National Aeronautics and Space Administration

The Core Flight System (cFS)

NASA quality flight software for science and exploration available to the world

Presenter:
Jonathan Wilmot NASA/GSFC
cFS Software Architect

cFS Introduction

- The core Flight System (cFS) is a software framework bundled with a suite of applications and tools created for NASA's mission of **science** and **exploration**
- Similar to Android and Apple's IOS, cFS creates a open platform for **sharing, collaboration, innovation**, and **commercialization**
- Unlike other frameworks, cFS is software written for flight systems with the reliability and process rigor required for **NASA Class A** missions while also being scalable & accessible to **student projects**

Winner of NASA 2020 Software of the Year

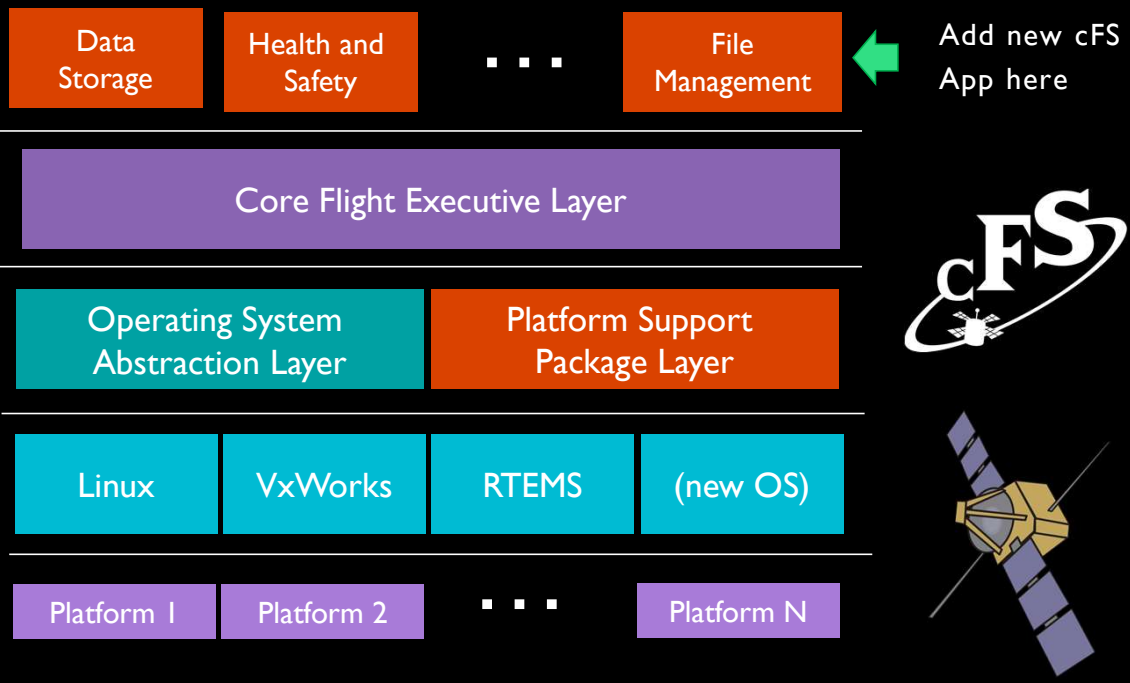
Space Applications have Unique Challenges

EXPECTATIONS	REALITY
24/7 uptime for years	Harsh environments cause transient and permanent faults
Complex autonomous/robotic systems	Processing performance a few generations old
Remote operations and maintenance	Communications at "dial-up" speeds

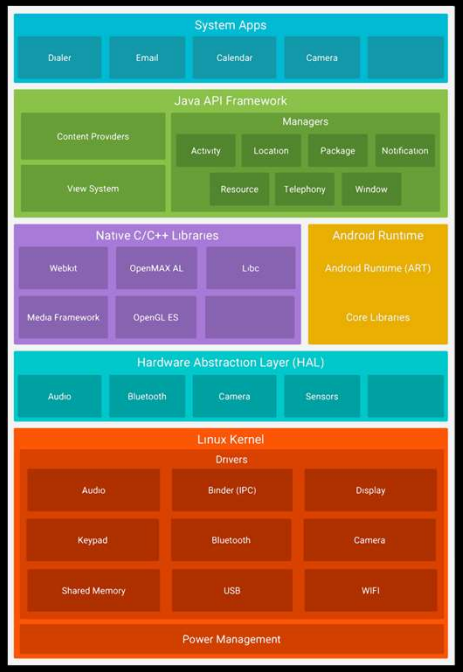
Solutions to these challenges are baked into cFS!

Layered Architecture Provides Flexibility

cFS layering is key to portability, and its wide applicability



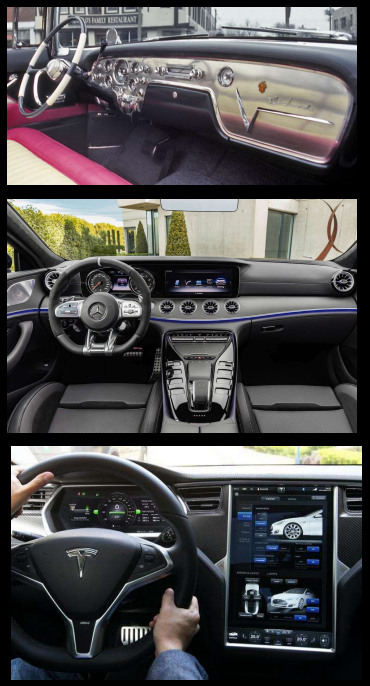
Add new cFS App here



Add new Android App here

cFS Enables a Paradigm Shift in Operations, Training, Integration and Testing Across Systems

- *How do I upload a new configuration or parameter limit?*
- All cFS services and applications have operational interfaces exposed to mission controllers, crew, and automation/AI engines
- Without cFS, each system brings its own proprietary mechanisms
- "Interoperability of systems is critical to ensure safe and robust space exploration." - ***Artemis Accords*** (May 15, 2020)
- cFS services for interoperability and commonality of operations were key to NASA including cFS in the ***"International Deep Space Interoperability Standards"*** baselined for the Artemis Program



How do I turn on the wipers?

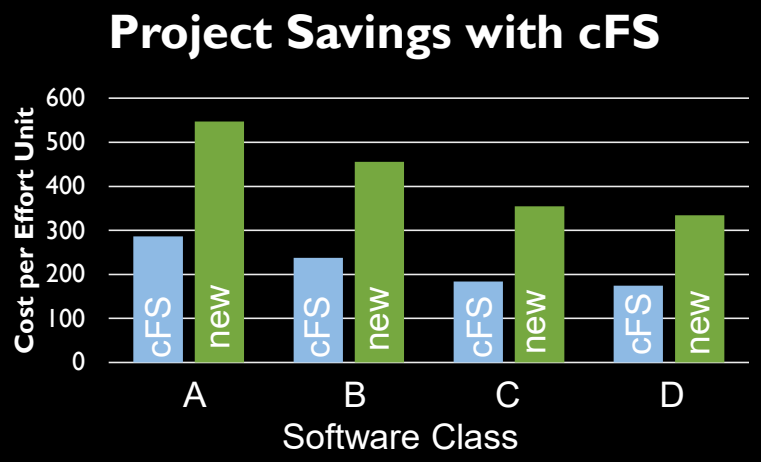
cFS Reduces Cost & Risk

cFS is a complete engineering solution – **Missions reuse more than code!**

- ✓NPR 7150.2C Compliant process
- ✓TRL 9
- ✓Years of mission experience baked in
- ✓Active community willing to help and share

The SEER-SEM relative cost for NASA software classes

Conservative estimate ~50%



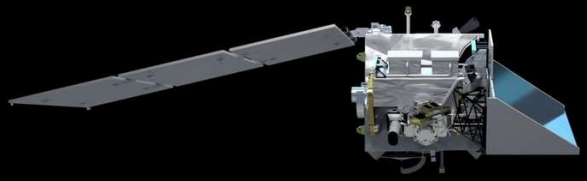
Reuse Category	Artifacts
Code	• Source Code • Unit Tests
Documentation	• Design Documentation • Development Standards • Test Reports • User's Guides • Application Developers Guide • API Reference Guides • Deployment Guides • Flight Operations Guides
Support Tools	• Unit Test Framework • Software Timing Analyzer • Simple Ground System

Artemis Program Use

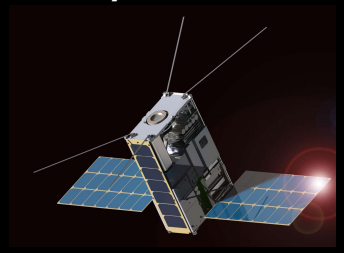
- cFS is a requirement in NASA's International Deep Space Interoperability Standards https://www.internationaldeepspacestandards.com/
- cFS is in process of Class A certification for Artemis Gateway at JSC
- International Artemis partners are using cFS in their modules
- Saving tens of millions of dollars across the Artemis program
- The open source release of cFS made this possible

Case Stories: cFS Layered Architecture to the Rescue

cFS enables seamless sharing of applications across NASA, industry and academic missions



PACE, Class B,
Operating System VxWorks



Lunar IceCube, Sub-Class D,
Operating System: RTEMS

- Lunar IceCube wanted to infuse the Delay/Disruption Tolerant Networking (DTN) technology and be the first node of the Solar System Internet around the Moon
- NASA's PACE mission development team had already implemented the cFS DTN application
- Lunar IceCube needed a DTN solution quickly to meet the schedule
- DTN cFS application was delivered in the morning and despite the difference in hardware and operating system, DTN was integrated and transferring data by early afternoon

Case Stories: cFS Saves the Day

Dellingr CubeSat fault recovery

- Commercial of the Shelf (COTS) hardware failures lead to loss of attitude control
- Existing Attitude Control software is too large to update due to slow and intermittent communications
- Re-purpose a small app and use cFS services to upload it in tiny chunks and activate the new algorithm
- CubeSat de-spun and operational again!

cFS services are engineered for reliability, operability and robustness in the unforgiving domain of space!

Case Stories: cFE can Save the World

Double Asteroid Redirection Test (DART)

- NASA's DART mission successfully demonstrated kinetic impactor technology, impacting an asteroid to adjust its speed and path.
- DART is the first-ever space mission to demonstrate asteroid deflection by kinetic impactor

NASA's first Planetary Defense Test used cFE!

NASA Software Architecture Review Board cFS Report

Quotes from the report:

- "Goddard's Flight Software Systems Branch, Code 582, recognized a truth that's not obvious and bears repeating: **"It was the software architecture that lived on, even as hardware came and went."** "
- " **"there was almost nothing we asked about that [GSFC] had not already thought about"** which speaks well for the depth of thought that has gone into the architecture. "

The Future: Where is cFS going next?

cFS will be powering more science and exploration missions to Mars, other planets, moons, asteroids, comets and our home planet, Earth!

The community is adding AI and automation layers above the cFS (ARC, Stennis, Emergent, DARPA, GSFC, JSC …)

JAXA and others are integrating cFS with Robotics Operating System

We are adding features for the next generation of high performance space processors

We are working with industry partners to port cFS to their latest products (Including BAE Systems, Aitech, WindRiver)

The cFS community is working on tools to integrate cFS into Model Based Systems Engineering

We are creating standards for interoperability of common system functions

What NASA Users are Saying

"cFS has stepped up to answer the needs of the Agency and global spacecraft community for critical spacecraft missions..."

Dr. Lorraine E. Prokop
NASA Technical Fellow

"… Dramatic schedule and budget efficiencies result because the challenges associated with integration, verification and validation occur only once but then the benefits are inherited by many far into the future.."

Robert J. Menrad
Associate Director for Space Communications, GSFC

"… appreciated was the ease of adopting cFS, which I attribute to its innovative and mature design."

E. Jay Wyatt
Manager, Space Networking and Mission Automation Program Office, JPL

"…cFS is a key software technology that will provide a Class A, Safety Critical framework to integrate the flight software or unique Gateway Modules into a single functional software system."

L. Neil Townsend
Gateway Software System Manager, JSC

What NASA Users are Saying

"We often utilize cFS as a training platform for interns and new career graduates; they can learn C, flight software methodologies, and can **develop their own cFS application in less than one day.**"

Justin R. Morris and Scott A. Zemerick
Independent Test Capability Team Leads, NASA – IV&V

"the Lunar IceCube NASA-university-private aerospace collaboration embodied the spirit of the cFS open source community. Development of such a sophisticated FSW system would not have been possible with the small team and constrained timeline, were it not for the use of cFS"

Dr. Ben Malphrus
Principal Investigator, Lunar IceCube

What NASA Users are Saying

"…choosing [cFS] as flight software framework was a very correct decision. It is a **flexible, mature and modular** architecture that greatly benefits its users, especially saving time and money in software development."

Danilo Miranda,
Project Manager, Visiona Space Technology S.A. (Brazil)


SPACENEWS

Visiona Emerges as Brazilian Space Sector's Industrial Champion

by Peter B. de Selding — May 4, 2015

""The cFS' architecture and suite of open source apps are well positioned to serve the future demands of the space industry including all branches of the government as well as commercial and academic organizations."

Dr. George W. Davis,
CEO, Emergent Space Technologies, Inc.

Positive Impacts

Space exploration is an expensive and risky world wide endeavor. NASA is leading the way with open systems for industry, academia and agencies

Cost Sharing
Cost Savings

Collaboration
Interoperability

Growing
Engineering Base

"cFS is a great example of the synergy that can be achieved between commercial business innovation and proven NASA/Government capabilities."

– Sharad Bhaskaran, Mission Director Astrobotic Technology, Inc

ASTROBOTIC

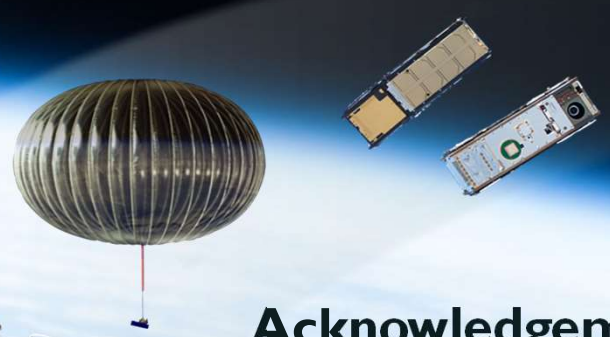
"With high confidence derived from the flight-proven technology of cFS, the software team spent more time concentrating on finding solutions for the mission."

– Jongyeob Park, Korea Astronomy and Space Science Institute

KASI Korea Astronomy and Space Science Institute

National Aeronautics and Space Administration

Questions?



Acknowledgements:

Gerardo Cruz-Ortiz	Deputy Program Manager
Alan Cudmore	cFS Platform Architect
Jacob Hageman	cFS CCB Chair
Elizabeth Timmons	Application Development Lead
Jonathan Wilmot	cFS Software Architect

And many thanks to the cFS development team

Acronyms

AFRL	Air Force Research Laboratory
AI	Artificial Intelligence
API	application programming interface
APL	Applied Physics Laboratory
App	Software Application
ARC	Ames Research Center
CFDP	CCSDS File Delivery Protocol
cFS	core Flight System
CLPS	Commercial Lunar Payload Service
CSA	Canadian Space Agency
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DTN	Delay/Disruption Tolerant Networking
ESA	European Space Agency
GEDI	Global Ecosystem Dynamics Investigation
GPM	Global Precipitation Measurement
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
GSFC	Goddard Space Flight Center

IOS	Internet Operating System (Apple)
IV&V	NASA's Independent Verification and Validation facility
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KARI	Korea Aerospace Research Institute
KSC	Kennedy Space Center
MMS	Magnetospheric Multiscale
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NextSTEP	public-private partnership exploration program
NICER	Neutron star Interior Composition Explorer
NPR	NASA Procedural Requirements
PACE	Plankton, Aerosol, Cloud and ocean Ecosystem
ROS	Robotics Operating System
RTEMS	Real-Time Executive for Multiprocessor Systems
SEER-SEM	Software estimation tools
TRL	Technology Readiness Levels
VIPER	Volatiles Investigating Polar Exploration Rover