Porting the core Flight System to the Dellingr Cubesat

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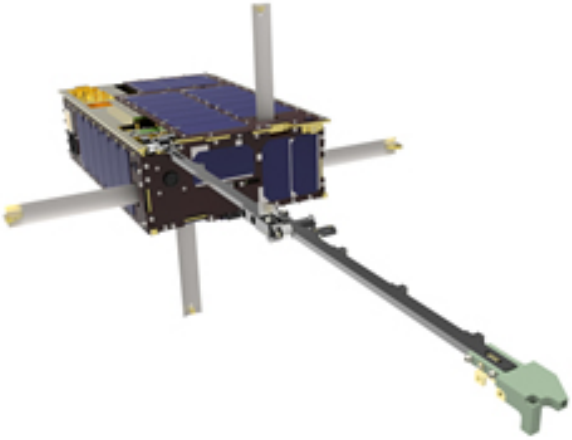


Background

- Dellingr is a Heliophysics 6U Cubesat developed at GSFC
  - “Dellingr” is named after the mythological Norse god of the dawn
- Originally planned as a one year ”skunkworks” effort
  - 1 person/year (1 FTE) for all flight software (FSW) including the Attitude Control System (ACS)
  - Selected Gomsapce Nanomind A712 platform for a 32 bit CPU with minimal power consumption
- After preliminary design review, I volunteered to port the cFS (OSAL/PSP) to the platform
  - After cFS port to a development board, project decided to use the cFS
- Revised plan
  - Original developer continued to work on the ACS
  - I worked on the cFS implementation and created mission app templates
  - Others worked on integrating device code, developing mission specific apps, and developing ground software

Dellingr Cubesat Hardware Overview (1)

DAGR:
Science
Magnetometers
(Internal and Boom Mounted)

Power:
Clyde Space EPS and Batteries

CPU:
Gomspace Nanomind A712d ARM processor

INMS:
Ion Neutral Mass Spectrometer

Experiments:
Thermal Louvre Deployment Camera

Comm:
L3 CADET Radio
3 Mbits down/9600 up
4 Gbytes packet Storage
(antenna by home depot)

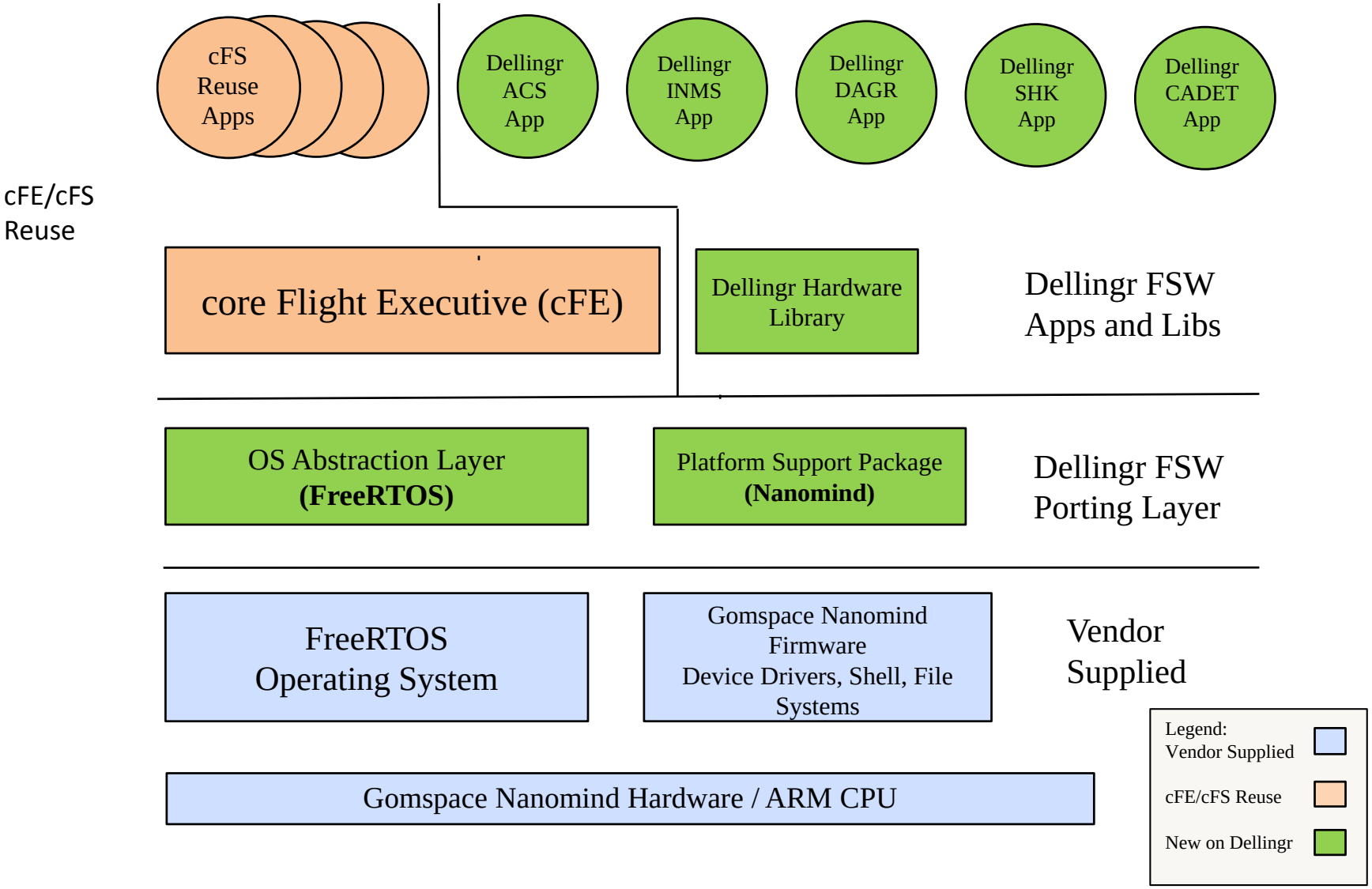
ACS:
Gyro, Fine Sun Sensors, Coarse Sun Sensors, GPS, Magnetometers, Reaction Wheels

Dellingr Facts:
- 6U Cubesat
- Delivered to ISS August 2017
- Deployed from Nanoracks Deployer On November 20, 2017

Dellingr Cubesat Hardware Overview (2)

- Processor Card - Gomspace Nanomind A712d
  - Atmel ARM7 CPU @ 40Mhz
  - 2 Megabytes SRAM
  - 2 x 4MB Flash Memory
  - Micro SD card
  - I2C, SPI, UARTs
  - Real Time Clock
  - Magnetometer, PWM, Analog Inputs

Dellingr Cubesat Flight Software Overview (1)

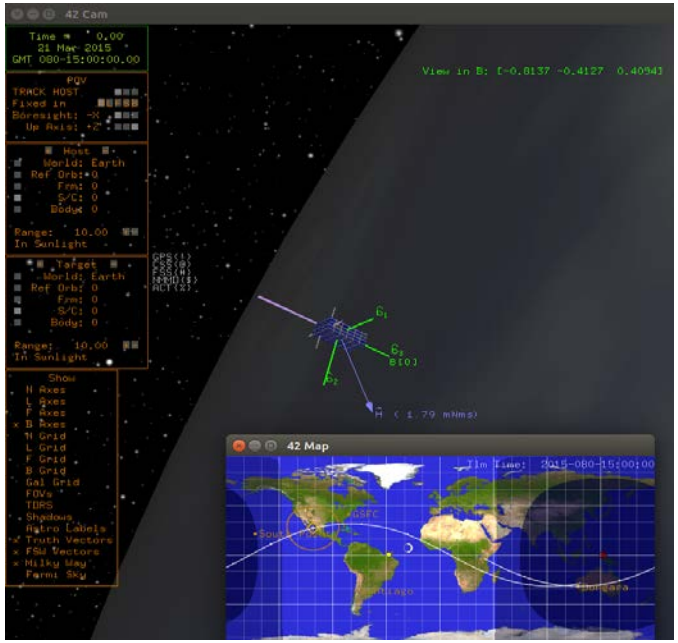


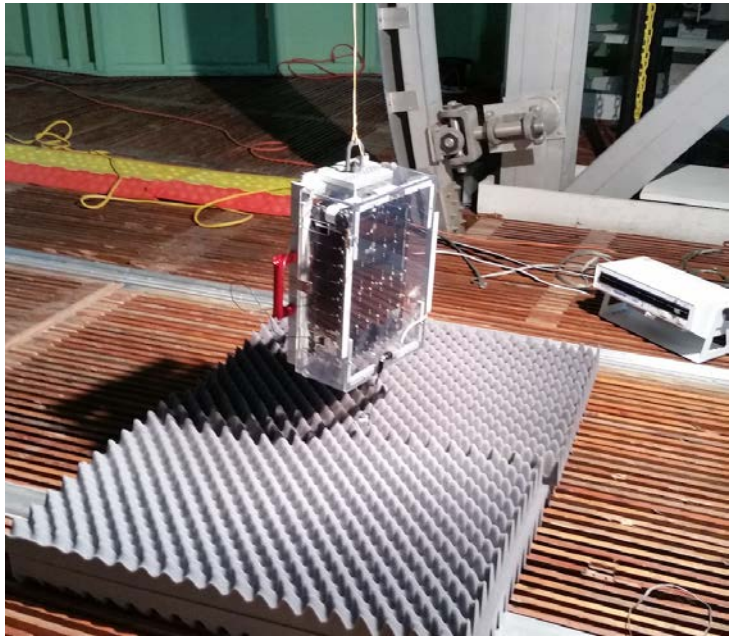
Dellingr Cubesat Flight Software Overview (2)

Vendor Software	**Reuse Software**	**New Software**
FreeRTOS OS	cFE Core	FreeRTOS OSAL Layer
Bootstrap/Startup Code	cFS Scheduler	cFE Platform Support Package
Device Drivers	cFS Stored Commands	Dellingr Hardware Library
File Systems	cFS Health and Safety	DAGR Instrument App
C Library	cFS Checksum	INMS Instrument App
	cFS Limit Checker	CADET Radio App
	cFS File Manager	ACS App
	cFS Memory Dwell	Ephemeris/GPS App
	cFS Memory Manager	Reaction Wheel App
	Static Loader (MMS)	File Downlink App
		File Downlink App
		Spacecraft Housekeeping App

Simulation on a Budget (1)

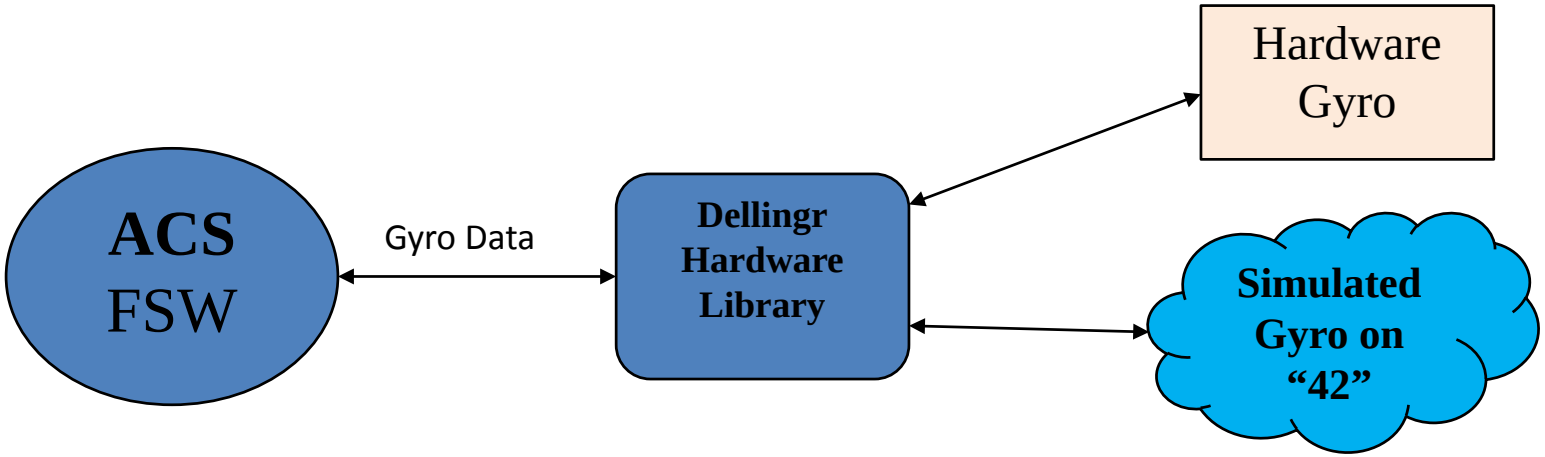
- **Dellingr did not have dedicated dynamic simulator such as the Goddard Dynamic Simulator (GDS) for ACS testing**
- **Simulation is accomplished with a combination of:**
  - **The open source dynamic simulator ”42” developed by GSFC Code 591**
  - **The “Dellingr Hardware Library” with an interface to the ”42” simulator**
- **Most of the ACS app debugging was done on cFS/Linux with 42**
- **When the Satellite was complete, we were able to do a spin test using the reaction wheels and sun sensors**





Simulation on a Budget (2)

- **Dellingr Hardware Library Details**
  - A cFS Library that abstracts all mission specific hardware
    - Focus is on the ACS Hardware
  - Allows FSW to run in the following configurations:
    - On-board computer with real hardware devices
    - On-board computer talking to 42 Simulator over a serial port
    - Linux computer talking to 42 Simulator over TCP/IP Socket
  - The ability to run the Dellingr Flight Software on Linux with the 42 speeds up ACS development and test
  - This model worked well and will be used for future efforts



Flight Software Challenges (1)

- **New Operating System: FreeRTOS**
  - Required a port of the Operating System Abstraction Layer (OSAL)
  - Once the OSAL was working, the most of the cFS just worked
- **On-board computer only has 2 Megabytes of RAM**
  - The cFS code has to run in Flash, since 2 Megabytes of RAM is not enough
  - Some cFS applications had to be left out to save room (CFDP file transfer, Housekeeping)
- **Flash file system is limited**
  - Only holds 64 files, not enough for all of the mission stored command sequences
  - Workaround is to “bundle” multiple stored command sequences into a single file
  - This is a generic solution that could be used on other missions
- **Cadet Radio Subsystem**
  - Half Duplex, not ideal for real time telemetry and commands
  - Very low data rate between on-board computer and radio/recorder limits amount of data spacecraft can produce at one time

Flight Software Challenges (2)

- **Limited Schedule and Budget**
  - The traditional FSW development lifecycle does not work here
  - Framework of the cFE/cFS provided a model to follow for new software, saving us from re-inventing the wheel
- **No ETU or Flat-Sat**
  - There is only one copy of the satellite hardware, and it was not always available for FSW development
  - FSW changes had accumulated right before Thermal Vacuum testing leading to last minute integration bugs and troubleshooting
- **Significant time spent working with device drivers and interfaces**
  - A Typical large mission has a limited set of known interfaces (1553/Spacewire, Serial)
  - Dellingr uses Serial, I2C, SPI, Analog, GPIO, and I2C extended interfaces
  - Multiple problems encountered with I2C and SPI interfaces that just needed more troubleshooting time and effort
  - Engineers end up being multi-discipline (FSW, Hardware, Mechanical, I&T)

Port Details: OS Abstraction Layer

- **Kernel**
  - Basic FreeRTOS port was fairly straightforward
    - All of the OS primitives are present
  - FreeRTOS has a configurable set of priorities (used 256)
  - Using FreeRTOS 8.x
- **File Systems**
  - FreeRTOS does not include a File System
  - Gomspace integrated firmware that included:
    - The “fatfs” open source Filesystem
    - UFFS filesystem for the flash memory
    - A POSIX API Virtual Filesystem Layer (VFS)
- **Network interfaces**
  - FreeRTOS does not include a network stack in the base kernel, but this was not needed for Dellingr
  - The Gomspace Cubesat Space Protocol (CSP) was used to transfer files to the flash over the serial port
- **Dynamic Loader**
  - Used a combination of MMS Static Loader and linking apps directly with the cFE Core and base OS image
  - Most mission apps were loaded from the file system

Port Details: Platform Support Package

- **PSP / Startup code**
  - Wanted to leverage the Gomspace Nanomind firmware
    - Modifications made to facilitate cFS port
    - The original Gomspace Shell was used for a diagnostics console
  - With only 2MB of RAM, the cFE/cFS code had to run in Flash
    - Only selected mission apps could be dynamically loaded to RAM
- **1HZ Time Source**
  - There was no 1hz time source for this system (GPS is not always powered)
  - The FreeRTOS 1000hz timer tick is used as the 1hz source
- **File Systems, Volume Table**
  - The /ram and /boot file systems are directly mapped to the OSAL
  - No path translation is needed
- **Restart Code**
  - Ties to the Gompace firmware reset function
- **Watchdog**
  - Uses the CPU watchdog feature
- **Flash/Nonvolatile access**
  - Due to time and schedule, the flash is readable via memory map for checksum, but not writeable outside of the file system

Lessons Learned (1)

- **Positive cFS Lessons:**
  - The cFS brought a development environment, FSW framework, and process to the project
    - Work could be broken up in to modules or cFS apps for developers to focus on
    - The modularity of an app helped isolate the code
  - The cFS allows you to focus on mission specific code and start to work on that immediately
  - The cFE and cFS functionality added a lot to the mission with little effort
    - FDC, stored commands, Limit Checker, Table Services, saved a lot of time in re-inventing software
  - The cFS cross platform capability allows us to develop and run on desktop Linux, Raspberry Pi, and other targets
    - Very useful for getting high level application logic working
- **Negative cFS Lessons:**
  - The cFS was a poor fit for Gomspace Nanomind processor
  - Experience was used to work around limitations of the platform – This was not a recommended port for cFS beginners
  - cFS experience helped with the selection and configuration of apps – Learning the cFS is beneficial before trying to develop a system

Lessons Learned (2)

- The 42 Simulator interface to the cFS enabled ACS development and debug
  - ACS algorithm checkout would have been very hard without it
- Not having a Flat Sat or second copy of the hardware was difficult
  - Having the cFS and simulation capability from day 1 would ease this problem, but not eliminate it
- Hardware devices were hard to work with, and hardware/software integration was time consuming
  - This was unavoidable no matter what the framework
  - I2C , SPI, UART interfaces are all “Finicky”
  - Used Standalone diagnostic code and even Arduino to test out devices
  - It was often easy to get a device working with a test program by itself but harder when in a multitasking environment with multiple devices operating

Conclusion

- Was the cFS the right choice for the Dellingr Cubesat?
  - Yes : There were compromises, but valuable lessons were learned that can immediately be applied to the next generation of Cubesats
  - We were able to leverage cFS experience and expertise to make up for shortcomings
- What would we do differently if starting over today?
  - If using the cFS, influence the hardware selection to take advantage of an existing port, or at least an easier port
  - Start defining mission specific applications and building a version of the FSW that runs on Linux or similar desktop board
  - Simulate hardware interfaces and integrate 42 simulator from early in the development
  - Consider the ground system earlier

Mission Status

- Dellingr was deployed from the International Space Station (ISS) on November 20, 2017