Verification and Validation of Simulation-To-Flight 1’s Semiautonomous On-Orbit Operations Utilizing nos³

NASA Operational Simulator for Small Satellites

John Lucas
John.P.Lucas@nasa.gov
www.nos3.org
Overview

- Introductions
- NOS\(^3\)
- STF-1
- cFS Manager Application
- Day In The Life
- On Orbit Operations
- Ground Station Testing
- Post-Processing
- Demonstration
- Path Forward

08/05/2017
NASA IV&V – JSTAR – NON-ITAR
APPROVED FOR PUBLIC RELEASE
Acquire, develop, and manage adaptable test environments that enable the **dynamic** analysis of software behaviors for multiple NASA missions.
• Flight Software
  – Core Flight System (cFS)
• Ground Station
  – Ball Aerospace COSMOS
• Dynamics Engine
  – 42
  – Provides visualization
• NOS Engine
  – Communication protocols
  – Hardware simulators
**Uses:**
- Early Development
- Integration
- Mission Planning / Training
- Verification and Validation

**Simulated Components:**
- BCT XACT
- Cadet UHF Radio
- Clyde Space Batteries / EPS
- Generic Science Instruments
- GomSpace Nanomind A3200 Sensors
- ISISpace Antenna
- NovAtel OEM 615 GPS
Simulation To Flight - 1

- First CubeSat from West Virginia
- Manifested for launch in early 2018
- Objectives
  - Open source simulator
    - Develop advanced toolset to identify and resolve software issues
    - Evidence on cost and time savings
  - Meaningful science
    - Five separate payloads from WVU
  - Outreach and continued collaborations
cFS Manager Application

“Main” app:

- Experiment Control
  - Active
  - Requirements
- Monitor
  - Power
  - Runtime
  - Success
  - Telemetry
  - Time

- Phases / Modes
  - Default
  - Allowed to deploy
  - Deployed
  - Operational

- States
  - Survival
  - Wait
  - Run
cFS Manager Application

- Experiment Command Codes
  - Stop
  - Pause
  - Resume
  - Run #

- Report
  - State
  - Telemetry

DATA (HK)
CMD
RADIO
EPS APP
EXPER.
EXPER. CHILD

CFS Message Bus

ANTS API
MGR APP

NASA IV&V – JSTAR – NON-ITAR
APPROVED FOR PUBLIC RELEASE
Day In The Life

- Explore the system
- Investigate areas of interest
- Search for bugs
- Train for the mission
- Verify concept of operations
On Orbit Operations

- Errors
  - Corruption
  - Invalid data
  - Stuck switch
  - Timeouts

- Failures
  - Bus
  - Component
  - Deployment
Ground Station Testing

- Build database and tables
- Verify
  - Endianness
  - Packing
  - Interpretation
- Validate
  - Scripts
  - Telemetry
Post-Processing

- Acquire
  - CSV generation
  - Maintain FIFO ordering

- Correlate Data
  1. Determine reset periods
  2. Correlate mission and GPS time
  3. Output in desired segments / formats

- Distribute
- Process
- Publish
Demo

Go to video
STF-1 Cost Savings

- COCOMO sloccount estimates:
  - 8.25 person-months for flight software development
    - Does not include unit, integration, and hardware testing
  - 24% of flight software was newly developed for the mission
    - Not including vendor provided drivers, RTOS, or simulators

- STF-1:
  - 6 persons over 3 months, in parallel
  - No hardware spares used

- Future missions:
  - Potential to re-use component software and simulators

<table>
<thead>
<tr>
<th>Software Component</th>
<th>Description</th>
<th>SLOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Flight System (CFS) + Platform Support Package (PSP)</td>
<td>GSFC reusable, flight heritage framework</td>
<td>50,000 + 7,000</td>
</tr>
<tr>
<td>Operating System Abstraction Layer (OSAL)</td>
<td>GSFC reusable operating system abstraction layer</td>
<td>41,000</td>
</tr>
<tr>
<td>STF-1 Apps</td>
<td>Newly Developed Software</td>
<td>34,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>139,000</strong></td>
</tr>
</tbody>
</table>
Path Forward

- Configuration manager
  - Integrate components for your specific mission
- Establish baseline for future missions
- Expand app / simulator store
  - Automate testing of all applications and system
  - Determine requirements to accept applications
- Further genericize entire simulator platform
- Provide options for core components
  - Dynamic engines, ground stations, targets, etc.
Questions?

NASA’s Independent Verification and Validation Program

STF-1

Making West Virginia’s First Spacecraft

John Lucas
John.P.Lucas@nasa.gov
www.nos3.org
Special thanks to the STF-1 team!

- NASA IV&V
- TMC² Technologies
- WVSGC
- WVU
  - LCSEE
  - MAE
  - Physics & Astronomy
- WVHTC
- Orbital ATK (WV)
- IngeniuTECH (WV)
Backup
Utilization of the NASA Operational Simulator for Small Satellites (NOS\textsuperscript{3}) for Verification and Validation (V\&V) of STF-1’s Semiautonomous On-Orbit Operations

Matt Grubbs\textsuperscript{1}, John Lucas\textsuperscript{1}, Justin Morris\textsuperscript{1}, and Scott Zemek\textsuperscript{1}

NASA Goddard Space Flight Center IV\&V Program, Fairmont, WV 26554 USA

The NASA Operational Simulator for Small Satellites (NOS\textsuperscript{3}) is a suite of software tools that significantly aids the SmallSat community with software development, integration and test (I\&T), mission operations/training, verification and validation (V\&V), and software systems checkout. NOS\textsuperscript{3} has been utilized extensively for NASA’s Simulation-to-Flight 1 (STF-1) cubesat mission with respect to V\&V of its semiautonomous science operations. NOS\textsuperscript{3} provides a software development environment, a multi-target build system, operational interface/ground software, dynamics and environment simulations, and software-based hardware models.

STF-1, a 3U cubesat due to launch in late 2017, is composed of five dissimilar science experiments: 1) A \textit{N}itride \textit{R}adiation \textit{D}urability experiment, 2) A global navigation system receiver for orbit determination, 3) Cluster of inertial measurement units for data aggregation, 4) A magnetospheric physics experiment including a Langmuir probe and particle counters, and 5) A visible light camera. Each of these experiments has its own set of software requirements, such as data acquisition times/infers, and operational specifications/modes. In addition to its science experiment software requirements, the STF-1 cubesat also has normal-operational software requirements, such as power monitoring, sensor data acquisition, experiment data storage, and uplink/downlink communications. These complex software requirements provide a significant V\&V challenge due to limited hardware test bed accessibility; all science experiment hardware is custom without spares, and flight hardware testing time is not adequate for complete flight software V\&V.

Due to the short-duration seven-minute ground contact windows, the STF-1 cubesat must perform its operations without ground contact. STF-1 requires semiautonomous on-orbit operations to manage its five complex science experiments. STF-1, which is utilizing Goddard Space Flight Center’s (GSFC) open-source Core Flight System (CFS), contains a Manager (MGR) application that implements a state machine for starting, stopping, and monitoring the science experiments without ground intervention. MGR is also responsible for watchdog timers, power monitoring, and handling error states.

NOS\textsuperscript{3} usage on STF-1 has allowed the team to execute months of MGR and additional flight software V\&V tests without monopolizing flight hardware testing time. The NOS\textsuperscript{3} hardware models’ fidelity is such that flight software executes unaware that physical hardware is not present. This allows the flight software binaries to be compiled for both the simulation environment and the flight computer without changing the source code. Multiple engineers are able to simultaneously test the flight software, perform long-duration-multiple-orbit test scenarios, and verify recorded telemetry by utilizing the NOS\textsuperscript{3} virtual machine on laptops.

NOS\textsuperscript{3} is expected to be open-source available to the entire SmallSat community by Summer 2017 to significantly assist projects with their flight software development. As NOS\textsuperscript{3} matures, additional hardware models will be added that are common to the small satellite community. Also planned in the near future is more hardware-in-the-loop functionality that allows a flight computer with I2C to connect to NOS\textsuperscript{3} simulators, thus providing representative data for additional flight software testing capabilities.

\textsuperscript{1} Systems Engineer, NASA IV\&V Independent Test Capability (ITC), RSI-Tech
\textsuperscript{2} Systems Engineer, NASA IV\&V ITC
\textsuperscript{3} Computer Engineer, NASA IV\&V ITC
\textsuperscript{4} Systems/Software Engineer, NASA IV\&V ITC, JPL Technologies
\textsuperscript{5} STF-1 will be launched as one of 14 satellites on the FlAba X mission, aboard a Rocket Labs Electron Launch Vehicle to an altitude of 500km with an inclination of 95 degrees.