

# core Flight System (cFS)

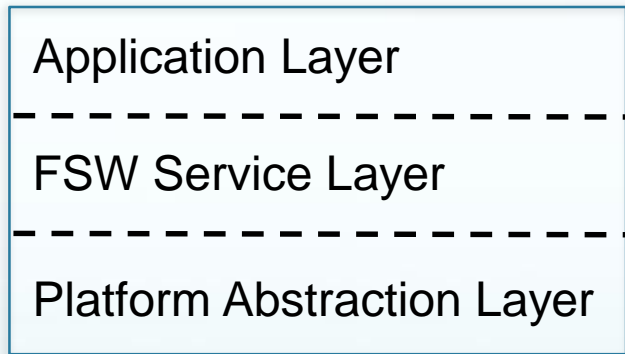
*A Low Cost Solution for SmallSats*

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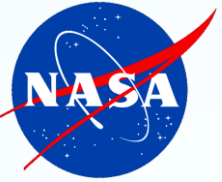


# What is the core Flight System?

- The cFS is a re-usable spacecraft flight software architecture and software suite that is both platform and project independent
- Layered architecture and compile-time configuration parameters make it scalable and portable to a wide range of platforms



- Original product created by NASA's Goddard Space Flight Center
- The FSW Service and Platform Abstraction layers are now controlled by a NASA multi-center configuration control board



## Recent cFS Success Stories

- Johnson's Morpheus: 14 months from concept to flight test in 2010
- Goddard's Class B missions: Global Precipitation Measurement (GPM) launched February 2014 and Magnetospheric Multiscale (MMS) launched March 2015
- Goddard's 2014 Class D balloon mission: Observatory for Planetary Investigations from the Stratosphere (OPIS)
  - Baseline command and data handling software was up and running on the target platform (Intel Core Duo/Xenomai) within a month and launched 6 months later
- DARPA's F6 program: Emergent funded (2013-2014) to develop Flight Software to Provide Autonomous Satellite Cluster Services
  - Cluster Flight System applications ported to cFS in less than 6 months and formally demonstrated in simulation test bed



# In Development - NICER

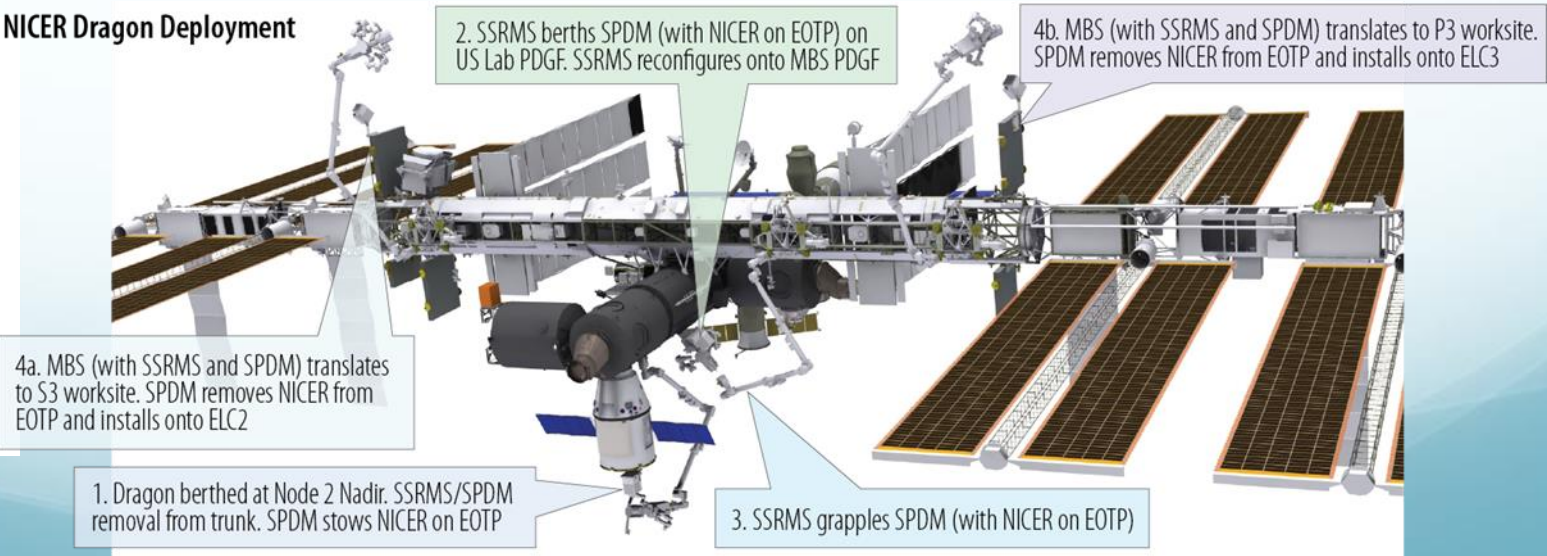
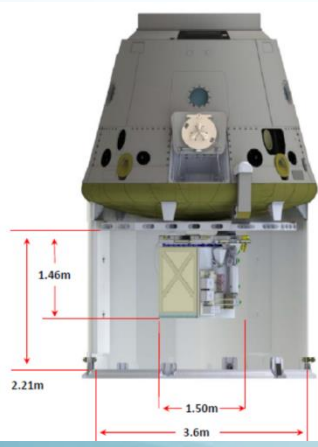
## Objectives

- Reveal the nature of matter in the interiors of neutron stars
- Uncover the physics of dynamic phenomena associated with neutron stars
- Determine how energy is extracted from neutron stars

## On-board Processor

- Broad Reach Engineering Radiation Hardened BRE440 PowerPC
  - 32 Bit RISC embedded processor
  - 83 MHz OSC (2 MIPS / MHz = ~166 MIPS)
- VxWorks 6.7

### NICER Dragon Deployment





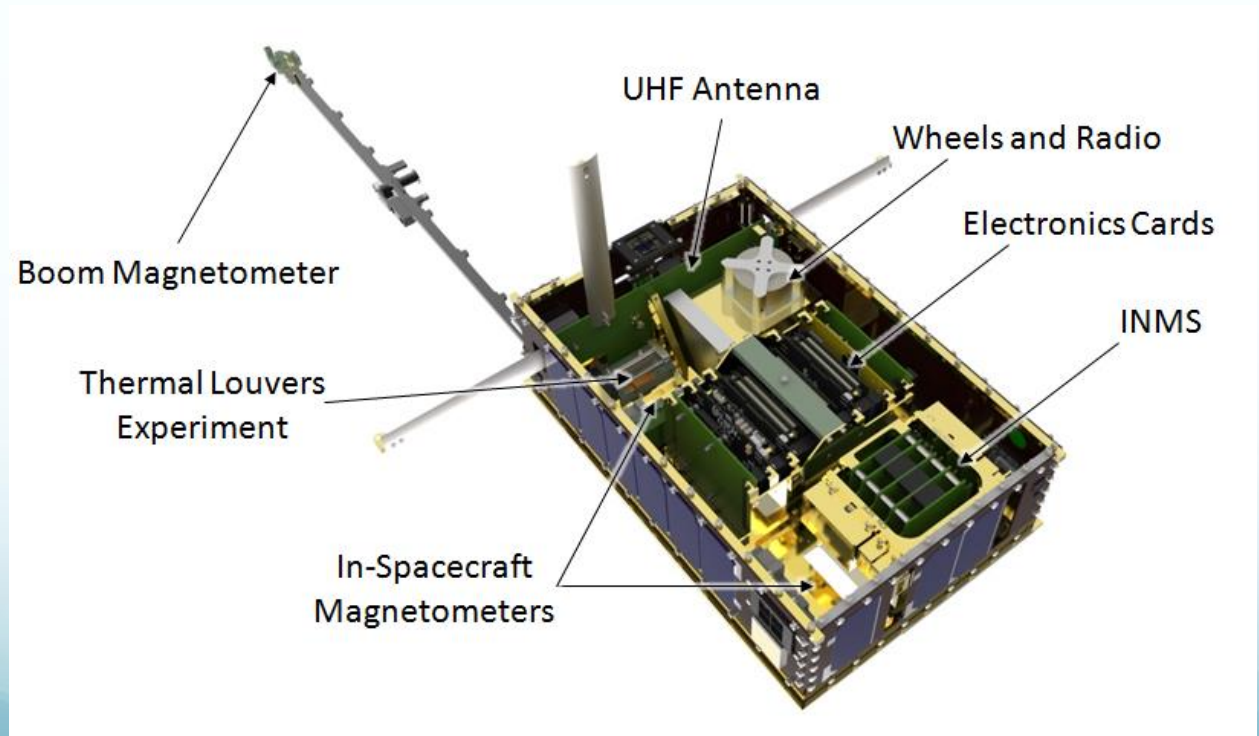
# In Development - Dellingr

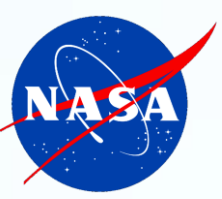
- Objectives

- Low cost science and technology demonstration

- On-board Processor

- ARM7
  - 40 Mhz, 2Mb RAM
- FreeRTOS





# In Development - PiSat

- Objectives
  - Low cost test bed
- On-board Processor
  - Raspberry Pi
  - Raspberry Pi OS (DEBIAN/Linux)



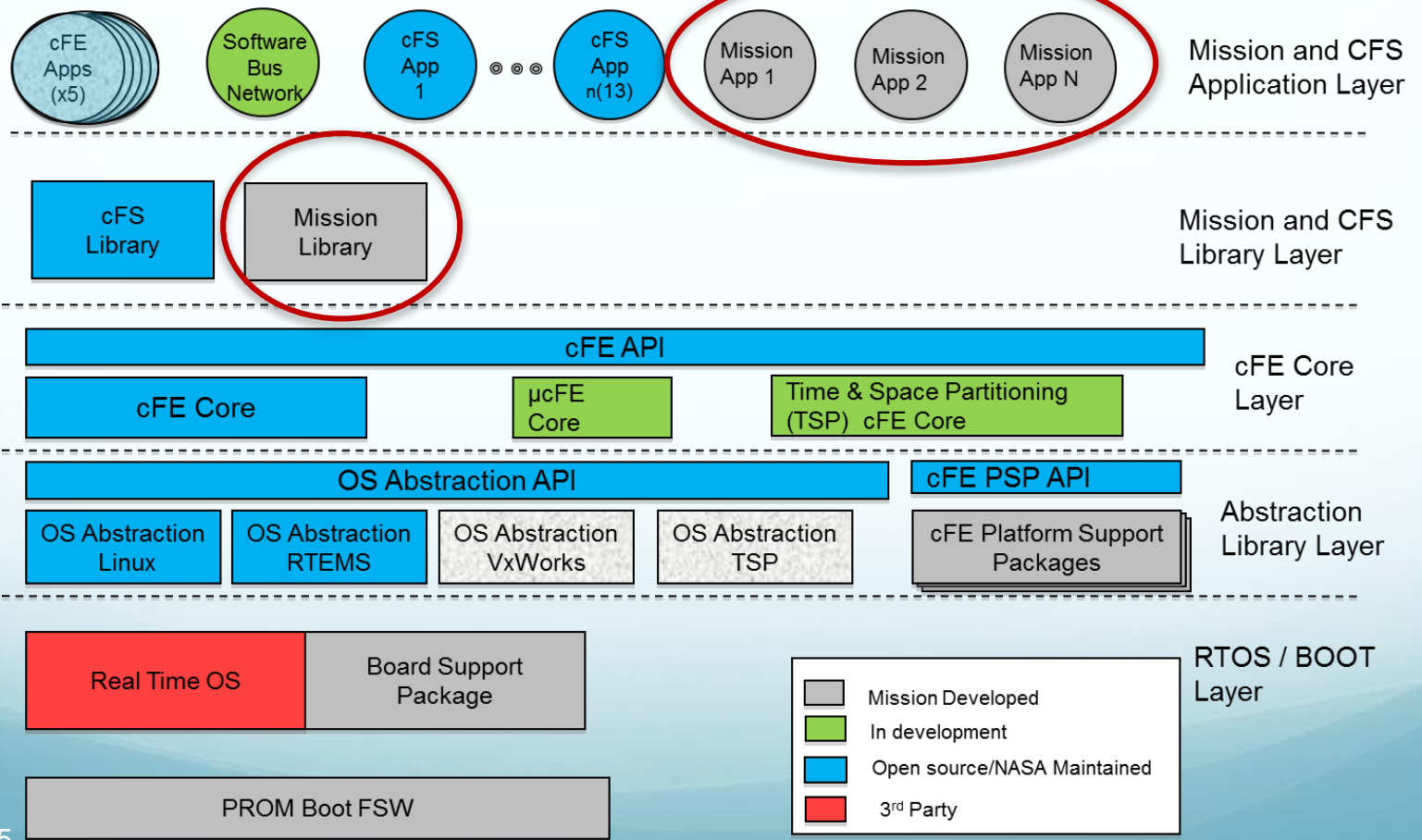


# cFS Architecture Highlights

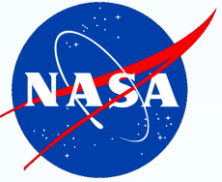


# cFS Key Features

- Layered architecture
  - Reusable components
  - Platform Independent
  - Supports advances in technology without changes to the framework







# cFS Core Services

## Executive Services

- Manages the software system

## Software Bus Services

- Provides publish/subscribe software bus messaging interface

## Time Services

- Provides spacecraft time

## Event Services

- Provides interface for sending, filtering, and logging event messages

## Table Services

- Provides interface to manage table images

**The cFS core layer is the system glue. It provides the common software functions that are needed by all missions.**



# cFS Applications

| Application          | Function   |
|----------------------|--|
| CFDP                 | Transfers/receives file data to/from the ground  |
| Checksum             | Performs data integrity checking of memory, tables and files   |
| Command Ingest Lab   | Accepts CCSDS telecommand packets over a UDP/IP port   |
| Data Storage         | Records housekeeping, engineering and science data onboard for downlink                                      |
| File Manager         | Interfaces to the ground for managing files  |
| Housekeeping         | Collects and re-packages telemetry from other applications.  |
| Health and Safety    | Ensures that critical tasks check-in, services watchdog, detects CPU hogging, and calculates CPU utilization |
| Limit Checker        | Provides the capability to monitor values and take action when exceed threshold                              |
| Memory Dwell         | Allows ground to telemeter the contents of memory locations. Useful for debugging                            |
| Memory Manager       | Provides the ability to load and dump memory.  |
| Software Bus Network | Passes Software Bus messages over Ethernet   |
| Scheduler            | Schedules onboard activities via (e.g. HK requests)  |
| Scheduler Lab        | Simple activity scheduler with a one second resolution   |
| Stored Command       | Onboard Commands Sequencer (absolute and relative).  |
| Telemetry Output Lab | Sends CCSDS telemetry packets over a UDP/IP port   |



# A Complete Engineering Solution



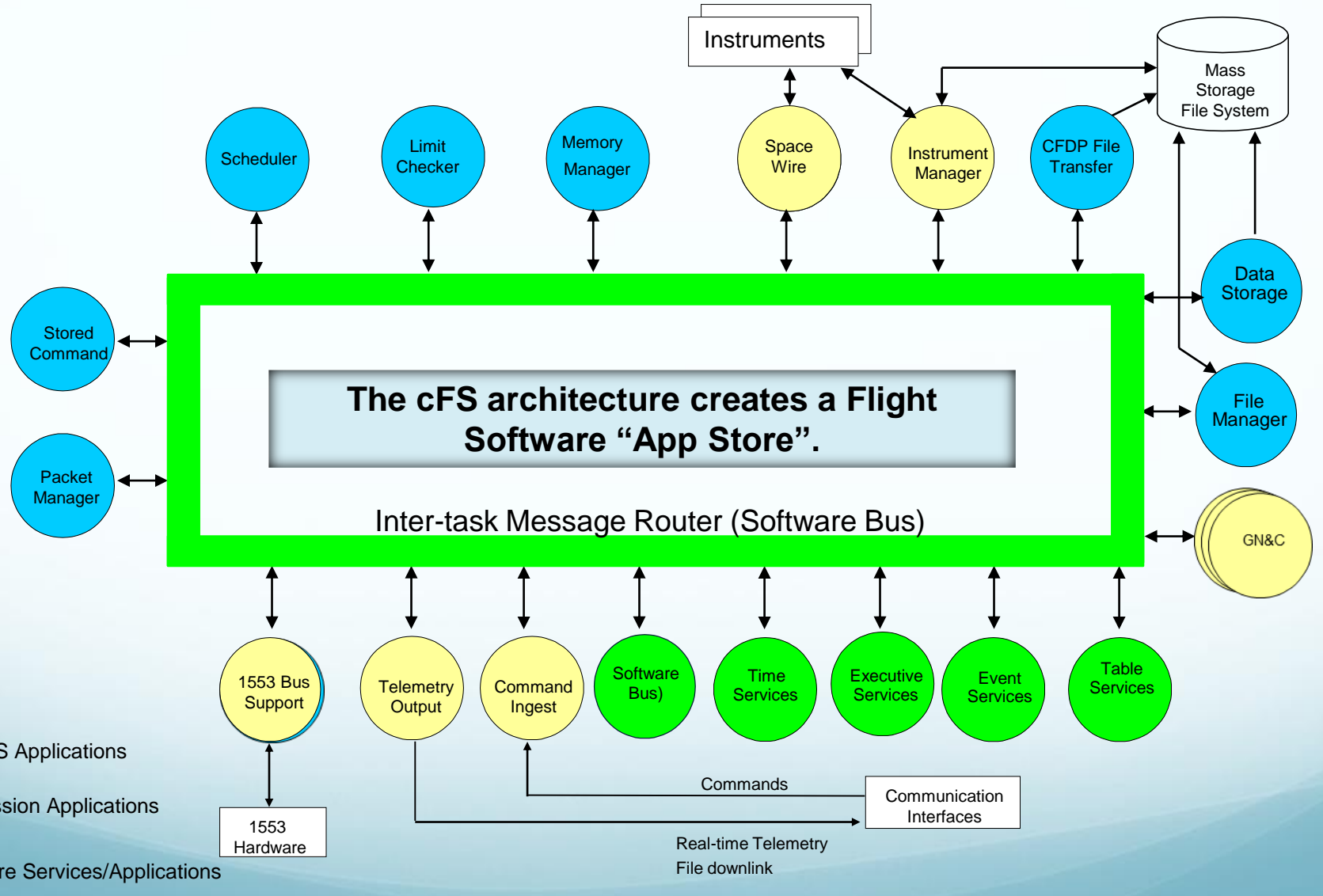
## Includes reusable:

- Requirements
- Source Code
- Design Documentation
- Development Standards
- Test Artifacts
- Tools
  - Unit Test Framework
  - Software Timing Analyzer
- User's Guides
  - Application Developers Guide
  - API Reference Guides
  - Deployment Guides
  - Flight Operations Guides
- Command & Telemetry GUI

**The CFS architecture reduces Non-Recurring Engineering (NRE) up to 90%**



# Component Based Architecture





# CFS Component Metrics

| Component             | Version | Logical Lines of Code | Configuration Parameters  |
|-----------------------|---------|-----------------------|---|
| Core Flight Executive | 6.3.2   | 12930                 | General: 17, Executive Service: 46<br>Event Service: 5, Software Bus: 29<br>Table Service: 10, Time Service: 32 |
| CFDP                  | 2.2.1   | 8559                  | 33  |
| Checksum              | 2.2.0   | 2873                  | 15  |
| Data Storage          | 2.3.0   | 2429                  | 27  |
| File Manager          | 2.3.1   | 1853                  | 22  |
| Health & safety       | 2.2.0   | 1531                  | 45  |
| Housekeeping          | 2.4.0   | 575                   | 8   |
| Limit Checker         | 2.2.1   | 2074                  | 13  |
| Memory Dwell          | 2.3.0   | 1035                  | 8   |
| Memory Manager        | 2.3.0   | 1958                  | 25  |
| Stored Commanding     | 2.3.0   | 2314                  | 26  |
| Scheduler             | 2.2.0   | 1164                  | 19  |

- Two scopes of configuration parameters: mission or processor
- Configuration parameters span a large functional range from a simple default file name to a system behavioral definition like the time client/server configuration



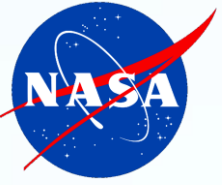
# Example Mission Code Metrics

## Global Precipitation Measurement (GPM)



- Noteworthy items
  - + cFE was very reliable and stable
  - + Easy rapid prototyping with heritage code that was cFE compliant
  - + Layered architecture has allowed COTS lab to be maintained through all builds
  - Addition of PSP changed build infrastructure midstream
  
- Lines of Code Percentages:

| Source               | Percentage |
|----------------------|------------|
| BAE                  | 0.3        |
| EEFS                 | 1.7        |
| OSAL                 | 2.1        |
| PSP                  | 1.0        |
| cFE                  | 12.4       |
| GNC Library          | 1.6        |
| CFS Applications     | 23.5       |
| Heritage Clone & Own | 38.9       |
| New Source           | 18.5       |



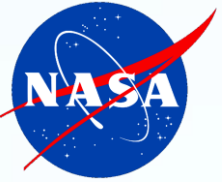
# Building a cFS Community



# cFS Contributions From Other Organizations

| Organization                  | Contribution  | Notes   |
|-------------------------------|---|---|
| Johnson Space Center          | Trick Simulator integration, Enhanced Build environment, Training materials, ITOS integration, multiple new platforms                   |   |
| Johnson Space Center          | Class A certification of OSAL, cFE and selected cFS applications  | Use in Orion Backup flight computer, video processing unit, and Advanced Space Suit |
| Johnson Space Center          | Enhanced Unit tests and increased code coverage, new performance analysis tool  |   |
| Glenn Research Center         | Code Improvements, modern build environment (cmake), Electronic Data Sheet integration  |   |
| Ames Research Center          | cFS community configuration management services, continuous integration build services  |   |
| Ames Research Center          | Simulink Interface Layer for auto-coding cFS applications   |   |
| JHU/APL                       | Multi-Core cFE/OSAL port  | Joint IRAD with GSFC, will be used for GSFC MUSTANG flight processor card           |
| DARPA/Emergent                | Fractionated Spacecraft / Distributed Mission cFS applications<br>Formation Flying  | Part of DARPA F6 project, they hope to make the apps available as open source       |
| Interns and misc contributors | cFS development tools are being created and shared by many organizations<br><br>Miscellaneous bug fixes reported via open source sites. |   |





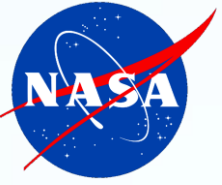
# Ongoings

## Technical Enhancements

- Integrated Development Environment (IDE)
- Automated tests (unit, functional, build...)
- CCSDS EDS specifications for cFS components
- Integrate Multi-core support into OSAL and cFE
- Integrate/Merge ARINC653 port into OSAL and cFE
- Integrate Dellinger Cubesat FreeRTOS OSAL Port
- Improve scheduler time synchronization
- Expand SB namespace beyond  $2^{11}$
- Lab upgrades
  - RTEMS 4.11 updates
  - VxWorks 6.9 updates
  - RAD750 simulator
  - MPC8377E: PowerQUICC II Pro Processor test beds
  - LEON3 test bed
  - MCP750 test bed

## Operational Enhancements

- Formalize cFS user community
- Web based app store

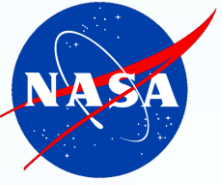


# Back Up



# Acronyms

- API Application Programmer Interface
- ARC Ames Research Center
- BAT Burst Alert Telescope
- CCSDS Consultative Committee for Space Data Systems
- CDH Command Data Handling
- CFDP CCSDS File Delivery Protocol
- cFE core Flight Executive
- CFS Core Flight System
- CMMI Capability Maturity Model Integrated
- FSW Flight Software
- GLAS Geoscience Laser Altimeter System
- GN&C Guidance, Navigation, and Control
- GPM Global Precipitation Measurement
- GSFC Goddard Space Flight Center
- JSC Johnson Space Center
- LADEE Lunar Atmosphere and Dust Environment Explorer
- LOC Lines of Code
- LRD Launch Readiness Date
- LRO Lunar Robotic Orbiter
- MAP Microwave Anisotropy Probe
- MMS Magnetic Multiscale Mission
- NRE Non-Recurring Engineering
- OSAL Operating System Abstraction Layer
- RBSP Radiation Belt Storm Probe
- RTEMS Real-Time Executive for Multiprocessor Systems
- SAMPEX Solar Anomalous and Magnetospheric Particle Explorer
- SARB Software Architecture Review Board
- SDO Solar Dynamics Observatory
- SMEX Small Explorer
- ST-5 Space Technology 5
- SWAS Submillimeter Wave Astronomy Satellite
- TRACE Transition Region and Coronal Explorer
- TRL Technology Readiness Level
- TRMM Tropical Rainfall Measuring Mission
- WIRE Widearea Infrared Explorer
- XTE X-Ray Timing Explorer



## Where is the cFS?

- cFE open Internet access at <http://sourceforge.net/projects/coreflightexec/>
  - Source code
  - Requirements and user guides
  - Tools
- OSAL open Internet access at <http://sourceforge.net/projects/osal/>
  - Source code
  - Requirements and user guides
  - Tools
- cFS application suite is also available on sourceforge



# Questions? Contact:

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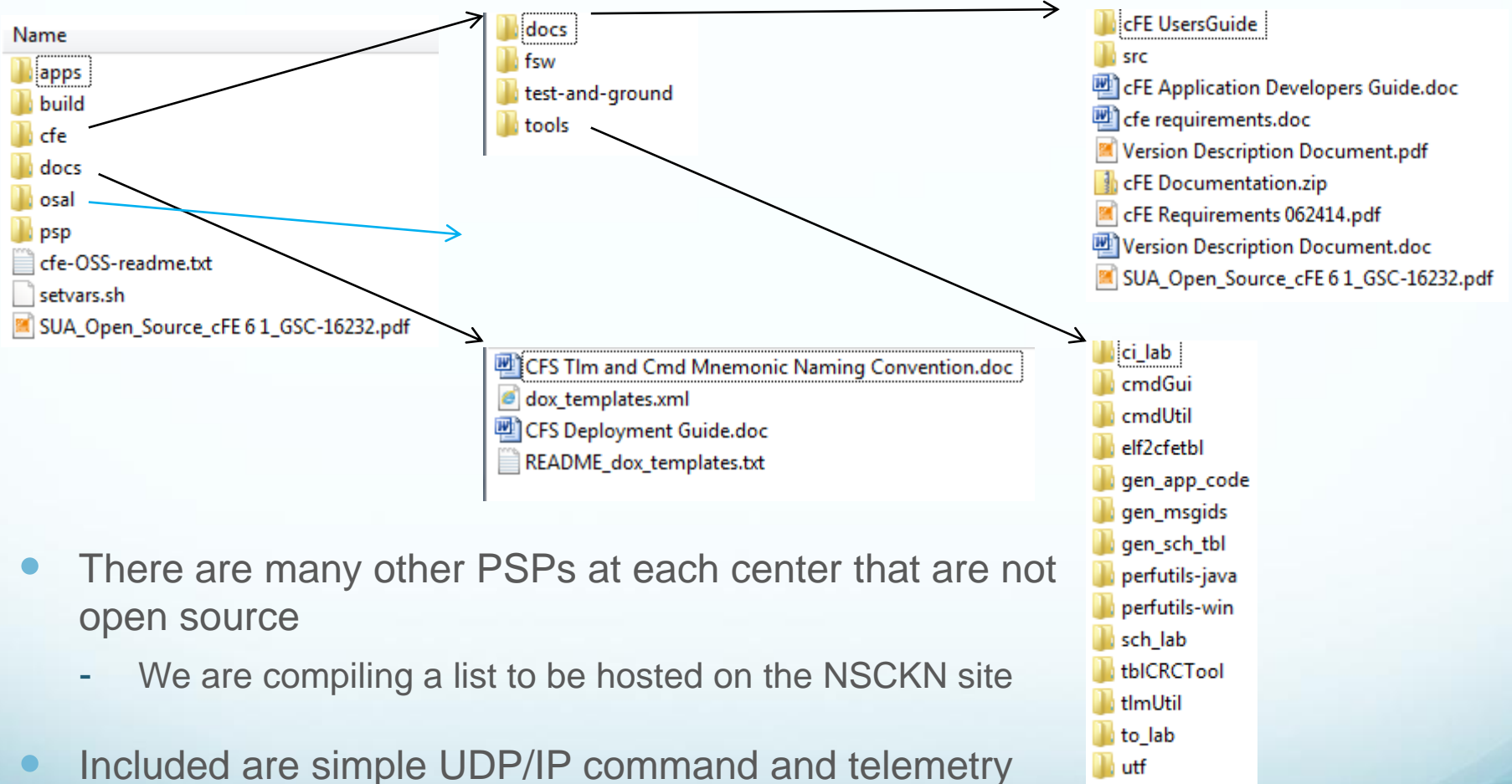
# Software Facts

|                         |  |
|-------------------------|--|
| Class                   | Class A, B and lower instantiations  |
| TRL                     | OSAL & cFE TRL 9, selected cFS Apps TRL 9  |
| CMMI                    | Certified level 2 for Class B (GSFC)<br>Certified level 3 for Class A (JSC)                        |
| Operating Systems       | VxWorks, RTEMS, Linux, ARINC 653   |
| Hardware Supported      | MCP750, BAE RAD750, Coldfire, LEON3, MCP405, BRE440, and many more at JSC, GRC, ARC, MSFC, and APL |
| Lines of Code           | 45K (LOC)  |
| Components available    | 13   |
| Documentation Available | Requirements, User's Guides, Deployment Guides, Design Documents, Test Plans, Test Reports         |

**cFS is a software system designed to address software quality and usability issues of performance, reliability, reuse, maintainability, and lifecycle cost.**



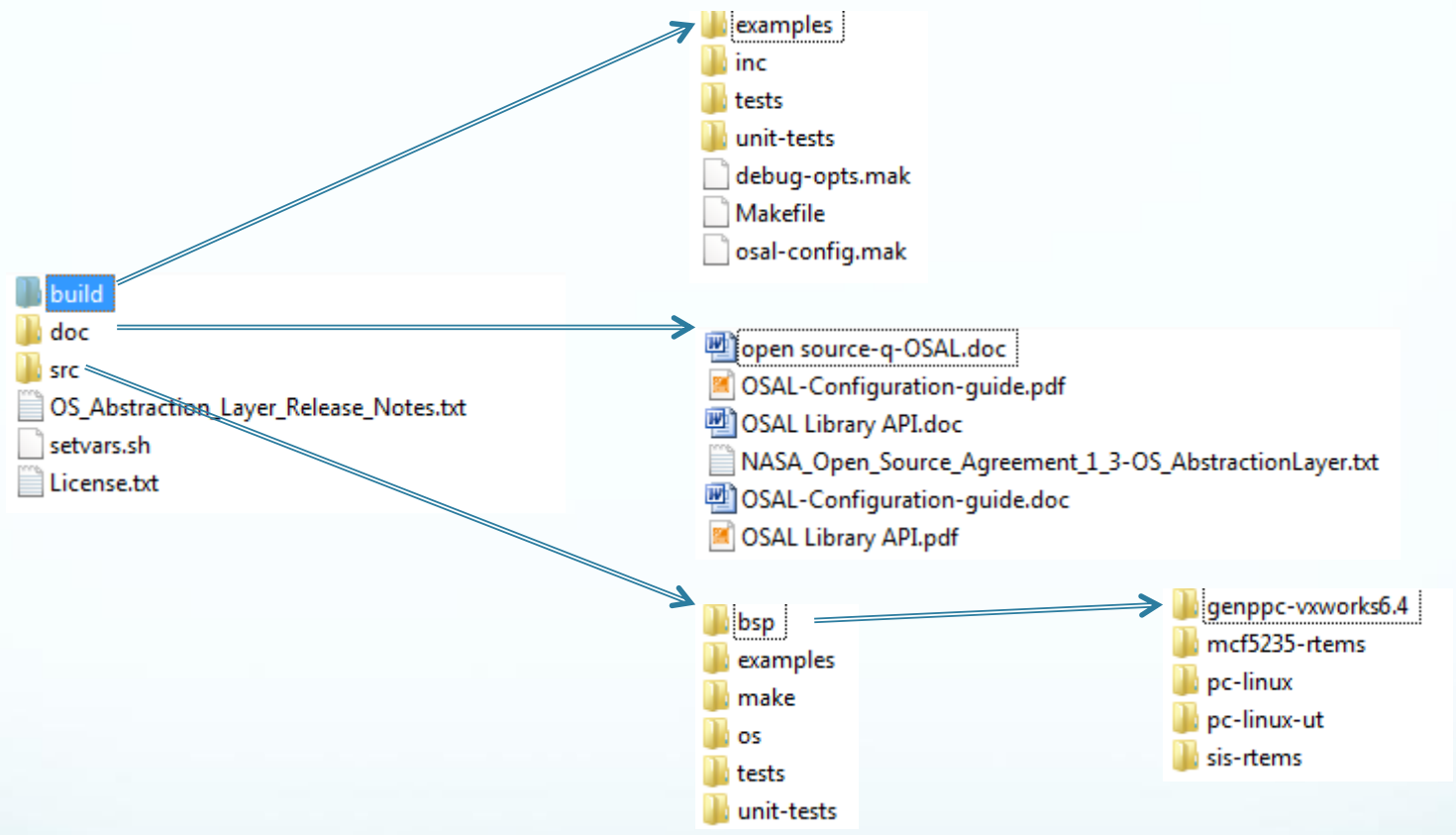
# What's in the in the cFE open source tarball



- There are many other PSPs at each center that are not open source
  - We are compiling a list to be hosted on the NSCKN site
- Included are simple UDP/IP command and telemetry GUIs



# What's in the in the OSAL open source tarball



- There are other BSPs at each center that are not open source
  - We are compiling a list to be hosted on the NSCKN site