GPM Mission's Best Practices: PERP

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Similar to other missions, the Global Precipitation Measurement (GPM) Core Observatory's Command and Data Handling (C&DH) subsystem is critical for operations of the spacecraft. The onboard C&DH system comprises of two fully redundant boxes - a primary and a cold backup. Within each box, amongst other components, is a Single Board Computer (SBC) that hosts the flight software (FSW) system. In the event of an SBC reset, the Flight Operations Team (FOT) is poised with a lengthy task of restoring the SBC to nominal configuration. Due to the complexity of the C&DH system, this may take many days at a time to complete. The spacecraft's FSW applications are located in Electronically Erasable Programmable Read-Only Memory (EEPROM) and are copied into Random Access Memory (RAM) upon SBC initialization/reset. Each SBC has two banks of EEPROM, with each bank containing a copy of the FSW. Since launch, there have been many configuration changes to tables and applications that have been loaded into just RAM. Unfortunately, these changes are vulnerable to being wiped during a SBC initialization/reset, when the RAM is overwritten by the EEPROM. Although the EEPROM loads the default FSW configurations, the process to command non-default individual table and application changes is very cumbersome and time consuming. This consequentially increases the time until the spacecraft is back into nominal Mission Science Mode (MSM) drastically. The GPM Power-On Reset (POR) Expedited Recovery Process (PERP) Design introduces a method of consolidating commands into a single file load which the SBC can process independently of the ground – decreasing recovery time, the level of TDRS support reliance, and human error. This tested design can be implemented across many other missions that utilize a similar core Flight Executive (cFE) platform; hence providing an easy-to-follow, safe, and efficient process that can be applied across the board.

I. Introduction

DATA loss is common amongst any computer reset. On-board spacecraft, such resets can carry greater risk potential as problems must be handled remotely, unlike having a hands-on approach like when dealing with a ground-based system. To mitigate such a risk, spacecraft C&DH systems house several redundant backups of important files. As the life of a mission carries out, files are updated to reflect operations changes. Some changes include updates to filter tables, relative time sequences, and even instrument-related configurations. Loading these changes to the EEPROM of the spacecraft would be the most efficient way to recover after a reset, but this process has associated risks which has restrained it from gaining approval during GPM's prime mission. For that reason, the PERP has been designed to mitigate certain risks, and ease the process of recovery after a reset/POR. Before delving into the process, it is beneficial to understand a few of the hardware and software components associated with a POR specific to GPM.

A. Hardware

All The C&DH components relevant to the PERP are the SBC, the EEPROM, and the SRAM. The SBC is a BAE Systems RAD750 Single Board Computer that hosts the GPM FSW, EEPROM, Static RAM (SRAM), and several other components. Each SBC contains two banks of EEPROM. The EEPROM File System (EEFS) is used to manage EEPROM and contains cFE startup scripts, uncompressed cFE object files, default FSW binary table files, compressed application object files, and libraries for all GPM FSW applications. The local memory SRAM is where all of the applications and tables reside, and where they are updated [1].

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B. Software

To better understand how the processor reset unfolds, a relevant description of the GPM FSW architecture resident in the SRAM is provided here. The primary software components of the FSW are the Operating System Abstraction Layer (OSAL), the cFE, and the Core Flight System (CFS) applications. The upper and lower layers are GPM-specific and are inherited from the Lunar Reconnaissance Orbiter (LRO) mission. The lower layers include the Real-Time Operating System (RTOS) VxWorks, the Boot Programmable Read-Only Memory (PROM), and the Board Support Package (BSP). These components were developed by BAE Systems specifically for LRO and were reused for GPM. Figure 1, taken from Ref. [1], depicts these FSW layers.
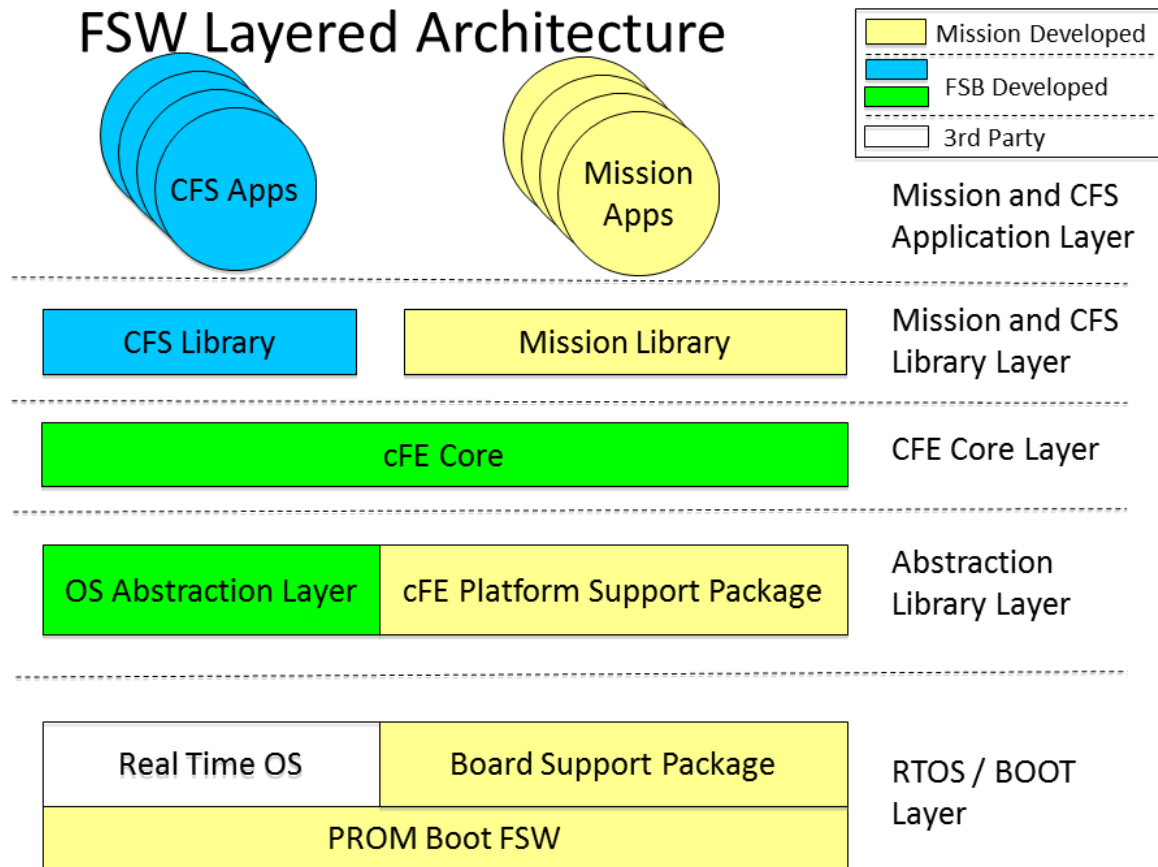

Fig. 1 FSW Layered Architecture

The OSAL and the Platform Support Package (PSP) together define a standardized FSW library interface that hosts the cFE. The cFE is an open source, portable, platform independent embedded system framework developed by National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) for the FSW of satellite data systems and instruments. It defines a set of mission independent, re-usable, core flight software services and operating environment. It also defines the platform and mission configuration parameters that are used to tailor how the cFE is built for a mission[†].

C. Power On vs. Processor Reset

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† https://sourceforge.net/projecs/coreflightexec/

The boot sequence of the SBC is initialized from two types of resets: power-on reset, and processor reset. The VxWorks OS indicates to the Start-Up ROM (SUROM) the type of reset and then boots accordingly. Table I below depicts the two reset types and the ways these resets may be initialized.

Table I. cFE Reset Types

Reset Type	Reset Subtype	Cause
Power On	Power cycle	Power having been removed and restored
	Command	cFE processing a reset command
	HW debug	Debug debug mode connection
	Bank switch	Reset reverted to a cFE power on due to a bank switch
	Undefined	Unknown reset type
Processor	HW watchdog	Watchdog timer expiring
	Exception	Processor exception
	Command	cFE processing a reset command

As mentioned above, a processor reset occurs by sending the ES Reset command, or autonomously via SBC's watchdog when it times out. This then boots the VxWorks OS from RAM and preserves the CDSs, logs, the file system on the DSB, Spacecraft Data Recorder (SDR) data, and several other critical tables and statuses. Hardware is not power cycled and hence some operational states are preserved.

A power-on reset on the other hand occurs by powering on the SBC, issuing an SCOM 'SBC RESET' hardware command, or autonomously via the S-COMM's Fault Detection Recovery (FDR) Field-Programmable Gate Array (FPGA). This forces the VxWorks OS to boot from EEPROM and clears the RAM Disk, Critical Data Stores (CDSs), Data Storage Board (DSB) and all of the logs.

D. Traditional Method

Prior to the PERP, had a reset occurred on board, the Flight Operations Team (FOT) would have been tasked with individually loading all non-default configurations. This would involve identifying the differences between the default EEPROM loaded files and the files that were loaded onto RAM, which were not in EEPROM. This in itself would take time to consolidate. Each file/table would take time to uplink, validate, and then activate. Concurrently, the Mission Planning engineers and FOT would have to schedule as many contacts with communications services as possible. Using this method, consecutive supports are key to returning the spacecraft to Mission Science Mode (MSM) in a timely manner and preventing data loss. The operations team would also go into 24x7 staffing until the health and safety of the spacecraft is confirmed, MSM is active, and science data is being downlinked without issue. This process can become costly for the customer due to premium shift charges that would be in place for all FOT members. Additionally, this process allows for there to be a greater possibility of operator error. Manually sending many commands in a short time period can make room for potential typos, out-of-order commands, etc.

II. PERP

The crux of the PERP design revolves around the main PERP load and the two key factors that allow for this load to execute. The PERP load is a single file containing a set of commands that dictate the loading and install of each individual element that is beyond default configuration of the EEPROM. Loading the EEPROM with out-of-configuration tables has a not been approved due to risk during prime mission, hence why it has not been approached as a solution by the FOT. The premise of the PERP is to reduce the amount of back and forth between the ground the spacecraft and let the spacecraft computer load and install the changes needed to be made, while the FOT monitors the health and safety at the ready. The two unique components and reasons GPM can facilitate this method are the Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol [CFDP] and the File Commanding (FC) application.

A. CFDP

GPM employs CFDP to transfer files to and from the spacecraft. This is the first key aspect to a reliable uplink of the PERP load, and any supplementary file, table, etc. With regards with the FSW mentioned above, CFDP is designed to interface with the cFE as a flight application. This flight application provides two modes for file transport: class 1 and class 2. Class 1 transfers are a one-way transfer with no feedback to the sender. This can be understood as a less reliable "send and forget" transfer. A class 2 uplink, on the other hand, is more reliable as the receiver sends an acknowledgement to the sender that the file has been received. Only then does the sender delete the file if configured. On-board GPM, this automates memory management of the recorder, and is the default transfer mode for all file downloads. Figure 2, tweaked from Ref. [2] to illustrate an uplink from the ground, depicts this process while displaying what happens when a file is interrupted during a transfer. The process is as follows: the sender sends file metadata, the file-data, and the end-of-file. The receiver then sends an acknowledgement of the end-of-file, and a finish. The sender then acknowledges the finish. If a part of the file data is interrupted, the receiver then sends a "Nak." The sender then sees the Nak and retransmits the interrupted file data until a successful finish is received from the receiver. In this manner, when the PERP load is sent to the spacecraft, the FOT can verify successful transfer and acceptance of the file by the spacecraft.
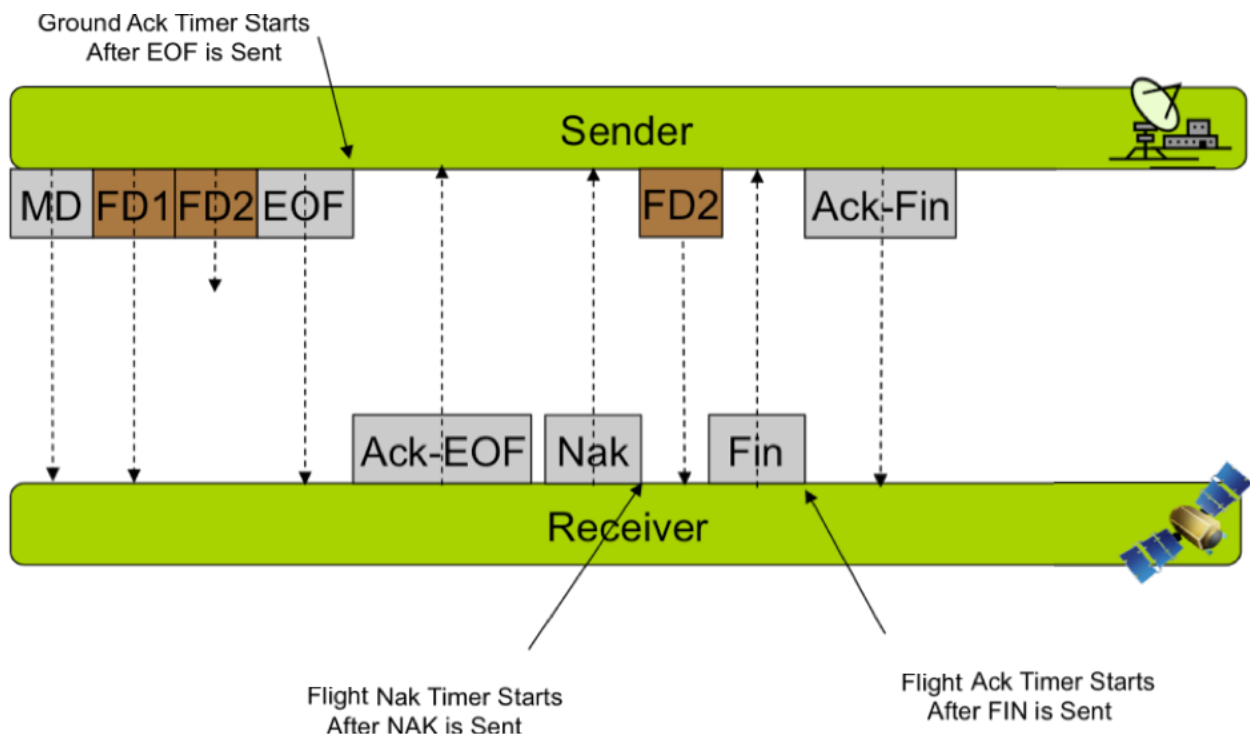

Fig. 2 CFDP Class 2 Protocol Messages – Missing Data

B. File Commanding

The FC application is the root application that grants the PERP load its ability to execute on-board. This application also interfaces with the cFE environment. This particular application processes ground uplinked binary files, reads command packets, and then routes commands to the appropriate receiver application. It processes no more than five commands per second and no less than one command per minute. The FC application uniquely allows for long commands that would otherwise not be accepted by the ground system, moreover it allows for these commands to be placed in an unlimited queue and optionally spaced out with specified delay parameters [3].

C. PERP Load

In building a PERP load, the following steps are followed:
1) Identify the required loads and the order in which they need to repopulate the RAM.
2) Build a procedure that performs the RAM reloading based on the outcome of Step 1.
3) Bring up the GPM simulator and run the procedure from Step 2 to completion.

4) Using the ground system event log file as an argument, capture the commands that were sent to the simulator and compile them.
5) Create an FC file from the output of Step 4 using the FC load builder scripts already utilized by the Dual-Precipitation Radar (DPR) and Global Positioning System (GPS) on-board.
6) Compress the FC file.

As indicated above, the PERP load itself is a binary FC file. Once in contact with either the Space Network (SN) or the Swedish Space Corporation (SSC) the FOT uplinks the load to the spacecraft using the ground system. The ground then sends the "File Commanding" command. Next, the FC application verifies the file and sends CCSDS command packets read from the file on the Software Bus at the specified command rate. These packets are then distributed at the end of a trigger pipe and processed on the appropriate bus [4].

D. Power-On Reset Expedited Recovery Process

A power-on reset begins the PERP. The spacecraft will then process through Launch Mode, to Rate Null Mode, and then to Sun-Point Mode (SPM). Once the health and safety of the spacecraft, telemetry, and commanding have been verified, the FOT will configure the spacecraft to the appropriate data rates and uplink the compressed FC PERP load file. The start of the PERP load will then be commanded from the ground system to uplink all the changes to RAM. If there are any additional changes that have not been included in the latest PERP load, they will have to be identified and uplinked individually. Once the load executes on-board, the FOT will then command the spacecraft from SPM to MSM following nominal procedure.

III. Results

The PERP load reduces the overall work-breakdown structure (WBS) from several days at around-the-clock operations to approximately one day for about 12 hours. To begin with, building the load can be done under an hour if the GPM simulator is active in MSM. Secondly, it reduces the number files to be uplinked from greater than 40 to one single recovery file. The file is can also be verified through the CRC and file-size checks that validate loading and execution success. This single file uplink also reduces the complexity of uplinking files in order, planning the timing of the uplink with SN or SSC passes, and the human error associated. The uplink can also occur during two consecutive low-rate passes and takes about half an hour. The file playback itself only takes about an hour and a half versus the many hours taken for individual file transfer.

Table II. WBS Comparison in hours

Activity	Traditional Estimate	PERP Estimate
Initial anomaly assessment	2	2
Scheduling of supports	8	2
Planning of RAM reload	3	1
CAM to reload RAM	3	1
Execution of RAM reload	40	2
FOT support required	720	72
Post-anomaly support	4	4
Total	**780**	**84**

Table II adopted from Ref. [4] depicts the estimated hours it would take for the recovery process to occur for both the traditional method and PERP. These are both estimates as a reset has not occurred on-board the GPM satellite, and hopefully will not occur. In this case this does happen, the hours are assessed as such: The initial anomaly assessment will take about the same time period as this portion is outside of either recovery process. The time taken for the scheduling of supports is drastically reduced as not as many supports need to scheduled. Scheduling supports requires back and forth communication with the support services being utilized and a "GO" to utilize the supports requested as there are many users who require support time. Traditionally, the planning of the load would take about three hours to identify the changes to the tables and configurations in RAM. With a PERP load ready, this would only require time to verify the load is up-to-date and to decide whether to generate a new load or individually load the remaining configuration changes. Subsequently, with less commands to undergo approval, the Command Authorization Meeting (CAM) would also be shortened. Then when finally loading the RAM, the process can be done in only two hours – half an hour to uplink, and an hour and a half to reload the RAM. Staffing for this process would at the least require

three real-time operations engineers, one mission planner, one guidance, navigation, and control (GNC) engineer, and one flight dynamics engineer. Finally, once the spacecraft is back in MSM, the FOT would monitor for about another four hours and to analyze the performance of the various subsystems. The difference between the two hourly estimates is about a factor of 9. Though this is a high-level estimate, it can be concluded that when considering the above activities, the PERP method can save a lot of time and reduce science data loss [4].

IV. Conclusion and Future Considerations

Any computer on-board a spacecraft is susceptible to a reset. Though the initialization types may vary, it is sound practice to have a plan in place to recover from such an anomaly in a prompt manner. Because of the way GPM's FSW has been designed, its usage of CFDP and the File Commanding application facilitate a loading of commands, the PERP load, on-board that allow the recovery to be expedited by a factor of about nine. Testing on GPM's simulator has shown that the method is safe, the timing is efficient, and is easy-to-follow for the most novice of FOT members. For those missions that have the flexibility to do so, GPM's FOT highly recommends a similar plan of action that reduces mission risk, saves time, and navigates back to the focus of the mission; just like one of GPM mission's best practices – the PERP design.

As of 2018, GPM's prime mission objectives have been met. Because of this, there are current considerations of loading the EEPROM with updated configurations. Doing so would then reduce the size of the PERP load as the spacecraft would then have the updated tables, time sequences, and other FSW changes from launch to 2018. When the RAM then reloads from the EEPROM after the initialization, it will require even less from the PERP load and may even speed up the recovery time by a greater factor. This process is currently undergoing development and testing, which are proceeding successfully. The FOT is optimistic about the success of this next step, as it will definitely aid in the recovery process were a power-on reset ever to occur on-board.

V. References

[1] McComas, D., Strege, S., Judy, S., McGraw, R.J., Smith, G. M., "GPM Project Core Spacecraft Flight Software Operations User's Guide," NASA GSFC Baseline Release per GPM-SCoRe-2356, Greenbelt, MD, 2014.
[2] McGraw, R., "Global Precipitation Measurement (GPM) CCSDS File Delivery Protocol (CFDP) Users Guide," NASA GSFC Rev 4.0, 2014.
[3] "GPM File Commanding (FC) User's Guide," NASA GSFC Rev 1.6, Greenbelt, MD, 2013.
[4] Gensel, J. M., "GPM POR Recovery Expedited Design," KBRwyle, Greenbelt, MD, 2016 (unpublished powerpoint presentation).