



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

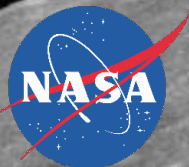
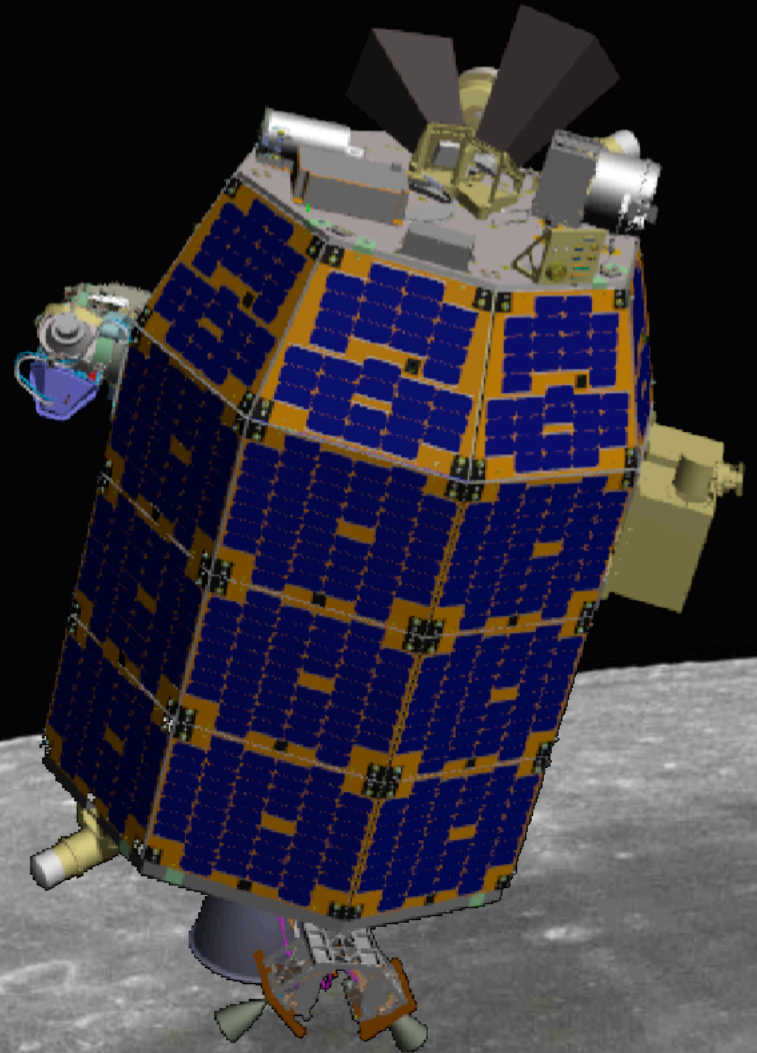
- Type: Small Orbiter - Category II, Enhanced Class D
- Provider: NASA ARC and NASA GSFC

Instruments

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

Launch Vehicle: Minotaur V

Launch Site: Wallops Flight Facility

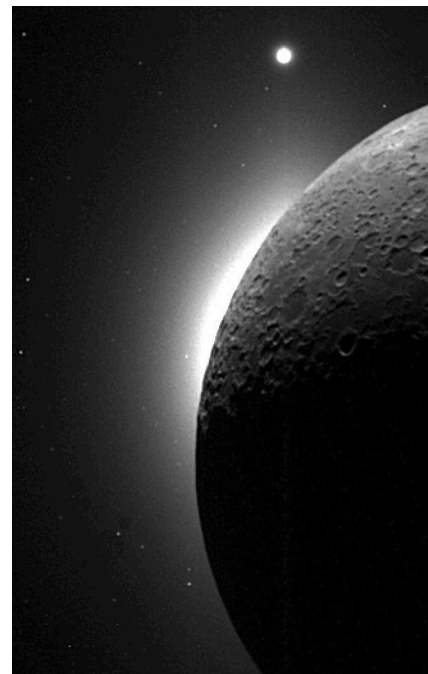




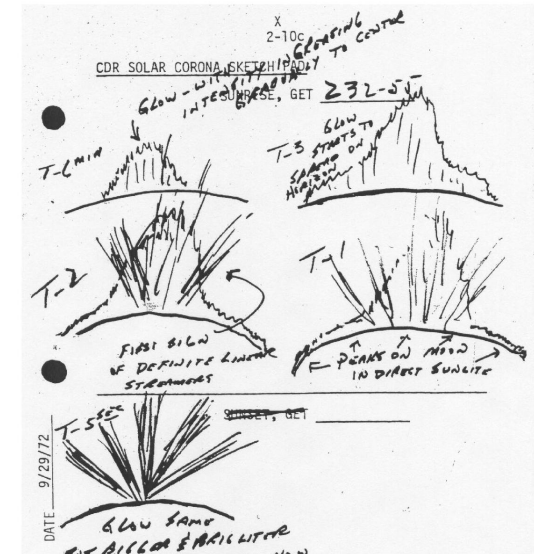
Star Tracker Images



- 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

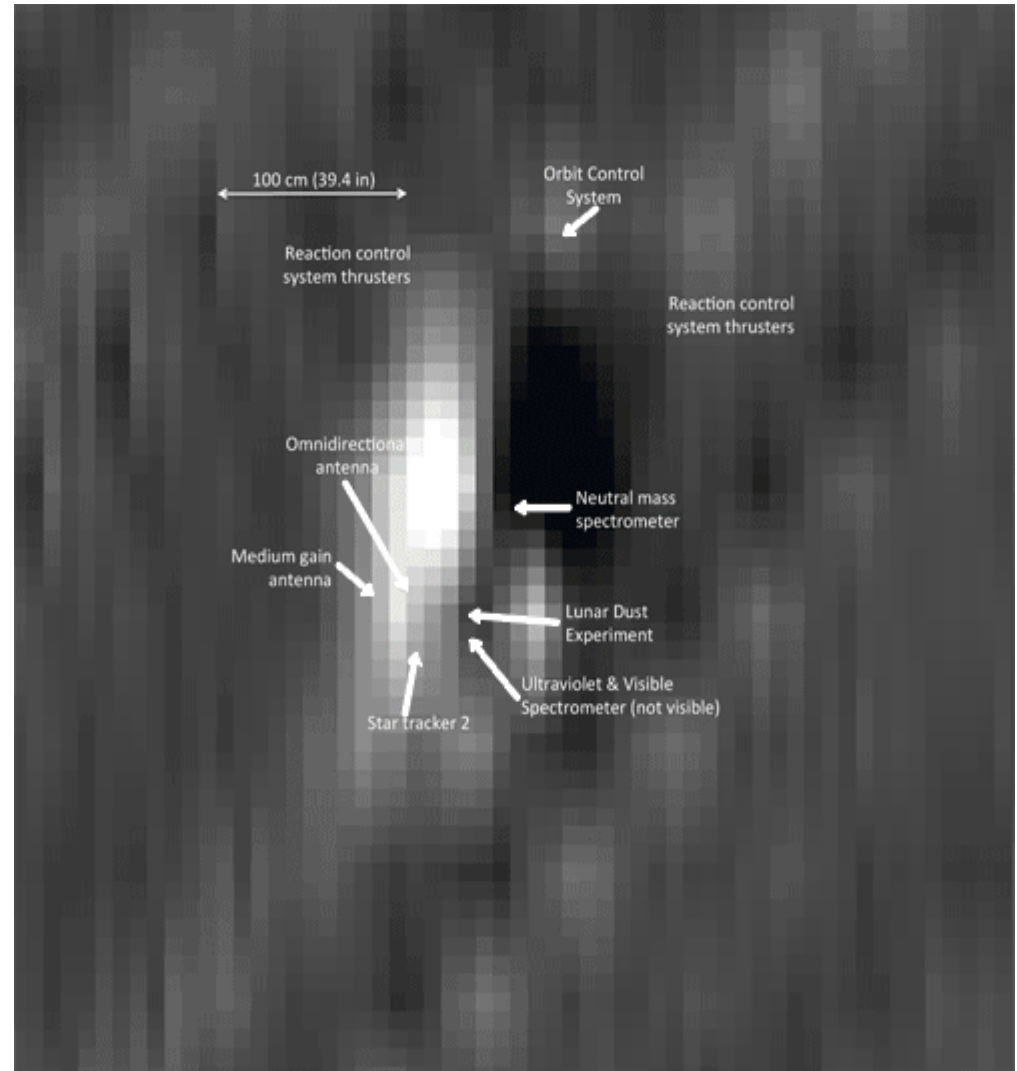
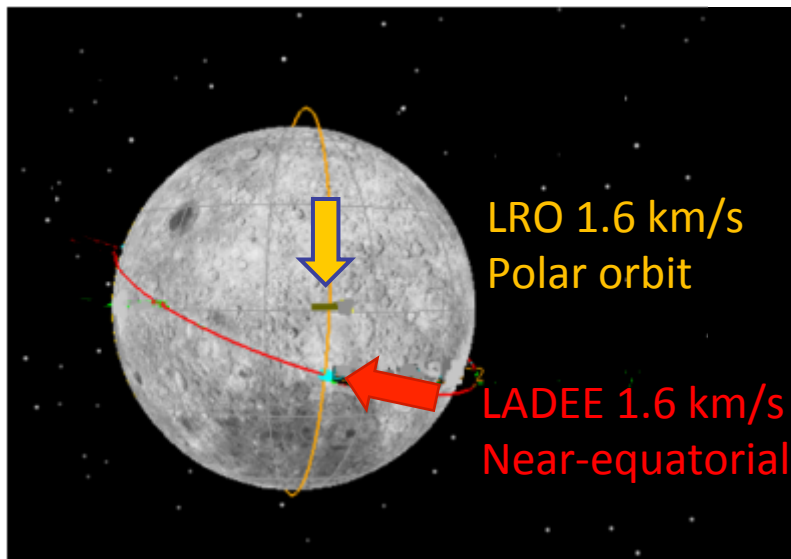


Gene Cernan's drawings of the lunar sunrise



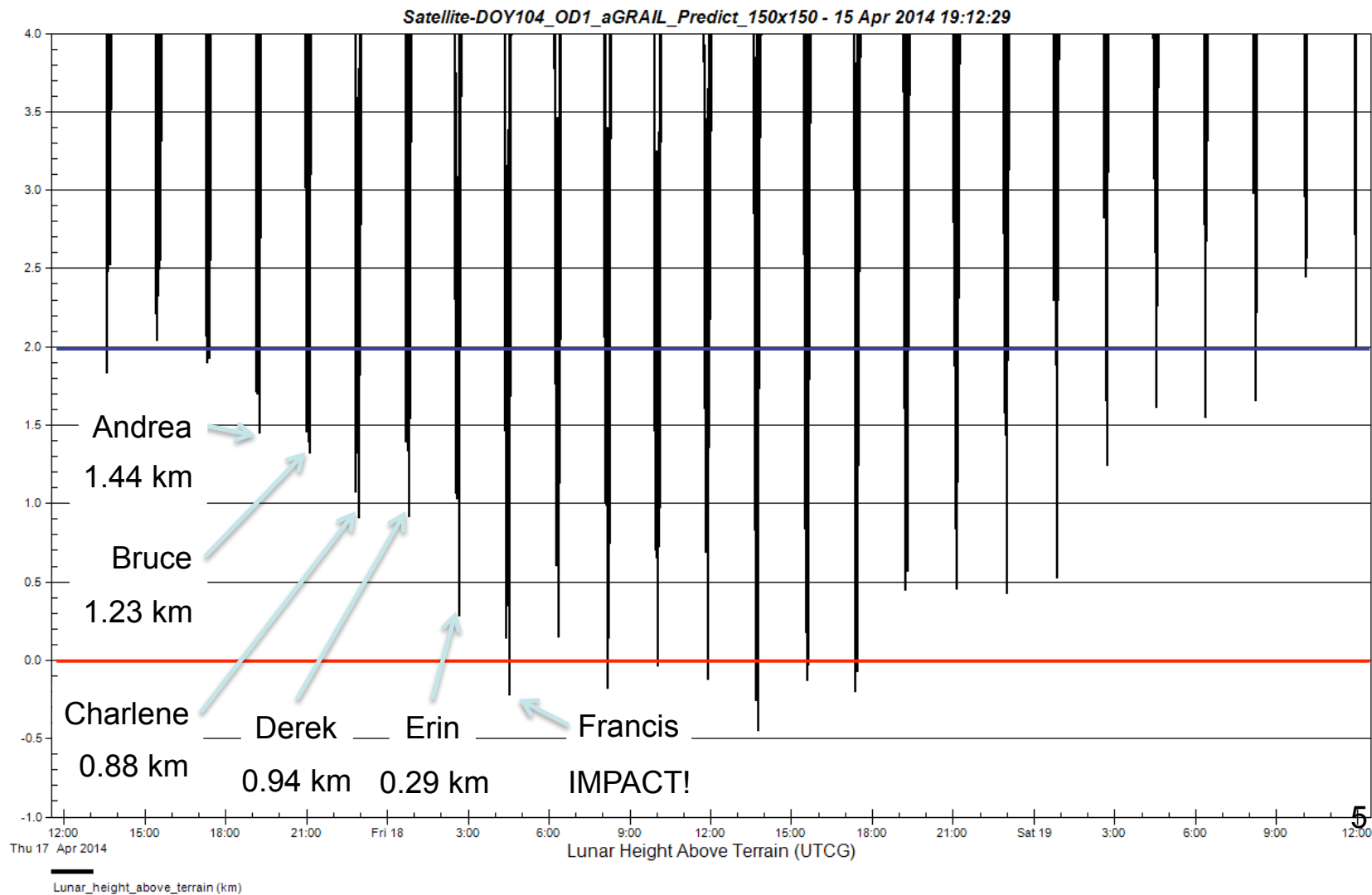
High Precision in Predicted Position

- 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





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.



CAST



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

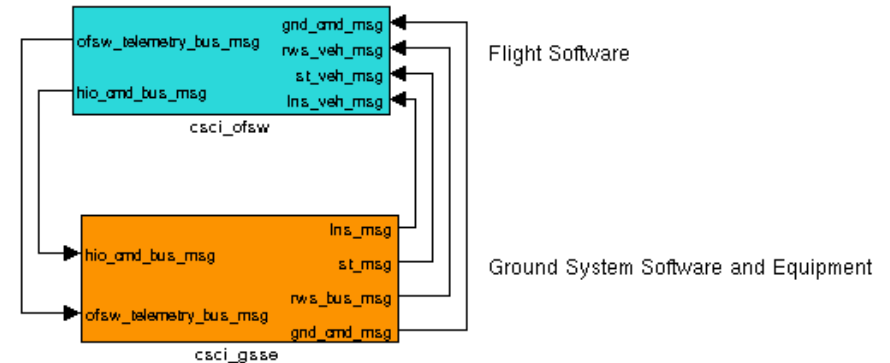


- Scope
 - Onboard Flight Software (Class B)
 - Support Software and Simulators (Class C)
 - Integration of FSW with avionics



LADEE

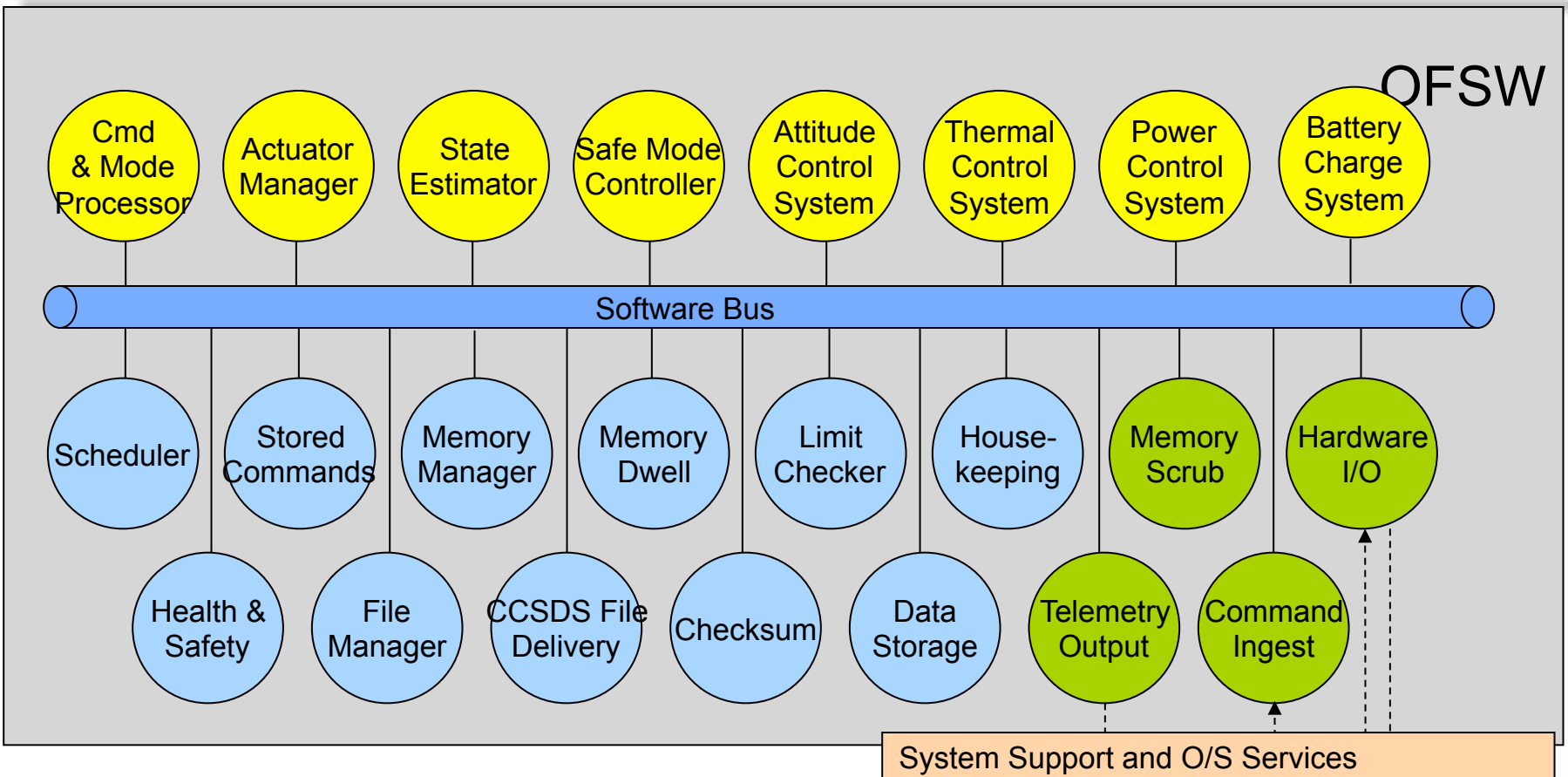
- Guiding Documents
 - NPR7150.2 Software Engineering Requirements
 - CMMI Level 2 or Equivalent
 - NASA-STD-8739.8 NASA Software Assurance Standard



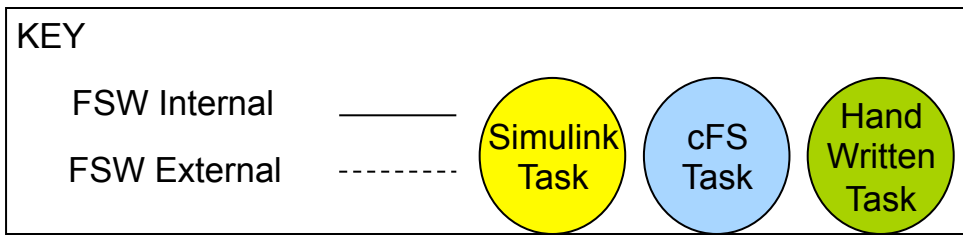
- Development Approach
 - Model Based Development Paradigm (prototyped process using a “Hover Test Vehicle”)
 - 5 Incremental Software Builds, 2 Major Releases
- Leverage Heritage Software
 - GSFC OSAL, cFE 5.2.0, cFS, ITOS
 - Broad Reach Drivers, VxWorks 6.8
 - Mathworks Matlab/Simulink 2010b & associated toolboxes
- Heritage Software Components frozen ~ 2011.



FSW Architecture



OFSW



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...