Infrastructure and Process Improvements After LADEE

Flight Software Workshop
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Common Avionics & Software Technologies (CAST)

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Lunar Atmosphere and Dust Environment Explorer

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: 0.94 km

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

SOFTWARE BUS

Cmd & Mode Processor
Actuator Manager
State Estimator
Safe Mode Controller
Attitude Control System
Thermal Control System
Power Control System
Battery Charge System

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

Checksum

System Support and O/S Services

Telemetry
Gnd_cmds
Hdwr_Cmds
Sensor Data

Simulink
Task

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…