The Core Flight System (cFS) Community: Providing Low Cost Solutions for Small Spacecraft

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Morpheus – An Early cFS Adopter

14 Months between receipt of cFS and

successful tethered flight test

“The cFS… It just worked.”
– Morpheus Software Lead

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A NASA Controlled Product Line

DOD and US industry
- Potential for standardization though the CCSDS and the Space Universal MOdular Architecture (SUMO) team sponsored by Office of the Director of National Intelligence

GRC – CPST and Advanced suit

APL - RBSP. Proposing use on Solar Probe, DoD programs.

ARC- LADEE

Kirtland AFB – Onboard Autonomous Planning System

GSFC: LRO, MMS, GPM, NICER, OPIS and many others.

Commercial - Moon Express (Lunar X-Prize)

JPL – Evaluating architecture for robotic missions and ESTO missions

JSC-Used Successfully on Morpheus. Using on AES projects , Habitats, Waypoint, Certified for Class A (human rated).

MSFC- Mighty Eagle Lander, AES RESOLVE

KSC-Evaluating for AES, sounding rockets and UAV's

JAXA's Engineering Digital Innovation Center
Next generation software architecture research

Korea Aerospace Research Institute
Lunar program

European Space Research and Technology Centre

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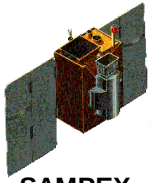
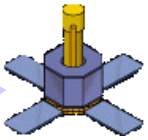
cFS Heritage

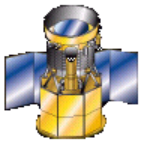


SAMPEX
(8/92)

SWAS
(12/98)

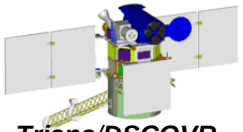


TRACE
(3/98)

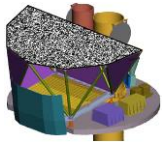


WIRE
(2/99)

SMEX-Lite



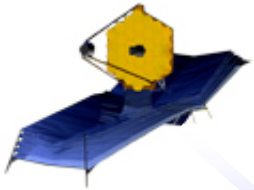
Triana/DSCOVR



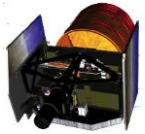
Swift BAT
(12/04)

XTE *(12/95)*

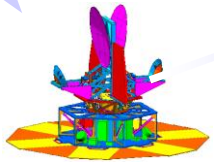
TRMM *(11/97)*



JWST ISIM (2018)

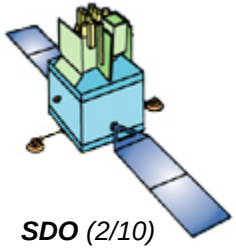


IceSat GLAS *(01/03)*

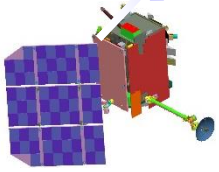


MAP *(06/01)*

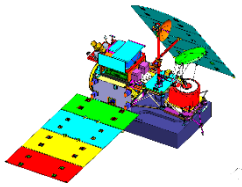
ST-5 *(4/06)*



SDO *(2/10)*



LRO *(6/09)*



GPM *(2/14)*

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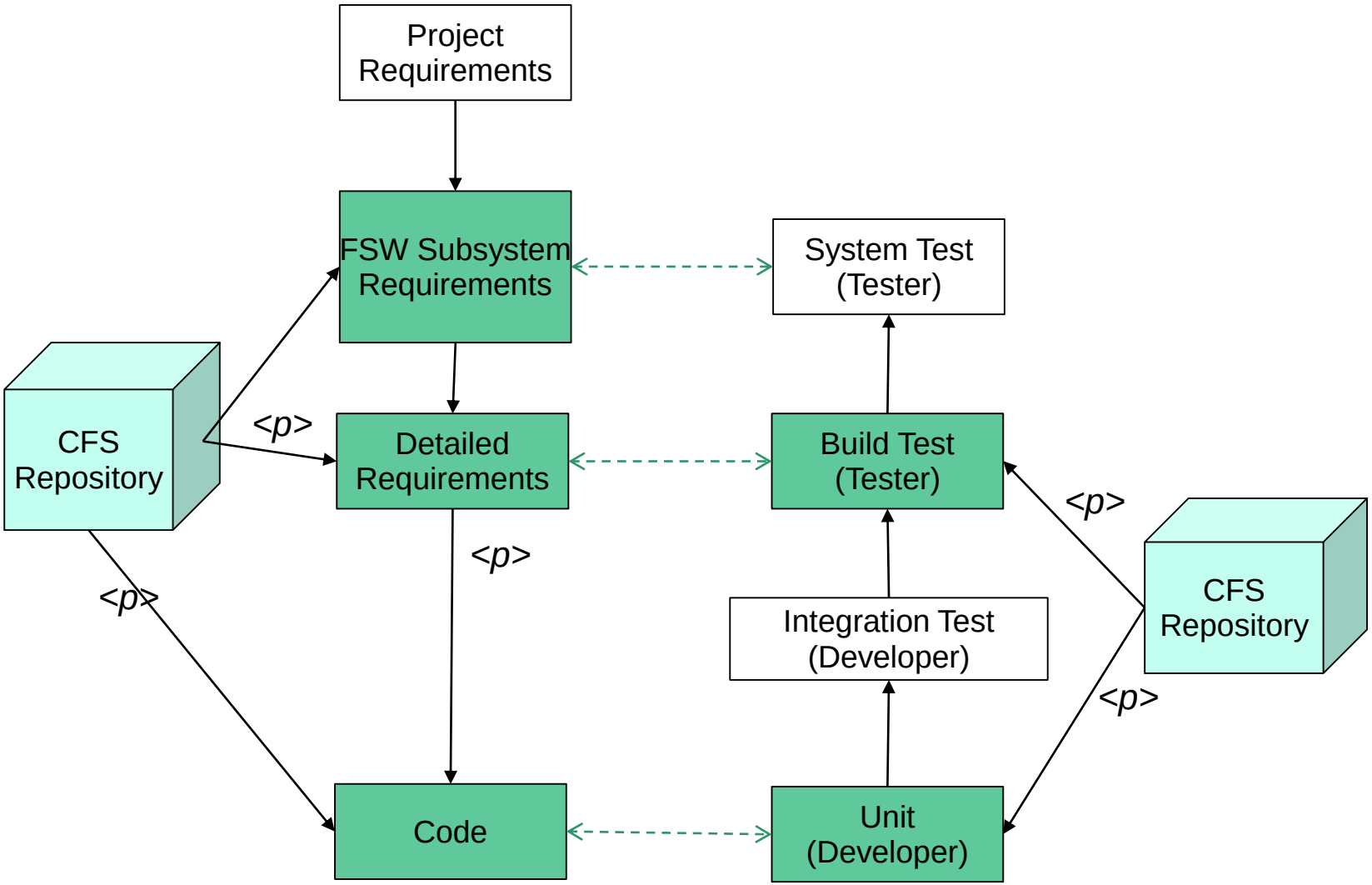
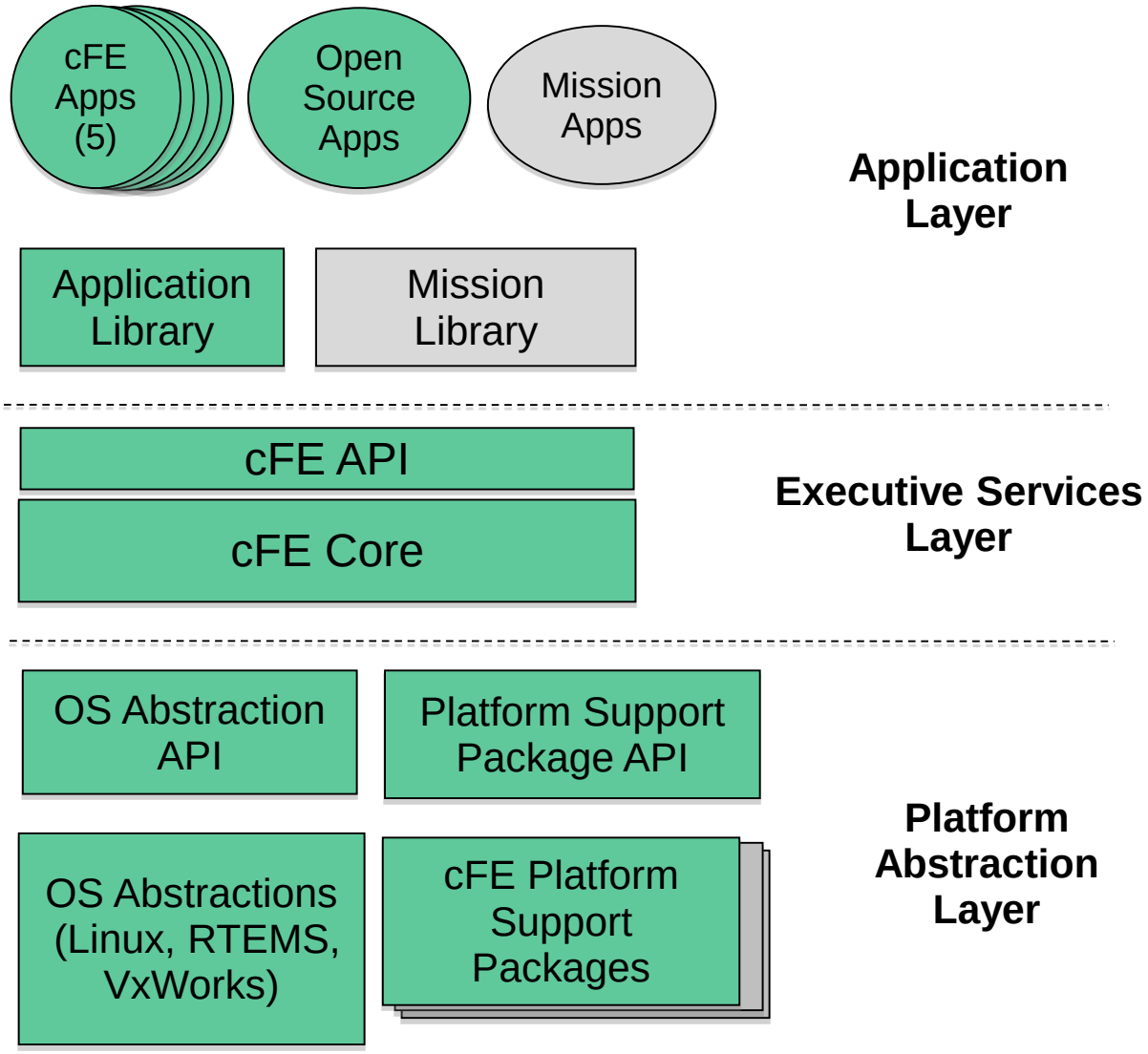
Lifecycle Artifact Reuse



cFS Layer Architecture



OS Abstraction Layer Platforms

Operating System	OSAL Version	Status	Target
POSIX/Linux	4.1.1	Production	Desktop Dev. use CentOS 6.x/Ubuntu 14.04 32 bit
RTEMS	4.1.1	Production	Flying on MMS Mission RTEMS 4.10/Coldfire
VxWorks	4.1.1	Production	Flying on GPM Mission vxWorks 6.4/PowerPC
FreeRTOS	4.2.x	In Dev.	GSFC Dellingr CubeSat Mission FreeRTOS/Arm
VxWorks 6.x SMP	4.3.x	In Dev.	vxWorks 6.7 LEON3 Dual Core
ARINC653	4.3.x	In Dev.	Green Hills Integrity OS
RTEMS 4.12+SMP	Future	Future	Future Release
Xenomai Linux	Future	Future	Future Release

cFE 6.5 Platform Support Packages

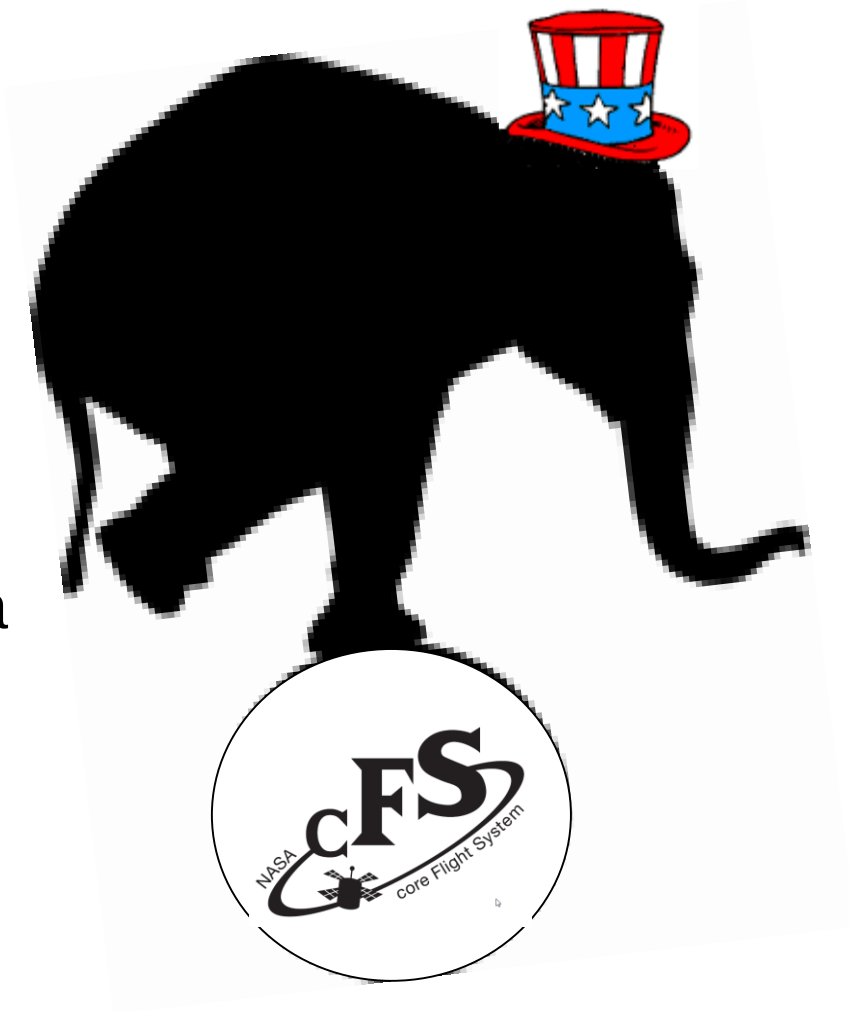
Board/Platform	OSAL Operating System	Status
CentOS/Ubuntu Linux Desktop	POSIX/Linux	Used on a balloon mission Common initial development/test environment
MMS Custom C&DH Coldfire	RTEMS	1 year in flight on MMS Mission
GPM RAD750	VxWorks	2 years in flight on GPM Mission
Gomspace Nanomind ARM CubeSat	FreeRTOS	Under development for GSFC Dellingr CubeSat Mission
GSFC MUSTANG Dual Core LEON3	VxWorks SMP	Under development for GSFC MUSTANG Dual Core LEON3 architecture

The Power of Community

1993 - Microsoft releases digital encyclopedia called Encarta

2001 - Wikipedia launched

2009 - Microsoft terminates Encarta



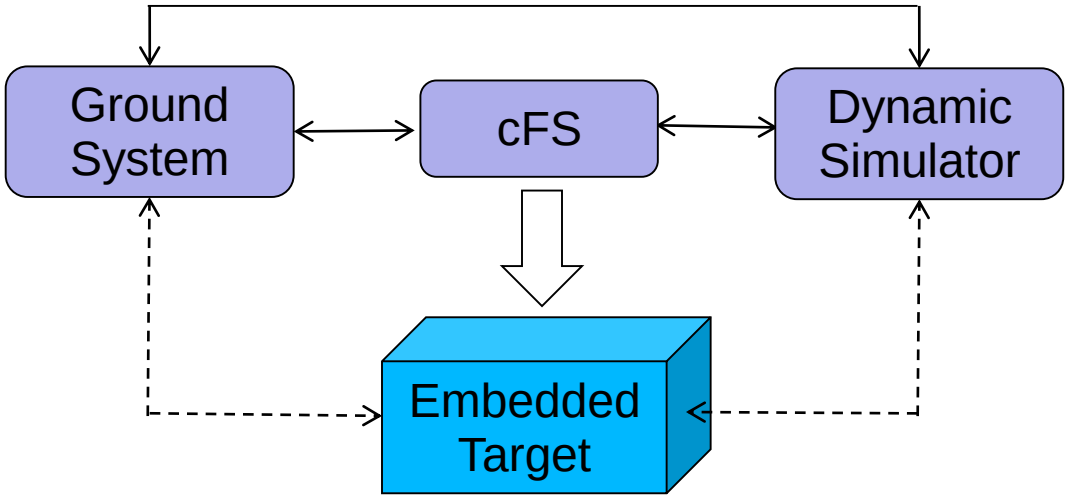
cfs.gsfc.nasa.gov

Coming soon…

coreflightsystem.org

- News
- Email sign up
- Documentation
- Discussion forums
- Links to software
- Submit trouble tickets
- Software Exchange
- Collaborative projects

cFS Starter Kits



- NASA Operational Simulator for Small Satellites (NASA's Independent V&V Facility)
  - Ground System: Ball Aerospace's COSMOS
  - Dynamic Simulator: NASA Goddard's 42
- The Hammers Company
  - Ground System: Hammer's Integrated Test and Operations System (ITOS)
  - Dynamic Simulator: Hammer's VIRTUALSAT®
- NASA Johnson Space Center
  - Ground System: Hammer's ITOS
  - Dynamic Simulator: NASA JSC Trick

Future Directions

- Model-Based Application Development
  - Simulink Interface Layer (SIL) allows cFS applications to be generated from Matlab Simulink models
- End-user certification
- Hardware vendor supplied device drivers & verification test scripts
- Embedded software school curriculums using cFS kits

Summary

- The cFS is an open source embedded software solution
- Opening our community: **coreflightsystem.org**
- Starter kits simplify adoption
- Enhancing component architecture for device plug-ins
- FSW Workshop, December 13-15, 2016 in Pasadena, CA
  - Hosted by NASA JPL, Aerospace Corporation, and Johns Hopkins University Applied Physics Laboratory
  - flightsoftware.jhuapl.edu
  - cFS Workshop on December 12th, 2016

Democratizing Space

Backup Slides

State of the Community Communication

- Mailing Lists
  - **cfs-community@lists.nasa.gov**
    - Contains all members
  - **cfs-community-ccb@lists.nasa.gov**
    - CCB members

- Public Websites
  - **https://cfs.gsfc.nasa.gov/**
    - General information and links to all open source code and documents on Sourceforge
  - **https://sourceforge.net/projects/xxx**
    - Multiple projects for different cFS components

- Restricted access (requires NDC account)
  - **https://nsckn.nasa.gov/Community**
    - NESC hosted server containing discussion forums, documents, meeting notes…
    - Approved for ITAR and Sensitive But Unclassified (SBU) material
  - **https://babelfish.arc.nasa.gov/**
    - ARC hosted server used for inter-center collaboration
    - Git andTrac used for source code configuration management and change requests
    - Not approved for ITAR material

Questions? Contact:

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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

cFS Metrics

cFE/ App	Logical Lines of Code (non-table)	Config. Parameters	EEPROM (bytes)
cFE	12,930	General: 17 Executive Service: 46 Event Service: 5 Software Bus: 29 Table Service: 10 Time Service: 32	341,561
CFDP	8,559	33	85,812
Checksum	2,873	15	35,242
Data Storage	2,429	27	40,523
File Manager	1,853	22	16,272
Health & Safety	1,531	45	15071
House-Keeping	575	8	8.059
Limit Checker	2,074	13	31,026
Memory Dwell	1,035	8	8,617
Memory Manager	1,958	25	15,840
Scheduler	1,164	19	35,809
Stored Command (124 command sequences)	2,314	26	104,960

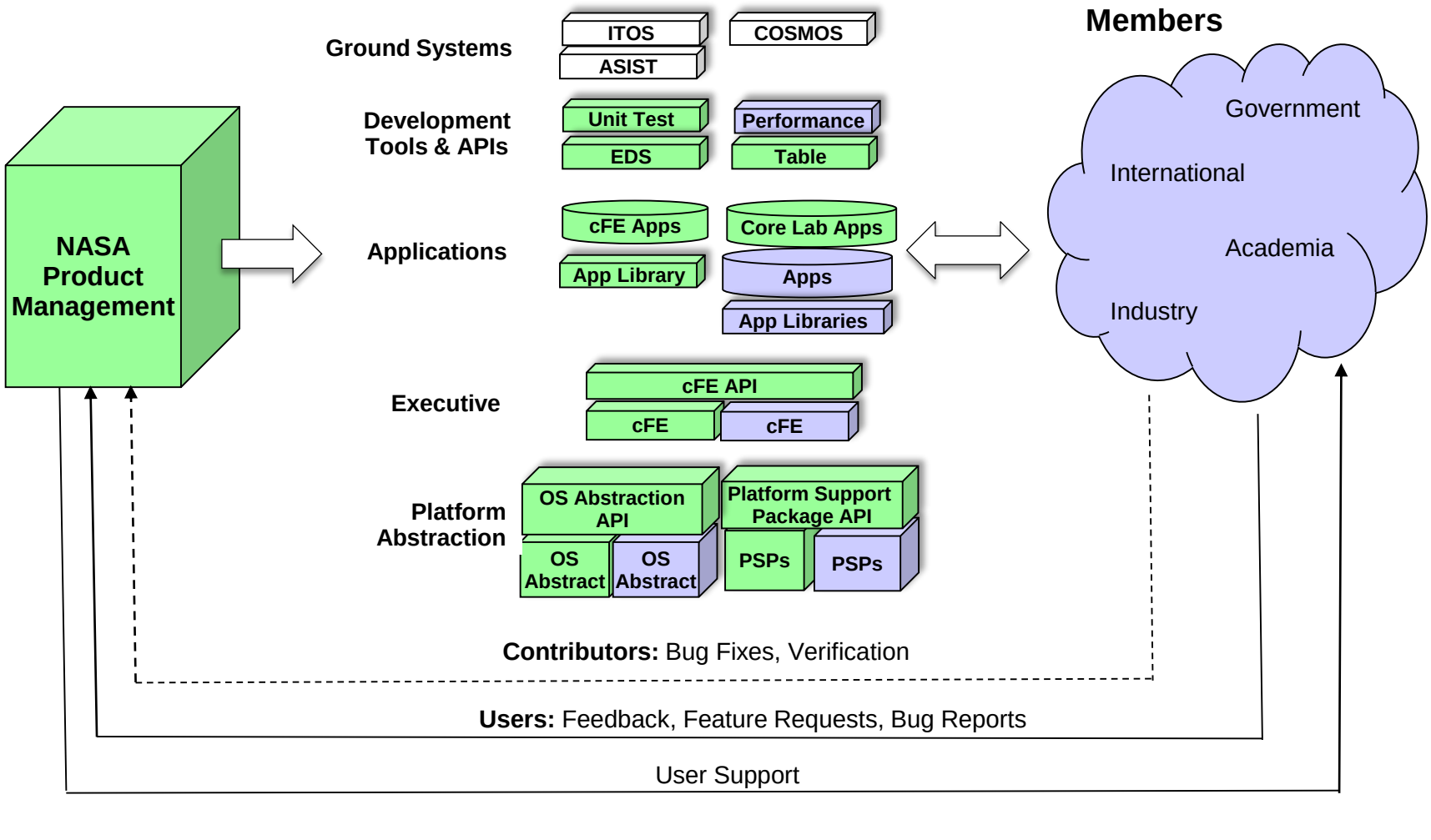
cFS Applications

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

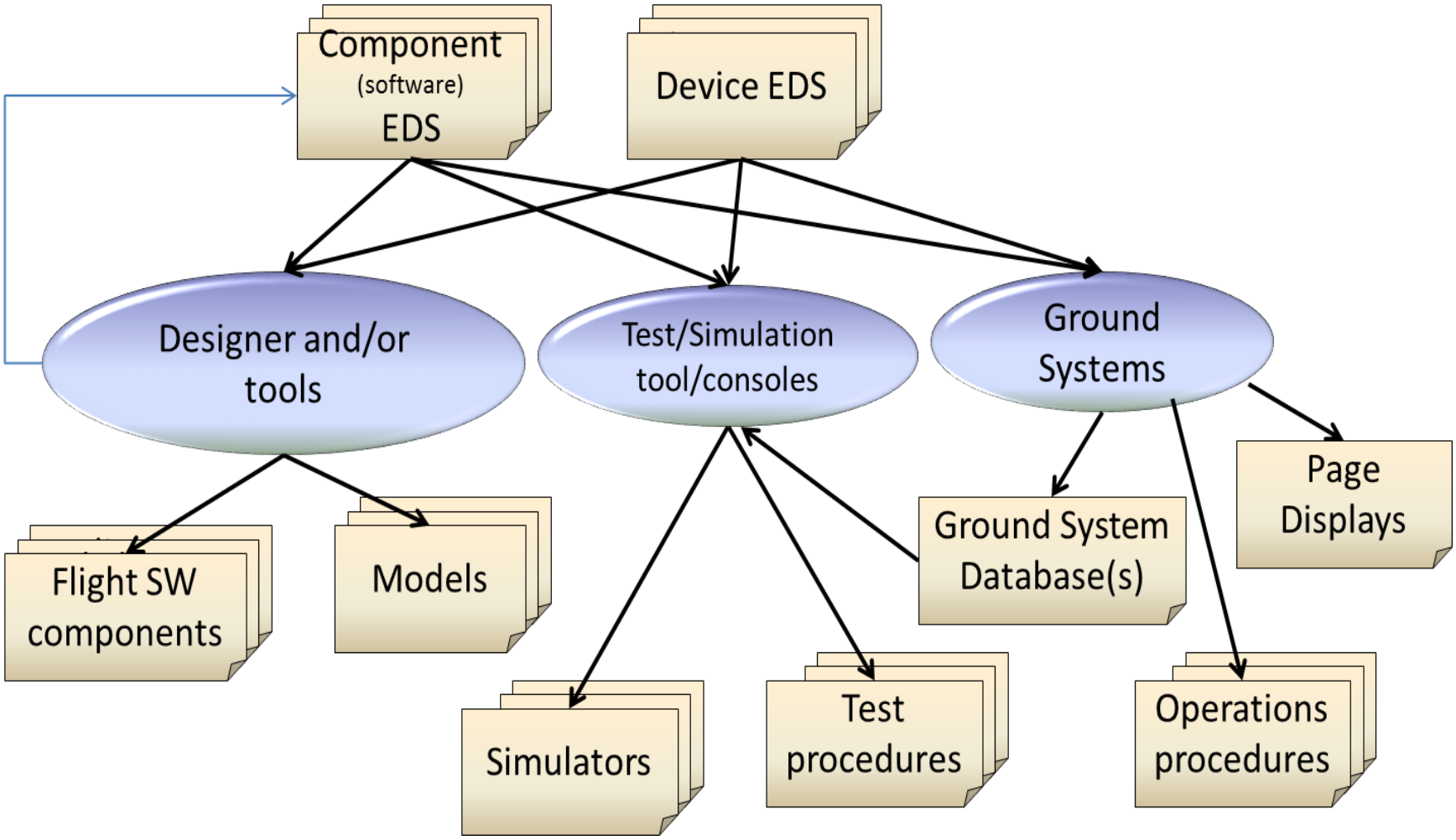
cFS Community Purpose

- Advance the creation, evolution, promotion, and support of a NASA Class B flight software system
  - Important we stay focused on our domain
- Cultivate both an open source community and an ecosystem of complementary products, capabilities, and services.
  - All inclusive in terms of organizations
  - No constraints on complementary products

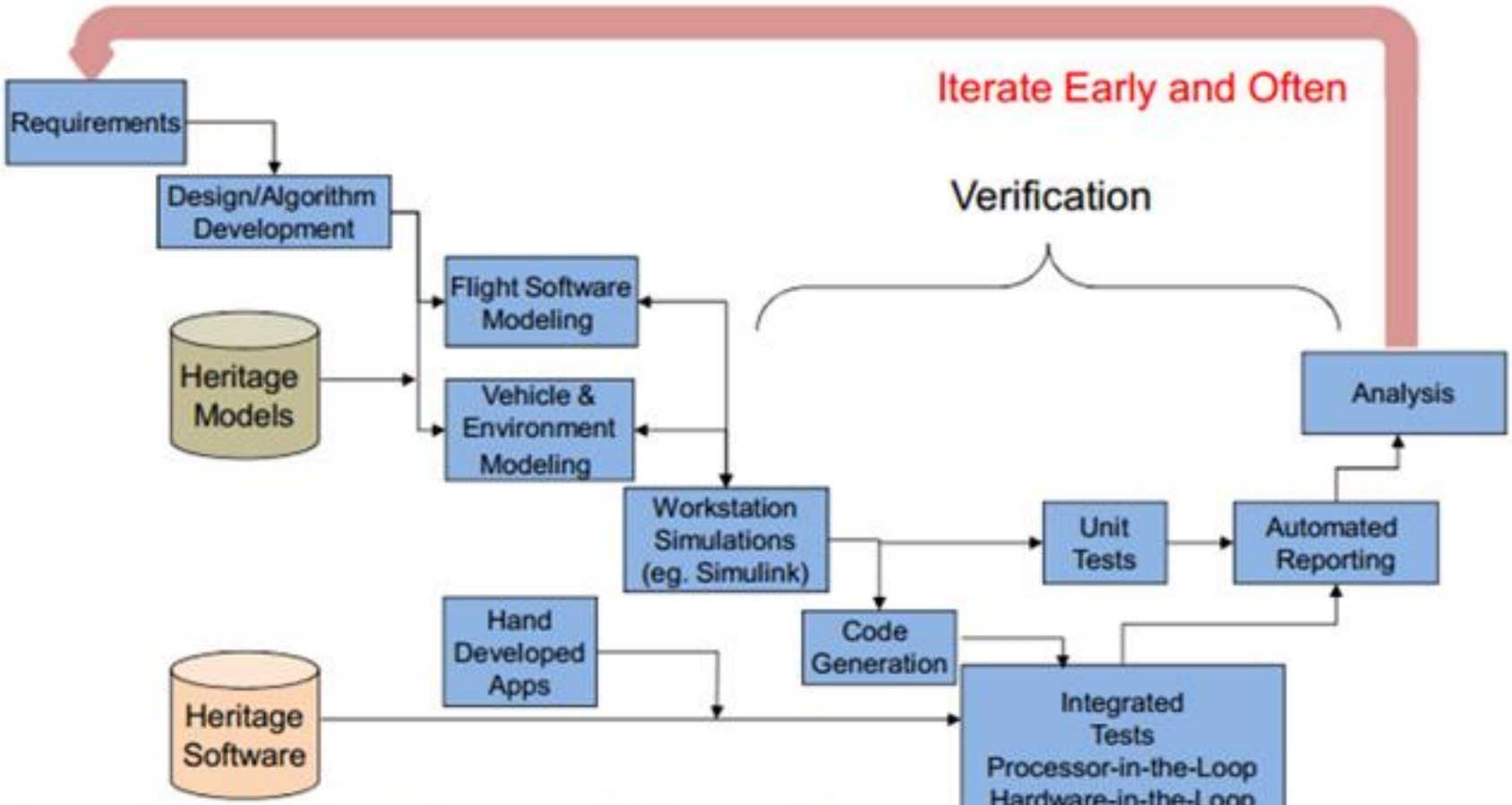
cFS Community



Electronic Data Sheets



Model-based Application Development



- Develop Models of FSW, Vehicle, and Environment
- Automatically generate High-Level Control Software
- Integrate with hand-written and heritage software.
- Iterate while increasing fidelity of tests – Workstation Sim (WSIM), Processor-In-The-Loop (PIL), Hardware-in-the-Loop (HIL)
- Automated self-documenting tests providing traceability to requirements

Automated Testing