



# Core Flight System Framework



November 2025



# Audience & Prerequisites

- **Objectives**
  - Describe the core Flight Executive (cFE) from a functional perspective
- **Intended audience**
  - Mostly targeted at software engineers, but systems engineers, non-FSW spacecraft discipline engineers, and technical project managers could also benefit.
- **Prerequisites**
  - Course Introductory material provided in the cFS overview slides and video



# Outline

1. cFS Architecture
2. cFS Framework Services
3. Application Layer Architectural Components
4. cFS Framework Deployment

Appendix A: Architectural Design Notation

Appendix B: Supplemental Architectural Material



Blue screens contain hands on cFS Basecamp exercises

- Basecamp is a lightweight environment with built-in tutorials for learning the cFS
- <https://github.com/cfs-tools/cfs-basecamp>

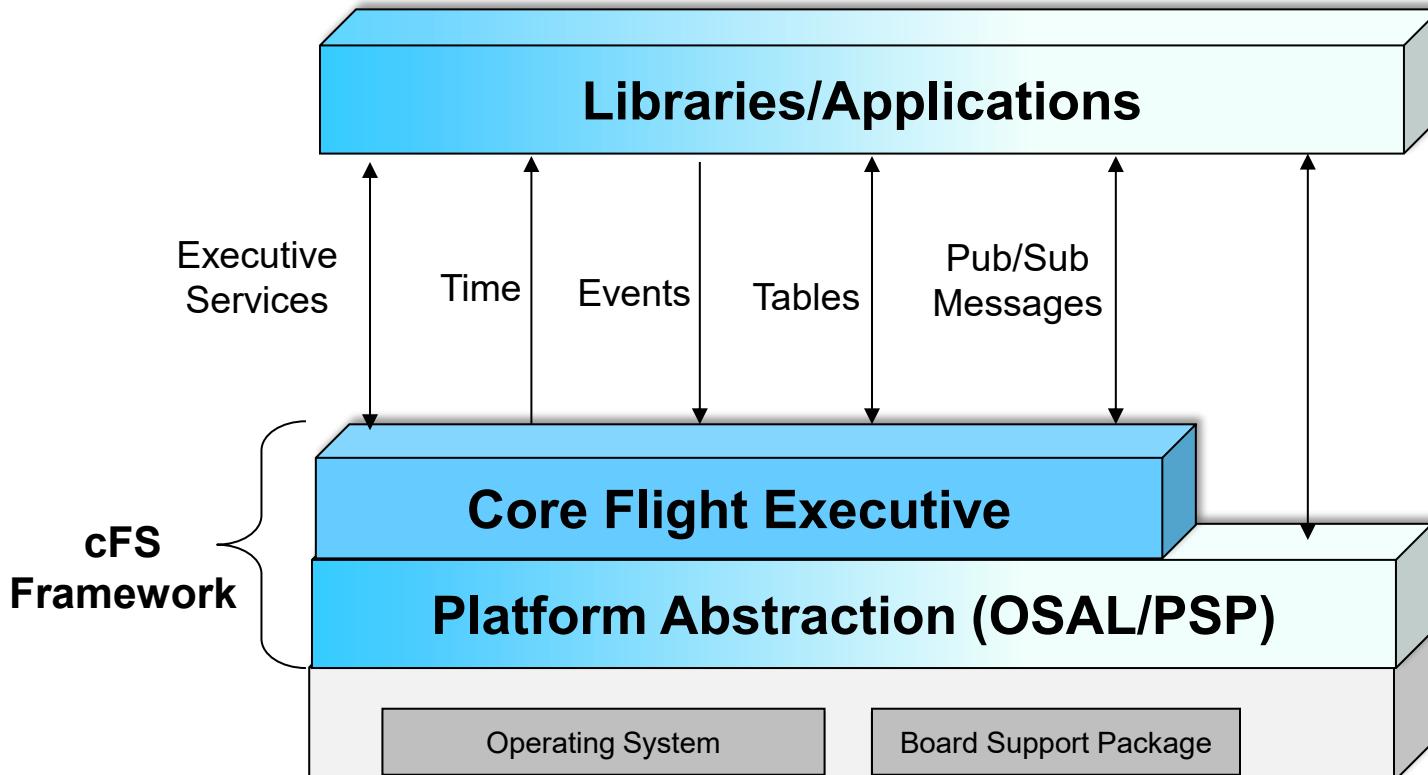


# cFS Architecture





# cFS Framework Interfaces



**OSAL:** Operating System Abstraction Layer  
**PSP:** Platform Support Package

## Executive Services (ES)

- Manage the software system and create an application runtime environment

## Time Services (TIME)

- Manage spacecraft time

## Event Services (EVS)

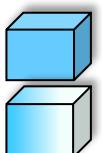
- Provide a service for sending, filtering, and logging event messages

## Software Bus (SB) Services

- Provide an application publish/subscribe messaging service

## Table Services (TBL)

- Manage application table images



= Reusable components



= Reusable components with custom code



# Platform Abstraction Layer (1 of 2)

## Operating System (OS)

- System software that manages computer hardware and software resources, and provides common services for computer programs
- Software services include scheduling different threads of execution, facilitating communication between threads, managing files, and managing memory for the entire system

## Realtime Operating System (RTOS)

- Supports multi-tasking with preemptive scheduling so time critical tasks execute deterministically

## Board Support Package (BSP)

- Contains hardware-specific boot firmware, device drivers and other routines to an operating system to function in a given hardware environment (i.e. a motherboard)



# Platform Abstraction Layer (2 of 2)

## Operating System Abstraction Layer (OSAL)

- A software library that provides a single Application Program Interface (API) to the core Flight Executive (cFE) regardless of the underlying operating system

## Platform Support Package (PSP)

- A software library that provides a single API to the underlying hardware board and BSP
- Library serves as the "glue" between the OS and the cFE
- During system initialization it performs BSP/OS specific setup and then calls cFE's entry point function

## Notes

- The cFS Framework defaults to the Linux and can be run on a personal computer
- The cFS Platform List <https://github.com/cfs-tools/cfs-platform-list> provides links to cFS ports



# Application Layer

- **Applications are architectural components that own and use cFE and operating system resources via the cFE and OSAL APIs**
- **cFS Framework Services provide an Application Runtime Environment**
  - Apps register for cFS Framework resources and services
  - Dynamic resource management allows apps to be restarted or replaced without restarting the system
- **Write once run anywhere the cFS Framework has been deployed**
  - Apps are portable across different hardware/operating platforms if they only depend on the cFE and Platform Abstraction layer APIs
  - Allows app development on a desktop deferring embedded software complexities such as cross compilation, deploying to target, etc.
  - Technology projects developed on a desktop have a path to flight projects
  - More powerful model than Smartphone apps that need to be rewritten for each platform



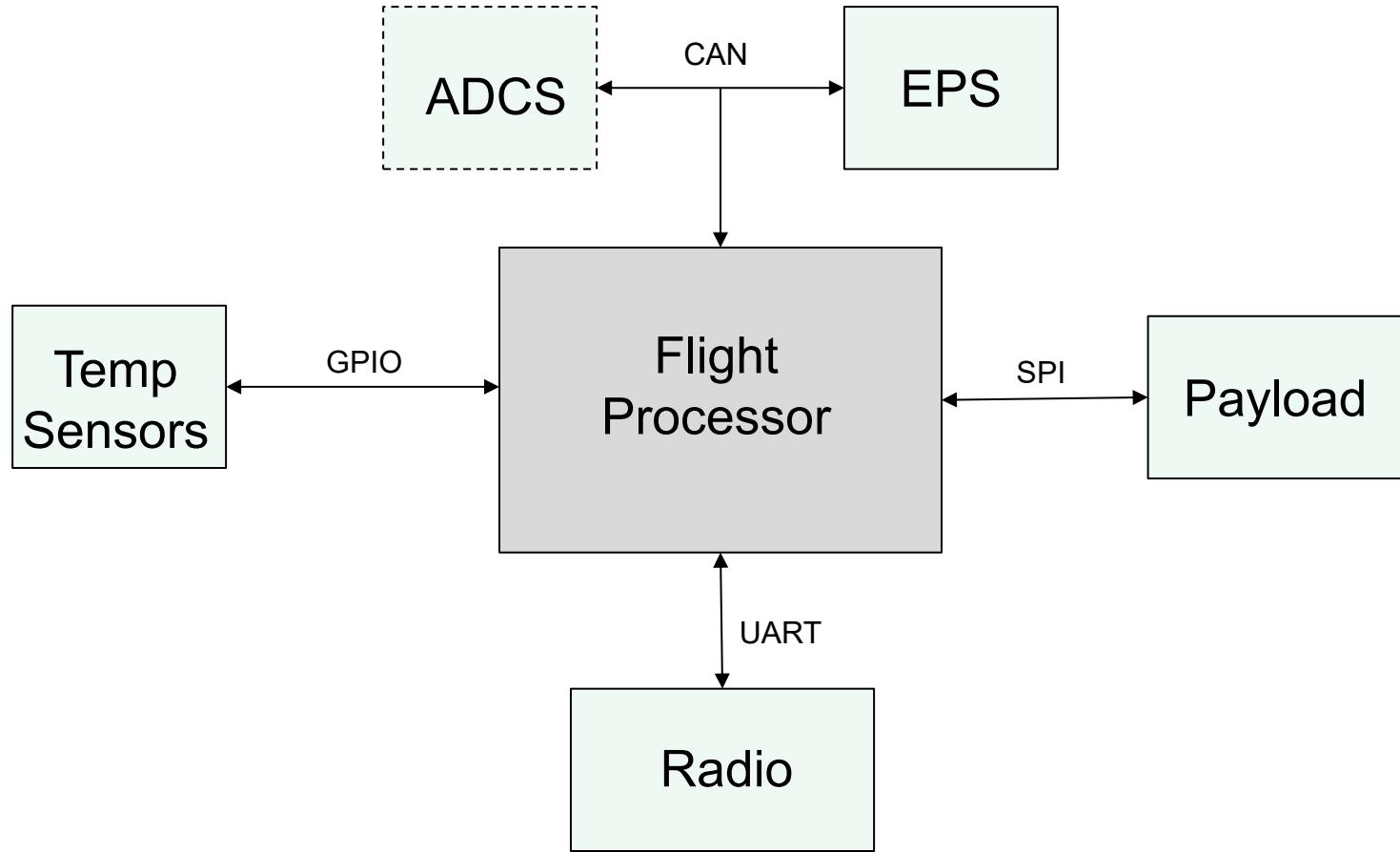
# cFS Mission Design Overview



- **The remaining slides in this section introduce a top-down mission app design process**
  - This process provides an application context for the cFS Framework section
- **FSW design begins with a hardware context that bounds the FSW problem space**
- **Initially you may not have a complete hardware context because you are performing trade studies**
  - Build vs buy, component supplier evaluation (influences interfaces), processor selection, etc.
- **In parallel, a mission functional requirements analysis is being performed that identifies the top-level FSW functional requirements**
  - The mission's operational concept plays a significant role in this analysis
  - Performance requirements and design constraints are also elicited which may effect the component selection
  - Simulations may be required to perform the analysis



# Example Hardware Context



ADCS

Represents external ADCS or ADCS sensors/actuators with controller in FSW

## ADCS

- Attitude Determination and Control System

## CAN

- Controller Area Network

## EPS

- Electric Power System

## GPIO

- General Purpose Input/Output

## SPI

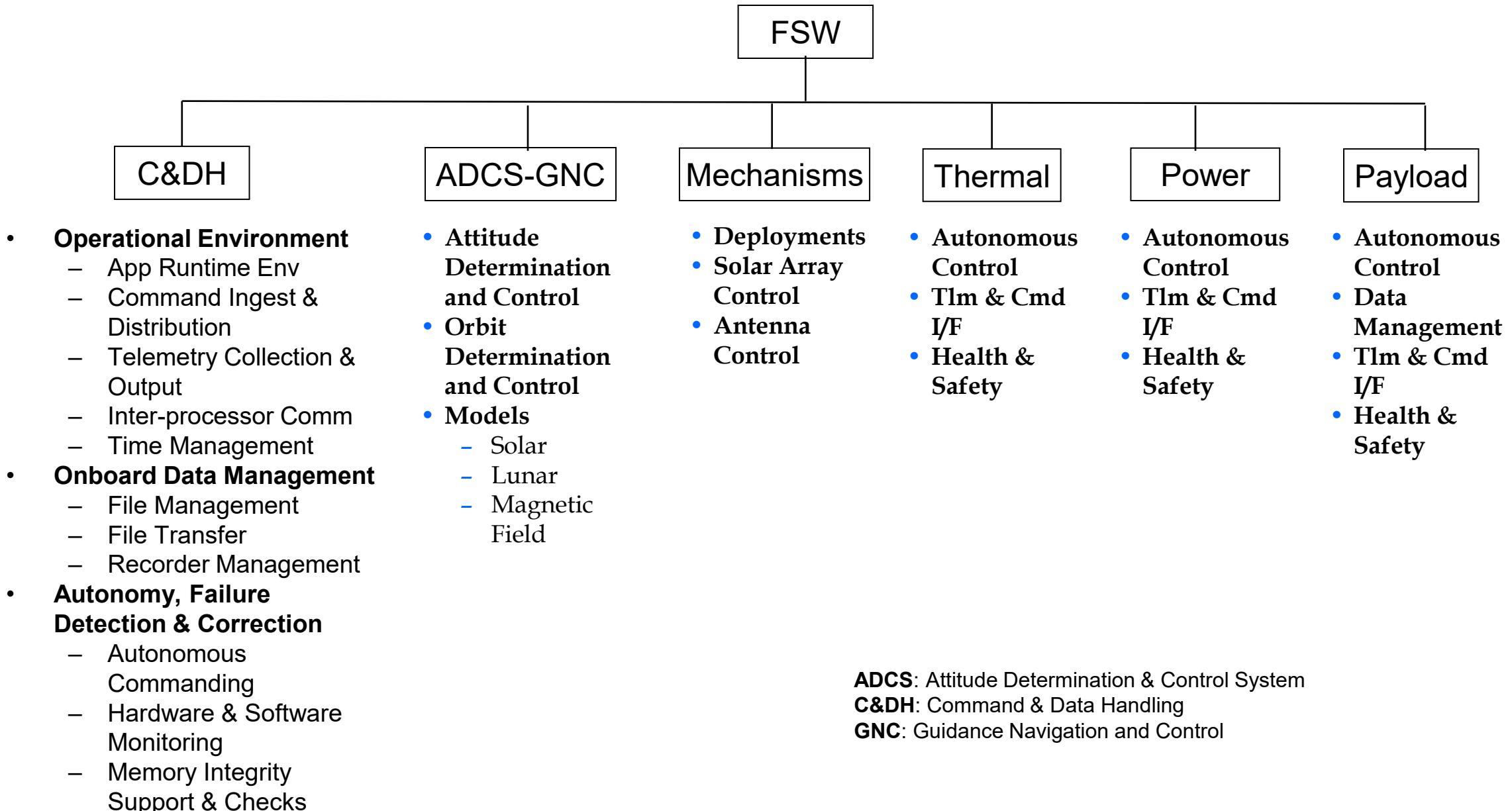
- Serial Peripheral Interface

## UART

- Universal Asynchronous Receiver/Transmitter..



# Example Spacecraft Flight Software Top-Level Requirements



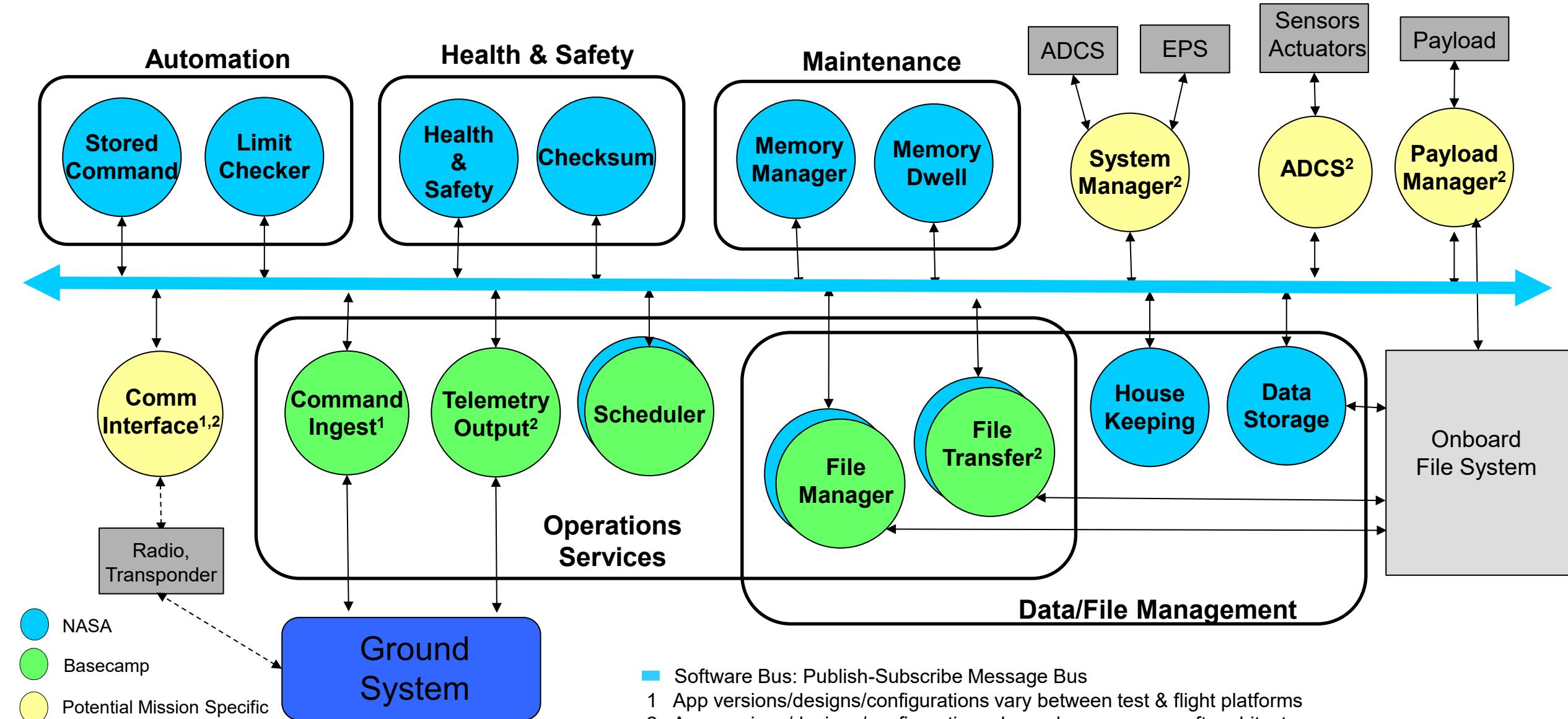


# App-Centric Design “Appcentricity”

- **Mission functional requirements are implemented in apps and libraries**
- **A critical cFS mission design mindset is to concurrently think about individual apps and groups of apps implementing functional requirements**
  - For example, one app could determine and publish the sun’s position relative to the spacecraft, a second app could subscribe to this data and control gimbaled solar arrays, and a third app could subscribe to both app’s data and monitor the data for fault conditions
- **The next slide shows an example mission app suite and highlights the following**
  - Groups of apps provide mission functionality
  - Apps communicate using a publish/subscribe messaging system called the *Software Bus*
  - Apps are used to manage external interfaces (note libraries and device drivers are not shown)
  - Mission app suites are typically composed of apps from multiple sources
- **The cFS’ app model is similar to but not analogous to the smart phone app-centric architecture**



# Example Mission App Suite “Lollipop Diagram”





# cFS Architecture Wrap Up



- **At this point you do not need to understand each app's functionality**
  - This diagram is being shown to illustrate that it is one of the goals of the FSW mission design process
- **Basecamp's *Systems Engineering* documents provide detailed information on the mission design process**
- **cFS's mission app-centric design is the primary motivation for application runtime environment provided by the *cFS Framework Services* described next**
- **Once you have an understanding of the cFS Framework Services, the application layer will be revisited in more detail in the *Application Layer Architectural Components* section**

# Install cFS Basecamp

1. Install cFS Basecamp following the instructions at <https://github.com/cfs-tools/cfs-basecamp>
2. The last step launches Basecamp using the command “*python3 basecamp.py*”



Basecamp is ready for exercises in the next section



# cFS Framework Services





# Outline

1. Executive Services (ES)
  2. Event Services (EVS)
  3. Software Bus Service (SB)
  4. Table Services (TBL)
  5. Time Services (TIME)
  6. Operating System Abstraction Layer (OSAL)
  7. Platform Support Package (PSP)
- 
- **This section briefly introduces each cFE service's functionality**
  - **Basecamp will be used to interact (send commands and observe telemetry responses) with each service**
  - **Basecamp training courses on each service provide more detail**



# Executive Services Overview



- **Initializes the cFE**
  - Identifies and reports startup/reset type
  - Maintains an exception-reset log across processor resets
- **Creates the application runtime environment**
  - Primary interface to underlying operating system task services & resources
  - Supports starting, stopping, and loading applications during runtime
- **Memory Management**
  - Provides a dynamic memory pool service
  - Provides Critical Data Stores (CDS) which are memory blocks that are preserved across processor resets if the platform supports it
  - Provides a system message log service where messages are stored in memory that can be written to a file on command



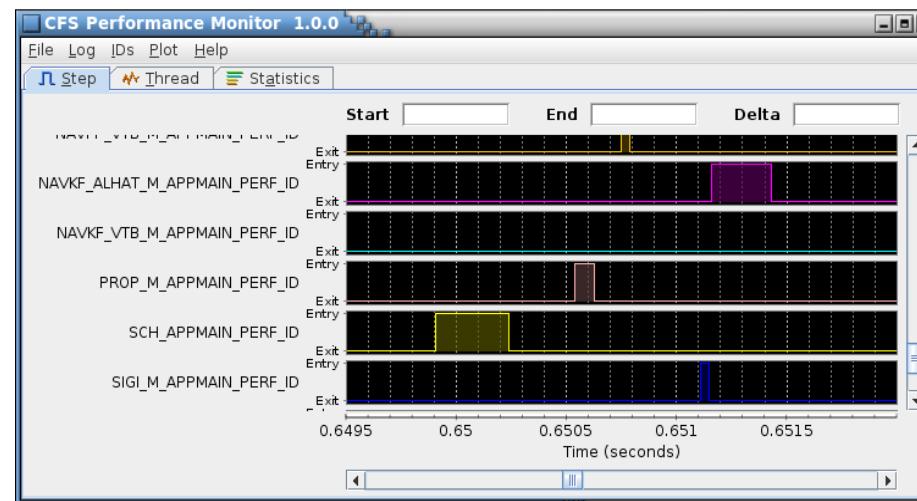
# Executive Services Application Support

- Applications are an architectural component that owns cFE and operating system resources
- Each application has a thread of execution in the underlying operating system (i.e. a task)
- Applications can create multiple child tasks
  - Child tasks share the parent task's address space
- Mission applications are defined in *cfe\_es\_startup.scr* and loaded after the cFE applications are created
- Application Restarts and Reloads
  - Start, Stop, Restart, Reload commands
  - Data is not preserved; application run through their initialization
  - Can be used in response to
    - Exceptions
    - On-board Failure Detection and Correction response
    - Ground commands



# Executive Services Performance Analyzer

- Provides a method to identify and measure code execution paths
  - System tuning, troubleshooting, CPU loading
- Executive Service provides Developer inserts execution markers in FSW
  - Entry marker indicate when execution resumes
  - Exit marker indicates when execution is suspended
  - CFE\_ES\_PerfLogExit() => CFE\_SB\_RcvMsg() => CFE\_ES\_PerfLogEntry()
- Operator defines what markers should be captured via filters and defines triggers that determine when the filtered marker are captured
- Captured markers are written to a file that is transferred to the ground and displayed using the cFS Performance Monitor (CPM) tool



# Executive Services Exercises - 1

1. Start the cFS



2. Scroll back in the *cFS Target Process Window* and look for cFE Executive Service (CFE\_ES) entries

Power on Reset

```
cFS Target Process Window    Telecommand: 127.0.0.1:1234    Telemetry: Local    Time: --Null--  
CFE_PSP: Cannot open EEPROM File: EEPROM.DAT  
CFE_PSP: Cannot create EEPROM Range from Memory Mapped file.  
CFE_PSP: Starting the cFE with a POWER ON reset.  
CFE_PSP: Clearing out CFE CDS Shared memory segment.  
CFE_PSP: Clearing out CFE Reset Shared memory segment.  
CFE_PSP: Clearing out CFE User Reserved Shared memory segment.  
1980-001-00:33:07.82679 CFE_ES_SetupResetVariables: POWER ON RESET due to Power Cycle (Power Cycle).  
1980-001-00:33:07.82685 CFE_ES_Main: CFE_ES_Main in EARLY_INIT state  
CFE_PSP: CFE_PSP_AttachExceptions Called  
1980-001-00:33:07.82715 CFE_ES_Main: CFE_ES_Main entering CORE_STARTUP state  
1980-001-00:33:07.82715 CFE_ES_CreateObjects: Starting Object Creation calls.  
1980-001-00:33:07.82715 CFE_ES_CreateObjects: Calling CFE_Config_Init  
1980-001-00:33:07.82718 CFE_ES_CreateObjects: Calling CFE_ES_CDSEarlyInit  
1980-001-00:33:07.82733 CFE_ES_CreateObjects: Calling CFE_EVS_EarlyInit  
1980-001-00:33:07.82735 CFE_EVS_EarlyInit: Event Log cleared following power-on reset
```

# Executive Services Exercises - 2

3. Next in the *cFS Target Process Window* find when the libraries and apps are loaded

cFS Target Process Window    Telecommand: 127.0.0.1:1234    Telemetry: Local    Time: 1002147

```
us_friteopen_lmpc();114:open(/dev/sim/usb:RAM/cfe_es_startup.scr); No such file or directory
1980-012-14:21:56.00799 CFE_ES_CreateObjects: Finished ES CreateObject table entries.
1980-012-14:21:56.00802 CFE_ES_Main: CFE_ES_Main entering CORE_READY state
1980-012-14:21:56.00811 CFE_ES_StartApplications: Cannot Open Volatile Startup file: /ram/cfe_es_startup.scr, Trying Nonvolatile.
1980-012-14:21:56.00813 CFE_ES_StartApplications: Opened ES App Startup file: /cf/cfe_es_startup.scr
1980-012-14:21:56.00961 CFE_ES_ParseFileEntry: Loading shared library: /cf/cfe_assert.so
1980-012-14:21:56.01227 [BEGIN] CFE FUNCTIONAL TEST
1980-012-14:21:56.01235 [BEGIN] 01 CFE-STARTUP
1980-012-14:21:56.01252 CFE_ES_ParseFileEntry: Loading shared library: /cf/app_c_fw.so
Application C Framework Library Initialized. Version 4.3.0
1980-012-14:21:56.01541 CFE_ES_ParseFileEntry: Loading file: /cf/app_c_demo.so, APP: APP_C_DEMO
1980-012-14:21:56.01753 CFE_ES_ParseFileEntry: Loading file: /cf/ci_lab.so, APP: CI_LAB_APP
1980-012-14:21:56.01926 CFE_ES_ParseFileEntry: Loading file: /cf/kit_to.so, APP: KIT_TO
1980-012-14:21:56.02111 CFE_ES_ParseFileEntry: Loading file: /cf/file_mgr.so, APP: FILE_MGR
1980-012-14:21:56.02264 CFE_ES_ParseFileEntry: Loading file: /cf/file_xfer.so, APP: FILE_XFER
1980-012-14:21:56.02395 CFE_ES_ParseFileEntry: Loading file: /cf/kit_sch.so, APP: KIT_SCH
```

Startup script

Basecamp  
Target  
Libs & Apps

# Executive Services Exercises - 3

## 4. Open CFE\_ES's Housekeeping (status) telemetry and browse its content

CFE_ES/Application/HK_TLM - Port 9003	
App ID:	64
Length:	150
Seq Cnt:	411
Time:	
<b>Payload</b>	
HousekeepingTlm.Payload.CommandCounter	: 0
HousekeepingTlm.Payload.CommandErrorCounter	: 0
HousekeepingTlm.Payload.CFECOREChecksum	: 65461
HousekeepingTlm.Payload.CFEMajorVersion	: 6
HousekeepingTlm.Payload.CFEMinorVersion	: 7
HousekeepingTlm.Payload.CFERevision	: 99
HousekeepingTlm.Payload.CFEMissionRevision	: 0
HousekeepingTlm.Payload.OSALMajorVersion	: 5
HousekeepingTlm.Payload.OSALMinorVersion	: 0
HousekeepingTlm.Payload.OSALRevision	: 0
HousekeepingTlm.Payload.OSALMissionRevision	: 255
HousekeepingTlm.Payload.PSPMajorVersion	: 1
HousekeepingTlm.Payload.PSPMinorVersion	: 4
HousekeepingTlm.Payload.PSPRevision	: 0
HousekeepingTlm.Payload.PSPMissionRevision	: 99
HousekeepingTlm.Payload.SysLogBytesUsed	: 3010
HousekeepingTlm.Payload.SysLogSize	: 3072
HousekeepingTlm.Payload.SysLogEntries	: 63
HousekeepingTlm.Payload.SysLogMode	: DISCARD
HousekeepingTlm.Payload.ERLogIndex	: 2
HousekeepingTlm.Payload.ERLogEntries	: 2
HousekeepingTlm.Payload.RegisteredCoreApps	: 5
HousekeepingTlm.Payload.RegisteredExternalApps	: 6
HousekeepingTlm.Payload.RegisteredTasks	: 16
HousekeepingTlm.Payload.RegisteredLibs	: 2
HousekeepingTlm.Payload.ResetType	: 1
HousekeepingTlm.Payload.ResetSubtype	: 1
HousekeepingTlm.Payload.ProcessorResets	: 1
HousekeepingTlm.Payload.MaxProcessorResets	: 2

cFE apps

Apps loaded via cfe\_es\_startup.scr

# Executive Services Exercises - 4

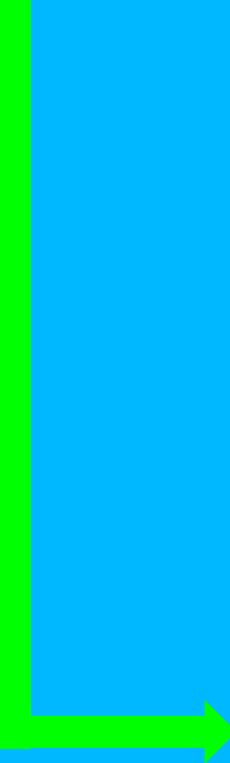
## 5. issue a CFE\_ES NoopCmd

Send CFE\_ES/Application/CMD Telecommand

Parameter Name	Type	Value
No Parameters		

cFS Target Process Window    Telecommand: 127.0.0.1:1234    Telemetry: Local    Time: 1001975

```
EVS Port1 66/1/KIT_SCH 200: Scheduler Table load updated 27 entries
EVS Port1 66/1/KIT_SCH 25: Successfully replaced table 1 using file /cf/kit_sch_schtbl.json
EVS Port1 66/1/KIT_SCH 101: KIT_SCH Initialized. Version 3.0.0
EVS Port1 66/1/APP_C DEMO 51: Child task initialization complete
EVS Port1 66/1/FILE_MGR 51: Child task initialization complete
EVS Port1 66/1/KIT_TO 307: Removed 0 table packet entries
EVS Port1 66/1/KIT_TO 311: Skip subscribing to tunnel message 0x0862(2146)
EVS Port1 66/1/KIT_TO 302: Successfully loaded new table with 35 packets
EVS Port1 66/1/KIT_TO 201: Packet Table load updated 59 entries
EVS Port1 66/1/KIT_TO 25: Successfully replaced table 0 using file /cf/kit_to_pkt_tbl.json
EVS Port1 66/1/KIT_TO 100: KIT_TO Initialized. Version 3.2.0
1980-012-14:19:24.17463 CFE_ES_Main: CFE_ES_Main entering APPS_INIT state
1980-012-14:19:24.17467 CFE_ES_Main: CFE_ES_Main entering OPERATIONAL state
EVS Port1 66/1/CFE_TIME 21: Stop FLYWHEEL
EVS Port1 66/1/KIT_TO 304: Telemetry output enabled for IP 127.0.0.1
EVS Port1 66/1/KIT_SCH 404: Major Frame Sync too noisy (Slot 0). Disabling synchronization.
EVS Port1 66/1/CFE_ES 92: Build 202508021004 by open-stemware@Open-STEMware, config basecamp
EVS Port1 66/1/CFE_ES 3: No-op command:
cFS Versions: cfe v6.8.0-rcl+dev1024, osal v5.1.0-rcl+dev619, psp v1.5.0-rcl+dev124
```





# Event Service Overview



- **Provides an interface for sending time-stamped text messages on the software bus**
  - Considered asynchronous because they are not part of telemetry periodically generated by an application
  - Processor unique identifier
  - Optionally logged to a local event log
  - Optionally output to a hardware port
- **Four event types defined**
  - Debug, Informational, Error, Critical
- **Event message control**
  - Apps can filter individual messages based on identifier
  - Enable/disable event types at the processor and application scope



# Event Message Filtering (1 of 2)



- **“Filter Mask”**
  - Used to determine when to send a filtered event
  - A bit-wise Boolean AND is performed on the event ID message counter and if the result is zero then the event is sent
  - Mask applied before the sent counter is incremented
- **“Filter Mask” Examples**
  - 0x0000 => Every message sent
  - 0x0003 => Every 4<sup>th</sup> message sent
  - 0xFFFF => Only first two messages sent
- **Reset filter**
  - Filters can be reset from an application or via command



Requires knowledge of binary and hexadecimal numbering systems



# Event Message Filtering (2 of 2)



- **The Software Bus ‘No Subscriber’ event message, Event ID 14**
  - See *cfe\_platform\_cfg.h* CFE\_SB\_FILTERED\_EVENT1
  - Default configuration is to only send the first 4 events
    - Filter Mask = 0xFFFF
- **CFE\_EVS\_MAX\_FILTER\_COUNT (*cfe\_evs\_task.h*) defines maximum count for a filtered event ID**
  - Once reached event becomes locked
  - Prevents erratic filtering behavior with counter rollover
  - Ground can unlock filter by resetting or deleting the filter

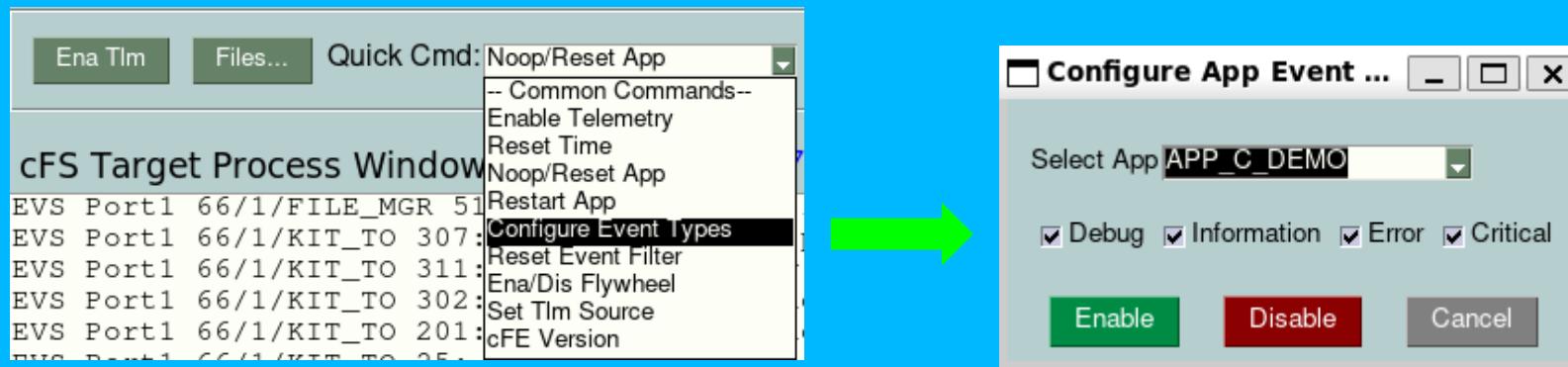


# Event Message Control

- **Processor scope**
  - Command allows events to be enabled/disabled based on type
    - Debug, Information, Error, Critical
- **Application scope**
  - Commands allow events to be enabled/disabled based on type
  - Commands allow all events to be enabled/disabled
- **Event message scope**
  - During initialization apps can register events for filtering for up to CFE\_EVS\_MAX\_EVENT\_FILTERS defined in *cfe\_platform\_cfg.h*
  - Command allows event filter masks to be modified

# Event Service Exercises - 1

1. Use the *Quick Command->Configure Event Type* menu to enable debug messages for the demo app, APP\_C\_DEMO

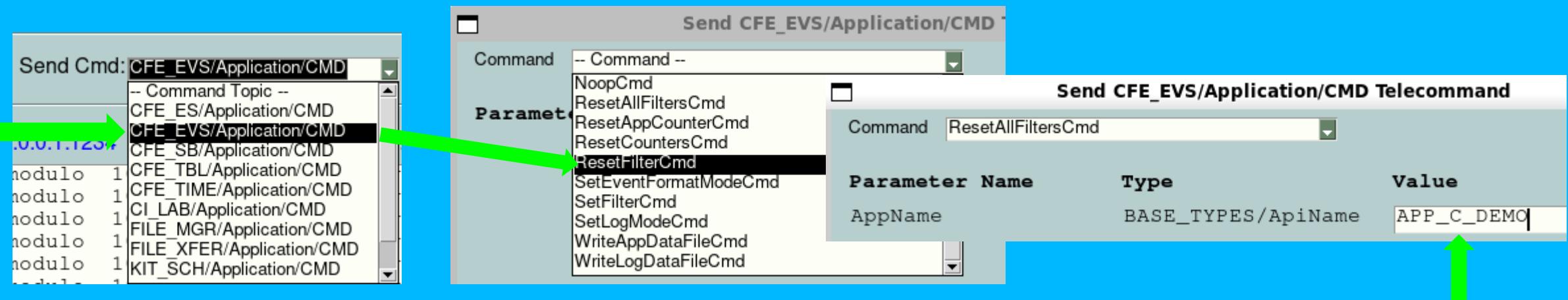


2. In the *cFS Target Process Window* you should see 8 debug event messages because this event is filtered to only send the first 8 occurrences

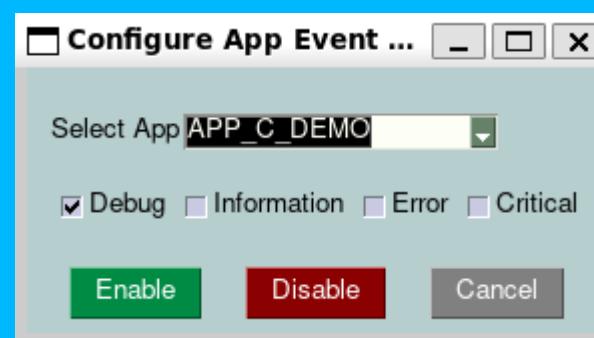
```
cFS Target Process Window   Telecommand: 127.0.0.1:1234   Telemetry: Local   Time: 1016319
EVS Port1 66/1/KIT_TO 302: Successfully loaded new table with 35 packets
EVS Port1 66/1/KIT_TO 201: Packet Table load updated 59 entries
EVS Port1 66/1/KIT_TO 25: Successfully replaced table 0 using file /cf/kit_to_pkt_tbl.json
EVS Port1 66/1/KIT_TO 100: KIT_TO Initialized. Version 3.2.0
1980-012-14:21:56.17667 CFE_ES_Main: CFE_ES_Main entering APPS_INIT state
1980-012-14:21:56.17673 CFE_ES_Main: CFE_ES_Main entering OPERATIONAL state
EVS Port1 66/1/CFE_TIME 21: Stop FLYWHEEL
EVS Port1 66/1/KIT_TO 304: Telemetry output enabled for IP 127.0.0.1
EVS Port1 66/1/KIT_SCH 406: Multiple slots processed: slot = 1, count = 2
EVS Port1 66/1/KIT_SCH 406: Multiple slots processed: slot = 1, count = 2
EVS Port1 66/1/KIT_SCH 404: Major Frame Sync too noisy (Slot 0). Disabling synchronization.
EVS Port1 66/1/APP_C_DEMO 120: Device data modulo 100, count.14193, new value 48
EVS Port1 66/1/APP_C_DEMO 120: Device data modulo 100, count.14194, new value 33
EVS Port1 66/1/APP_C_DEMO 120: Device data modulo 100, count.14195, new value 51
EVS Port1 66/1/APP_C_DEMO 120: Device data modulo 100, count.14196, new value 77
EVS Port1 66/1/APP_C_DEMO 120: Device data modulo 100, count.14197, new value 71
EVS Port1 66/1/APP_C_DEMO 120: Device data modulo 100, count.14198, new value 51
EVS Port1 66/1/APP_C_DEMO 120: Device data modulo 100, count.14199, new value 36
EVS Port1 66/1/APP_C_DEMO 120: Device data modulo 100, count.14200, new value 28
```

# Event Service Exercises - 2

3. Use *Send Command* menu to select CFE\_EVS's *ResetAllFiltersCmd*. Enter *APP\_C\_DEMO* for the *AppName*. Eight more debug event messages should appear in the *cFS Target Process Window*.



4. Use the *Quick Command* menu to disable APP\_C\_DEMO's debug events. Note you must unselect the other events so they don't get disabled. Repeat step 3 and you should not see any debug events.





# Software Bus Services Overview



- Provides an inter-application message service using a publish/subscribe model
- Routes messages to all applications that have subscribed to the message (i.e. broadcast model)
  - Subscriptions are done at application startup
  - Message routing can be added/removed at runtime
  - Sender does not know who subscribes (i.e. connectionless)
- Reports errors detected during the transferring of messages
- Outputs Statistics Packet and the Routing Information when commanded



# Software Bus Terminology



- **Pipe**
  - Destination to which SB Messages are sent
  - Queues that can hold SB Messages until they are dequeued and processed
- **Message**
  - A collection of typed data treated as a single entity
- **Buffer**
  - A contiguous block of binary data that is routed between applications
- **Applications receive *Buffers* and cast them to a specific *Message* type to use the data**



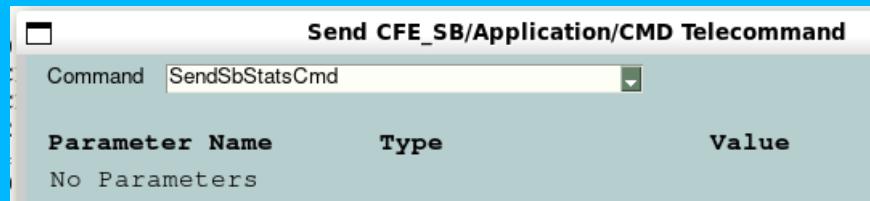
# cFS Message Module



- **The Caelum release (September 2021) introduced the Message Module**
- **The Message Module encapsulates the definition of Messages that are routed by the Software Bus**
- **The Message Module provides an API for accessing message header information**
  - This design decouples messages from Software Bus routing buffers
  - The Software Bus queries Messages for information
  - The Message payload data is not interpreted by the Message Module

# Software Bus Exercises - 1

1. First open CFE\_SB's *STATS\_TLM* window and then send CFE\_SB's *SendSbStatsCmd* command. This will populate the *STATS\_TLM* window. APP\_D\_DEMO's command pipe has a depth of 7 which is unique.



CFE_SB/Application/STATS_TLM - Port 9003			
App ID:	72	Length:	833
Seq Cnt:	1	Time:	
<b>Payload</b>			
StatsTlm.Payload.MsgIdsInUse	:	71	
StatsTlm.Payload.PeakMsgIdsInUse	:	71	
StatsTlm.Payload.MaxMsgIdsAllowed	:	256	
StatsTlm.Payload.PipesInUse	:	12	
StatsTlm.Payload.PeakPipesInUse	:	12	
StatsTlm.Payload.MaxPipesAllowed	:	64	
StatsTlm.Payload.MemInUse	:	3808	
StatsTlm.Payload.PeakMemInUse	:	3808	
StatsTlm.Payload.MaxMemAllowed	:	524288	
StatsTlm.Payload.SubscriptionsInUse	:	73	
StatsTlm.Payload.PeakSubscriptionsInUse	:	73	
StatsTlm.Payload.MaxSubscriptionsAllowed	:	4096	
StatsTlm.Payload.SBBuffersInUse	:	2	
StatsTlm.Payload.PeakSBBuffersInUse	:	9	
StatsTlm.Payload.MaxPipeDepthAllowed	:	50	
StatsTlm.Payload.PipeDepthStats[0].PipeId.BaseType	:	34996225	
StatsTlm.Payload.PipeDepthStats[0].MaxQueueDepth	:	32	
StatsTlm.Payload.PipeDepthStats[0].CurrentQueueDepth	:	0	
StatsTlm.Payload.PipeDepthStats[0].PeakQueueDepth	:	1	
StatsTlm.Payload.PipeDepthStats[0].Spare	:	0	
StatsTlm.Payload.PipeDepthStats[5].PipeId.BaseType	:	34996230	
StatsTlm.Payload.PipeDepthStats[5].MaxQueueDepth	:	7	
StatsTlm.Payload.PipeDepthStats[5].CurrentQueueDepth	:	0	
StatsTlm.Payload.PipeDepthStats[5].PeakQueueDepth	:	1	
StatsTlm.Payload.PipeDepthStats[5].Spare	:	0	

APP\_C\_DEMO's pipe stats →

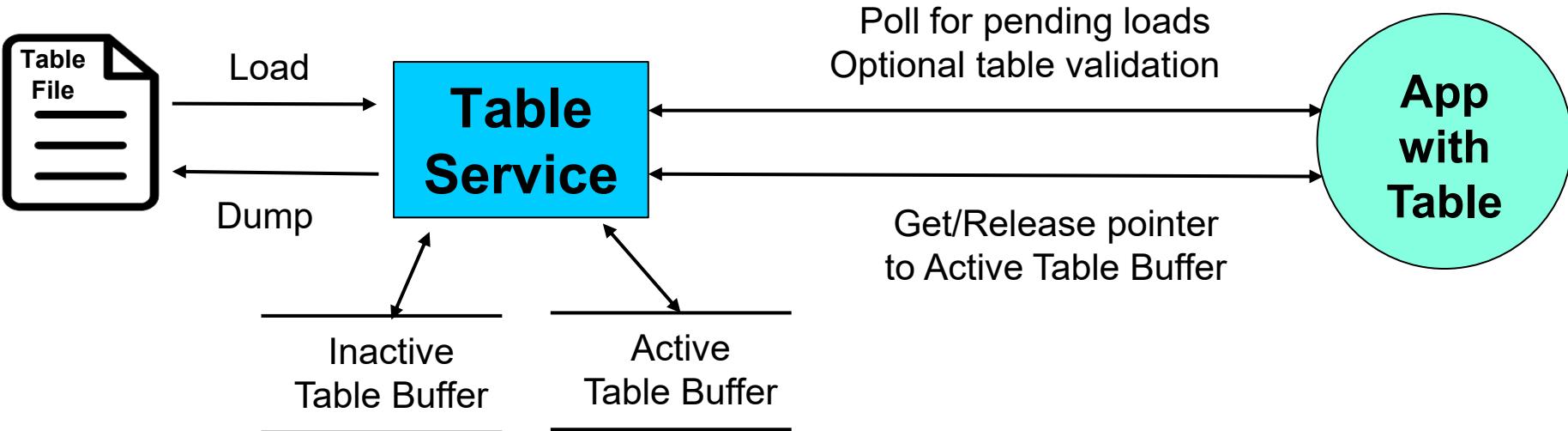


# Table Service Overview

- **What is a table?**
  - Tables are logical groups of parameters that are managed as a named entity
- **Parameters typically change the behavior of a FSW algorithm**
  - Examples include controller gains, conversion factors, and filter algorithm parameters
- **Tables service provides ground commands to load a table from a file and dump a table to a file**
  - Table loads are synchronized with applications
- **Tables are binary files**
  - Ground support tools are required to create and display table contents
- **The cFE can be built without table support**
  - Note the cFE applications don't use tables



# Table Service Functional Overview



- **Table service contains buffers that hold tables for all applications**
  - Active Table Buffer - Image accessed by app while it executes
  - Inactive Table Buffer - Image manipulated by ops (could be stored commands)
- **“Table Load” is a sequence of activities to transfer data from a file to the Active Table Buffer**
- **“Table Dump” is a sequence of activities to transfer data from either Table Buffer to a file**
- **Table operations are synchronous with the application that owns the table to ensure table data integrity**

# Table Service Exercises - 1

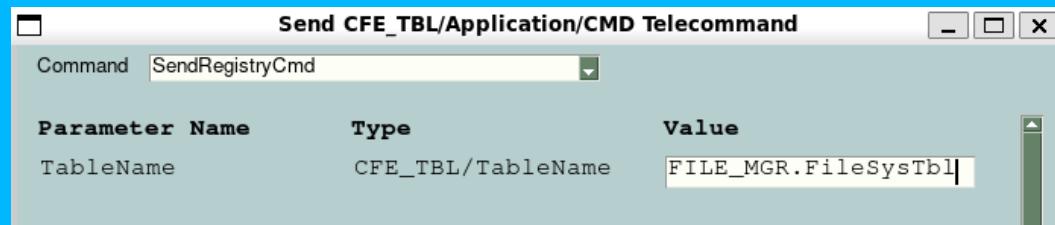
1. Open CFE\_TBL's Housekeeping (status) telemetry and browse its content
  - Basecamp uses app managed JSON table files except for File Manager (FILE\_MGR)
  - Basecamp's FILE\_MGR app is NASA's FM app refactored to use Basecamp's app framework; however, the original cFE binary table file was retained

The screenshot shows a terminal window with the title "CFE\_TBL/Application/HK\_TLM - Port 9004". The window displays housekeeping telemetry data in a table format. The columns are labeled "App ID: 75", "Length: 286", "Seq Cnt: 2", and "Tim". Below this, there is a section titled "Payload" containing numerous key-value pairs. The keys are mostly "HousekeepingTlm.Payload." followed by various metrics, and the values are either numerical or string representations. Some values are explicitly labeled with colons, while others are represented by ellipses.

App ID: 75	Length: 286	Seq Cnt: 2	Tim
<b>Payload</b>			
HousekeepingTlm.Payload.CommandCounter	:	0	
HousekeepingTlm.Payload.CommandErrorCounter	:	0	
HousekeepingTlm.Payload.NumTables	:	1	
HousekeepingTlm.Payload.NumLoadPending	:	0	
HousekeepingTlm.Payload.ValidationCounter	:	0	
HousekeepingTlm.Payload.LastValCrc	:	0	
HousekeepingTlm.Payload.LastValStatus	:	0	
HousekeepingTlm.Payload.ActiveBuffer	:	0	
HousekeepingTlm.Payload.LastValTableName	:		
HousekeepingTlm.Payload.SuccessValCounter	:	0	
HousekeepingTlm.Payload.FailedValCounter	:	0	
HousekeepingTlm.Payload.NumValRequests	:	0	
HousekeepingTlm.Payload.NumFreeSharedBufs	:	4	
HousekeepingTlm.Payload.MemPoolHandle.BaseType	:	34865154	
HousekeepingTlm.Payload.LastUpdateTime.Seconds	:	1011655	
HousekeepingTlm.Payload.LastUpdateTime.Subseconds	:	4105553655	
HousekeepingTlm.Payload.LastUpdatedTable	:		
FILE_MGR.FileSysTbl	:		
HousekeepingTlm.Payload.LastFileLoaded	:		
HousekeepingTlm.Payload.LastFileDumped	:		
HousekeepingTlm.Payload.LastTableLoaded	:		

# Table Service Exercises - 2

2. First open CFE\_TBL's *REG\_TLM* window and then send CFE\_TBL's *SendRegistryCmd* command for FILE\_MGR.FileSysTbl. This will populate the *REG\_TLM* window with FILE\_MGR.FileSysTbl details.



CFE_TBL/Application/REG_TLM - Port 9005	
App ID:	76
Length:	171
Seq Cnt:	1
Time:	
Payload	
TableRegistryTlm.Payload.Size	: 544
TableRegistryTlm.Payload.Crc	: 4294958550
TableRegistryTlm.Payload.ActiveBufferAddr	: 4243928944
TableRegistryTlm.Payload.InactiveBufferAddr	: 0
TableRegistryTlm.Payload.ValidationFuncPtr	: 2941524631
TableRegistryTlm.Payload.TimeOfLastUpdate.Seconds	: 1011655
TableRegistryTlm.Payload.TimeOfLastUpdate.Subseconds	: 4105553655
TableRegistryTlm.Payload.FileCreateTimeSecs	: 0
TableRegistryTlm.Payload.FileCreateTimeSubSecs	: 0
TableRegistryTlm.Payload.TableLoadedOnce	: 1
TableRegistryTlm.Payload.LoadPending	: 0
TableRegistryTlm.Payload.DumpOnly	: 0
TableRegistryTlm.Payload.DoubleBuffered	: 0
TableRegistryTlm.Payload.Name	:
FILE_MGR.FileSysTbl	
TableRegistryTlm.Payload.LastFileLoaded	:
/cf/filesys_tbl.tbl	
TableRegistryTlm.Payload.OwnerAppName	: FILE_MGR
TableRegistryTlm.Payload.Critical	: 0
TableRegistryTlm.Payload.ByteAlign4	: 0



# Time Service Overview

- **cFE Time Services provides time correlation, distribution and synchronization services**
- **Provides a user interface for correlation of Spacecraft Time to the ground reference time (epoch)**
- **Provides calculation of spacecraft time, derived from mission elapsed time (MET), a spacecraft time correlation factor (STCF), and optionally, leap seconds**
- **Provides a functional API for cFE applications to query the time**
- **Distributes a “time at the tone” command packet, containing the correct time at the moment of the 1Hz tone signal**
- **Distributes a “1Hz wakeup” command packet**
- **Forwards tone and time-at-the-tone packets**
- **Designing and configuring time is tightly coupled with the mission avionics design**



# Time Service Time Formats



- **Supports two formats**
- **International Atomic Time (TAI)**
  - Number of seconds and sub-seconds elapsed since the ground epoch
  - $\text{TAI} = \text{MET} + \text{STCF}$ 
    - Mission Elapsed Counter (MET) time since powering on the hardware containing the counter
    - Spacecraft Time Correlation Factor (STCF) set by ground ops
    - Note STCF can correlate MET to any time epoch so TAI is mandated
- **Coordinated Universal Time (UTC)**
  - Synchronizes time with astronomical observations
  - $\text{UTC} = \text{TAI} - \text{Leap Seconds}$
  - Leap Seconds account for earth's slowing rotation

# Time Service Exercises - 1

1. Open CFE\_TIME's Housekeeping telemetry window and observe the following

CFE\_TIME/Application/HK\_TLM - Port 9006

App ID:	77	Length:	37	Seq Cnt:	5834	Time:	1034990
Payload							
HousekeepingTlm.Payload.CommandCounter	:	0					
HousekeepingTlm.Payload.CommandErrorCounter	:	0					
HousekeepingTlm.Payload.ClockStateFlags	:	13280					
HousekeepingTlm.Payload.ClockStateAPI	:	INVALID					
HousekeepingTlm.Payload.LeapSeconds	:	37					
HousekeepingTlm.Payload.SecondsMET	:	34990	→				34990 MET
HousekeepingTlm.Payload.SubsecsMET	:	1467853606	→				+ 1000000 STCF
HousekeepingTlm.Payload.SecondsSTCF	:	1000000	→				
HousekeepingTlm.Payload.SubsecsSTCF	:	0					
HousekeepingTlm.Payload.AdjustmentFactor.Seconds	:	0					
HousekeepingTlm.Payload.AdjustmentFactor.Subseconds	:	0					

Telemetry message headers time stamped with Spacecraft Time

34990 MET  
+ 1000000 STCF  
-----  
1034990 Spacecraft Time



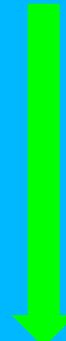
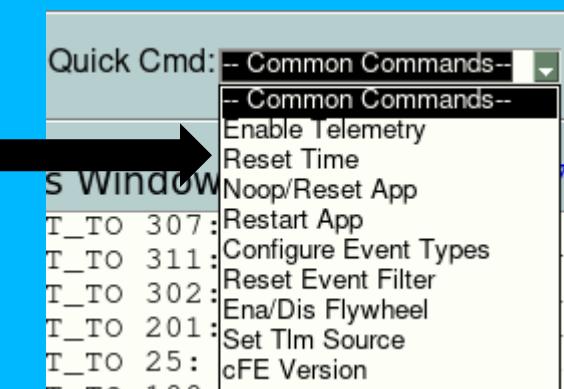
# Time Service Exercises - 2

## 2. Use the Quick Command menu to Reset Time

- Sends CFE\_TIME's SetMET and SetTime commands with 0 for seconds and sub seconds

Time reset to zero

CFE_TIME/Application/HK_TLM - Port 9006	
App ID:	77
Length:	37
Seq Cnt:	5855
Time:	7
Payload	
HousekeepingTlm.Payload.CommandCounter	: 2
HousekeepingTlm.Payload.CommandErrorCounter	: 0
HousekeepingTlm.Payload.ClockStateFlags	: 13280
HousekeepingTlm.Payload.ClockStateAPI	: INVALID
HousekeepingTlm.Payload.LeapSeconds	: 37
HousekeepingTlm.Payload.SecondsMET	: 8
HousekeepingTlm.Payload.SubsecsMET	: 1467647878
HousekeepingTlm.Payload.SecondsSTCF	: 4294967294
HousekeepingTlm.Payload.SubsecsSTCF	: 3903496059
HousekeepingTlm.Payload.AdjustmentFactor.Seconds	: 0
HousekeepingTlm.Payload.AdjustmentFactor.Subseconds	: 0



TBD: What's going on with STCF?

cFS Target Process Window displays events for each command

```
EVS Port1 66/1/CFE_TIME 13: Set MET -- secs = 0, usecs = 0, ssecs = 0x0
EVS Port1 66/1/CFE_TIME 12: Set Time -- secs = 0, usecs = 0, ssecs = 0x0
```

# Time Service Exercises - 3

## 3. Send a SetSTCFCmd

Send CFE\_TIME/Application/CMD Telecommand

Command: SetSTCFCmd

Parameter Name	Type	Value
Seconds	BASE_TYPES/uint32	1000
MicroSeconds	BASE_TYPES/uint32	0

CFE\_TIME/Application/HK\_TLM - Port 9006

App ID: 77 Length: 37 Seq Cnt: 5890 Time: 1148

Payload

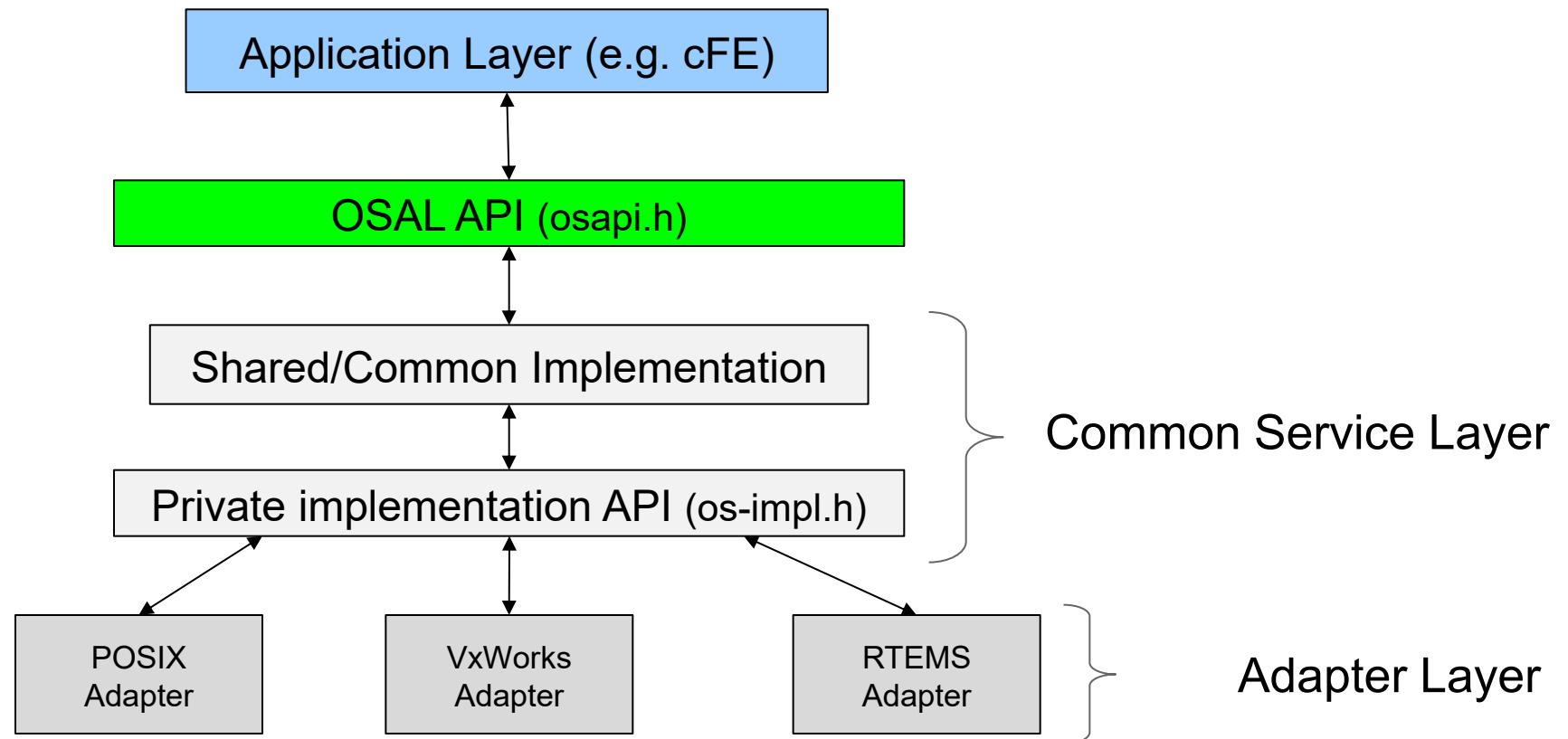
HousekeepingTlm.Payload.CommandCounter	:	3
HousekeepingTlm.Payload.CommandErrorCounter	:	0
HousekeepingTlm.Payload.ClockStateFlags	:	13280
HousekeepingTlm.Payload.ClockStateAPI	:	INVALID
HousekeepingTlm.Payload.LeapSeconds	:	37
HousekeepingTlm.Payload.SecondsMET	:	148
HousekeepingTlm.Payload.SubsecsMET	:	1464942048
HousekeepingTlm.Payload.SecondsSTCF	:	1000
HousekeepingTlm.Payload.SubsecsSTCF	:	0
HousekeepingTlm.Payload.AdjustmentFactor.Seconds	:	0
HousekeepingTlm.Payload.AdjustmentFactor.Subseconds	:	0

STCF Updated



# OSAL Layered Architecture

- The OSAL has its own layered architecture with an “application” API that is portable across different operating systems
  - The OSAL is a product that can be used independent of the cFS
  - The cFE is an OSAL application





# OSAL Layered Design Strategy

- **Maximize common service layer functionality and minimize OS adapter code**
  - Avoid duplicate implementations in each OS Adapter
  - Perform validation and error checking in the Common Service Layer so OS adapters can trust data and minimize logic
- **Ensure consistent behavior across operating systems**
  - No chance of one OS checking e.g. if an input is NULL but not the others.
  - If a race condition is found, it would be applied to all OS's with only one fix to the Common Service Layer. No additional work to copy to other implementations.
- **Use robust design practices in the Common Service Layer**
  - Mutex/Reference count every operation that needs it
  - “Best practices” for Symmetric Multiprocessing and highly multi-threaded systems
- **Reduce the cost of adding new OS Adapters**
  - Only “business logic” that is specific to an OS should be implemented



# Common Service Layer

- **Manage common operating resources like tasks, queues, mutexes, etc. as “Objects”**
- **Each Object has a Type and an Identifier (ID)**
  - A separate number space is used for each ID Type
  - Up to 64K allocations need to occur before an ID is repeated/reused
  - Zero is not a valid ID to catch uninitialized variable errors
- **Use Tables (not cFE tables) to manage Objects**
  - OS independent locking / unlocking semantics
- **Check the validity and state of a passed-in IDs across all Object Types and all OS implementations**
  - If valid, issue new Object ID's and find open Table entries



# Platform Support Package (PSP)

- **The PSP functions complete the Platform Abstraction API that is required by the cFE**
  - They serve as the "glue" between the OSAL/RTOS and the cFE Flight Software filling gaps that are not considered part of the OSAL
- **It's architectural role is equivalent to an OS Adapter with a slightly different scope**
  - A new implementation must be created for each platform
- **CFE\_PSP\_Main() is the entry point that an RTOS calls to start the cFE**
  - It performs any BSP/RTOS specific setup and then calls the cFE main entry point
- **The cfe\_psp.h file defines the entire API**
  - Example functions include getting the processor restart type, flushing a cache, etc.



# Application Layer Architectural Components

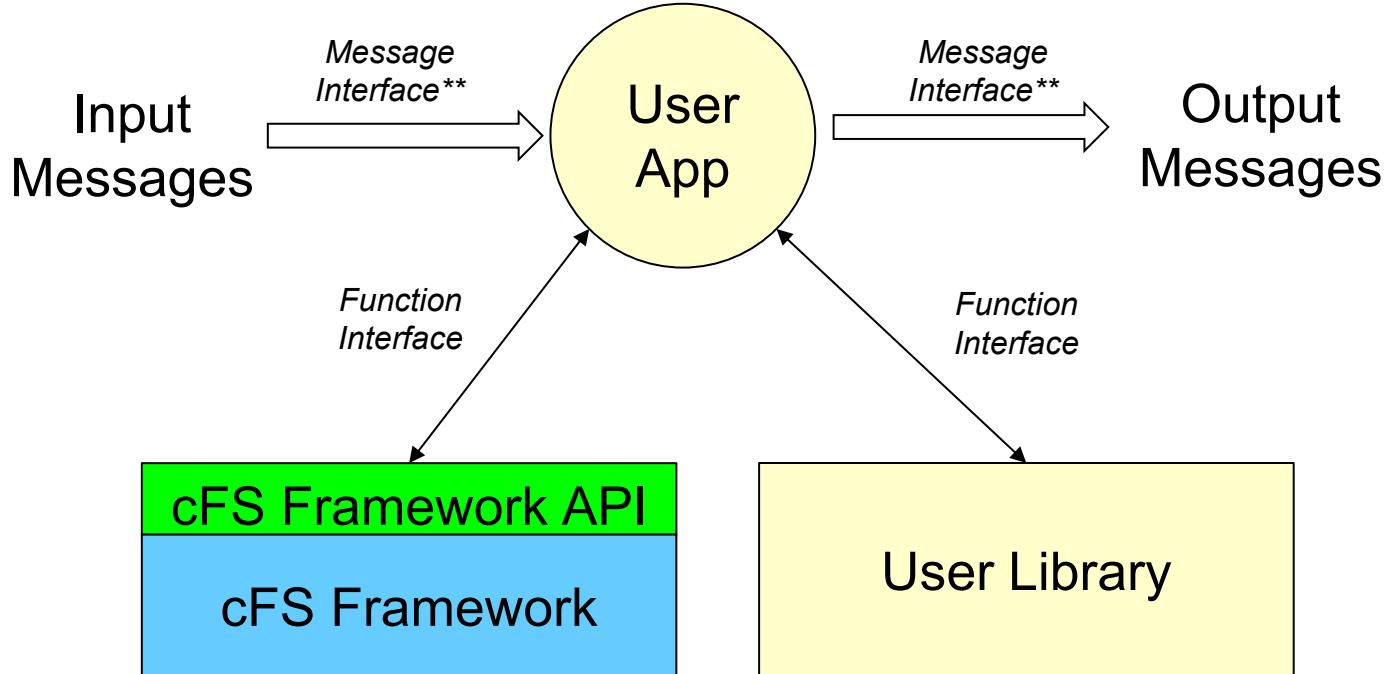


# Application Layer Introduction

- The cFS Application Layer contains Library and Application architectural components
- Architectural components have well defined context, interfaces, and relationships with other components
- A cFS library/application context is bounded by the following interfaces (see next slide)
  1. cFE, OSAL, and PSP services and Application Programmer Interfaces (APIs)
  2. The functional interfaces (APIs) defined by libraries
  3. The message interfaces defined by applications
  4. Platform-specific APIs
- This section discusses the first three interfaces
  - The cFS Systems Engineering document includes design patterns for using platform-specific APIs



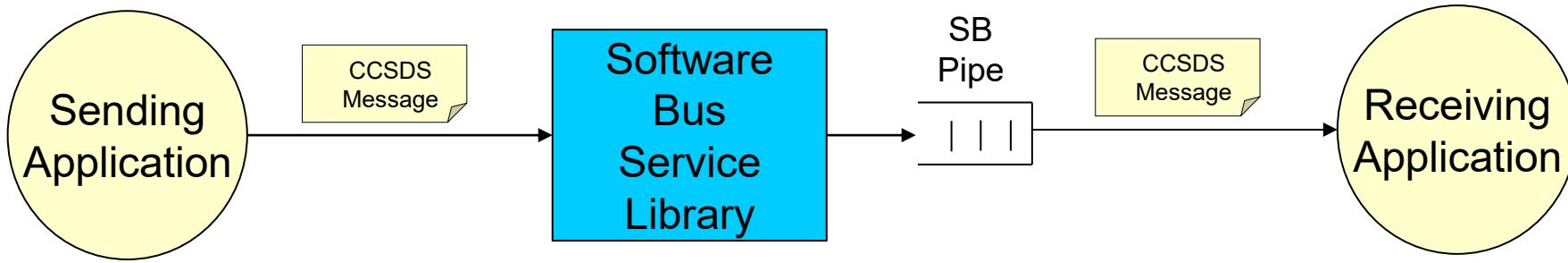
# Library & Application Context



\*\* Note that if messages are standardized then the concept of service apps could be established



# Message-Centric Application Design



- Inter-app communications using the **Software Bus** is an essential to app designs
- The **Software Bus** uses a one-to-many message broadcast model
  - Applications publish messages without knowledge of destinations
- To receive messages, applications create an **SB Pipe** (a *FIFO queue*) and subscribe to messages
  - Typically performed during application initialization
- If needed, apps can subscribe and unsubscribe to messages at any time for runtime reconfiguration
- **SB Pipes** used for application data and control flow
  - Poll and pend for messages



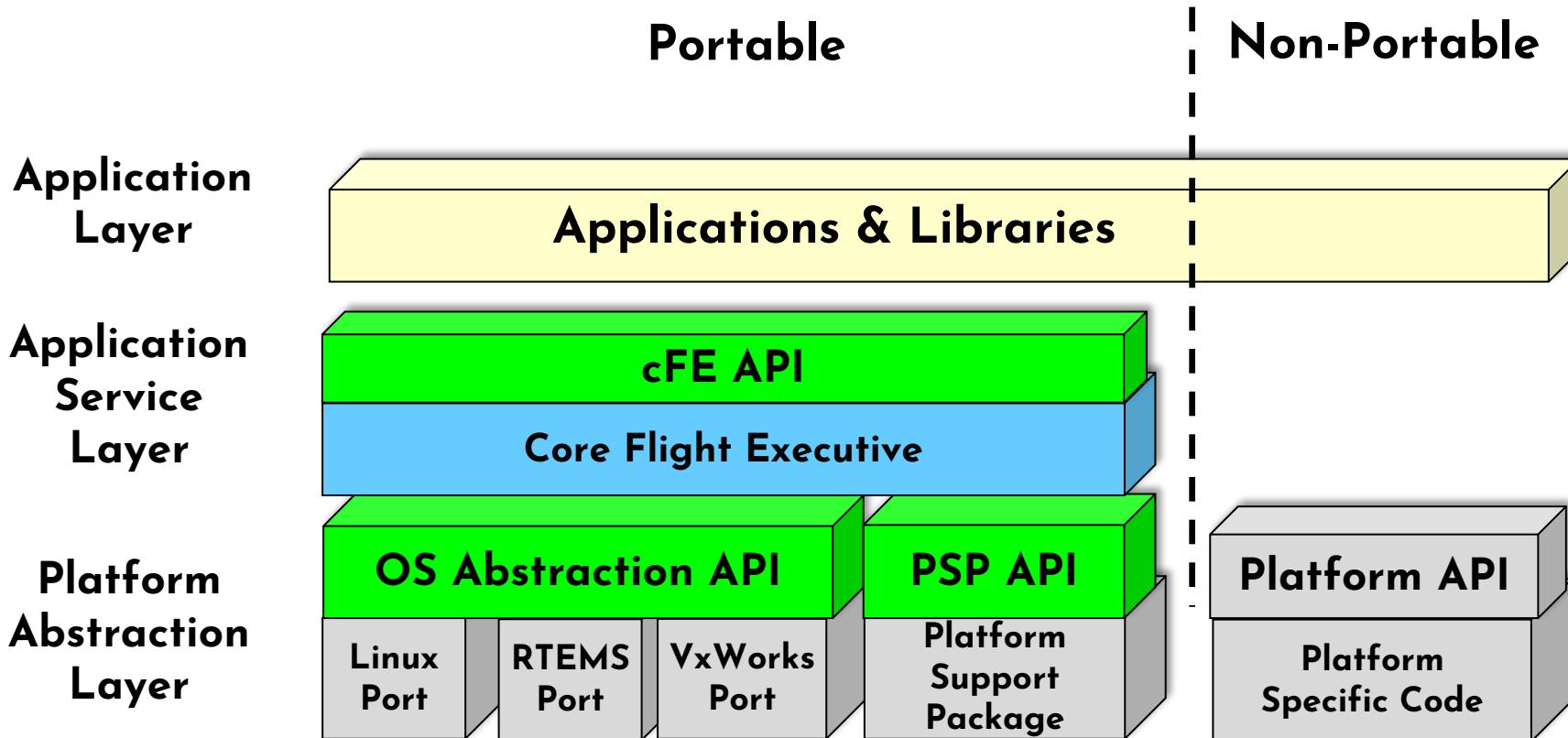
# Application Layer Design Concepts

- **Architecture component dynamic deployment model\*\***
  - cFS Framework is built as a single binary image
  - Libraries and applications built as individual object files
  - A startup script defines which lib/app objects are loaded
- **An essential cFS architectural design concept is that libraries and apps can be designed with interdependencies that allow groups of libs/apps to provide mission functionality**
  - Library interfaces are similar to the cFS's layered interfaces
  - App message interfaces are peer-to-peer however a dependency hierarchy can be created based on the producer-consumer relationships
  - This section introduces the Operations Services App Suite (OSAS) that must be included in every cFS target
  - The cFS Systems Engineering document contains more examples functional lib/app groups

\*\* Dynamic (runtime binding) is the default configuration. Static linking is supported.



# Library & Application Portability/Reusability



- **Libraries and apps are portable if they only use the cFS APIs shown in green**
- **Many mission specific apps may not be portable to a new mission unless the same platform is used**
  - This does not make them “non-compliant” components, just non-portable
  - Organizational goals, budgets and schedules drive whether to develop reusable component decisions



# Applications (1 of 2)

- **What is an Application?**
  - A thread of execution managed by the platform's operating system
  - They acquire and own resources using the Platform Abstraction and Application Service APIs
- **Resources are typically acquired during initialization and released when an application terminates**
  - Helps create a deterministic steady-state system
  - Helps achieve the architectural goal for a loosely coupled system that is scalable, interoperable, testable (each app can be separately unit tested), and maintainable
- **Apps can be reloaded during operations without rebooting**



# Applications (2 of 2)

- **Concurrent execution model**
  - Each app has its own priority-based thread of execution and can spawn child tasks with their own priority-based thread of execution
  - Supports complex realtime mission requirements
- **Reusable apps only use the cFS APIs**
  - Write once run anywhere the cFS framework has been deployed
  - Can be written in a desktop environment deferring embedded software development complexities such as cross compilation and target operating systems
  - Provides seamless application transition from technology efforts to flight projects
  - More powerful than the Smartphone situation where different apps are written for each platform



# Libraries (1 of 2)

- **What is a library?**
  - A collection of functions and data that are available for use by apps and other libraries
  - Architecturally they exist within the application layer
  - They cannot create tasks and they assume the AppID/TaskID of the caller
- **Libraries are not registered with Executive Services and do not have a thread of execution, so they have limited cFE API usage. For example,**
  - A library can't call CFE\_EVS\_Register() during initialization
  - The ES API does not provide a function for libraries analogous to CFE\_ES\_GetAppInfo()
- **Library functions execute within the context of the calling application**
  - CFE\_EVS\_SendEvent() will identify the calling app
  - Libraries can't register for cFE services during initialization and in general should not attempt to do so





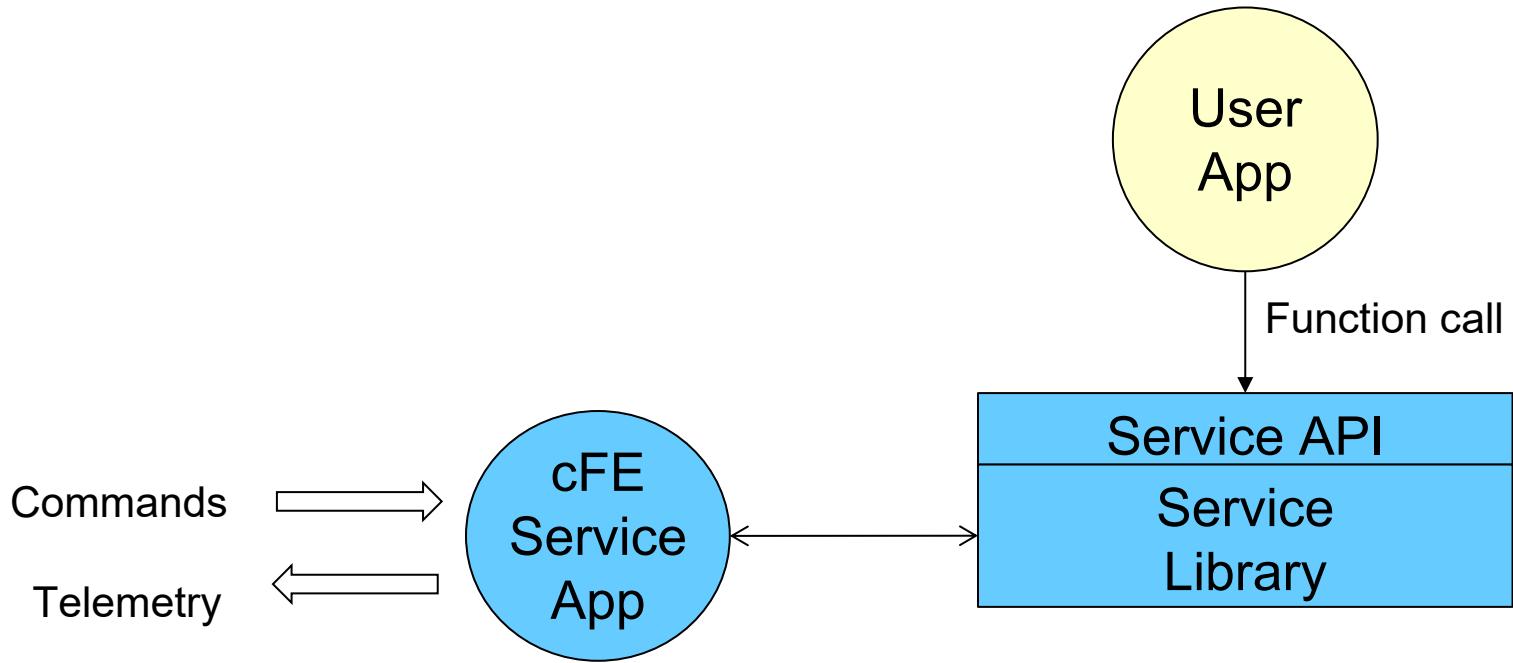
# Libraries (2 of 2)

- **Libraries can either be statically or dynamically linked**
  - Dynamic linking requires support from the underlying operating system
- **No cFE API exists to retrieve library code segment addresses**
  - Prevents apps like Checksum from accessing library code space
- **Libraries are specified in the `cfe_es_startup.scr` and loaded during cFE initialization**
  - When using dynamic linking, libraries must be loaded prior to components that use them
- **For libraries that require a ground interface, or some other more complex runtime environment, a helper app is created to provide this support**
  - The cFE's service design uses this approach





# cFE Service Design (1 of 2)



- **Each cFE service has**
  - A library that is used by applications
  - An application that provides a ground interface for operators to use to manage the service

→ = Software Bus Message



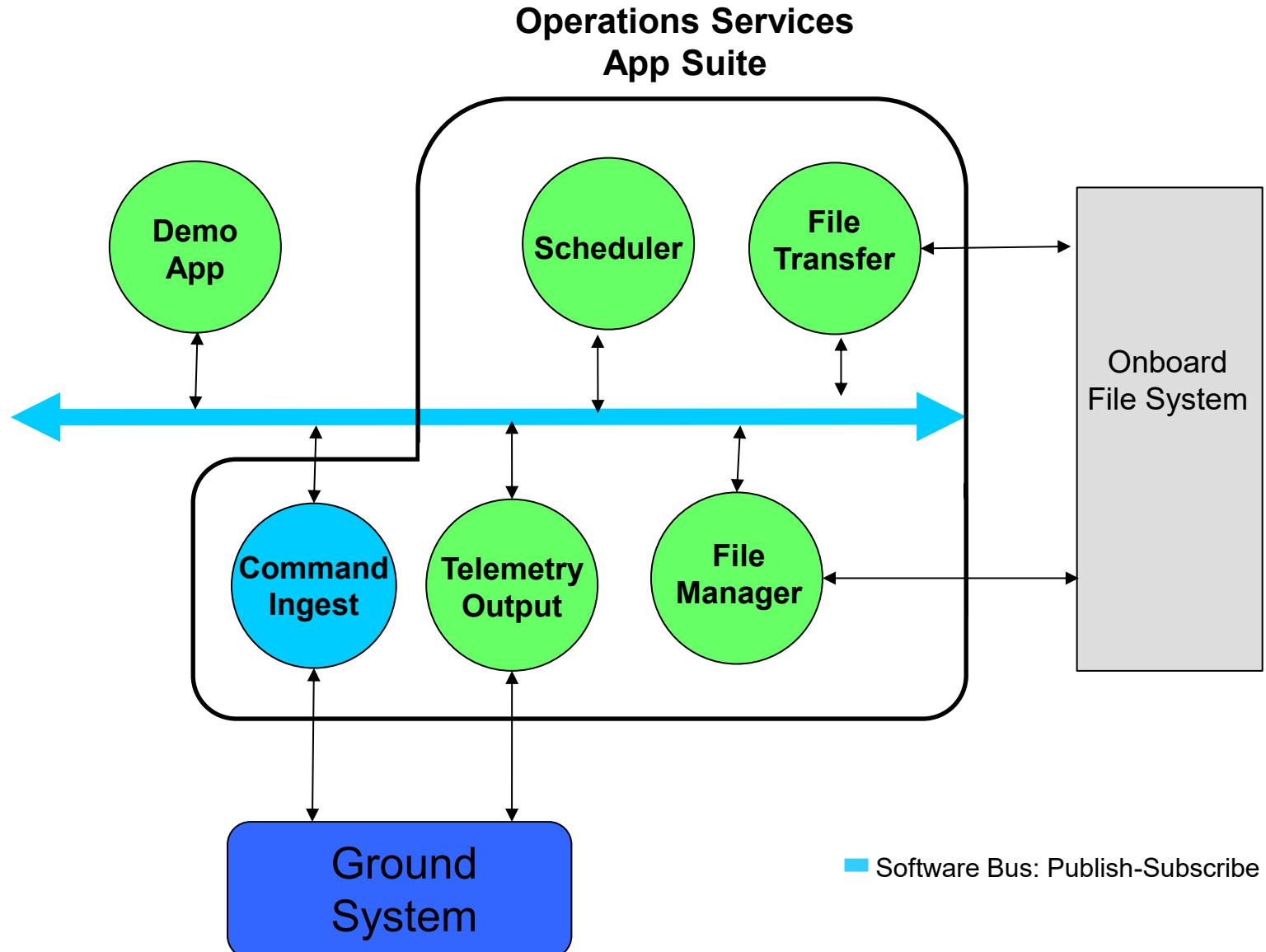
# cFE Service Design (2 of 2)



- **Each cFE Service App periodically sends status telemetry in a “Housekeeping (HK) Packet”**
  - Housekeeping is an historical term that means an application’s status
- **You can obtain additional service information beyond the HK packet with commands that**
  - Send one-time telemetry packets
  - Write onboard service configuration data to files



# Basecamp cFS Target





# Operations Services App Suite

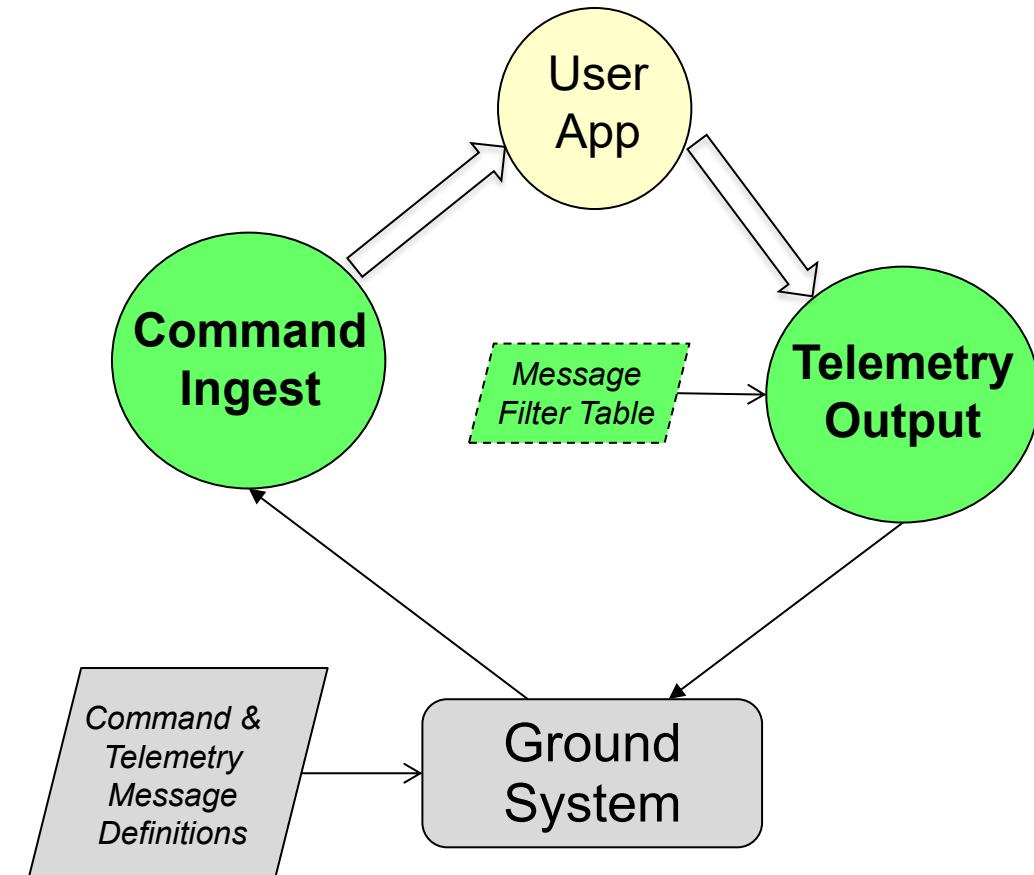


- **The Operations Service App Suite is a group of apps that provide functionality required by every cFS target in an operational system**
  - A target needs to communicate (receive commands and send telemetry) with at least one external system, typically a ground system
  - The cFS relies on files so a mechanism for transferring files between the target and an external system is needed, as well as remotely managing the target's directories and files
  - The cFS promotes designing synchronous systems so having an app synched with a 1Hz signal that sends periodic scheduling messages helps achieve this goal
- **An Operations Services App Suite is included in Basecamp's default Target\*\***

*\*\* A cFS target is an instantiation of the cFE Framework on a platform with a set of library and apps. Not to be confused with a distribution.*



# Command & Telemetry Context (1 of 2)

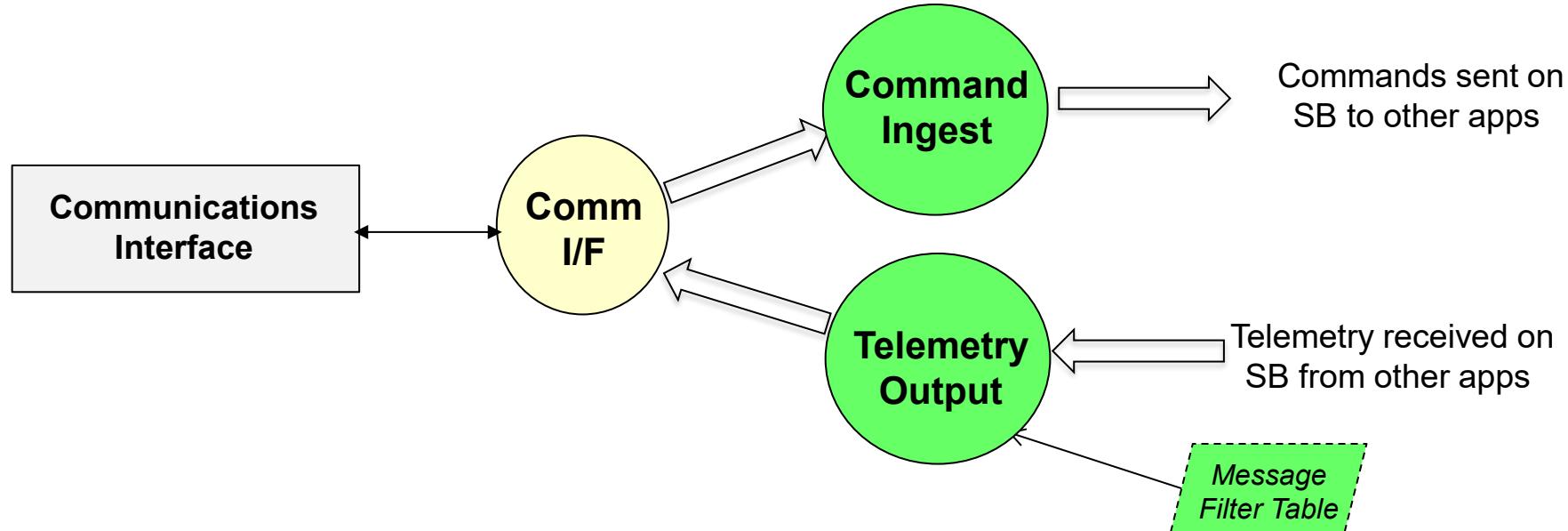


- **Command Ingest (CI) App**
  - Receives commands from an external source, typically the ground system, and sends them on the software bus
- **Telemetry Output (TO) App**
  - Receives telemetry packets from the software bus and sends them to an external source, typically the ground system
  - Optional *Filter Table* that provides parameters to algorithms that select which messages should be output on the external communications link

- **The ground and flight messages definitions must match**
  - Basecamp uses Electronic Data Sheets to define messages once and the EDS Toolchain creates ground and flight artifacts. See later slide “*Single EDS Definition*” for overview.
  - In many situations, developers must manually implement separate ground and flight definitions and ensure that they match



# Command & Telemetry Context (2 of 2)

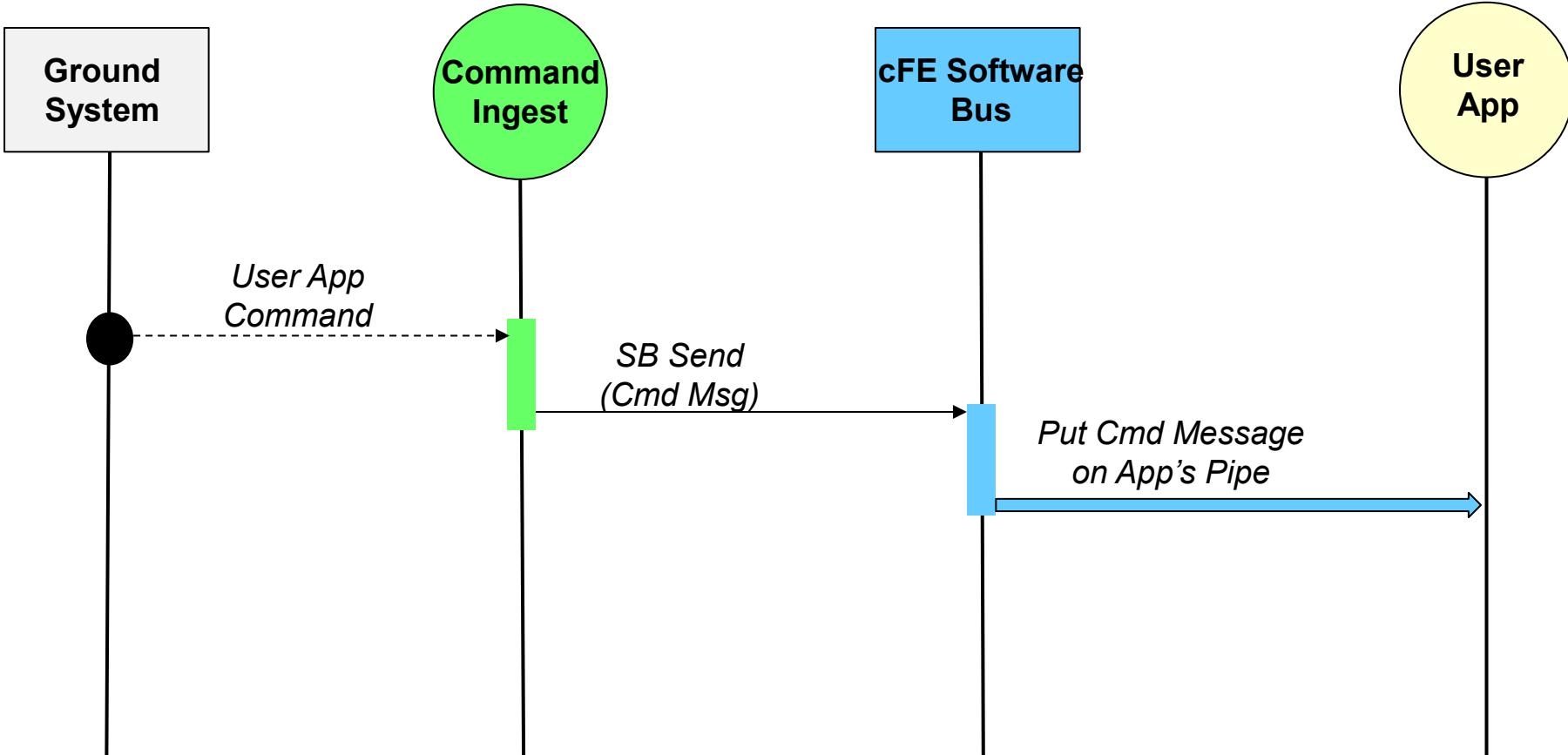


- **Mission external command and telemetry communications is more complicated for embedded systems**
  - An interface app is often used to manage the hardware interface and transferring messages between the Software Bus and the hardware interface
  - The Systems Engineering Document goes into more detail
- **The following versions of CI and TO are available as open source**
  - Basecamp versions use UDP and a JSON-defined filter table
  - cFS Bundle includes 'lab' versions that use UDP for the external comm
  - NASA's Johnson Space Center versions use a configurable I/O library for a different external comm links



# Telecommand from Ground to User App

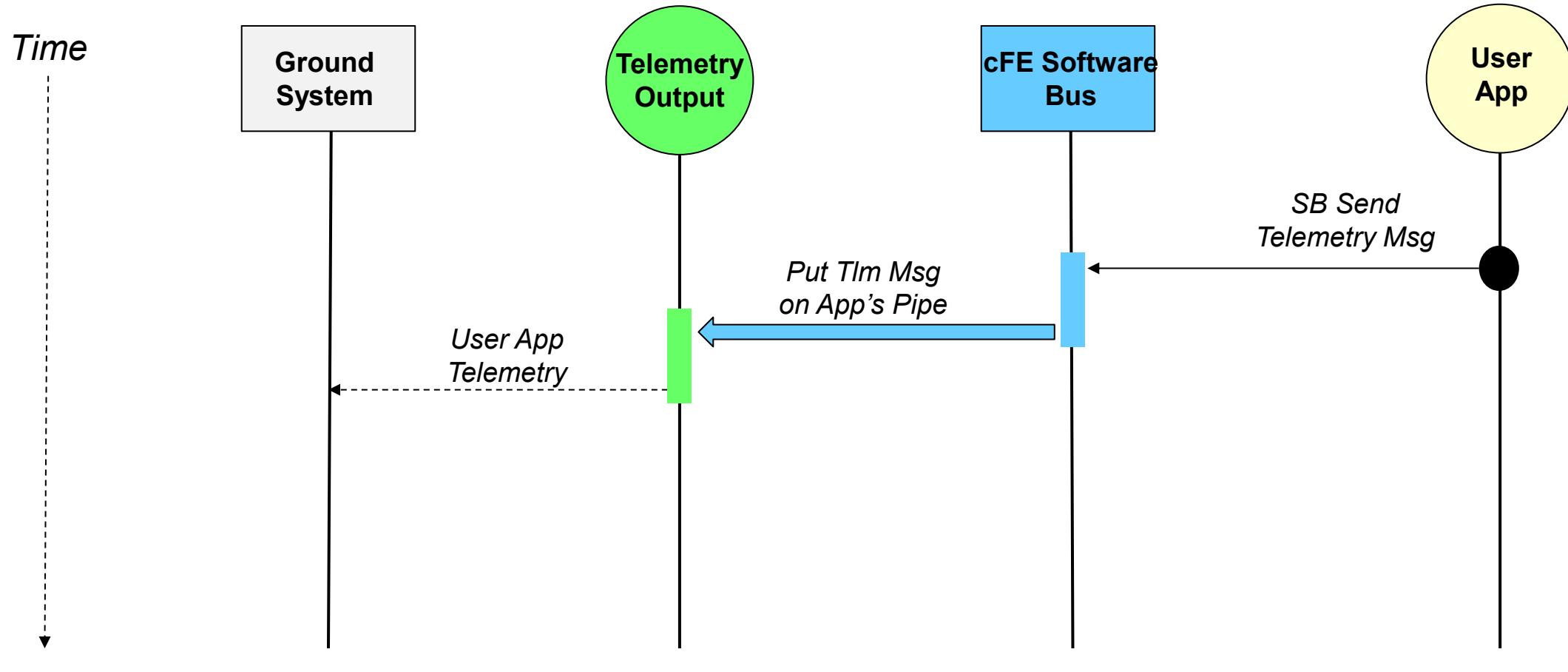
Time



● = Initial event

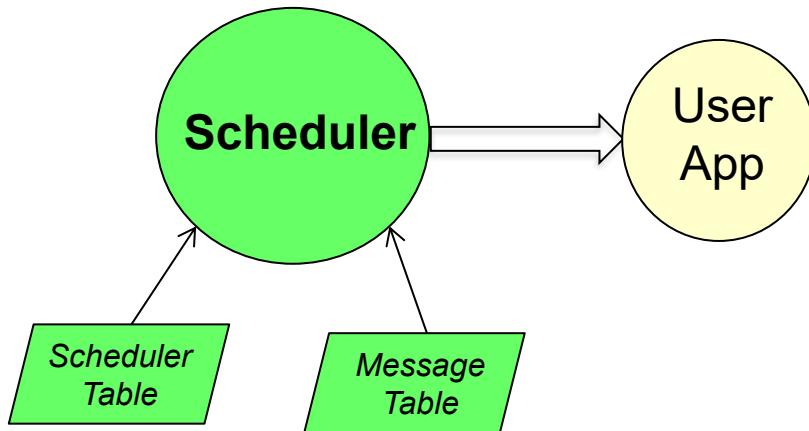


# Telemetry from User App to Ground





# Application Scheduling Context



- **Scheduler (SCH) App**
  - Synchronizes execution with clock's 1Hz signal
  - Sends software bus messages defined in the *Message Table* at time intervals defined in the *Scheduler Table*
- **Application Control Flow Options**
  - Pend indefinitely on a *SB Pipe* with subscriptions to messages from the Scheduler
    - This is a common way to synchronize the execution of most of the apps on a single processor
    - Many apps send periodic “Housekeeping” status packets in response to a “Housekeeping Request message from Scheduler
  - Pend indefinitely on a message from another app
    - Often used when an application is part of a data processing pipeline
  - Pend with a timeout
    - Used in situation with loose timing requirements and system synchronization Is not required
    - The SB timeout mechanism uses the local oscillator so the wakeup time may drift relative to the 1Hz



# Application Run Loop Messaging Example

Suspend execution until a message arrives on app's pipe

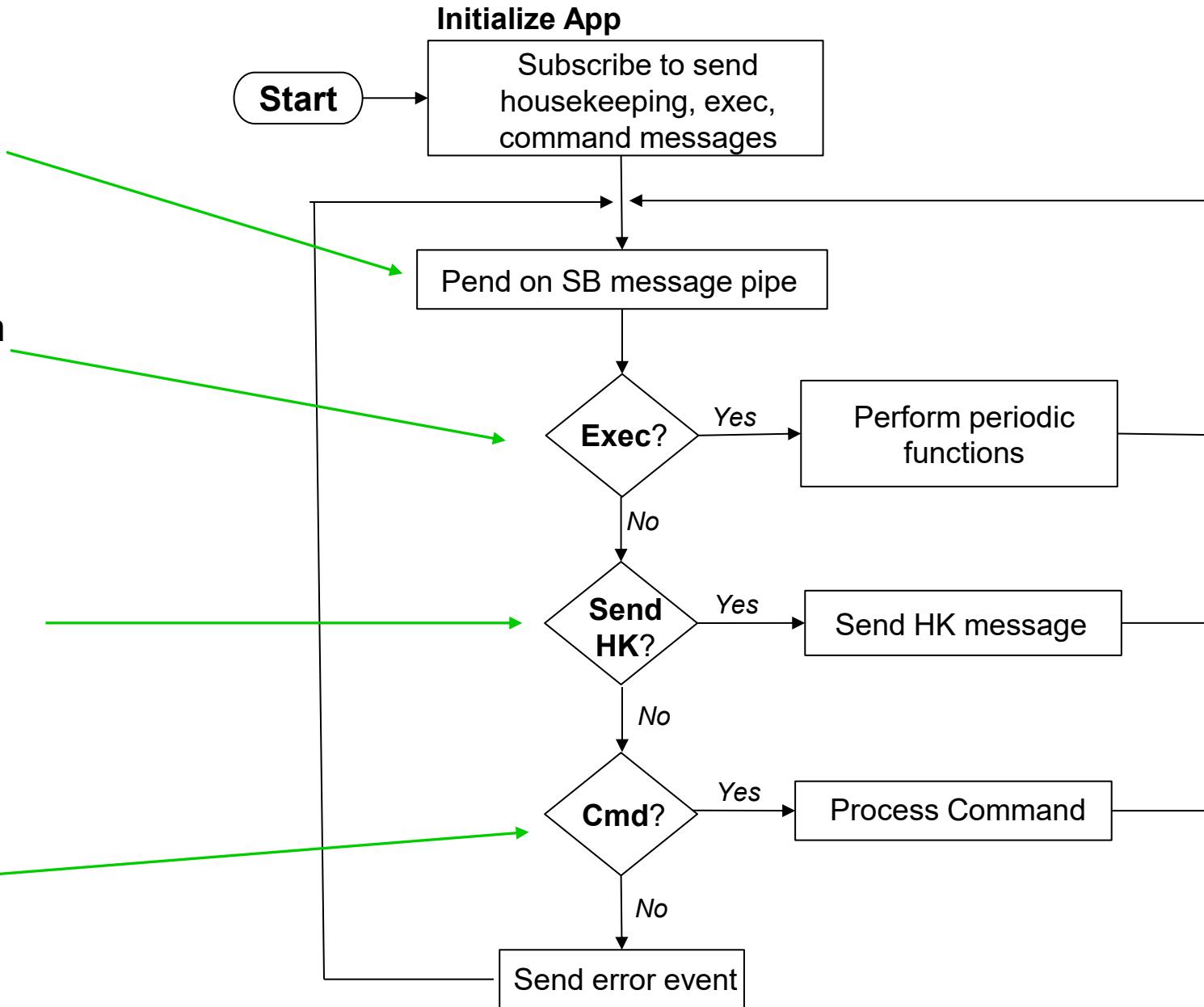
Periodic execute message from SCH app

Periodic *request housekeeping* message from SCH app

- Typically, on the order of seconds
- “Housekeeping cycle” convenient time to perform non-critical app functions

Process commands

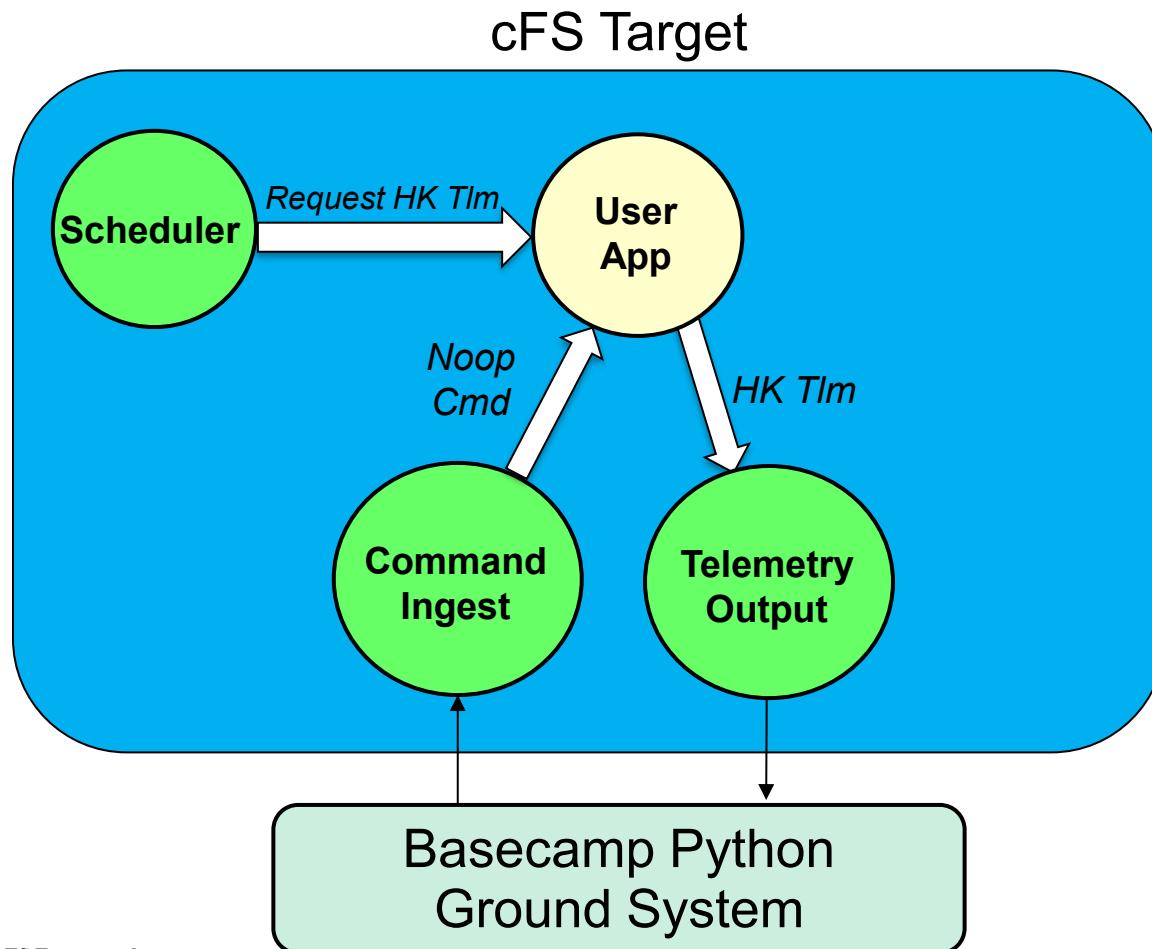
- Commands can originate from ground or other onboard apps





# Application Runtime Environment Summary

- By convention every app contains a “No Operation (NOOP)” command
- Walking through the NOOP command execution flow is a good way to understand the runtime environment provided by three of the operations services apps

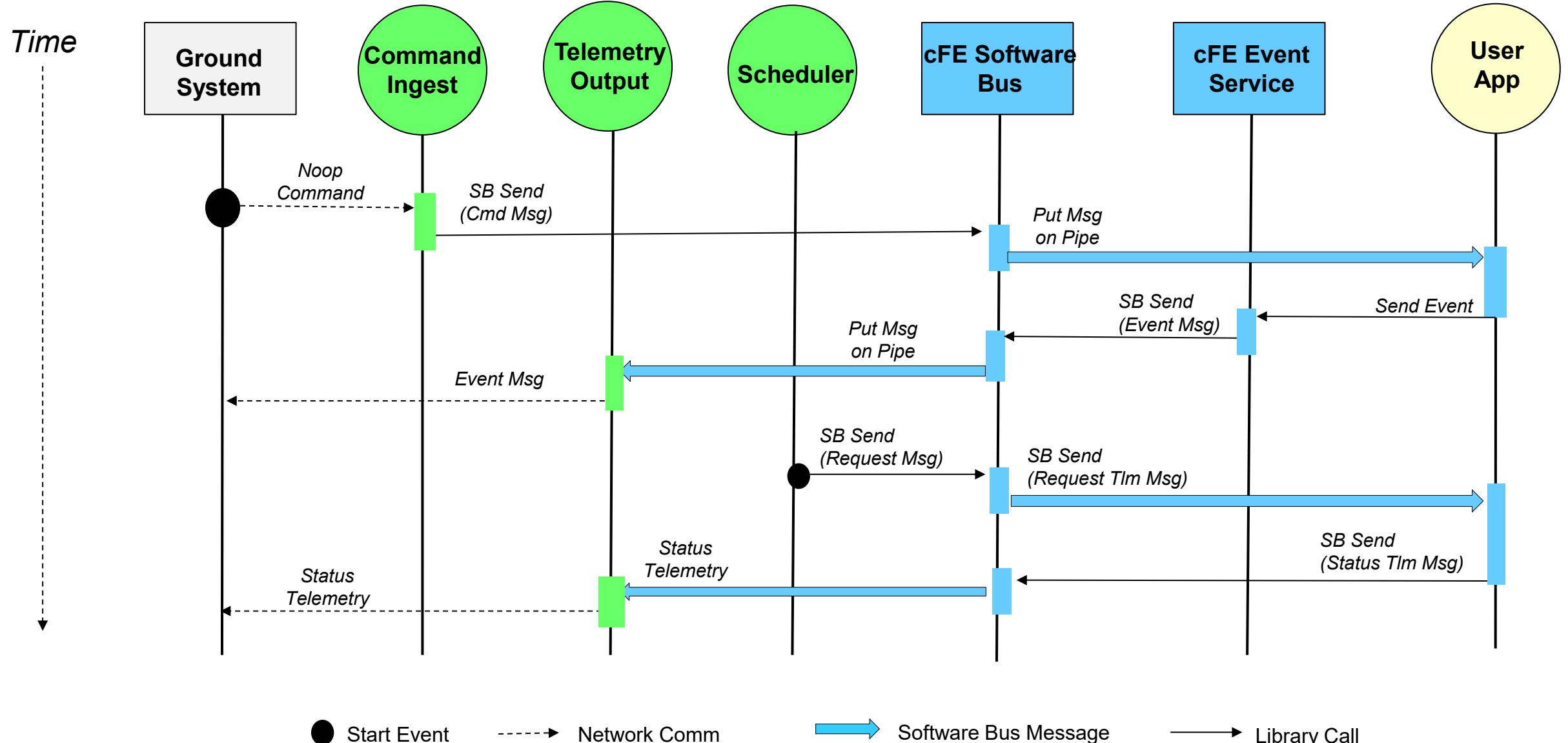


This sequence is illustrated on the next slide

1. When a user sends a NOOP command from the ground system an app responds with
  - An event message that contains the app's version number
  - Increments the command valid counter
2. The Scheduler app periodically sends a “Request Housekeeping Telemetry”
  - HK telemetry includes valid and invalid command counters



# No Operation (Noop) Command Sequence



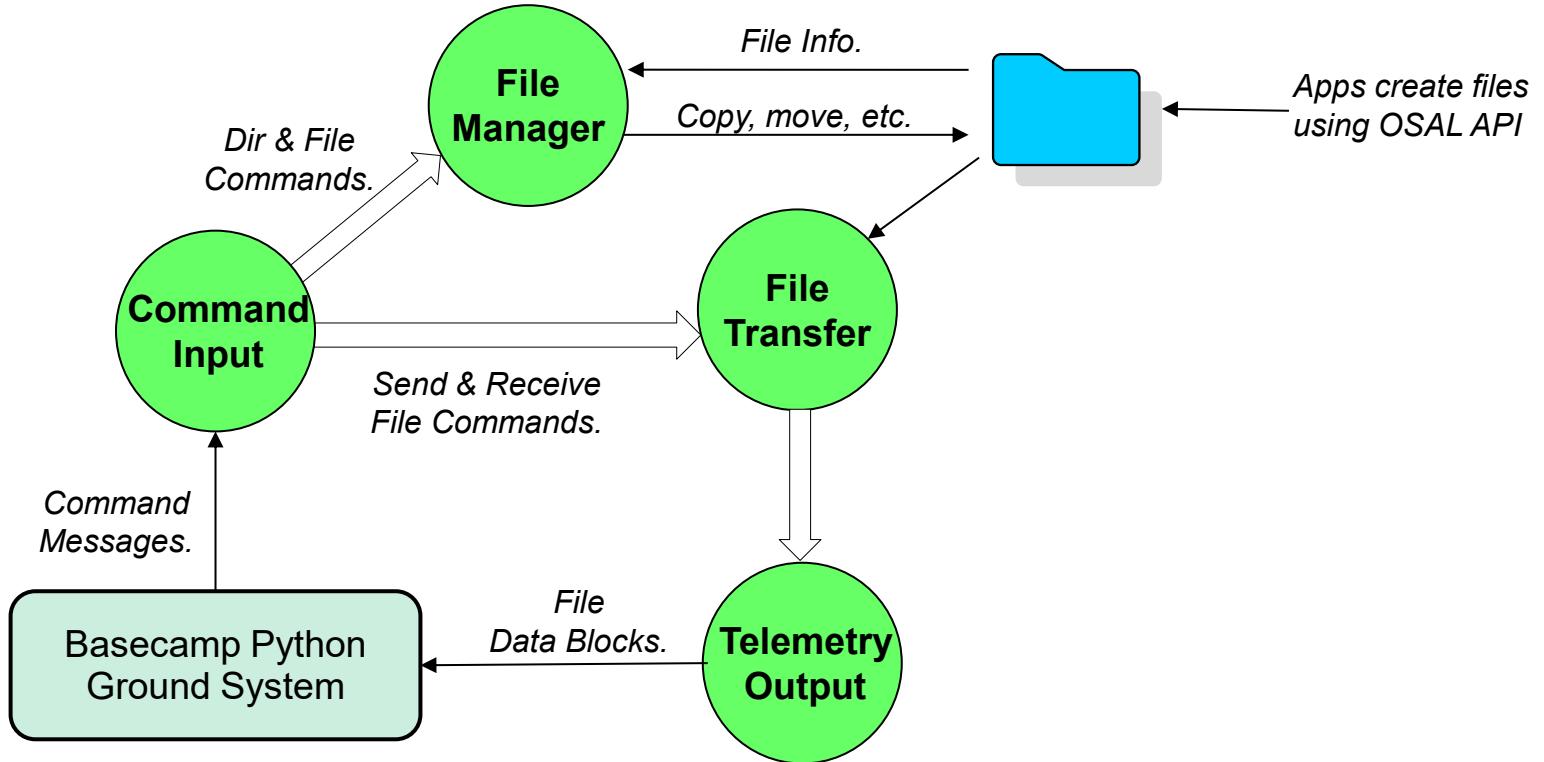


# File Management Operations Services App

- **The cFS relies on a file system so Basecamp's Operations Services App Suite contains two apps that provide the required functionality**
- **File Manager provides a ground command/telemetry interface for managing onboard directories and files**
  - The NASA File Manager app design was refactored to use an object-based design and Basecamp's application framework
- **File Transfer transfers files between flight and ground using a custom file transfer protocol implemented in both the flight and ground systems**
  - The protocol is very similar to the Class 1 CCSDS File Delivery Protocol (CFDP)
  - The protocol messages are defined using EDS



# File Management Ops Scenario Example



- **Apps create files using the OSAL API so the cFS Framework can manage files resource usage**
- **File Manager is used to manage directories and files**
  - Commands can originate from the ground or other onboard apps
- **File Transfer is used to transfer between the ground and flight**
  - Files are divided into data blocks that are transferred as CSSDS messages
  - The File Transfer to Telemetry Output message interface requires a mechanism to control the data rate



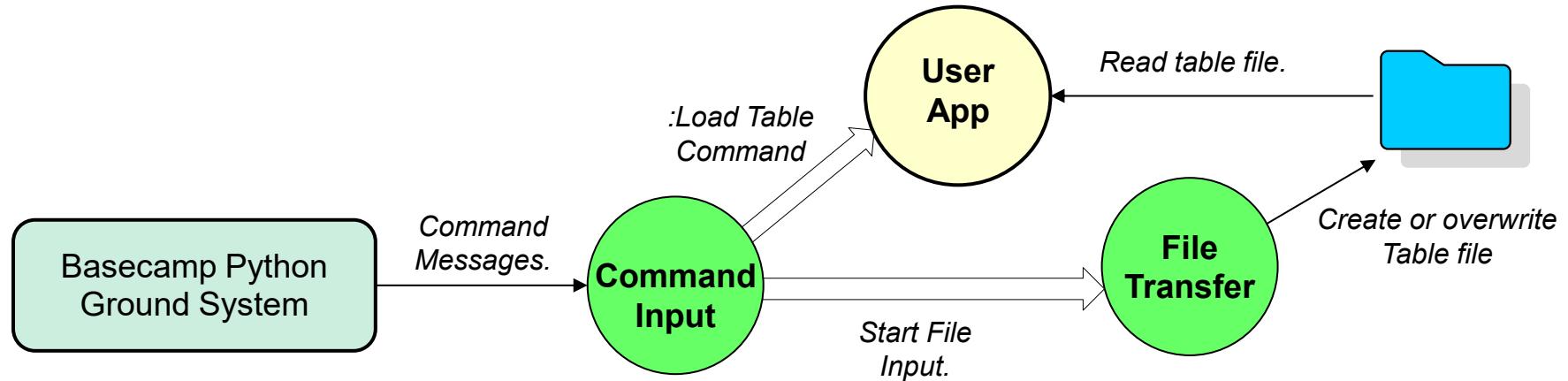
# Basecamp Tables



- **Basecamp apps do not use the cFS table service**
- **JSON files are used to define table parameters and values**
  - The cFS uses binary files
  - Onboard file management apps need to be present to manage table files
- **If a Basecamp app has a table then it provides table load and dump commands**
  - The Basecamp app framework provides table management and JSON parsing services
  - Developers must provide code for loading/dumping table data
- **All Basecamp apps have a JSON initialization file, but it is not a table**
- **The “Hello Table” code tutorial and Basecamp App Developer Guide describe how to create apps with tables**



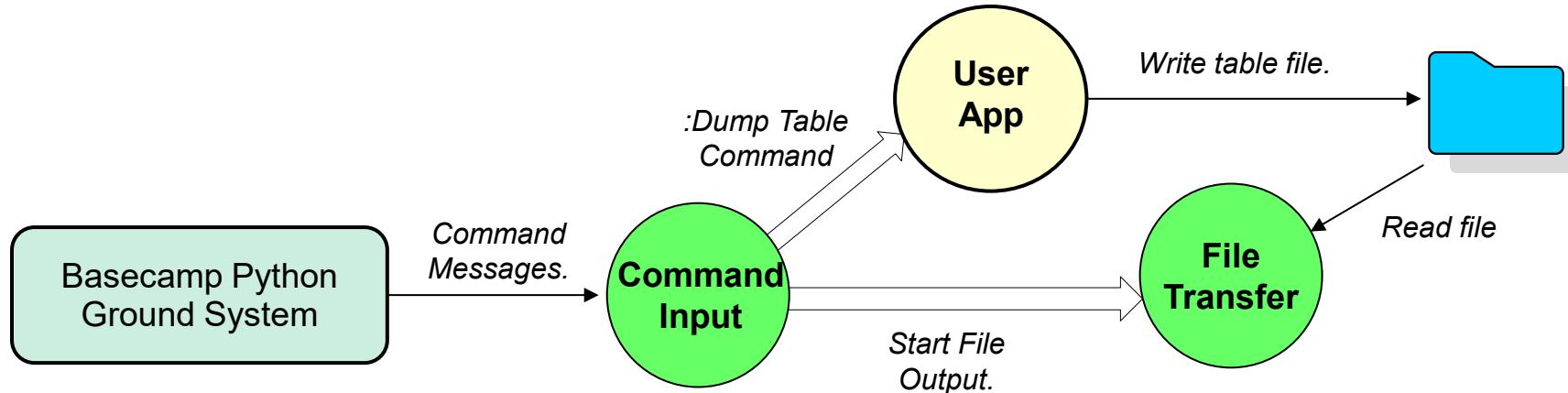
# Load Table



- 1. Use File Transfer to transfer the table file from the ground to an onboard directory**
  - The file can be located in any directory
- 2. Send a Table Load command to the user app**
  - The command specifies the table filename and directory
  - The user app parses the JSON file using basecamp app framework utilities and optionally validates the contents



# Dump Table



- 1. Send a Table Dump command to the user app**
  - The command specifies the directory and table filename
- 2. Use File Transfer to transfer the table file from an onboard directory to ground**



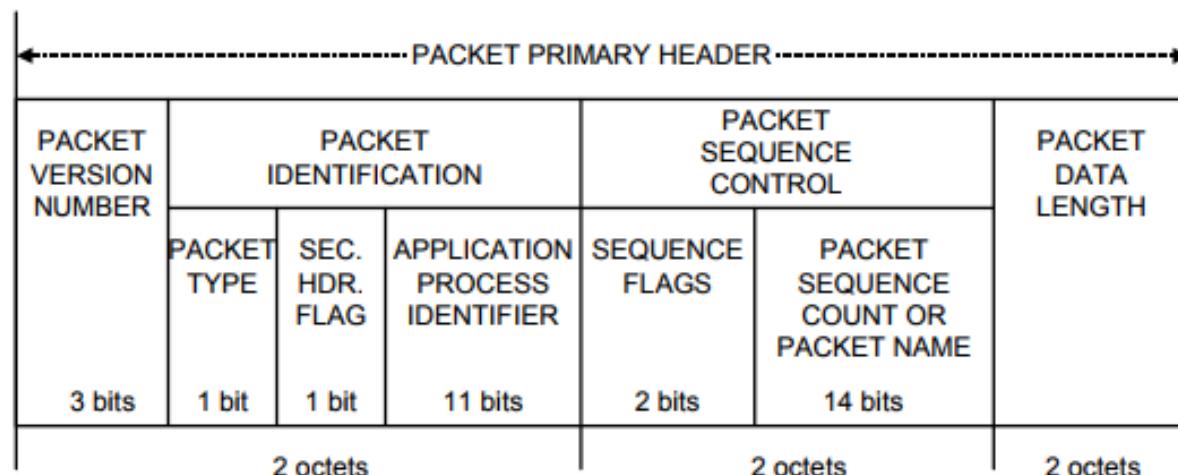
# cFS Message Definitions

- **As previously described, messages are a key component of the cFS architecture**
  - They are used for transferring data and can be used to control an application's execution
- **The next few slides describe how Electronic Data Sheets are used to define messages**
- **The Deployment Model section describes how the EDS toolchain is used to build a target**



# cFS Message Definitions (1 of 2)

- **Messages**
  - Data structures used to transfer data between applications
- **Consultative Committee for Space Data Systems (CCSDS) packet standard used for message format**
  - Simplifies data management since CCSDS standards can be used for flight-ground interfaces and onboard messages
  - In theory other formats could be used but has not occurred in practice
- **CCSDS Primary Header (Always big endian)**





# cFS Message Definitions (2 of 2)



- **“Packet” often used instead of “message” but not quite synonymous**
  - “Message ID” (first 16-bits) used to uniquely identify a message
  - “App ID” (11-bit) CCSDS packet identifier
- **Extended App ID naming domain**
  - cFE 6.6 supports CCSDS’s 2023 Space Packet Protocol updates for complex mission topologies including multiple spacecraft, multiple processors, etc.
- **CCSDS Command Packets**
  - Secondary packet header contains a command function code
  - cFS apps typically define a single command packet and use the function code to dispatch a command processing function
  - Commands can originate from the ground or from onboard applications
- **CCSDS Telemetry Packets**
  - Secondary packet header contains a time stamp of when the data was produced
  - Telemetry is sent on the software bus by apps and can be ingested by other apps, stored onboard and sent to the ground



# Electronic Data Sheet Standard

- An **Electronic Data Sheet (EDS)** is a formal specification of a device, system, or software interface in a machine-readable format
- A **CCSDS Spacecraft Onboard Interface Services (SOIS) EDS (SEDS)** is an EDS defined using the SOIS Dictionary of Terms and the SOIS EDS XML schema
- The **cFS Framework and EDS toolchain provide definitions that allow users to define command and telemetry messages**
  - *base\_types.xml* – Standardize common data types
  - *ccsds\_spacepacket.xml* – CCSDS packet headers and fields

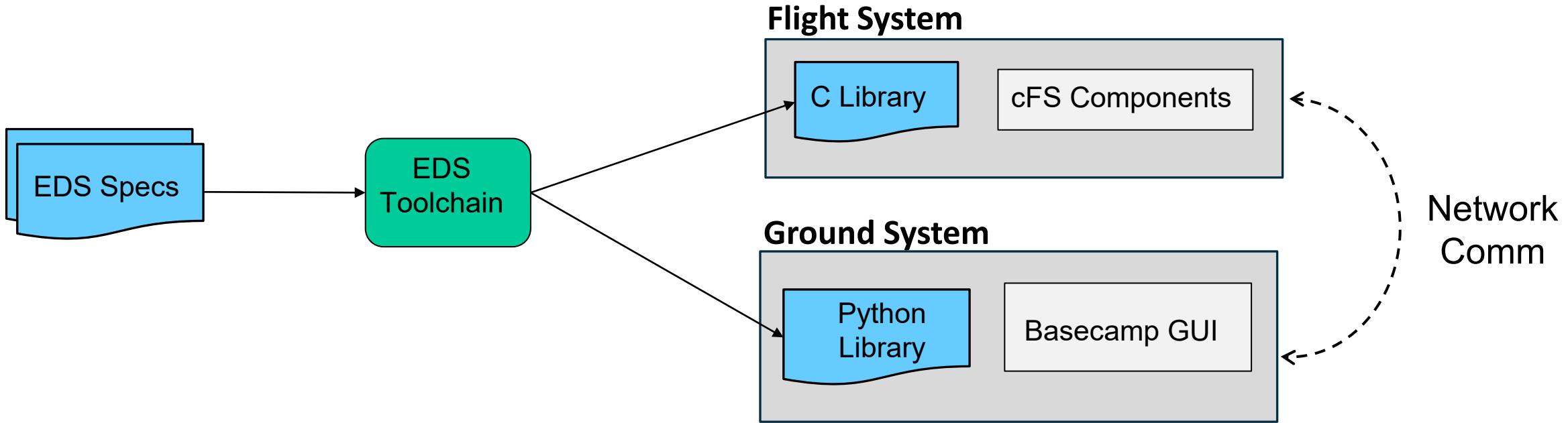


# EDS Message Identifiers

- A “*Topic ID*” uniquely identifies a message within a mission name space
- The EDS toolchain maps *Topic IDs* to *Message IDs* that are used on each processor running a cFS target
- *cfe-topicids.xml* defines a mission’s Topic IDs



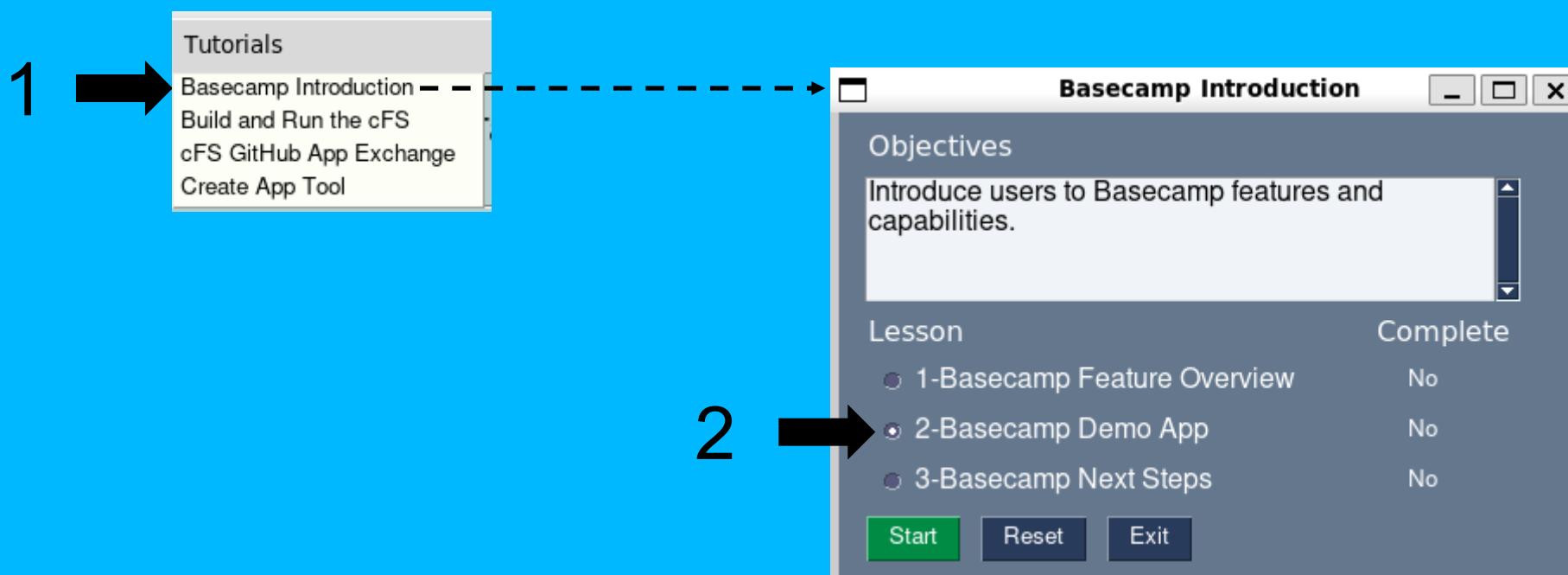
# Single EDS Definition



- **Each command and telemetry message is defined once using EDS**
- **The EDS is a network “on the wire” definition and the libraries created by the EDS toolchain manage local processor byte ordering (endianness) conversions**

# Demo App Operations

1. From the Tutorial dropdown list select “Basecamp Introduction” and do Lesson 2 “Basecamp Demo App”
  - Interacting with the Demo App illustrates how the Operations Services App Suite creates a unified system





# cFS Framework Deployment





# Framework Deployment Agenda

- 1. cFS Framework Modules**
- 2. cFS Framework Configuration Parameters**
- 3. Electronic Data Sheet Toolchain**
- 4. Complete Basecamp's 'Build and Run cFS' tutorials**

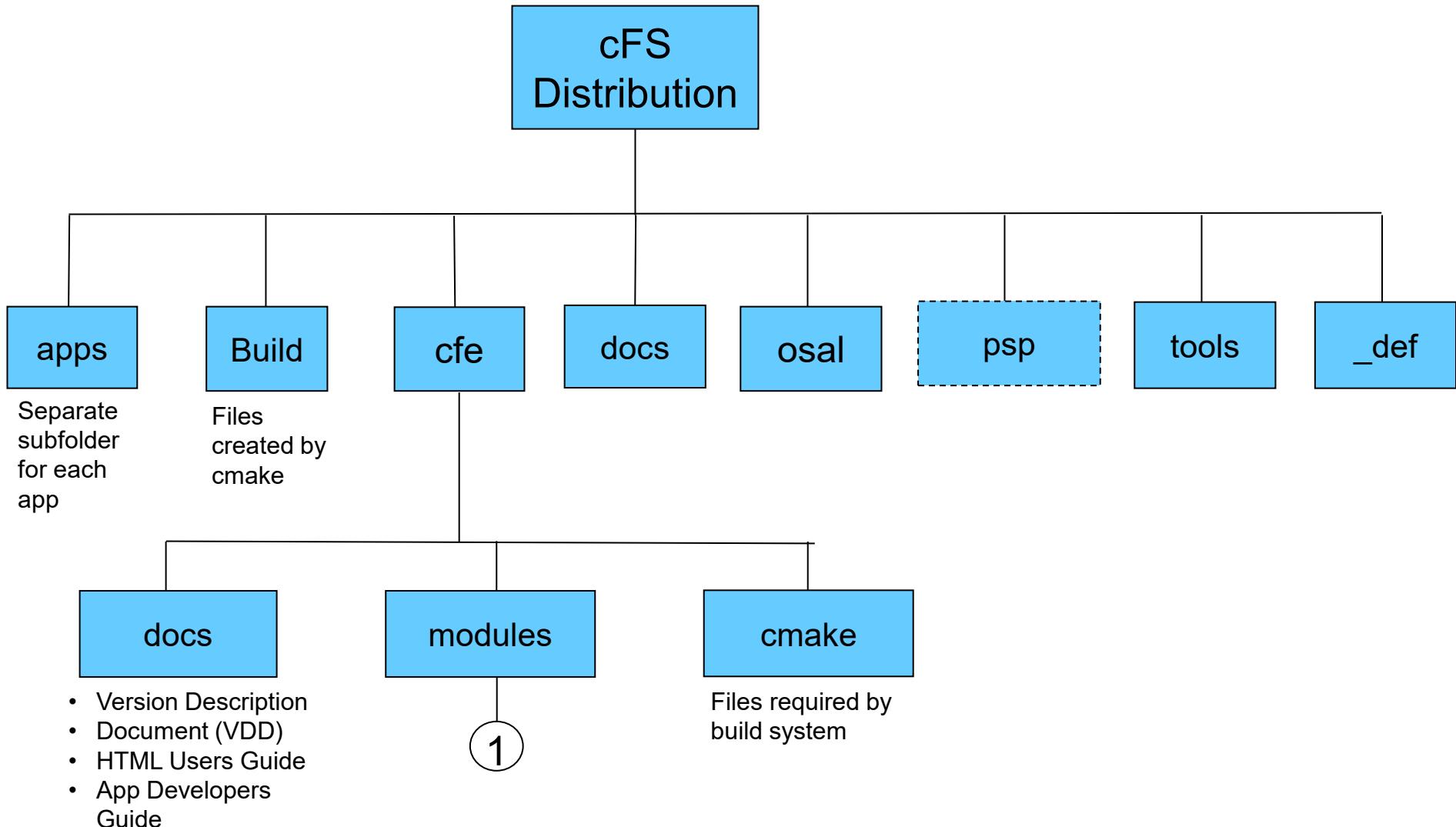


# Module Overview

- **The cFS framework is compiled and linked as a single binary**
- **cFS Caelum released in 2021 decomposes the cFS framework into Modules**
- **The Module structure allows advanced users to add, remove, or override entire core services as necessary to support their particular mission requirements**
- **cFE “out of the box” provides reference implementations that meet the needs of most missions**

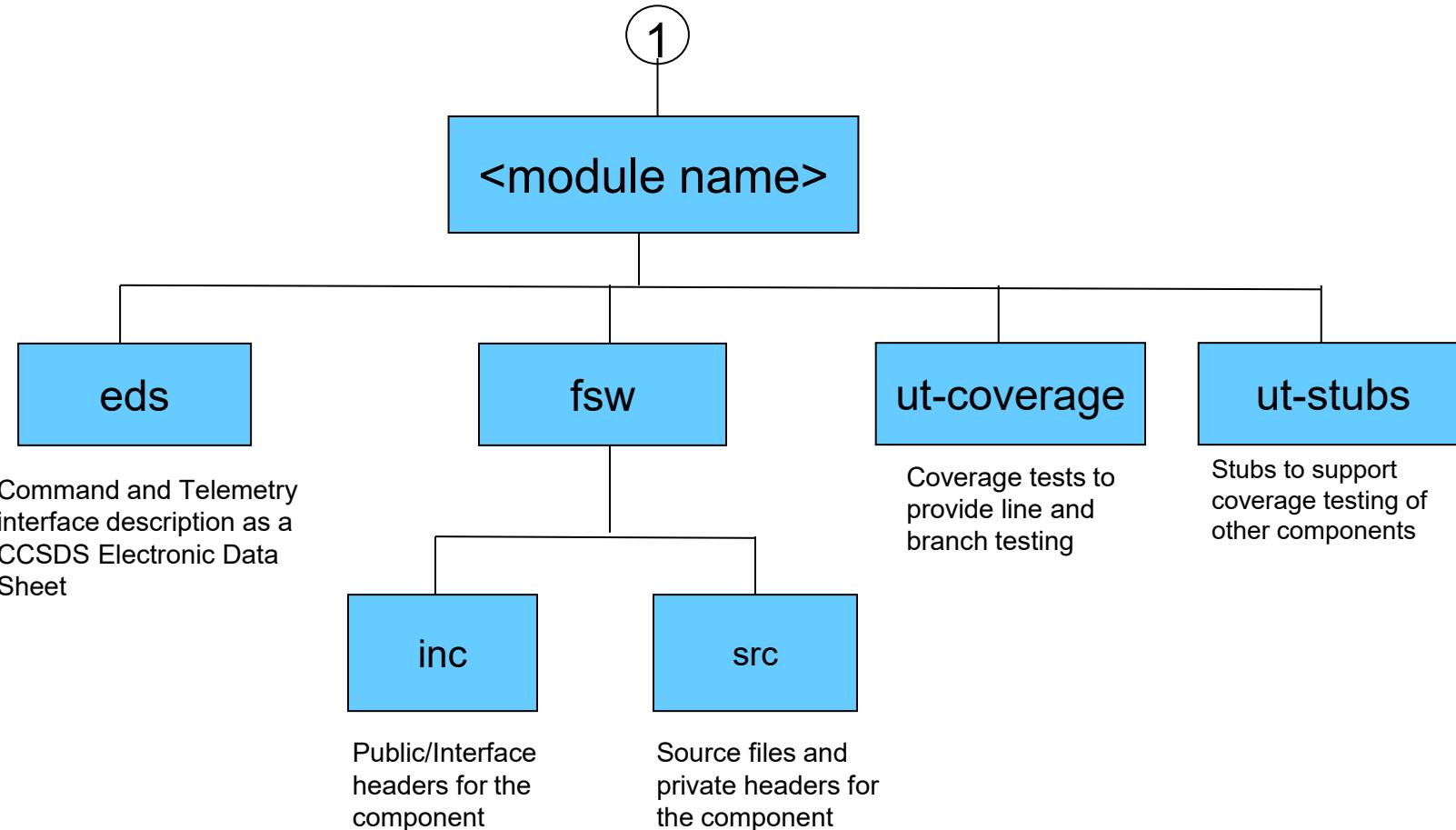


# cFS Mission Directory Structure





# Module Directory Structure





# Module Summary

Module	Purpose/Content
cfe_assert	A CFE-compatible library wrapping the basic UT assert library.
cfe_testcase	A CFE-compatible library implementing test cases for CFE core apps.
core_api	Contains the public interface definition of the complete CFE core - public API/headers only, no implementation.
core_private	Contains the inter-module interface definition of the CFE core - internal API/headers only, no implementation.
es	Implementation of the Executive Services (ES) core module.
evs	Implementation of the Event Services (EVS) core module.
fs	Implementation of the File Services (FS) core module.
msg	Implementation of the Message (MSG) core module.
resourceid	Implementation of the Resource ID core module.
sb	Implementation of the Software Bus (SB) core module.
sbr	Implementation of the Software Bus (SB) Routing module.
tbl	Implementation of the Table Services (TBL) core module.
time	Implementation of the Time Services (TIME) core module.



# Configuration Parameter Scope



- **Mission configuration parameters – used for ALL processors in a mission (e.g. time epoch, maximum message size, etc.)**
  - Default contained in:
    - \cfe\fs\mission\_inc\cfe\_mission\_cfg.h
    - \apps\xx\fs\mission\_inc\xx\_mission\_cfg.h. xx\_perfids.h
- **Platform Configuration parameters – used for the specific processor (e.g. time client/server config, max number of applications, max number of tables, etc.)**
  - Defaults contained in:
    - \cfe\fs\platform\_inc\cpuX\cfe\_platform\_cfg.h, cfe\_msgids\_cfg.h
    - \apps\xx\fs\platform\_inc\xx\_platform\_cfg.h, xx\_msgids.h
    - \osal\build\inc\osconfig.h
- **Just because something is configurable doesn't mean you want to change it**
  - E.g. CFE\_EVS\_MAX\_MESSAGE\_LENGTH

TODO: EDS config.xml



# Configuration Parameters Notes



- **Software Bus Message Identifiers**
  - cfe\_msgids.h (message IDs for the cFE should not have to change)
  - app\_msgids.h (message IDs for the Applications) are platform configurations
- **Executive Service Performance Identifiers**
  - cFE performance IDs are embedded in the core
  - app\_perfids.h (performance IDs for the applications) are mission configuration
- **Task priorities are not configuration parameters but must be managed from a processor perspective**
- **Note cFE strings are case sensitive**



# Configuration File Summary



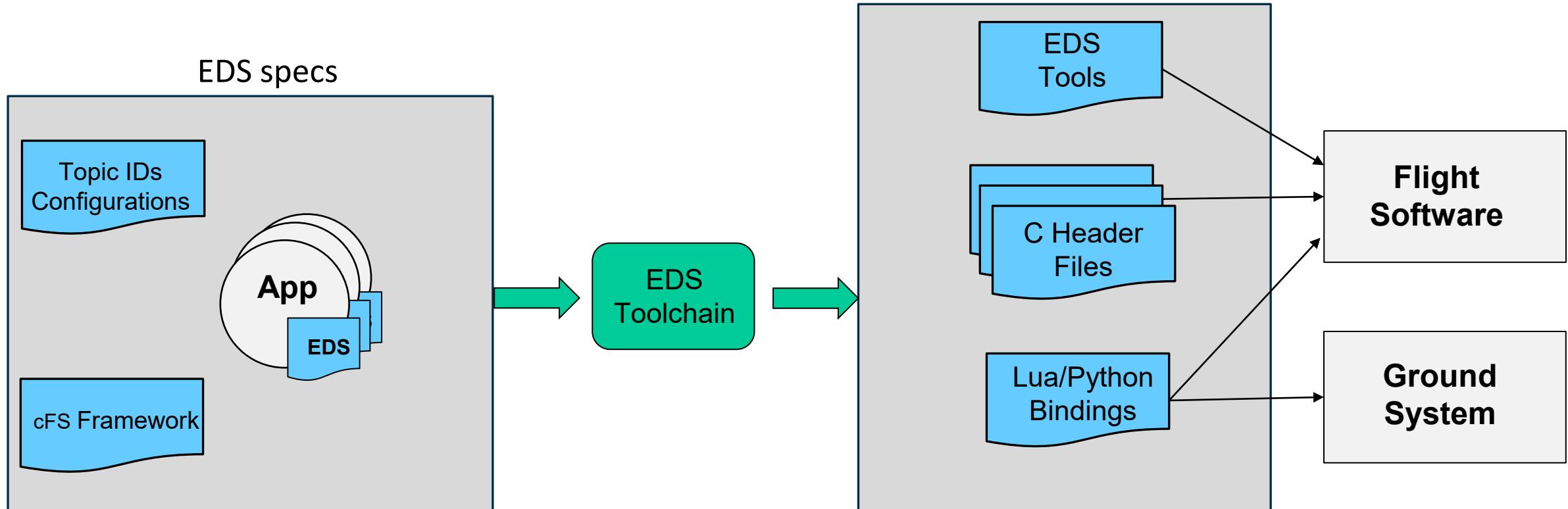
File	Purpose	Scope	Notes
cfe_mission_cfg.h	cFE core mission wide configuration	Mission	
cfe_platform_cfg.h	cFE core platform configuration	Platform	Most cFE parameters are here
cfe_msgids.h	cFE core platform message IDs	Platform	Defines the message IDs the cFE core will use on that Platform(CPU)
osconfig.h	OSAL platform configuration	Platform	
XX_mission_cfg.h	A cFS Application's mission wide configuration	Mission	Allows a single cFS application to be used on multiple CPUs on one mission
XX_platform_cfg.h	Application platform wide configuration	Platform	
XX_msgids.h	Application message IDs	Platform	
XX_perfids.h	Application performance IDs	Platform	

TODO: EDS config.xml



# Electronic Data Sheet Toolchain

The EDS toolchain processes EDS files producing ground and flight artifacts



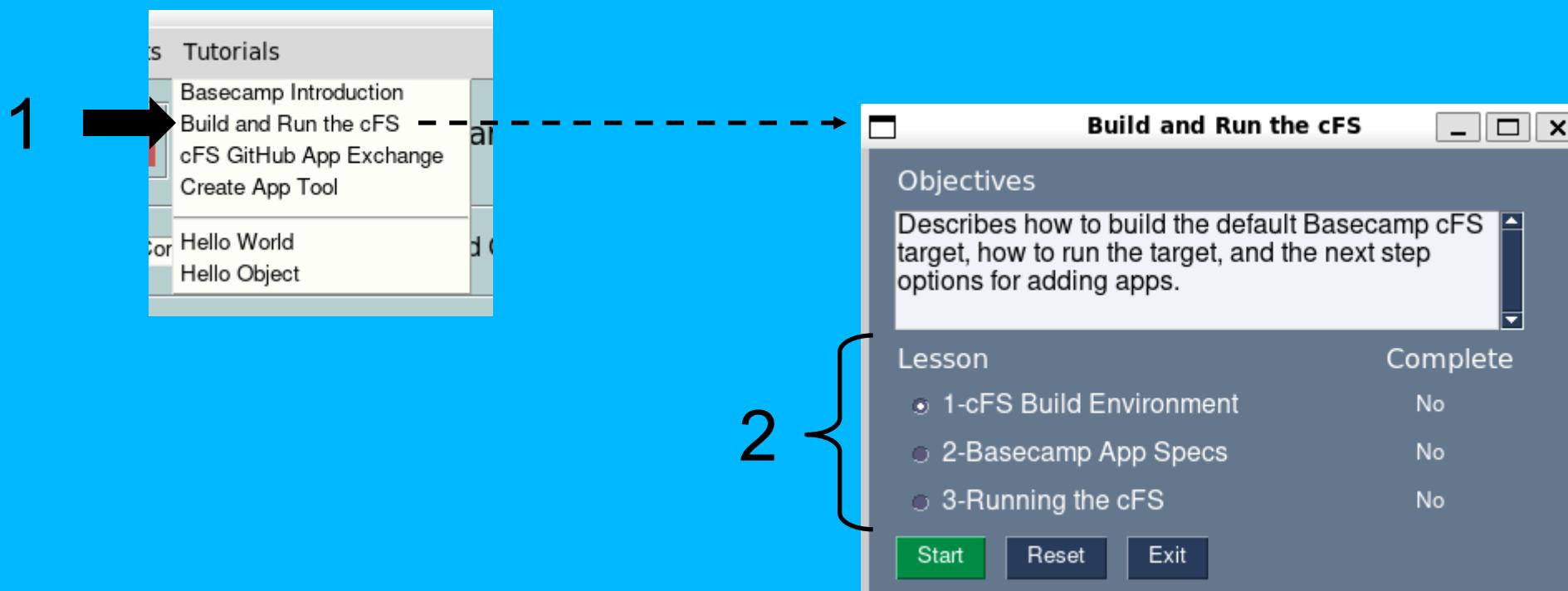


# Basecamp Topic ID Tool



- **Basecamp augments the cFS toolchain with a new “make target” called “topicids”**
  - Invoked at the command line with “*make topicids*”
  - It runs *cfe-eds-framework/basecamp\_defs/cfe\_topicids.py* prior to running the cFS “*make install*” target
- **Functions performed by *cfe\_topicids.py***
  1. Read mission Topic IDs defined in *cfe-topicids.xml*
  2. Update Topic ID values in library and application initialization parameter JSON files
  3. Update Topic ID values in application table parameter JSON files

1. From the Tutorial dropdown list select “Build and Run the cFS” and complete all lessons



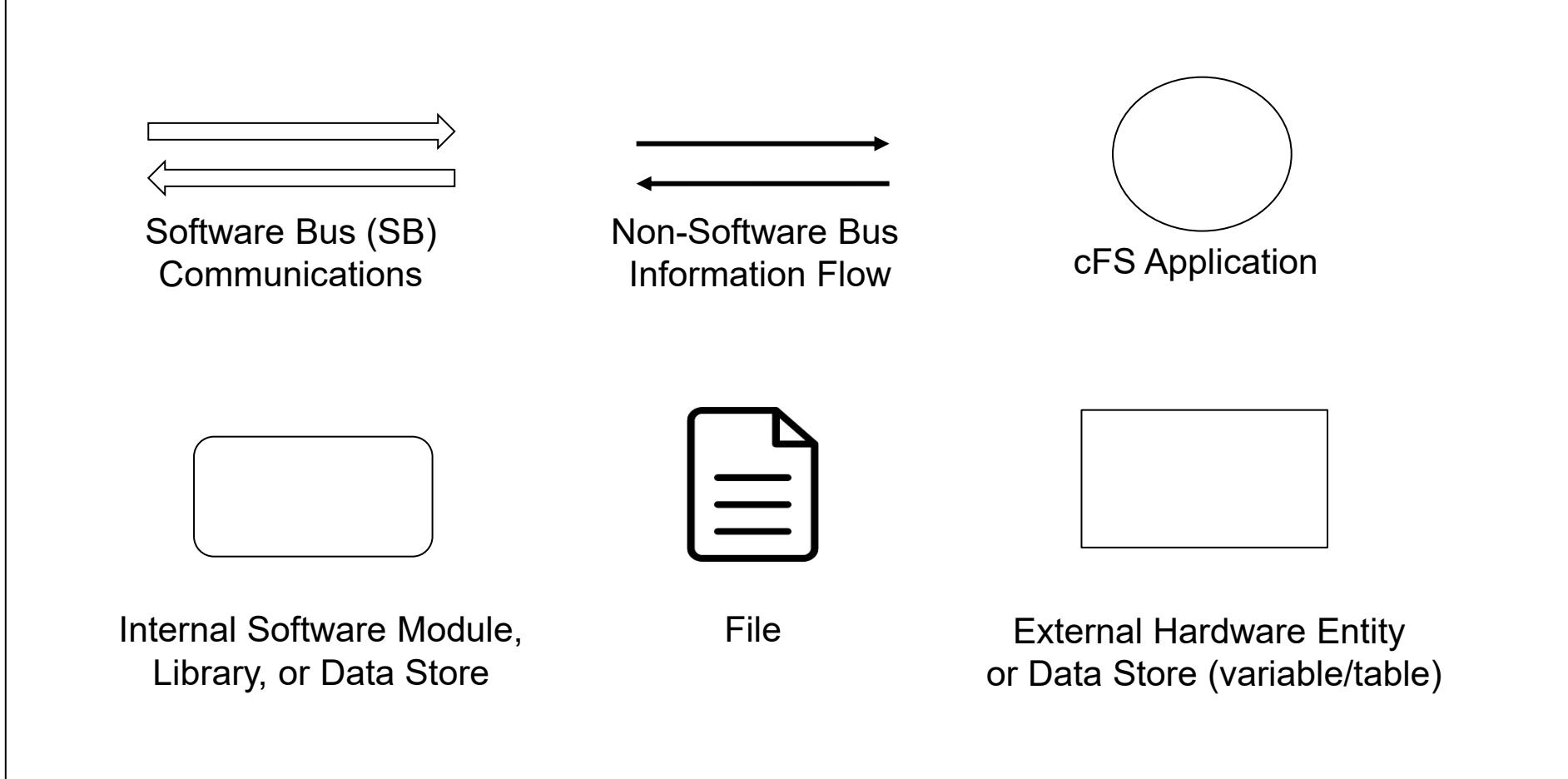


# Appendix A

# Architecture Design Notation



# Architecture Design Notation



- Common data flows such as command inputs to an app and telemetry outputs from an app are often omitted from context diagrams unless they are important to the situation



# cFE Service Slide Deck Template

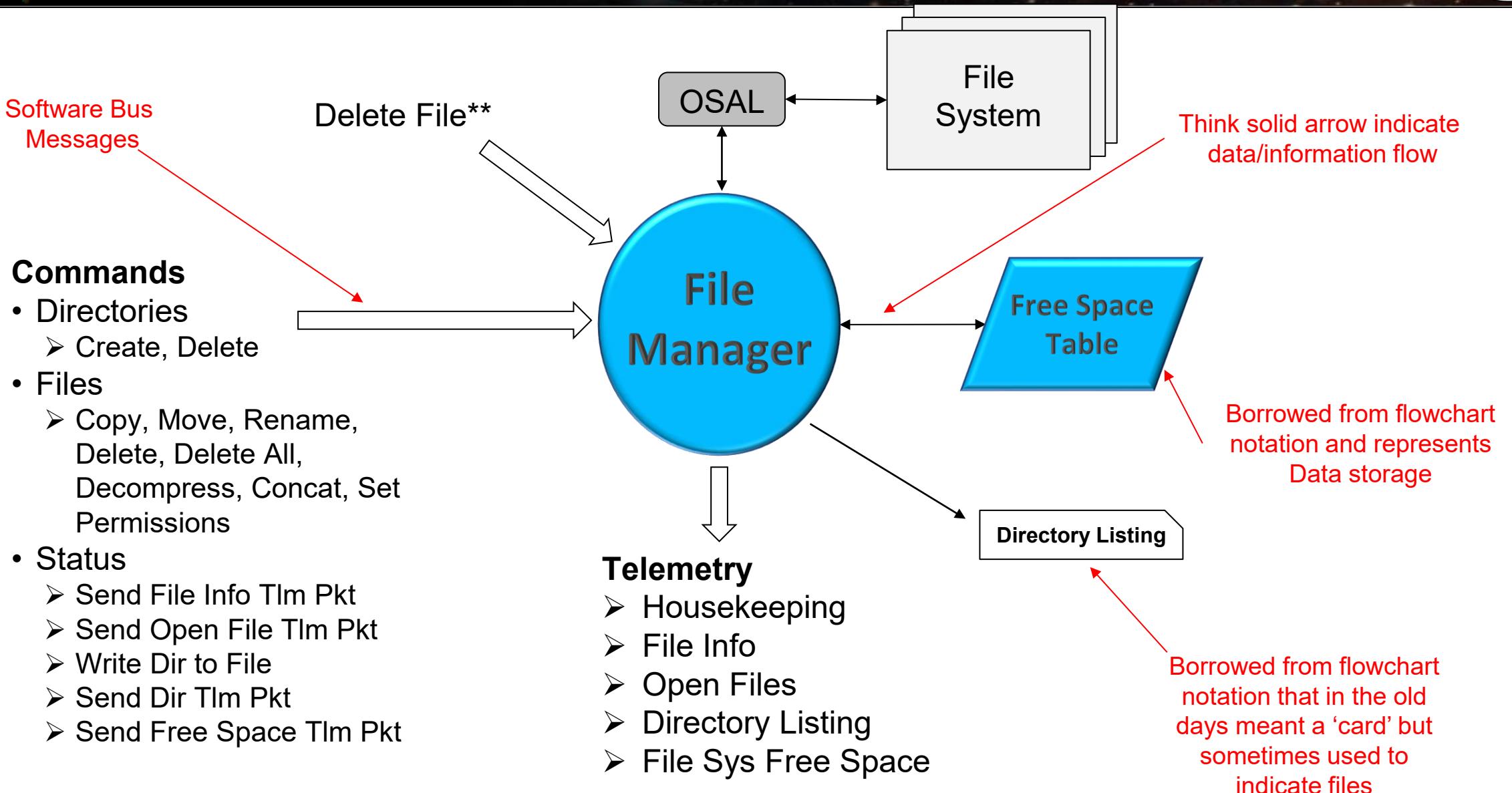


**The following general outline is used in each of the cFE service documentation slides**

- **Describe each service's main features from different perspectives**
  - System functions and operations
    - Feature Overview
    - Initialization and processor reset behavior
    - Onboard state retrieval
  - System integrator and developer
    - Configuration parameter highlights
    - Common practices
- **Student exercises are provided in a separate package**
  - Allows these slides to be maintained independent of the training platform and the training exercises can evolve independent of these slides



# Context Diagram Example 1

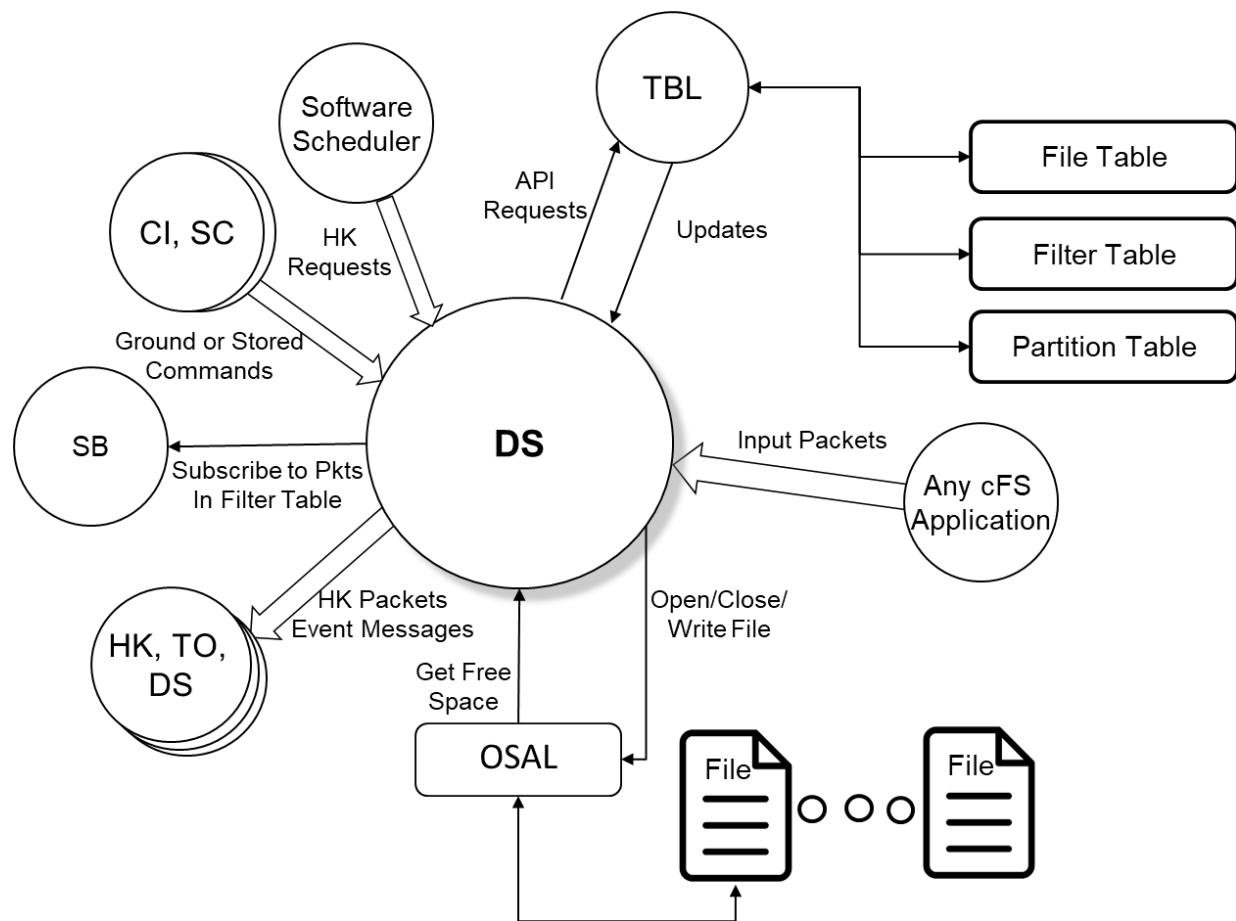


\*\* Onboard command that doesn't affect ground command counters



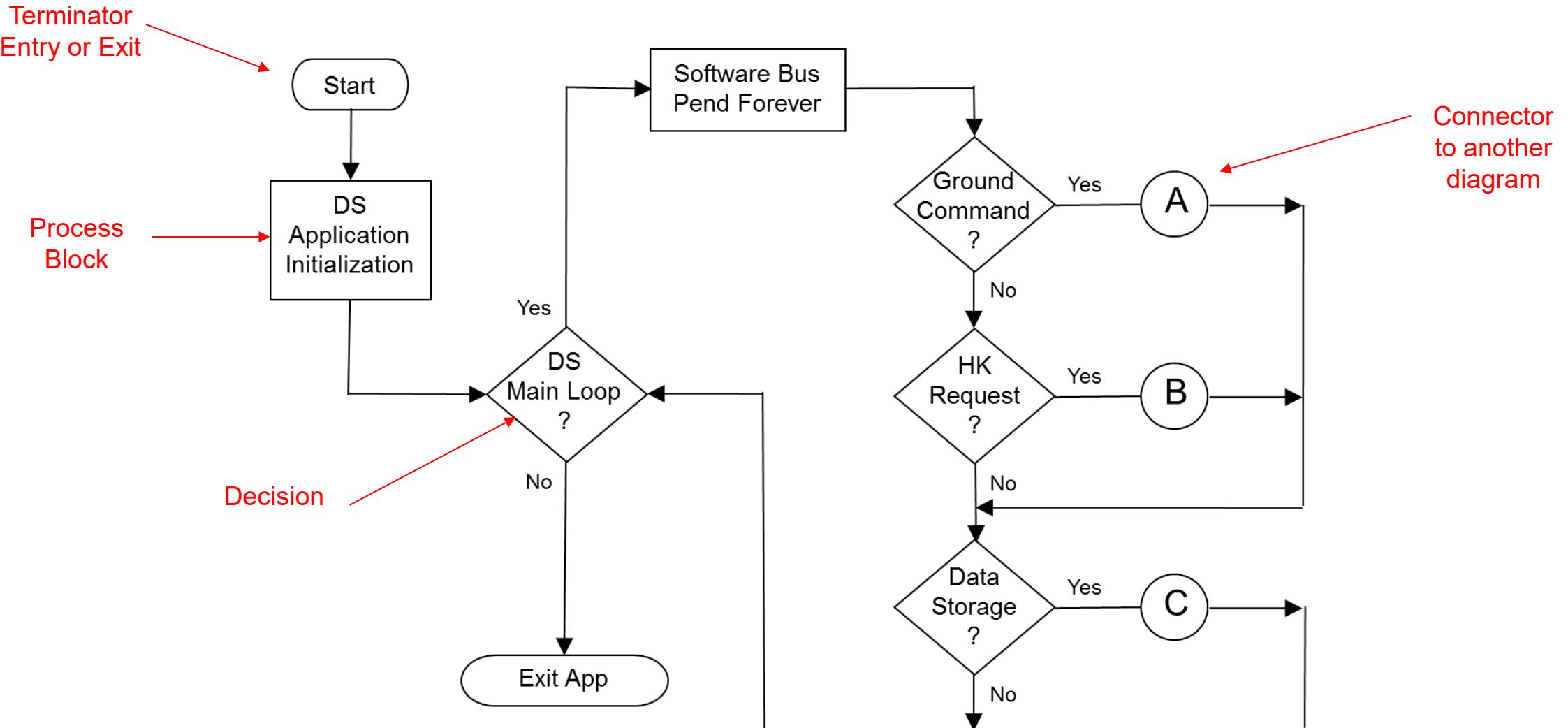
# Context Diagram Example 2

This is a more complete context diagram which is technically correct, but it can obscure the application-specific information that is most important. For example, HK request from the scheduler and outputting HK packet & event messages on the software bus are common design practice that may be omitted if people are comfortable with some assumptions. The important part of the diagram is showing interface boundaries to understand where control and data flow. Too much information is harder to maintain.





# Flowchart Example



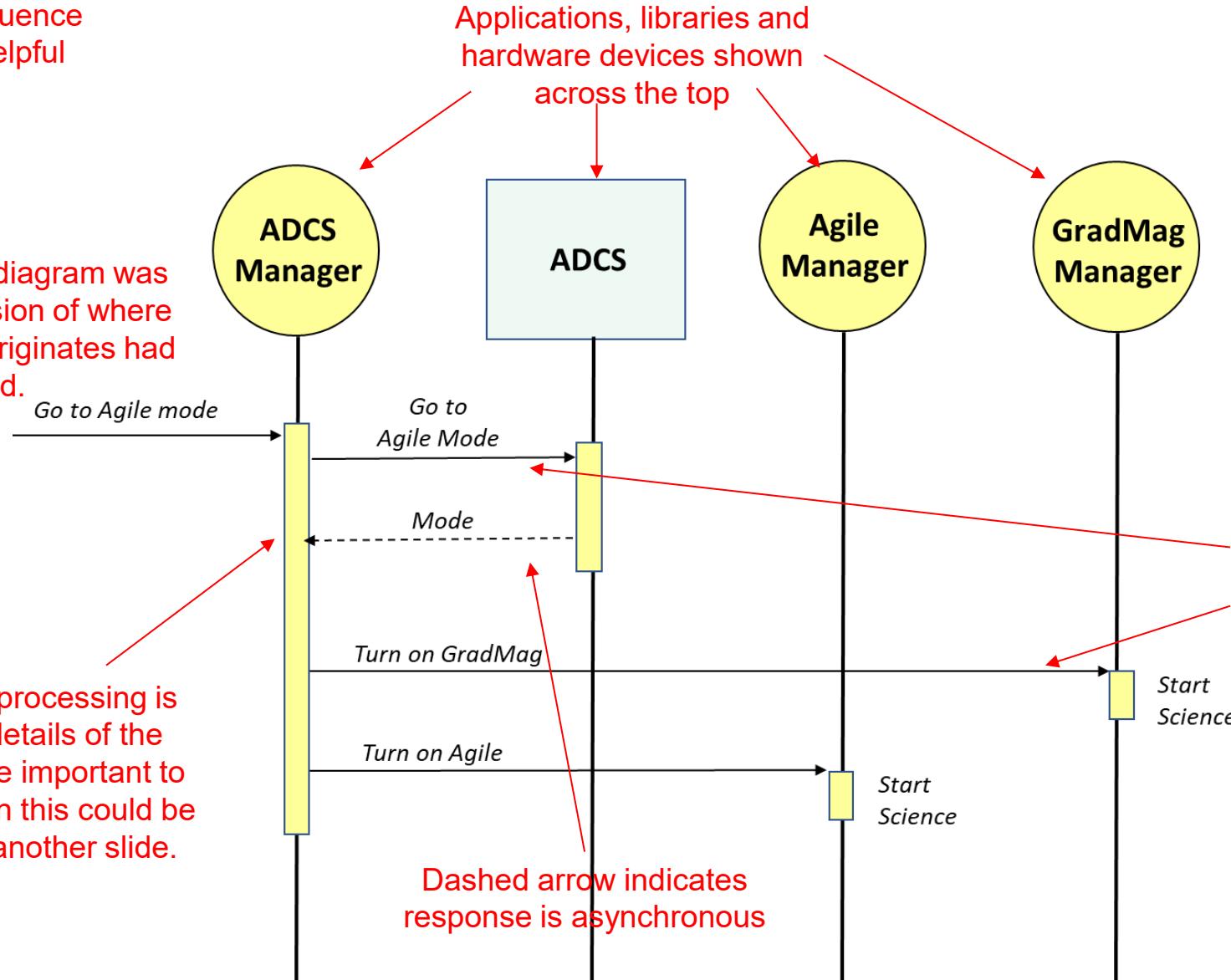


# App-Level Sequence Diagram Example

Often not show but if audience is unfamiliar with sequence diagram it can be helpful

Time

At the time this diagram was written the decision of where this command originates had not been decided.





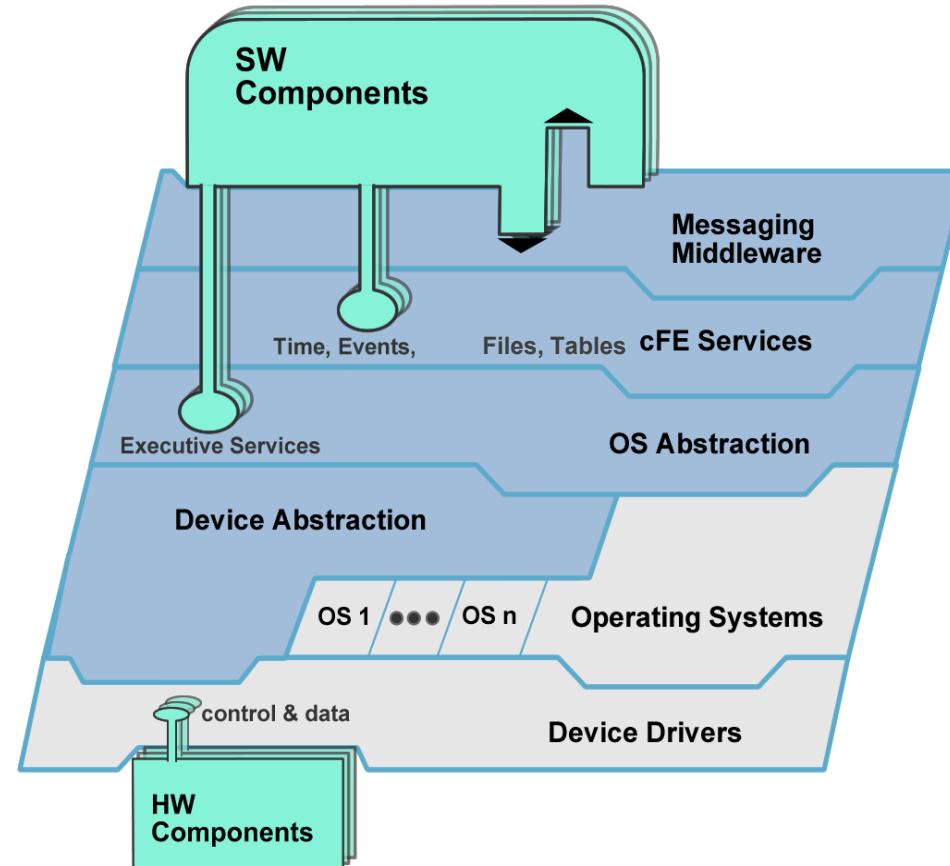
# Appendix B

## Supplemental Architectural Material



# Layered Service Architecture

- Each layer and service has a standard API
- Each layer “hides” its implementation and technology details.
- Internals of a layer can be changed -- without affecting other layers’ internals and components.
- Provides Middleware, OS and HW platform-independence.





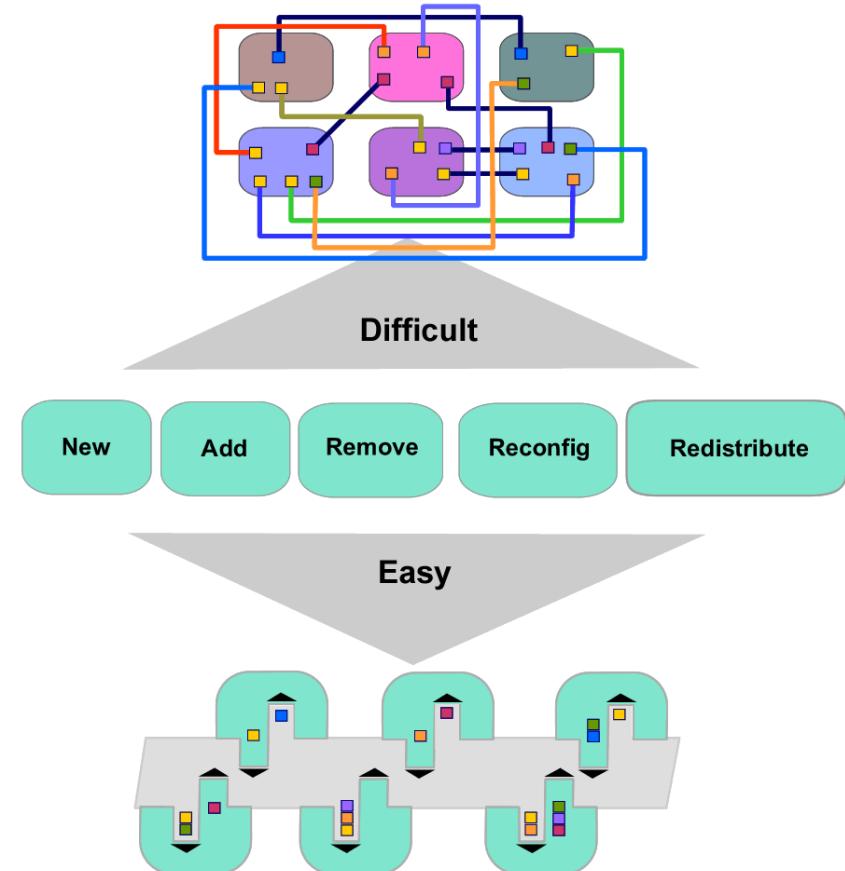
# Plug and Play

## 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.”

## Impact:

- Changes can be made dynamically during development, test and on-orbit even as part of contingency management
- Technology evolution/change can be taken advantage of later in the development cycle.
- Testing flexibility (test apps, simulators)



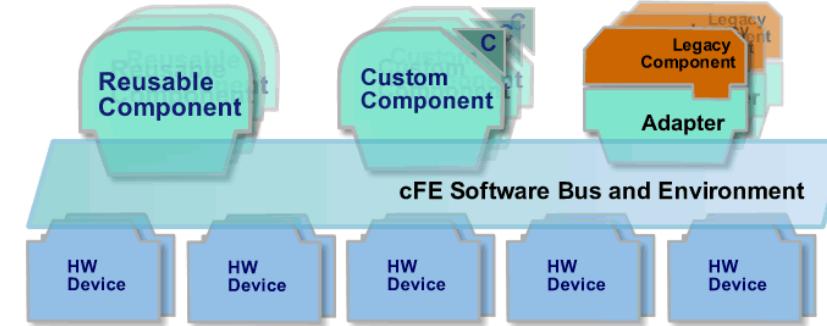
This powerful paradigm allows SW components to be switched in and out at runtime, without rebooting or rebuilding the system SW.



# Reusable Components

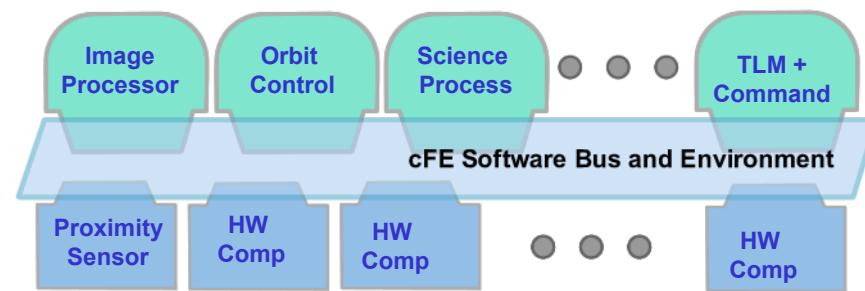
## Reusable Components

- 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



## Impact:

- 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 and don't "reinvent the wheel."





# cFS Metrics

cFE/ App	Logical Lines of Code (non-table)	Config. Parameters	EEPROM (bytes)
<b>cFE 6.4.0</b>	12,930	General: 17 Executive Service: 46 Event Service: 5 Software Bus: 29 Table Service: 10 Time Service: 32	341,561
<b>CFDP</b>	8,559	33	85,812
<b>Checksum</b>	2,873	15	35,242
<b>Data Storage</b>	2,429	27	40,523
<b>File Manager</b>	1,853	22	16,272
<b>Health &amp; Safety</b>	1,531	45	15,071
<b>House-Keeping</b>	575	8	8,059
<b>Limit Checker</b>	2,074	13	31,026
<b>Memory Dwell</b>	1,035	8	8,617
<b>Memory Manager</b>	1,958	25	15,840
<b>Scheduler</b>	1,164	19	35,809
<b>Stored Command (124 command sequences)</b>	2,314	26	104,960



# Example Mission Code Metrics

## Goddard Class B Mission

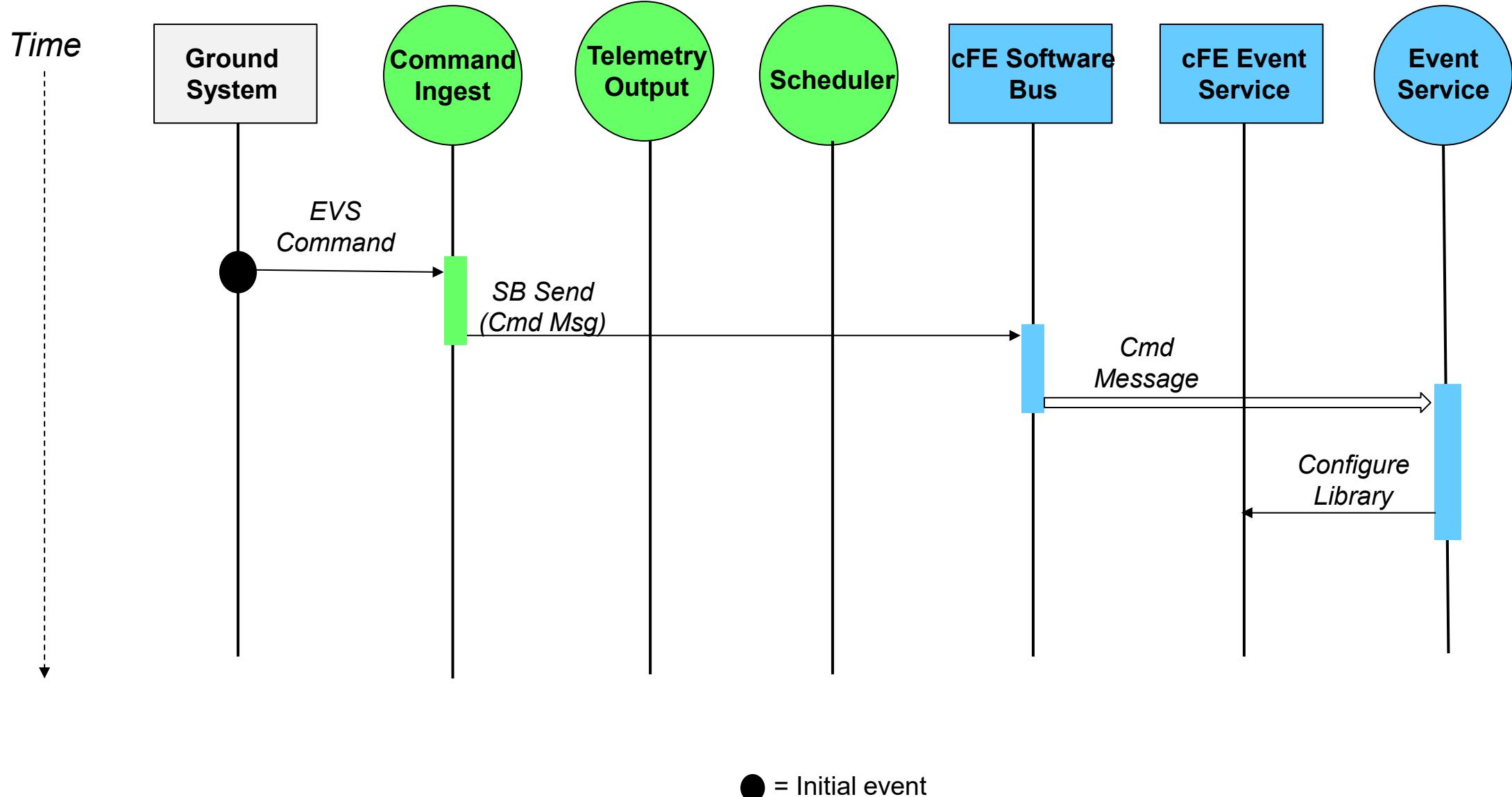


- **Noteworthy items**
  - + cFE was very reliable and stable
  - + Easy rapid prototyping with heritage code that was cFE compliant
  - + Layered architecture has allowed COTS lab to be maintained through all builds
  - Addition of PSP changed build infrastructure midstream
- **Lines of Code Percentages:**

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

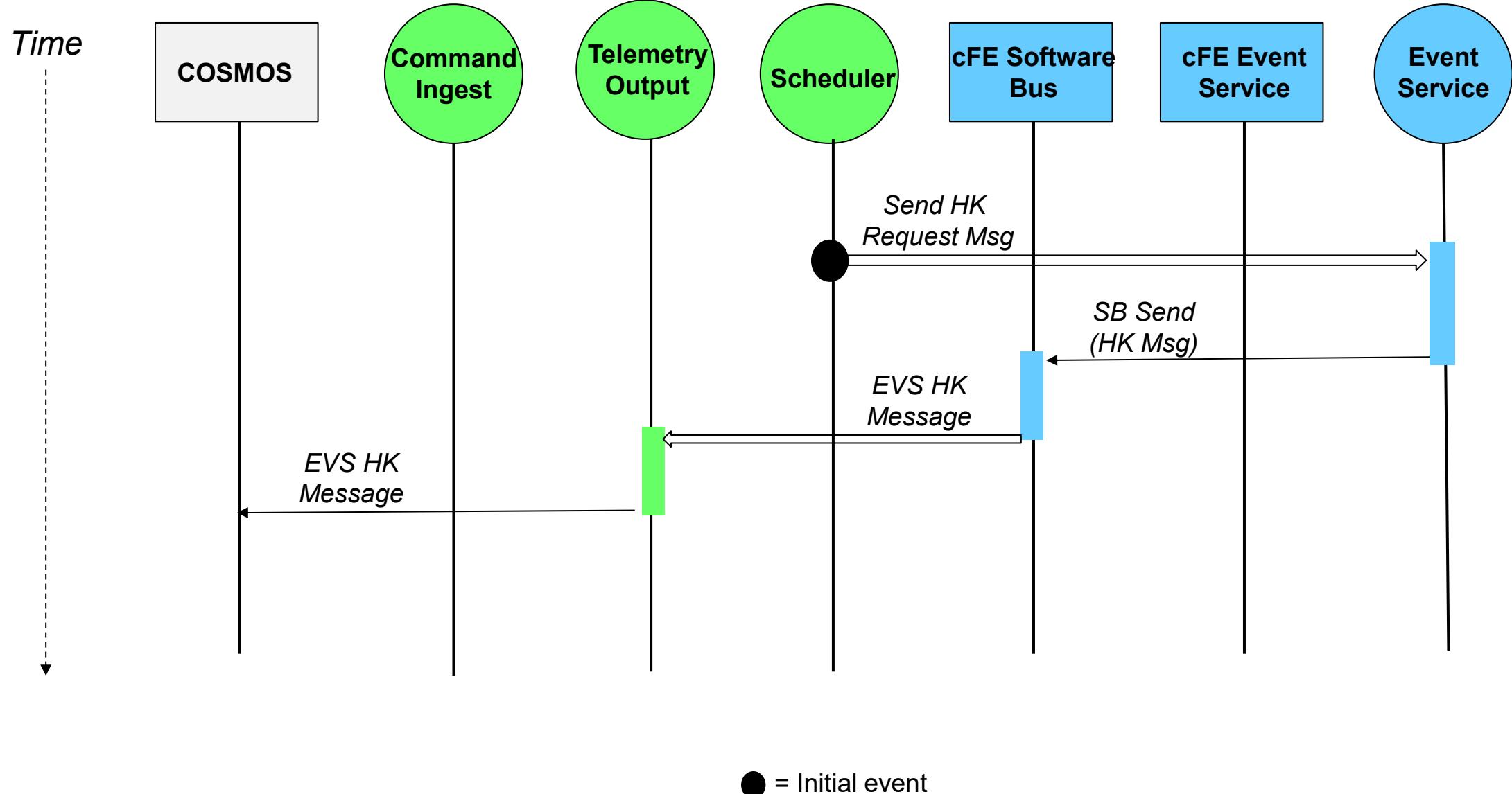


# Ops Sends EVS Configuration Command





# Event Service App Sends Housekeeping Telemetry





# References



- **cFE EDS Framework Toolchain**, <https://github.com/jphickey/cfe-eds-framework>
- **TODO**
  - CCSDS
  - Free RTOS JSON parser
  - cFS
  - Space Steps