LADEE Simulation for Mission Operations

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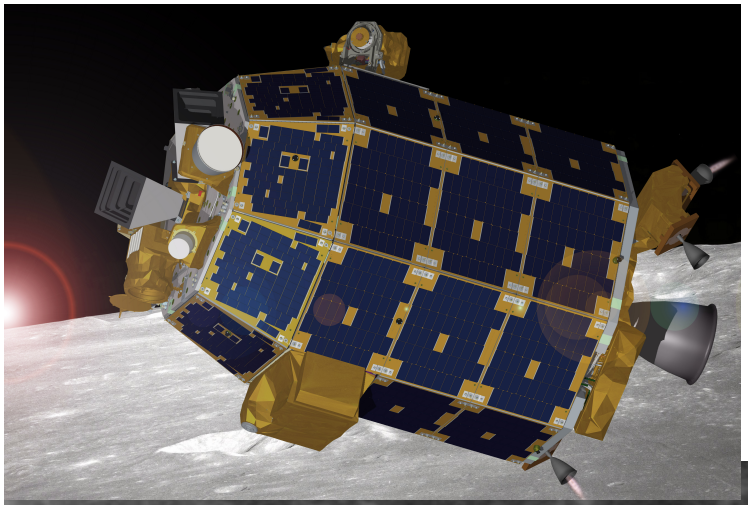
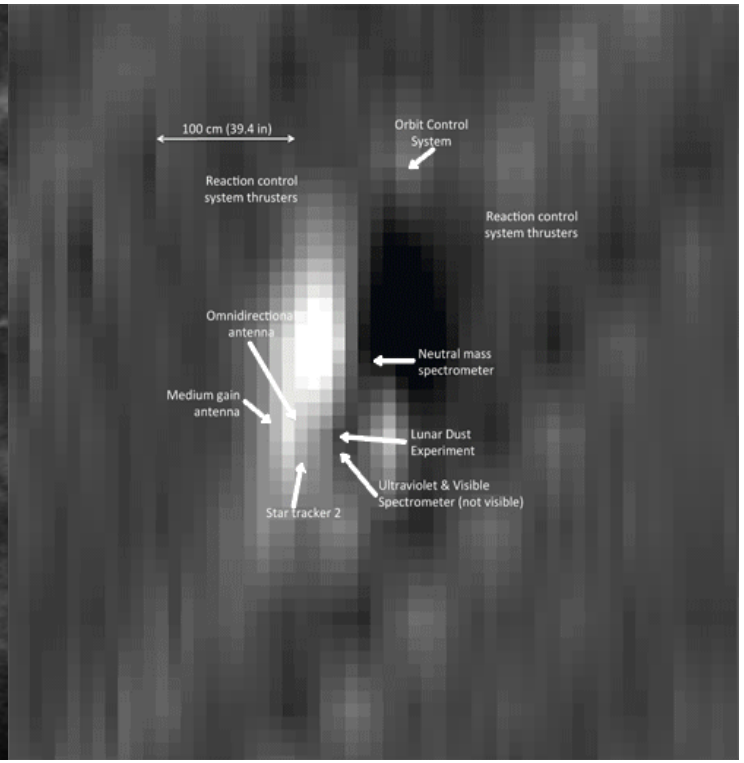
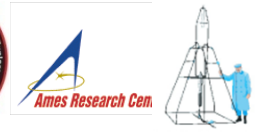
LADEE Mission Overview



- Lunar Atmosphere and Dust Environment Explorer (LADEE) was a NASA mission that will orbited the Moon and its main objective is to characterize the atmosphere and lunar dust environment.
  - Low cost, minimal complexity and rapidly prototyped "common bus" design.
  - Model-Based Software Development

- Determine the global density, composition, and time variability of the lunar atmosphere;
- Laser Communications Demonstration: 622 Mbs Record download rate from the Moon!



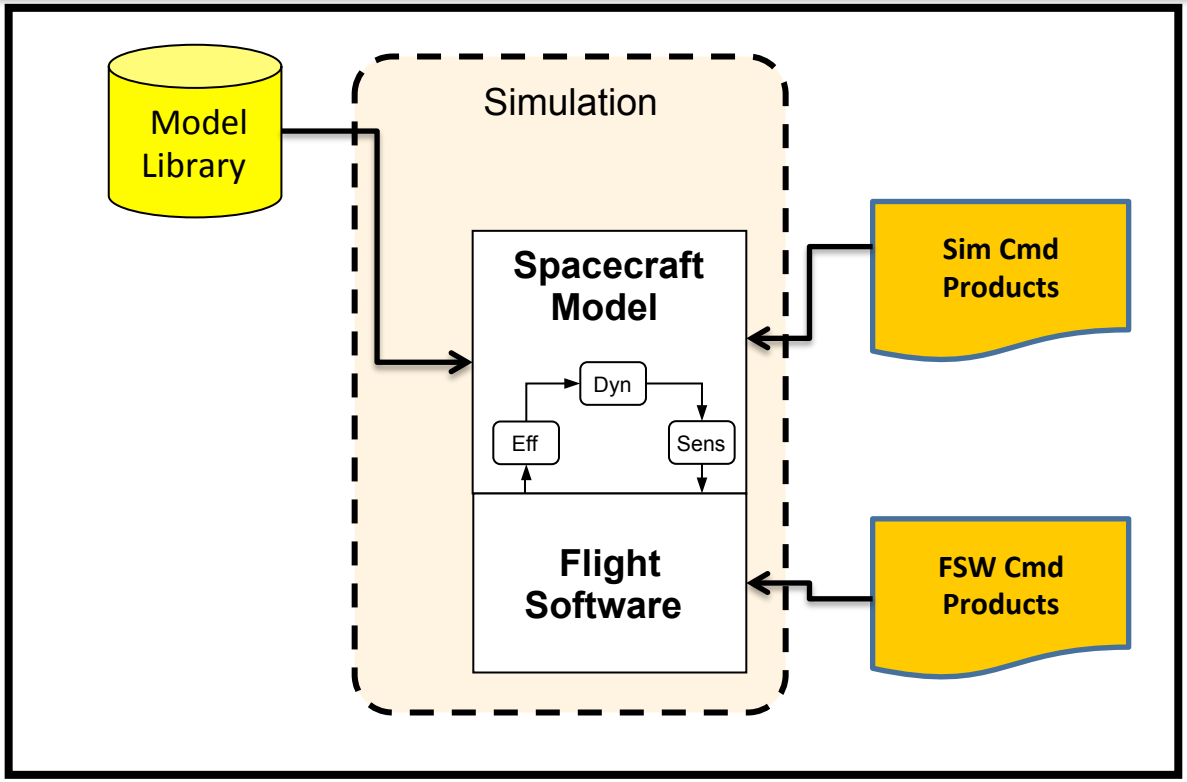


OVERVIEW OF SIMULATORS

LADEE Simulator Overview

Simulator	Platform	Description
WSIM **Workstation Simulations**	**Simulink on Windows, Mac, or Linux computers**	**•Models of GN&C, Prop, Power, & Thermal** **•Used by FSW to generate and test algorithms.** **•Provided to MOS for full sequence verification.** **•Much faster than real time (~10-50x) depending on selected fidelity of models and platform.**
PIL **Processor-in-the-Loop**	**PPC750 Processor(s) in Standalone chassis**	**•Includes all flight software functionality. Runs on 1 or 2 processors.** **•Multiple copies maintained by FSW as inexpensive system for real time software & fault management development.** **•Multiple copies provided to MOS for Training, GDS development, and Operations.**
HIL **Hardware-in-the-Loop**	**Avionics EDU with simulated vehicle hardware.**	**•Highest fidelity simulator includes hardware interfaces.** **•One copy maintained in FSW lab for software & fault management development and characterization.** **•Inexpensive version (no power cards) provided to MOS and I&T.** **•Runs in real time.**

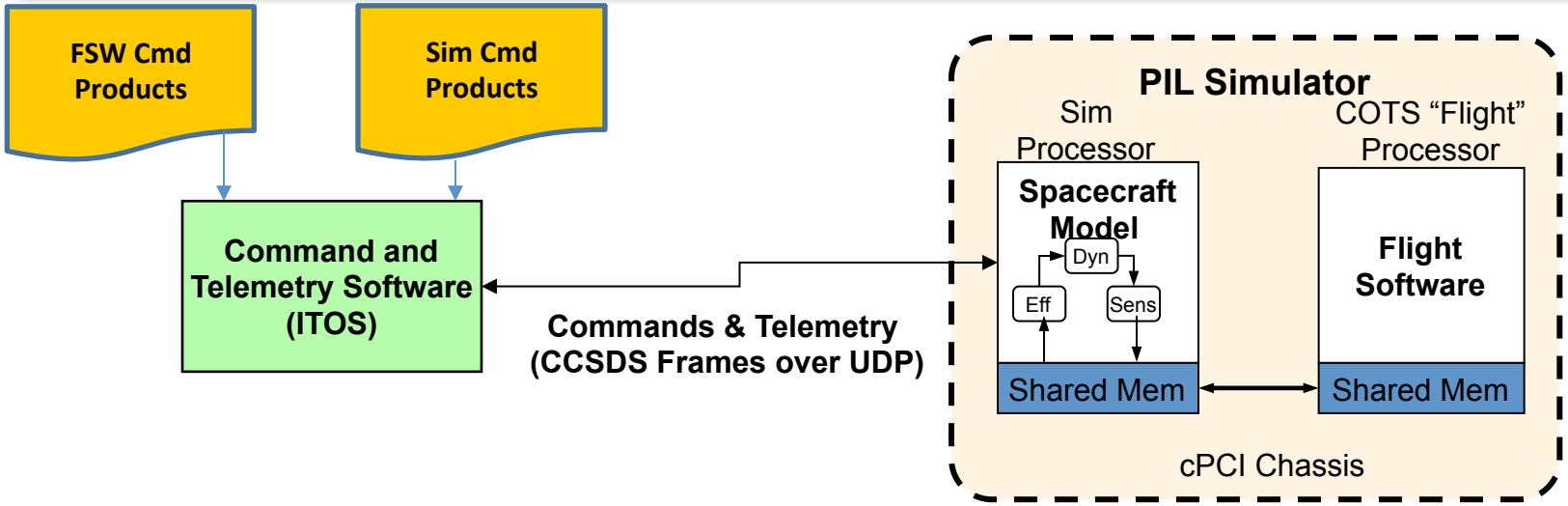
WSIM



Local Workstation

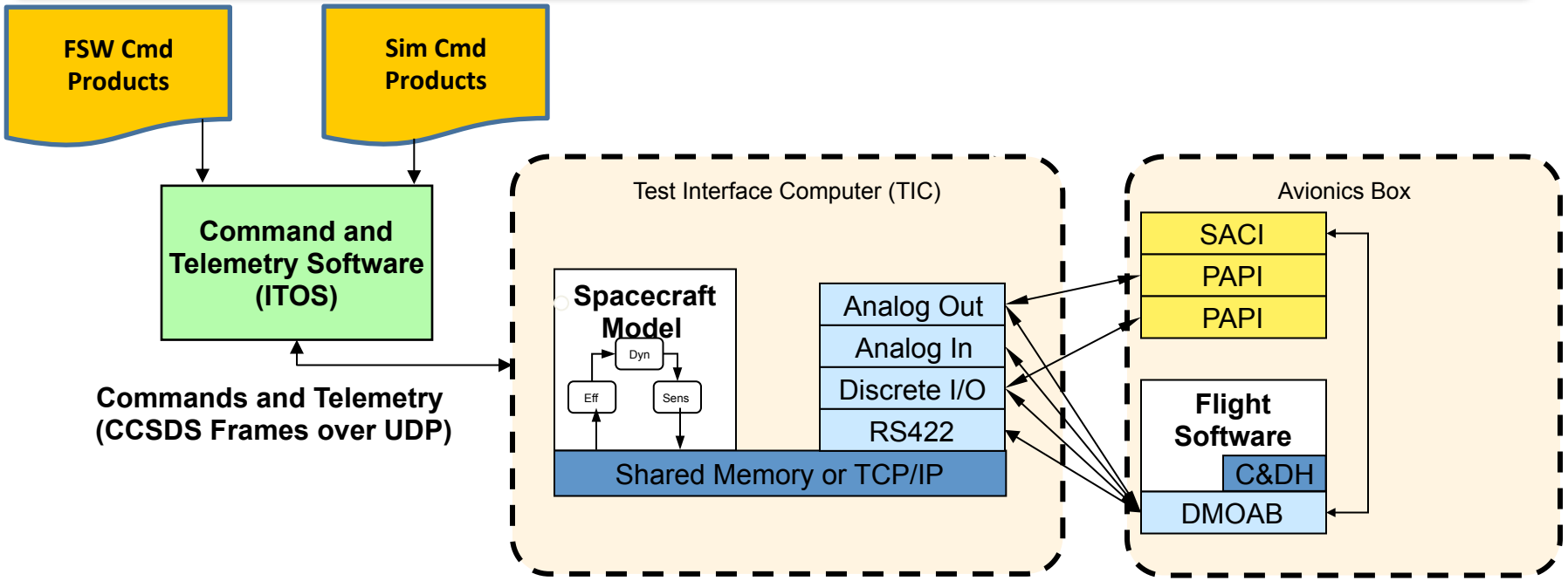
- Simulink Only - No Autocoded or Handwritten Software (cFE/cFS, TO, CI…)
- GN&C, Prop, Thermal, Power Models –Control and Plant
- Reads & Interprets ATS Source and STOL Proc Scripts
  - Limited functionality (eg. No Limit Checker Cmds)
- Outputs simulator data and fsw telemetry (not CCSDS packets) to file for post processing and analysis

PIL



- Models autocoded and running on RT processors with Handwritten Software (cFE/cFS, TO, CI…). Includes all FSW functionality.
- Inexpensive "flight-like" processor
- Utilizes ITOS
  - FSW C&T Interface (full dictionary)
  - Simulator Interface
  - CCSDS Frames over UDP
  - Can be separate workstations: Flight Controller, Sim Controller

HIL



- Models autocoded and running on RT processors with Handwritten Software (cFE/cFS, TO, CI…). Includes all FSW functionality.
- Utilizes IAU EDU with "flight-like" interfaces.
- Utilizes ITOS
  - FSW C&T Interface (full dictionary)
  - Simulator Interface
  - CCSDS Frames over UDP
  - Can be separate workstations: Flight Controller, Sim Controller

Simulator Uses in Ops

Use	Description	Simulator
Tactical Cycle	**Provide an accurate simulation for verification of maneuver plans during flight phase**	• **WSIM**: Verification of ACS aspects of command products. Spacecraft anomaly analysis. • **PIL**: Verification of maneuver plans. • **HIL**: Spacecraft anomaly troubleshooting.
Development	**Pre-flight verification of command sequences and ground procedures, troubleshooting during both development and flight phases**	• **PIL**: Verification of spacecraft command sequence templates and ground procedures • **HIL**: Verification of products that contain hardware-type commanding .
Training	**Provide a realistic flight environment to support SIMs and ORTs**	• **PIL**: Thread tests of operations procedures. • **HIL**: ORTs and Rehearsals.

DEVELOPMENT AND TESTING OF MISSION OPS PRODUCTS

Ops Testing with Simulators

Product	Description	Simulator Use
Utility STOL Procedures	Scripts used in command plans executed by Operations Command Controller. Also used by systems team to process flight data.	• Script unit tested and peer reviewed on **PIL** or **HIL**. • Most script exercised in Sims or ORTs
Ops Utility RTS	Pre-defined relative time command sequence files can be used in ATS or command plans. Ops RTSs developed by S/C engineers.	• Ops RTSs unit tested and peer reviewed on **PIL** or **HIL**.
ATS Templates	Common sequence of commands for repeated tasks such as maneuver sequence or Com profile.	• Developed and tested on **PIL** or **HIL** • Verified during **SIMs** and **ORTs**

Example ATS/RTS

Absolute Time Sequence

```
2013-152-00:29:59 /EVS_USRMSG MESSAGE="Beginning DeltaV Transition"

; use nominal gains (as opposed to rcs rate damping gains). applies to both off and on-pulsing rcs mo
; this is default gain setting, but ensure that the correct gains are used
2013-152-00:30:00 /acs_select_rcs_cont_gain_set gain_set=RCS_NOMINAL

; set OCS burn dur in milliseconds; does not start incrementing until fire command is given
;; assume for this example that burn duration is 60 seconds
2013-152-00:30:00 /act_set_ocs_thr_dur dur=60000

; *** NEW COMMAND: set duration for RCS thrusters off-pulse settling burn ***
; granularity is 100 milliseconds, units are milliseconds
; settling burn needs to be (at least) 20 seconds, want OCS burn to start 2 seconds after settling b
; and want change to on-pulsing to occur 100 milliseconds after start of OCS burn
2013-152-00:30:00 /acs_set_rcs_off_pulse_dur dur=20100

;; ** Allow 10 minutes to verify burn attitude and burn duration by ground **

;Turn VDU On
2013-152-00:40:00 /pcs_man_cmd_id switch_id=PCS_VDU_PWR, state=PCS_SW_ON, time=0
2013-152-00:40:00 /pcs_man_cmd_id switch_id=PCS_VDU_HK_PWR, state=PCS_SW_ON, time=0

;Activate Thruster HW I/O module. Wait 1 second after powering on VDU before activating thrio
2013-152-00:40:01 /thrio_activate

; Set the RW manual command to maintain speed when entering DV mode.
; Ground can override this in the ATS after the transition executes
2013-152-00:40:01 /act_set_rw rw1=0, rw2=0, rw3=0, rw4=0, mode1=ACCEL, mode2=ACCEL, mode3=ACCEL, mode
```

Relative Time Sequence

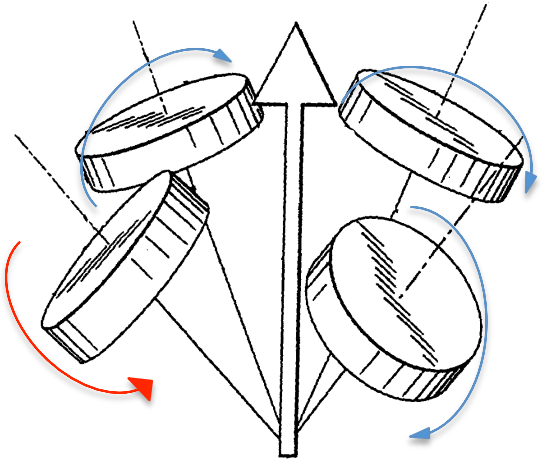
```
; Set the default ON heaters to ON
00:00:01 /tcs_man_cmd_id heater_id=TCS_LLC_SURV_HTR, state=ON
00:00:00 /tcs_man_cmd_id heater_id=TCS_UVS_PRI_SURV_HTR, state=ON
00:00:00 /tcs_man_cmd_id heater_id=TCS_UVS_RED_SURV_HTR, state=ON

;Set the default automated continuous CONTROLLED heaters to CNT
00:00:00 /tcs_man_cmd_id heater_id=TCS_LLC_STBY_HTR, state=CNT
00:00:00 /tcs_man_cmd_id heater_id=TCS_NMS_OPBO_HTR, state=CNT
00:00:00 /tcs_man_cmd_id heater_id=TCS_NMS_MEB_HTR, state=CNT
00:00:00 /tcs_man_cmd_id heater_id=TCS_NMS_RF_HTR, state=CNT
```

MISSION SIMULATIONS

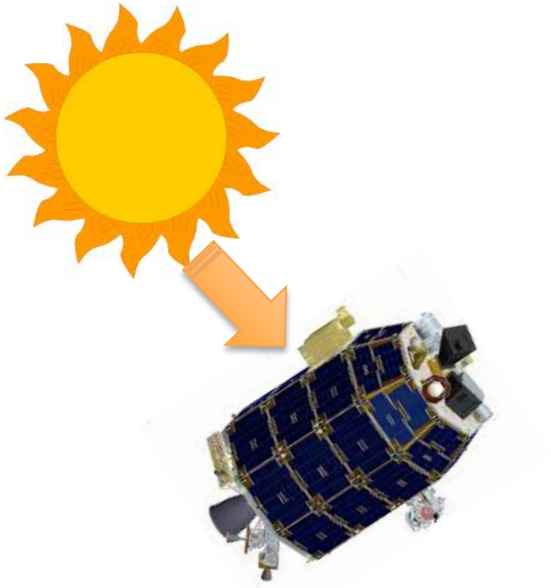
Mission Simulations

- Train and certify operators during Operation Readiness Testing (ORTs)
  - HIL used to simulate nominal operations for
    - Launch and Activation
    - Phasing Loop Maneuvers
    - Lunar Orbit Insertion (LOI)
    - 5 Day Science Orbit + Orbital Maintenance Maneuver
  - Spacecraft Anomalies injected to test operator response
  - Simulation runs 24 hours a day and events happen and same time of day as flight.

Example Fault Injection



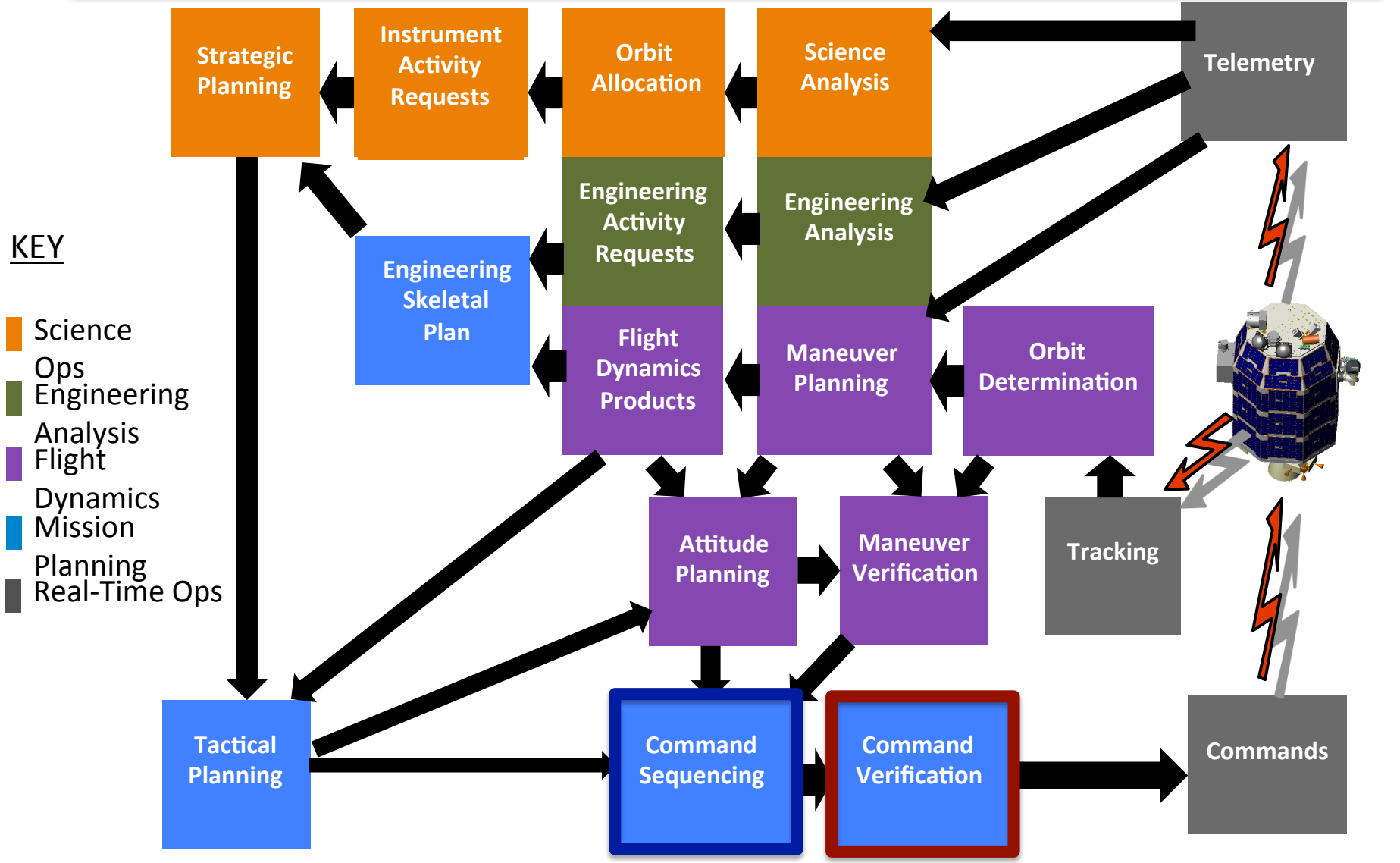
- Launch and Spacecraft Activation simulation
  - Polarity of 1 reaction wheel reversed during sim initialization.
  - Faulty wheel spun up to top speed causing 3 other wheels to try and counteract.
  - S/C unable to control attitude, one side “stuck” facing sun causing temps to increase



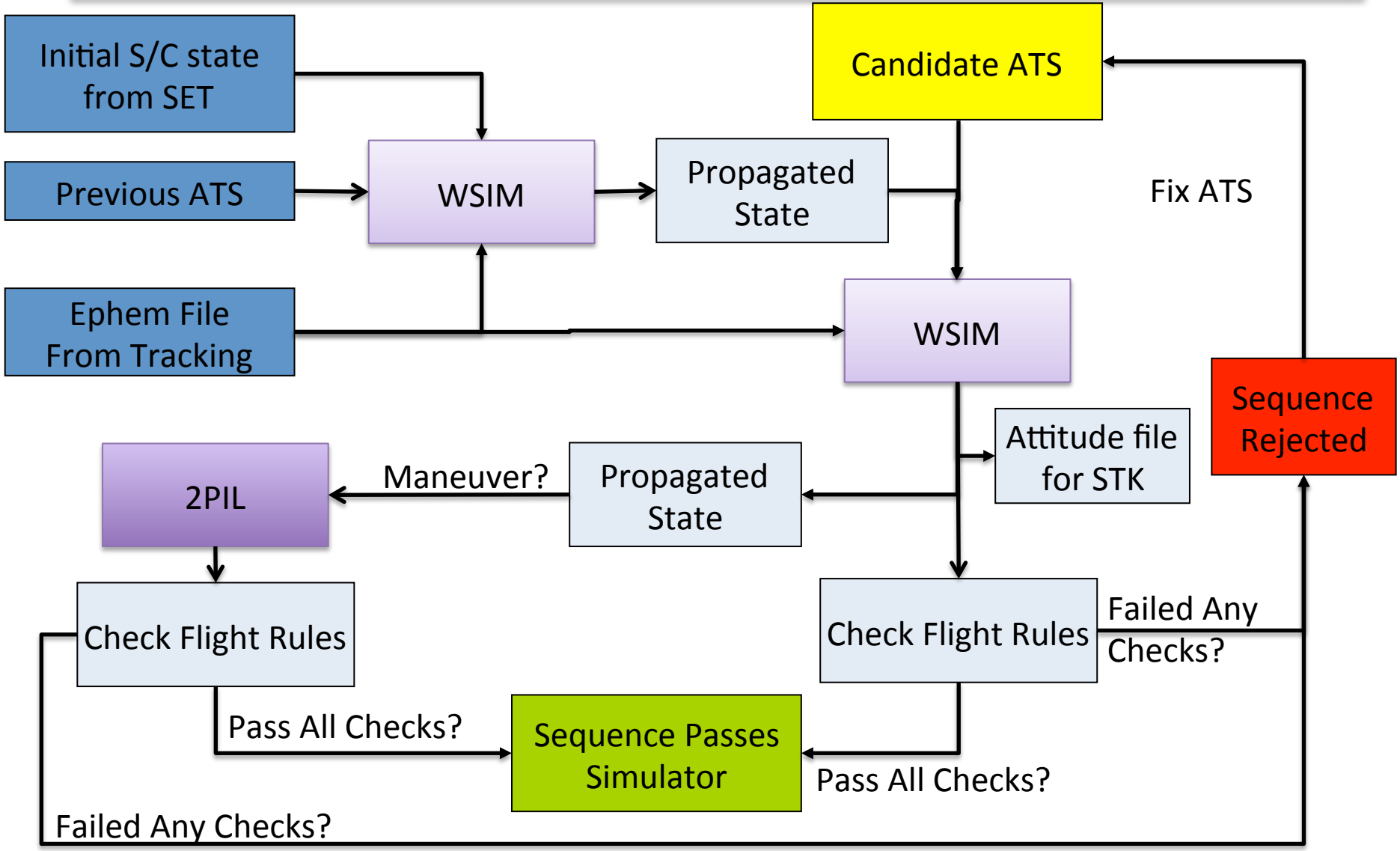
- On Actual Launch Day
  - Reaction wheel fault detection treated nominal behavior as anomalous and turned off all RWs
  - S/C unable to control attitude, one side “stuck” facing sun causing temps to increase
  - Cause of anomaly was different, but resulted with similar issues for flight team.

UPLINK VERIFICATION

Science Phase Ops Overview

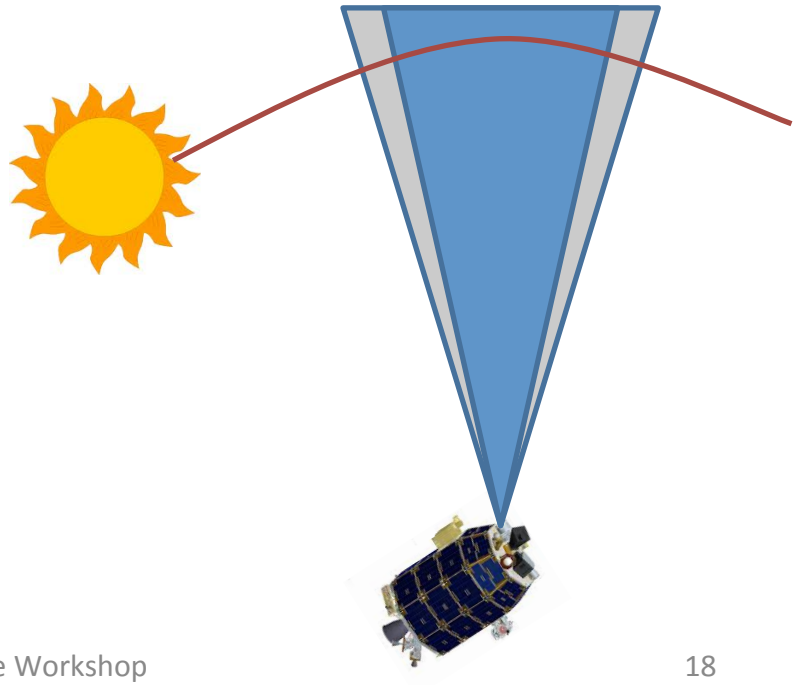


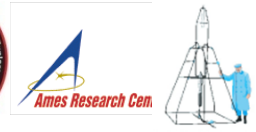
Simulation Verification Workflow



Example FR Check by WSIM

- FR-PL-LDEX-006 : LDEX Solar Pointing Constraint
  - LDEX's Micro Channel Plate is sensitive to UV light, high voltage should be disabled when the sun is in the instrument FOV.
  - The Rule: LDEX instrument high voltage will be powered off at least 120 seconds before the sun is predicted to be within the instrument field of view (169 degree cone) and off for at least 120 seconds after the predicted time when the sun leaves the instrument field of view
  - Static Flight Rule Checker does not know where the sun is relative to the LDEX boresight
  - WSIM models sun position, sun in sight, S/C attitude, and instrument power cycles
  - Post processing script checks
    1. Power on times for LDEX + buffer time
    2. Is the sun in view at these times or is it blocked by the Moon?
    3. Is the angle between the sun and LDEX boresight less than the half angle of the LDEX FOV at these times?

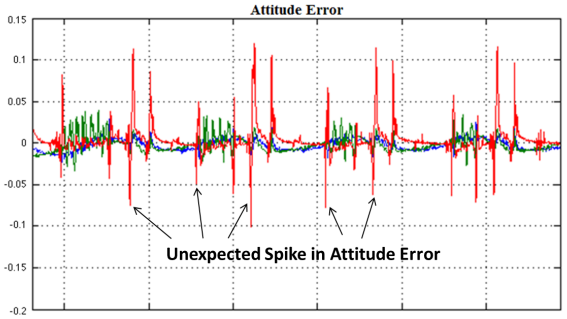


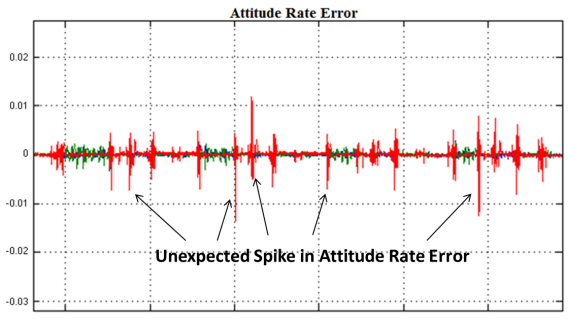



EXAMPLES FROM FLIGHT

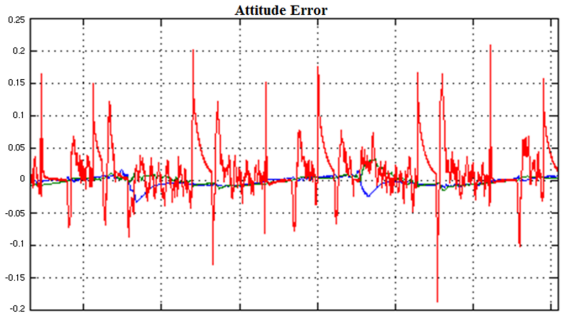
Debugging Star Tracker Anomaly

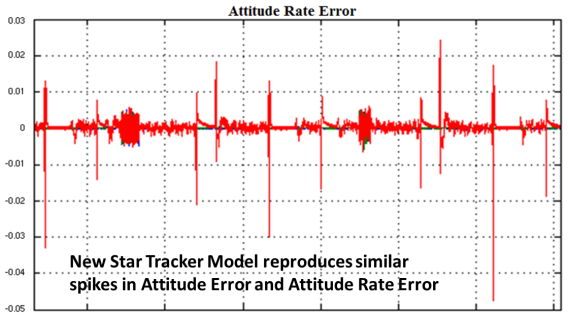
Flight Data



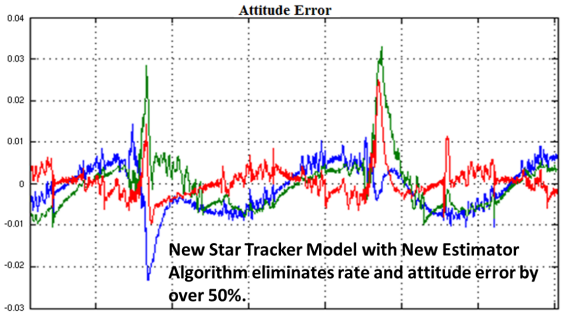


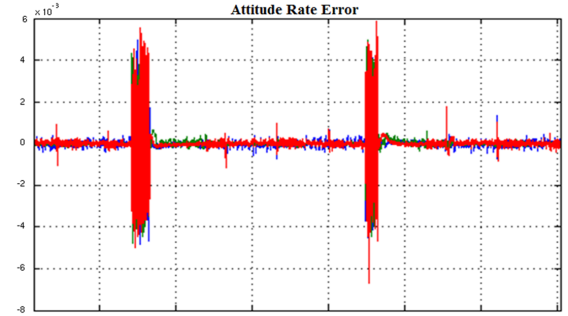
Simulation with New Star Tracker Model

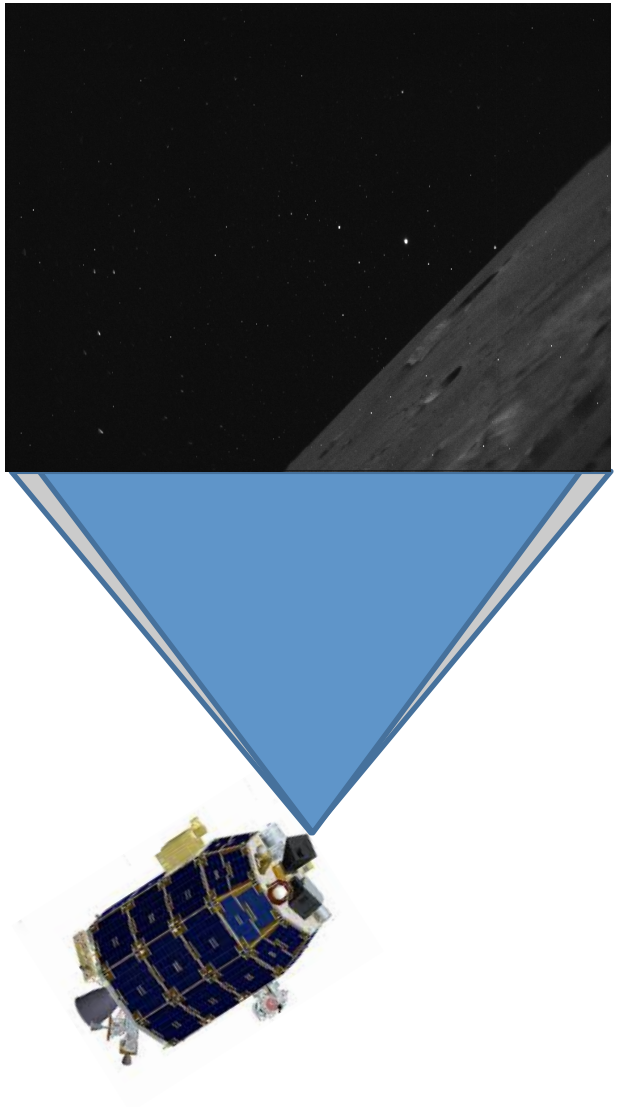




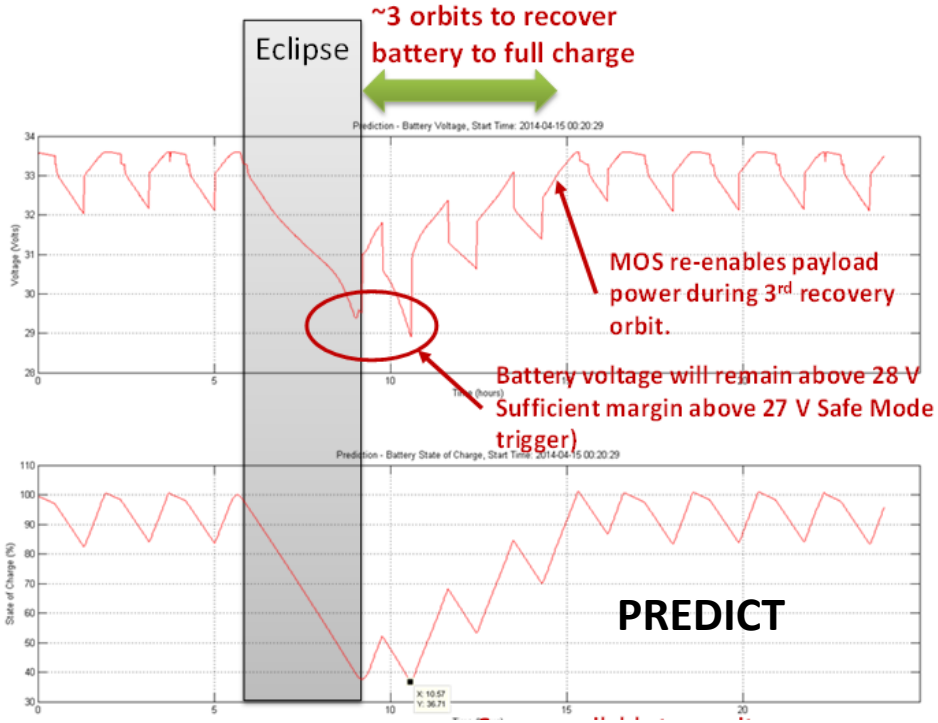
Simulation with New Star Tracker and New Estimator Models

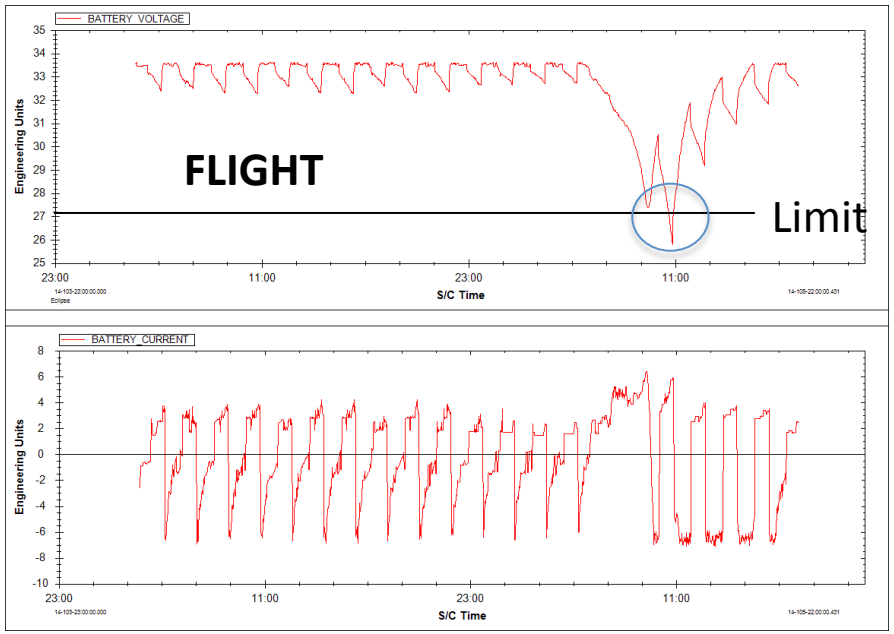






Power/Thermal During Eclipse





- Predicted Heater Power usage from thermal team model was 35W, actual was 93W
- Discrepancy due to out of date heater set points and invalid assumption of constant battery voltage
- WSIM model predicted safe mode due to low battery voltage to within 15 min of actual safe mode event.
- Integrated multi-domain model can identify invalid assumptions and out of date parameters.

CONCLUSIONS

Conclusions

- Design & Analysis environment is merged with the FSW Development & Verification environment means updates are immediately available.
- PIL and HIL simulators from auto-code create higher fidelity simulations for full onboard software and a tool for testing MOS products
- Using the same telemetry interface as Operations and I&T allows simulator reuse and early testing
- Ability to test software by injecting ”faults” provides a natural interface for the Operations Test Conductor to train mission operators.
- WSIM can be used as a fast-time tool to debug flight anomalies and verify flight commands prior to upload.

Future Work

- Rigorous comparison flight data and simulator performance
- Adapt simulator for future missions and generalize if necessary for reusability
- Take advantage of improvements and new features of Simulink