Flight Software Overview
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Solar Probe Plus
A NASA Mission to Touch the Sun
Overarching Science Objective

- To determine the structure and dynamics of the Sun’s coronal magnetic field, understand how the solar corona and wind are heated and accelerated, and determine what mechanisms accelerate and transport energetic particles.
Observatory: Anti-Ram Facing View
Observatory: Ram Facing View
High Level Concept of Operations

Primary Science (~11 days)  
Bisection 
Cruise/Downlink (~158-77 days)

Perihelion  
35Rs – 9.5Rs

Aphelion  
1.02AU – 0.73AU  
(45° slew 1.02AU to 0.82AU)

Solar Array Position
APL Developed Single Board Computer (x3):

- UT699E LEON3FT (Sparc V8 architecture) 80MHz from Cobham Colorado Springs
- 32 MB SRAM with EDAC
- 8 MB of MRAM (Non-Volatile Memory) 6.4 MB usable
  - 3.2 MB per logical bank
- FPGA facilitates NVM image verification during boot
- Boot loader executes out of NVM
- 256Gbits (32GBytes) NAND Flash Bulk Memory (SSR) on processor board
  - Memory mapped I/O
- SBC interfaces
  - UARTs to Avionics Redundancy Controller (ARC)
  - SpaceWire to spacecraft and instrument subsystems as well as other single board computers

FSW Design
Hardware Environment

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Flight Software Driving Requirements (1 of 2)

- Manage software operations on three processors
- Uplink command data files using CFDP
  - Provide additional uplink in BD mode
- Management of files on the SSR (256Gbit)
- Allow for reset in sufficient time for Solar Array Safing
- Retention of critical spacecraft information through processor resets
- Communicate to spacecraft elements external to computer
  - SpaceWire transactions
- Boot time
Flight Software Driving Requirements (2 of 2)

- Operate a 3-axis stabilized spacecraft
- Uplink data range of 7.125bps to 2Kbps
- Downlink frames at rates from 10bps up to 1Mbps
- Downlink recorded data files using CFDP
- Distribution of time and status
- Manage spacecraft time tagged commands
- Collect instrument data
- Manage spacecraft subsystem commands and collect spacecraft housekeeping data
- Record and downlink spacecraft housekeeping and instrument data
- Support fault protection & limited autonomous instrument safing
FSW Design
FSW Functionality (1 of 2)

- **Boot**
  - Simple boot loader; no commanding/telemetry

- **Command and Data Handling (C&DH)**
  - Command management
    - Uplink: receive transfer frames from transponder
    - Commands: real-time, macros, time tags, autonomy
    - Packets extracted and distributed locally or to a S/C subsystem
  - Telemetry
    - Receive telemetry from subsystems/individual applications
  - SSR management
    - Record/playback spacecraft and instrument data to/from a file system
FSW Design
FSW Functionality (2 of 2)

- **Command and Data Handling (C&DH) (Continued)**
  - Autonomy
    - Autonomous fault detection and safing/switchover on Prime
  - Software management
    - Memory object loading, CPU utilization, etc.

- **Guidance and Control (G&C)**
  - G&C sensor interface management, Three-axis control, momentum maintenance
  - Cruise phase & thruster control, 50 Hz attitude control, 1 Hz attitude estimation
FSW Design
Software on Three Processors

- Prime, Hot Spare, Backup Spare are all running the same software
  - Applications are controlled by Scheduler messages
    - Messages drive degree of application functionality
  - Some applications have knowledge of SBC logical state
  - Reduce power consumption and processor loading

- Prime sends Hot Spare (and Backup Spare during encounter) a status message at 1 Hz
  - Data includes:
    - Current spacecraft configuration
    - Raw star tracker data
    - Current time data
    - Current accumulated SA flap & feather and HGA step counts
    - Current spacecraft FM mode(s)
    - Safe Mode – Solar Array entry time
  - G&C code on spare will verify raw star tracker data

- Hot Spare promoted to Prime on Prime demotion
  - G&C primed via previously received message
  - Scheduler sends full compliment of messages to applications
FSW Design
FSW Context Diagram (Prime)

Spacecraft Interface Card (2)
Transponder (2)
WISPR DPU
WISPR

Avionics Redundancy Controller
Solid State Recorder (256 Gbit)

Flight Software

Thruster and Actuator Card (2)

RIU (2)
Thrusters
Star Tracker (2)
SES (2)
Reaction Wheels (4)

Pump Ctrl (2) PSE (2) PDU (2) S/C Test IMU (2) ECU (2) FIELDS SWEAP ISIS

Commands/Telemetry/Time
Application Selection
File Data

Commands/Telemetry
Commands/Telemetry
Commands/Telemetry

Timers Interrupts Etc.
Commands/Telemetry/ G&C Msg
Commands/Telemetry G&C Msg

Prime SBC
Hot Spare SBC
Backup Spare SBC

Key
Instruments
G&C
S/C Interfaces

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2015 Workshop on Spacecraft Flight Software
JHU/APL Flight Software

- **1990s/Early 2000s**
  - NEAR/ACE/TIMED
    - Even now, some of our code dates back this era

- **2000s**
  - MESSENGER/New Horizons/STEREO
    - Modify Last Mission
2000s

- Can we make the code more modular?
  - IRAD to make that happen

- Radiation Belt Storm Probes
  - Fleshed out many capabilities of using NASA/GSFC Core Flight Executive (cFE)
  - Collaboration with NASA/MSFC

- Radiation Belt Storm Probes (Van Allen Probes)
  - First full mission adaptation of cFE
  - Evolved into Core FSW

- Solar Probe Plus
  - First reuse of Core FSW on major mission
FSW Design
Software Layers (1 of 4)

- **Operating System**
  - Real-Time Executive for Multiprocessor Systems (RTEMS) with support from OAR Corporation
  - Build tools and RTEMS distribution from Cobham Gaisler
- **Operation System Abstraction Layer (OSAL)**
  - Provided by NASA/GSFC
  - Enables easy porting of applications that ran over VxWorks on the Van Allen Probes
NASA GSFC Core Flight Executive (cFE) middleware

- Provided by NASA/GSFC
- Enables common flight executive functions
- Well documented application programmer interface (API)
- Project-independent configuration management
- Applications are modular, independent, and decoupled

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<thead>
<tr>
<th>Core Flight Executive (cFE)</th>
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<tr>
<td>Operating System Abstraction Layer (OSAL)</td>
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<tr>
<td>RTEMS Real-Time Operating System</td>
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### Mission FSW Applications and Libraries

- Significant reuse from Van Allen Probes
- New development
  - Includes SpaceWire/CFDP Uplink/Flash file system

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**FSW Design**

**Software Layers (4 of 4)**

- **Scheduler**
- **Memory Manager**
- **Command Manager**
- **Time Tags**
- **Playback**
- **ITF Manager**
- **External SBC**
- **H/K Monitor**
- **File Ingest**
- **CFDP**
- **Memory Objects**
- **Command Ingest**
- **Autonomy**
- **Record**
- **Telemetry Output**
- **File Manager**
- **G&C**
- **S/C Interfaces**
- **CPU**
- **SPP**

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**Core Flight Executive (cFE)**

**Operating System Abstraction Layer (OSAL)**

**RTEMS Real-Time Operating System**

- High Reuse From Van Allen Probes
- Low Reuse From Van Allen Probes
- New for SPP
Software Running on Three Processors

- Amount of operation depends upon functionality
- Minimal operation is only receiving commands and producing telemetry

FSW Design
Functionality Across Processors

Core Flight Executive (cFE)
Operating System Abstraction Layer (OSAL)
RTEMS Real-Time Operating System

Full Operation
Reduced Operation
Minimal Operation
Questions?