A Reusable and Adaptable Software Architecture for Embedded Space Flight Systems

The Core Flight Software System (CFS)

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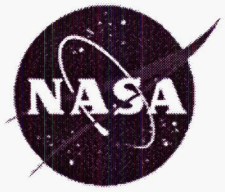


Some Challenges of the Space Software Domain

- High availability
  - Self Safing
  - Must run with minimal interruption for a few to tens of years
- Hardware is in a harsh environment
  - Bits can change due to radiation, blocks of memory can degrade and become unusable.
- Flight Processor (constraints)vary widely due to power and weight constraints
  - Processors are several generations behind terrestrial components
  - High end - 166 MHz PowerPC with 8meg non-volatile program store and 128MB RAM
  - Low end - 12MHz Coldfire embedded in gate array with 512k non-volatile and 4MB RAM
- Software must be remotely modifiable and still operate while changes are being made
- Many custom one of a kind interfaces for one of a kind missions
- Sustaining Engineering
  - Systems must be maintained long after the platform and systems are obsolete.
- Price of failure is high, tens to hundreds of millions of dollars

An Approach to the Challenges

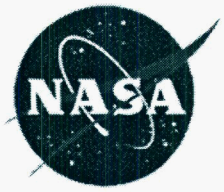
The Core Flight System is a platform-independent, reusable Flight Software (FSW) environment integrating a core flight executive, software component library, and Integrated Development Environment (IDE). It addresses some of the Space domain software challenges using key concepts of the GMSEC reference architecture

- **Layered Architecture**
- **Standard Middleware/Bus**
- **Application Programmer Interface**

} Core Flight Executive

- **Plug and Play**
- **Reusable Components**

} Component Library

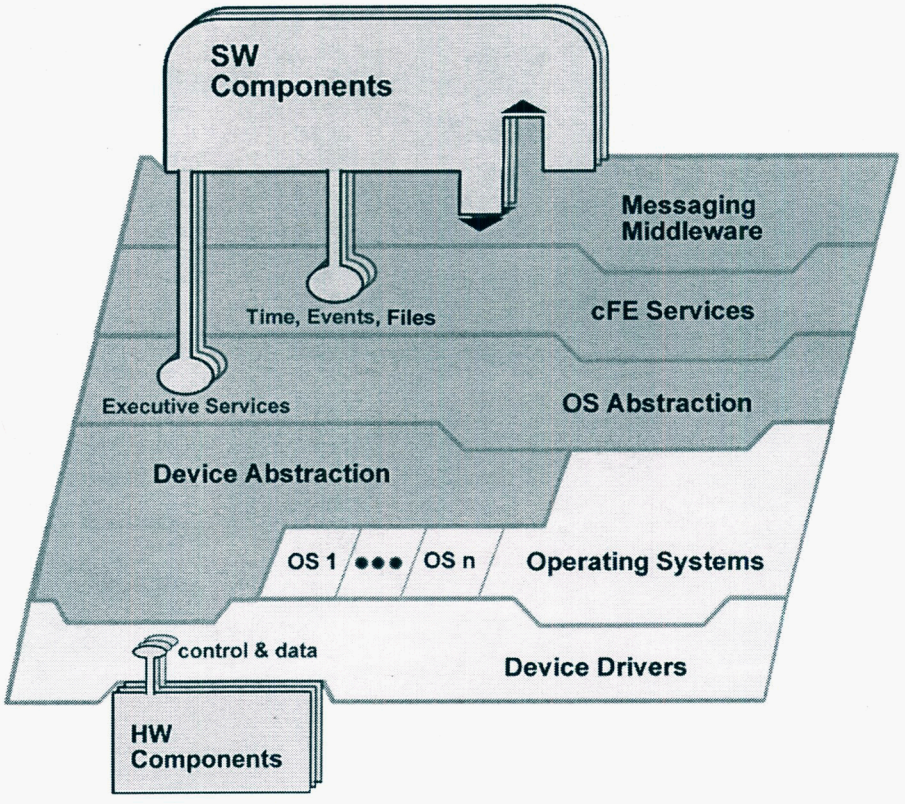


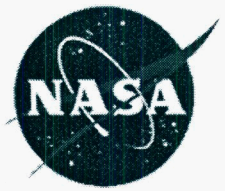
Key Concept #1

A Layered Architecture

- CFS internals are carefully layered.
- Each layer "hides" its implementation and technology details.
- Internals of a layer can be changed -- without affecting other layers' internals and components.
- Small-footprint, light-weight architecture and implementation minimizes overhead.

- **Benefits:**
- Eases technology infusion and evolution.
- Eases modification at all stages of development and on-orbit.
- Provides Middleware, OS and HW platform-independence.





Key Concept #2

Standard Middleware Bus

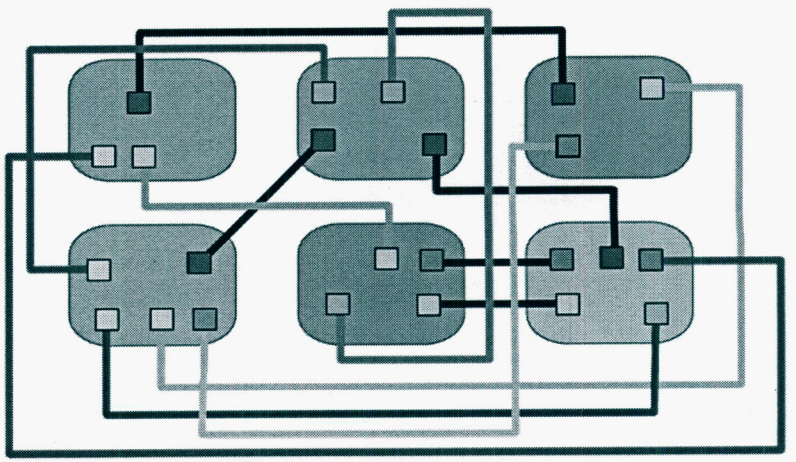
Publish/Subscribe

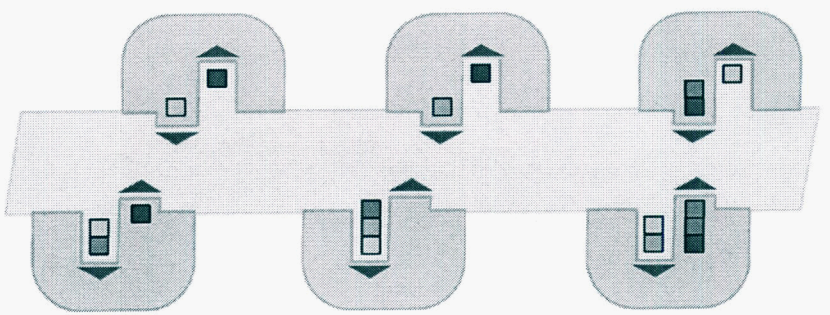
- **Components communicate over a standards-based Message-oriented Middleware/Software Bus.**
- The Middleware/ Software Bus uses a Publish/Subscribe model, so **cooperating components don't need to know the details of inter-communication** (location of others, protocols used, etc.).

Benefits:

- Simplifies component SW
- Minimizes interdependencies
- Supports HW and SW runtime "plug and play"
- Speeds development and integration.
- Enables dynamic component distribution and interconnection.

Legacy: Tightly-coupled, custom interfaces- data formats - protocols, internal knowledge, component interdependence





Publish/Subscribe: loosely-coupled, standard interface, data formats, protocols, & component independence

Key Concept #3

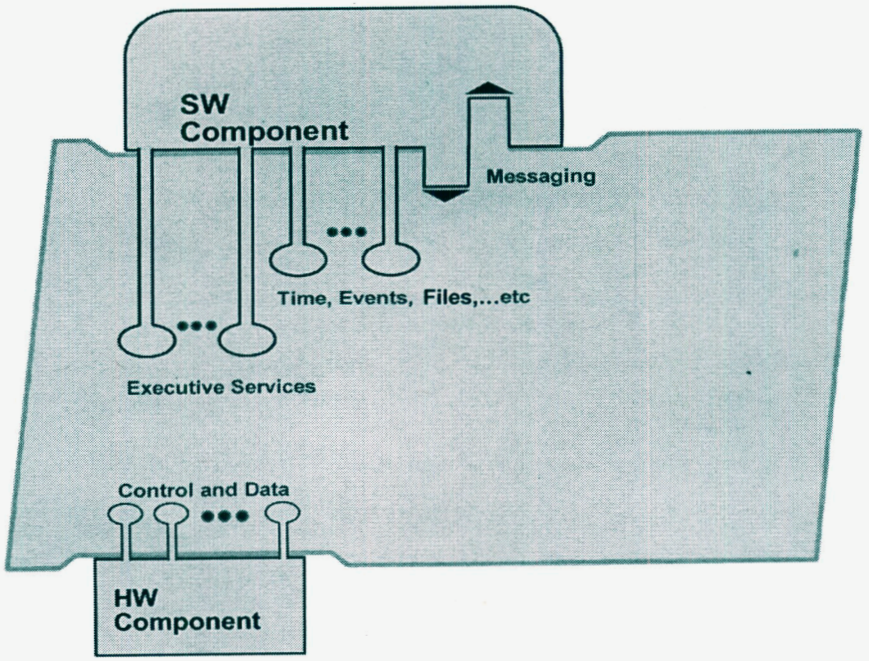
Standardized API for Software and Hardware Components

Application Programmer Interfaces

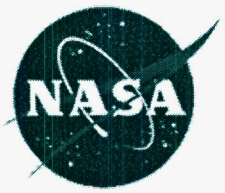
- CFS services and middleware communication bus has a **standardized, well-documented API**
- An **abstracted HW component API enables standardized interaction** between SW and HW components.

Benefits:

- Eases development and testing when using **distributed teams**
- With the framework already in place, a**pplications can be started earlier** in the development process
- **Don't need to wait for the target hardware** to be completed.
- **Simplifies integration, reduces development time, shortens schedules**.

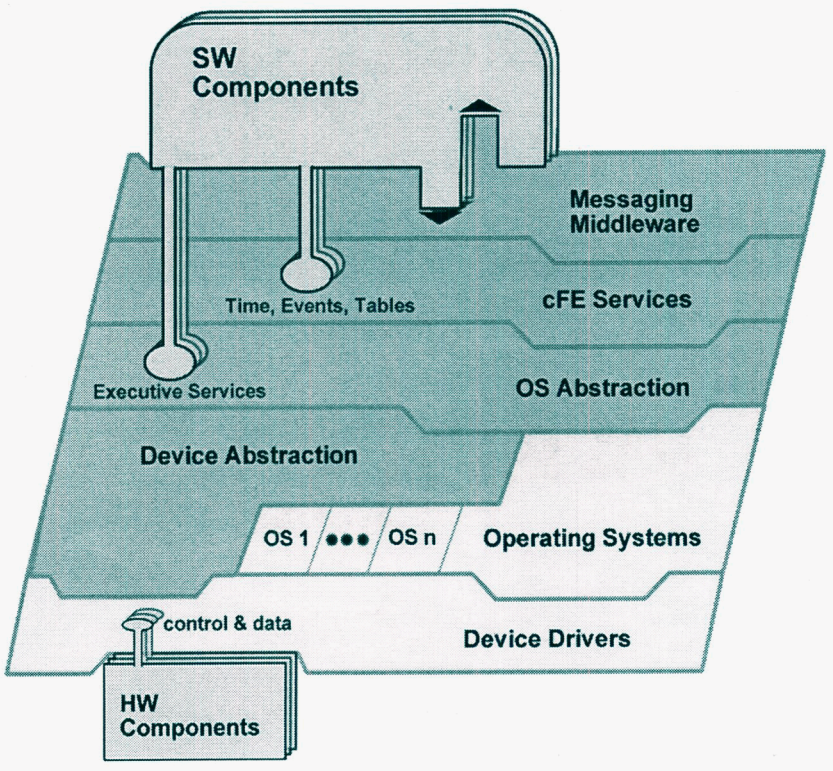


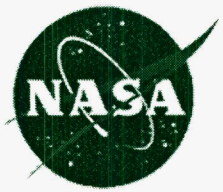
API supplies all functions and data components developers need.



Packaging the first 3 Concepts
The
Core Flight Software Executive (cFE)

- Strategic Software Layering
  - Software of a layer can be changed without affecting the software of other layers
- Advanced Message Handling
  - Eliminates manual configuration of FSW
  - Automates integration of FSW with applications and hardware components (Publish/Subscribe model
- Standardized, Abstracted Interfaces
  - Minimizes software impacts from flight hardware, RTOS(*), and application changes





CFS Key Concept #4

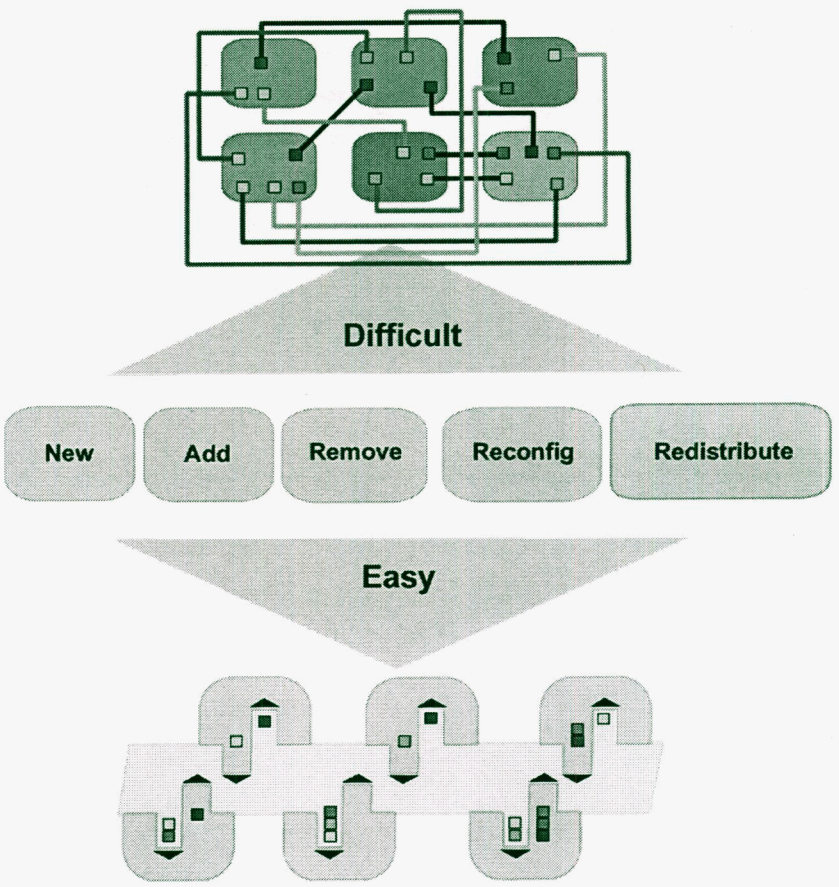
SW Components and HW Devices Plug and Play

Plug and Play

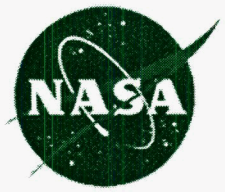
- cFE API's support add and remove functions
- SW **components can be switched in and out at runtime**, without rebooting or rebuilding the system SW.
- **Qualified Hardware and CFS-compatible software both "plug and play."**

Benefits:

- **Changes can be made dynamically** during development, test and on-orbit even as part of contingency management
- **Technology infusion and upgrades** can be taken advantage of later in the development cycle.
- **Testing flexibility**



This powerful paradigm allows SW components to be switched in and out at runtime, without rebooting or rebuilding the system SW.

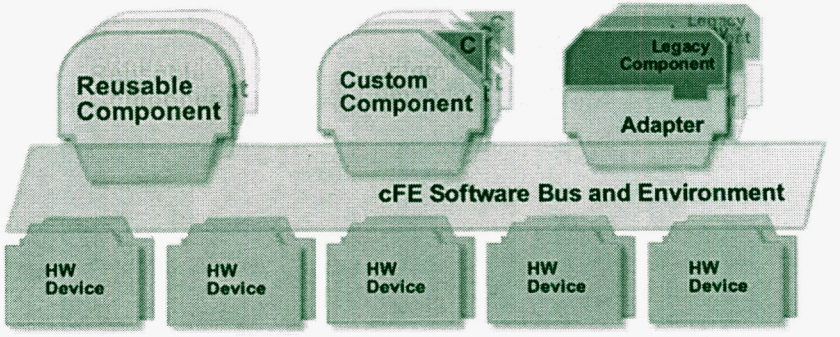


GFS Key Concept #5

Reusable Components

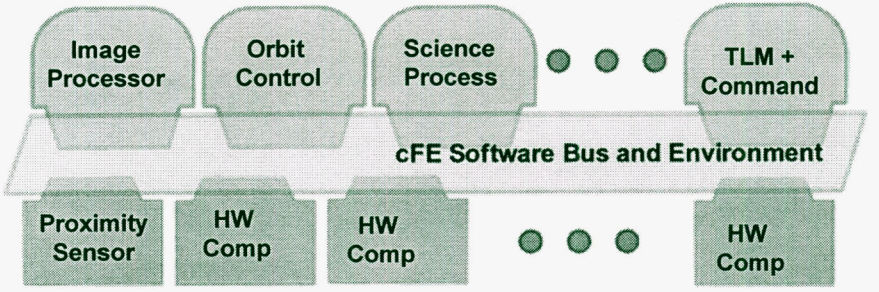
Reusable Components

- Common FSW functionality has been abstracted into a library of **reusable components and services**.
- **Tested, Certified, Documented**
- **A system is built from:**
  - Core services
  - Reusable components
  - Custom mission specific components
  - Adapted legacy components
  - Associated HW



Benefits:

- Reuse of tested, certified components supplies savings in each phase of the software development cycle:
- Reduces risk
- **Teams focus on the custom aspects** of their project.



Packaging the last 2 Concepts

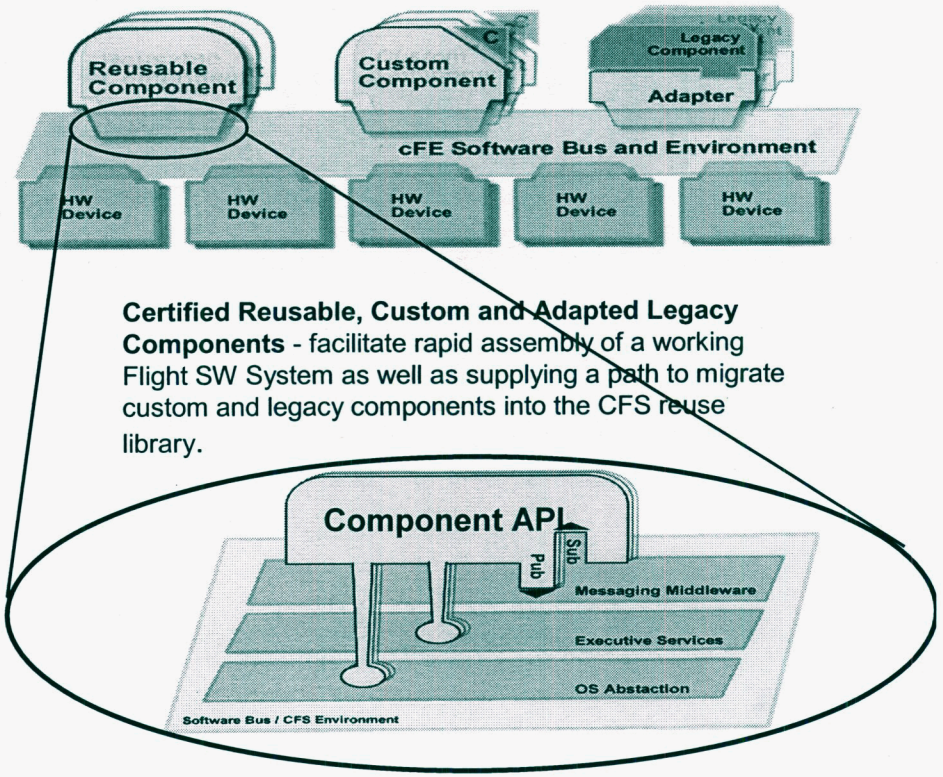
CFS Component Library

Flight Software Reuse Libraries

- Select pre-validated FSW components from FSW reuse libraries
- Validated common SW components include Requirements, Test Plan, Documentation

Mission-Unique Components

- Mission-unique FSW Components can be adapted for use
- Science applications developed on Scientist's desktop can plug into flight systems without change when developed with the API standards



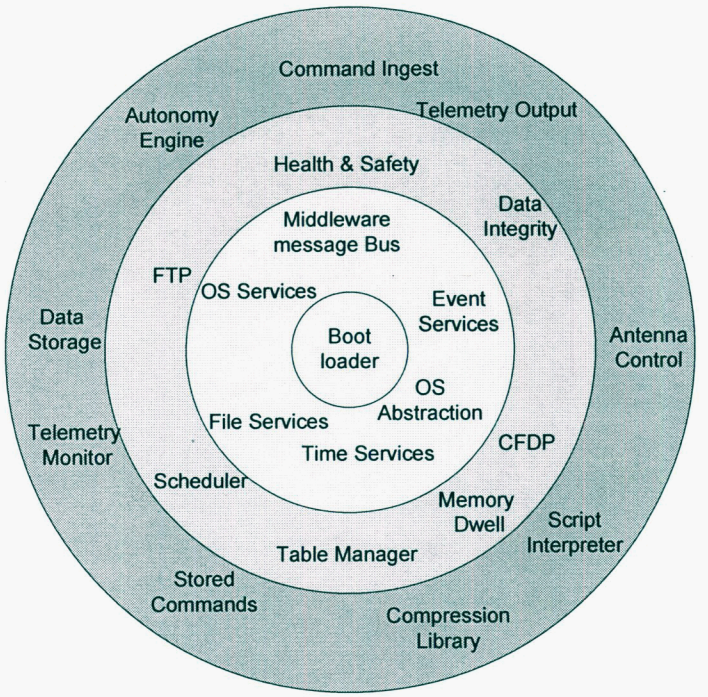
Certified Reusable, Custom and Adapted Legacy Components - facilitate rapid assembly of a working Flight SW System as well as supplying a path to migrate custom and legacy components into the CFS reuse library.

Component Standard API and Data Communication : components are loosely-coupled with a standard API and standard publish/subscribe intercommunications protocol and data formats. These features enable plug & play connectivity and dynamic integration / reconfiguration.

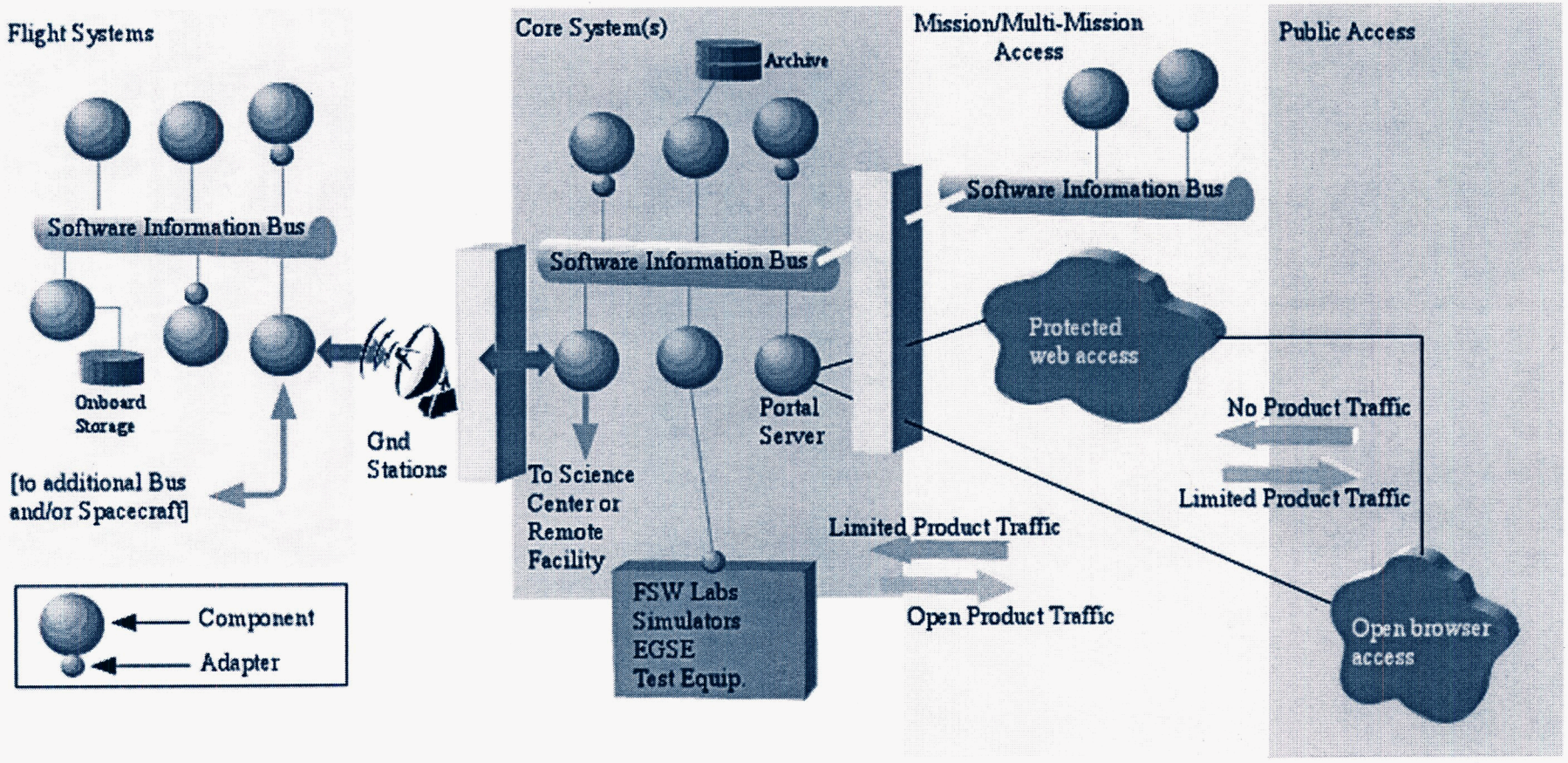
Multiprocessor/System of Systems
Rings of Functionality

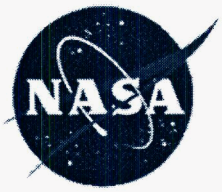
- **Interchangeable avionics boxes have a core ring of standard functions.**
  - **Actual code and implementation can be different for each vendor, but need to meet the API's and ICD's**
  - **Event messages to alert operators or other components of asynchronous data**
  - **Common software load/dump interfaces**
  - **Common set of file service interfaces**
  - **Core ring can use memory management unit (MMU) for self protection**
  - **Boot loader is in hardened ROM**

- Benefits
  - Speed prototyping and integration times
  - Compress schedule and reduce schedule risk
  - Common training for maintenance teams.
  - Reduced cost for FSW development and maintenance
  - Reduce training for on board trouble shooting for spacecraft personnel
  - Boxes can take on "personalities" as needed
  - Fewer flight spares needed



Next Steps
End-to-End





Status

- **Targeted Missions**
  - Original – Global Precipitation Measurement (GPM)
  - Current - Lunar Reconnaissance Orbiter (LRO)
- **2004 multi-CPU/Box prototype demonstrated**
  - **Core, generic FSW services and Software components**
  - **Dynamic application load and startup**
  - **Dynamic message bus reconfiguration after simulated "Box faults"**
- Version 2 cFE, delivered to LRO July 15 2005
- Process and Memory protection integration to start Q1 FY 2006
  - No API changes anticipated.
- Started work on an Integrated Development Environment (IDE) based on the open source Eclipse.