Magnetospheric MultiScale (MSS) System Manager

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Agenda

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  – Database

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  – System Manager Approach
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THE MISSION
Science of Magnetic Reconnection

- Study magnetic reconnection in the Earth's magnetosphere
- Magnetic reconnection converts magnetic energy into kinetic energy
  - Oppositely directed parallel field lines are pinched
  - They join and snap apart like a breaking rubber band

- Benefit: understanding of how the Earth lives with the Sun (e.g. Class X Flash 0156 GMT Tuesday, Feb. 15, 2011)
  - Power grid problems
  - Communications disruption
  - Aurora formation

Credit: European Space Agency
Spacecraft Description

The 4 MMS Spacecraft are

- Equipped with the standard ‘particles and fields’ instrument suit (7 types of instruments – multiple copies per spacecraft)
- Equipped with 8 science booms
  - 2 Axial (E-field)
  - 4 Wire (E-field) & 2 Magnetometer Radial
- Spin-stabilized at 3.0 rpm with spin-axis nearly parallel to ecliptic north
- Onboard controllers process GN&C sensor data & fire thrusters to achieve accurate ΔV while keeping the booms safe
  - Digital Sun Sensor & Star Camera
  - Accelerometer
  - Navigator GPS receiver with GEONS navigation s/w
- Equipped with 12 thrusters
  - 4 Axial 1-lbf (yellow)
  - 8 Radial 4-lbf (red)
Flight Dynamics Concept

Use the formation as a ‘science instrument’ to study the magnetosphere.

Need to prevent close approaches (<4 km).

Magnetic Field Lines

Night-side science (neutral sheet) bound by power (limits shadow duration).

Maneuvers used to maintain formation against relative drift.

Formation scale matches science scale.

Sun

March 25-27, 2014  GSAW Conference
MMS Mission Summary
(approximately 2.5 years in duration)

Phase 0
- No science
- Allowed Phase 1a start range
- No shadow > 1 hrs during first 2 weeks after launch

Phase 1a
- Perigee Raise: 1.04 Re → 1.2±0.1 Re
- 120-day commissioning
- Phase 1a start range

Phase 1b
- GSE Latitude: [-20°, 20°] when Apogee GSE time [14:00-10:00]
- Neutral Sheet Dwell
- Time >= 100 hrs
- No formation science

Phase 1x
- GSE Latitude: [-25°, 25°] when Apogee GSE time [14:00-10:00]
- No formation science

Phase 2a
- Apogee Raise: 12 Re → 25 Re
- No formation science

Phase 2b
- Neutral Sheet Dwell
- Time >= 100 hrs
- 180 days

Phase 0
- GSE Latitude: [-20°, 20°]
- 120 days

Phase 1a
- GSE Latitude: [-20°, 20°]
- 120 days

Phase 1b
- GSE Latitude: [-25°, 25°]
- 120 days
Phase-1 Orbit in the Life
with Formation Maintenance Maneuvers

Science Region of Interest (ROI)
(9 – 12 Re)

FM Maneuver #2

DSN: 4 @ 80 minutes each
- Wed and Saturday for maneuvers only
- Uplink CIDP BM commands
- Downlink C&DH and CIDP Recorders
- Uplink ATS loads (as needed)

Apogee

FM 2 Planning

Perigee

Phase 1: ~ 1 day orbit period
FM maneuvers ~ every 2 weeks

TDRS or NEN: 4 @ 15 mins each
(TDRS Prime, NEN Backup)
- Downlink GEONS data
- Downlink BM Metadata
- Uplink CIDP BM commands
- Uplink ATS Loads (as needed)

FM Maneuver #1

DSN: 4 @ 80 minutes each
- Uplink CIDP BM commands
- Downlink C&DH and CIDP Recorders
- Uplink ATS loads (as needed)

4+ GPS SVs
(≥4Re)
Why Automate? And How To?

• Automation needed handling the complexity
  – Large number of interactions
  – Goal to reduce human error and operations cost
  – Want dependable agent – must act like an ‘ideal operator’ that is never sick, always on time, able to handle multiple processes once taught
  – Want smart agent – must adapt to changing situations and know when to ask for help

• System Manager Automation framework using agents
  – User-defined Agents – core automation objects that respond to events or defined schedules by triggering forward-chain or backward-chain processes.
  – Process Control – collaborative set of agents that achieve objectives based on the state of the process flow via user-defined rules.
  – Adaptive Scheduling – existing schedules are altered based on incoming events
  – Operations Planning/Automated Recovery – target operational state is used to plan a proper course of action via backward-chaining (inferring the cause that gives a desired effect)
System Manager – Component Based Architecture

- Define Agents
- Activate Agents
- Enjoy Results

Agent Editor
- Assistant

End User Agents
- Mission Operations Tasks

End User Displays
- Mission Operations Displays

Logic System
- Rules
- Forward Chaining
- Backward Chaining

System Components
- Database*
- Communications
- Scheduling*
- Event Detection*

Simulation/Visualization
- Orbital Events
- Monitor Windows
- 3D Modeling, 2D Plots

Component-Based Architecture

Visio
- .NET Framework
  - Code Generation (C#, C++, Visual Basic, J Script)
  - Run-time Type Discovery
  - Parallel Task Library

XNA

DirectX

Mission Operations
System Manager
Industry Standard Software

* - components discussed below
Microsoft Visio is used to represent processes via assembly drawings.

Shapes represent system- and user-defined sub-processes, called parts.

Connectors specify the data and control (logic) linkages between parts.

States composing local knowledgebase

System-defined sub-process

View/Set Initial States

User-defined sub-process

Catalog of System and User-defined Parts

Assembly drawing defining new process
Scheduling Concepts: Processes, Activities, & Events

- Response Schedule is a list of *expected activities* to be performed, using defined processes, as a response to an event.
- Response Schedule is *dynamic* – based on external special requests (i.e. from MOC) and automated response to events, user/agents can add or remove activities.
- Automation uses the schedule in two ways:
  1. Perform activities currently on schedule (schedule-driven).
  2. Add an activity to the schedule as a response to a detected event (event-driven).

![Diagram showing the flow of expected events through schedules to user interface and automation with activity log and alert notification.](image)

### Operational Activities
- Testing Activities
- Analysis Activities

### Expected Events Schedules

### Automation
- Manages Schedule
- Controls Processes
- QAs Processes
- Distributes Products
- Archives Data

### Component(s)

### User Interface

### Activity Log

### Status

### Triggering Event Alert Notification
Database

- Database functionality using the Entity Framework forms the backbone for the automation

- Serves as the intermediary for inter-process communications
  - Used as media to transfer data between processes.

- Enables data mining and querying
  - User queries using transformations and operators defined by entities.
  - Metadata-based model allows for queries specifying multiple physical, dimensions, engineering units, coordinates systems, etc.
  - ‘Snapshot’ functionality allows for GUI data monitors and visualization to show internal state of process being executed
    - User entry point for debugging
    - Automated fault detection and (where possible) correction
CONTACT ANALYSIS
IMPLEMENTATION
Contact Analysis: Problem Definition

- Contact between the MMS spacecraft and the TDRS fleet is needed every perigee (see slide 7)
  - Important for science retrieval
  - Critical for formation maneuvers
- Motion model (line-of-sight & distance vs. time)
  - TDRS in correct geostationary boxes
  - MMS following its elliptical trajectory
- Antenna model (gain pattern & field-of-view (FOV))
  - TDRS-E/W S-band Single Access (SSA) antennas with 4 FOVs (simple, primary, elliptical extended x2 – ordered approximately from most to least available)
  - TDRS-Z SSA with simple FOV
  - MMS has upper & lower deck s-band omni (‘garden weasel’) antennas
- Objective
  - Find the simplest operational scenario (number of handoffs) that maximizes data rate (link margin)
Contact Analysis: System Manager Approach

• System Manager generated a set of predicted events
  – Logical yes/no for link between MMS and TDRS at a given data-rate (typical operations approach)
  – Constraint transitions (yes-to-no or no-to-yes) placed in a decision tree (not so-typical in operations)
    • Decision tree hierarchy based on the importance of mission rules/constraints (e.g. occultation has higher precedence than FOV)

• System Manager used an A* search algorithm to generate the optimal contact schedule
  – A* search works by finding the ‘shortest path’ across a ‘set of nodes’
  – The decision tree provides the nodes based on the constraint transitions
  – Link margin, antenna availability, data rates, etc. automatically built-in
Contact Analysis: Results

• System Manager analyzed a typical 2.5-year mission scenario
  – Able to find the best schedule (smallest number of hand-offs for the maximum date rate)
  – Statistically characterized the mission probability of successful contacts – e.g. 87% percent meet requirements, remaining 13% needs a workaround
  – Results consistent with official results from Space Network Loading and Modeling

• Performance
  – Analysis took several seconds on a typical Windows-based workstation
  – Results successfully vetted against hand-computations of all permutations (days of work)

• Operational benefit
  – Provides a robust way to find optimal results for given mission scenario
  – Gives a sense of how often MMS will have to work around network constraints
  – Makes a rapid response possible should base assumptions change