC funded a task to push the limits of CubeSat attitude control using COTS GN&C components along with a custom miniature propulsion system. The intent was to demonstrate 1DOF attitude control of a prototype 3U CubeSat on an air bearing in MSFC's Flight Robotics Laboratory, also known as "The Flat Floor" (Figure 4). SPRITE served as the primary facility for the development of the 3U CubeSat prototype. All activities related to component testing, system integration, system verification, and system testing were performed in SPRITE. The project was able to verify and demonstrate the GN&C system from sensor measurement (sun sensor and IMU), through flight software, to reaction wheel or micro-propulsion system command. SPRITE also enabled early assessment of component functionality as well as its fit and form factor within a rapid prototype benchtop version of the 3U CubeSat. This helped the engineers evaluate each component's performance and improve the mechanical and electrical interfaces early in the vehicle's design process.

Figure 4 : The Flat Floor

In FY13, MSFC is funding a follow-on project through its Technology Innovation Program (TIP) internal research and development fund. The aim of the FY13 project is to perform a ground demonstration of a CubeSat performing proximity operations with another small spacecraft in the Flat Floor facility. A 6U CubeSat will autonomously navigate and traverse itself across a 10x10 meter area of the Flat Floor and make a soft contact with a mock-up of the FASTSAT small spacecraft. The 6U CubeSat is currently in development and will utilize the same hardware as the 3U model, but it will include some enhancements. The 6U CubeSat will have more thrusters (for 2 translational degrees of freedom) and a video guidance sensor (VGS). The VGS provides a 6DOF state of the target vehicle relative to the chase vehicle. The 6U cubesat is still early in the design phase, and SPRITE will serve all of the same functions for this project as it did for the 3U project.

SPRITE will be particularly useful in interfacing and testing the VGS navigation system with the rest of the GN&C and command and data handling systems. SPRITE will also be useful in testing the new navigation system with new AR&C approach algorithms within the SPRITE simulation environment. Just recently SPRITE demonstrated sub-degree pointing with a 3U Cubesat using green-propellant cold-gas thrusters in the MSFC Flight Robotics Lab (FRL). Currently, a 6U Cubesat with integrated Advanced Video Guidance Sensor (AVGS) is being built in the SPRITE lab using cell phone components. This new 6U satellite test article will be used to demonstrate proximity operations using cold-gas propellant.

3.0 Conclusion

The SPRITE has become an integral tool for rapid development, design, test, and verification; provides the capability to support small project location needs; and supports the engineers in assessing innovative concepts, including COTS, custom hardware/software concepts, and lifecycle. SPRITE will continue to evolve as concepts are proven and technical interchanges occur and lessons learned are incorporated. This will result in better processes, more robustness and capability as

SPRITE continues to mature.