Infrastructure and Process Improvements After LADEE

Flight Software Workshop
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Common Avionics & Software Technologies (CAST)

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Objectives
• Measure Lunar Dust
• Examine the Lunar atmosphere
• 100 days in a low-equatorial lunar orbit

Key parameters
• Launched Sept 6, 2013
• Lunar Impact April 18, 2014

Spacecraft
• Type: Small Orbiter - Category II, Enhanced Class D
• Provider: NASA ARC and NASA GSFC

Instruments
• Science Instruments: NMS, UVS, and LDEX
• Technology Payload: Lunar Laser Communications Demo

Launch Vehicle: Minotaur V
Launch Site: Wallops Flight Facility
Star Tracker Images

- A series of star tracker images taken by LADEE. The lunar horizon is ahead, a few minutes before orbital sunrise.

Clementine spacecraft image of moon dust corona

Gene Cernan’s drawings of the lunar sunrise
High Precision in Predicted Position

- LADEE Orbit Determination team predicted the location of the spacecraft precisely enough for an LROC photo at a high velocity fly-by
  - Two spacecraft at a nearly perpendicular orbit crossing
  - Both travelling at 1.6 km/sec
Predicted Height Above Lunar Terrain

- Andrea: 1.44 km
- Bruce: 1.23 km
- Charlene: 0.88 km
- Derek: 0.94 km
- Erin: 0.29 km
- Francis: IMPACT!
Final Resting Place
LADEE Final Status

LADEE Flight Software
• On orbit table uploads regularly performed (ATS, RTS, FM, Thermal updates & defect reduction)
• 2 software patches to account for emergent star tracker behavior
• 1 unanticipated reboot (Interrupt Handling)
• Upload and reboot into new software load. Approximately a month’s continuous operation on the new load with no defects found.
• Team recertified for CMMI level 2 in May 2013

LADEE Mission
• Successful de-orbit 4/18/2014
• Lowest science operations conducted under 2 Km over the moon’s surface
• Successful Laser Communications demonstration: 622Mbs downlink rate. Very useful to be able to download a SDRAM partition in less than 2 minutes.
• Survived an eclipse!
• 188 days of lunar orbit, with approximately 200% of planned science data returned to the earth. All science goals met.
We have observed several new-start spacecraft projects at Ames abandon their efforts to utilize cFE/OSAL

- Difficulties absorbing extensive documentation
- Need experienced consultants.
- Unrealistic budget, schedule and expectations

Current Effort: Common Avionics & Software Technologies

- Goal: A consulting group that provides a modular and customizable software with support for common spacecraft functions.
- Software based on the LADEE architecture, but with core components updated to modern standards
  - OSAL (based on open source 4.1.1)
  - cFE (based on open source 6.3.2)
  - cFS (LADEE version, awaiting open source)
  - vxWorks 6.9
  - Matlab/Simulink 2014a
  - Additional RTOS: Linux/Xenomai, RTEMS
Flight Software Overview

• **Scope**
  - Onboard Flight Software (Class B)
  - Support Software and Simulators (Class C)
  - Integration of FSW with avionics

• **Guiding Documents**
  - NPR7150.2 Software Engineering Requirements
    - CMMI Level 2 or Equivalent
  - NASA-STD-8739.8 NASA Software Assurance Standard

• **Development Approach**
  - Model Based Development Paradigm (prototyped process using a “Hover Test Vehicle”)
  - 5 Incremental Software Builds, 2 Major Releases

• **Leverage Heritage Software**
  - GSFC OSAL, cFE 5.2.0, cFS, ITOS
  - Broad Reach Drivers, VxWorks 6.8
  - Mathworks Matlab/Simulink 2010b & associated toolboxes

• **Heritage Software Components** frozen ~ 2011.
FSW Architecture

- FSW Architecture
- OFSW
- Software Bus
- Scheduler
- Stored Commands
- Memory Manager
- Memory Dwell
- Limit Checker
- Housekeeping
- Memory Scrub
- Hardware I/O
- Health & Safety
- File Manager
- CCSDS File Delivery
- Checksum
- Data Storage
- Telemetry Output
- Command Ingest
- System Support and O/S Services
- Telemetry
- Gnd Cmds
- Hdwr Cmds
- Sensor Data
- GSFC OSAL, cFE, cFS, ITOS (GOTS)
- Broad Reach Drivers (MOTS)
- Simulink/Matlab, VxWorks (COTS)
Processors and Practices

Integrated with a range of processors

- Trade study to make it easier for spacecraft to identify acceptable processors with necessary performance and budget constraints.
- Initial Processors targeted:
  - Beagle Bone Black
  - Zynq
  - PowerPC 750
  - LEON

- Provide a set of Software Engineering Practices and Documentation to quick start spacecraft software development effort
  - Git
  - Confluence/JIRA
  - Bamboo Continuous Test
  - NPR 7150.2 required plans
  - Extensive Test Suite
  - Peer Review/Formal Inspection
Collaborations

The CAST group is in the process of Open Sourcing the “Simulink Interface Layer for cFE/cFS”

• Sample Simulink model and interface wrappers with detailed instructions for integration with cFE.
• Currently consistent with the open source 6.3.2 version of cFE
• Updating to 6.4.0 and will ensure that it is consistent with the open source version of cFS when GSFC is able to release it.
• Extensive legal process… no firm date for open source at this point, but it is available under a software usage agreement

We are participating in the cFS Working Group

• Several NASA centers collaborating on cFS development to avoid duplication of effort and speed updates to the open source code-base.

Proposing the new software and avionics base as a core for many upcoming missions:

• Resource Prospector, CubeSat line, LADEE follow-on…