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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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
    ▪ 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

Simulation Computer

Trick Simulation Framework

Dynamics Models

Sensor Input/ Effector Outputs

CFS Flight Software

Visualization Graphics Server (EDGE) & Display
Distributed CFS Demo Configuration

CPU A
- Scheduler 40Hz
- Test App 1 40Hz
- Software Bus
  - Telemetry Output 5Hz
  - Command Ingest 5Hz
  - Network Software Bus (sbn)

CPU B
- Scheduler 40Hz
- Test App 2 40Hz
- Software Bus
  - Telemetry Output 5Hz
  - Command Ingest 5Hz
  - Network Software Bus (sbn)

CPU C
- Scheduler
- Test App 3 20Hz
- Software Bus
- Network Software Bus (sbn)

Ground Display Computer (ITOS)
- Ethernet
- Wireless

Local Display (Java)

- Ethernet
- Wireless

Graphical Representation:

- Green lines: sbn over IP comm
- Blue lines: CCSDS over IP comm

Diagram Details:
- CPU A: Scheduler 40Hz, Test App 1 40Hz, Software Bus, Telemetry Output 5Hz, Command Ingest 5Hz, Network Software Bus (sbn)
- CPU B: Scheduler 40Hz, Test App 2 40Hz, Software Bus, Telemetry Output 5Hz, Command Ingest 5Hz, Network Software Bus (sbn)
- CPU C: Scheduler, Test App 3 20Hz, Software Bus, Network Software Bus (sbn)

Connections:
- Ethernet: CPU A - CPU B - CPU C
- Wireless: CPU A - CPU B - CPU C

Additional Elements:
- Ground Display Computer (ITOS)
- Local Display (Java)
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
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)

<table>
<thead>
<tr>
<th>Name</th>
<th>Test Runs</th>
<th>Test Cases</th>
<th>SLOC (physical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cFE API &amp; Unit Tests</td>
<td>18</td>
<td>1327</td>
<td>25916</td>
</tr>
<tr>
<td>OSAL API Verification Tests</td>
<td>6</td>
<td>377</td>
<td>7337</td>
</tr>
<tr>
<td>OSAL Coverage Unit Tests</td>
<td>7</td>
<td>612</td>
<td>11787</td>
</tr>
<tr>
<td>PSP API Verification Tests</td>
<td>5</td>
<td>76</td>
<td>1437</td>
</tr>
<tr>
<td>PSP Coverage Unit Tests</td>
<td>9</td>
<td>150</td>
<td>4072</td>
</tr>
<tr>
<td>Vertical Integration Test</td>
<td>1</td>
<td>1</td>
<td>5697</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>46</strong></td>
<td><strong>2543</strong></td>
<td><strong>56246</strong></td>
</tr>
</tbody>
</table>

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

- GRC
- JSC
- MSFC
- ARC
- PPA
- PC
- cRIO
- AMPS
- EAM
- SBN
- LC
- SysEff
- Log
- DiagExec
- TEAMS
- Controller
- AMPS
- PC
- Displays
- Audio
- Audio App
- Crew Audio

**Note:** The diagram illustrates the integration of various systems and controllers, highlighting the connections and interactions between different components.
AES AMO Project: Vehicle Systems Automation

Inter-task Message Router (Software Bus)

- State Estimation
- Fault Detection
- System Effects
- Planning
- Execution

PPA

AMPS

AMPS

CDS

Orion Battery

Stored Command

Packet Manager

Memory

Space Wire

Instrument

CFDP File Transfer

Mass Storage File System

Data Storage

File Manager

GN&C

1553 Bus Support

Telemetry Output

Command Ingest

Software Bus

Time Services

Executive Services

Event Services

Table Services

Real-time Telemetry File downlink

Communication Interfaces

Chart obtained from 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)
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

Legend:
-  ➔ API call
-  ➔ telemetry

I/O (socket or serial)

CFDP (CF App)
C3I-DEM

CFS Software Bus (CCSDS SPP)

TC-SDLP (for CI)
TM-SDLP (for TO)

UDP
RS-422

IO_Lib Services
Eg: trans_udp.c

CI/TO Application
Eg: CI_app.c

CI/TO Custom
Eg: CI_custom.c

IO_Lib Formats
Eg: dem.c

CFS Software Bus

Mission App
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

XTCE files used to create other product files

System representation SysML model is generated

XTCE files describing system representation is generated

Message IDs pulled from available user app pool

Larry Garner/Tietronix
# CFS Supported Platforms
(non-exhaustive)

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

### Platform Details

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

Flight Software

- 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)

Ground Software

- Displays & Controls
- Database (postgresql)
- Command & Data Dictionary
- ITOS Infrastructure (Goddard)
  (Data Com/Decom, Recon, Distribution, Display, Scripting, Recording, Post processing)
- Linux OS

Tool Chain

- 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

- Morpheus Specific System & I/O Models
- Dynamics, Time, Environment Models
- Generic Systems Models
- Trick Simulation Core (JSC)
- Linux OS

Software Reuse

- New Software
MMSEV

MMSEV – Orion Augmentation Module (OAM)
Advanced Space Suite: CWA CFS Software Architecture

New Applications

- Battery Management I/F
- iLoad Library
- State/Mode Manager
- PMAD (power/battery)
- FLASH Loader
- Consumable Monitoring

PLSS I/F

- SWME/BPV
- RCA
- Fan
- Primary O2
- Secondary O2
- TCV
- Pump
- Gas Sensor
- Sysmon
- Misc

Time Manager
- DCU
- Fault Manager
- Alarm Annunciator
- BIT
- Automated Checkout

Mem Manager
- Software Scheduler
- House Keeping
- Health & Safety Manager
- Limit Checker
- Software Bus
- Time Services
- Executive Services
- Event Services
- Table Services

Ground Support (e.g. PLSS LabView?)

Diagostic Port

Command
- Telemetry

Stored Command 1,2,3

Flash Storage Device

Data Storage

CF

Out-Of-Range Limit Table

Calibration Table

1 Limit Checker provides AEMU C&W
2 Stored Command provides Checkout & Configuration
3 Limit Checker, Stored Command, H&S Manager provide Recover & Restore

CFS Core Services
AEMU Custom Applications
CFS Configurable Applications
Application Specific Software