



Jon McBride Software
Test and Research

Lunar Environment Monitoring Station for Artemis-3 (LEMS-A3)

FSW Design, Development, and Testing Using a Digital Twin

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Jon McBride Software Test and Research (JSTAR)

- ❖ Digital Twin Development Team
- ❖ Risk Reduction Testing
- ❖ Simulation and Software Services



Mission	Platform
Integrated Tri-Program Simulation	ARRISTOTLE
Mars Sample Return, CCRS	CHASE
Europa Clipper	ECHOES
Gateway	Gateway-in-a-Box
Exploration Ground System (EGS)	GS2
HLS	HOOTLE
James Webb Space Telescope (JWST)	JIST
GSFC SmallSat Product Line	NOS3
Psyche	PHASE
Space Launch System	S3
Multi-Purpose Crew Vehicle (MPCV)	SOCRATES
LM Product Line	Soft Sim
Roman Space Telescope (RST)	WISP

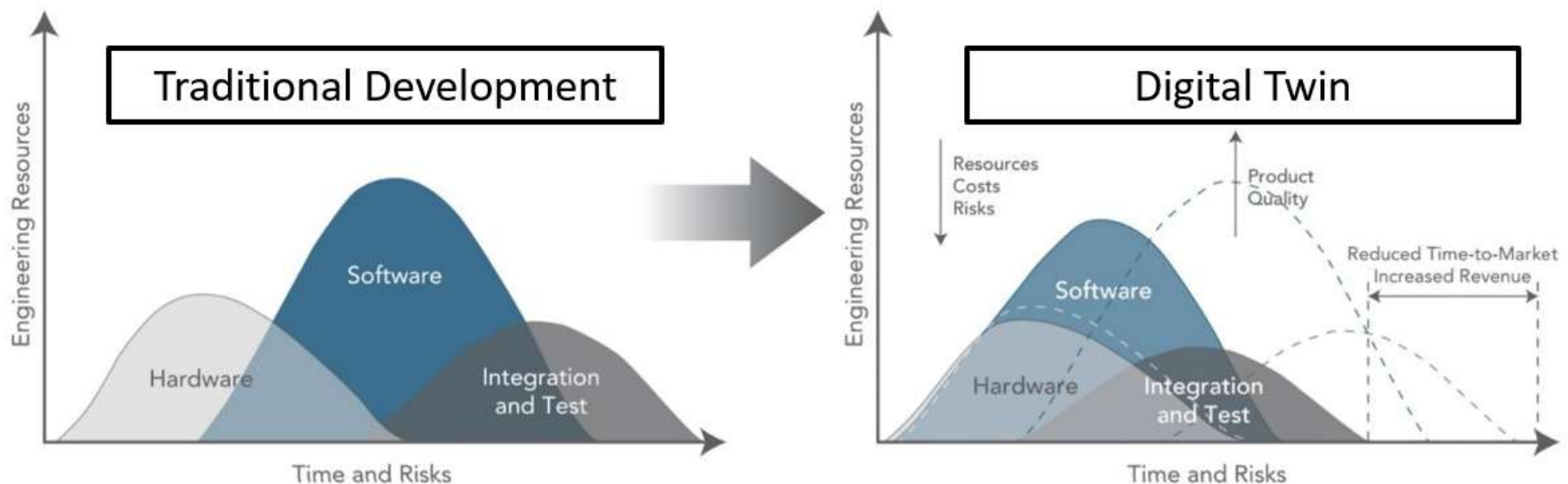


Captain Jon McBride was West Virginia's First Astronaut



Digital Twin Software Development and Testing

- ❖ Digital twins shift the traditional software development cycle
- ❖ Digital twins greatly increase test resources and opportunities



- ❖ [NASA Operational Simulator for Small Satellites \(NOS3\): The STF-1 CubeSat Case Study](#)

- ❖ Dustin M. Geletko, Matthew D. Grubb, John P. Lucas, Justin R. Morris, Max Spolaor, Mark D. Suder, Steven C. Yokum, Scott A. Zemerick

LEMS Introduction

The Lunar Environment Monitoring Station ([LEMS](#)) is a GSFC compact, autonomous, and self-sustaining seismometer suite designed to carry out continuous (day and night) monitoring of the lunar seismic environment at the South Polar region. [[Source](#)]



- ❖ Targeting the Artemis-III Mission – Mid-2027
- ❖ It is a self-powered, self-managed, and self-communicating flight system.
- ❖ It conducts science observations on the lunar surface continuously (day and night).
- ❖ It is fully autonomous, requires no assistance from Artemis crew beyond deployment.
- ❖ Is one of the first Artemis Missions and thus is a pathfinder for Astronaut device deployment
- ❖ This data will help scientists better understand the lunar crust and mantle, shedding light on the Moon's formation and evolution
- ❖ With the data retrieved from LEMS scientists will be able to characterize the structure of the local crust and mantle.



Team members during the final preparation of the Lunar Environment Monitoring Station (LEMS) engineering units for thermal-vacuum testing. During this test the LEMS prototype was subjected to the ultra-high vacuum and harsh thermal conditions that mimic the surface of the Moon to demonstrate the station can sustain itself and operate unassisted for long durations. (Photo Credit: NASA MSFC) [[Source](#)]



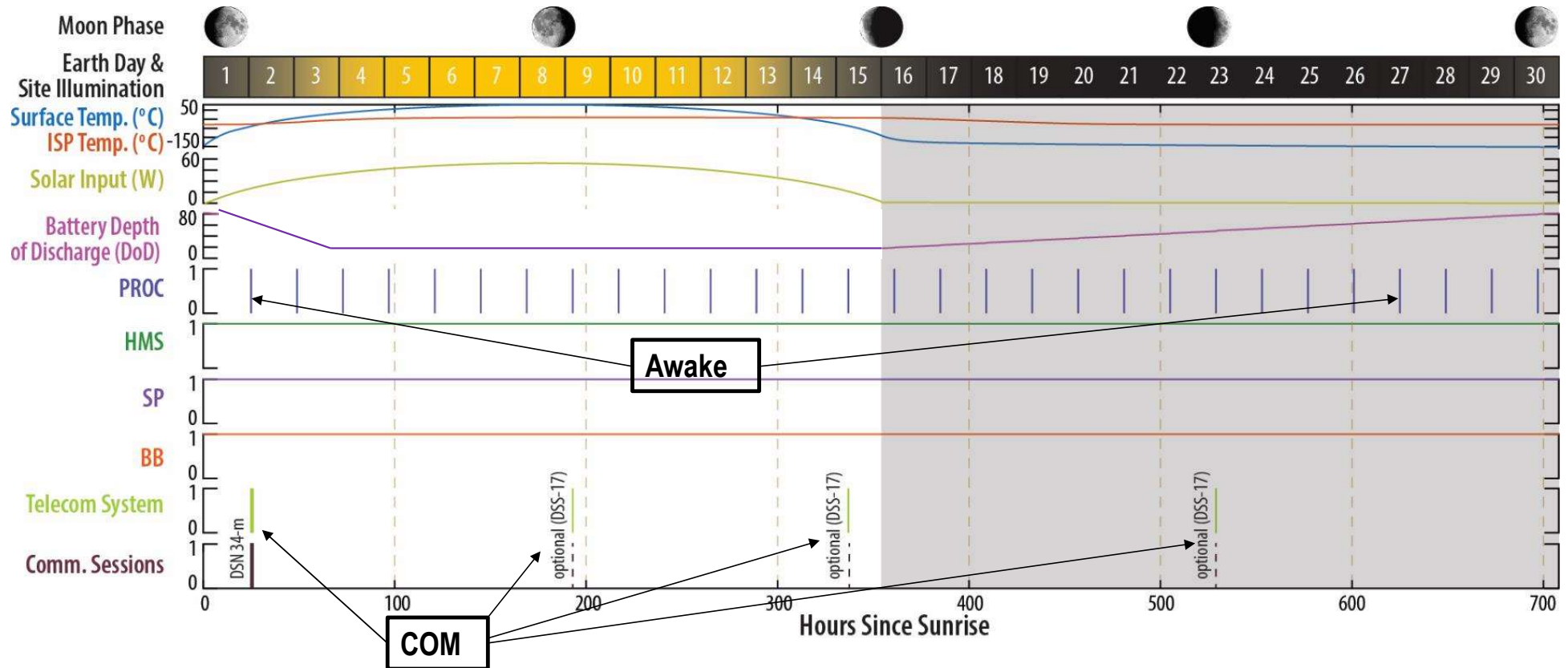
LEMS Introduction



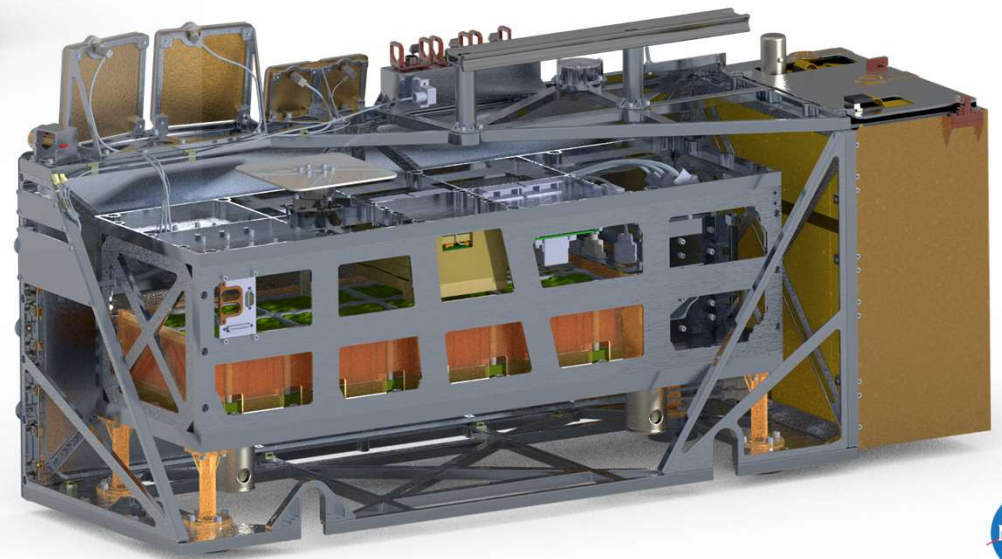
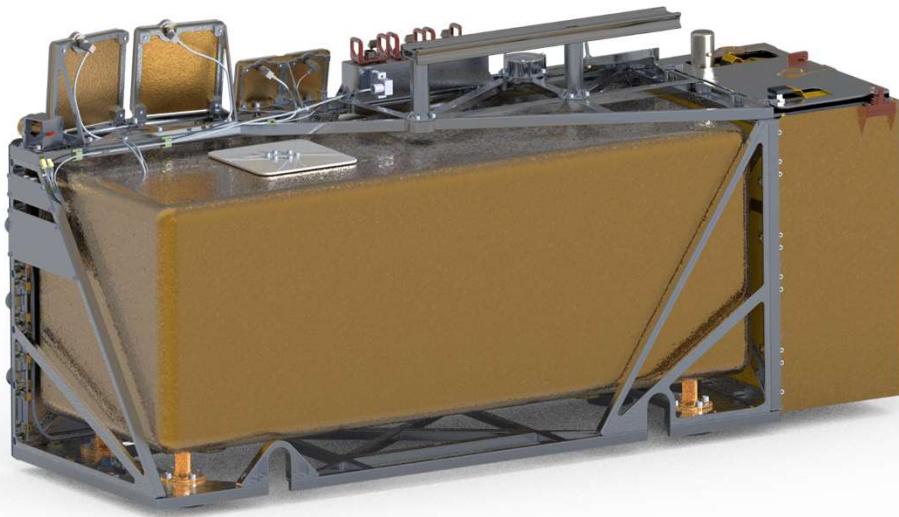
Artist's concept of an Artemis astronaut deploying an instrument on the lunar surface.
(Photo courtesy of NASA)
[\[Source\]](#)



LEMS Nominal Science Operations



LEMS System Overview



LEMS System Overview

Avionics

Processor Card (PROC)

RTG4 FPGA

16GB Flash

GPIO, I2C,
SPI, UART

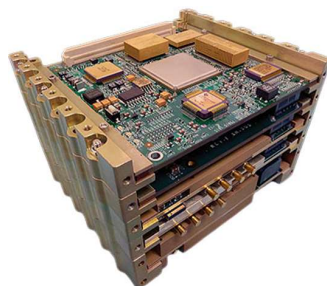
Hibernation Management System (HMS)

ProASIC3
FPGA

8GB Flash

24-bit ADC

Communications – IRIS Radio [\[Source\]](#)



❖ Processor Card (PROC)

- ❖ RTG4 FPGA with LEON3FT software, FPU
- ❖ 16GB NVRAM, 16MB SRAM, 1MB EEPROM
- ❖ RTEMS 5.1, cFS Draco-RC4

❖ Hibernation Management System (HMS)

- ❖ GSFC Developed
- ❖ Performs Data Management and Logging
- ❖ Operates Independently of the PROC

Power – Ibeos Electrical Power System (EPS)

[\[Source\]](#)



Instrumentation

Short Period (SP) Seismometer

Electronics

3 axis
sensing

Sonde

Very Broad Band (VBB) Seismometer

Electronics

3 axis
sensing

Sonde



LEMS Flight Software Overview

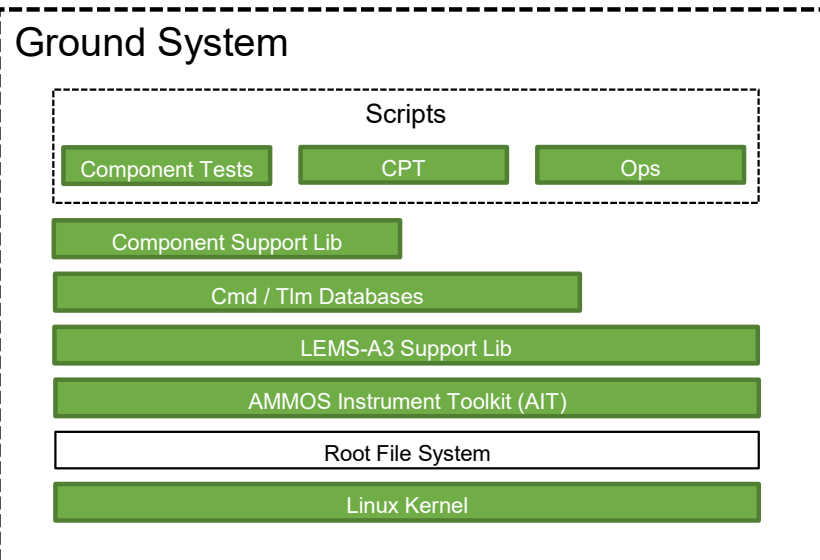
- ❖ Compliance with NPR7150.2D – Class C Flight Software – Not Safety Critical
- ❖ core Flight System (cFS)
 - ❖ Standard heritage cFS services and applications
 - ❖ Time services and distribution
- ❖ Command (CMD)
 - ❖ Receive and Ingest Commands
 - ❖ Enable uploads of new flight software while operating
 - ❖ Compliance with NASA STD-1006A for authenticated commanding
- ❖ Telemetry (TLM)
 - ❖ Produce live data upon request
 - ❖ Logging and management of various data types
 - ❖ CFDP Class 2 files transfers to the ground
- ❖ Fault Detection and Correction (FDC)
 - ❖ CPU hogging and utilization reporting
 - ❖ Uploading of applications / libraries
 - ❖ Watchdog monitoring



CryptoLib

LEMS Flight Software Overview

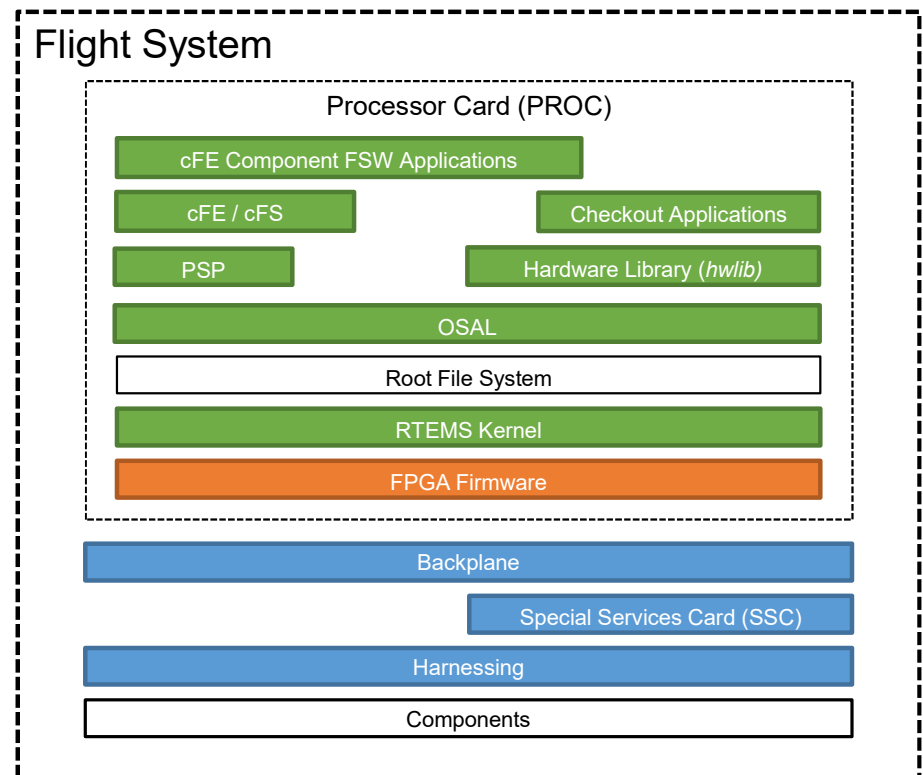
Ground System



Legend



Flight System



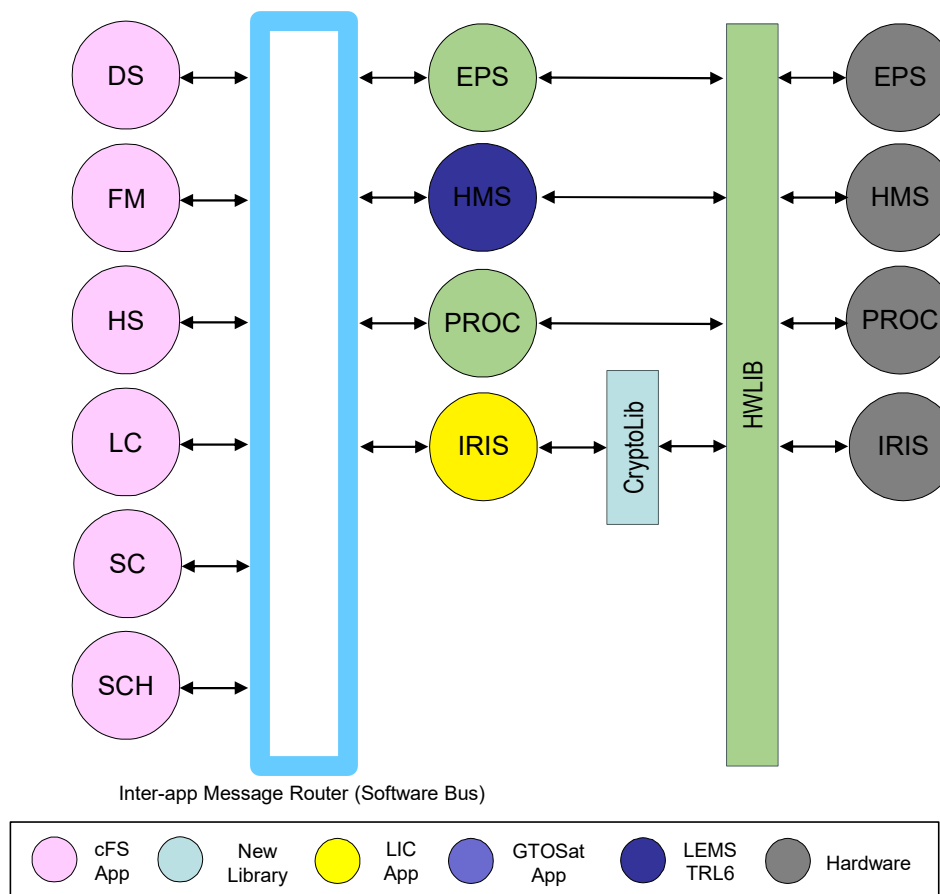
LEMS Flight Software Overview

❖ cFS Standard Applications

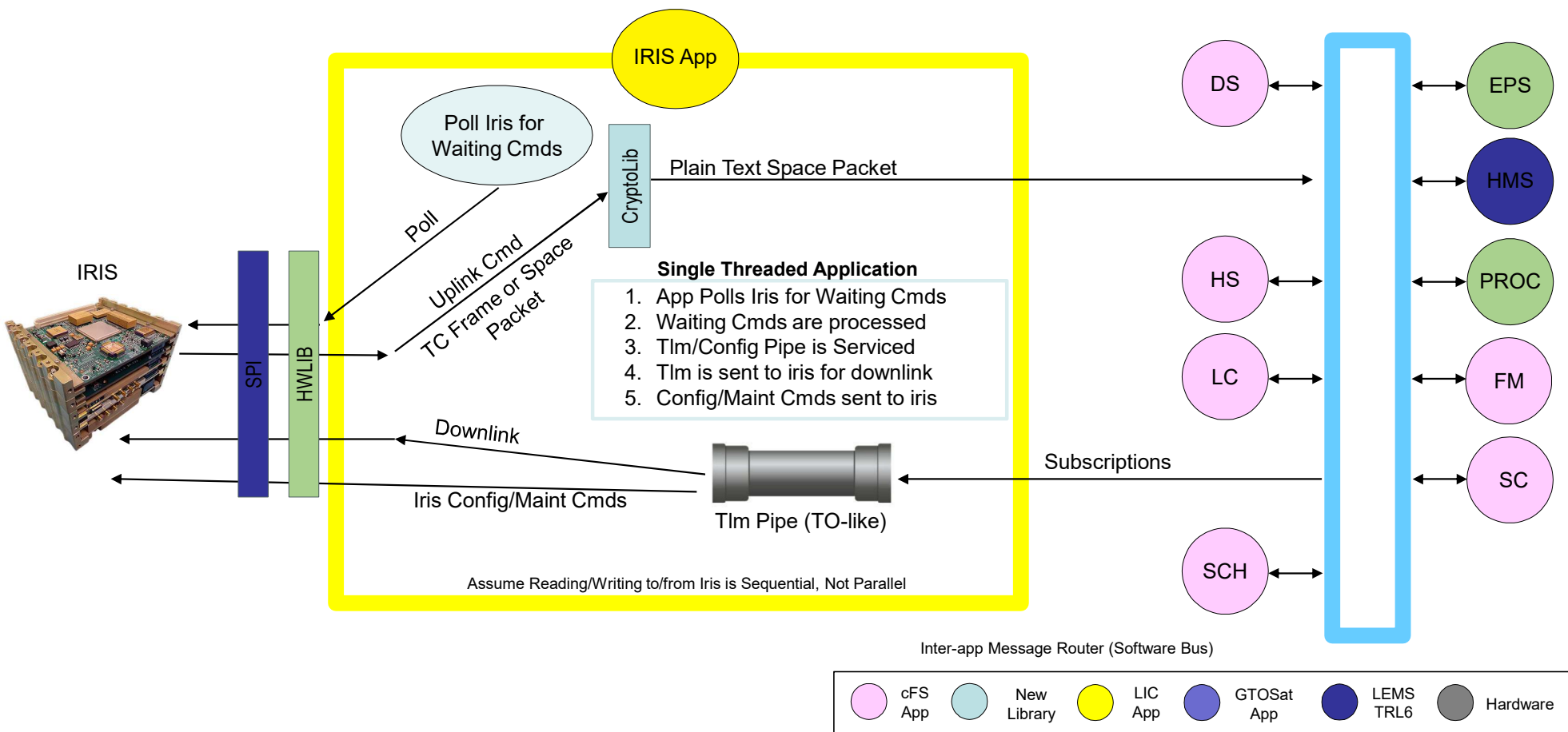
- Data Storage (DS)
- File Manager (FM)
- Health and Safety (HS)
- Limit Checker (LC)
- Stored Commands (SC)
- Scheduler (SCH)

❖ Component Applications

- GTOSat Heritage
 - Electrical Power System (EPS)
 - Processor (PROC)
 - Hardware Library (HWLIB)
- Lunar Ice Cube (LIC) Heritage
 - IRIS Radio
- TRL6 LEMS Heritage
 - Hibernation Management System (HMS)
- New
 - CryptoLib
 - STEIM2

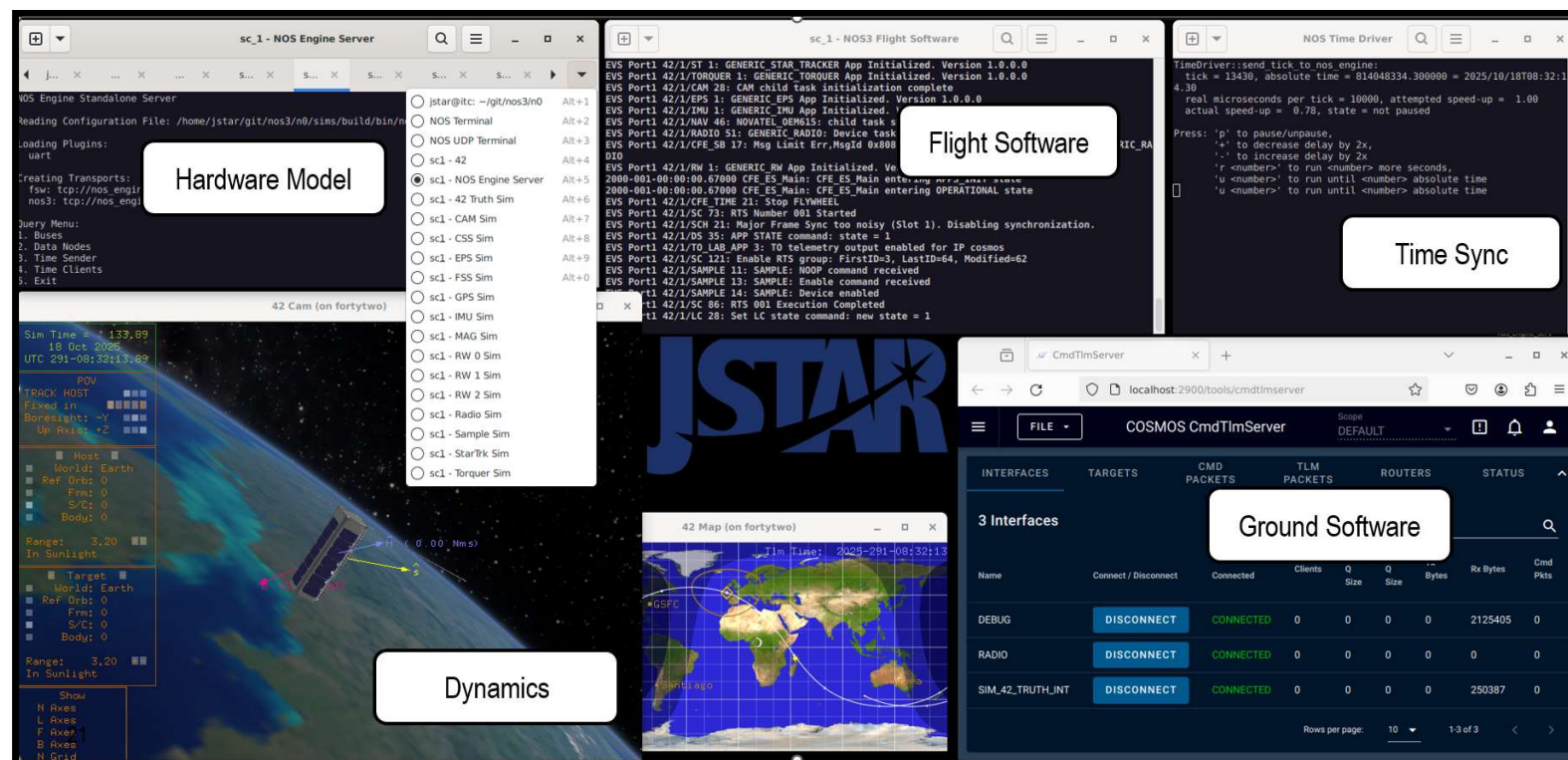


Iris App Architecture



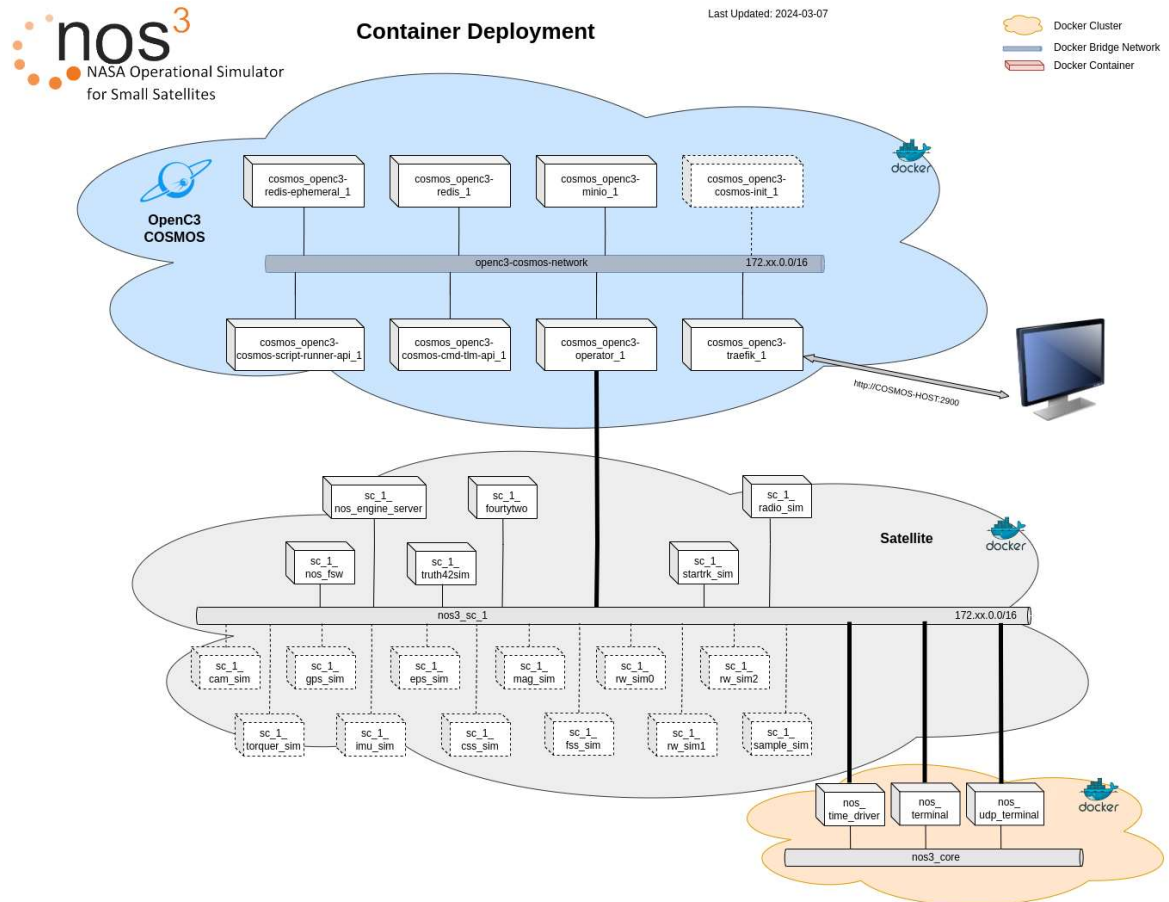
NASA Operational Simulator for SmallSats (NOS3)

- ❖ Virtual Spacecraft
- ❖ Flight Software
 - ❖ F-Prime, cFS
 - ❖ YAMCS Ground System
- ❖ Ground Station Software
 - ❖ Ball Aerospace COSMOS
 - ❖ YAMCS
- ❖ Dynamics / Visualization
- ❖ Component Simulators
 - GPS
 - Magnetometer
 - IMU
 - EPS
- ❖ Containerized



NOS3 Roadmap

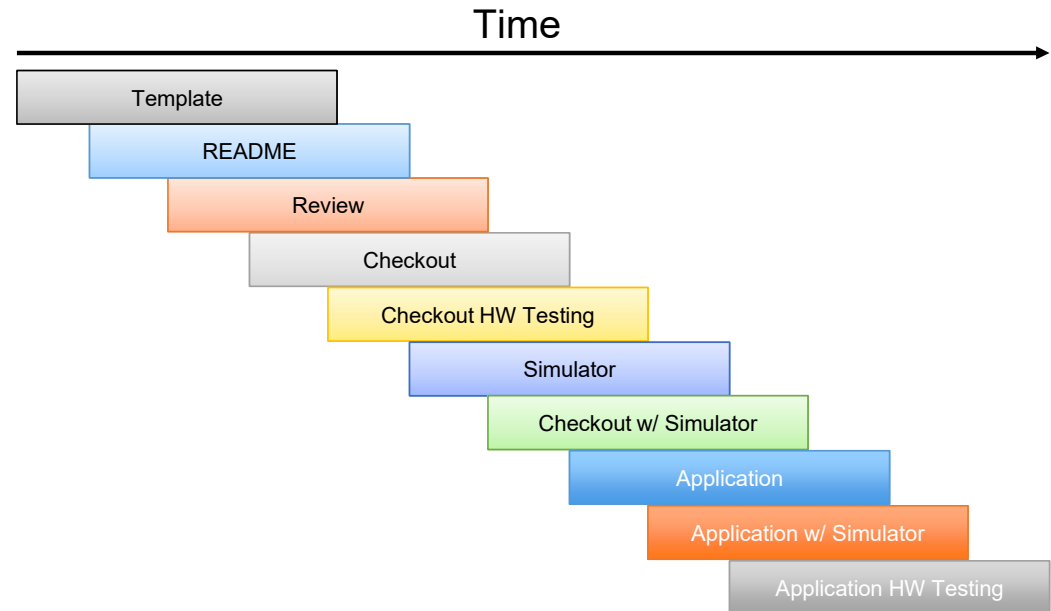
- ❖ Moving Toward NASA Operational Simulator (NOS)
- ❖ Utilized for All Missions – Not Only SmallSats
- ❖ Incorporating Processor Level Emulation from JSTAR Experience
 - ❖ Higher-Fidelity for Testing
 - ❖ Serves as Integrated Software Development and Testing Environment for All Targets
- ❖ Serves as Research and Development Test Bed for Raising TRL of Technologies
- ❖ NOS3 is a Pathway to On-Orbit Experimentation



Current Docker Architecture (courtesy of contributor B.J. Kowalski)

LEMS and NOS3: Development Workflow

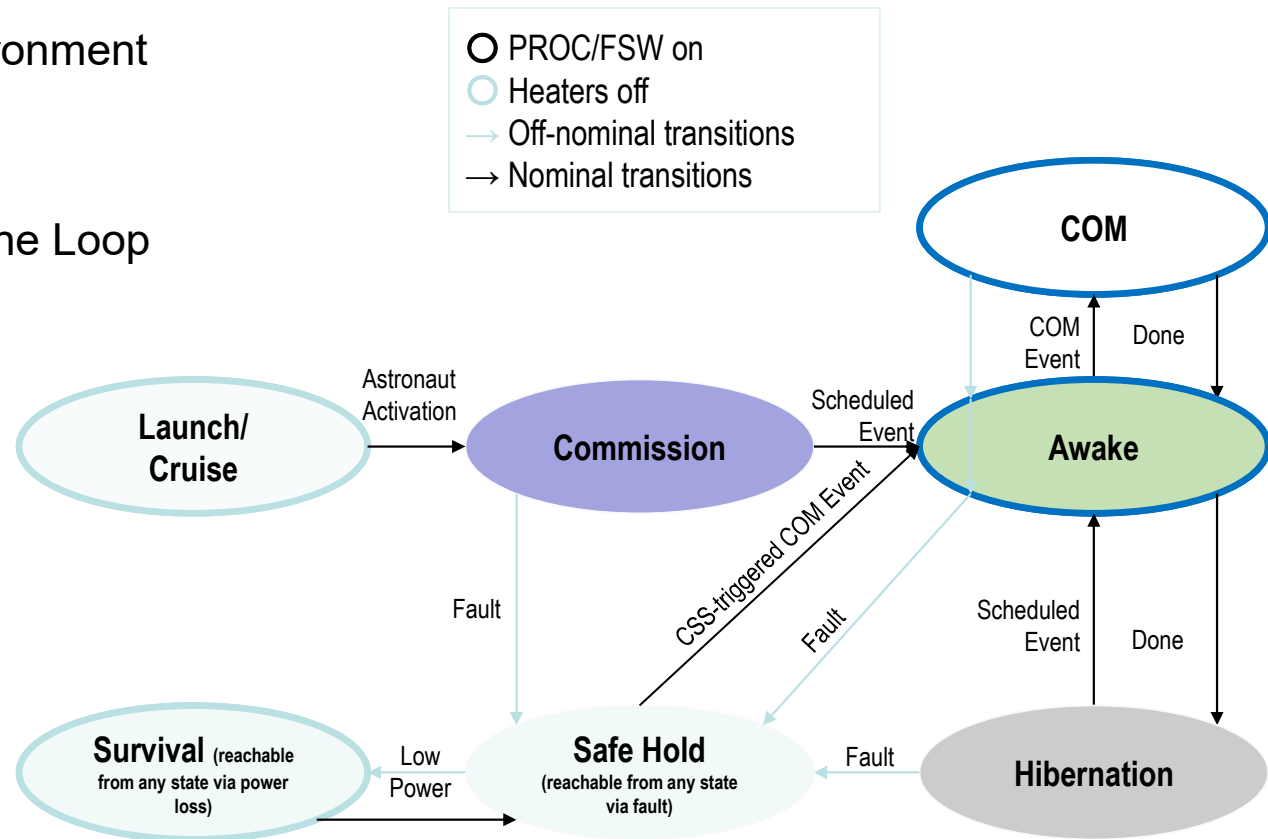
- ❖ LEMS Specific NOS3 Simulators Developed in Parallel with the Flight Software
 - Mission Customization
 - Example: Iris Radio Simulator + Iris cFS Application
- ❖ All Component Code Stored in Single Repository
 - App and Simulator Source “Near Each Other” to Ease Maintenance (Lesson Learned)
- ❖ LEMS / NOS3 Component Development Workflow
 - Leverage Templates for Starting (Part of NOS3)
 - Develop Standalone Checkout Software
 - Used for Simulator Development and Hardware / FlatSat Checkout
 - Workflow Ends with cFS App Working with Simulator and Hardware
 - Includes *TVAC Checkout Software* Automatically in the Development Workflow



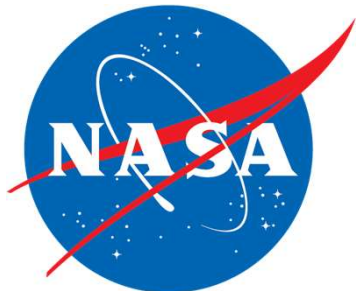
LEMS and NOS3: Integrated Dev/Test Environment

❖ Integrated LEMS Development Environment

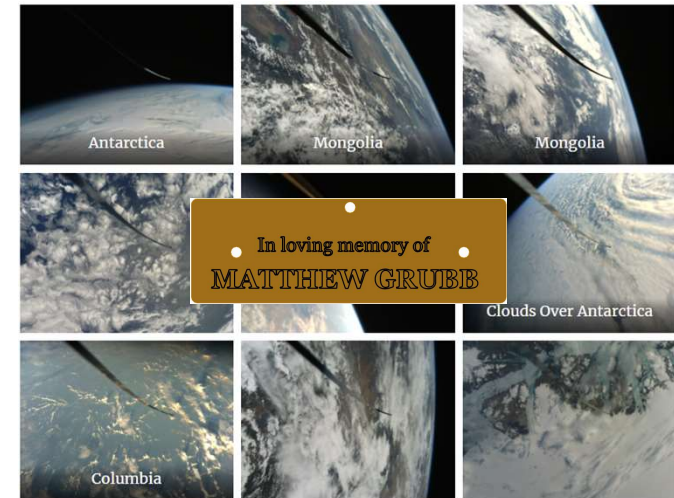
- cFS + LEMS Applications
- Capable of Mode Testing
- LEMS Ground Station Software In the Loop
- Flight Software V&V
 - Unit Tests (Automated)
 - Integration Tests (Automated)
- Operations Testing
 - Commissioning Scripts
 - Nominal Spacecraft Operations
 - File Uploads / Downloads



Questions?



IV&V



<http://stf1.com/news/?m=202212>



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