OpenSatKit (OSK)

Quick Start Guide

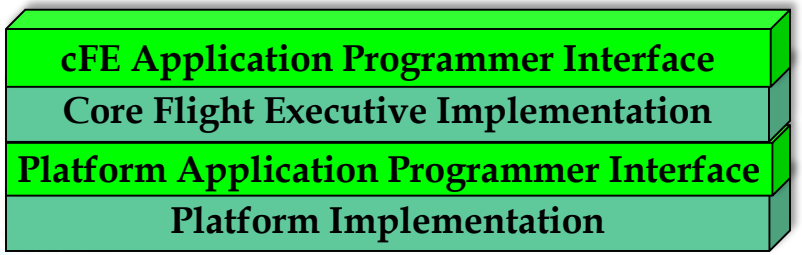
Introduction

- **The primary goals of OpenSatKit (OSK) are to**
  - Provide a core Flight System (cFS) training environment
  - Provide a cFS application development environment
  - Serve as a starting point for a new cFS-based project
- **The cFS is an open architecture that is designed to be ported and extended**
  - These attributes add end-user deployment/configuration complexity
  - OSK provides fully functional cFS system deployed on Linux, however…
- **OSK introduces additional complexity because it integrates two additional powerful software packages, COSMOS and the 42 Simulator, that have their own learning curve.**

There is a lot of high quality free software functionality so the rewards are high if you can persist through the learning curve!

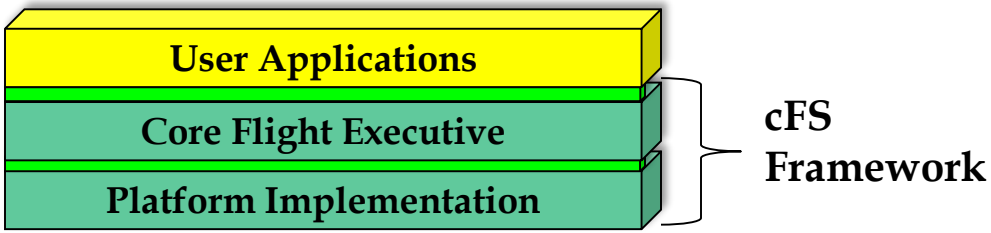
cFS Introduction

- A NASA multi-center configuration controlled open source flight software framework



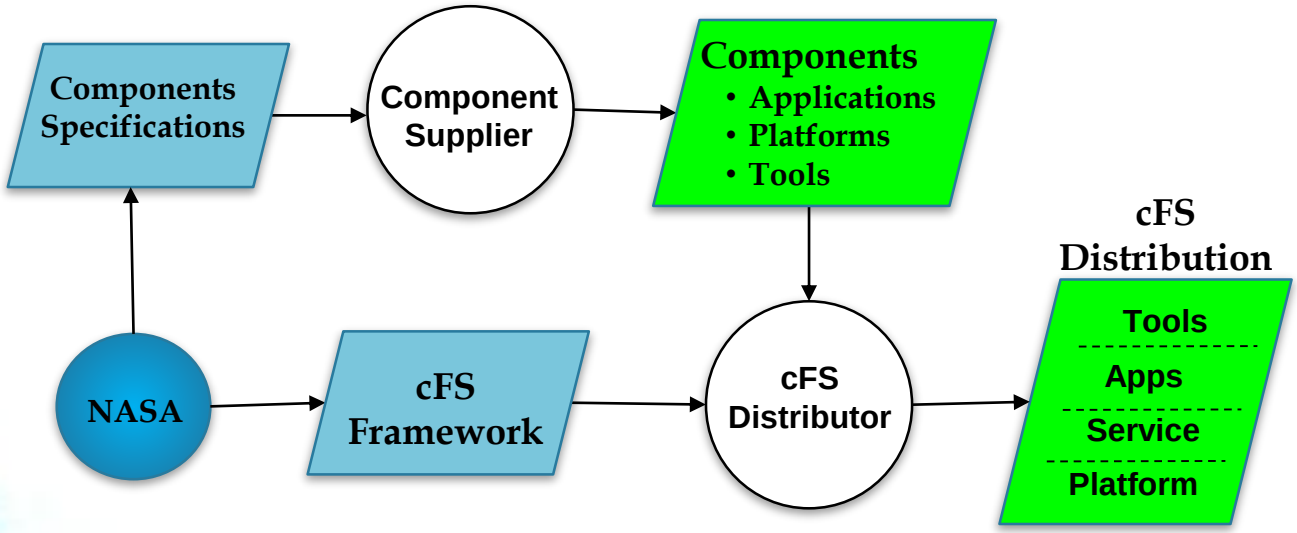
- Layered architecture with international standards-based interfaces
- Provides development tools and runtime environment for user applications
- Reusable NASA Class A/B lifecycle artifacts: requirements, design, code, tests, and documents

- The framework is ported to a platform and augmented with applications to create Core Flight System (cFS) distributions



- A worldwide community from government, industry, and academia

cFS Product Model

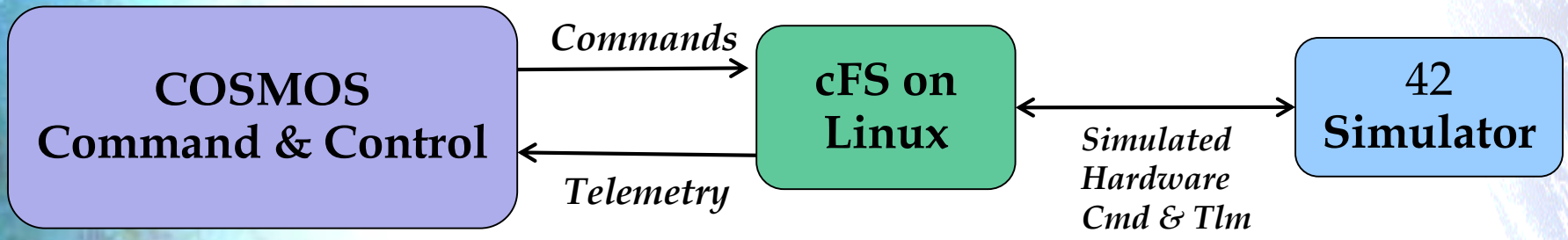


- A NASA multi-center configuration control board (CCB) manages releases of the open source cFS Framework and component specifications

- Community members (regardless of affiliation)
  - Supply applications, platforms, and tools
  - Create cFS distributions – OSK is a distribution

OSK Architecture

- **In addition to the cFS itself, OSK uses two additional open source applications**
  - Ball Aerospace's COSMOS command and control platform for embedded systems
  - NASA Goddard's 42 dynamic simulator
- **Each open source package is contained in its own OpenSatKit subdirectory**

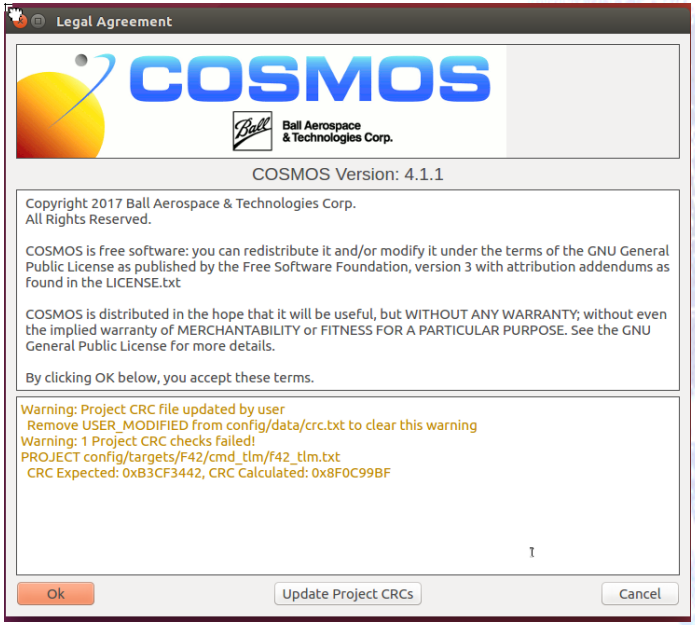


Approach

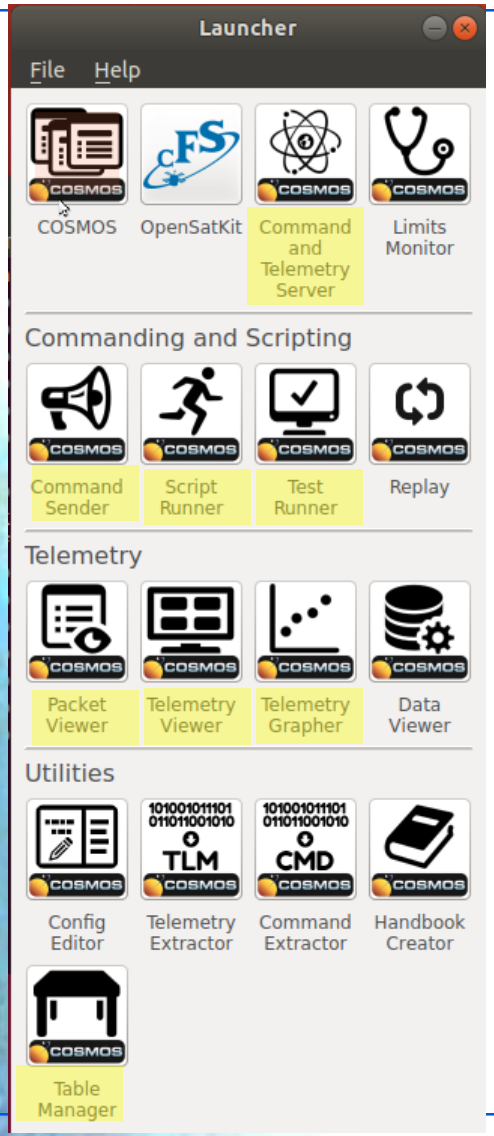
- **OSK comes with the cFS pre-configured for a fictitious satellite called SimpleSat (SimSat).**
  - The cFS can be used for many different types of embedded systems. A spacecraft was chosen due to the increased usage of the cFS on CubeSats
- **OSK implements extensive COSMOS configurations and customizations so COSMOS can serve as the primary OSK user interface**
- **OSK is arranged with the following user progression in mind**
  1. **Learn the cFS using SimSat to provide a context and working examples**
  2. **Manage and develop applications within the Linux desktop environment**
     a. Add apps by creating new apps or importing from the app library
     b. Configure runtime app suite
  3. **Extend OSK**
     a. Deploy the cFS to a target system
        i. Run benchmarks
        ii. Use OSK as a ground system for a remote system
     b. **Advanced application development and extensions**
        i. External Code Interface (ECI), ROS2 bridge, etc.

Running OpenSatKit (1 of 2)

- Open a terminal window (Ctrl-Alt-t)
- Navigate to the base directory where you installed OSK
  - "~/" is used to indicate the OSK base directory so "~/cfs" is equivalent to "/home/user/OpenSatKit-master/cfs" if OpenSatKit was installed in the home directory for an account named "user"
- Change directory to cosmos
  - cd ~/cosmos
- Start COSMOS
  - [~/cosmos]ruby Launcher
  - You'll see a screen similar to the right.
    - Select <OK>
    - This creates the "Launcher" screen shown on the next slide



Running OpenSatKit (2 of 2)



- **Each tools on the COSMOS "Launcher" runs as a separate Linux process with a Graphical User Interface (GUI)**
- **Shaded tool titles indicate the COSMOS tools used by OSK**
  - You do not have to invoke these tools directly
  - OSK screens launch COSMOS tools as they are needed to perform a task
  - A backup slide shows a COSMOS architectural view with the data flows between tools
- **Select "OpenSatKit" with a single click**
  - This launches COSMOS's Command and Telemetry Server, Telemetry Viewer, and displays OSK's main window
  - You can minimize the COSMOS tools, but don't close them
- **A picture of OSK's main window follows 2 slides that briefly describe each COSMOS tool**

COSMOS Tool Summary (1 of 2)

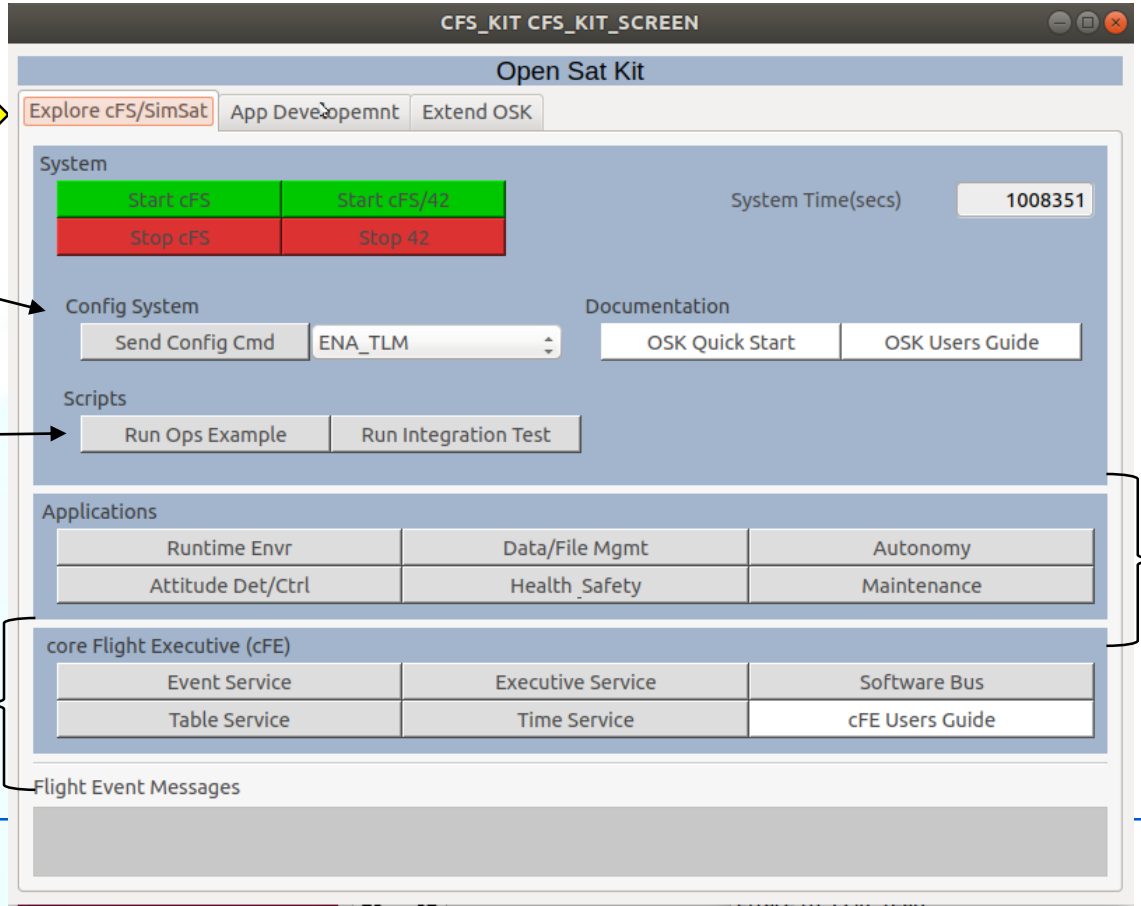
- **Launcher**
  - Provides a graphical interface for launching each of the tools that make up the COSMOS system
  - *Custom OSK ICON "cFS Starter Kit" launches OSK's main page*
- **Command and Telemetry Server**
  - Connects COSMOS to targets for real-time commanding and telemetry processing.
  - All real-time COSMOS tools communicate with targets through the Command and Telemetry Server ensuring that all communications are logged.
  - Localhost 127.0.0.1 used as cFS connection Targets created
- **Telemetry Viewer**
  - Provides a way to organize telemetry points into custom "screens" that allow for the creation of unique and organized views of telemetry data.
- **Command Sender**
  - Individually send any FSW command using GUI form
  - Raw data files can be used to inject faults
  - *OSK provides custom menus for common cFS commands*
- **Packet Viewer**
  - View any telemetry packet with no extra configuration necessary
  - *OSK provides custom telemetry screens functionally organized*

COSMOS Tool Summary (2 of 2)

- **Telemetry Grapher**
  - Real-time or offline graphing of any FSW telemetry point
  - *OSK provides convenient access through some of its custom screens*
- **Table Manager**
  - Edit and display binary files
  - *OSK provides definitions for most of the cFE binary files and a limited number of cFS application binary files*
- **Script Runner**
  - Develop and execute test procedures using Ruby Scripts and COSMOS APIs
  - *OSK provides additional APIs for functions like file transfer and binary file management*
- **Test Runner**
  - Test framework for organizing, executing, and verifying test scripts
  - *Currently OSK only includes some prototype scripts. The goal is to provide a complete test suite that can be extended by the user.*

Main OSK Window

- Three tabs ***Explore cFS/SimSat***, ***Manage Apps***, and ***Extend OSK*** provide the top-level organization
- ***Explore cFS/SimSat*** allows the user to learn the cFS using SimSat
- ***Manage Apps*** provides tools for adding, removing, and creating apps
- ***Extend OSK*** is in its infancy, but it's goal is to allow the user to bridge the cFS to other systems and control remote devices



Tabs

A few high level system-oriented commands

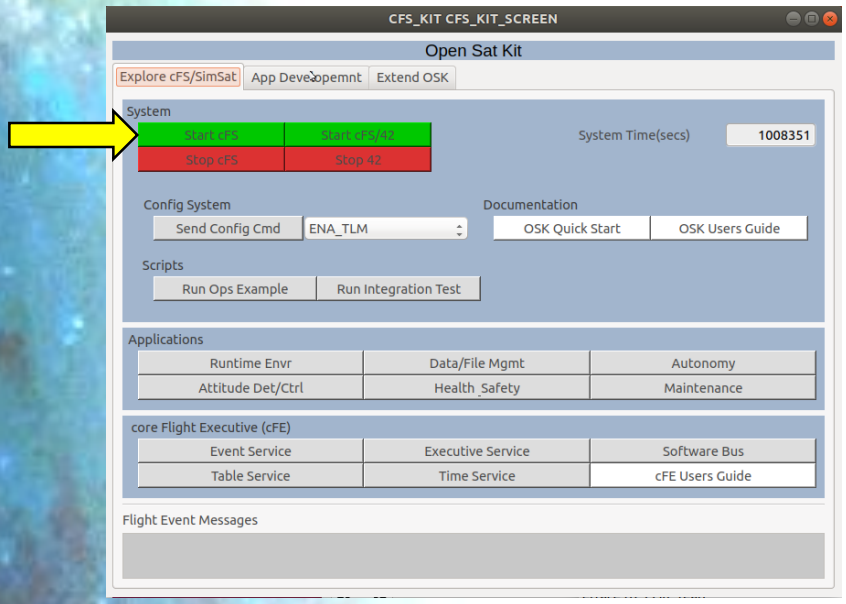
Launch scripts in script Runner

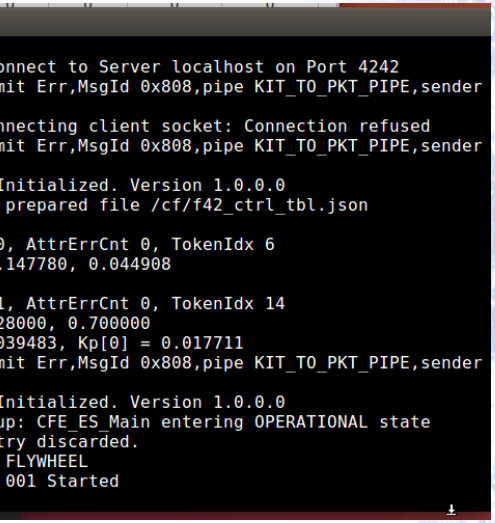
Explore apps arranged in functional groups

Explore 5 cFE services

Start the Flight Software (FSW)

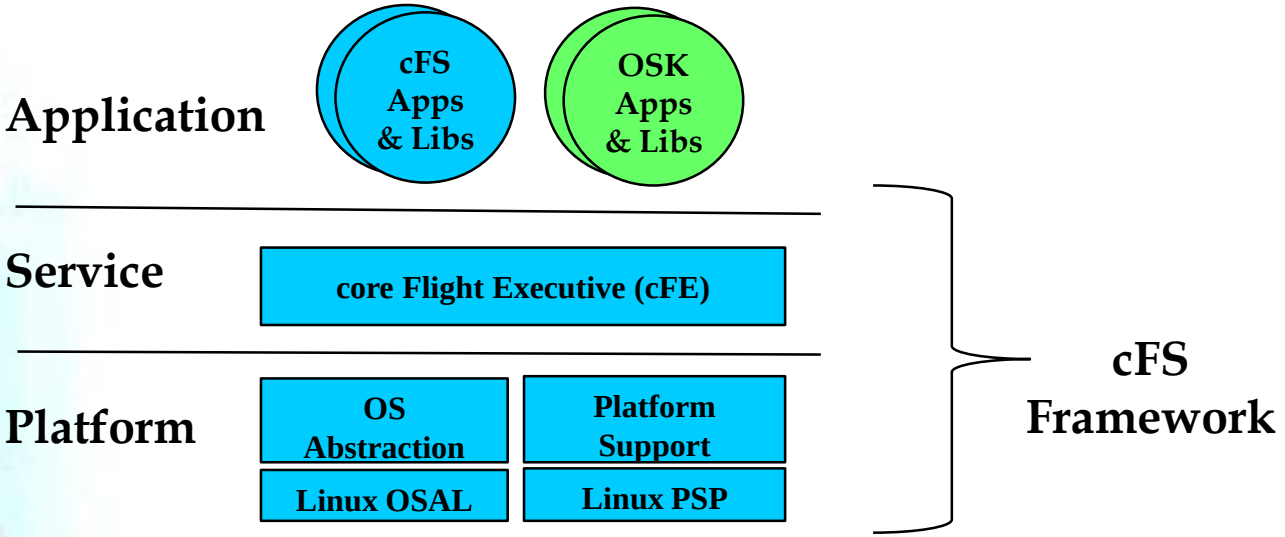
- **Click <Start cFS> to run the FSW. <Start cFS/42> is used later.**
  - A new terminal window is created for the Linux process running the cFS
  - Enter "osk" when prompted for a password.
- **In a few seconds the time box should turn white time with advancing**
  - If time doesn't advance click <Send Config Cmd> "ENA_TLM"





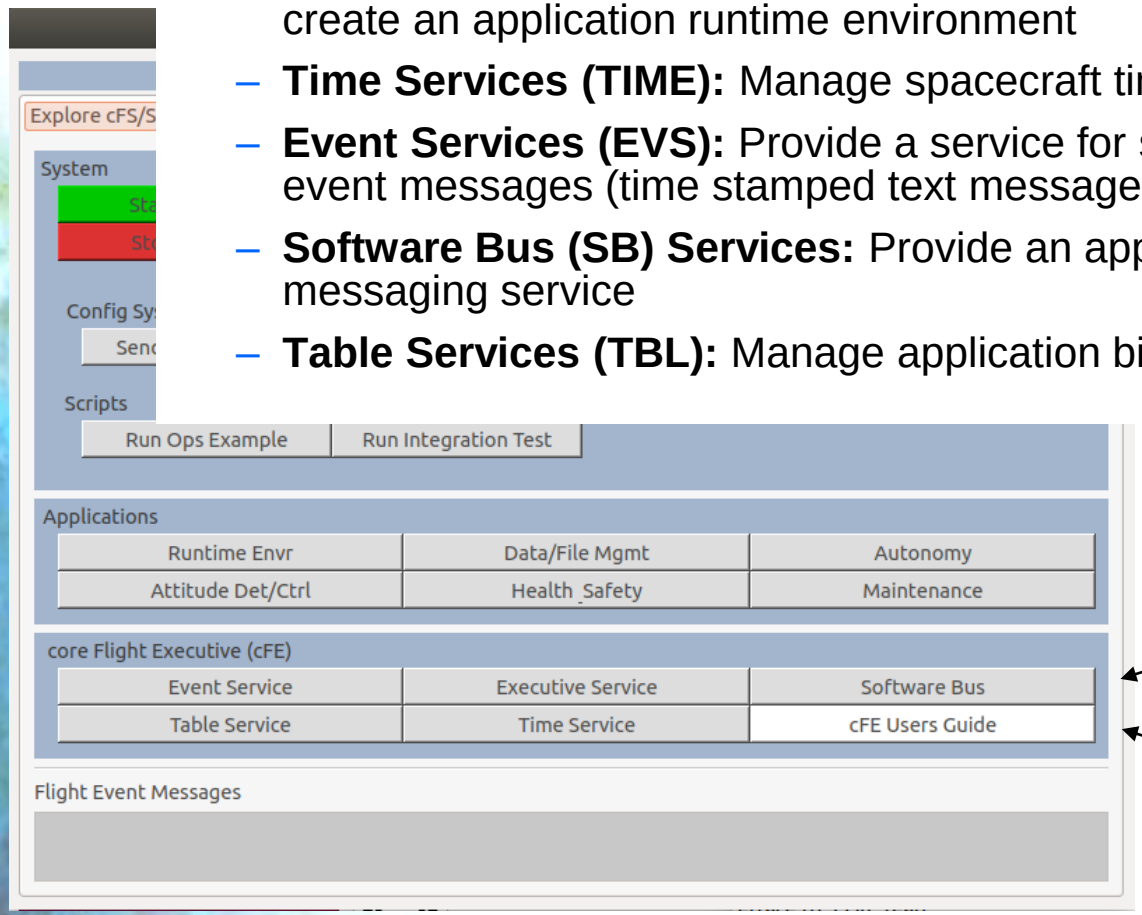
What Just Happened?

- The <Start cFS> button invoked a ruby script that created a new terminal window executing the "cFS Framework"
- The cFS Framework is the bottom two layers of the 3-tiered cFS architecture. It is a portable application runtime environment that uses a startup script (cfe_es_startup.scr) to determine which apps to load during initialization. OSK's startup script is configured for SimSat.



Core Flight Executive (cFE)

- **The cFE has 5 services**
  - **Executive Services (ES):** Manage the embedded 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 (time stamped text messages).
  - **Software Bus (SB) Services:** Provide an application publish/subscribe messaging service
  - **Table Services (TBL):** Manage application binary file table images

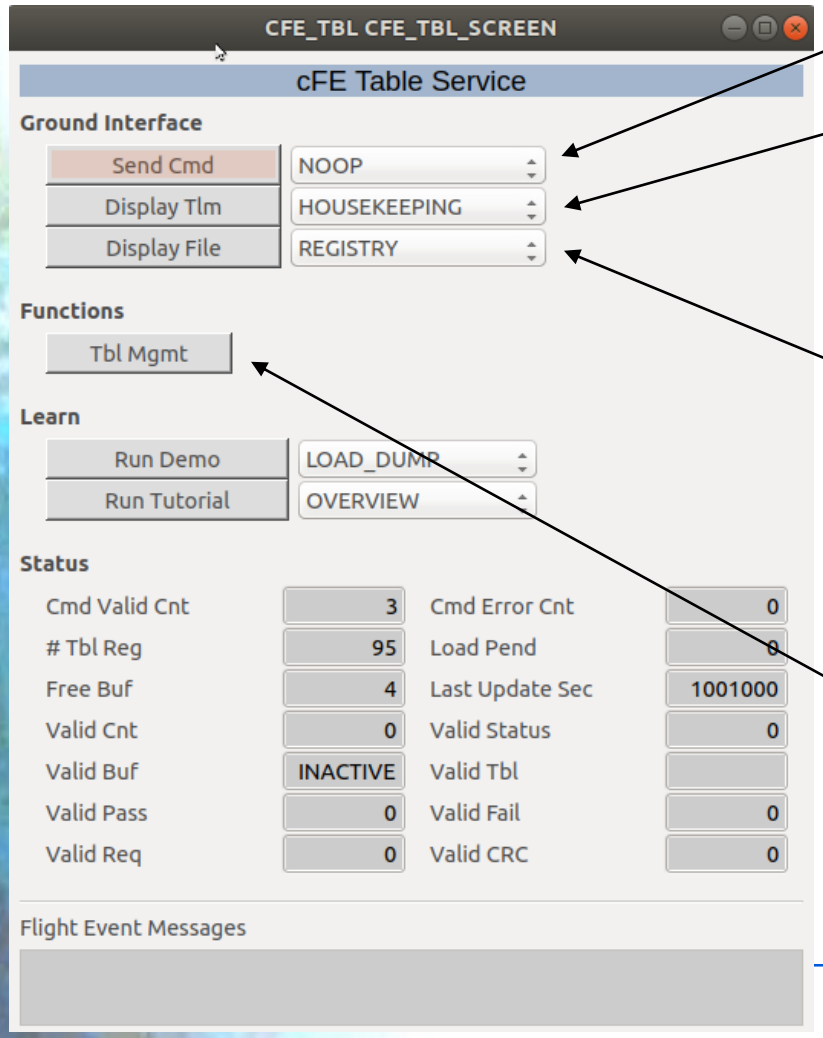


One button/screen for each service

cFE HTML User's Guide

cFE Service Screen (1 of 2)

- **Table Service screen shown. All cFE screens have the same layout but may not have every component/button**



Select and send commands

Display a telemetry packet using COSMOS's Packet Viewer.

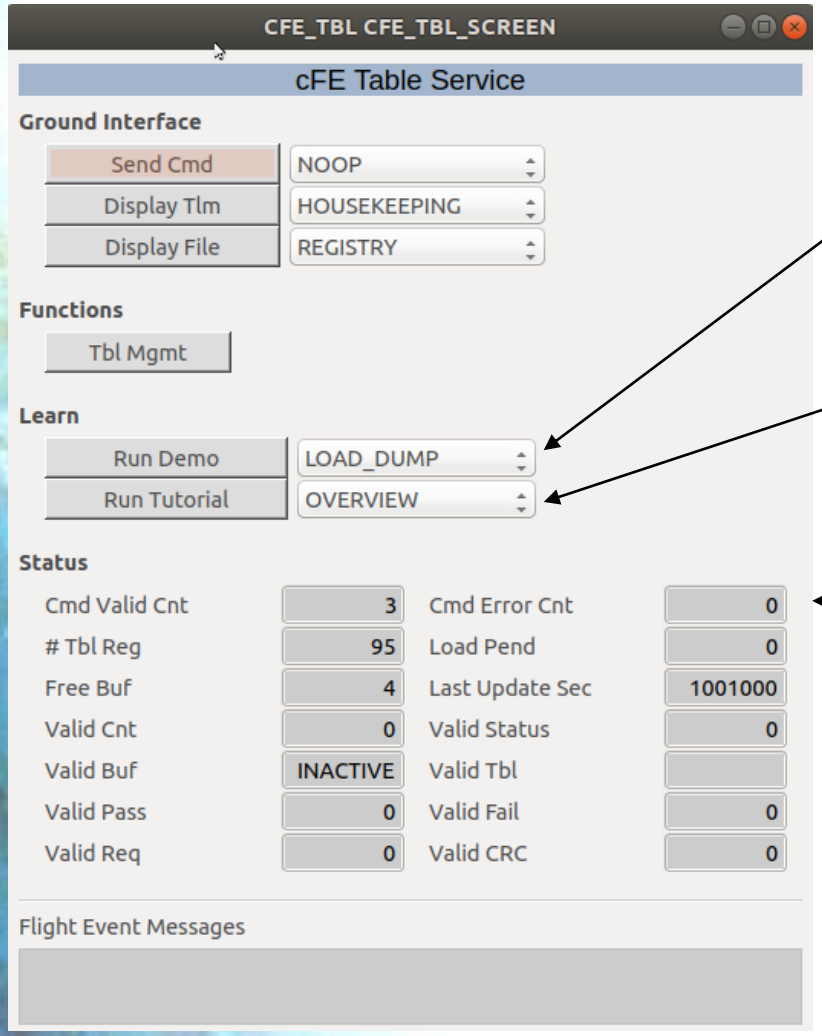
- Telemetry packets can be generated in response to a command
- E.g. Telemeter the registration information for a single table

Display a binary file using COSMOS's Table Manager

- Binary files can be generated in response to a command.
- E.g. Dump the entire table registry to a file

Display a screen that simplifies user interaction with a service

cFE Service Screen (2 of 2)



Select and run a demo

- Demos are a sequence of interactive screens that step the user through a task

Select and run a tutorial

- Tutorial are typically, but not limited to a set of slides coupled with a ruby script for exercises

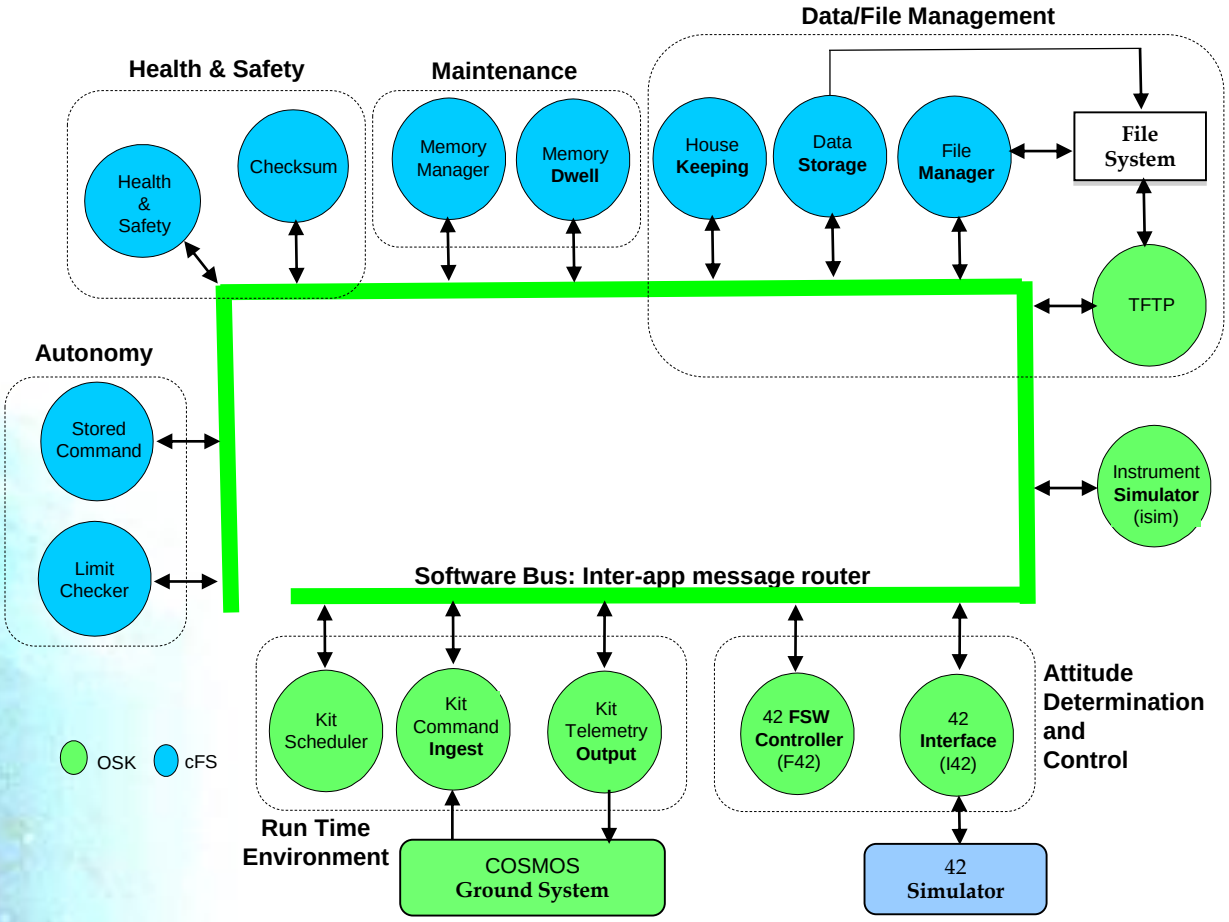
Each service generates a periodic "housekeeping" telemetry packet every few seconds

- The 'Status' section displays a portion of the housekeeping packet
- The entire packet can be displayed using the <Display Tlm> button in the Ground Interface section

Simple Satellite (SimSat)

- **SimSat provides a reference mission to provide context to**
  - Illustrate what applications are required and how they are configured and integrated as a system to meet the requirements
  - Demonstrate an example integration test script
  - Demonstrate an operational script
- **This does not include**
  - Porting SimSat to a new platform
  - Integrating hardware devices
- **SimSat is a**
  - Low Earth Orbit (LEO) satellite with one nadir-pointing science instrument
  - The instrument has
    - A detector that produces 10 bytes of data per second
    - A power the following sequence: Apply power, wait for instrument initialization (~20s), and command to enable science
  - The science team requires
    - A 1Hz auxiliary spacecraft data containing time, attitude, orbit data, and instrument status
    - Start science during a ground contact. Can be automated but ops prefers to monitor instrument health.
  - Ground contact resources/schedule are preplanned
    - Implies autonomous operations can be loaded on board using stored commands
  - FSW must autonomously monitor instrument health and power off the instrument in the event of a fault

SimSat Applications (1 of 3)



SimSat Applications (2 of 3)

- **The previous slide shows a cFS "bubble" chart where each app is a bubble and they communicate via messages on the software bus.**
  - The blue cFS apps are reusable open source apps that are available on https://github.com/nasa/xx where 'xx' is the abbreviated app name
  - The green OSK apps were written specifically for OSK
  - The external COSMOS and 42 interfaces use UDP and TCP respectively
- **Apps are designed to perform a dedicated function with clear interfaces and they operate in groups to achieve higher level mission objectives**

- **Runtime Environment Apps**
  - **Kit Command Ingest (KIT_CI)** receives CCSDS command packets from COSMOS and sends them on the Software Bus
  - **Kit Telemetry Output (KIT_TO)** reads CCSDS telemetry packets from the Software Bus and sends them to COSMOS
  - **Kit Scheduler (KIT_SCH)** contains tables that define when to send messages on the Software Bus
    - Apps can use these messages to perform synchronous activities, e.g. sending their housekeeping status packet

SimSat Applications (2 of 3)

- **Data/File Management**
  - **File Manager (FM)** provides a ground interface for performing common directory and file operations
  - **Data Storage (DS)** reads packets from the software bus and writes them to files according to table-defined
  - **Housekeeping (HK)** creates new telemetry packets from pieces of other telemetry packets. The new packets are written to the SB and can be stored and/or telemetered.
  - **Trivial File Transfer Protocol (TFTP)** transfers files between the flight and ground COSMOS. There's an open source CCSDS File Delivery Protocol (CFDP) app that will be added in a future release.

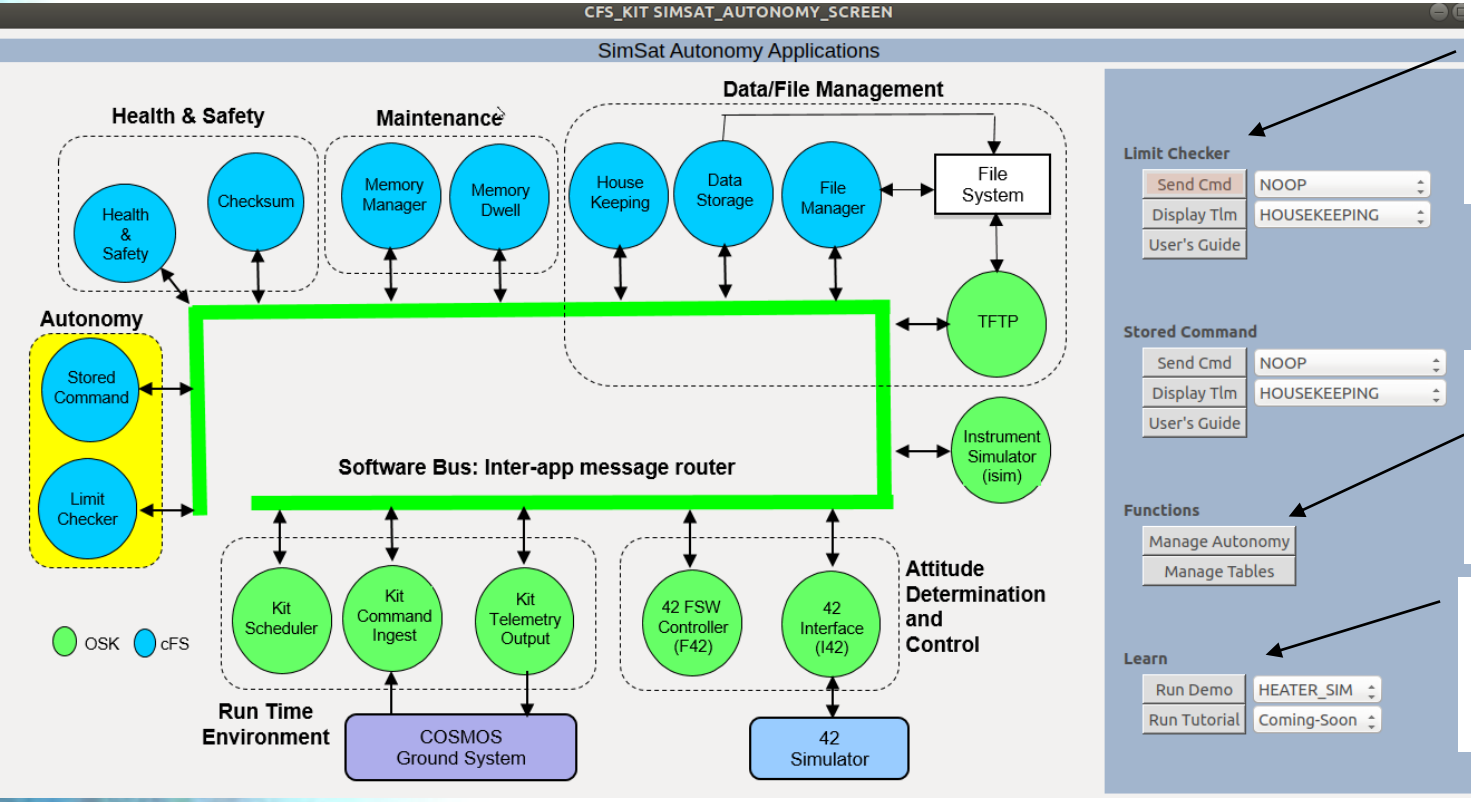
- **Autonomy**
  - **Limit Checker (LC)** monitors one or more telemetry values and start stored command relative time sequences (RTSs) in response to limit violations
  - **Stored Command (SC)** Provides services to execute preloaded, table-defined command sequences at predetermined absolute or relative time intervals

SimSat Applications (3 of 3)

- **Attitude Determination and Control Apps**
  - **42 Interface (I42)** manages a TCP/IP connection to 42 and transfers actuators/sensor packets to/from 42
  - **42 FSW (F42)** Implements the "ThreeAxisFsw" attitude control algorithm defined in 42
- **Maintenance**
  - **Memory Dwell (MD)** creates telemetry packets containing contents of memory location specified in dwell tables
  - **Memory Manager (MM)** provides read/write access to memory
- **Health & Safety**
  - **Checksum (CS)** monitors checksums across table-defined static code/data regions and reports errors
  - **Health & Safety (HS)** monitors table-defined application check-in and event messages and reporting errors and/or starting a RTS to address the issue

SimSat Application Screens

- **Each functional application group screen uses the following layout**



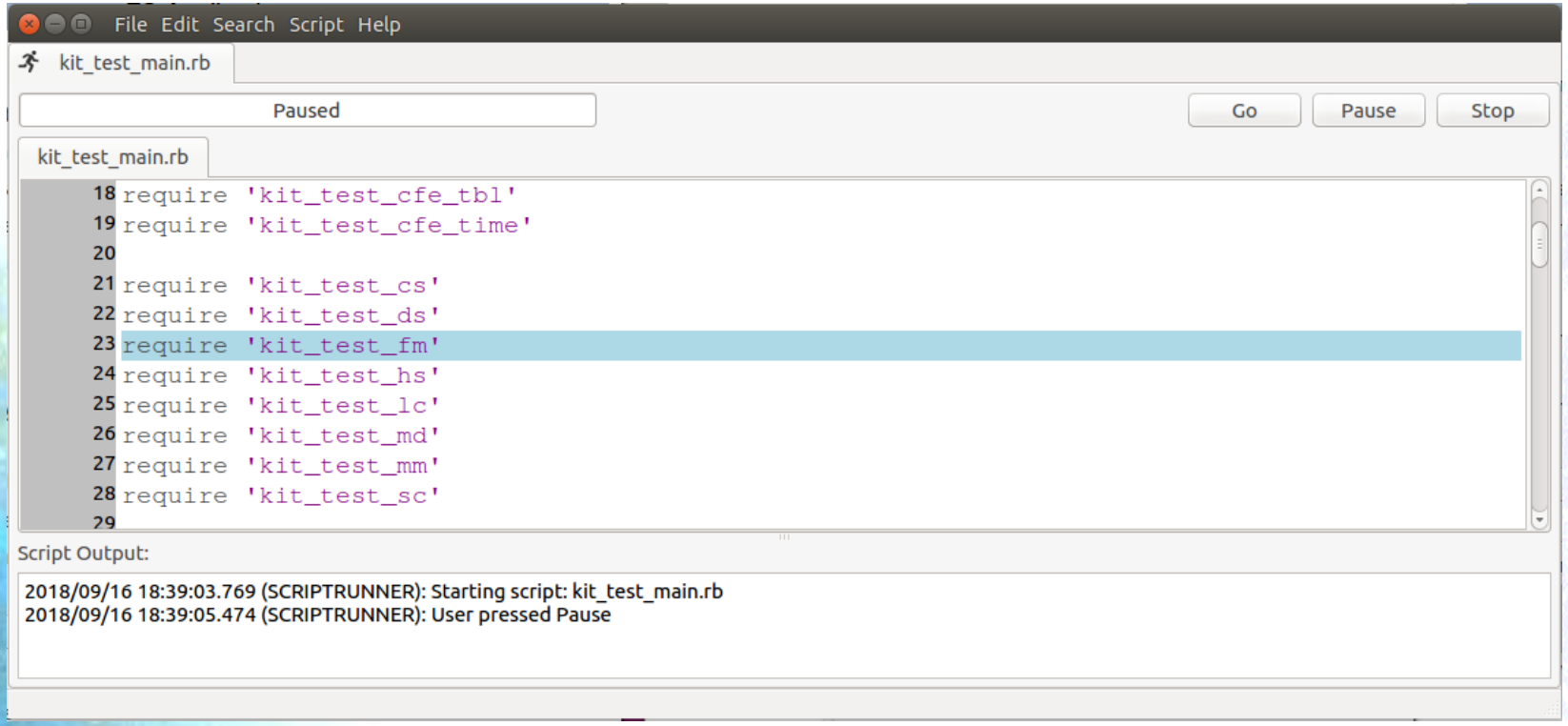
Quick access to each app's commands, telemetry, and user's guide

- *Binary Tables & Files coming soon*

Convenient functional screens for most common commands and relevant status. Listed at end of slide deck.

Launch demos (pre-defined screen sequences) and tutorials (slides and/or scripts)

SimSat Integration Script



- **Runs test script using Script Runner**
- **Issues Noop command to every application and verifies telemetry response**

SimSat Operational Script

- **Integration Scripts**
- **Operational Scripts**

Configuration and Convention Notes

COSMOS Configuration (1 of 2)

- **COSMOS *Target* (OpenSatKit/cosmos/config/targets)**
  - Architectural component, typically on an embedded system, that COSMOS can send commands to and receive telemetry from
  - For each target users can define command packets, telemetry packets, screens, and Ruby scripts.
  - Each FSW application is defined as a target
  - OSK defines a virtual target ***CFS_KIT*** to serve as the User's primary interface

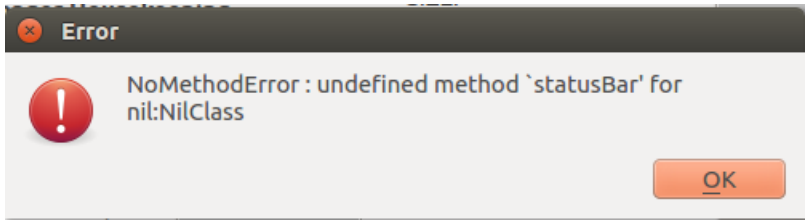
- **OSK scripts in *OpenSatKit/cosmos/lib* extend COSMOS scripting API**
  - API documentation is under development. See code for details

COSMOS Configuration (2 of 2)

- **OSK specific directories defined in *OpenSatKit/cosmos/cfs_kit***
  - */docs*: cFE and OSK documentation
  - */file_server*: Default location for file transferred to/from FSW
    - */table* subdirectory contains table files
    - COSMOS Table Manager file formats defined in */cosmos/config/tools/TableManager*
  - */tools*: cFE and OSK standalone tools
  - */tutorials*: Tutorial files

Minor Inconveniences (1 of 2)

- **OSK is a work in progress with a few known issues that you can ignore**
- **If you cancel an OSK dialogue you may see the follow COSMOS error dialogue.**

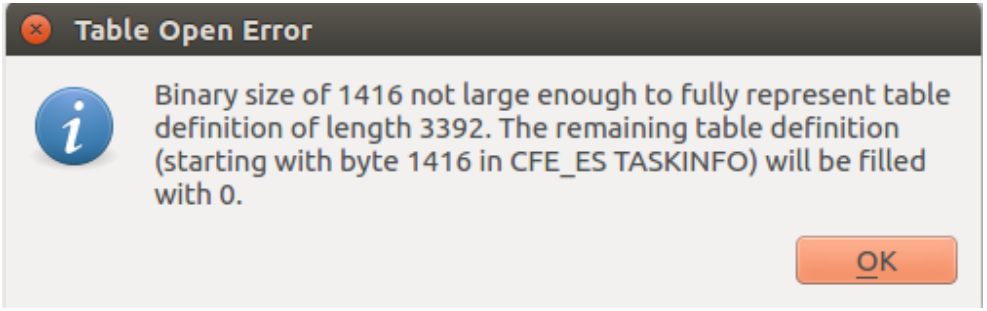


- **The FSW terminal window may display start and stop "FlyWheel" messages**
  - OSK is a non-realtime environment so the cFE time service is warning that's it's not operating within its real-time precision limits relative to a 1Hz timer
  - OSK is designed to help users learn functional features and only requires reasonable timing performance in order for the scheduler to execute its schedule correctly

```
EVS Port1 42/1/CFE_TIME 20: Start FLYWHEEL
EVS Port1 42/1/CFE_TIME 21: Stop FLYWHEEL
```

Minor Inconveniences (2 of 2)

- Some cFS binary files are variable length. The Table Manager definition files support fixed length files, therefore you may see an error dialog stating the file doesn't contain all of the records. This message is from cFE Executive Service Task Information file.



OSK Conventions

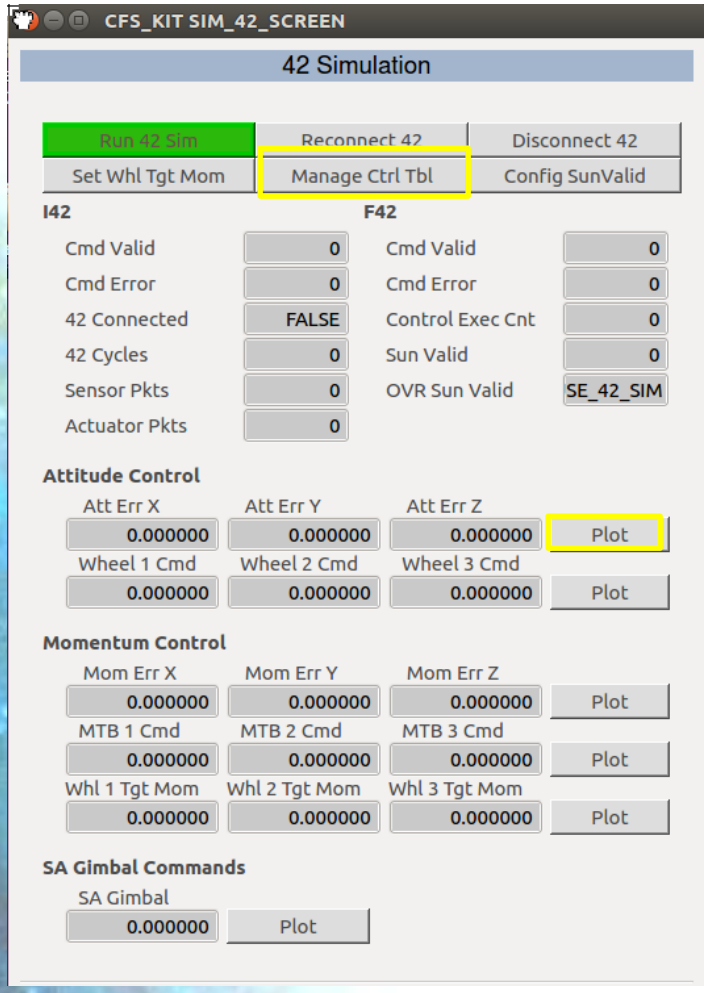
- **Most cFE services have commands that can generate a telemetry as part of the response or write information to a file**
  - The verbs ***list*** and ***send*** indicate information is sent in a telemetry packet.
  - ***Write*** is used when information is written to a file
- **The FSW directory /cf (compact flash) is used as the default location for onboard file creation and flight-ground file transfers**
  - This is mapped to *OpenSatKit/cfs/build/exe/cpu1/cf*
- **OpenSatKit/cosmos/cfs_kit/file_server is used as the default ground file location**
  - Table are located in the ***tables*** subdirectory
- **OSK often uses osk_tmp_bin.dat as a standard temporary binary file name to avoid clutter**
- **OSK does not "cheat" when working with ground and flight tables**
  - **Files are transferred between flight and ground locations and not accessed via shared locations within the VM**

OPEN SAT KIT

Running SimSat with 42

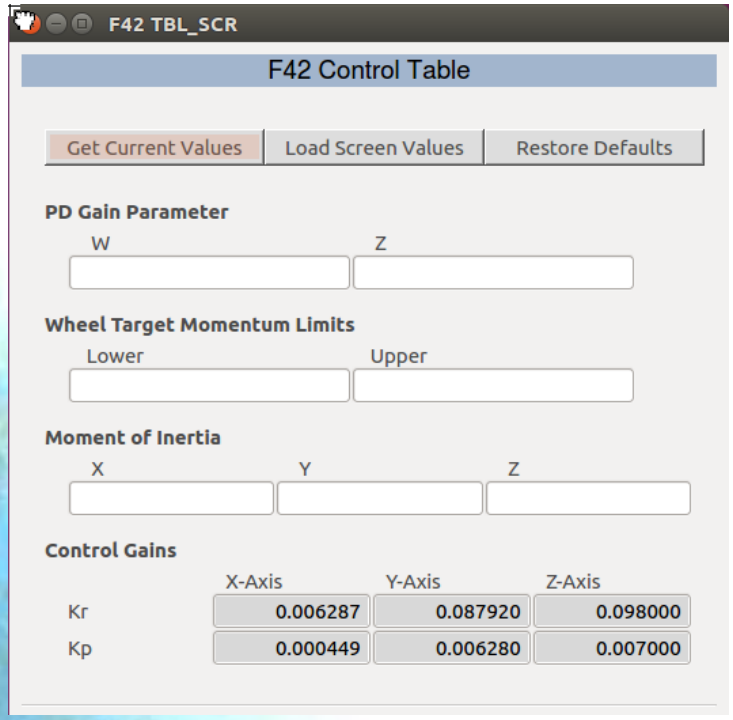
Needs 2.0 Updates

Tools: Preparing 42 Simulation

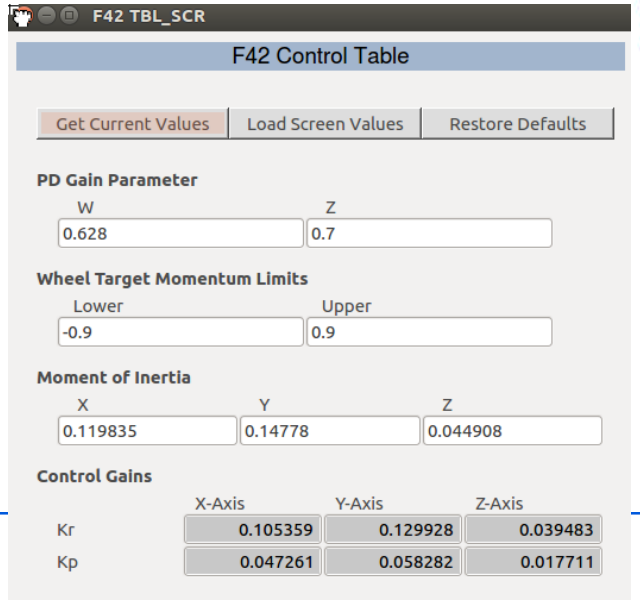


- From the kit main page on the previous slide select <42 Simulator> and the screen to the left will appear.
- The 2nd row of buttons allow you to change the behavior of the control algorithms running in the FSW and are described on the next slides
- Before running the sim you will open some additional windows that will be used for your class exercise
  - Manage Control Table
  - Plot Attitude Errors

42 Sim: Manage Control Table

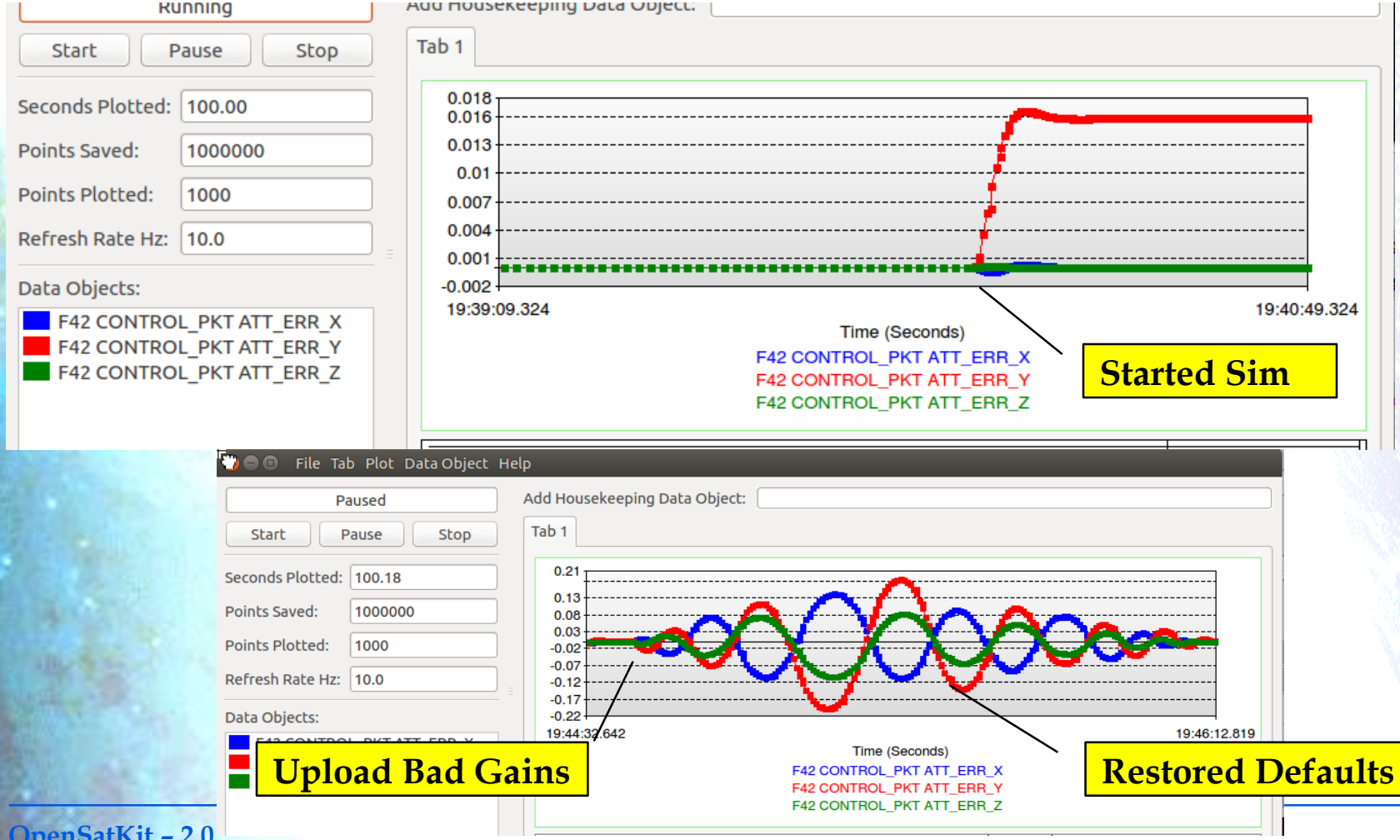


- Selecting <***Manage Control Table***> on the 42 Sim screen produces the screen to the left.
- Select <***Get Current Values***> and it will populate the screen with the current control table values. This takes a little time because it is transferring a file from flight to ground
- Edit the screen as desired and click <***Load Screen Values***> to replace the current control table values
- The defaults can be restored by clicking <***Restore Defaults***>

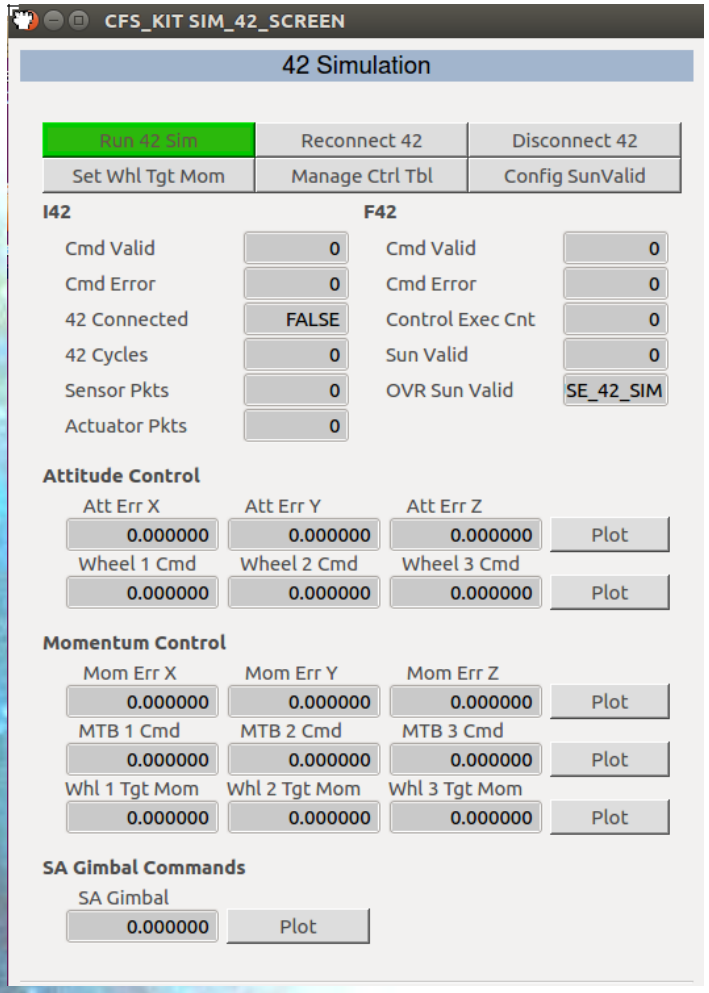


42 Sim: Plot Attitude Errors

- **Selecting <Plot> button next to the attitude errors produces the screen below**



42 Sim: Starting the Simulation

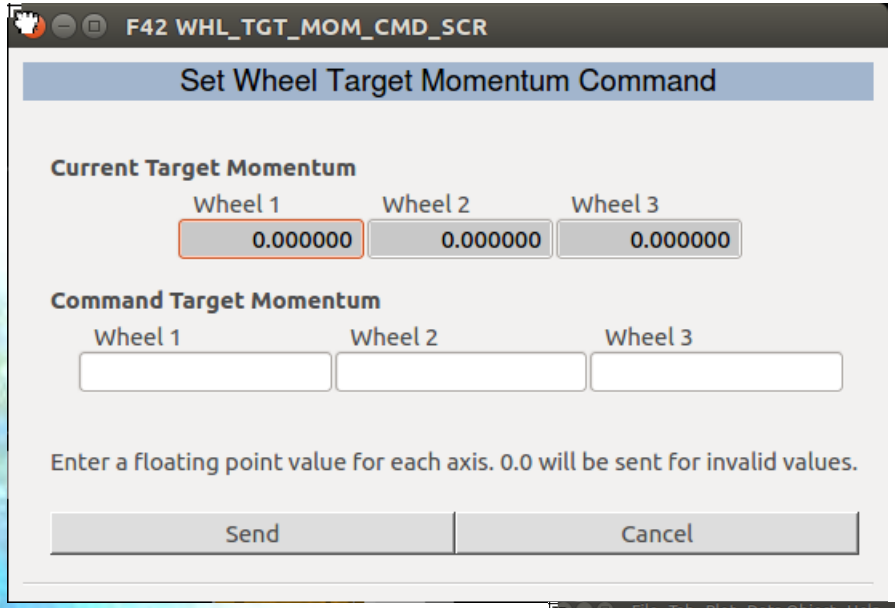


- Select <***Run 42 Sim***> which will start the 42 simulator in a new terminal window.
- The 42 configuration files used in the simulation are located in directory ***OpenSatKit/42/OSK***
- The simulation takes a while to initialize

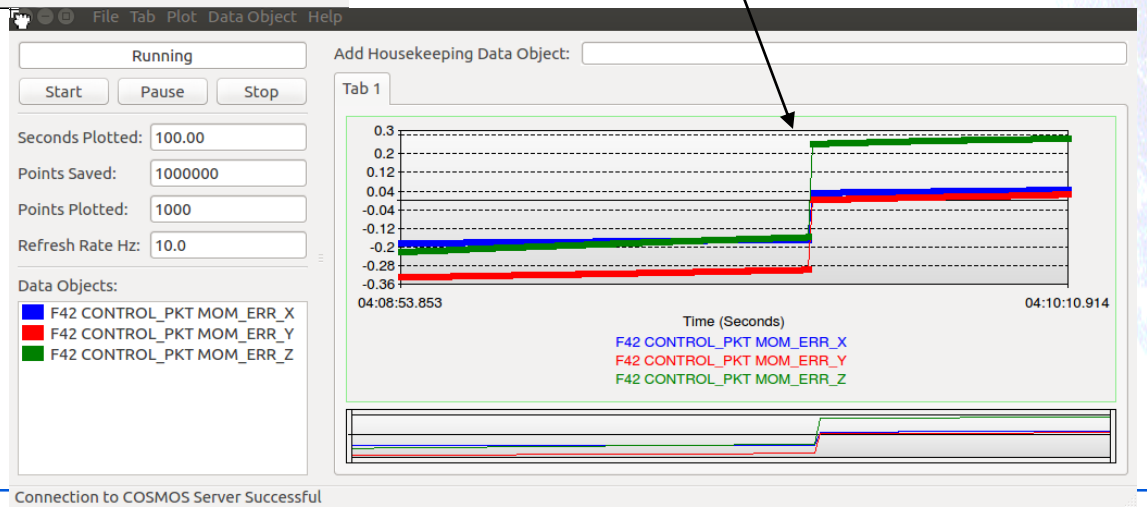
42 Sim: Additional Configuration Options

- The kit includes two additional configuration options that can be manipulated
  1. Wheel target Momentum
  2. Sun Valid Configuration

42 Sim: Set Wheel Target Momentum

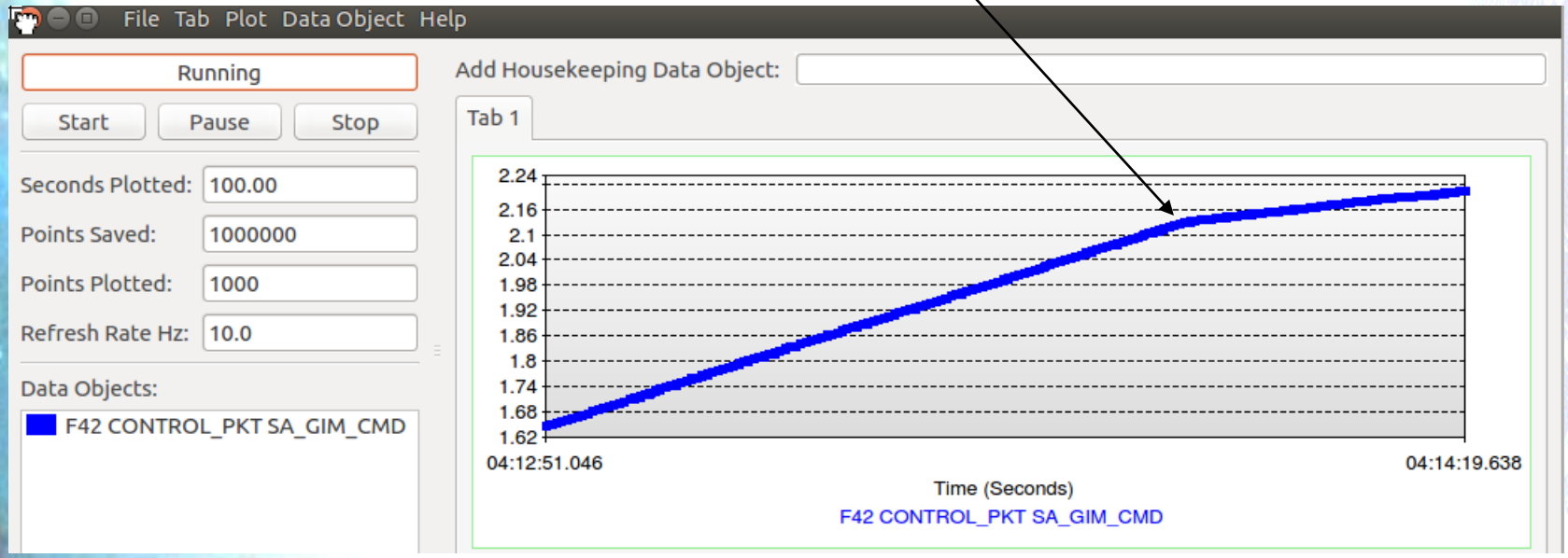


- The controller allows a non-zero (default) momentum to be stored in the wheels
- Enter new values and click <***Send***> to change the values
- The plot below shows a jump in momentum errors when new targets were selected



42 Sim: Configure SunValid

- Selecting <*Config SunValid*> to override the current sun valid flag
- The plot below shows gimbal command
  - The linear portion had a valid sun and the bend occurred when the SunValid was overridden to false.



42 Sim: Termination

1. Click <***Disconnect 42***> to end a 42 simulation that is running with the FSW

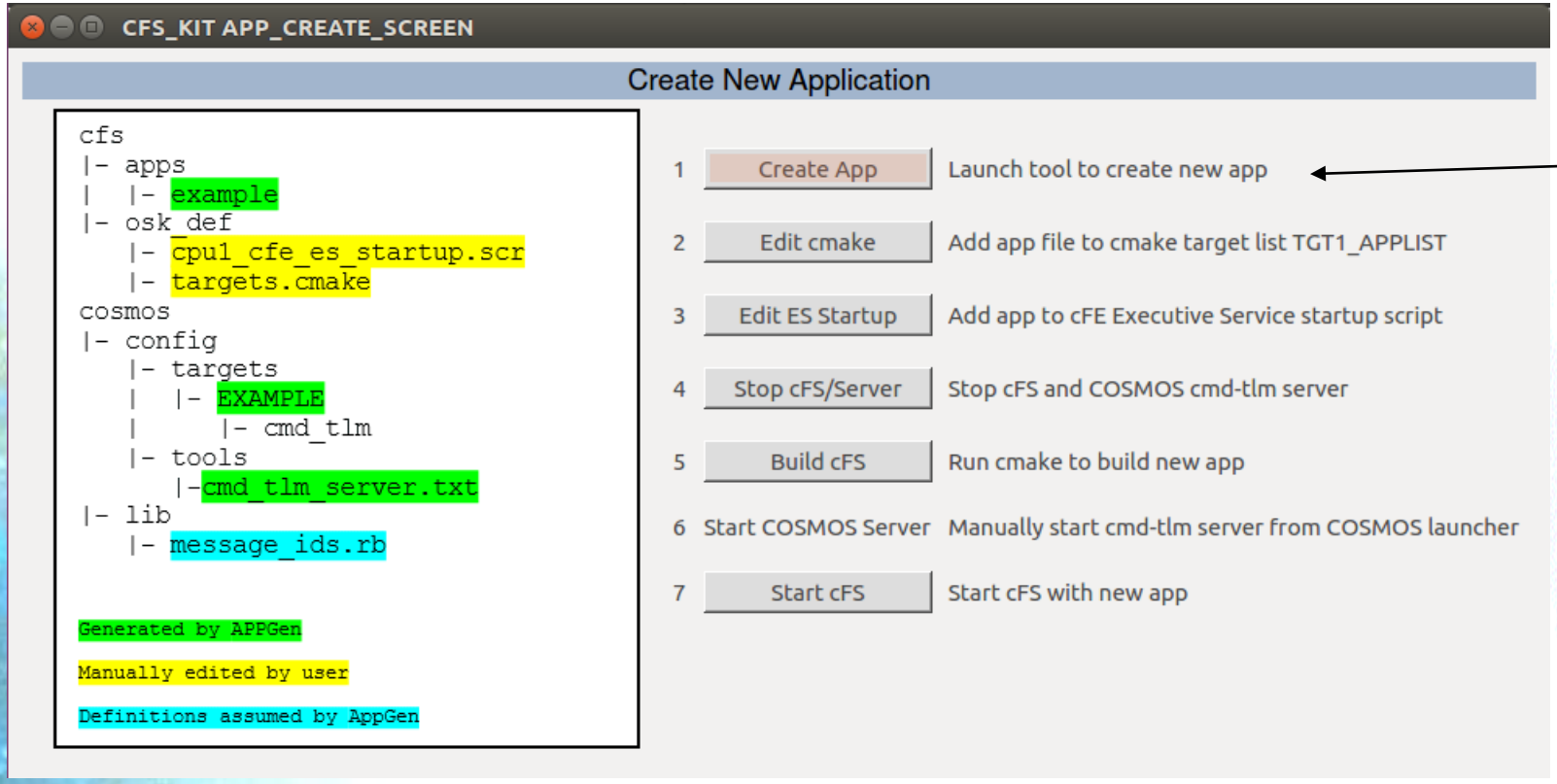
2. To terminate the flight software click on the terminal window with the FSW messages and then enter ctrl-c

3. Each of the cosmos windows will need to be closed individually. If you close the COSMOS TlmViewer window first it prompt you to close all of the telemetry screens at once.

Manage Applications

Needs 2.0 Updates

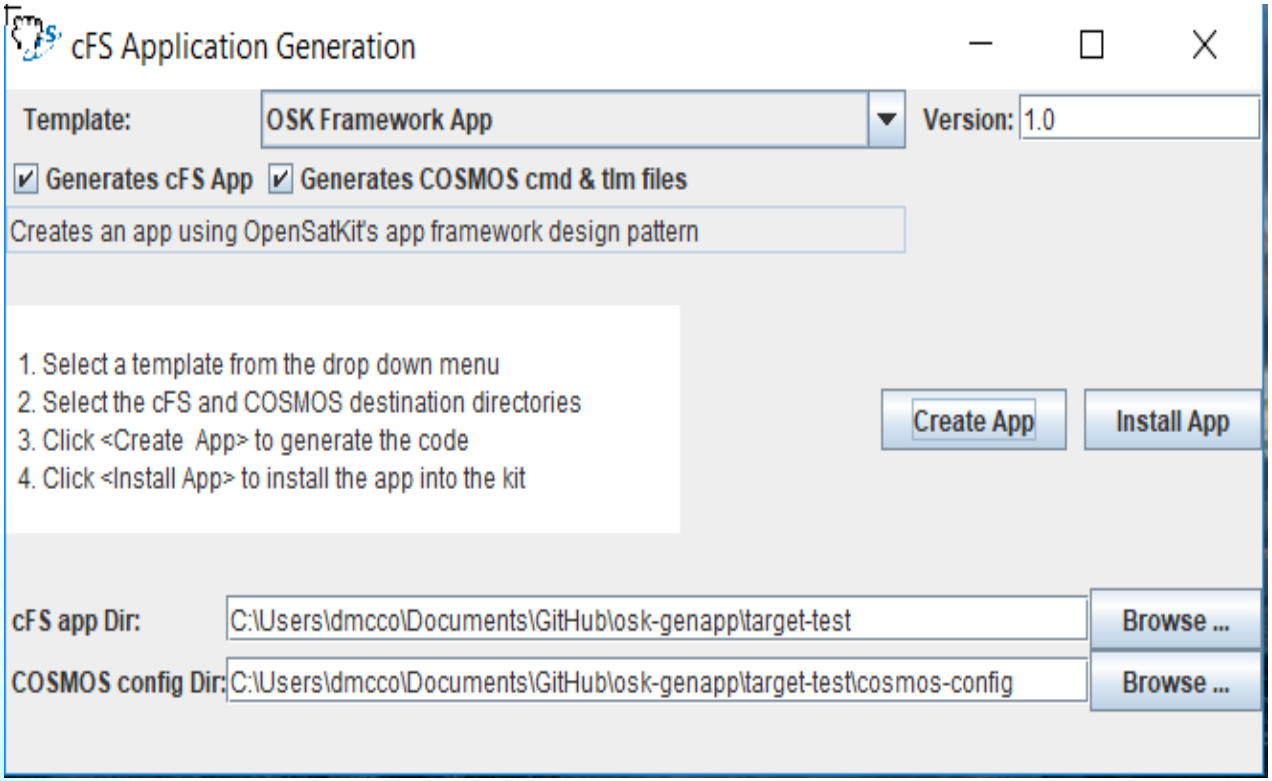
Tools: Create Application



See next slide

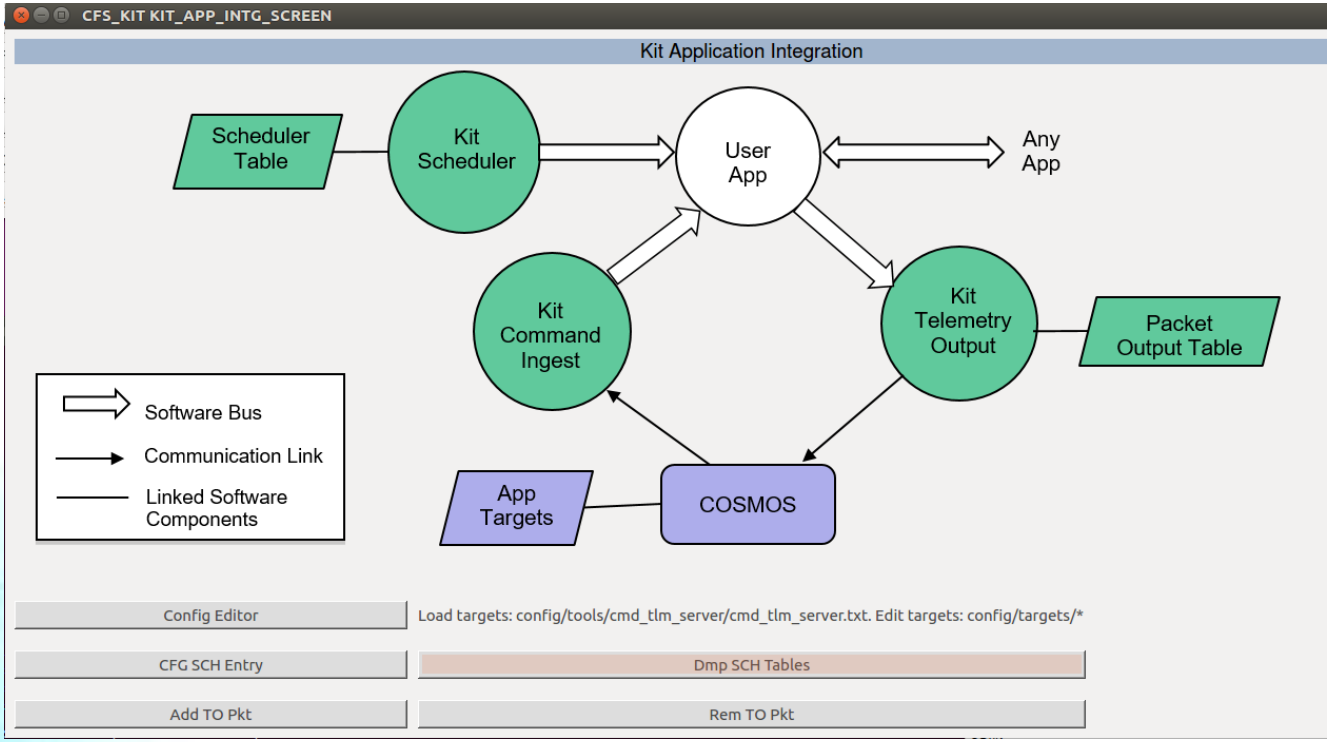
- Seven quick steps and a new app is created and integrated into the kit

Tools: Create Application



- Follow the instructions in the center of the dialogue. Create app generates the fsw source/make files, the cosmos target, and edits the COSMOS cmd-tlm-server config file.
- ***<Install App>*** has not been implemented. Follow the instructions on the previous slide

Kit App Integration



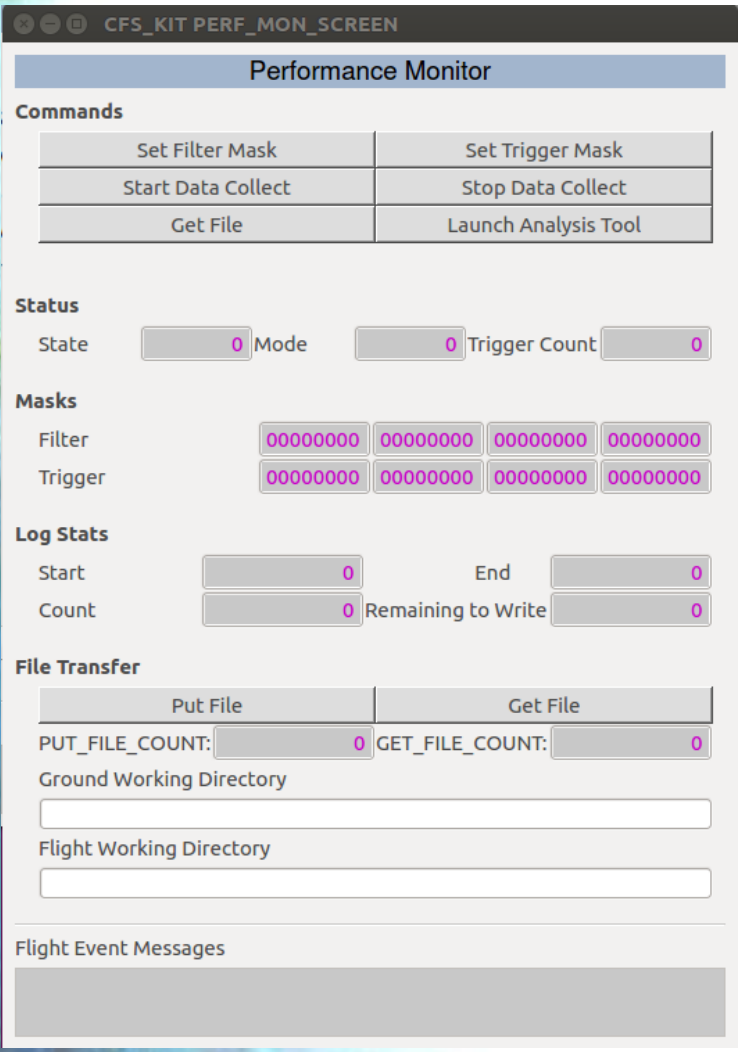
- **Goal is to provide easy access to COSMOS, KIT_TO, and KIT_SCH to integrate a new app**

Extending OSK

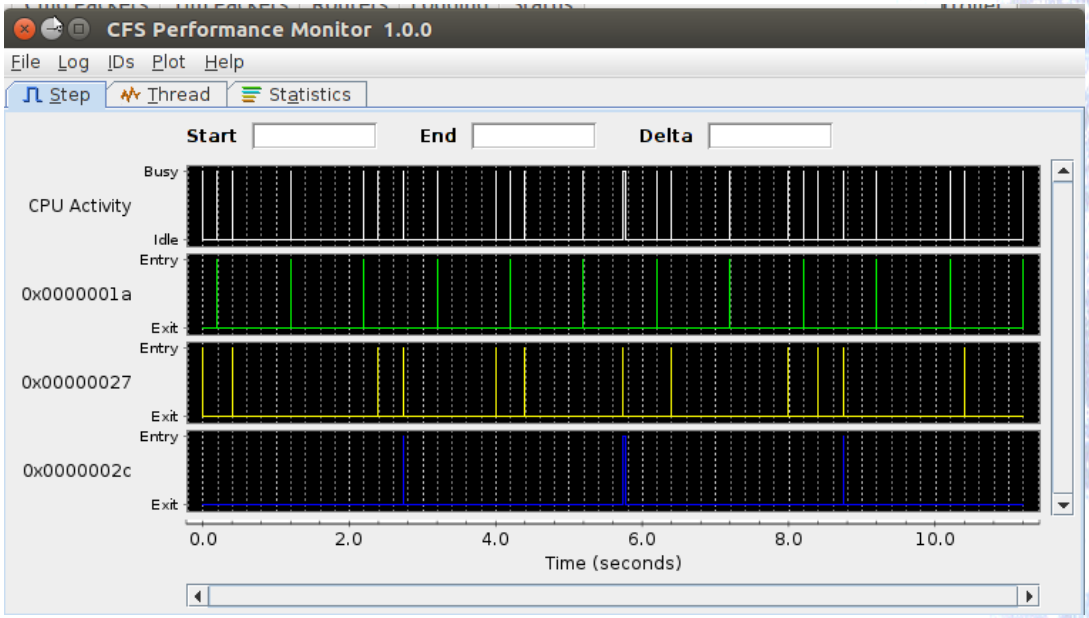
Tools: Benchmarks

Coming Soon…

Tools: Performance Monitor



- Capture FSW performance data using screen
- Download file and <Launch Analysis Tool>



Tools: PiSat Control

- This requires a PiSat which is currently not in the public domain

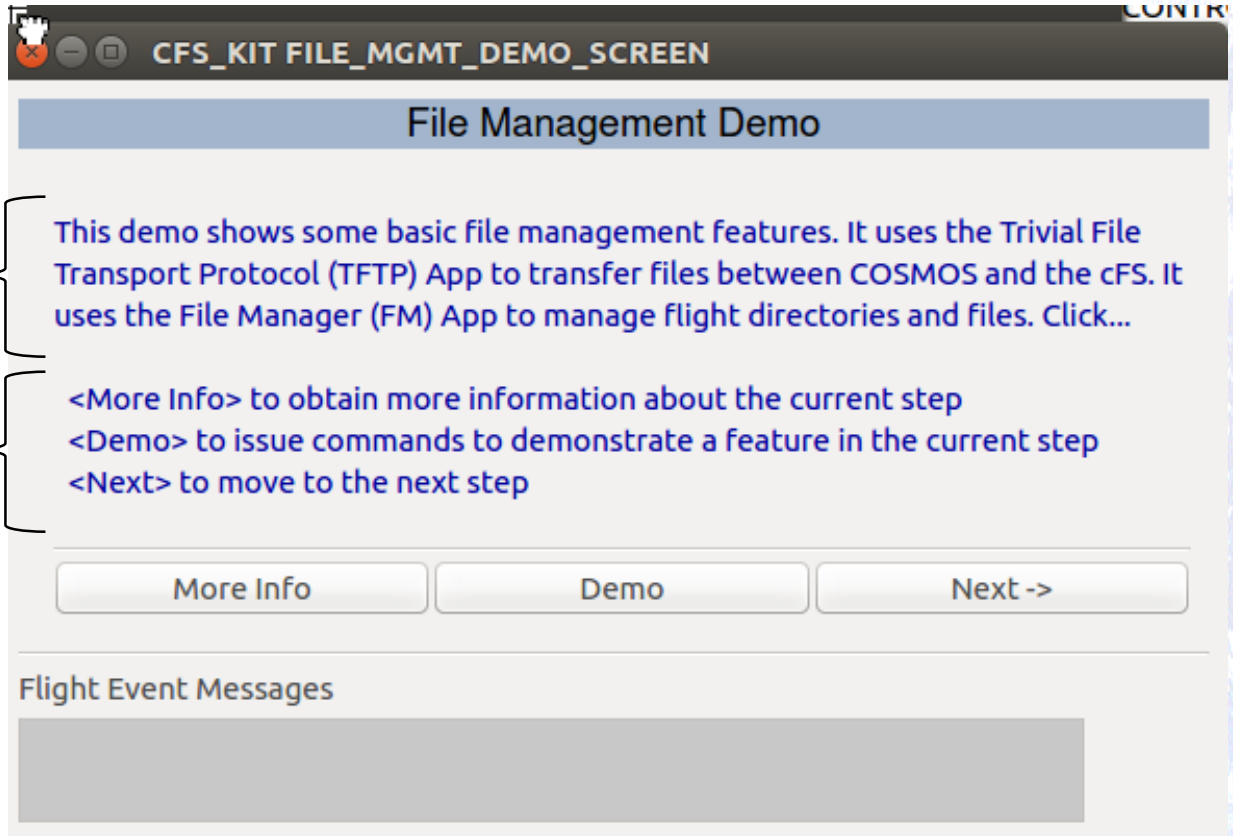
Demos

Demo Structure – FM Example (1 of 2)

- **Each demo follows a common user screen configuration**

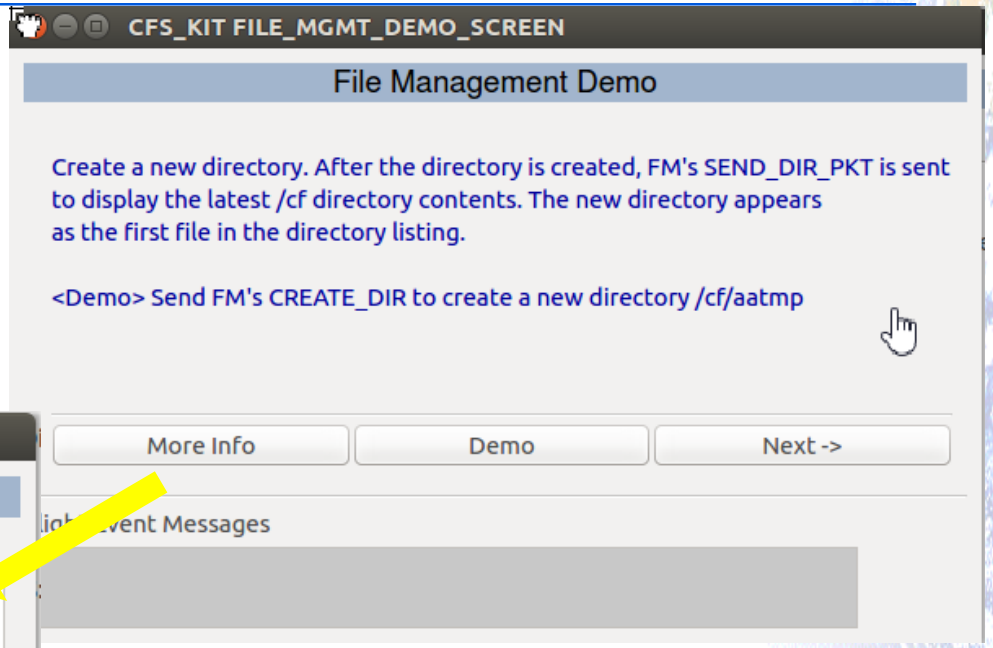
Description of current step

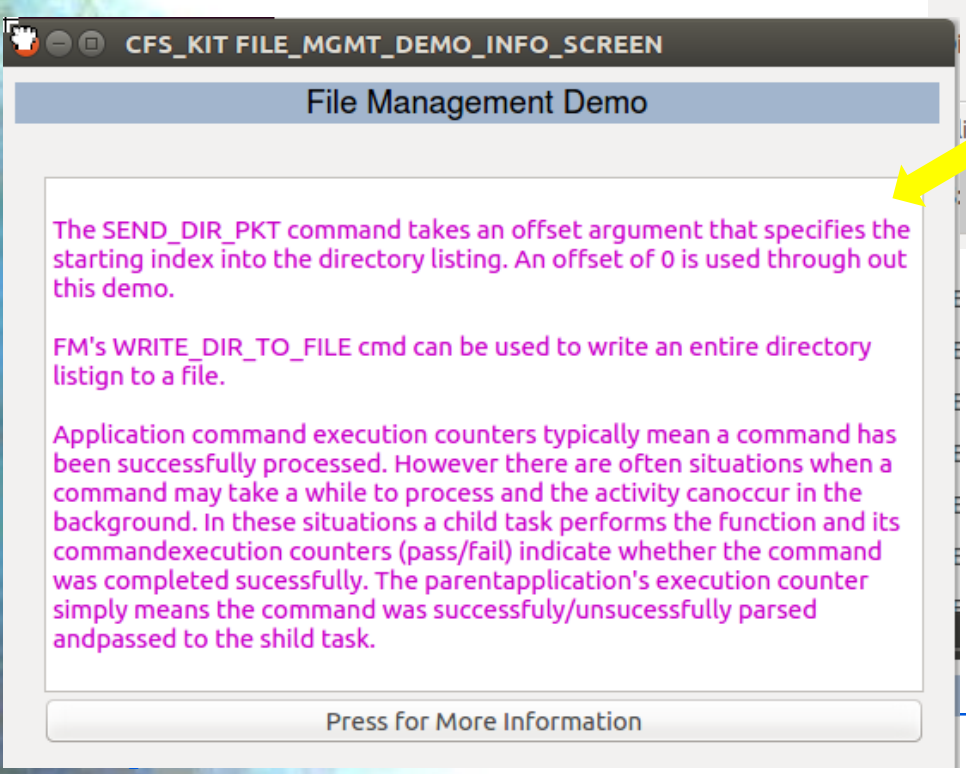
Button usage description



Demo Structure – FM Example (2 of 2)

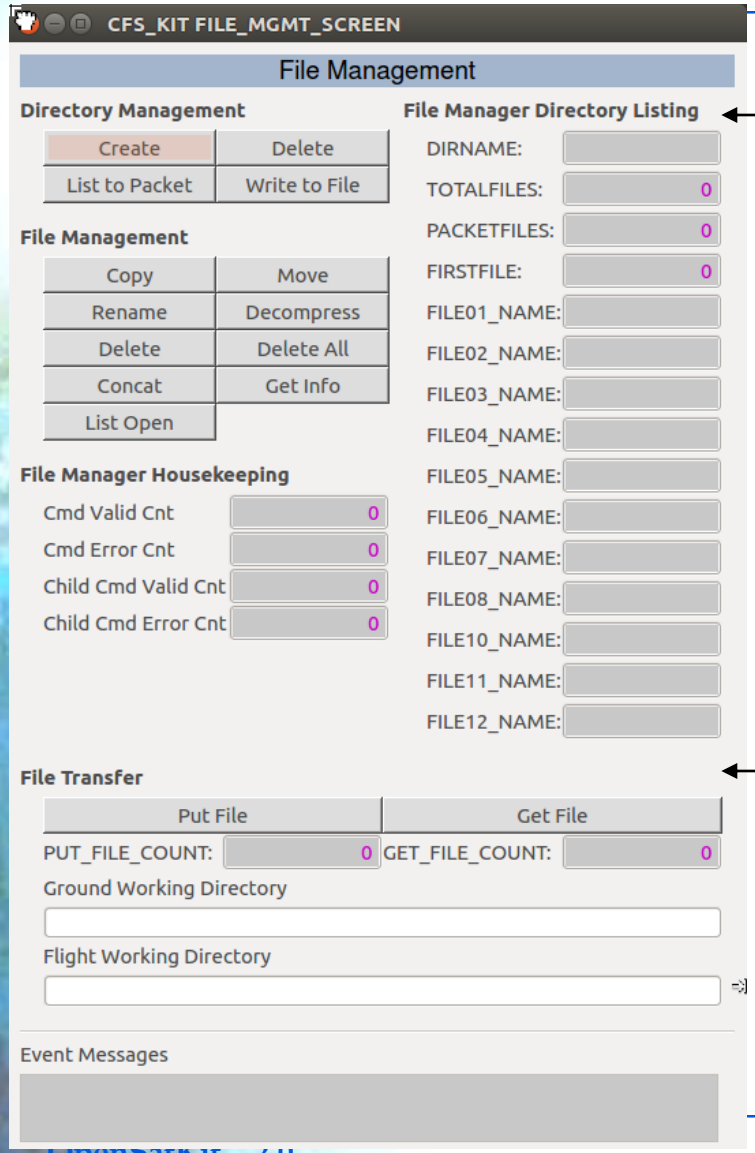
<More Info> provides detailed context-specific information





Application Functional Screens

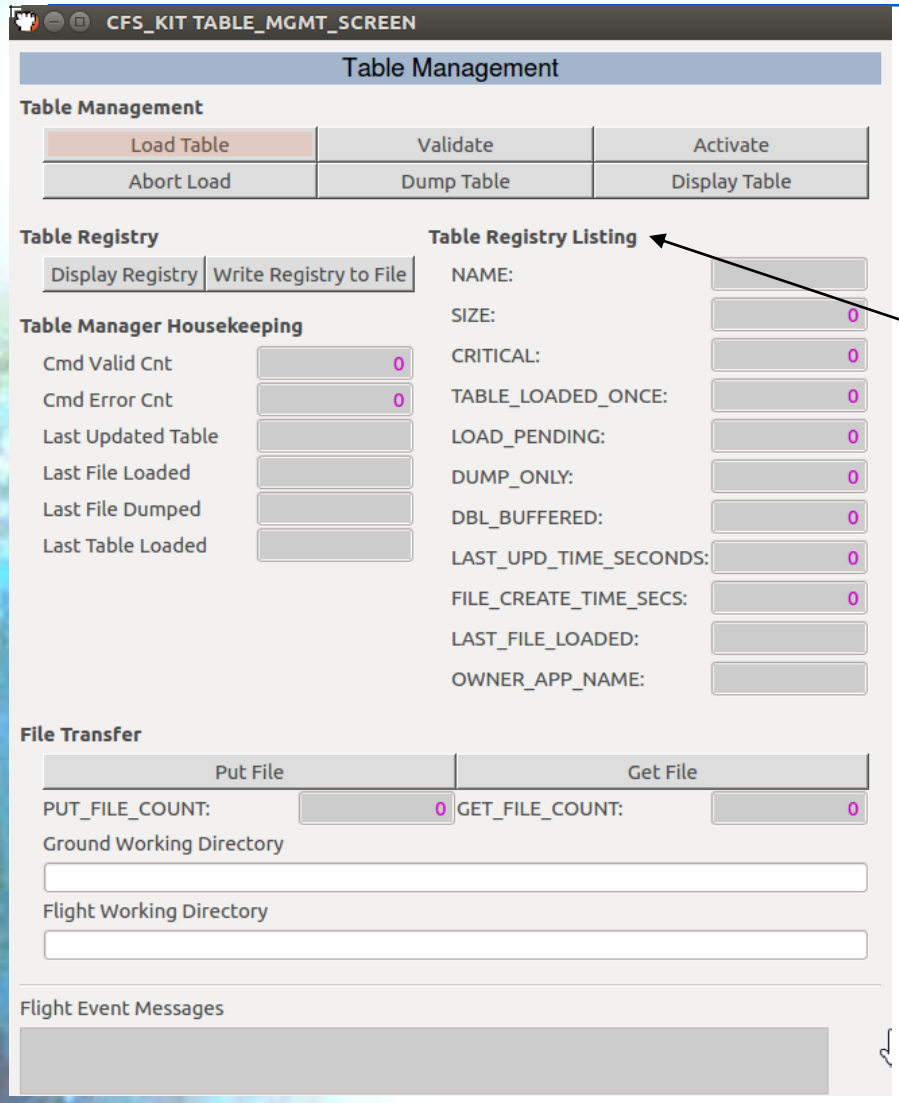
File Management



- <List to Packet> commands File Manage (FM)
  - To send a directory listing
  - The command uses a directory listing alphabetical "offset" to determine which file to start with in the listing
- OSK uses the verbs ***list*** and ***send*** to indicate information is sent in a telemetry packet.
- ***Write*** is used when information is written to a file

- <List to Packet> commands File Manage (FM)
  - To send a directory listing
  - The command uses a directory listing alphabetical "offset" to determine which file to start with in the listing

Table Management

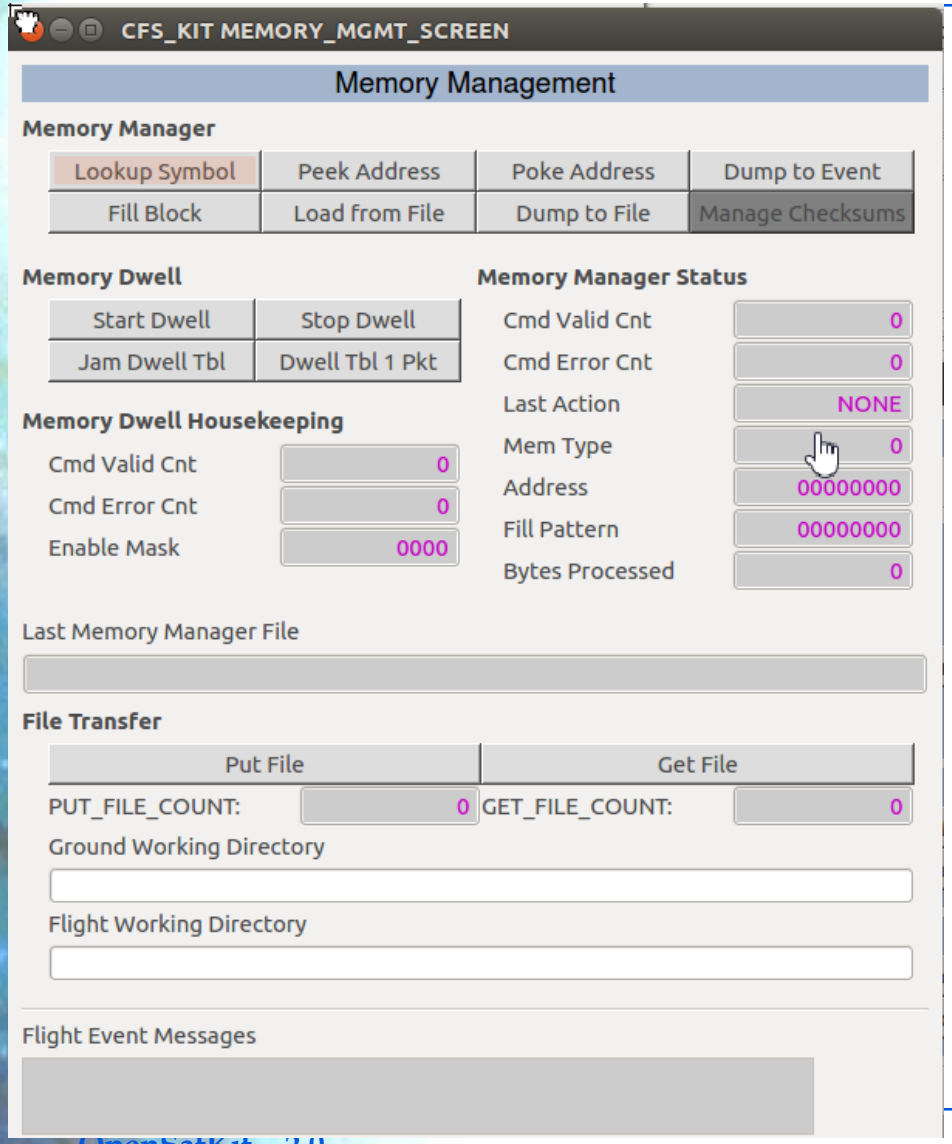


- Load a new FSW table
  <***Put File***> transfers file from ground to flight
  <***Load Table***> into table buffer
  <***Validate***> table via app validation function
  <***Activate***> new table

- <***Display Registry***> sends a table's registry information in a telemetry packet

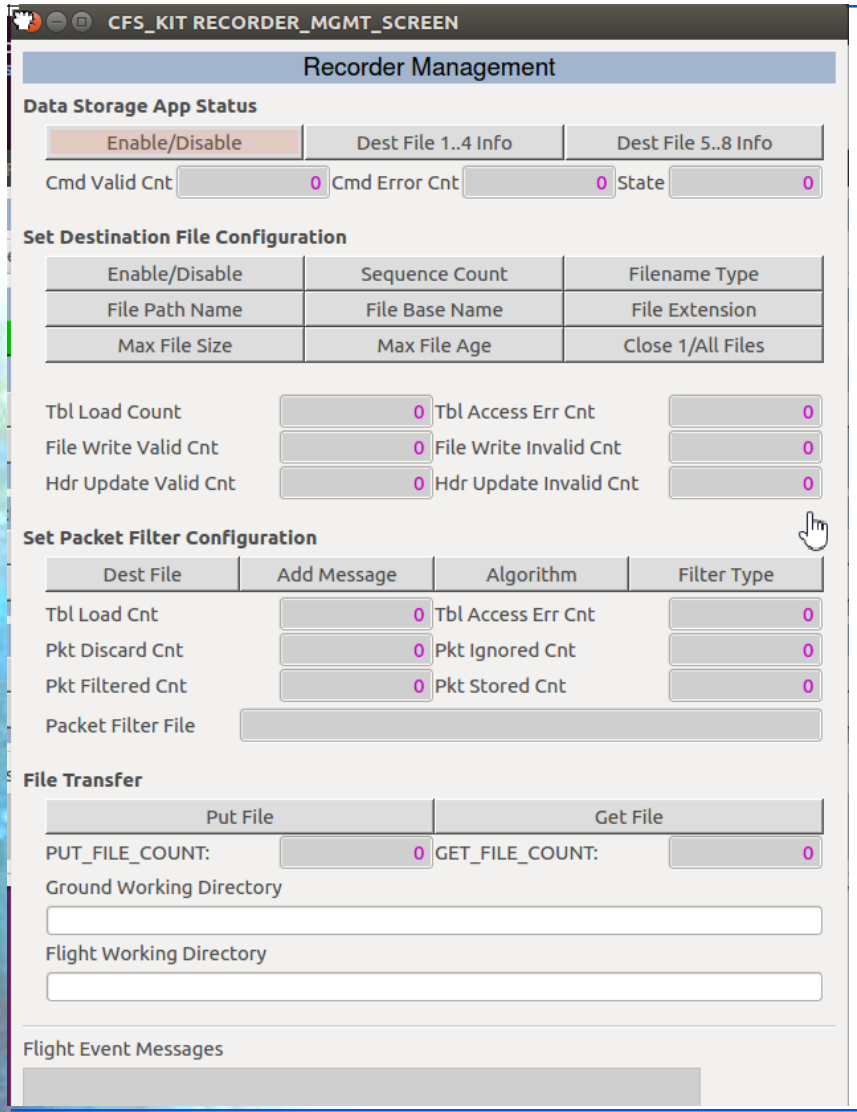
- Dump and display FSW table
  <***Dump Table***> to onboard file
  <***Get File***> transfers file from flight to ground
  <***Display Table***> launches COSMOS Table Manager to view file. Requires binary file definition.

Memory Management

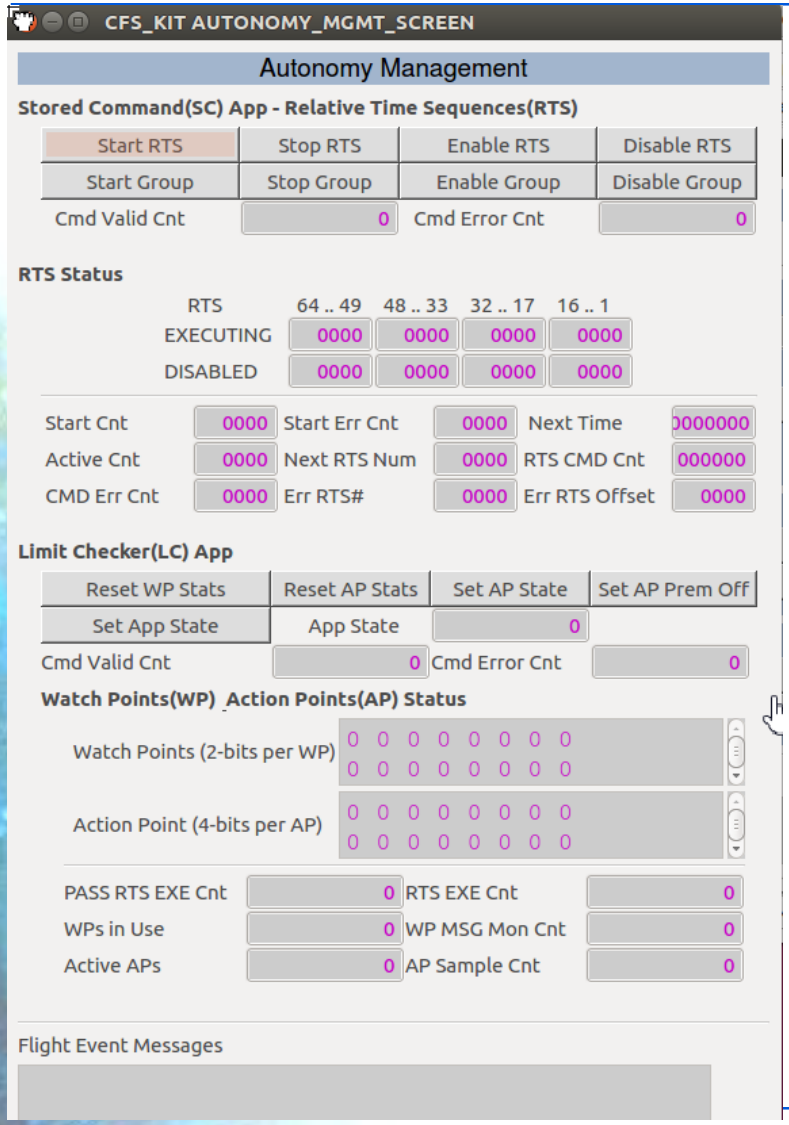


- Memory Manager (MM) and Memory Dwell (MD) apps are typically used for inflight maintenance.
- MM commands allow direct access to any memory location
- MD generates telemetry packets that contain the contents of table-specified memory locations
  - Only 1 dwell table telemetry packet is defined
  - *<Jam Dwell Table>* allows the dwell table to be loaded without using the table load service
- The FSW can easily be corrupted using memory manager
- The memory management demo is a good place to start since it demonstrates MM and MD using safe memory locations

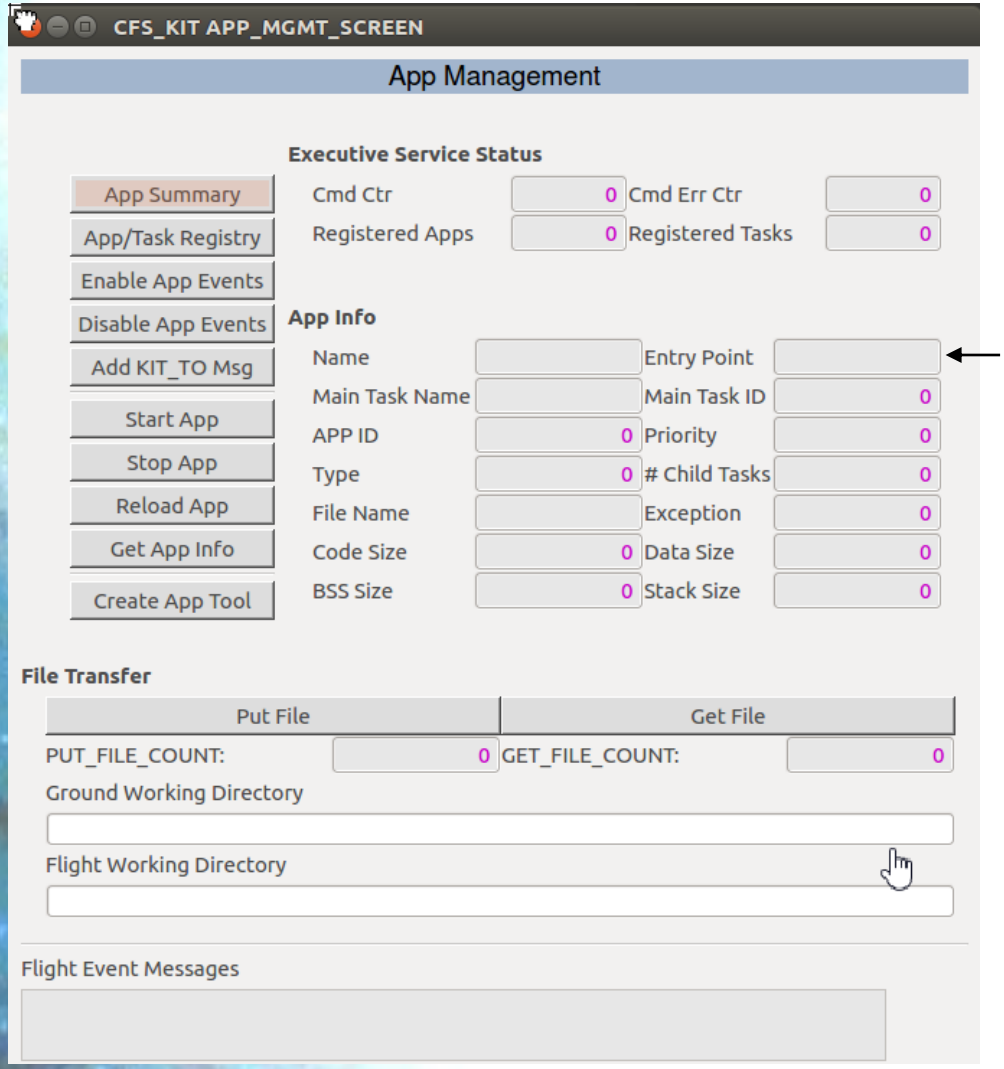
Recorder Management



Autonomy Management



Application Management



- *<Get App Info>* commands cFE executive services to send a telemetry packet with the command-specified app

- *<App/Task Registry>* commands cFE executive services to write app or task information to a file that can be transferred to ground via a *<Get File>*

COSMOS
Extras

COSMOS

Architecture and Context Diagram