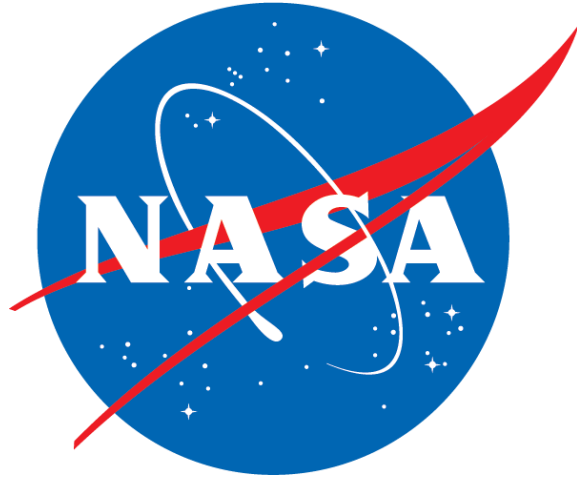




IV&V



Jon McBride Software
Test and Research

Software Digital Twins

*“The most valuable spacecraft component
that never leaves earth”*

Justin R. Morris, Katherine Johnson IV&V Program, JSTAR Lead

John P. Lucas, Katherine Johnson IV&V Program, Deputy JSTAR Lead

6/17/2025

Jon McBride Software Test and Research

➤ **Digital Twin Development Team**

- Team focused on the acquisition, development, deployment, and maintenance of test environments to support independent testing

➤ **Risk Reduction Testing**

- Directly support and work alongside development and verification teams to identify, execute, and record the results of independent tests

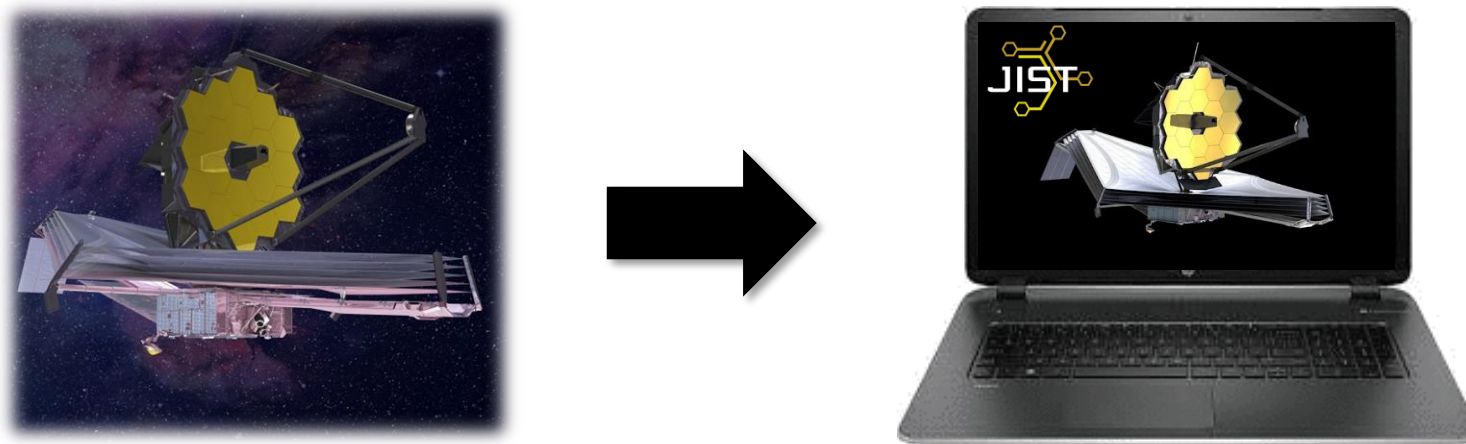
➤ **Simulation & Software Services**

- Provide flight software and simulation services directly to NASA missions and other government organizations



Digital Twins Enabled Via Hardware Emulation

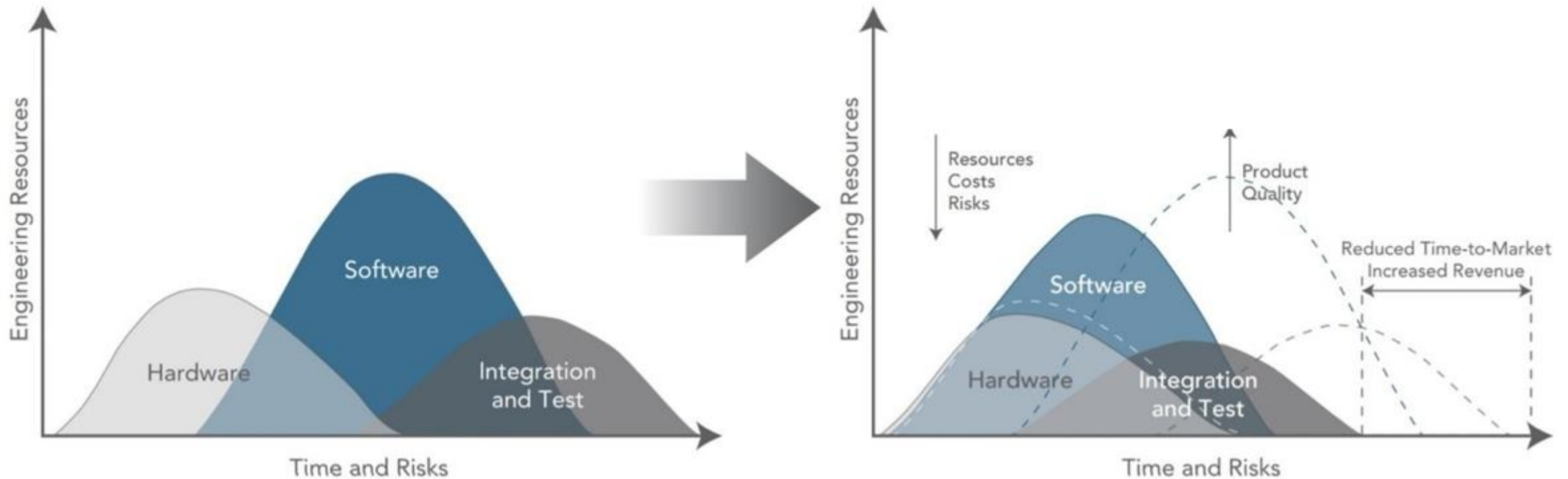
Condense entire flight system to a laptop or cloud solution



1. Flight computer hardware is **emulated**
2. Sensors / actuators are simulated
3. Flight software binaries executed as delivered
4. Ground operations software integrated as-is

Digital Twin Benefits

1. Digital twins shift the traditional software development cycle
2. Digital twins greatly increase test resources



[Shifting Left—Building Systems & Software Before Hardware Lands \(intel.com\)](#)
[NOS3: The STF-1 CubeSat Case Study](#)

Which disciplines benefit?

Developers

Software development environment
Early development opportunities before hardware arrives

I&T

Enables end-to-end testing early
Manipulate hardware models

Operations

Dry-run scenarios
Day in the life testing

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Increases available test resources
Code coverage
Exploratory testing

New Personnel

Training platform that you cannot break
Easily run lab tests to demonstrate faults

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Risk reduction testing and mission assurance
Hardware modeling and fault injection

Researchers

Integrate and demonstrate new technologies

Enabling Technology Spanning Multiple Disciplines

Digital Twin Example

The image displays a collection of software interfaces for a digital twin simulation, organized into several panels:

- Hardware Model:** A window titled "sc_1 - NOS Engine Server" showing a list of simulation components. A dropdown menu is open, listing various simulation modules such as "NOS Terminal", "NOS UDP Terminal", "sc1 - 42", "sc1 - NOS Engine Server", "sc1 - 42 Truth Sim", "sc1 - CAM Sim", "sc1 - CSS Sim", "sc1 - EPS Sim", "sc1 - FSS Sim", "sc1 - GPS Sim", "sc1 - IMU Sim", "sc1 - MAG Sim", "sc1 - RW 0 Sim", "sc1 - RW 1 Sim", "sc1 - RW 2 Sim", "sc1 - Radio Sim", "sc1 - Sample Sim", "sc1 - StarTrk Sim", and "sc1 - Torquer Sim".
- Flight Software:** A window titled "sc_1 - NOS3 Flight Software" displaying a log of system initialization and operational status. It includes messages like "EVS Port1 42/1/ST 1: GENERIC STAR TRACKER App Initialized. Version 1.0.0.0" and "EVS Port1 42/1/SC 73: RTS Number 001 Started".
- Time Sync:** A window titled "NOS Time Driver" showing time synchronization details, including "tick = 13430, absolute time = 814048334.300000 = 2025/10/18T08:32:14.30" and "real microseconds per tick = 10000, attempted speed-up = 1.00".
- Dynamics:** A window titled "42 Cam (on fortytwo)" showing a 3D visualization of a satellite in orbit around Earth. It includes a "Sim Time" display and a "POV" (Point of View) section with controls for "TRACK HOST", "Fixed in", "Boresight", and "Up Axis".
- Ground Software:** A window titled "COSMOS CmdTlmServer" showing a web-based interface for managing the simulation. It includes a "FILE" menu, a "Scope" dropdown, and a table of connected interfaces.

INTERFACES	TARGETS	CMD PACKETS	TLM PACKETS	ROUTERS	STATUS
3 Interfaces					
Name	Connect / Disconnect	Connected	Clients	Q Size	Rx Bytes
DEBUG	DISCONNECT	CONNECTED	0	0	2125405
RADIO	DISCONNECT	CONNECTED	0	0	0
SIM_42_TRUTH_INT	DISCONNECT	CONNECTED	0	0	250387

JSTAR – A Digital Twin Factory

Mission	Platform
Integrated Tri-Program Simulation	ARRISTOTLE
Roman Space Telescope (WISP)	WISP
Europa Clipper	ECHOES
Gateway	Gateway-in-a-Box
Exploration Ground System (EGS)	GS2
HLS Space-X	HOOTL
James Webb Space Telescope (JWST)	JIST
Open-Source Design Reference Mission	NOS3
Psyche	PHASE
Space Launch System	S3
Multi-Purpose Crew Vehicle (MPCV)	SOCRATES
LM Product Line	Soft Sim
International Space Station	MADE



Components and Products

➤ **Ground System Software**

- AIT
- AMPCS
- ASIST
- COSMOS
- ITOS
- OpenC3
- OpenMCT
- YAMCS

➤ **Communications**

- 1553
- CAN
- Ethernet
- I2C
- SPI
- SpaceWire

➤ **FSW**

- cFS
- F Prime

➤ **Processor Emulation**

- Simics
- QEMU – open source
 - GR740 / GR712
 - RAD750
 - PPC
 - Custom SoCs

➤ **Dynamics**

- Trick
- Goddard Dynamic Simulator
- Simulink
- 42

➤ **Design Reference Missions**

- NOS³

➤ **Training Packages**



High Severity Findings

Mission	Finding	Impact
Project A	Incorrect simulator code for the Right Booster Avionics Hydraulic Power Unit Controller #1 model results in a failure to activate during ALS, resulting in the vehicle entering off-nominal PAD_SAFING mode	Incorrect code in the simulator test environment HPUC model will result in essential capabilities of the Booster Avionics HPUC not being tested under nominal conditions.
Project A	Crash of the IDE or ODE partition occurred during Core Stage Flight or Core Stage Flight with Boosters, an Abort Recommendation indicating "Failure of Flight Critical Software" was not issued as required	Failure to report an abort condition will result in the loss of the FSW to report severe conditions that negatively impact mission success and safety
Project B	Inverted Gyro Data Validity Flags in Gyro Sensor Processing	Loss of Mission
Project B	Incorrect Command Hexadecimal in SCS 094 "COMM_Reset_Transponders	Loss of Communications
Project C	FSW writing to read-only register due to legacy code re-use	Incorrect hardware usage; Memory Corruption
Project C	FSW write to read-only downlink channel register fields	Incorrect hardware usage; Incorrect downlink configuration

Digital Twin Benefits

Cost Benefits

- ✓ **Enables parallel development efforts**
 - Does not block hardware availability
- ✓ Reduces physical hardware procurement costs
- ✓ Minimizes HWIL testing
- ✓ Decreases rework costs
 - Find software bugs earlier in lifecycle

Schedule Benefits

- ✓ **Accelerates development timeline**
 - Enables software testing before hardware available
- ✓ **Enables Automation (CI/CD Pipelines)**
- ✓ Reduces integration delays
- ✓ Shortens anomaly investigation time via rapid reproduction of simulated environment
- ✓ Faster flight software iteration cycles

Increased Test Opportunities

- ✓ **Increased failure scenario and edge case testing**
- ✓ Validation environment for fault management and recovery procedures
- ✓ Decreases likelihood of discovering critical issues during late integration phases
- ✓ MC/DC testing

Development Efficiency

- ✓ **Supports 24/7 automated testing**
- ✓ Reproducible test environments with consistent validation
- ✓ Facilitates knowledge transfer and training without risk to flight hardware

Digital Twins Benefit to CLDP

Mission	Description	Impact to CLDP
Accelerated Development Timeline	• Early software development before hardware availability • Parallel development approach for software and hardware • Component-based architecture for custom hardware models	• Enables commercial providers to start software development earlier • Reduces schedule risk across multiple missions • Supports diverse commercial implementation approaches
Risk Reduction through Simulation	• End-to-end testing of complex operations • Test flight software against simulated hardware failures • Validate command sequences before execution • Validate command sequences before execution • Increase TRL of flight software development, integration, and specific algorithms in a flight-like environment	• Supports commercial providers with varying flight heritage • Provides verification before costly hardware integration • Identifies potential issues before mission execution • Enables quantifiable risk assessment
Knowledge Continuity Across Missions	• Consistent training environment for operations team • Repository of verified simulation components • Standardized interfaces between NASA & commercial systems • Established pathway from simulation to flight operations	• Creates reusable assets for future opportunities • Maintains consistent processes across multiple deliveries • Facilitates knowledge transfer between missions • Establishes programmatic continuity despite provider diversity

Benefits to CLDP

1. Hardware Emulation and Digital Twin Development

- Significant QEMU (open-source) & Simics (COTS) emulation experience with high profile missions
 - Timing, Synchronization, Deployment, Containerization, Software Integration, Usability, and More
- Maintain Avionics Emulation Library and Internal CI/CD Pipeline

2. NASA Operational Simulator – www.nos3.org

- Equips vendors with complete open-source flight and ground software environment
- Offer training and/or training packages on using nos³



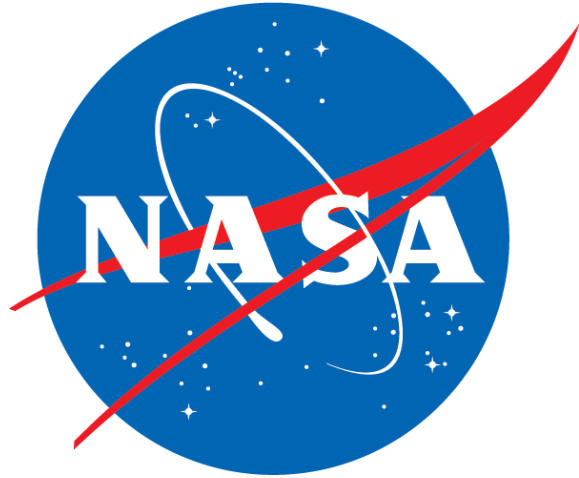
3. Risk Reduction Testing

- Memory Corruption
- Processor Resets
- Operational Testing

JSTAR In Review

- JSTAR - a digital twin factory
 - Highly flexible environments to support development and risk reduction testing
- Shift the software timeline
 - Less reliance on hardware
 - Increased test resources and opportunities
- Points of Contact
 - Justin.R.Morris@nasa.gov
 - John.P.Lucas@nasa.gov





IV&V



Jon McBride Software
Test and Research

Thank you for your time!

Increases Flight Software Insights

- Custom flight computer
 - RTEMS open-source operating system used
- IV&V developed emulator for custom flight computer
- Compared software test results from emulator to hardware test results
- Verified emulator is accurate flight computer model
- Emulator is an added software test asset that multiple mission roles can utilize

Category	Test Count	QEMU Model Results				WPC Hardware Results			
		Passed	Failed	Invalid	User Input	Passed	Failed	Invalid	User Input
Benchmarks	3	3	0	0	0	3	0	0	0
fstests	56	56	0	0	0	56	0	0	0
libtests	95	93	2	0	0	90	2	0	0
psxtests	107	106	1	0	0	106	1	0	0
psxtmtests	56	56	0	0	0	56	0	0	0
rhealstone	6	6	0	0	0	6	0	0	0
smptests	57	55	2	0	0	57	0	0	0
sptests	213	209	1	3	0	210	0	3	0
tmtests	42	41	0	1	0	42	0	0	0
Totals	635	625	6	4	0	629	3	3	0