Infrastructure and Process Improvements After LADEE

Flight Software Workshop
Dec 16, 2014

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
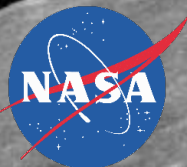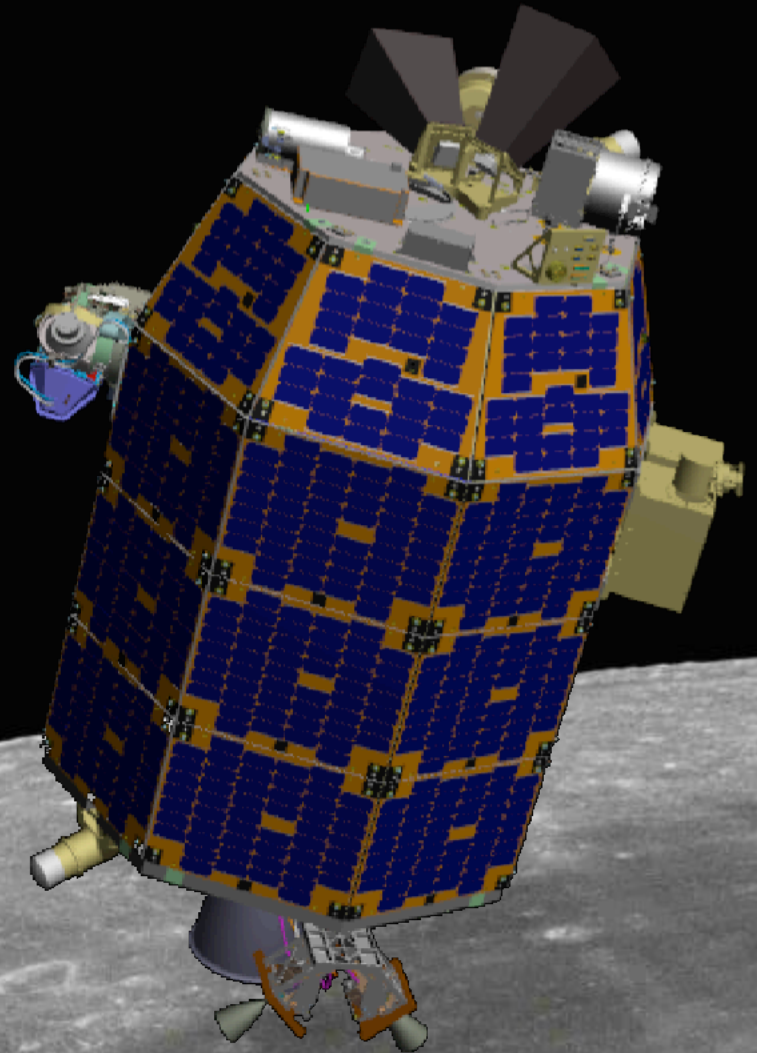- Lunar Impact April 18, 2014

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

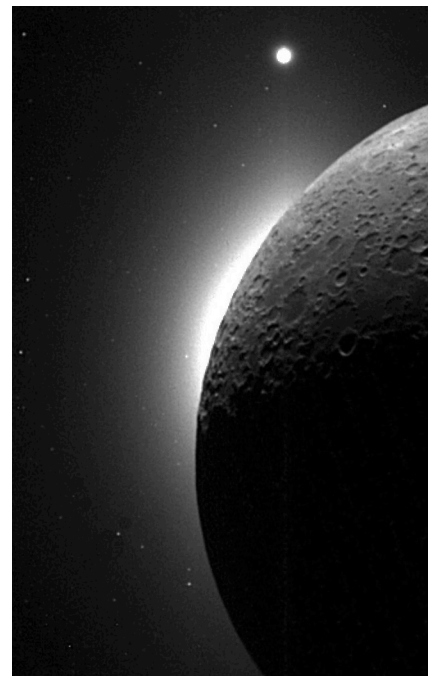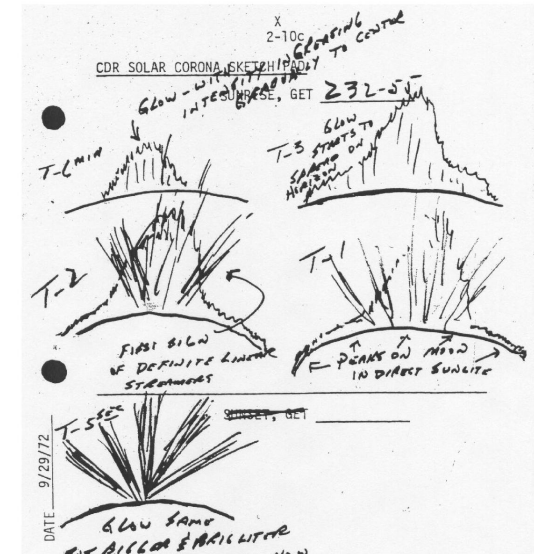**Launch Site: Wallops Flight Facility**

Star Tracker Images

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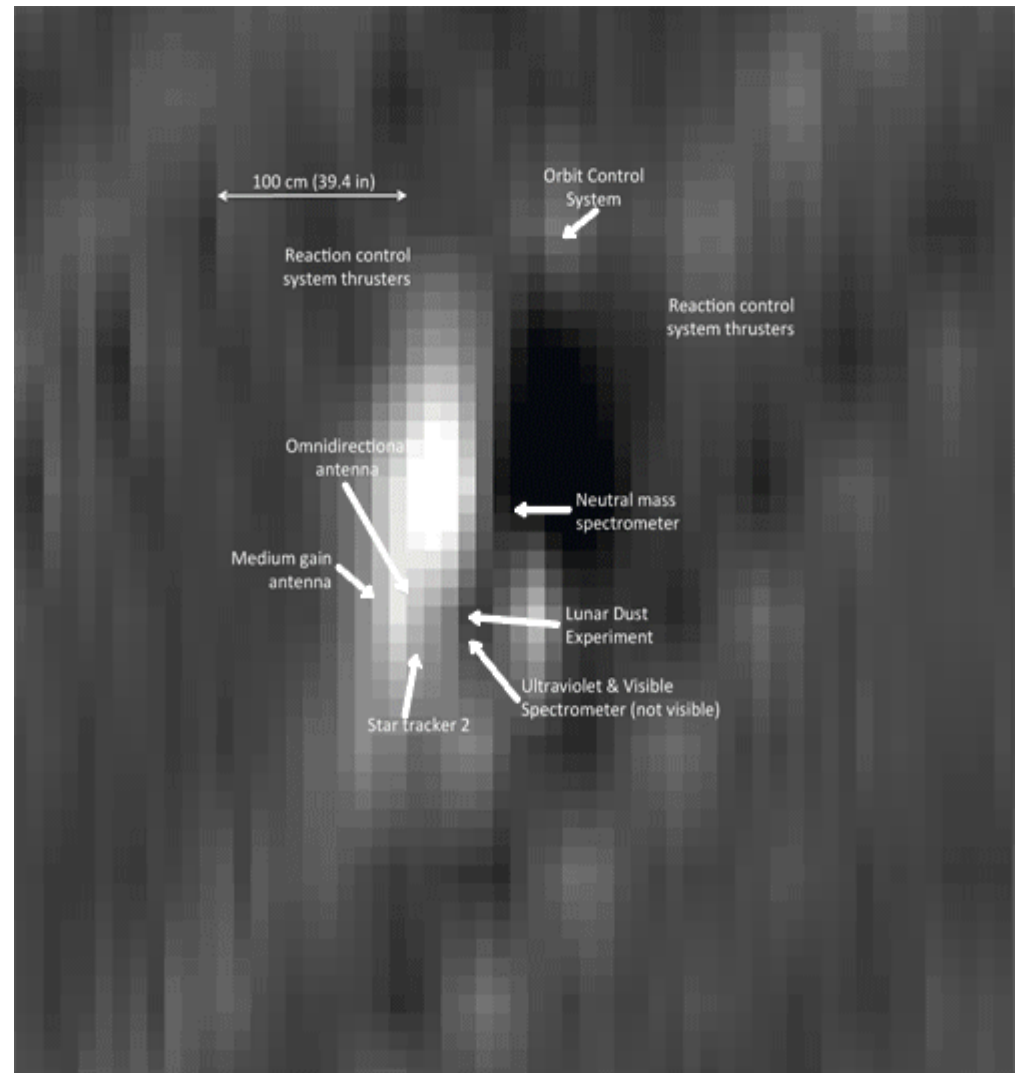

Clementine spacecraft image of moon dust corona

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

LRO 1.6 km/s
Polar orbit

LADEE 1.6 km/s
Near-equatorial

100 cm (39.4 in)

Orbit Control System

Reaction control system thrusters

Reaction control system thrusters

Omnidirectional antenna

Neutral mass spectrometer

Medium gain antenna

Lunar Dust Experiment

Ultraviolet & Visible Spectrometer (not visible)

Star tracker 2
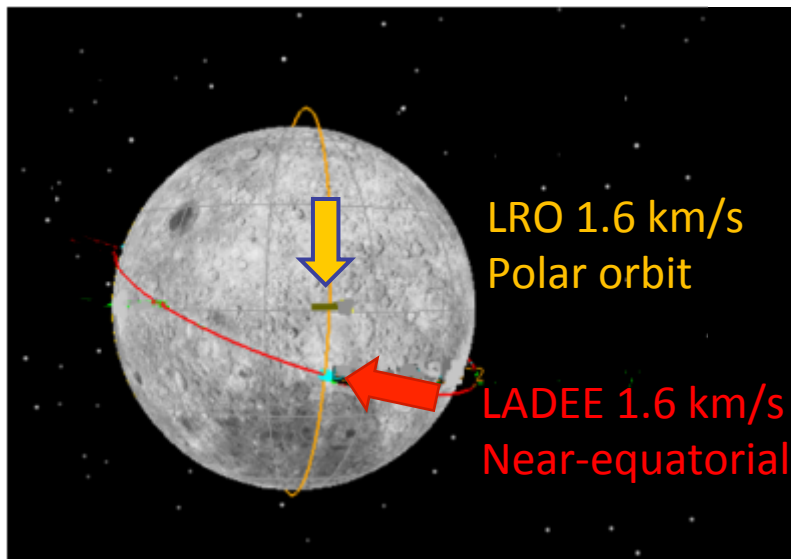
Predicted Height Above Lunar Terrain

Satellite-DOY104_OD1_aGRAIL_Predict_150x150 - 15 Apr 2014 19:12:29

Andrea
1.44 km

Bruce
1.23 km

Charlene
0.88 km

Derek
0.94 km

Erin
0.29 km

Francis
IMPACT!

12:00   15:00   18:00   21:00   Fri 18   3:00   6:00   9:00   12:00   15:00   18:00   21:00   Sat 19   3:00   6:00   9:00   12:00
Thu 17 Apr 2014

Lunar Height Above Terrain (UTCG)

Lunar_height_above_terrain (km)
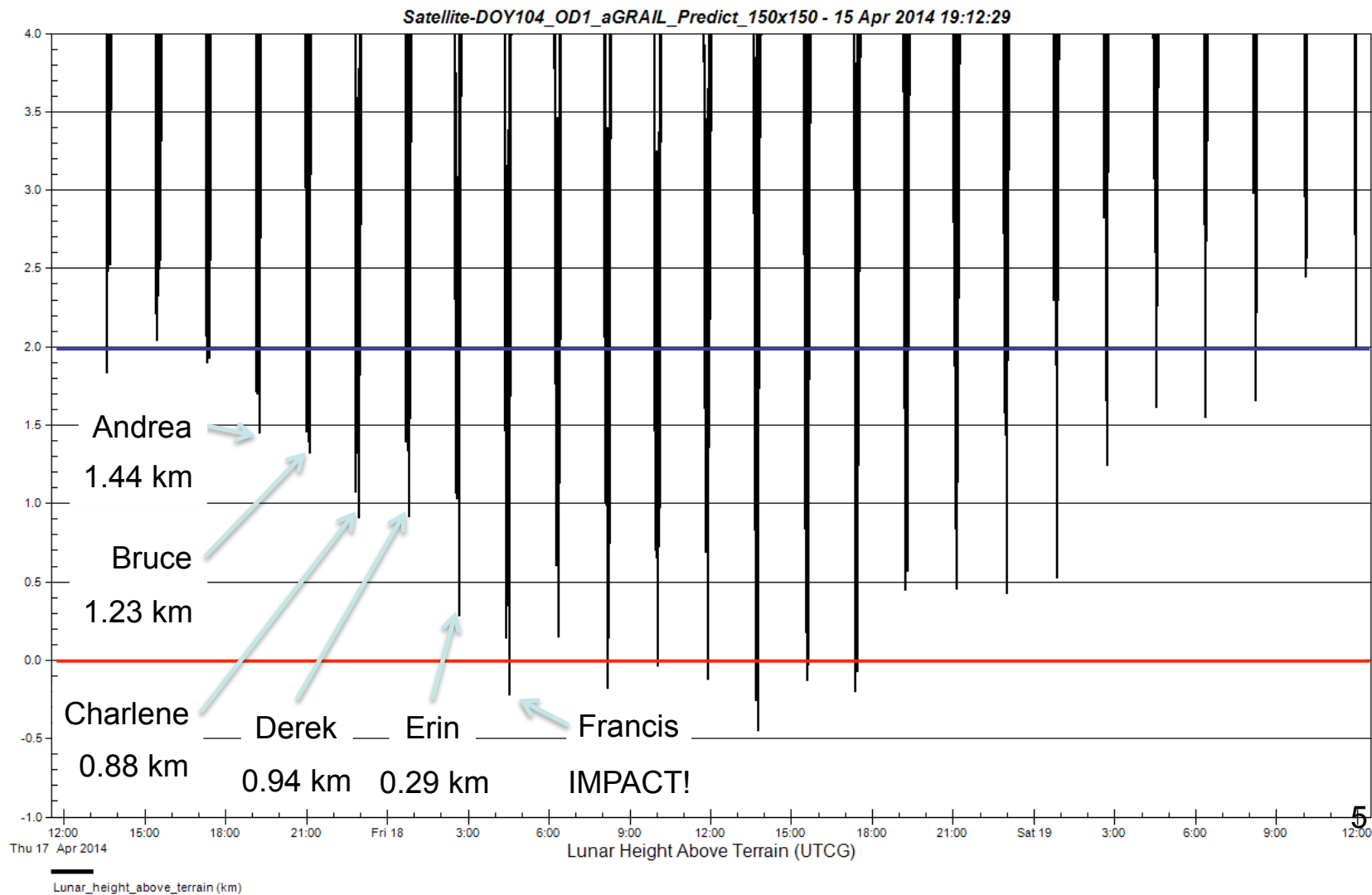
Final Resting Place

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
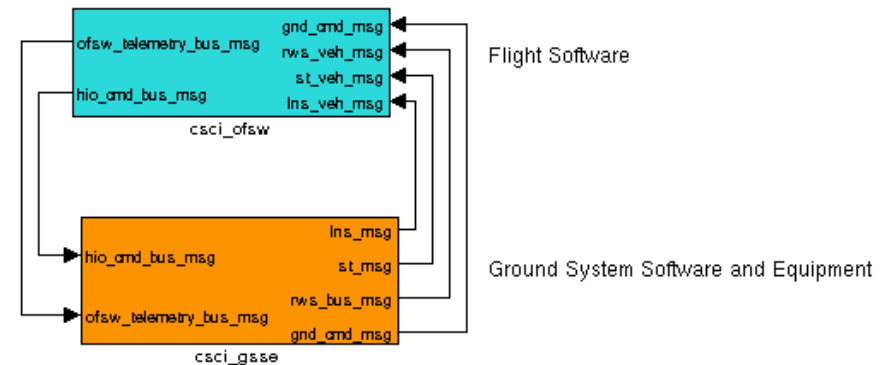
Flight Software Overview

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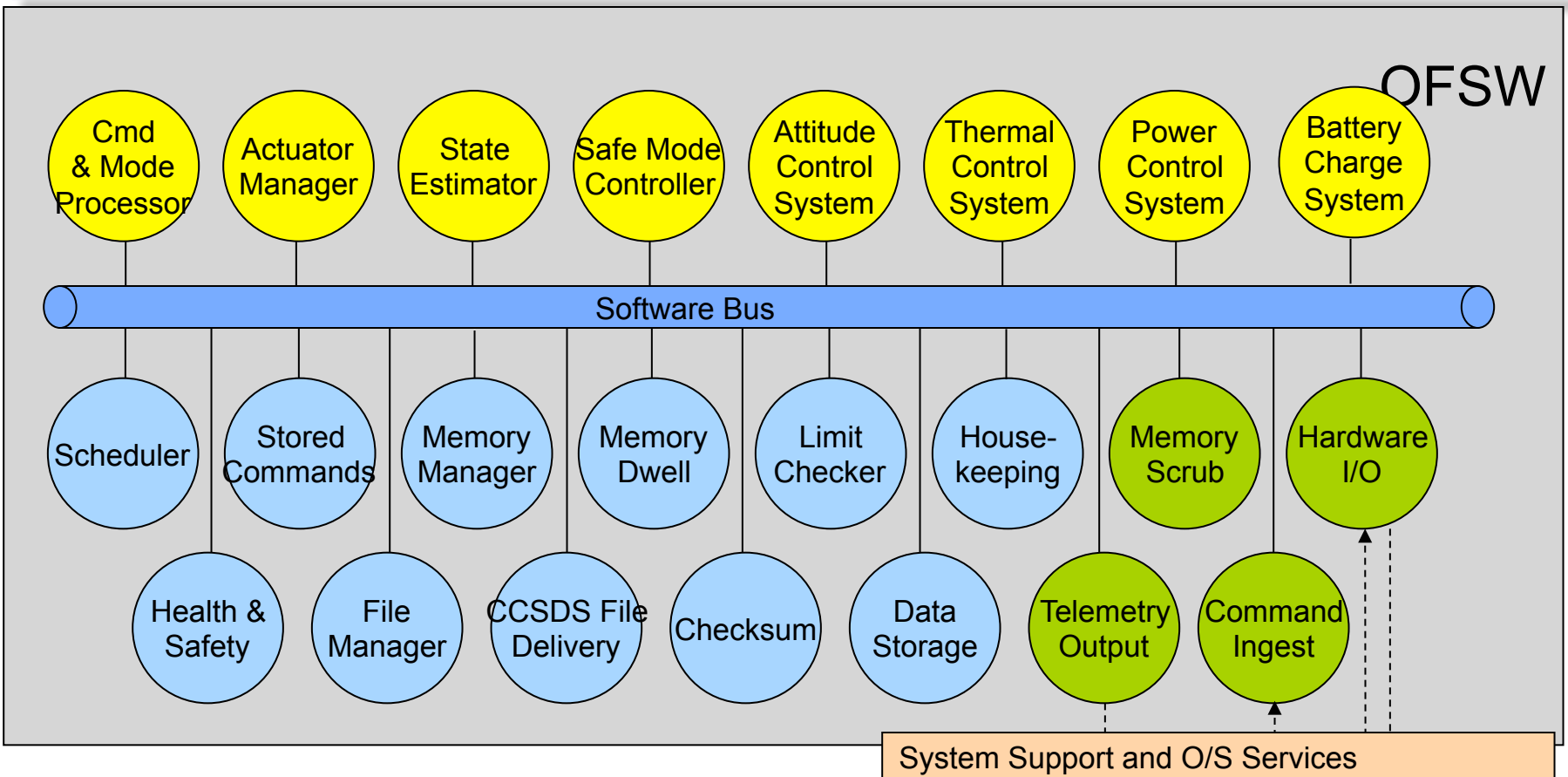 - Integration of FSW with avionics

- Guiding Documents
  - NPR7150.2 Software Engineering Requirements
    - CMMI Level 2 or Equivalent
  - NASA-STD-8739.8 NASA Software Assurance Standard
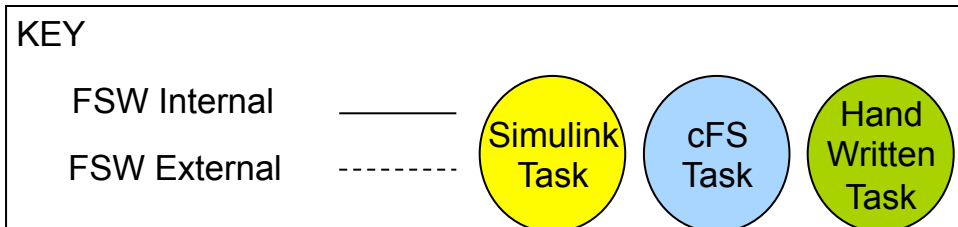
- Development Approach
  - Model Based Development Paradigm (prototyped process using a "Hover Test Vehicle")
  - 5 Incremental Software Builds, 2 Major Releases

- 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.

LADEE

FSW Architecture

OFSW

Software Bus

Top row (Simulink Tasks — yellow):
- Cmd & Mode Processor
- Actuator Manager
- State Estimator
- Safe Mode Controller
- Attitude Control System
- Thermal Control System
- Power Control System
- Battery Charge System

Middle row (cFS Tasks — blue):
- Scheduler
- Stored Commands
- Memory Manager
- Memory Dwell
- Limit Checker
- House-keeping
- Memory Scrub
- Hardware I/O

Bottom row:
- 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

KEY

| FSW Internal | ——— | Simulink Task | cFS Task | Hand Written Task |
| FSW External | - - - - | | | |

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…