National Aeronautics and Space Administration

Advanced Exploration Systems (AES) Core Flight Software (CFS) Project

- **Summary of Products (FY13-FY15)**
  - Plans for FY16
- **Additional CFS Projects at JSC**

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October 2015

CFS AES Project
Product Summary FY13 & FY14

- FY13 Products
  - CFS on Orion/B787 Platform – CFS on Partitioned Green Hills RTOS
  - Quad-Voting CFS System – CFS on Partitioned VxWorks RTOS, synchronizing & voting 4 computers
  - CFS within Trick Simulation
  - Distributed CFS – network-based software bus additions
  - Reusable Certification Test Suite (begin)
- FY14 Products
  - Class A CFS Certification on Integrity ARINC-653/Orion Primary Flight Platform
  - Performance Monitoring Tool
  - CFS Synch & Voting Software Development
  - Product Line
  - Command & Data Dictionary Ground Database Tool
  - Education/Outreach

AES CFS FY15 Software Tasks & Status

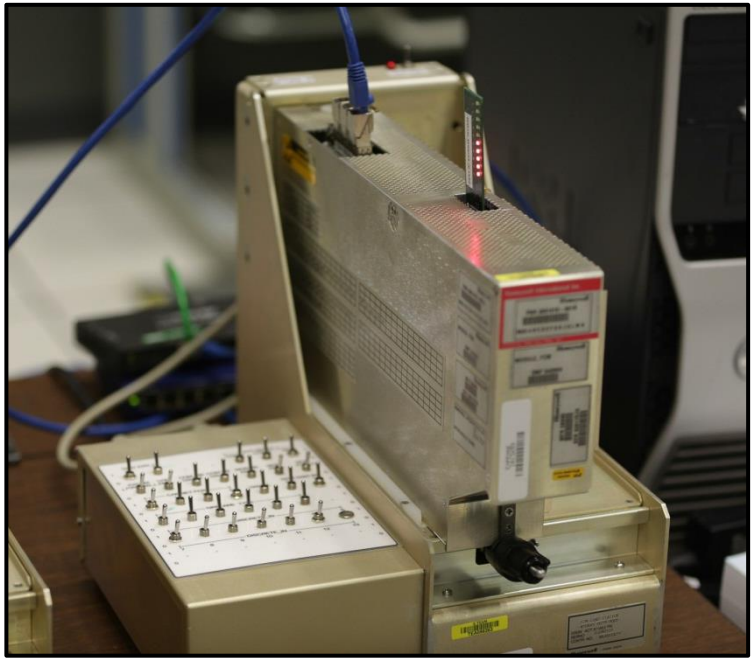
Major Tasks for FY15

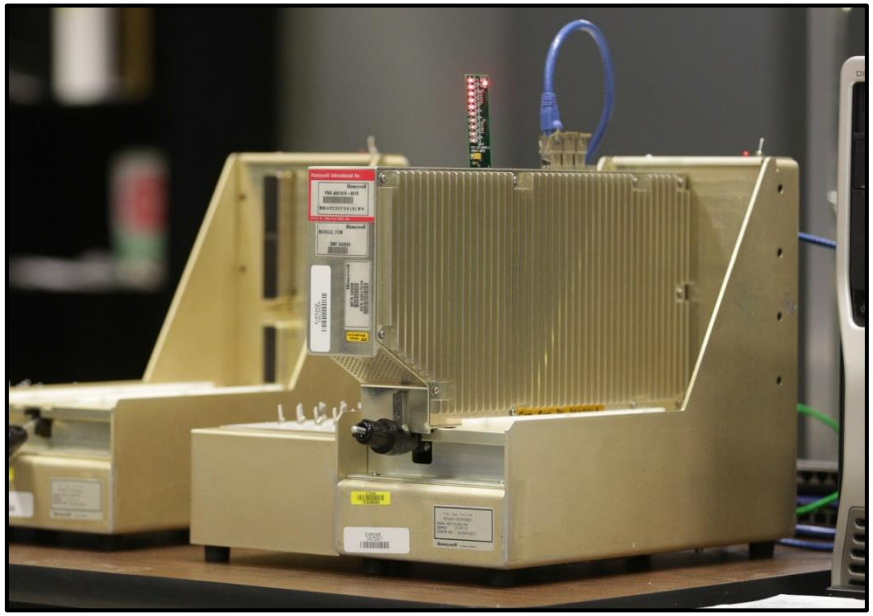
- CFS Class A Certification on VxWorks/LEON3 — Complete
  - Will be delivered to Orion program an GOTS after merge with main product line
  - Full-coverage UT Assert unit test suite
  - API unit tests
  - Vertical Integration tests
- Other AES Projects: — Ongoing, Much progress
  - Integration of AES Habitat Apps with CFS Message Bus/SBN
  - Migration of Autonomy Applications within CFS Framework

Additional Tasks for FY15

- Orion Backup Prototype/Analysis with CFS/LEON3 — Complete *(Demo Jan 2015)*
- Generic Command & Telemetry Apps — V1 Complete *(Demo 9/2015)*
  - CFS Communication Interface with C3I Standard — Complete *(Demo 9/2015)*
- CFS Synch & Voting Software Development — Added TTGbE *(Demo 9/2015)*
- Command & Data Dictionary Tools — 2 Tools *(Demo 9/2015)*
- Product Line — Active and Evolving
- Education / Outreach — Progress, Completion FY16
- Symmetric & Asymmetric Multicore Development — Deferred FY16

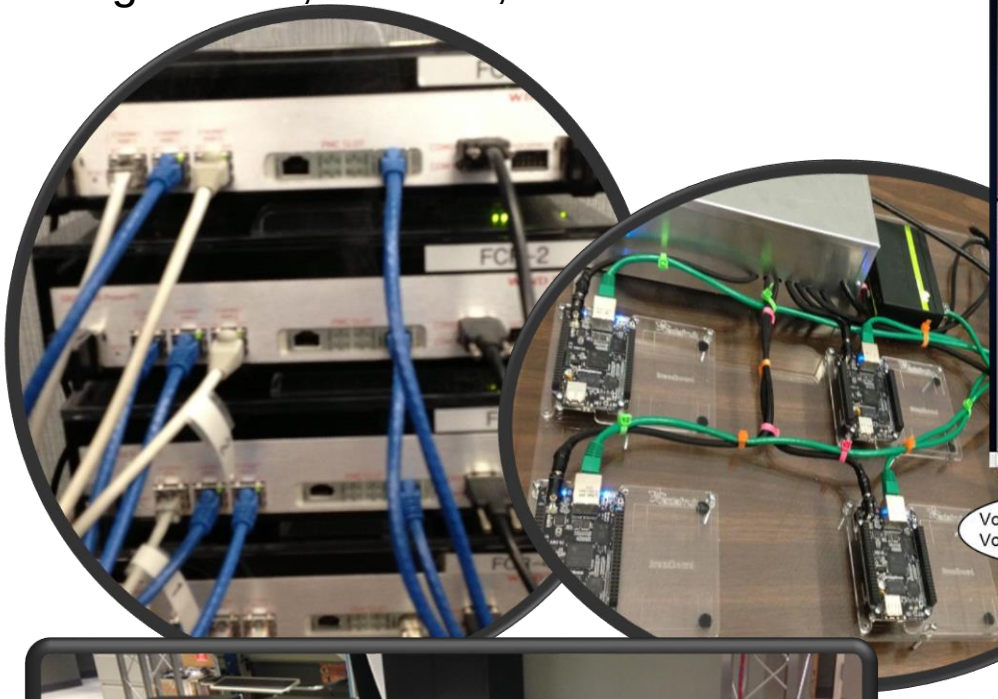
CFS on Partitioned ARINC-653 OS/B787 Class A Product Team



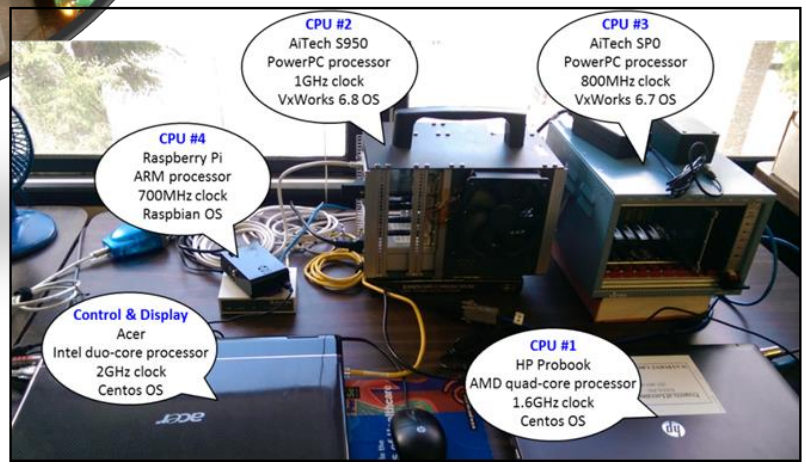


Synchronization & Voting

Homogeneous Voting:
Beagle Bone, Rad750, SP0



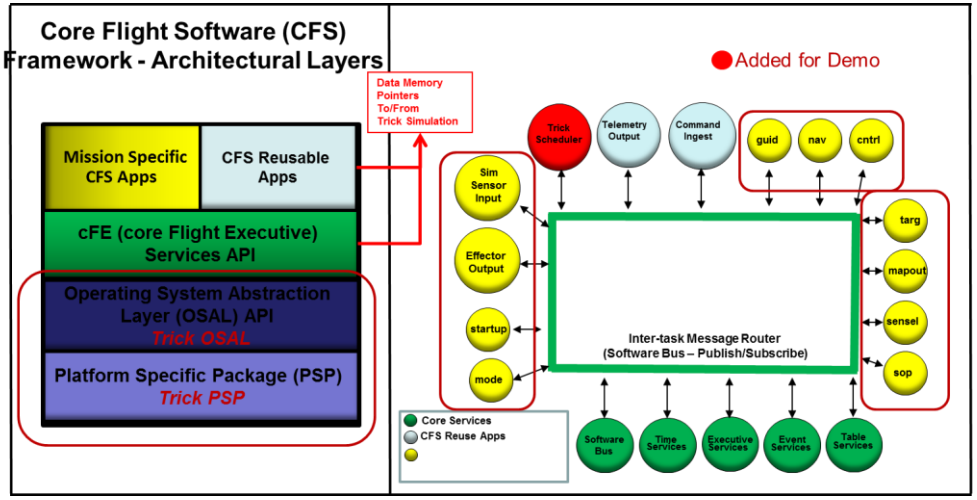
FY15 Sync & Voting over TTGbE

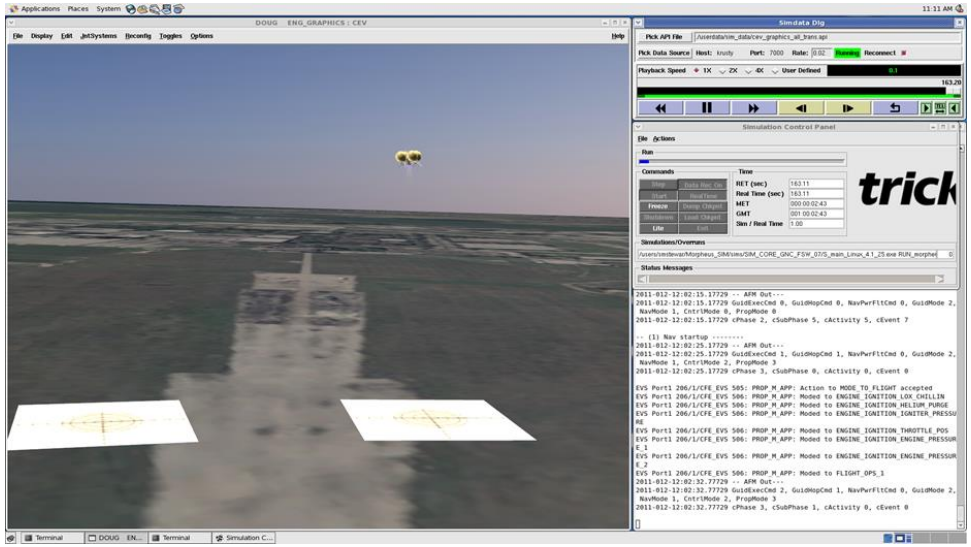


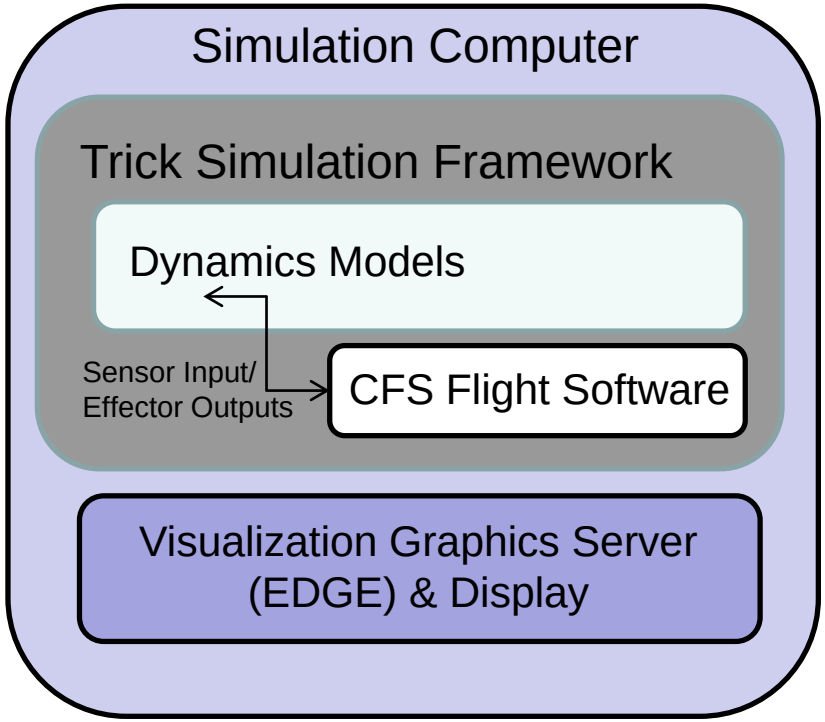
Heterogeneous Voting, Ethernet

CFS Embedded in Trick Simulation (single executable, Trick scheduler used)

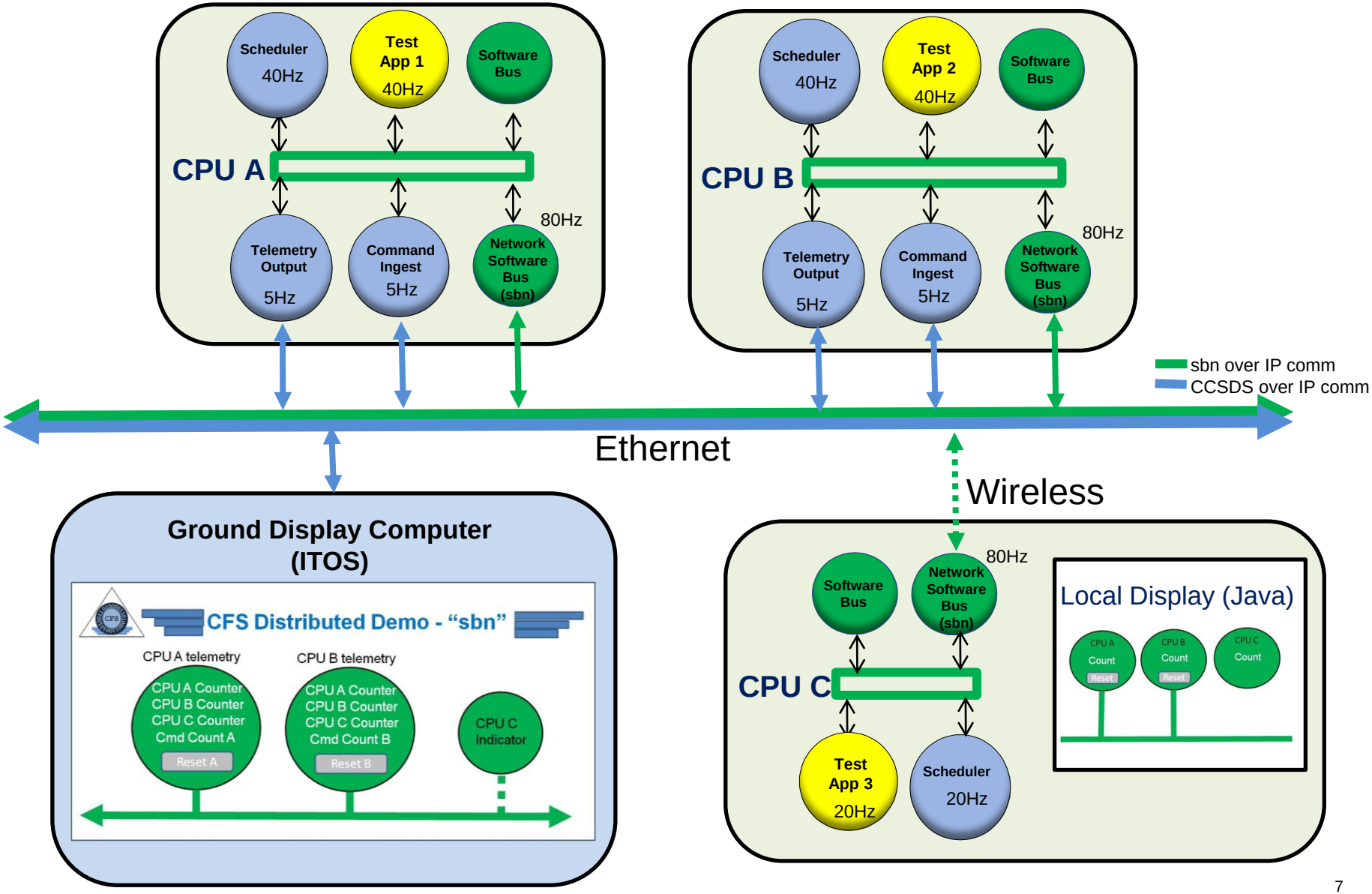
Morpheus Simulation w/ Flight Software







Distributed CFS Demo Configuration



Integrity/Orion Certification Testing Pics

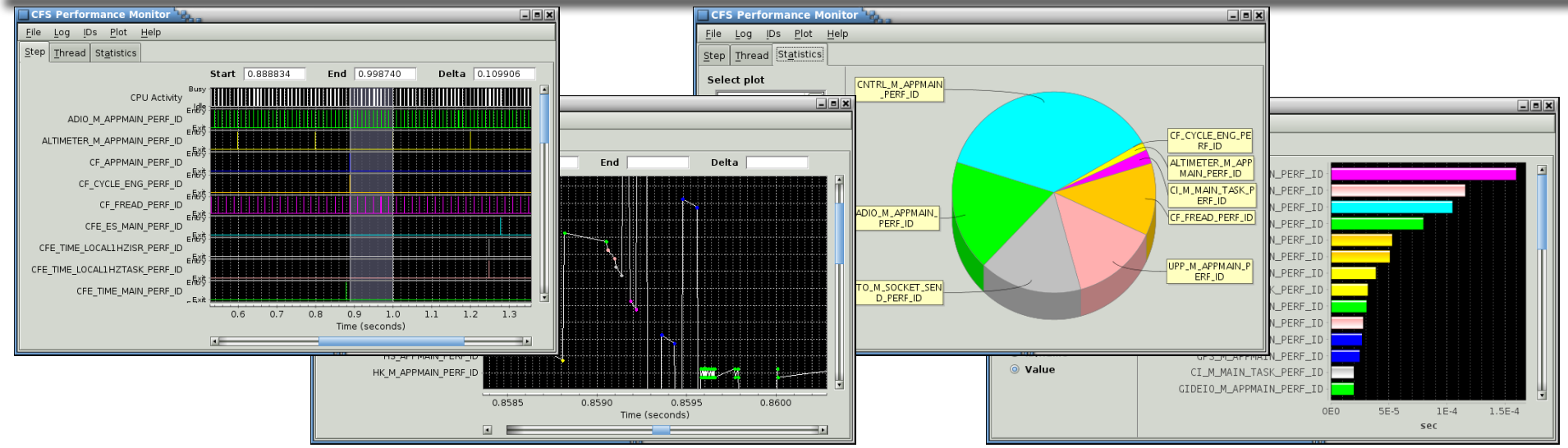
Verification testing on "SIMICS" hardware simulation platform

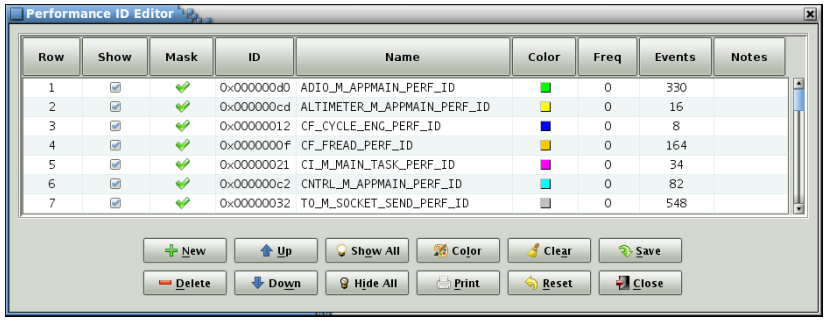
Kedalion Lab, Houston Remote Login

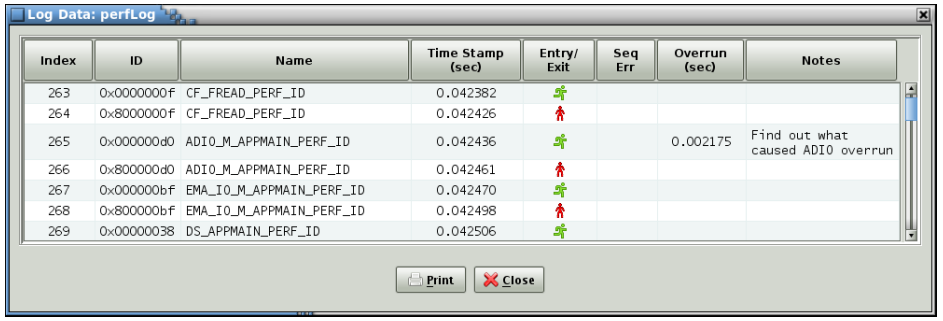
Validation testing on Orion Self Checking Pair EFT-1 rig

HOTH Laboratory, Lockheed Facility, Houston

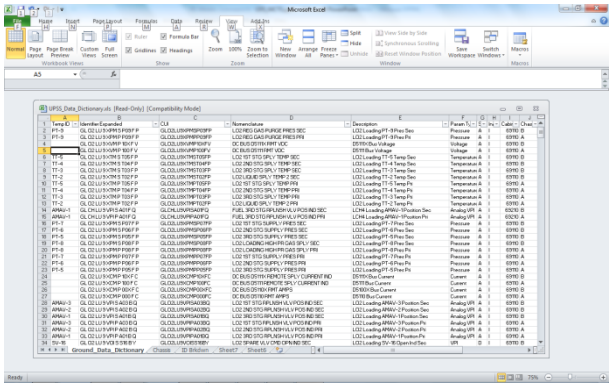
Performance Monitoring Tool Screenshots

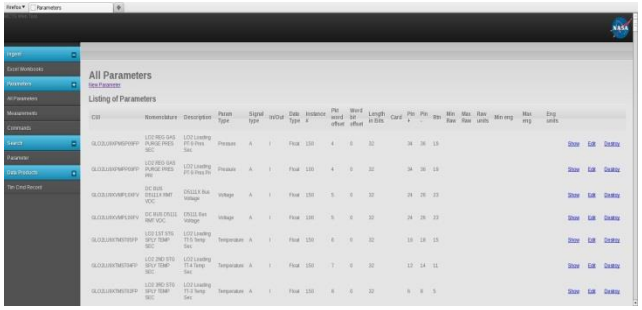






Mobile Command and Telemetry System

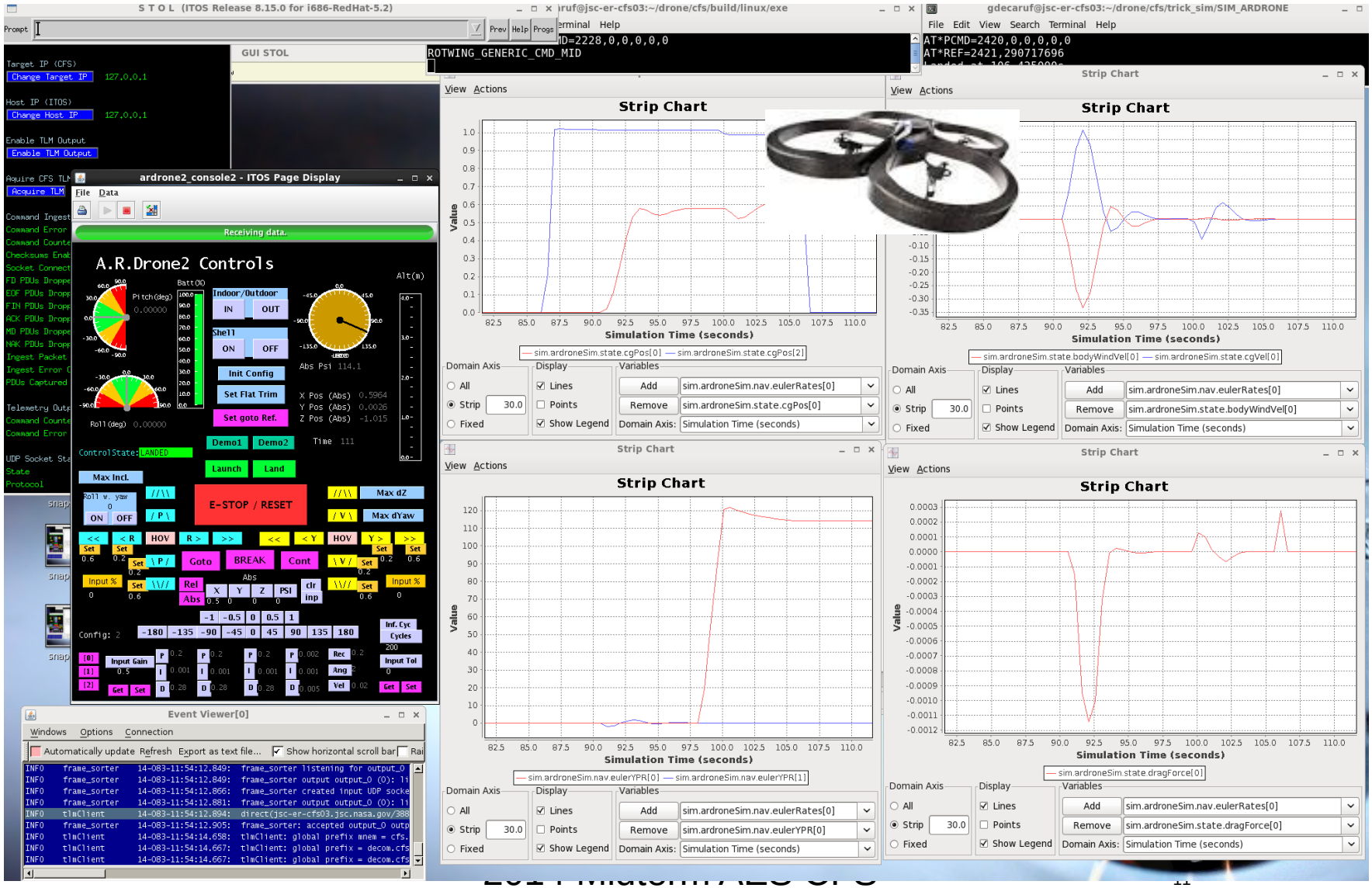




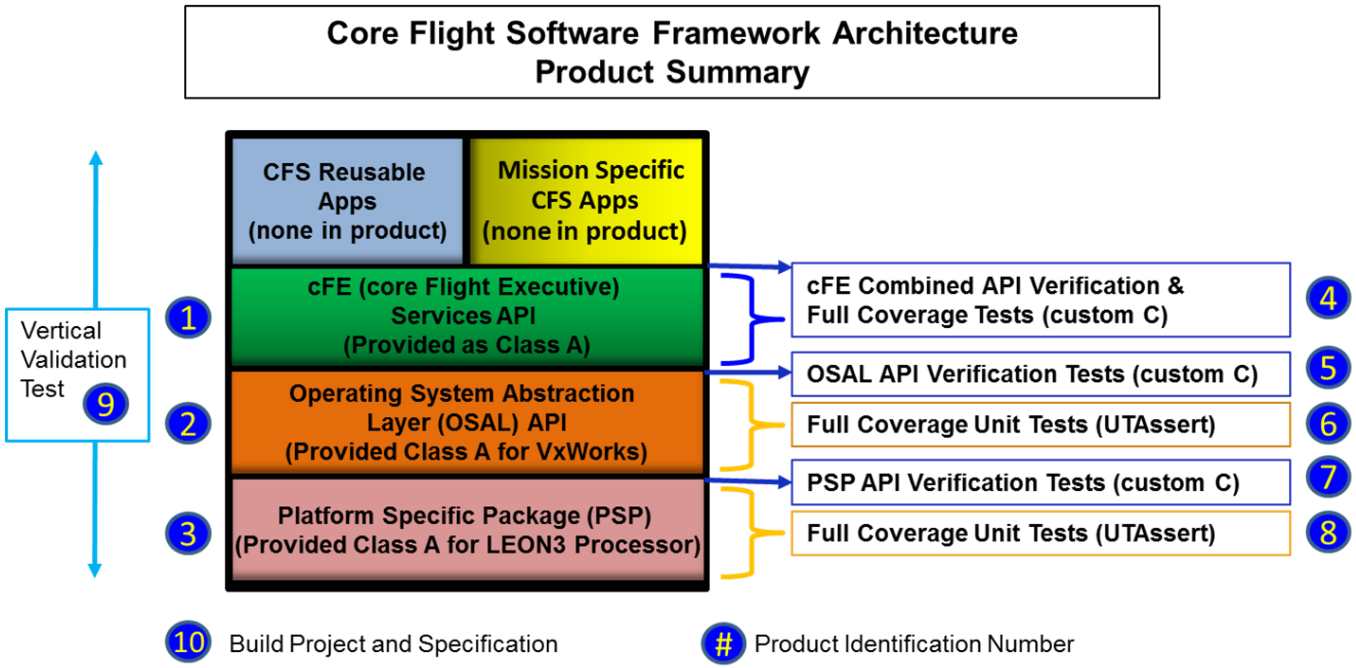

```
/*  Define graph for CCSDS processing of test PLC commands */
Graph gatewayCommandGraph{
        connections={
                /* Connect ccsds output to echo input */
                /* PortConnection{p1=cmd_ccsds.output  p2=echo.input},*/
                /* Connect echo output to network transmit input */
                        PortConnection{p1=echo.output  p2=UDP.input},
        },
        /*  Echo commands before they are transmitted  */
        itos.graph.EchoComponent.Type echo{},
        /*  Transmit command packets out gateway  */
        itos.graph.UDPSocketComponent.Type UDP{
                        configuration{
                                        foreign_host            {initialValue="XXX.XXX.XXX.XXX"},
                                        foreign_port            {initialValue="YYYY"},
                                        associate_on_start      {initialValue=1}
                                }
        }
},
DiscreteConversion offOnConv{
        Dsc Off {range=0, bgColor=blue, fgColor=white}
        Dsc On {range=1, bgColor=green, fgColor=white}
}
DiscreteConversion unknownOpenConv{
        Dsc Unknown {range=0, bgColor=blue, fgColor=white}
        Dsc Open {range=1, bgColor=green, fgColor=white}
}
DiscreteConversion openClosedConv{
        Dsc Open {range=0, bgColor=blue, fgColor=white}
        Dsc Closed {range=1, bgColor=green, fgColor=white}
}
DiscreteConversion openCloseConv{
        Dsc Open {range=0, bgColor=blue, fgColor=white}
        Dsc Close {range=1, bgColor=green, fgColor=white}
}
DiscreteConversion unknownClosedConv{
        Dsc Unknown {range=0, bgColor=blue, fgColor=white}
        Dsc Closed {range=1, bgColor=green, fgColor=white}
}

/*  Define graph entry point for PLC commands */
CommandDestination gatewayCommandDestination{
        port=gatewayCommandGraph.echo.input
},
```

- KSC developed general purpose data integration tool for managing command and telemetry metadata
- Intended to be generic in nature and applicable to any project using CFS or ITOS
- Web based interface built with Ruby on Rails
- Data can be ingested from a variety of formats including flat text files or Excel spreadsheets
- Imported into PostgreSQL relational database on which a wide variety of queries and reports can be run from MCTS provided GUI screens
- Currently capable of exporting data directly into ITOS compatible data record format
- Future enhancements include exporting data to XTCE format files as well as ‘C’ type data structure statements for compiling into CFS application code
- Demonstration held August 2014

Education/Course Idea: CFS on AR Drone Embedded with Trick Controls & Simulation



CFS VxWorks/LEON3 Class A Product/Test Suite Summary

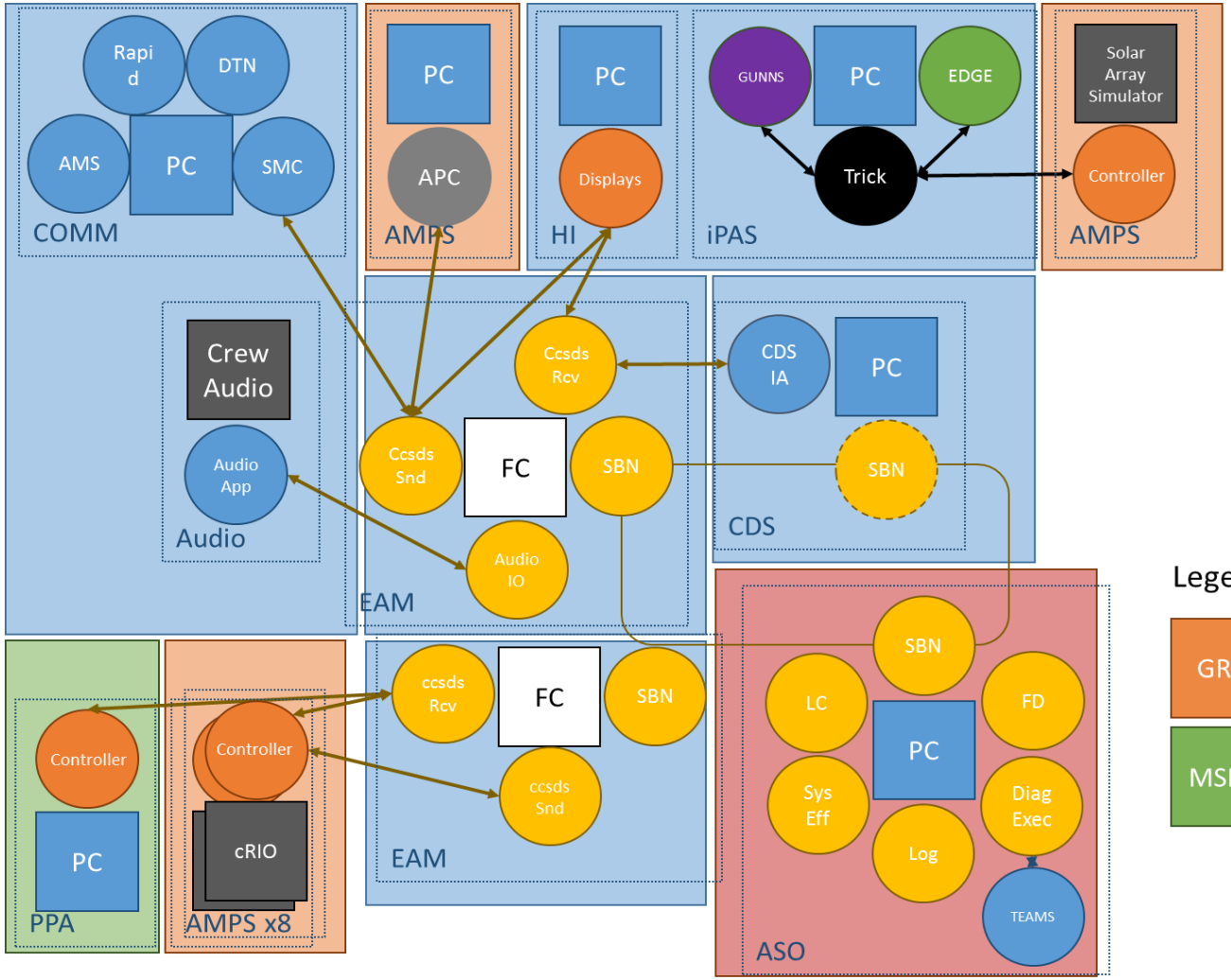


VxWorks Test Code Summary (FY15)			
Name	**Test Runs**	**Test Cases**	**SLOC (physical)**
cFE API & Unit Tests	18	1327	25916
OSAL API Verification Tests	6	377	7337
OSAL Coverage Unit Tests	7	612	11787
PSP API Verification Tests	5	76	1437
PSP Coverage Unit Tests	9	150	4072
Vertical Integration Test	1	1	5697
Totals	46	2543	56246

Products Include Full Documentation

- Test matrix
- Test Plan, Procedures, Report
- VDD, User's Guide
- Code inspections,
- static analysis results & actions
- Coverage analysis results & actions

AES Project Integration with CFS/sbn (FY15) (Habitat DRM)



- AMPS – AES Modular Power System
- AMS – Asynchronous Message Service
- APC – Autonomous Power Controller
- ARC – Ames Research Center
- ASO – Autonomous System Operations
- ccsdsRcv – CFS user app
- ccsdsSnd – CFS user app
- CDS – Cascade Distillation System
- COMM – Communications System
- cRIO – compact reconfigurable I/O
- DiagExec – Diagnoser Executive app
- DTN – Disruption Tolerant Networking
- EAM – Exploration Augmentation Module
- FC – flight computer
- FD – Failure Detector app
- GUNNS – General Use Nodal Network Solver
- GRC – Glenn Research Center
- HI – Human Interfaces
- IA – interface app
- iPAS – integrated Power, Avionics, &Software
- JSC – Johnson Space Center
- LC – Limit Checker app

Legend

- MSFC – Marshall Space Flight Center
- PC – personal computer
- PPA – Plasma Pyrolysis Assembly
- RAPID – Robotic control standard
- SBN – Software Bus Network app
- SM&C – Space Craft Monitoring and Control
- SysEff – System Effects app
- TEAMS – Real-time diagnostics and reasoner

AES AMO Project: Vehicle Systems Automation

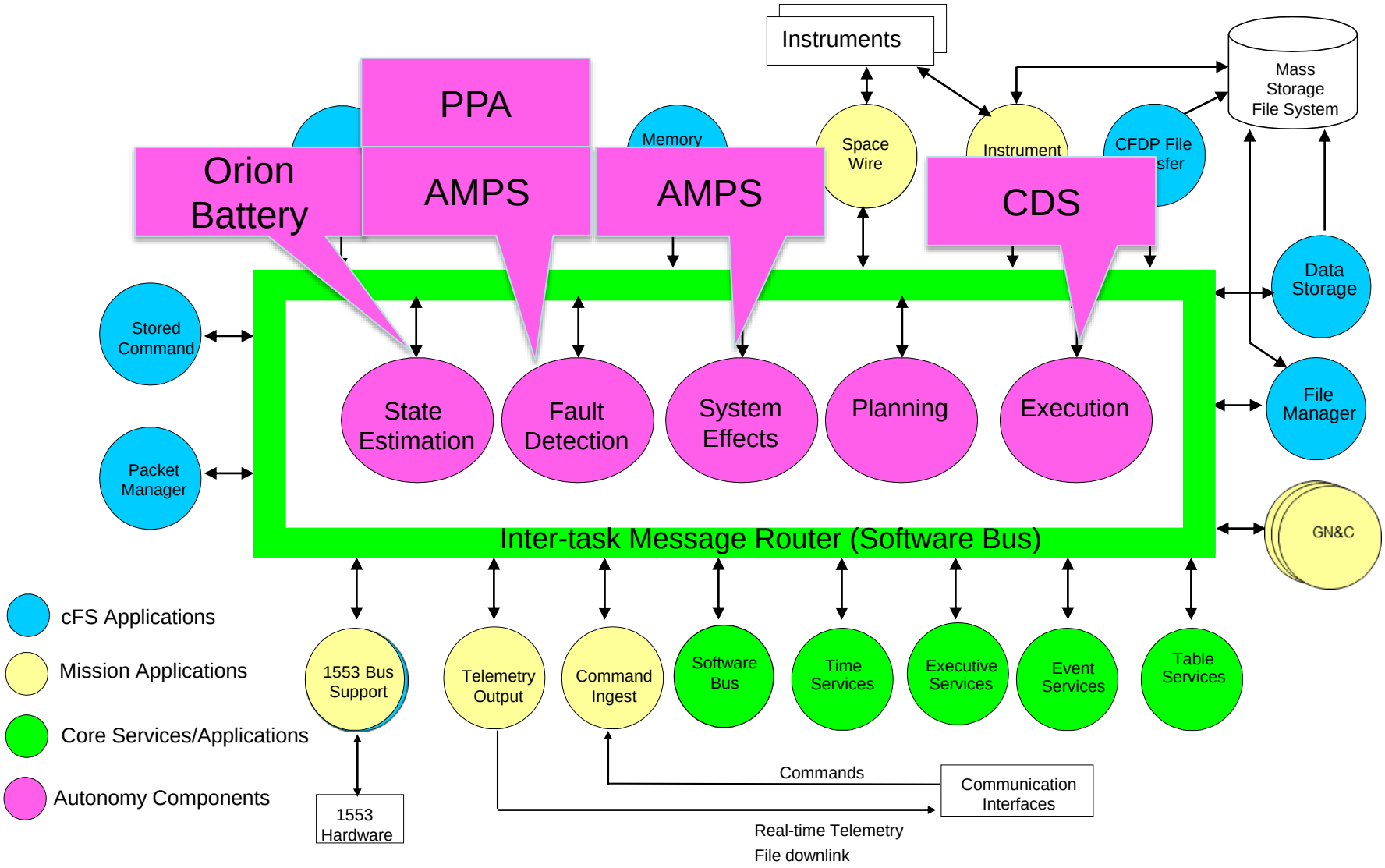
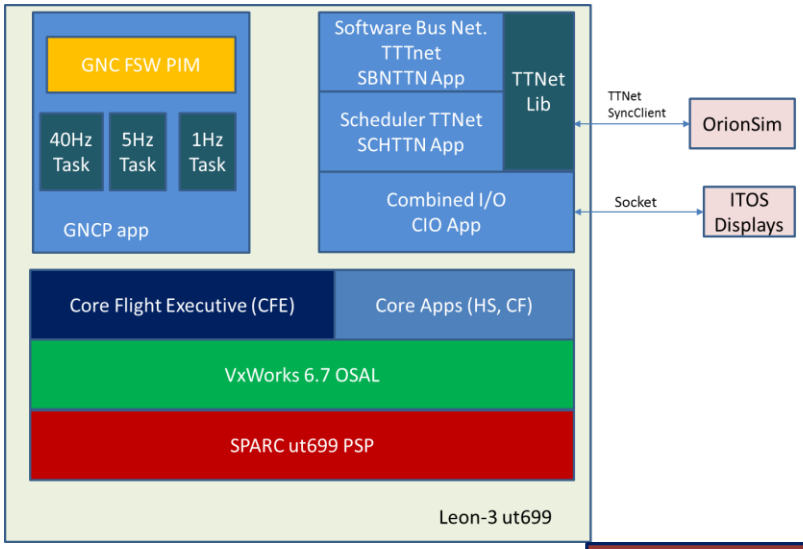
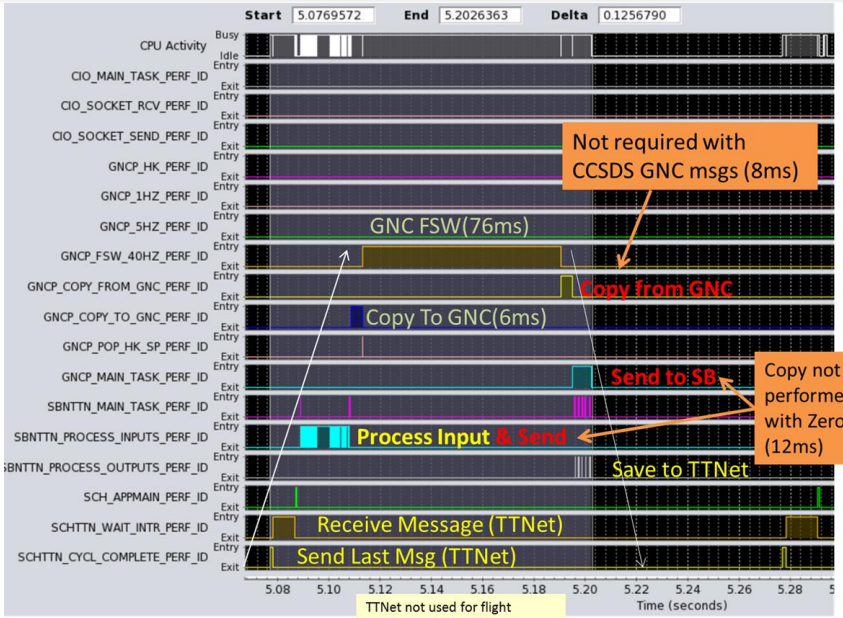
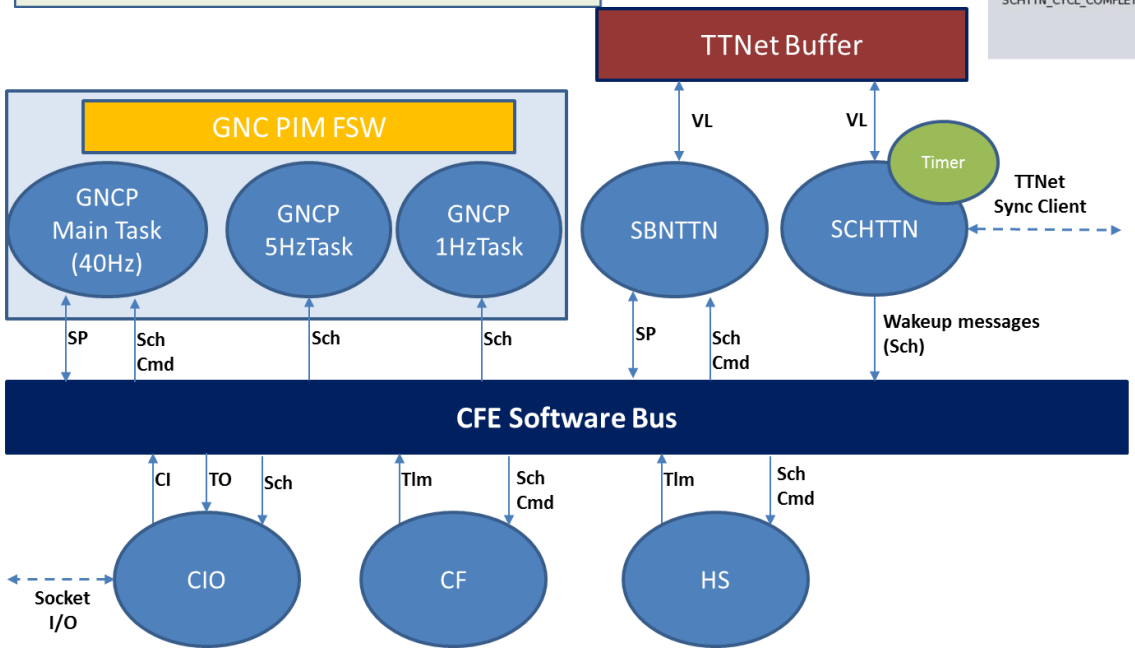


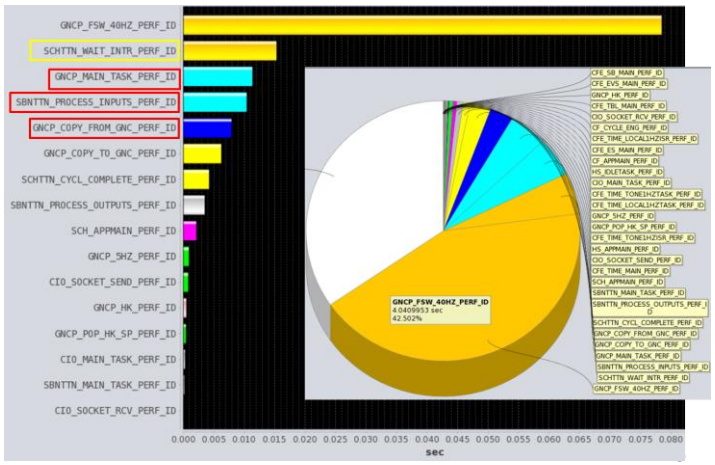
Chart obtained form FY15 AES AMO End of Year Review / Jeremy Frank / ARC

Orion Backup Computer Proof-of-Concept Architecture (EFT-1 Flight Code under CFS on LEON3 Processor)





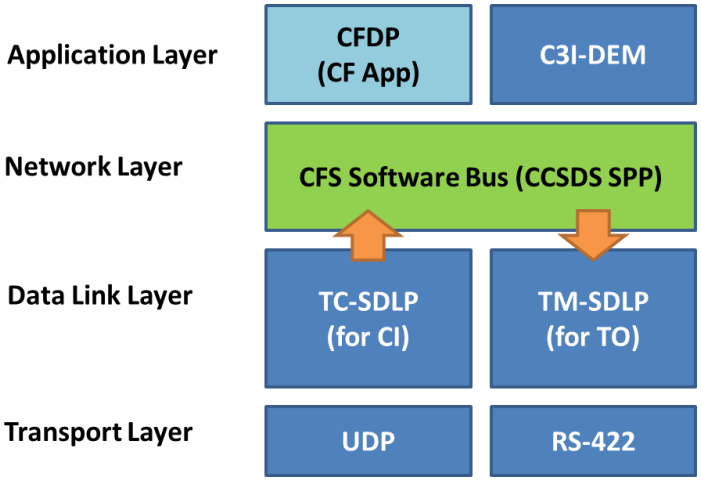


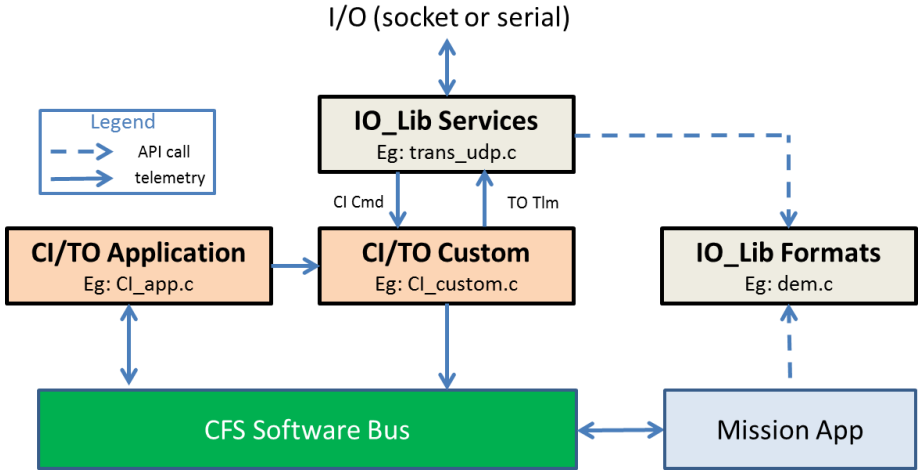


Generic TO/CI Apps with C3I Interface

Product Summary

- New applications to handle Command Inputs / Telemetry Outputs
- Designed such that it can be easily expanded and customized for specific mission needs through a library suite called IO_LIB.
- Multiple channels supported, reconfigurable through CFS tables
- Supports communication over UDP and RS-422
- CCSDS Space-Data Link Protocols: TM-SDLP, TC-SDLP, COP-1
- Integration with the File Transfer Application (CF) for CFDP file transfers

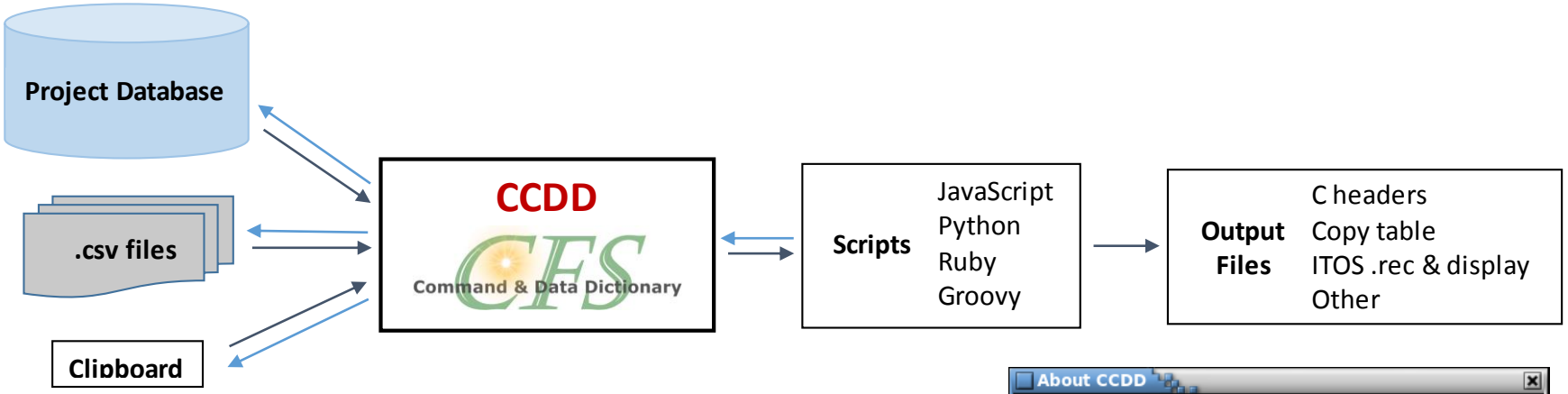




CFS Command & Data Dictionary Tool (CCDD)

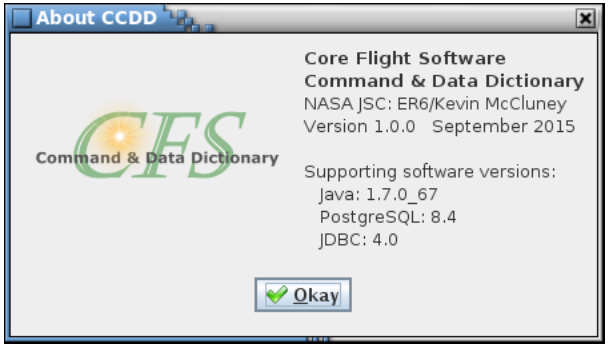
Product Summary

- Provides a means for managing CFS and CFS application variable structure and command message information in a PostgreSQL database
- Data can be accessed by user-defined scripts using built-in access functions; e.g., to create output files (C headers, HK copy table, etc.)

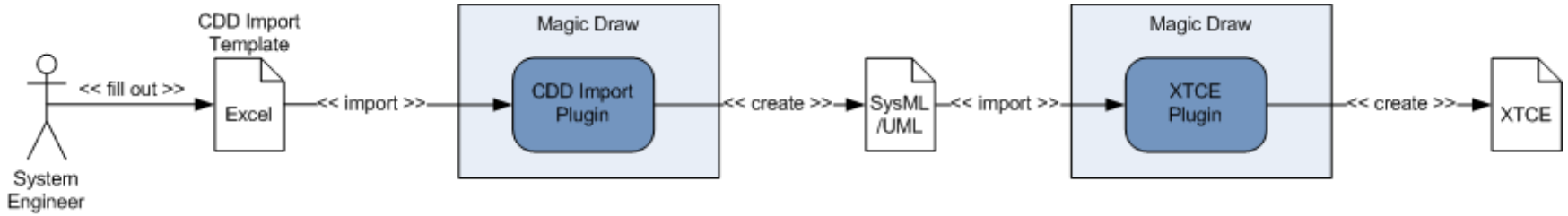


Demo Description

- Basic application functionality
  - Project creation
  - Data entry
  - Data customization
  - Script access



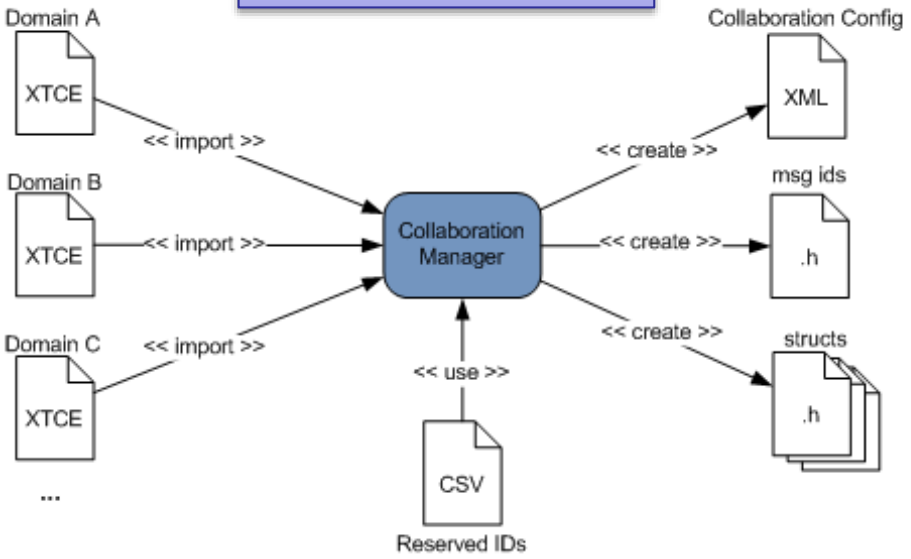
Collaboration Manager Tool



System Engineer describes system command and telemetry lists

System representation SysML model is generated

XTCE files describing system representation is generated



XTCE files used to create other product files

Message IDs pulled from available user app pool

Larry Garner/Tietronix

CFS Supported Platforms
(non-exhaustive)

Platform	OS	Project	Status / Notes
RAD750	vxWorks 6.4	LRO,RBSP, GPM	Project tested.
RAD750	RTEMS 4.10	ICESat-2/ATLAS	Early in instrument test program
Rad Hard Coldfire (5208)	RTEMS 4.10	MMS	Project tested.
LEON3	RTEMS 4.10	Solar Probe Plus	In Development for SPP mission
MCP750 PPC	vxWorks 6.4	cFE/CFS Project	Tested. Used as baseline CFS development platform.
PC / x86	Linux	n/a	Not formally tested. Used by JSC.
Coldfire MCF5235 board	RTEMS 4.10	n/a	Not formally tested. Used for RTEMS Development, and MMS board.
LEON3 – generic – (simulator, multiple COTS boards)	RTEMS 4.10	n/a	Not tested. Not in CFS CM. Used for LEON3 development. Can be used on LEON3 Simulator.
Coldfire Simulator (qemu 68k)	RTEMS 4.10	n/a	Not formally tested. Used for OSAL / cFE development
TILERA	Linux	Maestro IRAD (FY12)	Not formally tested. Compatible with Desktop PC linux version.
MCP750 PPC	vxWorks 6.x	Memory Protection IRAD (FY11)	Adds memory protection to standard cFE. Not formally tested. Not integrated with cFE repository.
PC x86	Linux	Multi-Core IRAD (FY12)	Adds multi-core CPU capability to cFE. Not formally tested. Not integrated with cFE repository.
Leon3	PikeOS	Virtualization IRAD (FY12)	Adds ability to run in partitioned OS. Prototype. Not integrated with cFE repository.

Platform	OS	Project	Status / Notes
Aitech S950 (PPC750FX)	vxWorks 6.7	Morpheus	In JSC CM. Integration tested on real Morpheus Vehicle hardware. Flown on Morpheus test vehicle.
RTD pc386-IDAN, PC104, Pentium M	RTEMS 4.10	ISS Downmass/Micro Capsule	In JSC CM. Integration tested on real Micro Capsule hardware.
RTD IDAN Core 2 Duo	SUSE Linux	DoD Payloads Office STPSat-4	In development. Used only for C&DH, payload data handling, data recording(ds), file downlink (CFDP,) extensive onboard autonomy (sc)
Acro Virtex 5	VxWorks 6.9	AEMU	In development.
Space Micro Proton P400k	VxWorks SMP 6.8	MMSEV, AAE	In JSC CM. MMSEV FY13.
Maxwell SCS750	VxWorks 6.9 RTEMS 4.10	EAM, AAE	In JSC CM. EAM/DSH
787FCM	Integrity ARINC	AES CFS	In JSC CM. Class A cert. ARINC653 cFE, OSAL.
OrionSCP	Integrity ARINC	AES CFS	In JSC CM ARINC653 cFE, OSAL.
750FCR	VxWorks ARINC 6.8	AES CFS	In JSC CM FTSS SW fault containment with a voting quad architecture.
Trick (simulation environment)	Linux	AES CFS	In JSC CM RPM
LEON3	VxWorks 6.7	Orion BFS	In JSC CM. Class A cert. BFS prototype. Currently in ic-sgd-dev-trac-10-merge branch, release Dec 2015
AiTech SP0	VxWorks 6.9	AES Voting, RPM?, AA2?	Currently in ic-sgd-dev-trac-10-merge branch, release Dec 2015
BeagleBone, Raspberry Pi	Linux, Raspian Linux	Misc, voting, outreach/drone	

AES CFS FY16 Tasks/Tentative

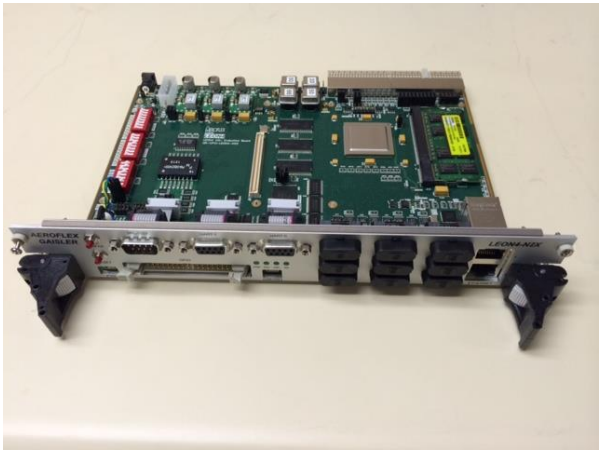
Task Name	Focus, activities, description
Product Line	Community Product Line: CCB, product evolution, changes, merges, open source releases
AES Project Deployment	Continue deployment of CFS products in "field" of other AES projects and/or users Continue migration of AES project apps to CFS
Multicore	- Get Symmetric Multicore Processing (SMP) OSALs working on LEON4 & Tilera 36 - Get Asymmetric Multicore Processing (AMP) environment set up on LEON4 & Tilera 36 - Perform SMP Analysis - load balancing with processor intensive apps & characterize performance - Perform AMP Analysis – - Investigate multiple OS's/Hypervisor on different cores - different applications on different cores, - sbn between cores - put synch/voting on selected cores - Put autonomy apps on cores & measure performance
Generic TO/CI	- Enhancements to support outstanding requirements/design items approved for implementation - Enhancements in support of Orion DEM updates
Sync/Voting	- Apply to real-world application (AA-2 GNC) - Study, stress & characterize performance on TTGbE with real applications using data
Xenomai OSALs	- Get default-skin Xenomai version of CFS running on UEIPAC platform - study performance with sample apps & timing tests - modify OSAL if necessary, get new PSP working - Develop partitioned version of Xenomai for CFS - Utilize test applications on partitions & study performance
sbn	- Acquire latest & stress test - Merge latest sbn into product line - Stress test performance with multiple deployments on multiple machines and higher speeds - Enhance as Needed supporting multiple AES distributed projects
CCDD	- Complete development, adding XML, XTCE & clean up - Possible add EDS - Deploy to uses & provide updates/maintenance/improvements as needed
Education/Outreach	- Complete deployment package for universities

Symmetric Multiprocessing CFS Development

- Symmetric Multiprocessing (SMP) Support
  - Description
    - Provide a generic SMP Operating System Abstraction Layer (OSAL) supporting multi-core processor architectures
  - Accomplishments
    - Prototype implementation of CFS on dual core Space Micro Proton board and VxWorks SMP complete
      - Apps can be allocated to specific cores to deterministically balance processing load or to improve performance of certain apps
  - Remaining Work (FY15)
    - Implement on SPARC LEON 4 quad-core, Tilera 36-core
    - Merge SMP support modifications into mainline CFS

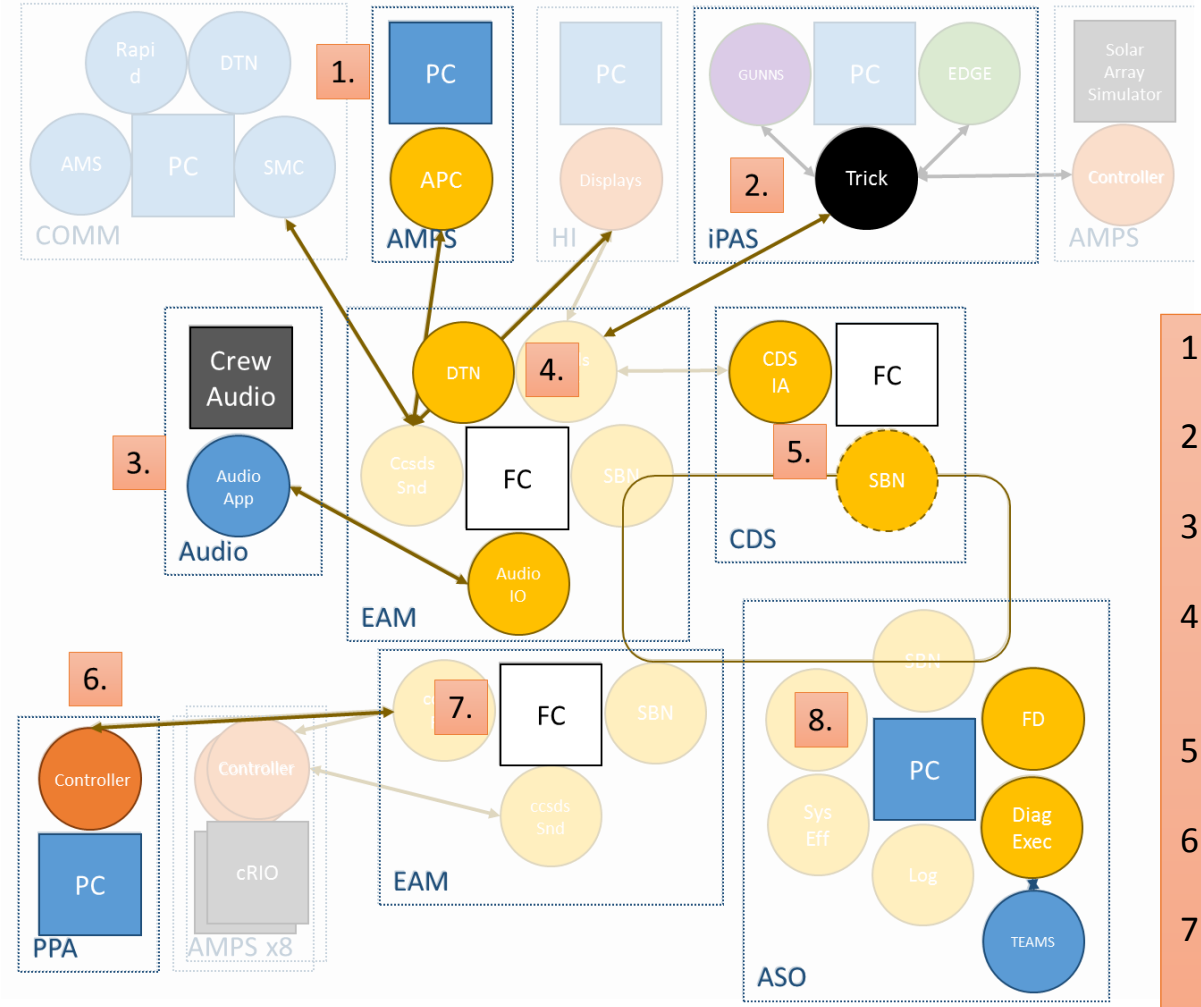
Proton

LEON4 quad-core



Tilera 36-core

FY16 Software development plan



Planned maturity for FY16

1. Mature AMPS Autonomous Power Controller (APC)
2. Enable telemetry from TRICK integrated vehicle systems simulation
3. Develop CFS controller app for onboard crew audio system
4. Deploy Disruption Tolerant Networking (DTN) capability onto flight computer platform
5. Mature embedded controller of Cascade Distiller System (CDS)
6. Expand CFS/LabVIEW interface of Plasma Pyrolysis Assembly (PPA)
7. Deploy CFS builds to path-to-flight model avionics
8. Expand fault detection models within Autonomous Systems Operations (ASO) suite

Projects Use of CFS at JSC

- Morpheus Lander (VxWorks, Aitech S950)
- AES CFS, Avionics & Software Projects (already discussed)
- MMSEV (VxWorks, S950)
- Downmass MicroCapsule (RTEMS, Pentium)
- Other AES Projects:
  - Advanced IMU Space Suit (Linux, Vertex 5 microblaze)
  - ASO, DTN, CDS, AMPS…
- DoD Payloads Office STPSat-4 Deployed Payload (SUSE Linux, RTD IDAN Core 2 Duo)*
- Orion Vision Processing Unit (VPU)*
  - Includes Backup Flight System (BFS) (VxWorks, LEON3)
- Orion Video Processing Unit (Linux, I5)*
- Orion AA-2 Flight Experiment (VxWorks, TBD)*

* Flight Projects in Development

Morpheus Software Components

Software Reuse
New Software

Flight Software

C

CFS Core Apps | Morpheus Specific Applications | Custom Sensor/ Effector Apps

CFS Infrastructure (Goddard)

VxWorks 6.7 Operating System

PPC 750GX Processor, cPCI (AiTech)

I/O Devices (Serial, 1553, A/D)

Tool Chain

Open Source

- VMWare (local PC/Mac)
- Eclipse (local IDE)
- CentOS/Linux (local VM OS)
- GNU C/C++, Java (compile/Xlate)
- Subversion (CM)
- Redmine (change tracker)
- Hudson (build checker)
- UCC (code count metrics)
- Windriver Workbench (target IDE/OS)
- Parasoft C++test (standards checker)

Simulation Software

C++

EDGE Visualization

Morpheus Specific System & I/O Models

Dynamics, Time, Environment Models | JEOD

Generic Systems Models | Valkyrie

Trick Simulation Core (JSC)

Linux OS

Ground Software

Java

Displays & Controls

scripts

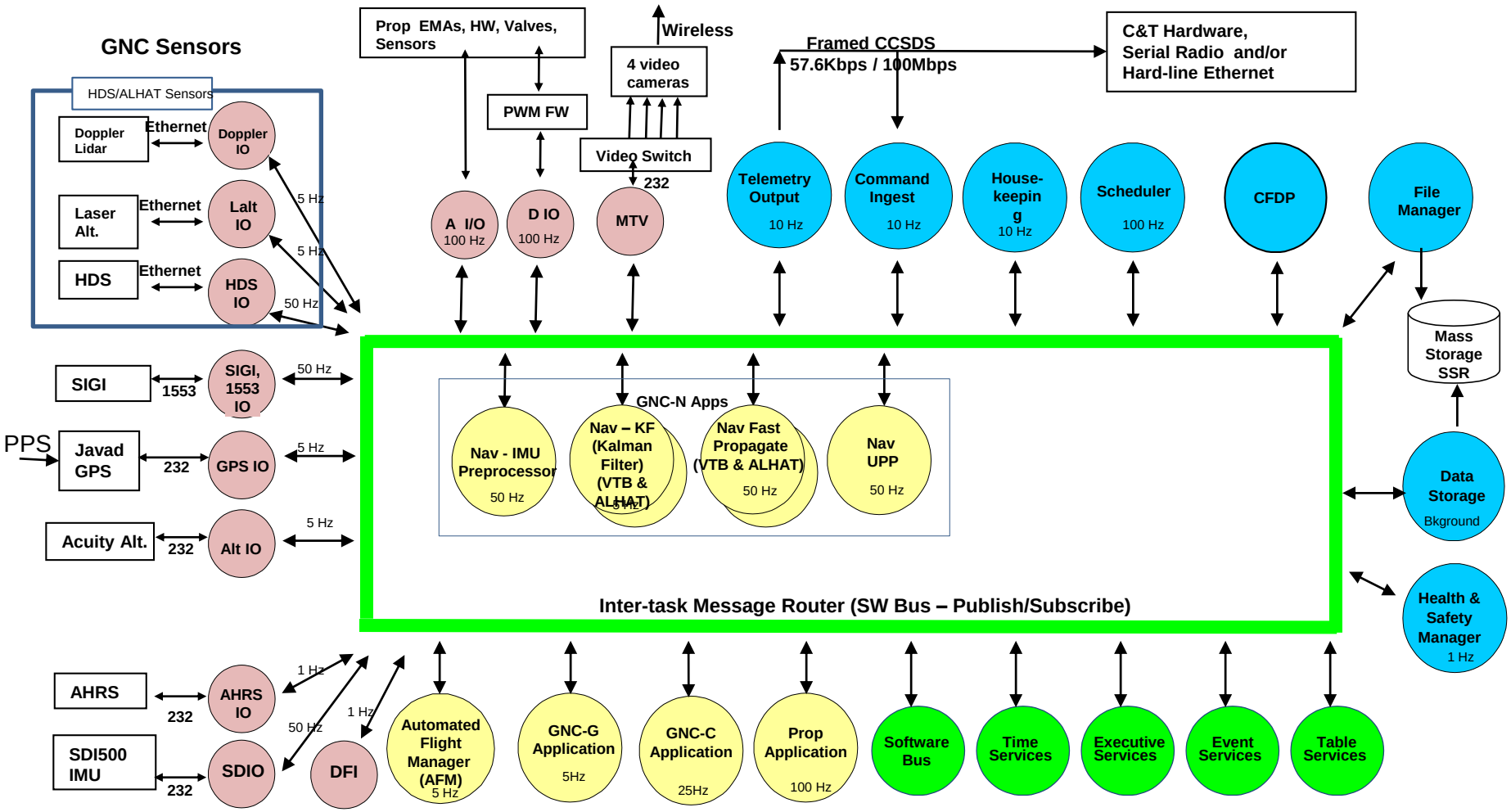
Database (postgreSQL)

Command & Data Dictionary

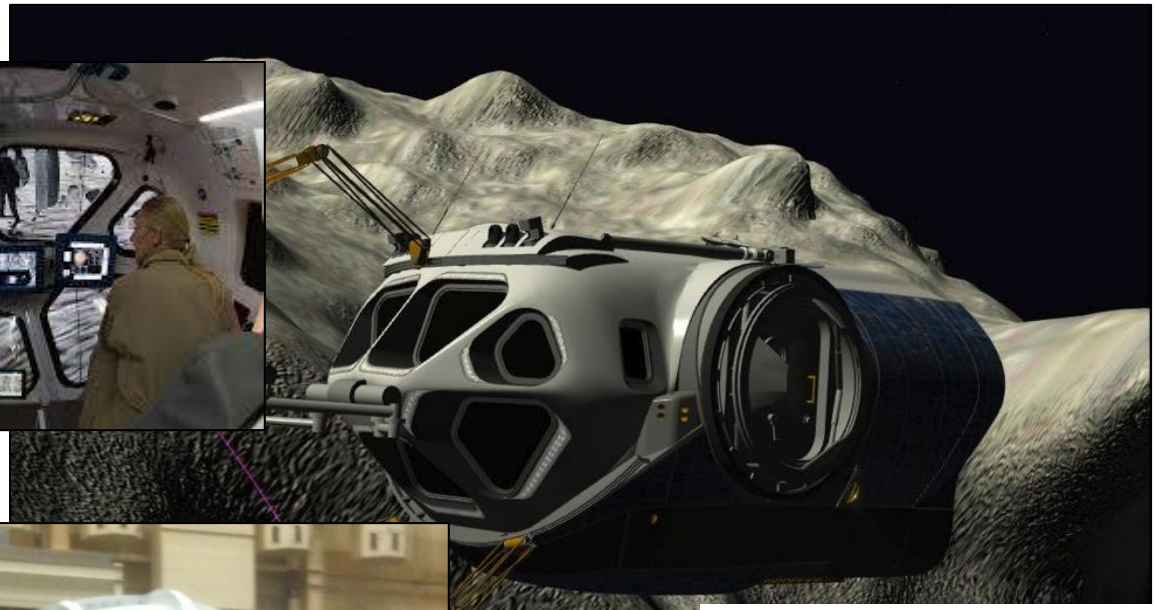
ITOS Infrastructure (Goddard)
(Data Com/Decom, Recon, Distribution, Display, Scripting, Recording, Post processing)

Linux OS

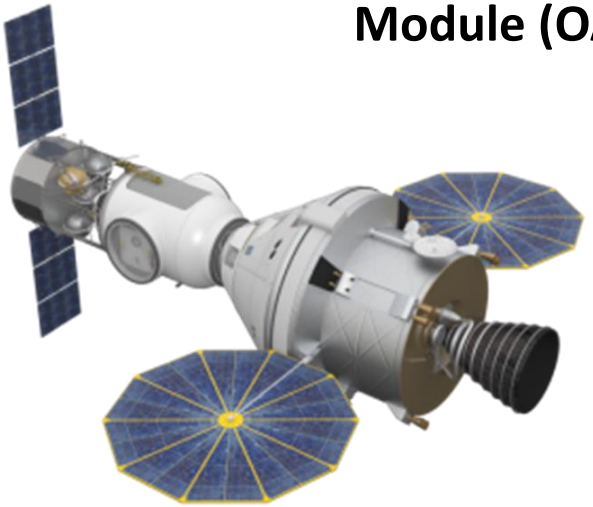
Morpheus Flight Software Architecture



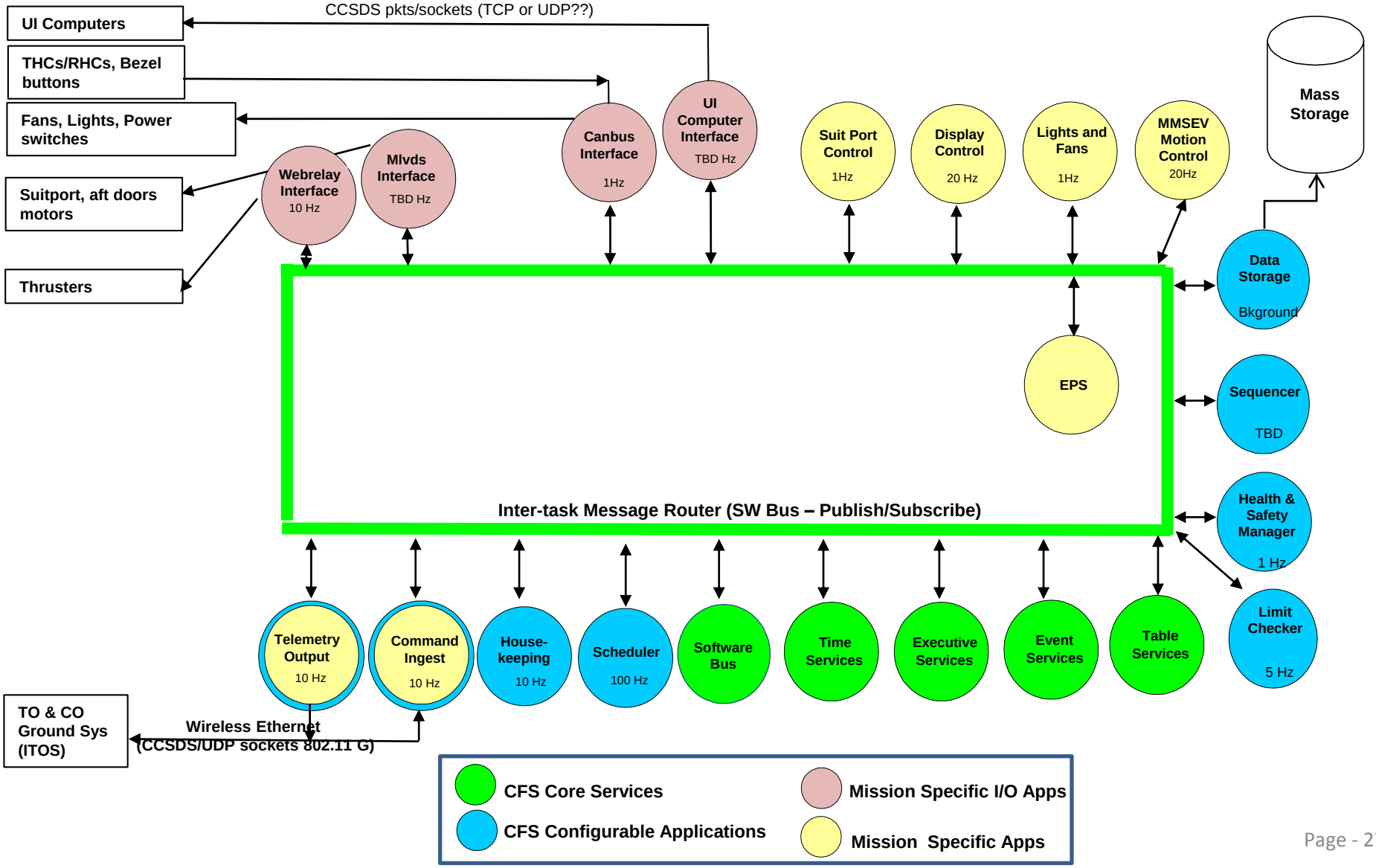
MMSEV



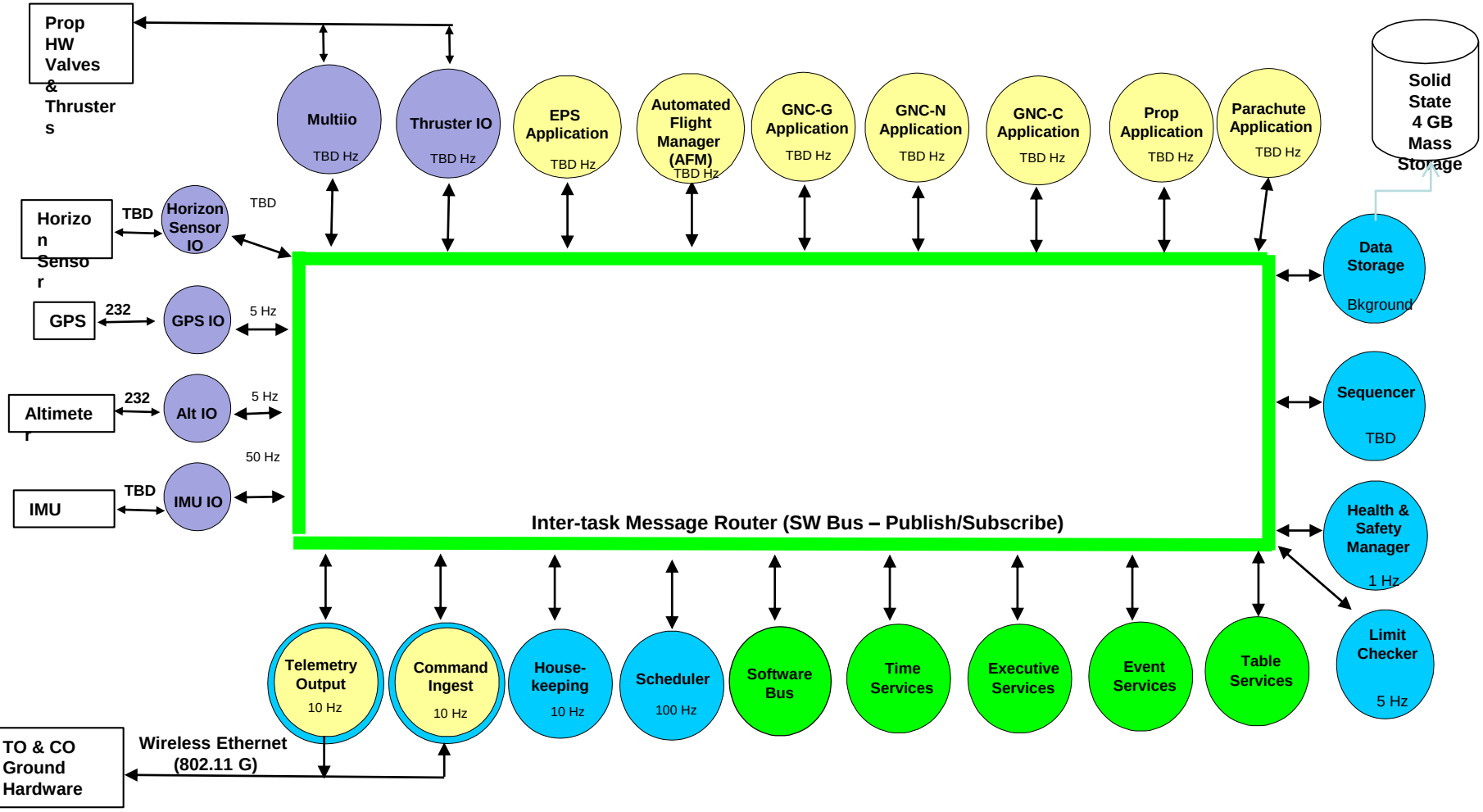
MMSEV – Orion Augmentation Module (OAM)



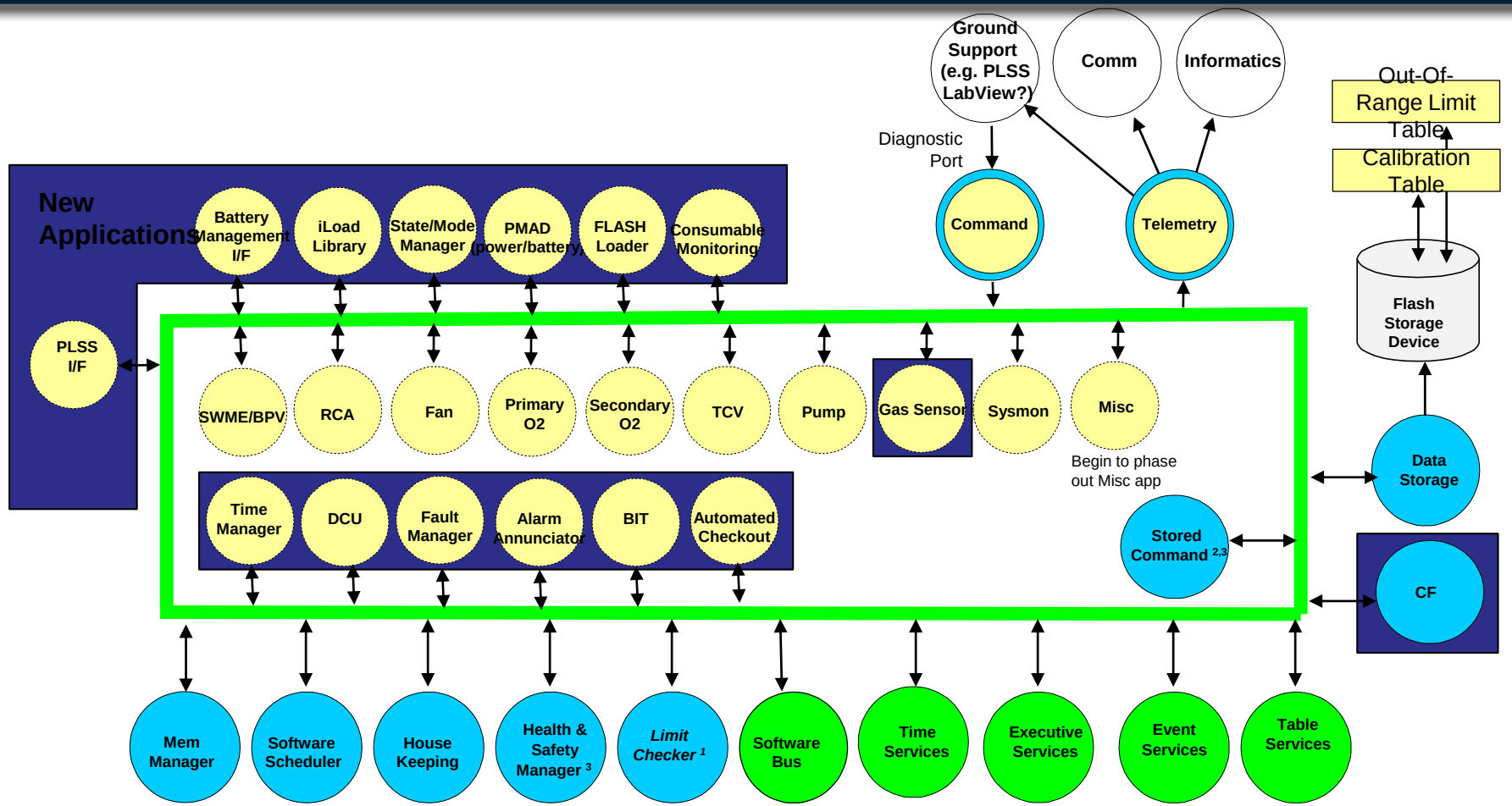
MMSEV CFS Architecture



Downmass Microcapsule Software Flight Software Architecture



Advanced Space Suite: CWA CFS Software Architecture



[1] Limit Checker provides AEMU C&W

[2] Stored Command provides Checkout & Configuration

[3] Limit Checker, Stored Command, H&S Manager provide Recover & Restore