Magnetospheric MultiScale (MSS) System Manager

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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).

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

Formation scale matches science scale.

Maneuvers used to maintain formation against relative drift.

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

Sun

February 24-27, 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
  - ~02:00
- 120-day commissioning
- GSE Latitude [-20°, 20°] when Apogee GSE time [14:00-10:00]

Phase 1b
- Apogee Raise
  - 12 Re → 25 Re
- Neutral Sheet Dwell
  - Time >= 100 hrs
- No formation science

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

Phase 2a
- 10:00
- 90 days
- Apogee Raise
  - 12 Re → 25 Re
- No formation science

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

Phase 0
- 12:00
- 06:00
- 18:00

Phase 1a
- 12:00
- 06:00
- 18:00
- 19:00
- 17:00

Phase 1b
- 12:00
- 06:00
- 18:00

Phase 1x
- 12:00
- 06:00
- 18:00
- 117°

Phase 2b
- 12:00
- 06:00
- 18:00
- 117°
Phase-1 Orbit in the Life with Formation Maintenance Maneuvers

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

FM Maneuver #1
- TDRS or NEN: 4 @ 15 mins each (TDRS Prime, NEN Backup)
  - Uplink CIDP BM commands
  - Downlink BM Metadata
  - Uplink CIDP BM commands
  - Uplink ATS Loads (as needed)

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

Apogee

FM 2 Planning

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

FM Maneuver #2

Perigee

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

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 → 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
• Code Generation (C#, C++, Visual Basic, J Script)
• Run-time Type Discovery
• Parallel Task Library

.NET Framework

XNA

DirectX

Mission Operations
System Manager
Industry Standard Software

* - components discussed below
Process Representation

- **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.
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 of scheduling concepts](image-url)
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