Low Cost
Mission Operations Workshop

JPL
Jet Propulsion Laboratory
Pasadena, California

April 1994
Low Cost Mission Operations Workshop

Agenda

8:00  Welcome  John R. Casani

8:10  Introduction
   April 5:  Gael F. Squibb
   April 6:  Esker K. Davis
   April 7:  Gael F. Squibb

8:20  Overview  Gael F. Squibb

Mission Operations Element Briefings

9:00  Science Data Processing and Analysis  William B. Green

10:00 Mission Design, Planning, and Sequencing  Dr. Thomas W. Starbird

11:30 Lunch

12:30 Data Transport and Delivery  Robert E. Edelson

13:30 Mission Coordination and Engineering Analysis  Michael H. Hill

14:30 Summary  Gael F. Squibb

15:30 Panel Discussion  Gael F. Squibb, Moderator

16:30 Unscripted Demos

18:00 End of Day
Low Cost Mission Operations Workshop

OVERVIEW

Gael F. Squibb
Manager: Flight Projects Mission Operations
Development Program Office

OUTLINE

- DEFINITION OF MISSION OPERATIONS (OPS)
- MISSION OPERATIONS (MOS) ELEMENTS
- THE OPERATIONS CONCEPT
- MISSION OPERATIONS FOR TWO CLASSES OF MISSIONS
  - OPERATIONALLY SIMPLE
  - OPERATIONALLY COMPLEX
DEFINITION OF MISSION OPERATIONS

- A MISSION OPERATIONS SYSTEM IS COMPOSED OF:
  - THE GROUND DATA SYSTEM (GDS)
    - HARDWARE AND SOFTWARE LOCATED ON THE GROUND AND SOFTWARE LOCATED IN THE SPACECRAFT (S/C)
    - USED TO
      - CONTROL THE SPACECRAFT AND SCIENCE INSTRUMENTS
      - PROCESS INFORMATION FROM THE SPACECRAFT AND SCIENCE INSTRUMENTS
  - THE OPERATIONS ORGANIZATION
    - THE PEOPLE AND PROCEDURES USED TO
      - CONTROL THE SPACECRAFT AND SCIENCE INSTRUMENTS
      - PROCESS INFORMATION FROM THE SPACECRAFT AND SCIENCE INSTRUMENTS

MISSION OPERATIONS

- PLAN & OBJECTIVES
- ARCHIVING
- SCIENCE DATA PROCESSING
- **TWO MAJOR PROCESSES**
  - UPLINK PROCESS (U/L)
  - DOWNLINK PROCESS (D/L)

- **THESE PROCESSES ARE LINKED TOGETHER**
  - ON ONE END WITH THE DATA TRANSPORT AND DELIVERY SYSTEM THAT IS USED TO COMMAND THE SATELLITE AND TO RECEIVE ITS TELEMETRY
  - THE RECEIVED DATA OFTEN CHANGES THE MISSION PLAN AND/OR SEQUENCES
OVERVIEW

OUTLINE

- DEFINITION OF MISSION OPERATIONS (OPS)
- MISSION OPERATIONS (MOS) ELEMENTS
- THE OPERATIONS CONCEPT
- MISSION OPERATIONS FOR TWO CLASSES OF MISSIONS
  - OPERATIONALLY SIMPLE
  - OPERATIONALLY COMPLEX

MISSION OPERATIONS ELEMENTS

- NINE GENERIC ELEMENTS DESCRIBE THESE PROCESSES
  - FIVE OF THESE NINE ELEMENTS DEAL WITH BOTH THE UPLINK AND DOWNLINK PROCESSES

- NOTE: TODAY'S USER IS, OR MAY BE, INVOLVED IN NEARLY EVERY ASPECT OF OPERATIONS, SO WE NO LONGER SHOW A USER / SCIENTIST BOX OR ELEMENT
THE NINE MISSION OPERATIONS ELEMENTS

1. MISSION PLANNING
2. SEQUENCE DEVELOPMENT
3. MISSION CONTROL
4. DATA TRANSPORT AND DELIVERY
5. NAVIGATION
6. SPACECRAFT (S/C) PLANNING AND ANALYSIS
7. SCIENCE PLANNING AND ANALYSIS
8. SCIENCE DATA PROCESSING
9. ARCHIVING
COMBINING THE NINE ELEMENTS

- The elements can be combined depending on
  - the complexity of the mission
  - the spacecraft
  - the instrument

- Combining elements can take place in the ground data system, the operations organization, or both

- Current missions are combining the nine elements into a system that performs the same functions, but with fewer elements
  - staff are performing multiple functions, crossing traditional organizational boundaries

- Voyager and Mars Pathfinder both have operations organizations with two teams
**JPL**

**ELEMENT DESCRIPTIONS**

- For each of the nine elements:
  - Input, function, and output charts are included at the end of this presentation.

- These charts are a basic checklist to ensure that a mission has included all operations processes required.

---

**2. SEQUENCE DEVELOPMENT**

<table>
<thead>
<tr>
<th>INPUTS</th>
<th>FUNCTIONS</th>
<th>OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLAN OR MODIFIED PLAN</td>
<td><strong>PRE-LAUNCH</strong></td>
<td></td>
</tr>
<tr>
<td>MISSION RULES</td>
<td>VERIFY CAPABILITY TO GENERATE FLIGHT SEQUENCES</td>
<td></td>
</tr>
<tr>
<td>FLIGHT RULES</td>
<td>GENERATE HIGH ACTIVITY / CRITICAL PERIOD SEQUENCES AND TEST ON FLIGHT SYSTEM</td>
<td></td>
</tr>
<tr>
<td>MISSION PHASE PLAN</td>
<td>SOMETHING USED TO GENERATE SYSTEM INTEGRATION AND TEST SEQUENCES</td>
<td></td>
</tr>
<tr>
<td>SEQUENCE REQUESTS</td>
<td><strong>POST-LAUNCH</strong></td>
<td></td>
</tr>
<tr>
<td>MISSION CONTROL</td>
<td>INTEGRATION OF MISSION PHASE PLAN WITH CURRENT REQUESTS FROM MISSION CONTROL</td>
<td></td>
</tr>
<tr>
<td>SPACECRAFT</td>
<td>SPACECRAFT AND INSTRUMENT TEAMS</td>
<td></td>
</tr>
<tr>
<td>INSTRUMENT</td>
<td>INSTRUMENT AND SPACECRAFT PARAMETER GENERATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>DETAILED SEQUENCE GENERATION</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>VALID COMMANDS</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MISSION RULE CHECKS</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TIMELINE GENERATION</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>SEQUENCE REVIEW AND APPROVAL</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>SIMULATION OF SOME SEQUENCES</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>SYSTEM &amp; SUBSYSTEM ANALYSIS OF SEQUENCE</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>COMMAND LOAD PRODUCT GENERATION</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>PLANMED REAL-TIME COMMAND GENERATION</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>AS-FLOWN SEQUENCE OF EVENTS GENERATION</strong></td>
<td></td>
</tr>
</tbody>
</table>

---

*Low Cost Mission Operations Workshop*
PREVIEW OF LOW COST CONCEPT

- The following discussion along with the element presentations will show approaches which will lead to a low cost mission operations system.

- Mars Pathfinder has followed most of these concepts.

- The total development cost for the ground data system:
  - $5.9 million
  - Approximately 4% of the $150 million development cost
  - Past missions have spent 10% to 15%.

ALLOCATION TO MOS ELEMENTS

- Operations concept input attributes
DEFINITION OF MISSION OPERATIONS (OPS)

MISSION OPERATIONS (MOS) ELEMENTS

THE OPERATIONS CONCEPT

MISSION OPERATIONS FOR TWO CLASSES OF MISSIONS
  - OPERATIONALLY SIMPLE
  - OPERATIONALLY COMPLEX

WHAT MUST THE ELEMENTS DO FOR A GIVEN MISSION

THE OPERATIONS CONCEPT ENABLES A MISSION TO MINIMIZE LIFE CYCLE COSTS

DEVELOPING AN OPERATIONS CONCEPT IS A PROCESS THAT INVOLVES MULTIPLE DISCIPLINES, WORKING TOGETHER TO DESCRIBE (IN THE SYSTEM USER'S TERMS) THE OPERATIONAL ATTRIBUTES OF ALL ELEMENTS OF THE SYSTEM
**OPERATIONS CONCEPT**

**ATTRIBUTES**

- Stresses the way the system will be operated and used (operational characteristics) and in terms that are understood by the operators of the system and the recipients of the data from the system.

- Focuses on areas that are:
  - Not understood
  - Controversial
  - Drivers for the system

- Fosters a common understanding of processes among diverse elements of a project.

**AN OPERATIONS CONCEPT CONSIDERS BOTH FLIGHT & GROUND ELEMENTS**

- **FLIGHT SEGMENT**
  - Telecommunications
  - Data Capture & Accountability
  - Data Processing & Spacecraft Control
  - Avionics
  - Instrument Data Handling
  - Spacecraft Margins

- **GROUND SEGMENT**
  - Mission Operations (Elements 1 through 9)
DATA RECEIPT AND EDITING

1. THE ASC RECEIVES THE MERGED TELEMETRY, VERIFIES COMPLETENESS AND READABILITY, AND CONDUCTS LIMIT CHECKS AND OTHER DATA QUALITY TESTS AS A SCREENING FUNCTION.

2. THE ASC EITHER INFORMS THE OCC THAT THE DATA WAS RECEIVED CORRECTLY OR REQUESTS DATA RE-TRANSMISSION.

3. THE ASC RECEIVES ANCILLARY DATA (EPHEMERIS AND OTHER RELEVANT NON-TELEMETRY DATA) UPDATES FROM THE OCC VIA THE OPERATIONS DATABASE.

4. THE ASC DECOMMUTATES AND FURTHER PROCESSES THE TELEMETRY; ASSOCIATES DATA SEGMENTS WITH POINTINGS, OBSERVATIONS, AND INSTRUMENTS; AND EDITS AND CHECKS THE DATA.
   - DATA GATHERED FROM SPLIT OBSERVATIONS ARE ASSOCIATED AND ACCUMULATED.
   - THE ASC CONCATENATES ALL DATA SEGMENTS FOR INDIVIDUAL OBSERVATIONS TO FORM LEVEL 0 TELEMETRY AND THAT OBSERVATION'S STATUS IS UPDATED.
   - THE PROCESSING SEQUENCE IS CONFIGURED, PARAMETERS ARE SET, AND THE PROCESSING IS INITIATED.

5. THE ASC ARCHIVES THE PROCESSED TELEMETRY AND UPDATED ANCILLARY DATA AS LEVEL 0 PRODUCTS AND PROCEEDS TO LEVEL 1 PROCESSING.
OVERVIEW

OUTLINE

- DEFINITION OF MISSION OPERATIONS (OPS)
- MISSION OPERATIONS (MOS) ELEMENTS
- THE OPERATIONS CONCEPT
  - MISSION OPERATIONS FOR TWO CLASSES OF MISSIONS
    - OPERATIONALLY SIMPLE
    - OPERATIONALLY COMPLEX
AN OPERATIONALLY SIMPLE MISSION

MISSION SCOPE, OBJECTIVES, AND SCIENCE REQUIREMENTS

- THE PURPOSE OF THIS MISSION IS TO STUDY THE PROPERTIES OF THE SOLAR WIND FOR A PERIOD OF TWO YEARS, FROM A LOCATION OUTSIDE THE EARTH’S BOW SHOCK.

- A HALO ORBIT ABOUT THE L1 EARTH-SUN LIBRATION POINT WAS SELECTED TO MEET THAT MINIMUM REQUIREMENT, WHILE MINIMIZING COMMUNICATIONS REQUIREMENTS AND TRAJECTORY COMPLEXITY.

- THE INSTRUMENTS MUST FACE INTO THE AVERAGE DIRECTION OF ARRIVAL OF THE SOLAR WIND RELATIVE TO THE SPACECRAFT, WHOSE 30 km/s MOTION PERPENDICULAR TO THE SOLAR RADIUS DIRECTION CANNOT BE IGNORED; THIS LEADS TO THE REQUIREMENT THAT THE SPACECRAFT SPIN AXIS POINT 4° AHEAD OF THE SUN.

AN OPERATIONALLY COMPLEX MISSION

MISSION SCOPE, OBJECTIVES, AND SCIENCE REQUIREMENTS

- THE PURPOSE OF THIS MISSION IS TO RENDEZVOUS WITH A SHORT-PERIOD COMET, TO STUDY ITS SURFACE MORPHOLOGY AND COMPOSITION WITH REMOTE-SENSING INSTRUMENTS, AND THEN TO GRAB A SAMPLE OF SURFACE MATERIAL FOR ANALYSIS ONBOARD THE SPACECRAFT.

- IT IS ASSUMED THAT THE ONLY WAY TO RENDEZVOUS WITH THE TARGET, GIVEN THE AVAILABLE LAUNCH VEHICLES FOR THE MISSION, IS VIA DELTA VEGA TRAJECTORIES.

- IT IS FURTHER ASSUMED THAT THE BODY IS SMALL AND IRREGULAR, ITS SPIN VECTOR IS NOT KNOWN, AND ITS EPHEMERIS IS NOT WELL KNOWN A PRIORI.

- FURTHERMORE, THE FICTITIOUS COMET IS KNOWN TO BE WEAKLY AND IRREGULARLY ACTIVE, SO CERTAIN SAFEGUARDS (OR RETREAT STRATEGIES) MUST BE BUILT INTO THE SCENARIO FOR THE CLOSE APPROACH REQUIRED TO GET THE SAMPLE.
<table>
<thead>
<tr>
<th>COMPLEX</th>
<th>SIMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Fixed Launch Period requires MORE contingency / reserves to ensure launch readiness of MOS.</td>
<td>Flexible Launch Period</td>
</tr>
<tr>
<td>Characteristic determination of primary target to achieve mission objectives</td>
<td>Data Collection Mission</td>
</tr>
<tr>
<td>Site selection required to achieve mission objectives</td>
<td>Data Collection Mission</td>
</tr>
<tr>
<td>Optical Navigation required to achieve follow mission plan</td>
<td>Angles and Doppler</td>
</tr>
<tr>
<td>Automated (onboard) target acquisition required</td>
<td>Data Collection Mission</td>
</tr>
</tbody>
</table>

- Additional development costs and operations testing / maintenance

Assumed the same programmatic guidelines
MISSION PHILOSOPHIES, STRATEGIES, AND TACTICS

Assumed same mission philosophies, strategies, and tactics

OPERATIONS CONCEPT INPUTS

INSTRUMENT CHARACTERISTICS

<table>
<thead>
<tr>
<th>COMPLEX</th>
<th>SIMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument pointing required</td>
<td>vs. Spinner, no instrument pointing</td>
</tr>
<tr>
<td>Planning software</td>
<td>requirements</td>
</tr>
<tr>
<td>Sequencing software</td>
<td>vs. Spinner</td>
</tr>
<tr>
<td>Pointing reconstruction software</td>
<td></td>
</tr>
<tr>
<td>Spacecraft pointing control and</td>
<td>vs. Autonomous Instrument</td>
</tr>
<tr>
<td>stability requirements</td>
<td>mode changes</td>
</tr>
<tr>
<td>Calibration sequences and analysis</td>
<td>vs.</td>
</tr>
<tr>
<td>Instrument control by ground-generated</td>
<td></td>
</tr>
<tr>
<td>sequences</td>
<td></td>
</tr>
<tr>
<td>Sequence generation and validation</td>
<td></td>
</tr>
<tr>
<td>capabilities required</td>
<td></td>
</tr>
</tbody>
</table>
### JPL OPERATIONS CONCEPT INPUTS

#### SPACECRAFT CHARACTERISTICS

<table>
<thead>
<tr>
<th>COMPLEX</th>
<th>SIMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pointing control and stability</td>
<td>vs. Spinner</td>
</tr>
<tr>
<td>- See Instrument Characteristics slide</td>
<td></td>
</tr>
<tr>
<td>Margins</td>
<td>vs. Positive margins</td>
</tr>
<tr>
<td>- Zero to negative margins</td>
<td>vs. Low-gain S-band</td>
</tr>
<tr>
<td>- Sequence validation at subsystem level</td>
<td></td>
</tr>
<tr>
<td>- Manpower and software costs</td>
<td></td>
</tr>
<tr>
<td>- High-gain X-band</td>
<td>vs. Single fixed</td>
</tr>
<tr>
<td>- Pointing required for dumps</td>
<td></td>
</tr>
<tr>
<td>- Data mode changes for weather</td>
<td></td>
</tr>
<tr>
<td>- Increased sequence complexity</td>
<td></td>
</tr>
<tr>
<td>- Data rate requirements</td>
<td></td>
</tr>
<tr>
<td>- Multiple selectable to maximum data return</td>
<td></td>
</tr>
<tr>
<td>Subsystem Interactions</td>
<td>vs. Positive margin and no interaction</td>
</tr>
<tr>
<td>- Multiple Interactions</td>
<td></td>
</tr>
</tbody>
</table>

---

#### END-TO-END INFORMATION SYSTEM (EEIS) CHARACTERISTICS: UPLINK

<table>
<thead>
<tr>
<th>COMPLEX</th>
<th>SIMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacecraft conformity to MOS existing interface and command capabilities</td>
<td>vs. New concepts not yet implemented in MOS</td>
</tr>
<tr>
<td>- Allows use of existing capabilities</td>
<td></td>
</tr>
<tr>
<td>Instrument generation capabilities greater than recorder storage capabilities for one week</td>
<td>vs. Positive margin</td>
</tr>
<tr>
<td>- Most monitor recorder storage state and/or require more tracking resources</td>
<td></td>
</tr>
<tr>
<td>Sequences determined from data closed loop process</td>
<td>vs. Data collection and analysis mission</td>
</tr>
<tr>
<td>- Time criticality function of mission plan</td>
<td></td>
</tr>
<tr>
<td>Margin analysis required</td>
<td>vs. Positive margin</td>
</tr>
</tbody>
</table>

---

Low Cost Mission Operations Workshop
## End-to-End Information System (EEIS) Characteristics: Downlink

<table>
<thead>
<tr>
<th>Complex</th>
<th>Simple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conform to CCSDS standards</td>
<td>Same</td>
</tr>
<tr>
<td>- Allows use of existing MOS capabilities</td>
<td></td>
</tr>
<tr>
<td>Margin analyses required</td>
<td>Positive margin</td>
</tr>
<tr>
<td>Health and safety based on predicts</td>
<td>Predicts not required since sequences will not drive health and safety</td>
</tr>
</tbody>
</table>

## Ground System Characteristics

<table>
<thead>
<tr>
<th>Complex</th>
<th>Simple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacecraft compatibility with ground system capabilities and interfaces</td>
<td>Same</td>
</tr>
<tr>
<td>Navigation accuracy requiring specialized sequences and data gathering</td>
<td>Simple navigation process</td>
</tr>
<tr>
<td>Sequencing complexity</td>
<td>Simple or autonomous sequencing</td>
</tr>
</tbody>
</table>
END USER'S DATA PRODUCT DEFINITION

- Similar requirements for both
- Nothing special
- No drivers that exceed MOS capabilities

FOUR ADDITIONAL ELEMENTS

- FOUR ADDITIONAL ELEMENTS NEED TO BE CONSIDERED FOR THE SUCCESSFUL DEVELOPMENT, IMPLEMENTATION, AND OPERATION OF A MISSION OPERATION SYSTEM, WHICH ARE NOT DISCUSSED TODAY
  - SYSTEM ENGINEERING, INTEGRATION, AND TEST
  - COMPUTERS AND COMMUNICATION SUPPORT
  - DEVELOPMENT AND MAINTENANCE
  - MANAGEMENT
ELEMENT BRIEFINGS

SCIENCE DATA PROCESSING
MOS Elements 8 and 9
William B. Green

MISSION PLANNING and SEQUENCING
MOS Elements 1 and 2
Dr. Thomas W. Starbird

MISSION DATA TRANSPORT and DELIVERY
MOS Element 4
Robert Edelson

MISSION COORDINATION and
ENGINEERING ANALYSIS
MOS Elements 3, 5, 6, and 7
Michael H. Hill
THE ELEMENT BRIEFINGS AND THE ASSOCIATED DEMONSTRATIONS WILL:
- DISCUSS MULTIMISSION SOFTWARE CAPABILITIES
  - ADAPTATION REQUIRED FOR A SPECIFIC MISSION
  - OPERATIONS SERVICES AVAILABLE

THE THEMES OF THESE ELEMENT BRIEFINGS
- JPL HAS THE ABILITY TO IMPLEMENT AND OPERATE A MISSION OPERATIONS SYSTEM FOR A MISSION
- THE CAPABILITIES FOR MANY OF THE MISSION OPERATIONS ELEMENTS MAY BE DELIVERED TO A P.I. FOR USE AT HIS/HER LOCATION
- THE P.I. MAY PERFORM A FUNCTION AT HIS/HER LOCATION AND INTERFACE WITH JPL CAPABILITIES BY COMPLYING WITH INTERFACE DEFINITIONS
THE 13 MOS ELEMENTS

1. Mission Planning and Integration
2. Sequence Development
3. Mission Control
4. Data Transport and Delivery
5. Navigation
6. Spacecraft Planning and Analysis
7. Science Planning and Analysis
8. Science Data Processing
9. Archiving and Mission Database
10. System Engineering Integration and Test
11. Computers and Communication Support
12. Development and Maintenance
13. Management
## 1. MISSION PLANNING AND INTEGRATION

### Inputs
- Mission Objectives
- Science Requirements
- Satellite Capabilities
- MOS Capabilities
- Goals & Visions
- Customer Scientists
- Project MGT.
- Spacecraft Designers
- Instrument Designers

### Functions
- **Pre-Launch**
  - Mission Plan Generation
  - Description of Mission Phases
  - Mission Rules Development
  - Items that Must be Checked During Sequence Generation
  - Mission Phase Plan (In both sequence and timeline form)
  - Top Level Sequence for Each Mission Phase
  - Integration of Science and Engineering Requests
  - Long-Range DSN Scheduling

### Outputs
- Pre-Launch Mission Plan
- Mission Rules
- Mission Phase Plan

### Status vs Plan
- Spacecraft
- Instrument
- Position Location
- Mission Control

### Post-Launch
- Assessment of Achievements vs Plan
- Updates to Plan
- Updates to Mission Rules

### Modified Plan / Rules

---

## 2. SEQUENCE DEVELOPMENT

### Inputs
- Plan or Modified Plan
- Mission Rules
- Flight Rules
- Mission Phase Plan
- Sequence Requests
- Mission Control
- Spacecraft
- Instrument

### Functions
- **Pre-Launch**
  - Verify Capability to Generate Flight Sequences
  - Generate High Activity / Critical Period Sequences and Test on Flight System
  - Sometimes Used to Generate System Integration and Test Sequences

- **Post-Launch**
  - Integration of Mission Phase Plan with Current Requests from Mission Control
  - Spacecraft and Instrument Teams
  - Instrument and Spacecraft Parameter Generation
  - Detailed Sequence Generation
  - Valid Commands
  - Mission Rule Checks
  - Timeline Generation
  - Sequence Review and Approval
  - Simulation of Some Sequences
  - System & Subsystem Analysis of Sequence
  - Command Load Product Generation
  - Planned Real-Time Command Generation
  - As-Flown Sequence of Events Generation

### Outputs
- Detailed Sequences
- Timelines
- Command Load in Mnemonic Form
### 3. MISSION CONTROL

<table>
<thead>
<tr>
<th>INPUTS</th>
<th>OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLANS</td>
<td>PASS REPORTS</td>
</tr>
<tr>
<td>SEQUENCES</td>
<td>ALARMS</td>
</tr>
<tr>
<td>LIMITS</td>
<td>SPACECRAFT</td>
</tr>
<tr>
<td>SPACECRAFT</td>
<td>INSTRUMENT</td>
</tr>
<tr>
<td>INSTRUMENT</td>
<td>POSITION</td>
</tr>
<tr>
<td>POSITION LOCATION</td>
<td></td>
</tr>
<tr>
<td>COMMAND FILES</td>
<td></td>
</tr>
<tr>
<td>REAL-TIME DATA</td>
<td></td>
</tr>
<tr>
<td>TELEMETRY</td>
<td></td>
</tr>
<tr>
<td>GROUND DATA</td>
<td></td>
</tr>
<tr>
<td>SYSTEM (GDS)</td>
<td></td>
</tr>
<tr>
<td>MONITOR</td>
<td></td>
</tr>
</tbody>
</table>

#### FUNCTIONS

- PRE-LAUNCH
- PREPARE BASELINE PROCEDURES
- VALIDATE REAL-TIME CAPABILITIES
- COMMAND TELEMETRY ALARM CHECKING
- VALIDATE CAPABILITY TO CONFIGURE, CONTROL, AND MONITOR THE GROUND SYSTEM
- SUPPORT INTEGRATION & TEST
- POST-LAUNCH UPLINK CONVERSION OF MNEONICS TO BINARY CMDS
- REAL-TIME PASS SUPPORT
- R/T COMMANDS COMMAND LOADS
- DOWNLINK
- HEALTH & SAFETY MONITORING
- TELEMETRY MEASUREMENTS VS ALARMS
- ONBOARD MEMORY READOUT AND VERIFICATION
- COORDINATION
- SHORT-TERM DSN SCHEDULING
- GENERATION OF INTEGRATED FLIGHT/GRID SEQ
- MONITOR / CONTROL R/T GROUND DATA SYSTEM
- COORDINATE INSTITUTIONAL SUPPORT
- VALIDATE CONFIGURATION & MONITOR PERFORMANCE

### 4. DATA TRANSPORT AND DELIVERY

<table>
<thead>
<tr>
<th>INPUTS</th>
<th>OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANTENNA PREDICTS</td>
<td>TELEMETRY DATA</td>
</tr>
<tr>
<td>BINARY COMMANDS</td>
<td>TRACKING DATE</td>
</tr>
<tr>
<td>GROUND SEQUENCES</td>
<td>TRACKING PASS REPORTS</td>
</tr>
<tr>
<td>R/F PREDICTS</td>
<td></td>
</tr>
</tbody>
</table>

#### FUNCTIONS

- PRE-LAUNCH
- TEST AND VALIDATE FACILITIES
- PARTICIPATE IN END-TO-END TESTS WITH SPACECRAFT AND INSTRUMENTS TO VALIDATE UPLINK AND DOWNLINK FUNCTIONS

#### OUTPUTS

- TELEMETRY DATA
- TRACKING DATE
- TRACKING PASS REPORTS
- STATION QOC REPORTS
- ENG / SCIENCE DATA TO MISSION DATABASE
### 4. DATA TRANSPORT AND DELIVERY

#### INPUTS
- Antenna Predicts
- Binary Commands
- Ground Sequences
- R/F Predicts

#### OUTPUTS
- Telemetry Data
- Tracking Date
- Tracking Pass Reports
- Station QQC Reports

#### Functions

<table>
<thead>
<tr>
<th>Post-Launch (Real Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplink</td>
</tr>
<tr>
<td>Reception of Command Messages from the Mission Database</td>
</tr>
<tr>
<td>Transmission of Commands</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition of Signal and Two-Way Communications Established</td>
</tr>
<tr>
<td>Reception of Telemetry</td>
</tr>
<tr>
<td>Decryption</td>
</tr>
<tr>
<td>De-Comm...</td>
</tr>
<tr>
<td>De-Commutation and Packet Extraction (CCSDS Standards)</td>
</tr>
<tr>
<td>Data Quality and Completeness Determination</td>
</tr>
<tr>
<td>Display and Conversion of Telemetry Channels</td>
</tr>
<tr>
<td>Generation of Angle and Doppler Tracking Data</td>
</tr>
<tr>
<td>Transmission of Data to Control Center/Scientist Population of Project Database</td>
</tr>
</tbody>
</table>

---

#### Functions

<table>
<thead>
<tr>
<th>Post-Launch (Non-Real-Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing of Dump Data, If Data Rate Greater Than Bandwidth to Control Center</td>
</tr>
<tr>
<td>Data Quality and Completeness Determination</td>
</tr>
<tr>
<td>Engineering Data Record Generation</td>
</tr>
<tr>
<td>Instrument Data Record Generation</td>
</tr>
</tbody>
</table>

| Engineering Data Record Generation |
| Instrument Data Record Generation |
| Engineering Data Record Generation |
| Instrument Data Record Generation |

---

**Low Cost Mission Operations Workshop**

---

**GFS - 7**
5. NAVIGATION

**FUNCTIONS**

**INPUTS**
- TRACKING DATA
- STATION PASS DATA

**OUTPUTS**
- TRAJECTORIES
- MANEUVER DESIGN
- ATTITUDE RECONSTRUCTION

**PRE-LAUNCH**
- TEST AND VALIDATE SYSTEM
- SUPPORT PRE-LAUNCH MISSION DESIGN ACTIVITIES

**POST-LAUNCH**
- UPLINK
  - UPLINK CARRIER REQUIRED FOR DOPPLER
  - MANEUVER DESIGN
- DOWNLINK
  - ORBIT DETERMINATION
  - TRAJECTORY ANALYSIS
  - MANEUVER ANALYSIS
  - ATTITUDE / POINTING DETERMINATION AND PLANNING
  - GENERATE AND RE-GENERATE TRAJECTORIES

---

6. SPACECRAFT PLANNING AND ANALYSIS

**FUNCTIONS**

**INPUTS**
- CHANNELIZED TELEMETRY DATA PLANS
- SEQUENCES
- ALARMS / PASS REPORTS
- MANEUVER DESIGNS

**OUTPUTS**
- FLIGHT RULES
- SPACECRAFT STATUS VS PLAN
- SPACECRAFT LIMITS
- SPACECRAFT SEQUENCE REQUESTS
- PROCESSED SPACECRAFT DATA

**PRE-LAUNCH**
- PARTICIPATE IN SATELLITE SYSTEM TESTS
- GENERATE SPACECRAFT ALARM LIMITS
- GENERATE FLIGHT RULES
- GENERATE SPACECRAFT CALIBRATION FILES

**POST-LAUNCH**
- TYPICALLY, REAL-TIME MONITORING IS DONE BY MISSION CONTROL; SPACECRAFT PLANNING AND ANALYSIS IS DONE IN NONREAL-TIME
- UPLINK
  - MISSION PLANNING AND SEQUENCE SUPPORT
- DOWNLINK
  - CALIBRATION SUPPORT
  - SPACECRAFT ASSESSMENT
  - TREND ANALYSIS
  - ENGINEERING CALIBRATION ANALYSIS
  - SPACECRAFT FLIGHT SOFTWARE ASSESSMENT AND MAINTENANCE
  - ANOMALY INVESTIGATION
  - LEAD SUPPORT

---

Low Cost Mission Operations Workshop
## 7. SCIENCE PLANNING AND ANALYSIS

### FUNCTIONS

**INPUTS**
- PRE-LAUNCH
  - TEST AND VALIDATE SYSTEM
  - PARTICIPATE IN SATELLITE SYSTEM TESTS
  - GENERATE INSTRUMENT LIMITS
  - GENERATE INSTRUMENT CALIBRATION FILES

**OUTPUTS**
- INSTRUMENT STATUS VS PLAN
- INSTRUMENT LIMITS
- INSTRUMENT SEQUENCE REQUESTS
- PROCESSED INSTRUMENT DATA

**SEQUENCES**
- POST-LAUNCH
  - TYPICALLY, REAL-TIME MONITORING IS DONE BY MISSION CONTROL; INSTRUMENT PLANNING AND ANALYSIS IS DONE IN NONREAL-TIME
  - UP/LINK
  - MISSION PLANNING / SEQUENCE SUPPORT
  - DOWN/LINK
  - INSTRUMENT ASSESSMENT
  - QUICK LOOK ANALYSIS
  - CALIBRATION ANALYSIS
  - TREND ANALYSIS
  - INSTRUMENT FLIGHT SOFTWARE ASSESSMENT AND ANALYSIS
  - ANOMALY INVESTIGATION
  - LEAD SUPPORT

## 8. SCIENCE DATA PROCESSING

### FUNCTIONS

**INPUTS**
- DECOMPRESSION (IF REQUIRED)
- DOWNLINK
- AGGREGATION OF PACKET LEVEL DATA INTO INSTRUMENT DATA RECORDS (LEVEL 0)
- CORRELATION OF INSTRUMENT DATA RECORDS WITH ANCILLARY AND ENGINEERING DATA
- GENERATION OF INSTRUMENT DATA CATALOGS AND INDEXES
- GENERATION OF HIGHER LEVEL SCIENCE DATA RECORDS (LEVEL 1 AND ABOVE)
- PREPARATION OF ARCHIVAL DATA RECORDS FOR DELIVERY TO THE PLANETARY DATA SYSTEM (PDS) AND NSSDC
- DATA ANALYSIS
- PUBLIC INFORMATION OFFICE PRESS RELEASE PREPARATION
- INSTRUMENT PERFORMANCE ANALYSIS

**OUTPUTS**
- DEVIATIONS FROM MISSION PLAN
- ARCHIVAL DATA RECORDS
- HARD COPY PRODUCTS
- PRESS RELEASES
- INSTRUMENT CALIBRATION FILE UPDATES
9. ARCHIVING AND MISSION DATABASE

INPUTS
- TLM DATA
- PROCESSED DATA FROM MOS ELEMENTS
- FINAL SCIENCE PRODUCTS FROM P.L.'S

FUNCTIONS
- PRE-LAUNCH
  - REPOSITORY OF CONTROLLED FILES
  - TELEMETRY DICTIONARY
  - COMMAND DICTIONARY

- POST-LAUNCH
  - DOWNLINK:
    - DEPOSITORY FOR:
      - ORIGINAL DATA RECORDS
      - PROJECT DATABASE OF CHANNELIZED DATA
      - LEVEL 1 PRODUCTS
      - PROCESSED DATA

- TYPES OF ARCHIVES
  - CODMAC REPORT - DATA ARCHIVED WITH USERS WHO USE THE DATA
  - DORMANT ARCHIVES: AFTER USE OF DATA HAS BEEN COMPLETED

OUTPUTS
- ARCHIVED DATA TO MOS ELEMENTS & SCIENTISTS
- PLANETARY DATA FINAL ARCHIVE IS MISSION DATABASE

10. SYSTEM ENGINEERING INTEGRATION AND TEST

INPUTS
- PROJECT REQUIREMENTS
- OPS CONCEPT
- DATA FLOW DIAGRAMS

FUNCTIONS
- GROUND DATA SYSTEM ENGINEERING SUPPORT RECEIVED FROM ALL MOS ELEMENTS
- GROUND DATA SYSTEM INTEGRATION
- MISSION SIMULATION, TEST, AND TRAINING SUPPORT
- SYSTEM PERFORMANCE EVALUATION
- GENERATION AND MAINTENANCE OF SOFTWARE INTERFACE SPECIFICATIONS
- NETWORK SECURITY

OUTPUTS
- INTEGRATION & TEST PLAN
- TRAINING PLAN
- PROCEDURES
- SOFTWARE INTERFACE SPECIFICATIONS
- SECURITY PLANS & TESTS
11. COMPUTERS AND COMMUNICATION SUPPORT

FUNCTIONS

ACQUISITION, INSTALLATION, AND CHECKOUT OF HARDWARE ELEMENTS OF GROUND DATA SYSTEM (GDS)

MAINTENANCE OF WORKSTATIONS AND NETWORKS OF THE GDS

INSTALLATION, CHECKOUT AND MAINTENANCE OF DATA AND VOICE COMMUNICATION ELEMENTS OF GDS

OUTPUTS

COMPUTER WORKSTATIONS

NETWORK OR NETWORK ACCESS TO GDS ELEMENTS

VOICE COMMUNICATION SYSTEM

12. DEVELOPMENT AND MAINTENANCE

FUNCTIONS

THESE ARE FUNCTIONS WHICH CONTINUE THROUGHOUT THE LIFE CYCLE OF THE PROJECT

SPECIAL ATTENTION MUST BE PAID TO THESE FUNCTIONS IF THEY ARE PLANNED TO GO ON IN PARALLEL WITH THE OPERATIONAL PHASE OF THE MISSION

THE MAGNITUDE OF THE DEVELOPMENT AND MAINTENANCE EFFORT MUST BE UNDERSTOOD BEFORE THE OPERATIONAL PHASE, AND THE ORGANIZATION AND PROCEDURES MUST REFLECT THIS ACTIVITY

OUTPUTS

SOFTWARE DEVELOPMENT AND MAINTENANCE PLAN

MODIFIED SOFTWARE
13. MANAGEMENT

FUNCTIONS

PRE-LAUNCH
- Working with other project elements to ensure compatibility with mission, payload, and spacecraft design
- Managing a large software development effort
- Interface coordination: receivables & deliverables
- Change control and program control
- Contract and procurement administration
- Contingency and resource management

OUTPUTS
- Project policies and guidelines
- Decisions
- Approvals
- Direction
- Goals and vision of project

INPUTS
- Requirements
- Operations concepts
- Goals and vision of sponsor

OUTPUTS
- Project policies and guidelines
- Decisions
- Approvals
- Direction
- Goals and vision of project

INPUTS
- Status vs plan
- Reports
- User satisfaction
- Sponsor satisfaction

FUNCTIONS (continued)

POST-LAUNCH
- Management of MOS resources to ensure mission objectives are met
- Management of operations schedule
daily activities of operations teams
- Process for review and approval of planned command activities
- Management of development and maintenance activities required during operations
- Risk management

OUTPUTS
- Decisions
- Approvals
- Change authorization
• INPUT CHARACTERISTICS ARE GIVEN ON THE FOLLOWING PAGES

AN OPERATIONALLY SIMPLE MISSION

MISSION SCOPE, OBJECTIVES, AND SCIENCE REQUIREMENTS

- THE PURPOSE OF THIS MISSION IS TO STUDY THE PROPERTIES OF THE SOLAR WIND FOR A PERIOD OF TWO YEARS, FROM A LOCATION OUTSIDE THE EARTH'S BOW SHOCK

- A HALO ORBIT ABOUT THE L1 EARTH-SUN LIBRATION POINT WAS SELECTED TO MEET THAT MINIMUM REQUIREMENT, WHILE MINIMIZING COMMUNICATIONS REQUIREMENTS AND TRAJECTORY COMPLEXITY

- THE INSTRUMENTS MUST FACE INTO THE AVERAGE DIRECTION OF ARRIVAL OF THE SOLAR WIND RELATIVE TO THE SPACECRAFT, WHOSE 30 km/s MOTION PERPENDICULAR TO THE SOLAR RADIUS DIRECTION CANNOT BE IGNORED; THIS LEADS TO THE REQUIREMENT THAT THE SPACECRAFT SPIN AXIS POINT 4° AHEAD OF THE SUN
AN OPERATIONALLY COMPLEX MISSION

MISSION SCOPE, OBJECTIVES, AND SCIENCE REQUIREMENTS

- THE PURPOSE OF THIS MISSION IS TO RENDEZVOUS WITH A SHORT-PERIOD COMET, STUDY ITS SURFACE MORPHOLOGY AND COMPOSITION WITH REMOTE-SENSING INSTRUMENTS, AND THEN GRAB A SAMPLE OF SURFACE MATERIAL FOR ANALYSIS ONBOARD THE SPACECRAFT.

- IT IS ASSUMED THAT THE ONLY WAY TO RENDEZVOUS WITH THE TARGET WITH THE LAUNCH VEHICLES AVAILABLE FOR THE MISSION IS VIA DELTA VEGA TRAJECTORIES.

- IT IS FURTHER ASSUMED THAT THE BODY IS SMALL AND IRREGULAR, ITS SPIN VECTOR IS NOT KNOWN, AND ITS EPHEMERIS IS NOT WELL KNOWN A PRIORI.

- FURTHERMORE, THE FICTITIOUS COMET IS KNOWN TO BE WEAKLY AND IRREGULARLY ACTIVE, SO CERTAIN SAFEGUARDS (OR RETREAT STRATEGIES) MUST BE BUILT INTO THE SCENARIO FOR THE CLOSE APPROACH REQUIRED TO GET THE SAMPLE.

AN OPERATIONALLY SIMPLE MISSION

MISSION PLAN

- LAUNCH VEHICLE = DELTA 2
- LAUNCH DATE = FLEXIBLE
- MISSION DURATION = 2 YEARS + 107 DAYS
- TRAJECTORY & MANEUVER CHARACTERISTICS
  - 107 DAYS TRANSFER ORBIT TO L1
  - 65 M/SEC DELTA V FOR NAVIGATION TO ORBIT INSERTION
  - TWO LOOPS AROUND HALO PER YEAR
  - MAINTENANCE MANEUVERS EVERY 8 WEEKS
    - DELTA V FOR MAINTENANCE 35 M/SEC
- ORBIT DETERMINATION
  - DOPPLER & RANGING
  - CONTINUOUS L > L+ 2 WEEKS
  - CRUISE 1/WEEK
  - INSERTION - 2 WEEKS > +1 WEEK
    - 1 PASS PER DAY
  - 24 HOURS CONTINUOUS DURING ORBIT INSERTION
- LIGHT TIME TO L1 IS > BURN TIME
AN OPERATIONALLY COMPLEX MISSION

MISSION PLAN

- LAUNCH VEHICLE = DELTA 7925
- LAUNCH DATE = 15 DAY WINDOW
- MISSION DURATION = 7 YEARS
- TRAJECTORY AND MANEUVER CHARACTERISTICS
  - DEEP SPACE MANEUVER, 0.5 km/s
  - EARTH FLYBY, 300 km ALTITUDE L+2 YRS
  - DEEP SPACE MANEUVER AT 4AU 2.0 km/s
  - ACQUIRE TARGET
    - APPROACH FROM DARK SIDE, SEE ONLY THE CRESCENT
    - RENDEZVOUS BURN AT 1.3 AU 0.8 km/s AT L+6 YEARS
    - SLOW FLYBYS TO DETERMINE MASS AND ROTATION OF BODY

MISSION PLAN (continued)

- ORBIT THE NUCLEUS FOR 1 YEAR
  - APHELION AT 4 AU; PERIHELION AT 1 AU
  - SUN / EARTH ANGLE TO 45°
  - 1 WEEK ORBITAL PERIOD
  - MANEUVERS:
    - STATION KEEPING 1/MONTH
    - ORBIT PLANE CHANGE 1/4 MONTHS
    - MAP WITH SEVERAL REMOTE SENSING
    - PICK A SITE FROM WHICH TO GRAB A SAMPLE
    - GET THE SAMPLE AND ANALYZE IT ON BOARD

- RETURN 100 MBITS/DAY FROM 2AU
- ORBIT DETERMINATION
  - OPTICAL NAVIGATION REQUIRED
  - AUTOMATIC TARGET ACQUISITION REQUIRED

- LIGHT TIME =
AN OPERATIONALLY SIMPLE MISSION

MISSION PHILOSOPHIES, STRATEGIES & TACTICS

- LIFE CYCLE COSTS WILL BE MINIMIZED
- INITIAL CUT AT MINIMIZING LIFE CYCLE COSTS IS TO USE EXISTING GROUND SYSTEM CAPABILITIES
- AFTER FIRST DESIGN OF FLIGHT AND GROUND SEGMENTS, COST DRIVERS WILL BE IDENTIFIED AND EXPLAINED TO SCIENCE WORKING GROUP
- SCIENCE WORKING GROUP AND PROJECT WILL ATTEMPT TO LOWER COST DRIVERS AND LIFE CYCLE COST ESTIMATE

AN OPERATIONALLY COMPLEX MISSION

MISSION PHILOSOPHIES, STRATEGIES & TACTICS

- LIFE CYCLE COSTS WILL BE MINIMIZED
- INITIAL CUT AT MINIMIZING LIFE CYCLE COSTS IS TO USE EXISTING GROUND SYSTEM CAPABILITIES
- AFTER FIRST DESIGN OF FLIGHT AND GROUND SEGMENTS, COST DRIVERS WILL BE IDENTIFIED AND EXPLAINED TO SCIENCE WORKING GROUP
- SCIENCE WORKING GROUP AND PROJECT WILL ATTEMPT TO LOWER COST DRIVERS AND LIFE CYCLE COST ESTIMATE
AN OPERATIONALLY SIMPLE MISSION

PROGRAMMATIC

CONCURRENT ENGINEERING PRACTICES WILL BE USED

COLLOCATION OF PARTICIPANTS DURING DESIGN PHASE

AN OPERATIONALLY COMPLEX MISSION

PROGRAMMATIC

CONCURRENT ENGINEERING PRACTICES WILL BE USED

COLLOCATION OF PARTICIPANTS DURING DESIGN PHASE
AN OPERATIONALLY SIMPLE MISSION

INSTRUMENT CHARACTERISTICS

- INSTRUMENT POINTING - NOT REQUIRED
- NUMBER OF INSTRUMENTS = 3
  - FIELDS AND PARTICLES
- INSTRUMENT CONTROL
  - MODE CHANGES ARE AUTONOMOUS
  - NO GROUND COMMANDING OR SEQUENCE REQUIRED FOR DATA GATHERING
  - NO CALIBRATION SEQUENCES OR MANEUVERS REQUIRED
  - INSTRUMENT SOFTWARE UPDATEABLE BUT NOT REQUIRED
- INSTRUMENT OUTPUT
  - PACKET OUTPUT TO SPACECRAFT
  - INSTRUMENT DATA OUTPUT CONTINUOUS AT 1000 BPS

AN OPERATIONALLY COMPLEX MISSION

INSTRUMENT CHARACTERISTICS

- INSTRUMENT POINTING
  - BODY FIXED INSTRUMENTS
  - COMMON FIELD OF VIEW
  - SPACECRAFT POINTING
    - CONTROL REQUIRED = 0.32°
    - STABILITY = 10-3° over 10 seconds
- NUMBER OF INSTRUMENTS = 3 REMOTE SENSING
- INSTRUMENT CONTROL
  - TYPICAL IMAGING SEQUENCES
  - BUTTON UP WHEN DUST HAZARD TOO STRONG
  - INSTRUMENT SOFTWARE UPDATEABLE
  - MODE CHANGES VIA STORED SEQUENCE
- INSTRUMENT OUTPUT
  - INSTRUMENT OUTPUT BURST MODE
  - INSTRUMENTS OUTPUT PACKETS
AN OPERATIONALLY COMPLEX MISSION

SPACECRAFT CHARACTERISTICS

- ATTITUDE CONTROL
  - 3 AXIS STABILIZED
  - SUN AND START SENSORS
  - POINTING CONTROL 0.32°
  - STABILITY -10-3° over 10 seconds
  - REACTION WHEEL FOR POINTING
- POWER
  - POWER MARGIN ZERO AT START OF ORBITAL PHASE
  - SOLAR PANELS & BATTERIES REQUIRE CAREFUL MANAGEMENT TO BALANCE POWER AND THERMAL CONSTRAINTS
- R/F
  - HIGH-GAIN ANTENNA
  - X-BAND
- DATA SYSTEM
  - 8 SELECTABLE DATA RATES
  - ON BOARD SOLID STATE RECORDER 2 GBIT CAPACITY
- PROPULSION
  - 2 PROPULSION SYSTEMS
  - DEEP SPACE BURNS
  - ORBIT KEEPING

AN OPERATIONALLY SIMPLE MISSION

SPACECRAFT CHARACTERISTICS

- ATTITUDE CONTROL
  - SPIN STABILIZED
  - SPIN AXIS 4° OFF SUNLINE IN T DIRECTION
  - SPIN AXIS ADJUSTED AUTONOMOUSLY ONCE PER DAY
  - ACCURACY ± 1° (CONTROL & KNOWLEDGE)
- POWER
  - FIXED SOLAR ARRAYS
  - POWER MARGIN >=25% WITH ALL INSTRUMENTS ON
- R/F
  - S-BAND DOWNLINK
  - SLOTTED WAVEGUIDE ARRAY
- DATA SYSTEM
  - DATA COLLECTION CONTINUOUS
  - 1100 (1000 SCIENCE + 100 health & safety)
  - ALL DATA PACKETIZED
  - SOLID STATE RECORDER (2 GBITS)
  - 30 KBPS DUMP RATE
  - 10 BPS FAULT RECOVERY RATE
- PROPULSION
  - 10 NEWTON THRUSTERS
AN OPERATIONALLY COMPLEX MISSION

EEIS CHARACTERISTICS

- UPLINK
  - SATELLITE
    - STORE AND DUMP PROCESS REQUIRED FOR SCIENCE DATA
    - ON-BOARD OP NAV REQUIRED DUE TO RENDEZVOUS REQUIREMENTS
    - LIGHT TIME > MANEUVER DURATION
    - ON-BOARD MANEUVER DETERMINATION COUPLED WITH PROPULSION
      CONTROL
  - GROUND SYSTEM
    - SEQUENCES DETERMINED FROM DATA
    - CONTENTION BETWEEN INSTRUMENTS FOR DATA GATHERING
    - SCIENCE USER INPUT REQUIRED FOR SEQUENCE GENERATION

- DOWNLINK
  - SATELLITE
    - SPACECRAFT AND INSTRUMENTS CONFORM TO CCSDS STANDARDS
  - GROUND SYSTEM
    - CONSUMABLES TO MANAGE
    - SOME SUBSYSTEMS HAVE ZERO TO NEGATIVE MARGIN
    - SPACECRAFT ANALYSIS AT SUBSYSTEM LEVEL DUE TO MARGIN
      DEFICIT
    - MISSION CONTROL - HEALTH AND SAFETY BASED ON PREDICTS

AN OPERATIONALLY SIMPLE MISSION

EEIS CHARACTERISTICS

- UPLINK
  - SATELLITE
    - SINGLE ON-BOARD COMPUTER FOR DATA COLLECTION, PROCESSING
    - AND ATTITUDE CONTROL - PROCESSOR LANGUAGE = 'C'
    - INSTRUMENTS HAVE THEIR OWN MICRO PROCESSORS. LANGUAGE ALSO C
    - INSTRUMENTS AND SPACECRAFT DATA SYSTEM CONFORM TO CCSDS
      STANDARDS
    - SOLID STATE RECORDER ALLOWS DATA STREAM METERING, DUMP AND R/T
      - ALL SUBSYSTEMS HAVE MARGINS
  - GROUND SYSTEM
    - ON-BOARD ATTITUDE UPDATES REQUIRE EPHEM UPDATES ONCE PER MONTH
    - NO CONFLICT RESOLUTION REQUIRED FOR SEQ GENERATION
    - NO SEQUENCES REQUIRED FOR NORMAL OPERATIONS
    - NO RESOURCE MANAGEMENT OR PREDICTION REQUIRED

- DOWNLINK
  - SATELLITE
    - SPACECRAFT AND INSTRUMENTS CONFORM TO CCSDS STANDARDS
  - GROUND SYSTEM
    - EDR'S WILL BE TIMED ORDERED SERIES OF PACKETS
    - MISSION CONTROL - HEALTH AND SAFETY LIMITS ONLY, NO PREDICTIONS
      REQUIRED
    - SPACECRAFT ANALYSIS AT SYSTEM LEVEL ONLY
    - NO CONSUMABLES TO MANAGE
AN OPERATIONALLY COMPLEX MISSION

GROUND SYSTEM CHARACTERISTICS

- **COMPATIBILITY**
  - SPACECRAFT DATA SYSTEM IS COMPATIBLE WITH AMMOS TELEMETRY SYSTEM
  - R/F COMPATIBLE WITH DSN

- **NAVIGATION**
  - OPTICAL NAVIGATION REQUIRED

- **SEQUENCING**
  - INSTRUMENT SEQUENCING BASED ON RETURNED DATA REQUIRED
  - INSTRUMENT POINTING GENERATION REQUIRED
  - DATA COLLECTION AUTOMATIC
  - SEQUENCES REQUIRED FOR MANEUVERS
  - PRE-PLANNED SEQUENCES REQUIRED FOR INSTRUMENT TURN-ON AND CALIBRATION
    - THESE SEQUENCES WILL BE THE SAME AS THOSE USED DURING SYSTEM TEST

AN OPERATIONALLY SIMPLE MISSION

GROUND SYSTEM CHARACTERISTICS

- **COMPATIBILITY**
  - SPACECRAFT DATA SYSTEM IS COMPATIBLE WITH AMMOS TELEMETRY SYSTEM
  - R/F COMPATIBLE WITH DSN

- **NAVIGATION**
  - NO SPECIAL NAVIGATION REQUIREMENTS

- **SEQUENCING**
  - NO INSTRUMENT SEQUENCING REQUIRED
  - DATA COLLECTION AUTOMATIC
  - SEQUENCES REQUIRED FOR MANEUVERS
  - PRE-PLANNED SEQUENCES REQUIRED FOR INSTRUMENT TURN-ON AND CALIBRATE SAME AS THOSE USED DURING SYSTEM TEST
AN OPERATIONALLY SIMPLE MISSION

USER DATA PRODUCT DEFINITION

- QUICK-LOOK DATA FOR HEALTH CHECKS, INCLUDING SPIN-AXIS POINTING AND INSTRUMENT OPERATION
- EXPERIMENT DATA RECORDS FOR NONREAL-TIME ANALYSIS

AN OPERATIONALLY COMPLEX MISSION

USER DATA PRODUCT DEFINITION

- IMAGING DATA IN FRAME FORMAT
- NO CALIBRATION REQUIRED
- SPICE KERNELS
Low Cost Mission Operations Workshop

SCIENCE DATA PROCESSING and ANALYSIS

William B. Green
Functional Area Manager: Operational Science Analysis
Multimission Operations Systems Office
INTRODUCTION

- Future low cost mission operations will increasingly involve science teams supporting flight operations from their home institutions.

- Technology evolution supports distributed operations support scenarios:
  - High-performance workstations
  - High-speed networks
  - Platform-independent software

Science Operations Support Workstation

- Mission planning & sequence development tools
- Spacecraft performance & analysis tools
- Position location planning & analysis tools
- Science data processing tools
- Local database & data management tools

JPL’s Approach to Distributed Science Operations—

The “SOPC”

- “Science operations planning computer” (SOPC) concept was first utilized to support Mars Observer and is planned for Cassini.
  - Capabilities can be readily adapted to discovery missions.

- Concept involves packaging mission support tools in a UNIX-based workstation environment distributed to science teams.

- SOPC capabilities can be a combination of JPL- and P.I.-developed operations support tools.

- JPL long-term maintenance of JPL-developed software tools.

- Many of the tools shown today can be provided within a “SOPC.”
SCIENCE DATA PROCESSING AND ANALYSIS

OUTLINE

- DATA FLOW AND PRODUCTS
- ONBOARD SCIENCE INSTRUMENT DATA PROCESSING
- SCIENCE INSTRUMENT DATA RECORD ASSEMBLY
- SCIENCE DATA MANAGEMENT
- SCIENCE ANALYSIS PROCESSING SUPPORT
- SCIENCE DATA PRODUCT GENERATION

DATA FLOW

- DATA TRANSPORT AND DELIVERY
- NAVIGATION
- INSTRUMENT PACKETS
- SCIENCE DATA RECORD ASSEMBLY
- SCIENCE ANALYSIS
- SCIENCE PRODUCT GENERATION
- SCIENCE DATA MANAGEMENT
- SPICE KERNELS
PRODUCTS

RELATIONSHIPS BETWEEN SPACECRAFT AND GROUND DATA SYSTEMS

- TECHNOLOGY SUPPORTS INCREASED PROCESSING OF SCIENCE DATA ON THE SPACECRAFT. EXAMPLES:
  - DATA COMPRESSION
    - LOSSLESS AND LOSSY CAN BE ADAPTIVE
    - INSTRUMENT SIGNATURE REMOVAL
    - INFORMATION EXTRACTION
    - ENCODING TO PREVENT DATA LOSS IN THE TELEMETRY LINK
  - SOME ONBOARD PROCESSING MUST BE REVERSED ON THE GROUND. EXAMPLES:
    - DECODING
    - DECOMPRESSION
SCIENCE DATA PROCESSING AND ANALYSIS

OUTLINE

- DATA FLOW AND PRODUCTS
- ONBOARD SCIENCE INSTRUMENT DATA PROCESSING
- SCIENCE INSTRUMENT DATA RECORD ASSEMBLY
- SCIENCE DATA MANAGEMENT
- SCIENCE ANALYSIS PROCESSING SUPPORT
- SCIENCE DATA PRODUCT GENERATION

TYPICAL FLOW OF SCIENCE INSTRUMENT DATA THROUGH SPACECRAFT DATA SYSTEM

Phenomena of Interest

INSTRUMENT 1 PROCESSOR
PACKETIZED DATA P11 P12 P13...

Phenomena of Interest

INSTRUMENT 2 PROCESSOR
PACKETIZED DATA P21 P22 P23...

Phenomena of Interest

INSTRUMENT 3 PROCESSOR
PACKETIZED DATA P31 P32 P33...

SPACECRAFT DATA SYSTEM

HEADER INST1 INST2...

INST1 P11 P12 P13... INST2 P21 P22... INST3 P31 P32... ERROR REDUCTION ENCODING

FRAMEs CONTAINING A SERIAL BIT STREAM TRANSMISSION
ADVANCED END-TO-END SIMULATION FOR ONBOARD PROCESSING (AESOP)

- NASA-FUNDED UNIX-BASED SOFTWARE SYSTEM USED TO DESIGN SCIENCE INSTRUMENT PACKETS
- ASSISTS IN EVALUATING ROBUSTNESS OF PACKET FORMAT DESIGN IN PRESENCE OF NOISE OR PACKET LOSS

DEMONSTRATION

- COMPRESSED IMAGES (JPEG COMPRESSION) DOWNLINKED WITH NO ERROR CORRECTION CODE, BIT ERROR RATE (BER) $10^{-4}$
- SAME IMAGE COMPRESSION AND BER WITH REED-SOLOMON CODING
- COMPARISON OF COMPRESSED IMAGE (COMPRESSION RATIO APPROXIMATELY 20:1) WITH UNCOMPRESSED IMAGE TO ILLUSTRATE DATA LOSS IN COMPRESSION

SCIENCE DATA PROCESSING AND ANALYSIS

OUTLINE

- DATA FLOW AND PRODUCTS
- ONBOARD SCIENCE INSTRUMENT DATA PROCESSING
  - SCIENCE INSTRUMENT DATA RECORD ASSEMBLY
- SCIENCE DATA MANAGEMENT
- SCIENCE ANALYSIS PROCESSING SUPPORT
- SCIENCE DATA PRODUCT GENERATION
**SCIENCE INSTRUMENT DATA RECORD ASSEMBLY**

**FRAMES**
- DATA TRANSPORT AND DELIVERY SYSTEM
- FRAME SYNCH, DECODING
- Packets Separated by Instrument (P) 1, P12, ...

**SENSOR-SPECIFIC PROCESSING**
- ENGINEERING DATA PROCESSING
- DECOMPRESSION
- SENSOR SIGNATURE REMOVAL

**DATA RECORD**
- HEADER RECORD(S) IN POS-FORMAT
- SELECTED SPICE KERNEL AND ENGINEERING DATA
- O11, O12
- O13
- ...

**INSTRUMENT DATA RECORD—INSTRUMENT 1**

**SCIENCE DATA RECORD ASSEMBLY DEMONSTRATIONS**

**DEMONSTRATION 1: IMAGE DATA RECORD ASSEMBLY**
- Aggregation of selected SPICE kernel data with image data record
- Assembly of Saturn image from individual packet data
- Note arrival of packet data out of time sequence

**DEMONSTRATION 2: REAL-TIME IMAGE DISPLAY**
- Day-long simulation of real-time image displays generated during data acquisition
- Future implementations will be X-window based, supporting viewing of real-time displays at science team home institutions and other remote sites

**DEMONSTRATION 3: PARTICLE AND FIELDS INSTRUMENT REAL-TIME PROCESSING**
- Demonstrates real-time processing of Galileo plasma wave subsystem (PWS) data during Galileo Earth-2 encounter in December 1992
- Processing is performed using LinkWinds science data analysis system (developed in JPL's Division 52 under NASA funding)
- PWS data is Fourier transformed and displayed in false color in real time
- Additional LinkWinds analysis tools are applied in real time as data is received
COST DRIVERS--

JPL SCIENCE INSTRUMENT DATA RECORD ASSEMBLY

- PERCENTAGE OF ACQUIRED SOURCE DATA IN THE EXPERIMENT DATA RECORD (EDR)
  - REQUIREMENTS FOR 100% OF DATA MAY DRIVE OPERATIONS COSTS BY REQUIRING MULTIPLE PLAYBACKS AND DATA-MERGE OPERATIONS
  - IS "REAL-TIME" DATA RECORD ASSEMBLY AND DISTRIBUTION REQUIRED, OR CAN DATA BE PROCESSED IN BATCHES AT TIMES NOT DRIVEN BY DATA ACQUISITION TIMES?

- TIMELINESS OF SPICE KERNEL DATA
  - PRECISION OF NAVIGATION INFORMATION INCREASES WITH TIME
  - INSTRUMENT DATA ANALYSIS MAY IMPROVE NAVIGATION DATA PRECISION
  - WAITING FOR THE BEST POSSIBLE SPICE KERNEL DATA BEFORE PRODUCING EXPERIMENT DATA RECORDS CAN CAUSE MULTIPLE PRODUCTION RUNS

- VOLUME OF DATA
  - DISTRIBUTION QUANTITIES OF FINAL PRODUCTS SUPPORTED BY PROJECT FUNDING
  - DISTRIBUTION MEDIA USED FOR FINAL PRODUCTS
    - DIGITAL MEDIA—TAPE, CD-ROM
    - FILM MEDIA—QUANTITY AND NUMBER OF COPIES DISTRIBUTED

IMPLEMENTATION OPTIONS--

JPL SCIENCE INSTRUMENT DATA RECORD PRODUCTION

- ADAPT JPL MULTIMISSION CAPABILITIES, PRODUCE FINAL EDR'S AT JPL FACILITIES
  - JPL TRANSmits ASSEMBLED DATA RECORDS (REAL TIME AND FINAL EDR) TO SCIENCE TEAM SITE(S) ELECTRONICALLY
  - JPL TRANSfers SELECTED DATA RECORDS ON REQUEST TO SCIENCE TEAM SITE(S) (ELECTRONICALLY OR VIA CD-ROM SHIPMENT)

- SCIENCE TEAM IMPLEMENTS AND OPERATES FACILITIES TO PRODUCE FINAL EDR'S
  - JPL TRANSmits PACKET-LEVEL DATA TO SCIENCE TEAM FACILITY
  - SCIENCE TEAM IS RESPONSIBLE FOR OPERATIONAL SUPPORT OF DATA RECORD PRODUCTION

- EDR'S ARE PRODUCED AT SCIENCE TEAM FACILITIES USING MULTIMISSION SOFTWARE AND PROCEDURES ADAPTED BY JPL
  - JPL DELIVERS TESTED SOFTWARE AND PROCEDURES TO P.I. SITES
  - SCIENCE TEAM IS RESPONSIBLE FOR OPERATIONAL SUPPORT TO DATA RECORD PRODUCTION
SCIENCE DATA PROCESSING AND ANALYSIS

OUTLINE

- DATA FLOW AND PRODUCTS
- ONBOARD SCIENCE INSTRUMENT DATA PROCESSING
- SCIENCE INSTRUMENT DATA RECORD ASSEMBLY
  - SCIENCE DATA MANAGEMENT
  - SCIENCE ANALYSIS PROCESSING SUPPORT
  - SCIENCE DATA PRODUCT GENERATION

SCIENCE DATA MANAGEMENT

REQUIREMENTS AFTER RECEIPT OF DATA

- NEED TO BE ABLE TO LOCATE ALL VERSIONS OF ALL DATA RECEIVED TO DATE, BASED ON VARIOUS SEARCH CRITERIA
- ABILITY TO DISCRIMINATE BETWEEN DIFFERENT VERSIONS OF SAME INSTRUMENT DATA
  - DIFFERENT SPACECRAFT DOWNLINKS (WITH DIFFERENT PROCESSING OPTIONS?)
  - DIFFERENT DEEP SPACE NETWORK (DSN) STATION PLAYBACKS
  - DIFFERENT LEVELS OF INSTRUMENT DATA PROCESSING
  - DIFFERENT DATA QUALITY LEVELS ON DIFFERENT VERSIONS OF DOWNLINK DATA
- NEED TO CORRELATE ANCILLARY DATA WITH INSTRUMENT DATA
  - GEOGRAPHIC REFERENCE FRAMEWORK FOR OBSERVATIONS
  - CORRELATION OF INSTRUMENT ENGINEERING DATA WITH OBSERVATIONAL DATA
- ABILITY TO CORRELATE OBSERVATIONS BETWEEN MULTIPLE INSTRUMENTS
SCIENCE DATA MANAGEMENT SYSTEM
CAPABILITIES REQUIRED DURING OPERATIONS

- Interactive user database query and data retrieval, based on multiple search criteria
- Generation and automatic e-mail distribution of standard reports
  - Summary of daily data receipt by instrument
  - Project management reports that summarize processing status
- Automatic initiation of processing sequences, based on receipt of anticipated data

SCIENCE DATA QUERY/RETRIEVAL DEMONSTRATIONS

- Demonstrations utilize "DBVIEW," a multimission user interface to science databases developed at JPL
- System utilizes the Sybase database, a commercially available database management system (DBMS)
- Client software supports remote science users, without need for Sybase site licenses at remote sites

DEMONSTRATION 1: DAILY REPORT

A typical daily report, transmitted to a science team via electronic mail that lists most recently acquired data

DEMONSTRATION 2: INTERACTIVE QUERY

Initiation of a query by a science team member at a remote site, searching for all data that meets selected search criteria
SCIENCE DATA MANAGEMENT SYSTEM DURING MISSION OPERATIONS:

IMPLEMENTATION OPTIONS

- SERVER LOCATED AT JPL, DATABASE LOCATED AT JPL, CLIENT SOFTWARE OPERATES IN USER WORKSTATIONS
  - UTILIZE JPL MULTIMISSION CAPABILITIES AND SHARED OPERATIONS STAFF
  - ALL INSTRUMENT DATA, ANCILLARY DATA, AND ASSOCIATED CATALOGS ARE MAINTAINED AT JPL USING COMMERCIAL DBMS TECHNOLOGY FOR THE DURATION OF THE MISSION
  - SECURE LINKS OR PUBLIC DOMAIN NETWORKS SUPPORT REMOTE SCIENCE QUERY/RETRIEVAL VIA JPL-PROVIDED CLIENT SOFTWARE OR PUBLIC-DOMAIN TOOLS
  - CENTRALIZED SYSTEM ACCEPTS AND CATALOGS DATA PRODUCTS GENERATED AT REMOTE SCIENCE SITES

SCIENCE DATA MANAGEMENT SERVER AT JPL
SCIENCE DATA MANAGEMENT SYSTEM DURING MISSION OPERATIONS:

IMPLEMENTATION OPTIONS (Continued)

- DISTRIBUTED DATABASE CONCEPTS
  - JPL TRANSFERS PACKETS OR DATA RECORDS TO TEAM SITE (DESCRIBED PREVIOUSLY)
  - SCIENCE TEAM ASSUMES RESPONSIBILITY FOR CATALOG GENERATION AND MAINTENANCE, AND FOR SUPPORT OF SCIENCE TEAM QUERY/RETRIEVAL
  - POTENTIAL USE OF JPL-DEVELOPED CAPABILITIES IN THESE SCENARIOS

SCIENCE DATA MANAGEMENT SUPPORT AT SCIENCE TEAM SITE(S)

- ON-LINE STORAGE
  - SCIENCE DATA RECORDS
  - CATALOGS
  - SCIENCE PRODUCTS
  - SELECTED SPICE KERNEL DATA

- SERVER
  - PHYSICAL MEDIA (ON DEMAND)
  - NETWORK ACCESS

- QUERIES
  - ELECTRONIC FILE TRANSFER
  - REPORTS
  - NEW PRODUCTS

- REMOTE USER WORKSTATION
- JPL-PROVIDED CLIENT SOFTWARE
- PUBLIC DOMAIN TOOLS (MOSAIC, Gopher, etc.)
SCIENCE DATA PROCESSING AND ANALYSIS

OUTLINE

- DATA FLOW AND PRODUCTS
- ONBOARD SCIENCE INSTRUMENT DATA PROCESSING
- SCIENCE INSTRUMENT DATA RECORD ASSEMBLY
- SCIENCE DATA MANAGEMENT
- SCIENCE ANALYSIS PROCESSING SUPPORT
- SCIENCE DATA PRODUCT GENERATION

SCIENCE ANALYSIS PROCESSING SUPPORT:

IMPLEMENTATION OPTIONS

- SOFTWARE FOR PRODUCTION OF HIGHER ORDER SCIENCE ANALYSIS PRODUCTS AVAILABLE FROM MULTIPLE SOURCES:
  - JPL AND OTHER GOVERNMENT AGENCIES
    - VICAR, LINKWINDS, PICS (USGS)
  - COMMERCIAL SOURCES
    - IDL, PVWAVE, AVS
  - PUBLIC DOMAIN PACKAGES
    - KHOROS
  - P.I. AND SCIENCE TEAM FACILITIES
- EVOLVING TECHNOLOGY SUPPORTS INCREASING ROLE FOR SCIENCE TEAMS IN PRODUCTION OF HIGHER LEVEL PRODUCTS BEYOND THE EDR
- INDIVIDUAL SCIENCE TEAMS WILL MAKE DECISIONS ON SUPPORTING SCIENCE ANALYSIS
- PROCESSING BASED ON THEIR OWN CAPABILITIES, AVAILABLE FACILITIES, AND COST
- JPL CAPABILITIES ARE AVAILABLE TO SUPPORT SCIENCE ANALYSIS AT SCIENCE FACILITIES OF NASA-FUNDED SCIENCE TEAM MEMBERS
JPL SCIENCE ANALYSIS PROCESSING SUPPORT

DEMONSTRATION: CAPABILITIES NOT NORMALLY FOUND IN
COMMERCIALY AVAILABLE OR PUBLIC-DOMAIN SOFTWARE

• CARTOGRAPHIC PROJECTIONS FOR BODIES OTHER THAN
  THE EARTH
• INTERFACE WITH ANCILLARY DATA FILES (e.g., SPICE
  KERNEL, SPACECRAFT ENGINEERING DATA SOURCES)
• ABILITY TO HANDLE DATA SETS OF LARGE DIMENSIONS (e.g.,
  LARGE DIGITAL IMAGE MOSAICS, MULTISPECTRAL
  INSTRUMENTS)
• RADIOMETRIC RECONSTRUCTION OF COLOR IMAGERY FROM
  MULTIPLE IMAGES ACQUIRED THROUGH SPECTRAL FILTERS
• IMAGE REGISTRATION TO LESS THAN ONE PIXEL ACCURACY

JPL SCIENCE DATA PROCESSING AND ANALYSIS

OUTLINE

• DATA FLOW AND PRODUCTS
• ONBOARD SCIENCE INSTRUMENT DATA PROCESSING
• SCIENCE INSTRUMENT DATA RECORD ASSEMBLY
• SCIENCE DATA MANAGEMENT
• SCIENCE ANALYSIS PROCESSING SUPPORT
• SCIENCE DATA PRODUCT GENERATION
SCIENCE DATA PRODUCT GENERATION

- The principal investigator's deliverable to NASA is an archival-quality data record in planetary data system (PDS) compatible format.
- PDS is responsible for post-mission data retention and dissemination.
- P.I. determines content of PDS deliverable product:
  - Level of processing of instrument data
  - Delivery of instrument calibration data
  - Ancillary data incorporated into data product
  - Software
  - Documentation
- Current medium of choice for PDS products is CD-ROM.

DEMONSTRATION: PLANETARY ANALYSIS TOOL (PLATO)
- NASA-funded software that supports query and retrieval of image data from PDS CD-ROMs.
- Demonstration illustrates retrieval of image data based on specific search criteria.
- PLATO also supports application of instrument calibration files to image data, interface with SPICE kernels, automatic mosaicking, and other features.

THE PLANETARY DATA SYSTEM (PDS)

- Organization:
  - PDS discipline nodes define scientific objectives and establish priorities for restoration of older data sets.
    - Nodes include geosciences, atmospheres, planetary plasma interactions, imaging, rings, small bodies, navigation ancillary information facility (NAIF), SPICE kernel.
  - PDS central node at JPL establishes standards and works with active missions to define archival PDS-compatible data sets.
- Role:
  - Provide the best planetary data to the most users forever.
- Data restoration role:
  - Publish complete archive products from past planetary missions following product design, peer review of data and descriptive labels, and validation of the products.
JPL ADAPTATION EXAMPLE—MARS PATHFINDER

- PAYLOAD
  - LANDER STEREO COLOR CAMERA, ROVER CAMERAS, AXP

- APPROACH
  - JPL MULTIMISSION FACILITIES USED FOR:
    - REAL-TIME PROCESSING, DECOMPRESSION, DATA RECORD FORMATION, PHOTOPRODUCTS, REAL-TIME DISPLAY, DATABASE MAINTENANCE AND CATALOG, PRODUCTION OF PDS-COMPATIBLE EDR'S ON CD-ROM
    - DEDICATED UNIX WORKSTATION USED TO SUPPORT THESE ACTIVITIES
  - LANDER IMAGING SCIENCE TEAM PERFORMS HIGHER LEVEL LANDER IMAGE PROCESSING
  - ROVER NAVIGATION TEAM PERFORMS STEREO IMAGE ANALYSIS AND ROVER NAVIGATION COMPUTATION
  - AXP SCIENCE TEAM PERFORMS PROCESSING BEYOND LEVEL 0

- TOTAL DEVELOPMENT FOR LESS THAN $200K IN REAL-YEAR DOLLARS BY ADAPTING JPL MULTIMISSION CAPABILITIES THAT SUPPORT THE FUNCTIONS SHOWN ABOVE

JPL "UNSCRIPTED DEMONSTRATIONS" LATER TODAY IN VON KARMAN AUDITORIUM

- AESOP
  - ADVANCED END-TO-END SIMULATION OF ONBOARD PROCESSING

- VICAR
  - INSTRUMENT DATA PROCESSING SOFTWARE

- LINKWINDS
  - SCIENCE ANALYSIS SUPPORT SYSTEM

- PLATO
  - PROCESSING AND DISPLAY OF IMAGE DATA FROM PDS DATA SETS

- DBVIEW
  - SCIENCE DATA MANAGEMENT SYSTEM CLIENT SOFTWARE

- STEREO AND ANIMATION
## SCIENCE DATA PROCESSING AND ANALYSIS

<table>
<thead>
<tr>
<th>INPUT</th>
<th>FUNCTIONS</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSTRUMENT PACKET DATA</td>
<td>DECOMPRESSION (IF REQUIRED)</td>
<td>DEVIATIONS FROM BASELINE MISSION PLAN</td>
</tr>
<tr>
<td>ANCILLARY DATA (SPICE KERNE</td>
<td>AGGREGATION OF PACKET LEVEL DATA INTO INSTRUMENT DATA RECORDS (LEVEL 0)</td>
<td>INSTRUMENT CALIBRATION FILE UPDATES</td>
</tr>
<tr>
<td>L DATA)</td>
<td>CORRELATION OF INSTRUMENT DATA RECORDS WITH ANCILLARY AND ENGINEERING DATA</td>
<td>QUICK-LOOK AND ARCHIVAL DATA RECORDS</td>
</tr>
<tr>
<td>ENGINEERING DATA</td>
<td>GENERATION OF INSTRUMENT DATA CATALOGS AND INDICES</td>
<td>SCIENTIFIC PAPERS</td>
</tr>
<tr>
<td></td>
<td>GENERATION OF HIGHER LEVEL SCIENCE DATA RECORDS (LEVEL 1 AND ABOVE)</td>
<td>HARD COPY PRODUCTS</td>
</tr>
<tr>
<td></td>
<td>PREPARATION OF ARCHIVAL DATA RECORDS FOR DELIVERY TO PDS AND NSSDC</td>
<td>PRESS RELEASES</td>
</tr>
<tr>
<td></td>
<td>DATA ANALYSIS</td>
<td>REAL-TIME DATA DISPLAY</td>
</tr>
<tr>
<td></td>
<td>PUBLIC INFORMATION OFFICE PRESS RELEASE PREPARATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>INSTRUMENT PERFORMANCE ANALYSIS</td>
<td></td>
</tr>
</tbody>
</table>

---

Low Cost Mission Operations Workshop

WBO - 33
Low Cost Mission Operations Workshop

MISSION DESIGN, PLANNING, and SEQUENCING

Dr. Thomas W. Starbird
Sequence System Engineer
Multimission Operations Systems Office
JPL  MISSION DESIGN, PLANNING, AND SEQUENCING

OUTLINE

- UPLINK PROCESS
- UPLINK PLANNING PROCESSES
- ADAPTATION SUMMARY
- HOW TO REDUCE COSTS
- PARTNERSHIP OPTIONS

JPL  UPLINK PLANNING AND SEQUENCING

TRANSFORM SCIENTIFIC AND ENGINEERING GOALS INTO SPACECRAFT EVENTS
**UPLINK PROCESSES**

- MISSION DESIGN
- MISSION PLANNING
- SCIENCE OBSERVATION GENERATION
- OBSERVATION INTEGRATION
- POINTING OBSERVATION DESIGN
- SEQUENCE GENERATION AND INTEGRATION
- COMMAND LOAD GENERATION
- SEQUENCE VERIFICATION
- GROUND SEQUENCE GENERATION

**BEFORE MISSION OPERATIONS**

- TRAJECTORY CHOSEN
- OPERATIONS CONCEPT DEVELOPED
- SCIENCE SCENARIOS DEVELOPED
- GROUND TOOLS DEVELOPED
TRAJECTORY TO MARS

Launch: 11/24/96 - Arrival: 09/21/97

UPLINK PROCESSES

- Mission Design
- Mission Planning
- Science Observation Generation
- Observation Integration
- Pointing Observation Design
- Sequence Generation and Integration
- Command Load Generation
- Sequence Verification
- Ground Sequence Generation
## Mission Rules, Guidelines, Constraints

### Examples
- Schedule spacecraft events that require real-time monitoring during prime shift.
- Do not require uplinks during solar conjunction.
- Do not overwrite critical data stored on recorder until playback data is verified.
- Record critical data as well as transmitting it in real time.
- Record telemetry 15 minutes before and after critical activities.
- Allocate resources to activities and mission phases, to ensure adequate resources for future tasks.

## Uplink Processes

- Mission Design
- Mission Planning
- Science Observation Generation
- Observation Integration
- Pointing Observation Design
- Sequence Generation and Integration
- Command Load Generation
- Sequence Verification
- Ground Sequence Generation
SCIENCE OBSERVATION GENERATION

- DETERMINE OBSERVATION OPPORTUNITIES BASED ON
  - SCIENCE GOALS
  - GEOMETRY, EPHEMERIDES, AND SCIENCE MODELS
- SPECIFY OBSERVATION AT HIGH LEVEL

SCIENCE OBSERVATION GENERATION

DEMONSTRATION OF SEQ_POINTER FOR
PLANETARY ENCOUNTER OF SATURN

- VISUALIZING IMAGING FOOTPRINTS ON SATURN
- CHANGE TIME OF OBSERVATION
  - FOOTPRINTS CHANGE
- CHANGE NUMBER OF MOSAIC IMAGES
SEQ_POINTER

- GENERATES, DESIGNS, AND MODELS REMOTE-SENSING OBSERVATIONS
  - COMPUTES GEOMETRIC QUANTITIES
    - EPHEMERIDES (SPACECRAFT and SOLAR BODIES)
    - CONICS
    - SPICE KERNEL (INTEGRATED TRAJECTORY)
  - COORDINATE SYSTEMS
  - 3-D IMAGE, TARGET BODY, AND FOOTPRINTS
  - LIGHTING ANGLES, SLANT RANGE TO TARGET...
  - APPLIES SPACECRAFT CHARACTERISTICS
    - FIELD OF VIEW
    - SLEW / TURN RATES, CONSTRAINTS
    - ONBOARD CAPABILITIES (e.g., MOSAIC)
  - IS INTERACTIVE WITH USER
  - READS / WRITES FILE INTERFACES, WITH SEQ_GEN

No adaptation required
- Requires adaptation to project needs

Low Cost Mission Operations Workshop

SEQ_POINTER SCREEN DUMP
UPLINK PROCESSES

- MISSION DESIGN
- MISSION PLANNING
- SCIENCE OBSERVATION GENERATION
- OBSERVATION INTEGRATION
- POINTING OBSERVATION DESIGN
- SEQUENCE GENERATION AND INTEGRATION
- COMMAND LOAD GENERATION
- SEQUENCE VERIFICATION
- GROUND SEQUENCE GENERATION

PLANNING

SEQUENCING

PLANNING AND SEQUENCING CAN BE GEOGRAPHICALLY DISTRIBUTED OR CENTRALIZED
OBSERVATION INTEGRATION

- MERGE SCIENCE OBSERVATIONS, ENGINEERING, AND NAVIGATION ACTIVITIES

- MODEL KEY LIMITED OR SHARED RESOURCES (SPACECRAFT AND GROUND)
  - INTERACTION OF OBSERVATIONS WITH SPACECRAFT RESOURCES
  - INTERACTION OF OBSERVATIONS WITH GROUND (e.g., TRACKING STATIONS)
  - INTERACTION OF OBSERVATIONS WITH EACH OTHER
  - INTERACTION OF OBSERVATIONS WITH ENGINEERING AND NAVIGATION

- RESOLVE CONFLICTS

OBSERVATION INTEGRATION

DEMONSTRATION OF PLAN-IT II FOR PROTOTYPE OF EARTH OBSERVING SYSTEM (DOS) DISTRIBUTED SCHEDULING CONCEPT

- GENERATE TARGET OBSERVATIONS

- GENERATE SLEWS TO CORRECT POINTING CONFLICTS

- GENERATE GLOBAL MAPPING OBSERVATIONS TO FILL AVAILABLE TIME

- ACCEPT REMOTE, EXTRA OBSERVATION REQUEST AND RESOLVE CONFLICT
PLAN-IT-II (Prototype for APGEN)

- The state-of-the-art "Spread Sheet" approach to timeline integration and conflict detection / resolution
- Panoply of resource types, constraint types
  - Adapter chooses
- Panoply of actions to change plan
  - Applied by user or algorithm
- Full connectivity between activities and resources
  - Reports all contributors to conflicts
- Discrete events and interval activities
- Multiple levels of abstraction
- Adapter can automate planning strategies
  - Example: place observation to minimize conflicts
- Handles event-driven implications
- Adapt function is part of the tool

- or ø = Fixed
- ø or ø = Adapter-defined

PLAN-IT-II SCREEN DUMP
**UPLINK PROCESSES**

- MISSION DESIGN
- MISSION PLANNING
- SCIENCE OBSERVATION GENERATION
- OBSERVATION INTEGRATION
- POINTING OBSERVATION DESIGN
- SEQUENCE GENERATION AND INTEGRATION
- COMMAND LOAD GENERATION
- SEQUENCE VERIFICATION
- GROUND SEQUENCE GENERATION

**POINTING OBSERVATION DESIGN**

- COMPLETE DETAILS OF EACH OBSERVATION

- USE SPACECRAFT AND INSTRUMENT CHARACTERISTICS AS WELL AS GEOMETRY, e.g.
  - FIELDS OF VIEW
  - SLEW / TURN RATES AND CONSTRAINTS
**JPL**

**UPLINK PROCESSES**

- MISSION DESIGN
- MISSION PLANNING
- SCIENCE OBSERVATION GENERATION
- OBSERVATION INTEGRATION
- POINTING OBSERVATION DESIGN
- SEQUENCE GENERATION AND INTEGRATION
- COMMAND LOAD GENERATION
- SEQUENCE VERIFICATION
- GROUND SEQUENCE GENERATION

---

**JPL**

**SEQUENCE GENERATION AND INTEGRATION**

- CONVERT SCIENCE, ENGINEERING AND NAVIGATION ACTIVITIES INTO SPACECRAFT "TERMINOLOGY"
- MERGE ALL ACTIVITIES REQUESTED
- EXPAND TO MNEMONIC SPACECRAFT COMMANDS (AND CALLS TO ONBOARD BLOCKS)
- CHECK FLIGHT, MISSION, AND COMMON-SENSE RULES
- PRODUCE MNEMONIC SEQUENCE
- PREDICT SPACECRAFT EVENTS
SEQUENCE

- CONSISTS OF SPACECRAFT COMMANDS
  - LOW LEVEL (e.g., FLIP SWITCH)
  - HIGH LEVEL, DETERMINISTIC (e.g., MOSAIC SLEWS) ("ON-BOARD BLOCKS")
  - HIGH LEVEL, STATE-DEPENDENT (e.g., ROVER TRAVERSE) ("BEHAVIORS")

- TIME-BASED OR EVENT-DRIVEN

- EXECUTED IN REAL TIME OR STORED IN SPACECRAFT MEMORY

STORED SEQUENCE

- WHOLE SEQUENCE UPLINKED AT ONE TIME

- STORED IN SPACECRAFT MEMORY

- EACH COMMAND EXECUTED BY SPACECRAFT AT SCHEDULED TIME OR EVENT

- WHY STORED SEQUENCES?
  - ACCOMMODATES DELAYS IN FLIGHT TIME
  - USES LESS GROUND STATION
  - MAKES EXACT TIMING OF UPLINK TIME UNIMPORTANT
  - ALLOWS SPACECRAFT ACTIVITY WHEN NOT VISIBLE OR STATION IS UNAVAILABLE
  - CAN VERIFY RECEIPT OF ALL COMMANDS BEFORE EXECUTION OF ANY
  - IS A STEP TOWARD AUTONOMOUS SPACECRAFT
LIGHT TIME

- TIME FOR MESSAGE TO TRAVEL FROM EARTH TO AND FROM SPACECRAFT
- LIMITS GROUND PARTICIPATION IN ACTIVE SPACECRAFT

**TODAY'S ROUND TRIP LIGHT TIME from EARTH**

<table>
<thead>
<tr>
<th>spacecraft</th>
<th>time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GALILEO</td>
<td>58</td>
</tr>
<tr>
<td>VOYAGER 1</td>
<td>15 hours 13 minutes</td>
</tr>
<tr>
<td>VOYAGER 2</td>
<td>11 hours 48 minutes</td>
</tr>
<tr>
<td>MAGELLAN</td>
<td>26 minutes</td>
</tr>
<tr>
<td>ULYSSES</td>
<td>48 minutes</td>
</tr>
<tr>
<td>PIONEER 10</td>
<td>16 hours 35 minutes</td>
</tr>
<tr>
<td>PIONEER 11</td>
<td>11 hours 8 minutes</td>
</tr>
</tbody>
</table>

SEQUENCE GENERATION AND INTEGRATION

DEMONSTRATION OF SEQ_GEN FOR PROTOTYPE OF CASSINI ULTRAVIOLET SPECTROMETER PLANNING

- EXPANSION OF SPACECRAFT BLOCKS (MACROS) TO LOW-LEVEL COMMANDS
- CONFLICT IDENTIFICATION AND RESOLUTION
- GRAPHING OF MODEL ATTRIBUTES
BLOCKS

- Groups low-level commands for a high-level action
- One block yields several commands
  - Either a fixed list of commands
  - Or governed by parameters and logic
  - Examples: maneuver, mosaic
- Expanding commands can be done on ground or on spacecraft
- Can be reused
- Designs out conflicts; enforces how to operate spacecraft
- Fosters human-level thinking
  - Spacecraft can expand into demands
  - Blocks are pre-tested, which eliminates need for testing commands that use the block
- Cost ingredients:
  - Sequencing is cheaper to sequence at block level
  - Too expensive to handcraft every sequence
  - Fewer and simpler blocks are easier to design and test

SEQUENCE INTEGRATION - CONSTRAINT CHECKING

A sequence must pass many rules gates
EXAMPLE RULES AND CONSTRAINTS
CHECKED IN SEQUENCE INTEGRATION

- Play back stored data before it is overwritten
- Downlink rate must not exceed link capability
- Transmit only when tracking station is allocated
- Don't use more propellant per orbit than allocated
- Cover instruments before firing thrusters
- Don't issue too many commands at once - processor may drop some
- Fire the thrusters every 62 days to clear the lines
- Don't try to slew too fast (will exceed available power and picture will smear)
- Don't take more then 50k images - no budget to process extras
- Don't make sequences bigger than memory on spacecraft
- Don't command an instrument that is off (except to turn it on)
- Don't put too much data on the bus at once
- Don't turn within 30° of sun for more than one hour

Some rules disappear or simplify with margins and pre-allocation of time and resources

SEQ_GEN

- Knows mnemonic spacecraft commands, blocks, models and rules
- Expands blocks to commands
- Models effect on spacecraft, checks rules
  - Predictions are read in spice kernels
  - Predictions may be needed to analyze anomalies
- Shows violations
- Is user interactive

□ or □ = No adaptation required
□ = Requires adaptation
UPLINK PROCESSES

- MISSION DESIGN
- MISSION PLANNING
- SCIENCE OBSERVATION GENERATION
- OBSERVATION INTEGRATION
- POINTING OBSERVATION DESIGN
- SEQUENCE GENERATION AND INTEGRATION
- COMMAND LOAD GENERATION
- SEQUENCE VERIFICATION
- GROUND SEQUENCE GENERATION

COMMAND LOAD GENERATION

SEQ GEN 00101100 00101100: To 7B2E
10100100 10100100: To 7B2F
10111011 10111011: To 7C41

CONVERT

MISSION

MEMORY

PACKAGING

MOMONICS

TO

DATA

SPACECRAFT

BITS

BASE

MANAGEMENT

PROTOCOL
JPL

COMMAND LOAD GENERATION

• JPL HAS MULTIMISSION CAPABILITY
  - COST SAVINGS HINTS:
    • USE CCSDS * STANDARDS
    • USE "COMMAND DATABASE" TO EXPRESS COMMANDS
      - INITIALLY AND FOR UPDATES
      - DIRECTS MULTIMISSION SOFTWARE
    • USE SIMPLE MEMORY MANAGEMENT SCHEME
      - ONGROUND OR ONBOARD

*CCSDS: Consultative Committee for Space Data Systems

UPLINK PROCESSES

• MISSION DESIGN
• MISSION PLANNING
• SCIENCE OBSERVATION GENERATION
• OBSERVATION INTEGRATION
• POINTING OBSERVATION DESIGN
• SEQUENCE GENERATION AND INTEGRATION
• COMMAND LOAD GENERATION
• SEQUENCE VERIFICATION
• GROUND SEQUENCE GENERATION

PLANNING
SEQUENCING
**SEQUENCE VERIFICATION**

- A BIT-LEVEL SIMULATOR IS SOFTWARE THAT SIMULATES THE PROCESSING OF THE SEQUENCE BY THE SPACECRAFT
  - USES BINARY FLIGHT SOFTWARE
  - USES BINARY COMMAND LOAD

- BIT-LEVEL SIMULATION MAY BE DESIRABLE FOR
  - CHECKING SEQUENCES
  - TESTING FLIGHT SOFTWARE

- JPL HAS MULTIMISSION CAPABILITY
  - ADAPTER SUPPLIES MODELING MODULES
  - COST SAVINGS HINT:
    - 1750A PROCESSOR SIMULATION MODULES BEING IMPLEMENTED
  - \( \square \) or \( \bigcirc \) = No adaptation required
  - \( \bigcirc \) or \( \square \) = Requires adaptation

---

**UPLINK PROCESSES**

- MISSION DESIGN
- MISSION PLANNING
- SCIENCE OBSERVATION GENERATION
- OBSERVATION INTEGRATION
- POINTING OBSERVATION DESIGN
- SEQUENCE GENERATION AND INTEGRATION
- COMMAND LOAD GENERATION
- SEQUENCE VERIFICATION
- GROUND SEQUENCE GENERATION
GROUND SEQUENCE GENERATION

- CREATE SCHEDULES FOR GROUND ACTIONS TO SUPPORT SPACECRAFT ACTIVITY
- GENERATE SEQUENCE OF EVENTS (GROUND INTEGRATED WITH SPACECRAFT)
- DEEP SPACE NETWORK (DSN) CONFIGURATION COMMANDS AND SCHEDULE
- PREDICTED TElemetry

GROUND SEQUENCE GENERATION

DEMONSTRATION OF SEG AND SEG SHELL FOR MARS OBSERVER

- SEG HELPING USER CHOOSE INPUT FILES
- CHOOSE SUBPROCESSES TO EXECUTE
- VIEW SEQUENCE OF EVENTS
- VIEW DSN KEYWORDS FILE
SEG SHELL

- CONTROLS OPERATION OF SEG
  - PRESENTS FILE NAMES, LETS USER CHOOSE OR OVERWRITE FILES
  - ALLOWS USER SELECTION OF FUNCTIONS TO EXECUTE

- ADAPTER CAN BE CONFIGURED TO CONTROL OTHER PROGRAMS

- or ○ = No adaptation required
- ○ or ○ = Requires adaptation

SEG SHELL SCREEN DUMP
JPL

SEG (SEQUENCE OF EVENTS GENERATOR)

- DERIVE DSN CONFIGURATION COMMANDS / SCHEDULE FROM SPACECRAFT SEQUENCE
  - BASED ON ADAPTER-SUPPLIED TABLES
  - WRITES "DSN KEYWORD FILE"

- DERIVES TELEMETRY PREDICTIONS FROM SEQUENCE COMMANDS
  - BASED ON ADAPTER-SUPPLIED TABLES

- DISPLAYS SPACE FLIGHT OPERATIONS SCHEDULE

- HAS USER INTERACTIVE EDITOR
  - EXTRACTS OR HIGHLIGHTS SUBSETS
  - PUTS CHANGE BARS

- or ○ = No adaptation required
- ○ or ○ = Requires adaptation

Low Cost Mission Operations Workshop

JPL

SEG SCREEN DUMP

Low Cost Mission Operations Workshop
UPLINK PLANNING PROCESSES

- **MISSION DESIGN**
  - PRE-LAUNCH
  - DESIGN TRAJECTORY
- **MISSION PLANNING**
  - MISSION PLAN, HIGH-LEVEL TIMELINES
  - MISSION RULES, GUIDELINES, CONSTRAINTS
  - CONTINGENCY PLANS
- **SCIENCE OBSERVATION GENERATION**
  - PLAN OBSERVATIONS BASED ON GEOMETRY AND EPHEMERIDES
- **OBSERVATION INTEGRATION**
  - MERGE SCIENCE, ENGINEERING, AND NAVIGATION ACTIVITIES
  - MODEL ATTRIBUTES OF INTEREST TO SCIENTISTS, PLUS KEY LIMITED OR SHARED RESOURCES
  - RESOLVE CONFLICTS
- **POINTING OBSERVATION DESIGN**
  - ADD DETAILS, USING KNOWLEDGE OF SPACECRAFT
    - FIELDS OF VIEW
    - ABILITY TO DO TURNS
    - ABILITY TO MOVE SCAN PLATFORM
- **SEQUENCE GENERATION AND INTEGRATION**
  - EXPAND TO MNEMONIC INSTRUCTIONS CORRESPONDING TO ONES UNDERSTANDABLE BY SPACECRAFT
  - MERGE ENGINEERING AND SCIENCE
  - CHECK RULES: FLIGHT, MISSION, COMMON SENSE
- **COMMAND LOAD GENERATION**
  - TRANSLATE MNEMONICS TO BITS
  - MANAGE SPACECRAFT MEMORY
  - PACKAGE INTO SPACECRAFT PROTOCOL
- **VERIFICATION**
  - SIMULATE EXECUTION BY FLIGHT SOFTWARE OF THE COMMAND LOAD
- **GROUND SEQUENCE GENERATION (UPLINK MISSION CONTROL)**
  - PLAN COORDINATED GROUND ACTIVITIES, SUCH AS DSN
INTEGRATION AND SEQUENCING

LIGHT TIME FILE
DSN VIEW PERIODS AND ALLOCATIONS FILES

REQUEST GENERATION & INTEGRATION
PLANET-5 (RAPID PROTOTYPE)

SASF

ENGINEERING AND NAVIGATION ACTIVITIES

- CPF: COMMAND PACKET FILE: CONTAINS SEQUENCE IN SPACECRAFT PROTOCOL
- PEF: PREDICTED EVENTS FILE
- SASF: SPACECRAFT ACTIVITY SEQUENCE FILE: CONTAINS BLOCKS & SPACECRAFT INSTRUCTIONS
- SOE: SEQUENCE OF EVENTS: CONTAINS GROUND AND SPACECRAFT EVENTS
- SSF: SPACECRAFT SEQUENCE FILE: CONTAINS SPACECRAFT COMMANDS IN MÉNEMIC FORM
- HSSM: HIGH SPEED SCIENCE SIMULATION

SEQUENCE GENERATION & INTEGRATION
SEQ

VERIFICATION
HSMN

COMMAND LOAD GENERATION
SEORAM

GROUND SEQUENCE GENERATION
SEQ

DSN KEYWORDS FILE
SOE

SEQUENCE OF EVENTS: CONTAINS GROUND AND SPACECRAFT EVENTS

Low Cost Mission Operations Workshop

ADAPTATION SUMMARY OF JPL MULTIMISSION UPLINK SOFTWARE

- DEFINE SPACECRAFT CHARACTERISTICS RELATED TO POINTING (e.g., FIELDS OF VIEW, TURN RATES, CONSTRAINTS, MOSAIC) (TABLES + C)
- IDENTIFY KEY, HIGH-LEVEL LIMITED OR SHARED RESOURCES; BUILD MODELS INTO PLANNING SOFTWARE (TABLES)
- DEVELOP AUTOMATED SCHEDULING STRATEGIES, ADD TO PLANNING SOFTWARE (LISP)
- DEFINE SPACECRAFT COMMANDS, PUT INTO COMMAND DATA BASE (LITTLE LANGUAGE)
- DEFINE BLOCKS, PUT INTO SEQUENCING SOFTWARE (LITTLE LANGUAGE)
- DEFINE FLIGHT AND MISSION RULES – BUILD SEQUENCING SOFTWARE MODELS TO CHECK (SOME OF) THE RULES (TABLES, LITTLE LANGUAGE, C OPTIONAL)
- DEFINE SPACECRAFT MEMORY MANAGEMENT (WHETHER IT IS DONE ONBOARD OR ON THE GROUND) – PUT IT INTO SOFTWARE
  - MACROS (IF ON GROUND)
- DEFINE COMMAND/TELEMETRY RELATIONSHIPS (TABLES)
- DEFINE SPACECRAFT ACTION IMPLICATIONS ON DSN ACTIVITY (TABLE)
- DEFINE PROGRAM CONTROL SHELL

Low Cost Mission Operations Workshop
HOW TO REDUCE COSTS

• USE EXISTING MULTIMISSION SOFTWARE
  - CHEAPER TO ADAPT THAN TO BUILD NEW
  - REDUCTION OF MAINTENANCE COSTS BY AMORTIZATION
    OVER MULTIPLE PROJECTS
  - APPLICABLE TO SIMPLE AND COMPLEX MISSIONS
  - ADDITIONAL CAPABILITY IN RESERVE (FALLBACK)

• MINIMIZE PAPER INPUTS / INTERFACES

• FOLLOW STANDARDS
  - CCSDS TELECOMMAND
  - FILE FORMATS
    • IEEE FLOATING POINT
    • CRC / CHECKSUM
    • SIMPLE SPACECRAFT CLOCK

HOW TO REDUCE COSTS (continued)

• DESIGN SPACECRAFT, MISSION, AND OPERATIONS
  CONCURRENTLY
  - USE MARGINS IN SPACECRAFT TO AVOID OPERATIONS
    COMPLEXITY
  - PLAN TO AVOID CONFLICT: ALLOCATIONS AND BLOCKS

• USE INTERPLANETARY MISSION EXPERIENCE OF JPL

• IF CCSDS STANDARDS ARE FOLLOWED AND SPACECRAFT
  INFORMATION IS AVAILABLE, A BASIC UPLINK GROUND
  SYSTEM CAN BE MADE AVAILABLE IN THREE TO SIX
  MONTHS
PARTNERSHIP OPTIONS:
JPL WITH SELECTED PRINCIPAL INVESTIGATORS

- UPLINK OPERATIONS SYSTEM
  - PLANNING / EXECUTION
  - PEOPLE
  - SOFTWARE

- UPLINK SOFTWARE SYSTEM
  - DESIGN
  - ADAPTATION
  - MAINTENANCE: ACCESS TO UPGRADES

- UPLINK COMPONENTS
  - OPERATIONS
  - ADAPTED SOFTWARE

ACKNOWLEDGEMENTS

TODAY'S DEMONSTRATIONS ARE PRESENTED BY THE FOLLOWING PEOPLE:

POINTER: Jeff Boyer, POWTER Cognizant Engineer

Plan-IT-II: Curt Eggemeyer, Plan-IT-II Researcher and Developer
Stephen Peters, Concept and Adaptation for Plan-IT-II's application to EOS

SEQ_GEN: Jose Salcedo, SEQ_GEN Cognizant Engineer

SEG: William Heventhal III, SEG Cognizant Engineer

Command Tool Kit: Jeff Biesiadecki, Cognizant Engineer
Charles Ames, Cognizant Engineer
Cassie Mulnix, Programmer
UNSCRIPTED DEMONSTRATIONS

- SEQ_POINTER
  REMOTE SENSING OBSERVATION GENERATION AND DESIGN

- PLAN-IT-II
  ACTIVITY REQUEST GENERATION AND INTEGRATION

- SEQ_GEN
  SEQUENCE GENERATION AND INTEGRATION

- SEG SHELL AND SEG
  SEQUENCE OF EVENTS GENERATOR AND ITS OPERATIONAL SHELL

- COMMAND TRANSLATION TOOL KIT
  COMMAND MNEMONICS, BIT PATTERNS, AND CORRESPONDING TELEMETRY
MISSION DATA TRANSPORT and DELIVERY

Robert E. Edelson
Functional Area Manager: Telemetry
Multimission Operations Systems Office
DATA TRANSPORT AND DELIVERY

OUTLINE

- DATA TRANSPORT PROCESS
- DSN MISSION SUPPORT
  - DSN MISSION SUPPORT FUNCTIONS
- DATA SYSTEM OPERATIONS MISSION SUPPORT
  - TELEMETRY DATA PROCESSING DEMONSTRATION
  - DATA TRANSPORT FUNCTIONS
  - ON-LINE STORAGE CONTENT
  - DATA QUERY DEMONSTRATION
- PERFORMANCE
- HOW TO REDUCE COST
- MARS PATHFINDER DEMONSTRATION
- CONCLUSION
DATA TRANSPORT DATA PROCESSING (continued)

Workstation Data Processing

Engineering Data Processing

- Decom Maps
- Decommute & Channelize
- CDRs (DN only)
- Conversion parameters
- Alarm Limits & Algorithms
- Alarm Check
- DN and EU
- ECDRs (DN, EU; alarm state)
- To Spacecraft Analysis

Legend:
- CDR: Channeled Data Record
- DN: Data Number
- EU: Engineering Units
- ECDR: Expanded Channeled Data Record

Science Data Processing

- Decom Maps
- Decommute & Channelize
- CDRs (DN only)
- Conversion parameters
- Derive & Convert
- DN and EU
- Algorithms
- Science Application
- To Science Analysis

Low Cost Mission Operations Workshop
ACQUIRE TELEMETRY DATA FROM SPACECRAFT AND PROVIDE IT TO FLIGHT PROJECTS

ACCEPT COMMAND DATA FROM FLIGHT PROJECTS, TRANSMIT COMMANDS TO SPACECRAFT, AND CONFIRM COMMAND TRANSMISSIONS

WHEN REQUIRED, GENERATE RADIOMETRIC, RADIO SCIENCE, AND VERY LONG BASELINE INTERFEROMETRY (VLBI) DATA FOR FLIGHT PROJECTS AND OTHER USERS

GENERATE PREDICTIONS FOR SIGNAL ACQUISITION

SCHEDULE COMMUNICATIONS WITH SPACECRAFT

PARTICIPATE WITH FLIGHT PROJECTS IN THEIR TEST AND TRAINING

COMPATIBILITY TEST TRAILER AVAILABLE FOR TEST SUPPORT AT REMOTE SITES

Further information is available in the DSN document:

DSN Support of Earth Orbiting and Deep Space Missions
JPL DATA SYSTEMS OPERATIONS MISSION SUPPORT

TELEMETRY DATA PROCESSING DEMONSTRATION

- AUTOMATIC CONFIGURATION AND INITIATION OF OPERATIONS
- ESTABLISHING INTERFACE WITH DEEP SPACE NETWORK
- INITIATION OF TELEMETRY INPUT AND DATA STREAM PROCESSING
- INITIATION OF ON-LINE STORAGE AND ESTABLISHING DATA ROUTING
- INITIATION OF WORKSTATION DISPLAYS AND REAL-TIME PROCESSING OF DATA FOR VOYAGER, ULYSSES, AND GALILEO (AS AVAILABLE)
USER WORKSTATION CAPABILITIES
- DATA NUMBER / ENGINEERING UNITS CONVERSION
- DERIVED CHANNELS
- ALARM LIMIT CHECKING
- PRESENTATION TOOLS FOR CHANNEL VALUE DISPLAY:
  - TABULAR DISPLAYS (TEXT)
  - DATA FLOW DISPLAYS
  - CHANNEL vs. TIME DISPLAYS
  - CHANNEL vs. CHANNEL DISPLAYS

DATA TRANSPORT FUNCTIONS
- INTERFACE WITH DEEP SPACE NETWORK (DSN) FACILITIES TO RECEIVE SPACECRAFT TELEMETRY AND GROUND MONITOR DATA
- TRANSFER OF COMMAND FILES TO THE DSN FOR RADIATION TO THE SPACECRAFT
  - DATA CAPTURE AND STAGING
    - SPACECRAFT/INSTRUMENT TELEMETRY DATA
    - GROUND SYSTEM PERFORMANCE DATA
  - TELEMETRY PROCESSING
    - FRAME SYNCHRONIZATION
    - PACKET EXTRACTION
    - CHANNELIZATION
    - ERROR CORRECTION
    - TIME ORDERING
    - DATA RECALL
    - DATA BESTING
  - ☑ or ☐ No adaptation required
  - ☐ or ☑ Requires adaptation to project needs
DATA TRANSPORT FUNCTIONS (continued)

- ON-LINE STORAGE
  - ON-LINE DATA STORAGE IN EACH PROJECT'S DATABASE (VARIABLE DEPENDING ON PROJECT NEED, TYPICALLY PROVIDE 32 GBYTES OF ON-LINE STORAGE)
  - EACH PROJECT'S DATABASE SUPPORTS OVER 25 SIMULTANEOUS QUERIES

- DATA DISTRIBUTION
  - NEAR-REAL-TIME OR NONREAL-TIME
  - AUTOMATED OR ON DEMAND
  - LOCAL OR REMOTE

SECURE REMOTE ACCESS VIA SCIENCE OPERATIONS PLANNING COMPUTERS (SOPC's) FROM PRINCIPAL INVESTIGATOR'S FACILITY (CAN DO ANALYSIS WHEREVER NEEDED)

- No adaptation required
- Requires adaptation to project needs

DATA TRANSPORT EXAMPLES:

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Highest Data Rate (bps)</th>
<th>Nominal Data Rate (bps)</th>
<th>Storage Capacity (Gbytes)</th>
<th>Amount of Data Stored (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voyager 1</td>
<td>1.4K</td>
<td>160</td>
<td>2.4</td>
<td>180</td>
</tr>
<tr>
<td>Voyager 2</td>
<td>7.2K</td>
<td>600</td>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>Ulysses</td>
<td>40K</td>
<td>8192</td>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>Galileo</td>
<td>40</td>
<td>16</td>
<td>6</td>
<td>240</td>
</tr>
<tr>
<td>Mars Observer</td>
<td>85K</td>
<td>Variable</td>
<td>32</td>
<td>100</td>
</tr>
<tr>
<td>Discovery Possibilities</td>
<td>1K - 100K</td>
<td>Variable</td>
<td>2 - 40</td>
<td>-100</td>
</tr>
</tbody>
</table>
MISSION DATABASE - TYPES OF DATA

Distributed Mission Database
- Navigation Files
- Radiometric Data
- DSN Performance Data
- Sequence & Command Files

Science & Engineering Data
- On-Line Storage (Data Transport)
- Near-Line Accessible Storage (Data Transport)
- Image/Science Storage
- Archive

DATA TRANSPORT FUNCTIONS (continued)

- SYSTEM MONITOR AND CONTROL

- TEST AND TRAINING SUPPORT
  - DATA SIMULATION
  - SYSTEM TEST AND INTEGRATION
  - SUPPORT FOR USER ACCEPTANCE TESTING
  - SUPPORT DURING FLIGHT SYSTEM TESTING (TEST TELEMETRY AND COMMAND SYSTEM)

- No adaptation required
- Requires adaptation to project needs
DATA QUERY
DEMONSTRATION

(How to examine spacecraft data)

WORKSTATION EXAMPLE:
- INITIATING DATA ACCESS AND ESTABLISHING DATA ROUTING
- INITIATING WORKSTATION DISPLAYS AND PROCESSING DATA FOR VOYAGER, ULYSSES, AND GALILEO (AS AVAILABLE)
- TYPES OF QUERIES:
  - PROVIDE DATA "FROM NOW ON"
  - PROVIDE DATA "FROM TIME 'A' ON"
  - PROVIDE DATA IN RANGE FROM TIME 'A' TO TIME 'B'
  - PROVIDE CHANNEL 'X' DATA FROM 'A' TO 'B'

PERSONAL COMPUTER EXAMPLE:
- DEMONSTRATION OF INTERFACE TO A MAC
  - LOW COST PC's OR MAC's CAN BE AND HAVE BEEN USED TO PROCESS AND DISPLAY INSTRUMENT DATA

PERFORMANCE

- GROUND PROCESSING OF SPACECRAFT TELEMETRY DATA

<table>
<thead>
<tr>
<th>DATA RATE</th>
<th>TYPES OF PROCESSING</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 bps to 224 Kbps</td>
<td>Real-Time (Spacecraft to On-Line Storage)</td>
</tr>
<tr>
<td>Up to ~ 500 Kbps</td>
<td>Multiple data streams or Direct connection</td>
</tr>
<tr>
<td>&gt; 500 Kbps *</td>
<td>Data System Adaptation Required</td>
</tr>
</tbody>
</table>

- DATA SYSTEMS OPERATIONS SUPPORT UP TO 24-HOURS PER DAY, 7-DAYS PER WEEK (AS NEGOTIATED WITH PROJECT)
- LOW LATENCY FOR DATA ACCESS - DATA AVAILABLE IN "REAL-TIME" AFTER RECEIPT AT JPL (TYPICALLY THE TIME REQUIRED TO FRAME SYNC THREE FRAMES)
- TIME-ORDERED, COMPLETE DATA SET

* DSN to 900 Kbps
HOW TO REDUCE COST

- ADAPT EXISTING SYSTEM VS DEVELOP A NEW SYSTEM
- USE STANDARDS (e.g., CCSDS) FOR LOWEST COST ADAPTATION
  - ADAPTA11ON BY TABLE UPDATES
  - 90% OR MORE OF PROJECT REQUIREMENTS ARE MET BY EXISTING SYSTEM (MARGINAL COST FOR ADDING A MISSION IS SMALL, e.g., DEVELOPMENT FOR MARS PATHFINDER PROJECT LESS THAN $0.5M)
- REDUCE OPERATIONS AND MAINTENANCE COSTS THROUGH SHARING WITH OTHER MISSIONS (BASELINE SUPPORT NOT CHARGED TO PROJECTS)
- DEFINE AND ENFORCE SYSTEM AND DATA SECURITY RULES

CCSDS: Consultative Committee for Space Data Systems

HOW TO REDUCE COST (continued)

- FOLLOW STANDARDS (ONE PATH THROUGH THE STANDARDS):
  - FOLLOW CCSDS TRANSFER FRAME FORMATS
  - USE THE CCSDS UNSEGMENTED SPACECRAFT CLOCK
  - USE ONE TRANSFER FRAME FORMAT
  - USE VARIABLE LENGTH PACKETS THAT FOLLOW THE CCSDS STANDARD
  - HAVE EACH PACKET TIME-TAGGED WITH THE SPACECRAFT CLOCK AT THE BEGINNING OF THE PACKET
  - DEFINE ALL THE PACKET IDENTIFIERS EARLY
  - USE THE IEEE STANDARDS FOR FLOATING POINT VALUES INSIDE THE PACKETS
  - USE CCSDS STANDARD ALIGNMENT AND PACKING RULES (NON-VAX, IBM) STRUCTURE (IF CCSDS STANDARDS ARE FOLLOWED AND SPACECRAFT INFORMATION IS AVAILABLE, A BASIC GROUND DATA SYSTEM CAN BE OPERATING IN LESS THAN THREE MONTHS)
• MINIMIZE CHANGES IN REQUIREMENTS OR DESIGN
• USE DATA RATES WITHIN DSN CAPABILITIES
• OPTIMIZE ON-LINE STORAGE REQUIREMENTS
  – TRADEOFF BETWEEN HARDWARE AND OPERATIONS COMPLEXITY
• INVOLVE GROUND SYSTEM EARLY IN FLIGHT SYSTEM DESIGN AND DEVELOPMENT (e.g., TEST TELEMETRY AND COMMAND SYSTEM)
• PROVIDE CLOSE SUPPORT TO GROUND SYSTEM TESTERS (e.g., COMBINED TEST TEAM); PARTICIPATE IN GDS TESTING EARLY

TEST TELEMETRY AND COMMAND SYSTEM (TTACS)

• PROVIDES INTEGRATED GROUND DATA SYSTEM PROCESSING SUPPORT
  – SPACECRAFT (OR SYSTEM TESTBED) INTERFACE
  – DATA CAPTURE AND STAGING
  – DATA DISTRIBUTION AND DISPLAY
• SUPPORT FOR SIMULTANEOUS FLIGHT AND GROUND SOFTWARE DEVELOPMENT
• SPACECRAFT ASSEMBLY, TEST, LAUNCH OPERATIONS (ATLO) TEST SUPPORT
• SPACECRAFT FLIGHT SYSTEM TESTBED SUPPORT (POST-LAUNCH)
MARS PATHFINDER DATA FLOW
DEMONSTRATION

- INITIATE MARS PATHFINDER GROUND DATA SYSTEM
  SOFTWARE
  - INTERFACE WITH SPACECRAFT SOFTWARE
  - INITIALIZE TELEMETRY PROCESSING
  - USER DISPLAYS

- SIMULATION OF SOL 1 ENTRY, DESCENT, AND LANDING
  (FIRST DAY ON MARS)
  - RECEIPT OF ENGINEERING DATA FOR ENTRY, DESCENT, AND
    LANDING
  - RECEIPT OF PANORAMA DATA
  - RECEIPT OF ROVER DATA

- DEMONSTRATION OF CHANNEL DEFINITION

- DEMONSTRATION OF EXCEL USE FOR MARS PATHFINDER
  DATA

CONCLUSION

- GROUND DATA SYSTEM ELEMENTS ARE FULLY
  INTEGRATED (INCLUDING COMMAND [UPLINK], DEEP
  SPACE NETWORK, AND PLANETARY DATA SYSTEM)

- SYSTEM IS PROVEN FOR MISSIONS OF ALL SIZES
  - SMALL MISSIONS (e.g., VOYAGER INTERSTELLAR MISSION,
    MAGELLAN GRAVITY MAPPING, MARS PATHFINDER)
  - MODERATE MISSIONS (e.g., MARS OBSERVER)
  - LARGE MISSIONS (e.g., GALILEO, CASSINI)
Low Cost Mission Operations Workshop

MISSION COORDINATION and ENGINEERING ANALYSIS

Michael H. Hill
Functional Area Manager: Spacecraft Analysis
Multimission Operations Systems Office
JPL MISSION COORDINATION AND ENGINEERING ANALYSIS

- MISSION COORDINATION
- NAVIGATING THE SOLAR SYSTEM
- UNDERSTANDING THE SPACECRAFT

JPL MISSION COORDINATION FUNCTIONS

DSN TRACKING CHANGES

REAL-TIME CHANGES
PROJECT RESOURCE NEGOTIATION - ALLOCATION

DSN TRACKING
CONFIGURATION VERIFICATION

MISSION CONTROL TEAM

TELEMETRY FLOW
DSN to USER PATH
CONFIGURATION REROUTING

COMMANING

PERFORMANCE MONITORING

Low Cost Mission Operations Workshop
SPACECRAFT COMMANDING

- MNEMONICS
  - SEQUENCE FILES
  - COMMAND DATABASE
  - REAL-TIME COMMANDS

- BITS
  - GROUND SYSTEM
  - SPACECRAFT PROTOCOL
  - COMMAND PACKAGING

- COMMAND RADIATION
- COMMAND LINK
- CONFIGURATION

- MISSION CONTROL TEAM

- COMMAND VERIFICATION
  - RECEIPT
  - EXECUTION

SPACECRAFT PLANNING AND ANALYSIS

- MISSION COORDINATION
- NAVIGATING THE SOLAR SYSTEM
- UNDERSTANDING THE SPACECRAFT
JPL

NAVIGATING THE SOLAR SYSTEM

- EPHEMERIDES OF CELESTIAL BODIES
- GRAVITY MODELING
- NAVIGATION PLANNING
- ORBIT DETERMINATION
  - OPTICAL NAVIGATION
  - RADIOMETRIC
- MANEUVER AND TRAJECTORY ANALYSIS
- NAVIGATION ANCILLARY INFORMATION FACILITY (NAIF)
  - SPICE INFORMATION SYSTEM

JPL

EPHEMERIS DEVELOPMENT AT JPL

PLANETARY EPHEMERIDES

NATURAL SATELLITE EPHEMERIDES

COMET AND ASTEROID EPHEMERIDES

DATA GOES TO NAIF FOR ARCHIVING AND DISTRIBUTION

ESSENTIAL TO FLIGHT PROJECTS

WORLDWIDE CUSTOMERS
  NASA, ESA, IKI, ISAS
  APL, BMDO
  USNO
  MAJOR OBSERVATORIES
CONTINUOUS EPHEMERIS IMPROVEMENTS

OBSERVERS
- Optical & Radar Observations
- Spacecraft Astrometric Data
- Occultation and Eclipse Data
- Millisecond Pulsar Data
- Lunar Laser Ranging Data
- Very Long Baseline interferometer (VLBI) Data

EPHEMERIS DEVELOPMENT
- Reduce Astrometric Data
- Validate Data
- Improve Dynamic Models
- Improve Masses, Constants, and Station Coordinates
- Update Initial Conditions
- Update Ephemerides

ASTROMETRIC DATA

EPHEMERIS PRODUCTS
- Ephemerides for Solar System Objects
  - 8 Planets & Moon
  - 80 Natural Satellites
  - 1000's of Asteroids & Comets
- Reference Orientation
- Planet & Satellite Orientation Parameters (poles, rotation)

EPHEMERIDES

GRAVITY MODELING

100 Milligals = 1 mm/sec²

180 km

Change in Acceleration 2 - 30 milligals

Gravity Central Body = 820,000 milligals

Mountain or Buried Mass of Unknown Density
NAVIGATION PLANNING

- Perform navigation analysis of mission options as required
- Assess navigation capability in terms of delivery, knowledge accuracies and propellant usage
- Support the uplink design for navigation issues
- Plan radiometric tracking and optical navigation schedules

ORBIT DETERMINATION (OD)

- Combination of engineering disciplines
  - Orbital mechanics
  - Spacecraft dynamics
  - Tracking system characteristics
  - Statistical estimation and filtering theory
- Spacecraft trajectory is numerically integrated to a precision consistent with project requirements
  - Considers non-gravitational accelerations
    - Attitude stabilizations thruster firings
    - Solar radiation
    - Atmospheric drag – etc.
- Radiometric observables computed based on geometry and dynamics between tracking stations and the integrated spacecraft trajectory
  - Accounts for Earth orientation and tracking station motions (precession, nutation, rotation, tides, plate motion)
  - Detailed modeling of the radiometric observable
ORBIT DETERMINATION (continued)

- Radiometric and optical navigation data is conditioned to remove "bad data" and prepare the data for the OD process.
- Estimation and filtering processes have been developed to handle the specific accuracy requirements for OD.

OD SOFTWARE

- Orbit determination is a computer-intensive activity
  - Series of programs to perform the above activities
  - JPL system has 1,000,000 lines of code
  - Heritage back to the early 1970's
  - Executed on UNIX workstations
- Typically minor modifications for adaptation to a new mission
  - Modular, well-documented code
  - Standard interfaces

OPTICAL NAVIGATION

Predicted target location (based on ephemeris data)

Ancillary data to NAIF for distribution

Observed target location

Star at infinity

Optical navigation frame of target and known star
MANEUVER AND TRAJECTORY ANALYSIS

- DESIGN AND ANALYSIS
- MANEUVER IMPLEMENTATION
- REAL-TIME MONITORING
- MANEUVER RECONSTRUCTION
- TRAJECTORY-RELATED PRODUCTS
  - USED BY BOTH ENGINEERING AND SCIENCE IN MISSION OPERATIONS

SPICE INFORMATION SYSTEM

ANCILLARY DATA
- LOCATION, ORIENTATION, SIZE, AND SHAPE OF TARGET BODIES
- LOCATION AND ORIENTATION OF THE SPACECRAFT AND ITS SCIENCE INSTRUMENTS
- LOG OF INSTRUMENT AND SPACECRAFT COMMANDS, AND GROUND DATA SYSTEM ACTIVITIES

USERS
- VOYAGER, MAGELLAN, GALILEO, CLEMENTINE, HUBBLE SPACE TELESCOPE, MARS 94, RADIOASTRON, CASSINI, MARS PATHFINDER

SPICE ANCILLARY INFORMATION SYSTEM IS USED FOR
- EVALUATION OF MISSION DESIGN FROM A SCIENCE PERSPECTIVE
- OBSERVATION PLANNING FOR ONBOARD INSTRUMENTS
- INTERPRETATION OF SCIENTIFIC OBSERVATIONS
## Advantages of Using the SPICE System

- Mature, proven approach that requires minor mission-specific adaptations
- The P.I.'s staff may already be familiar with SPICE from previous work
- Ease of archiving, since SPICE is NASA's standard for archiving ancillary data from planetary missions in the Planetary Data System (PDS)
- Comes with a Navigation Ancillary Information Facility (NAIF) Toolkit for accessing and manipulating the SPICE data
- Facilitates correlation of data across multiple missions and instruments
- Comes with good documentation
  - Written for the outside user

## Navigation Adaptability

<table>
<thead>
<tr>
<th>Component</th>
<th>Adaptation Required</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ephemerides</td>
<td>No adaptation</td>
<td>Adhere to interface specifications for the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ephemerides files</td>
</tr>
<tr>
<td>Orbit Determination</td>
<td>Development</td>
<td>New data types</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No adaptation required for standard set of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OD parameters</td>
</tr>
<tr>
<td>Trajectory Analysis</td>
<td>Adaptation</td>
<td>Non-gravitational models depending on the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spacecraft characteristics</td>
</tr>
<tr>
<td>Maneuver Analysis</td>
<td>Adaptation</td>
<td>Model thruster configurations and characteristics and mission constraints on maneuver implementation</td>
</tr>
<tr>
<td>SPICE</td>
<td>Minimum adaptation</td>
<td>Required to interface the telemetry data and mission sequencing products using NAIF tool kit</td>
</tr>
</tbody>
</table>
### Navigation Low Cost Mission Operations Considerations

<table>
<thead>
<tr>
<th>Mission Description</th>
<th>Number of Observations and Time Between Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimize the Amount of Activity</td>
<td>Number of Observations with Different Instruments</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accuracy Requirements</th>
<th>Reduces the Number of Trajectory Correction Maneuvers Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimize the Delivery Accuracy to the Target Body</td>
<td>Reduces the Amount of Orbit Determination Required</td>
</tr>
<tr>
<td></td>
<td>Reduces the Amount of Tracking Data Required Which Affects the DSN Scheduling</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spacecraft Design</th>
<th>Use Reaction Wheels Instead of Thrusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimize the Effects of Non-Gravitational Forces</td>
<td>Use Thrusters in Balanced Pairs</td>
</tr>
<tr>
<td></td>
<td>Minimize the Projected Area Imbalance To Reduce Solar Pressure Torques and Accelerations</td>
</tr>
</tbody>
</table>

### Spacecraft Planning and Analysis

- Mission Coordination
- Navigating the Solar System
- Understanding the Spacecraft
UNDERSTANDING THE SPACECRAFT

- REAL-TIME MONITORING OF SPACECRAFT HEALTH
- SPACECRAFT HEALTH ASSESSMENT - TREND ANALYSIS
- SPACECRAFT RESOURCE MANAGEMENT
- MANEUVER DESIGN AND RECONSTRUCTION
- INSTRUMENT POINTING AND ENGINEERING CALIBRATIONS
- FLIGHT SOFTWARE MAINTENANCE
- MULTIMISSION SPACECRAFT ANALYSIS SYSTEM
  - A LOOK TO THE FUTURE

REAL-TIME MONITORING OF SPACECRAFT HEALTH

- VERIFY EXECUTION OF ONBOARD SEQUENCES AND REAL-TIME COMMANDS
- MONITOR SPACECRAFT TELEMETRY FOR ALARM VIOLATIONS
- MONITOR COMPONENT TRENDS IN REAL TIME
- MONITOR TELEMETRY LINK MARGINS

MISSION CONTROL ANALYSIS SYSTEM

- CAN BE USED ANYWHERE
- ADAPTABLE VIA SCRIPTS
- USED FOR BOTH INSTRUMENTS ENGINEERING SUBSYSTEMS
SPACECRAFT HEALTH AND STATUS
TREND ANALYSIS

- SCIENCE INSTRUMENT
  - POWER
  - THERMAL PROFILES
  - MODE AND CONFIGURATION CHANGES
- PROPULSION
  - THRUST LEVEL
- TELECOM
  - PREDICTED VS ACTUAL LINK MARGINS
- SPACECRAFT STATE TRACKING
  - PREDICTED vs ACTUALS
- ATTITUDE CONTROL
  - CELESTIAL SENSOR INTENSITIES
  - GYRO DRIFTS
  - MOMENTUM WHEEL LOADING AND UNLOADING
- POWER
  - RTGs
  - BATTERIES

TREND ANALYSIS TOOLS
- SELECTION AND EDITING OF TLM DATA
- PROCESSED DATA DEFINITION
- PLOTTING
- STATISTICAL ANALYSIS
- LOCAL ARCHIVING
- REPORT GENERATION
- SCRIPTING TOOL
- AUTOMATED ANALYSIS PROCESSES

SPACECRAFT RESOURCE TRACKING AND MANAGEMENT

- SCIENCE INSTRUMENTS
  - MODE CHANGE CYCLES
  - FILTER WHEEL USAGE
- FUEL CONSUMPTION
- BATTERY DEPTH OF DISCHARGE CYCLES
- RTG AND SOLAR CELL POWER DEGRADATION
- LIFE TIME LIMITS ON
  - HARDWARE ON-OFF CYCLES
  - ACTUATOR TOTAL ANGLE OF TRAVEL
  - TAPE RECORDER TRACK USAGE
- MOMENTUM WHEEL SATURATION UNLOADING CYCLES
IMPLEMENTING THE MANEUVER

RECONSTRUCTING THE MANEUVER

SPACECRAFT ATTITUDE AND THRUSTER PERFORMANCE DATA

ATTITUDE ESTIMATES
ATTITUDE ERRORS

MANEUVER RECONSTRUCTION

THRUSTER PERFORMANCE
MISALIGNMENTS
MASS PROPERTIES

NAVIGATION DELTA - V
MAGNITUDE AND DIRECTION ESTIMATES

CONTROL AXIS MISALIGNMENTS

FUTURE MANEUVER DESIGNS
ENGINEERING CALIBRATIONS

- INERTIAL REFERENCE UNITS (GYROS)
- ACCELEROMETERS
- CELESTIAL SENSORS
  - SUN SENSORS
  - STAR TRACKERS
  - HORIZON SENSORS
- HIGH GAIN ANTENNA POINTING
- PLATFORM POINTING
  - FIXED
  - ARTICULATING

BIAS
SCALE FACTORS
DRIFT

FUTURE
SCIENCE
SEQUENCES

ELECTRO-
MECHANICAL
OFFSETS
MISALIGNMENTS

INSTRUMENT POINTING CALIBRATION
IMAGING

PREDICTED
ACTUAL

ERROR MODEL
ESTIMATOR

ACTUATORS AND
SENSORS
ELECTRO-MECHANICAL
BIASES AND OFFSETS

FUTURE
SCIENCE
SEQUENCES
INSTRUMENT POINTING CALIBRATION
NON-IMAGING

TOPEX

ERROR MODEL ESTIMATOR
ACTUATORS / SENSORS AND INSTRUMENT ELECTRO-MECHANICAL BIASES AND OFFSETS

ALTIMETER BORESIGHT

FLIGHT SOFTWARE MAINTENANCE PARAMETER UPDATES

SPACECRAFT CALIBRATION RESULTS
FLIGHT SOFTWARE CHANGES
ENGINEERING TESTS
MEMORY READOUT AND COMPARE
SEQUENCE INPUTS
UPDATES
MULTI-MISSION SPACECRAFT ANALYSIS
A LOOK TO THE FUTURE

UPLINK TOOLS
- REVIEW
- APPROVAL
- ENG ACT REQUEST
- SUBSYSTEM PREDICTION

DOWNLINK
- SYSTEM PERFORMANCE
- SPACECRAFT STATE
- TRACKING
- SUBSYSTEM
- PERFORMANCE ANALYSIS
- SUBSYS TREND ANALYSIS
- ENG DATA MANAGEMENT

END TO END
- CALIBRATION
- MANEUVER DESIGN & RECONSTRUCTION
- MODEL MAINTENANCE
- ON-LINE REFERENCE
- TEAM ADMINISTRATION

COMMON COMPONENTS
COMMON USER INTERFACE

WORKSTATION LAYER
MULTIMISSION GROUND DATA SYSTEM

TOOLS AND ADAPTABILITY
- REAL-TIME MONITORING AND TRENDING
- MANEUVER IMPLEMENTATION & RECONSTRUCTION
- SPACECRAFT SENSOR CALIBRATION
- SCIENCE INSTRUMENT POINTING CALIBRATION
- MSAS

ADAPTATION IS ACCOMPLISHED BY THE USE OF SCRIPTS TO CUSTOMIZE THE DATA DISPLAYS AND TO AUTOMATE THE TRENDING VIA BATCH RUNS

MANEUVER IMPLEMENTATION DESIGN AND PROCESSES ARE IN PLACE, CUSTOMIZATION OF THE SPACECRAFT MODELS DEPENDING ON THE HARDWARE COMPLEMENT AND PERFORMANCE CHARACTERISTICS

GENERIC DESIGN IN PLACE - SPECIFIC MODEL DEVELOPMENT REQUIRED FOR THE SPACECRAFT HARDWARE SET

GENERIC DESIGN IN PLACE - SPECIFIC MODEL DEVELOPMENT REQUIRED FOR THE SPACECRAFT HARDWARE SET

FUTURE ADAPTATIONS CAN BE ACCOMPLISHED BY THE ADDITION OF MISSION SPECIFIC MODELS WITHIN THE ANALYSIS ARCHITECTURE

Low Cost Mission Operations Workshop

IHP - 31

Low Cost Mission Operations Workshop

IHP - 32
LOW COST MISSION OPERATIONS
ENGINEERING ANALYSIS

REAL-TIME MONITORING AND TRENDING

- Fly with large margins
- Monitor a limited set of system trends and control the spacecraft as a system
- Monitor for alarm violations only

MANEUVER IMPLEMENTATION & RECONSTRUCTION

- Relax performance requirements to minimize the amount of reconstruction required
- Move the functions to the spacecraft

SPACECRAFT SENSOR CALIBRATION

- Relaxed performance requirements reduces or eliminates the need for calibrations
- Move some calibration functions to the spacecraft

SCIENCE INSTRUMENT POINTING CALIBRATION

- Relaxed performance requirements reduces or eliminates the need for calibrations

DEMONSTRATIONS

NAVIGATION

- Optical navigation
- Real-time radiometric monitoring
- XMIRAGE: Orbit determination

SPACECRAFT ANALYSIS

- Mission control analysis
- Flight software memory state tracker
- MARVEL: Automated telemetry monitoring system
- VULCAN: Solar flare modeling and visualization
<table>
<thead>
<tr>
<th><strong>SUMMARY</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• MISSION COORDINATION IS HANDLED BY AN INSTITUTIONAL MISSION CONTROL TEAM</td>
</tr>
<tr>
<td>- CONFIGURATION AND CONTROL OF THE GROUND DATA LINKS TO AND FROM THE DSN</td>
</tr>
<tr>
<td>- COMMANDING - PACKAGING &amp; PROTOCOLS</td>
</tr>
<tr>
<td>- REAL-TIME MONITORING</td>
</tr>
<tr>
<td>• NAVIGATION</td>
</tr>
<tr>
<td>- RECOGNIZED SOURCE OF DATA FOR PLANETARY, SPACECRAFT, ASTEROID, AND COMET EPHEMERIDES</td>
</tr>
<tr>
<td>- ORBIT DETERMINATION TOOLS</td>
</tr>
<tr>
<td>• OPTICAL NAVIGATION AND RADIOMETRIC TRACKING</td>
</tr>
<tr>
<td>• SPACECRAFT HEALTH AND MONITORING</td>
</tr>
<tr>
<td>- CORE SET OF TOOLS FOR REAL-TIME MONITORING AND TRENDING</td>
</tr>
<tr>
<td>- MISSION-SPECIFIC TOOLS DEPEND ON SPACECRAFT HARDWARE CONFIGURATION AND DEVICES</td>
</tr>
<tr>
<td>• HARDWARE CALIBRATION</td>
</tr>
<tr>
<td>• INSTRUMENT POINTING CALIBRATION</td>
</tr>
<tr>
<td>• ATTITUDE RECONSTRUCTION</td>
</tr>
</tbody>
</table>
Low Cost Mission Operations Workshop

SUMMARY

Gael F. Squibb
Manager: Flight Projects Mission Operations
Development Program Office

OUTLINE

- ADDITIONAL SERVICES
- LOW COST CONSIDERATIONS
- MARS PATHFINDER DEVELOPMENT COSTS
- TECHNOLOGY
- A LOOK TO THE FUTURE
ADDITIONAL SERVICES

• RESOURCE ALLOCATION PROCESS (RAP)
• TRAINING AND READINESS
• LAUNCH OPERATIONS SUPPORT
• END-TO-END INFORMATION SYSTEM (EEIS) ENGINEERING

RESOURCE ALLOCATION PLANNING PROCESS FOR THE DEEP SPACE NETWORK

ESSENTIAL TO UNDERSTAND THE PROCESS
THE SYSTEM IS ALMOST ALWAYS OVERSUBSCRIBED
USERS MUST PLAN AHEAD
CONFLICTS CAN BE RESOLVED WHEN IDENTIFIED EARLY
FLEXIBILITY IS VITAL
JPL

ADDITIONAL SERVICES

MISSION OPERATIONS SYSTEM TRAINING & READINESS

- GROUND DATA SYSTEM FAMILIARIZATION
  - WORKBOOKS
  - LECTURES
- WORKSTATION APPLICATION TRAINING
  - BASIC WORKSTATION
  - POWER USER TOOLS
- MISSION OPERATIONS POSITIONAL TRAINING AND CERTIFICATION
- PROJECT SCENARIO TRAINING EXERCISES
  - FAULT RECOVERY EXERCISES
- END-USER WORKSTATION SYSTEM CONFIGURATION AND USER CONSULTING

JPL

ADDITIONAL SERVICES

LAUNCH OPERATIONS SUPPORT

- JPL RESIDENT OFFICE AT CAPE CANAVERAL PROVIDES:
  - SAFETY TRAINING, BADGING, AND SECURITY ASSISTANCE
  - RECEIVING AND HANDLING OF SPACECRAFT AND SCIENCE INSTRUMENTS
  - HELP IN SCHEDULING USE OF EASTERN LAUNCH SITE FACILITIES
  - HELP IN PUBLICATION OF REQUIRED DOCUMENTATION
  - TECHNICAL SUPPORT FOR LAUNCH PREPARATION PROCESS
  - INTERFACE TO KENNEDY SPACE CENTER (KSC)
- JPL PROVIDES TECHNICAL SUPPORT TO LAUNCH CAMPAIGN
  - SPACECRAFT SYSTEM TEST OPERATIONS
  - SPACECRAFT LAUNCH ANOMALY TEAM
  - GROUND DATA SYSTEM OPERATIONS
  - INTERFACE TO JPL OPERATIONS CENTER

Low Cost Mission Operations Workshop
JPL

ADDITIONAL SERVICES

END-TO-END INFORMATION SYSTEM ENGINEERING

- JPL HAS EXPERIENCED ENGINEERS TO ASSIST PROJECTS AND P.I.'S IN DESIGNING A COST-EFFECTIVE END-TO-END INFORMATION SYSTEM, WHICH INCLUDES GROUND AND FLIGHT COMPONENTS OF THE INFORMATION SYSTEM.

JPL

SERVICES

- PROJECT DESIGN CENTER (PDC)

- FLIGHT SYSTEM TESTBED (FST)
SUMMARY OUTLINE

- SERVICES
- LOW COST CONSIDERATIONS
  - MARS PATHFINDER DEVELOPMENT COSTS
  - TECHNOLOGY
  - A LOOK TO THE FUTURE

LOW COST CONSIDERATIONS

- FACTORS
  - COMPLEXITY OF THE MISSION
  - OPERABILITY OF THE SPACECRAFT AND INSTRUMENTS
  - DESIGN OF THE MISSION OPERATIONS SYSTEM
  - MANAGEMENT RISK POLICIES
- GROUND APPROACHES FOR A GIVEN FLIGHT SYSTEM
  - PERFORM FUNCTIONS MORE EFFICIENTLY
  - ELIMINATE FUNCTIONS AND CAPABILITIES
  - USE LOWER COST STAFF
  - ASSUME GREATER RISK
LOW COST CONSIDERATIONS

MISSION PLANNING AND ANALYSIS

- Ensure that spacecraft and instruments have positive margins so that sequences do not have to be validated from an engineering point of view.
- Examine spacecraft autonomy vs ground sequencing of appropriate functions.
- Design the mission and spacecraft to minimize the number of mission and flight rules to check.
- Maximize operability and ensure minimum amount of interaction between subsystems.

SYSTEM OVERVIEW

Diagram showing the system overview with labeled processes and interactions.
LOW COST CONSIDERATIONS

SEQUENCE DEVELOPMENT

• REDUCE THE NUMBER OF SEQUENCES THAT MUST BE PRODUCED

• ELECTRONIC REVIEW OF SEQUENCE

• SET APPROVAL LEVEL AT LOWEST POSSIBLE LEVEL: WHAT IS THE VALUE ADDED BY THIS APPROVAL LEVEL?

• MINIMIZE SEQUENCE CHANGES DURING THE SEQUENCE DEVELOPMENT PERIOD

• USE AN INTEGRATED SET OF SEQUENCING TOOLS RATHER THAN MANY INDIVIDUAL TOOLS

• USE CONTINUOUS RUNNING SEQUENCE WITH TIME GAPS FOR SEQUENCE OVERLAYS

• DEVELOP SEQUENCE DEVELOPMENT STRATEGY THAT ELIMINATES CONFLICTS

• BLOCK TIMES FOR COMPATIBLE REQUESTS

• ADOPT A PRIORITY SCHEME THAT ALLOWS AUTOMATIC RESOLUTION OF CONFLICTS

• USE REUSABLE BLOCKS

• PERFORM SEQUENCE VALIDATION OF FUNCTION WITH ACCEPTABLE DATA-RETURN RISK
LOW COST CONSIDERATIONS

MISSION CONTROL

- SHARING OPERATORS BETWEEN MISSIONS
- MULTI-TASK OPERATORS WITH RELATED TASKS
- HAVE GROUND AND FLIGHT SYSTEMS THAT ACCOMMODATE CHANGE
- USE GRAPHICAL USER INTERFACES THAT REDUCE THE REQUIREMENTS ON THE MISSION CONTROLLERS FOR DETAILED GROUND OR FLIGHT KNOWLEDGE
- AUTOMATED ANALYSIS OF GROUND AND FLIGHT INFORMATION WHICH IDENTIFIES OR ANTICIPATES PROBLEM AREAS

DATA TRANSPORT AND DELIVERY

- MINIMIZE AMOUNT OF DSN COVERAGE REQUIRED
- DESIGN THE SPACECRAFT AND INSTRUMENT DATA CONTENT, STRUCTURES, AND FORMATS TO MATCH THE CAPABILITIES OF THE EXISTING TRANSPORT AND DELIVERY SYSTEMS
  - USE SPECIFIC STANDARDS TO ENSURE COMPATIBILITY OF SPACECRAFT DATA SYSTEM AND GROUND DATA SYSTEM
- USE VARIABLE LENGTH PACKETS, AS OPPOSED TO MANY SPECIFIC FORMATS
LOW COST CONSIDERATIONS

NAVIGATION

- Understand accuracy requirements vs navigation cost
- Minimize demands of maneuver frequency
  - Three maneuvers in five days for each orbit will be costly
- Understand DSN services (free) vs project-specific functions and attempt to minimize project-specific requirements
- Trade off onboard navigation functions vs ground-based functions accommodated by sequence development

SPACECRAFT PLANNING AND ANALYSIS

- Design the spacecraft so it can be analyzed at the system level
  - Ensure direct measurements of system-level parameters
- Maintain subsystem margins
- Minimize interactions
- Have robust safing capability
- Minimize the need for real-time analysis of engineering data
- Use automated analysis tools
LOW COST CONSIDERATIONS

SCIENCE PLANNING AND ANALYSIS

- USE EXISTING PLANNING TOOLS
- CONSIDER COMBINING PLANNING AND ANALYSIS FUNCTIONS FOR SPACECRAFT AND SCIENCE INSTRUMENTS
- CONSIDER AUTOMATION OF INSTRUMENT DATA - GATHERING SEQUENCES
- DURING THE DESIGN PHASE, ASK THE QUESTION: HOW WILL I DETERMINE THE INSTRUMENT COMMANDS BASED ON SCIENTIFIC PARAMETERS FOR AN OBSERVATION?
- MINIMIZE THE NEED FOR SEQUENCES BASED ON DATA RECEIVED (ADAPTIVE OR NOT KNOWN)

SCIENCE DATA PROCESSING

- USE EXISTING TOOLS
- UNDERSTAND THE AVAILABILITY OF ANCILLARY DATA NEEDED FOR SCIENCE DATA PROCESSING
- UNDERSTAND ROBUSTNESS OF PROCESSING-TO-DATA-LOSS OR DROPOUTS. REQUIRES UNDERSTANDING OF THE DATA TRANSPORT PERFORMANCE RELATIVE TO SCIENCE DATA
  - COMPRESSION
  - FORMATTING
ARCHIVING

- DEVELOP THE PLAN EARLY AND ENSURE THAT THE CAPABILITIES EXIST, RATHER THAN TRY TO PUT TOGETHER CAPABILITY TO MEET ARCHIVE REQUIREMENTS LATE
  - ANCILLARY DATA NEEDED
  - SUPPORTING DOCUMENTATION

MOS MANAGEMENT

- ASSIGN STAFF TO MULTIPLE TASKS
- USE GRADUATE STUDENTS FOR SOME FUNCTIONS
- KEEP OPERATIONS ORGANIZATION SIMPLE
- MINIMIZE INTERFACES BETWEEN GROUPS
  - LOOK AT RECEIVABLES AND DELIVERABLES FOR EACH GROUP
- ESTABLISH COST-EFFECTIVE RISK-AVOIDANCE POLICIES
The following projects are operating with specific cost constraints and have traded off capabilities and science return vs cost:
- Mars Pathfinder
- Voyager:
  - Extended Mission
- Pluto

Most early planetary missions were operated under a performance paradigm, and were not designed to minimize operational and life cycle costs.
JPL MARS PATHFINDER OPERATIONS ORGANIZATION

with Operations Functional Assignments

Mission Director

- Operations management - day-to-day

- DSN Teams
  - Memory recovery
  - Tracking data recovery
  - Data transport
  - Tracking data pre-processing

- MISO Teams
  - Ongoing ops test and training
  - AMOS ops and maintenance
  - Flight element command
  - Data management
  - Telemetry data processing

Low Cost Mission Operations Workshop

JPL VOYAGER FLIGHT TEAM ORGANIZATION CHANGES

FUNCTION-ORIENTED ORGANIZATION

PROJECT MANAGEMENT

FLIGHT TEAM MANAGEMENT

GDS STAFF

SPOT

SEQ

SVC

NAV

FOT

NOTE: Staffing numbers reflect 1983 staffing/1990 staffing - (46.5/26.5)

PROCESS-ORIENTED ORGANIZATION

PROJECT / FLIGHT TEAM MANAGEMENT

UPLINK TEAM

- SEQUENCE GENERATION
- COMMAND
- TRANSMISSION AND VERIFICATION

DOWNLINK TEAM

- MISSION CONTROL
- SYSTEM ANALYSIS
- S/C SUBSYSTEM ANALYSIS
- DATA MANAGEMENT

Low Cost Mission Operations Workshop
JPL
PLUTO CRUISE OPERATIONS

PLUTO OPS TEAM CHEF 1.0 FTE

SECRETARY, DATA TECH 2.0 FTE

SC SYSTEM ENGINEERING 1.5 FTE

PLANNING & SCHEDULING 2.0 FTE

EEMOS POST-LAUNCH DEV. 1.5 FTE

DATA MGT. & COORDINATION 1.0 FTE

NAVIGATION OPERATIONS 0.5 FTE

- 9.5 FTEs

INSTRUMENT CONTROLLER ANALYSTS 1.0 FTE
ANALYSTS 3.0 FTE
PROPULSION CONTROLLER ANALYSTS .5 FTE
SOS CONTROLLER ANALYSTS 3.0 FTE
SCE CONTROLLER ANALYSTS 1.0 FTE
TELECOM CONTROLLER ANALYSTS 1.0 FTE
POWER/TC CONTROLLER ANALYSTS .5 FTE
THERMAL CONTROLLER ANALYSTS .5 FTE

- 10.5 FTEs

+ TJO UNIVERSITY SUPPORT
+ TJO UNIVERSITY SUPPORT
+ TJO UNIVERSITY SUPPORT
+ TJO UNIVERSITY SUPPORT
+ TJO UNIVERSITY SUPPORT
+ TJO UNIVERSITY SUPPORT
+ TJO UNIVERSITY SUPPORT
+ TJO UNIVERSITY SUPPORT

TOTAL JPL CRUISE OPS = 25 FTEs
(FOR TT20 5C)

Low Cost Mission Operations Workshop
GFS - 20

JPL
SUMMARY OUTLINE

- SERVICES
- LOW COST CONSIDERATIONS
- MARS PATHFINDER DEVELOPMENT COSTS
- TECHNOLOGY
- A LOOK TO THE FUTURE

Low Cost Mission Operations Workshop
GFS - 30
SPACECRAFT TECHNOLOGY TO ENABLE LOWER COST OPERATIONS
- MARGINS
- LARGER MEMORIES AND FASTER CPU's
- SOLID STATE MEMORIES AND ONBOARD DATA MANAGEMENT

SPACECRAFT CONTROL AND SEQUENCING
- EVENT-DRIVEN SEQUENCING
- ONBOARD MANEUVER COMPUTATION
- PROCESS CONTROL (RULE-BASED SEQUENCES)
- UPLINK SERVICE SPECIFICATION
- STANDARDIZED DATA COLLECTION, RETRIEVAL, STORAGE, AND TRANSPORT

MOS TECHNOLOGY
SPACECRAFT MARGINS

MICRO-SPACECRAFT TECHNOLOGY MUST ENSURE THAT SPACECRAFT USING THESE TECHNOLOGIES HAVE SIGNIFICANTLY GREATER MARGIN THAN THE CURRENT GENERATION OF SPACECRAFT, ESPECIALLY IN THE FOLLOWING AREAS:
- POWER
- THERMAL
- TELECOMMUNICATIONS
- DATA STORAGE
- COMPUTATIONAL SPEED
• LARGER MEMORIES AND FASTER CPU’s WILL ENABLE USE OF
  - STANDARD OPERATING SYSTEMS
  - MODERN PROGRAMMING LANGUAGES
  - SPACECRAFT AUTONOMY TO REDUCE MISSION OPERATIONS COSTS
  - HIGHER LEVEL SEQUENCE LANGUAGES ONBOARD
  - HIGHER LEVEL SIMULATIONS (IF REQUIRED), SINCE ADEQUATE MARGINS WILL ELIMINATE NEED FOR MICRO-SECOND SIMULATIONS

• DSN OVERLOADING WILL REQUIRE SHORTER TRACKS, WHICH WILL DRIVE THE NEED FOR LARGER SOLID-STATE RECORDERS

• EASY DATA MANAGEMENT OF THESE RECORDERS (PC-LIKE EASE) MUST BE INCLUDED TO KEEP OPERATIONAL COSTS DOWN
  – RECORDER MODELING OF DATA LOCATION IS COST-PHOBITIV

• SHORTER DSN TRACKS WILL ALSO DRIVE THE NEED FOR HIGHER DATA TRANSMISSION RATES FOR THE OUTER PLANETARY MISSIONS

• JOINT SPACECRAFT AND DSN TECHNOLOGY THRUSTS ARE REQUIRED
• EVENT-DRIVEN SEQUENCING
  - REQUIRED FOR MISSIONS SUCH AS ASTEROID SAMPLE
  - NASA HAS LITTLE EXPERIENCE IN THIS TYPE OF
    SEQUENCING BECAUSE WE HAVE DEVELOPED SEQUENCES
    IN THE TIME DOMAIN BOTH FOR PLANETARY AND
    ASTROPHYSICS MISSIONS
• ONBOARD COMPUTATION OF MANEUVERS
  - MORE COMPUTER POWER MAY ALLOW ONBOARD OPTICAL
    NAVIGATION WHICH COULD BE REQUIRED FOR SOME
    MISSIONS
• UPLINK PROCESS CONTROL
  - APPLY RESULTS OF PROCESS CONTROL RESEARCH TO
    SPACECRAFT CONTROL
  - RULE-BASED SEQUENCING
  - CLEMENTINE IS USING FIRST SUCH SPACECRAFT AND
    GROUND S/W
  - NEED TO VALIDATE NEW RULES ON GROUND BEFORE
    SENDING RULES TO SPACECRAFT
    - IMPLIES COMMON GROUND AND SPACECRAFT SHELL
      FOR PROCESS CONTROL

• UPLINK SERVICE SPECIFICATIONS
  - THE DOWNLINK SERVICE SPECIFICATION (CCSDS) HAS
    ENABLED STANDARDIZATION OF TRANSPORT AND
    PROCESSING OF SPACECRAFT DATA
  - AN UPLINK SERVICE SPECIFICATION WILL ENABLE THE
    STANDARDIZED CONTROL OF SPACECRAFT WHICH FOLLOW
    THE STANDARD (FROM A DATA SYSTEM POINT OF VIEW)
  - WORK HAS JUST STARTED BUT NEEDS TO BE ESCALATED IN
    IMPORTANCE & FUNDING

• STANDARDIZED DATA COLLECTION, RETRIEVAL,
  STORAGE, AND TRANSPORT
  - THIS FUNCTION IS THE SAME FOR ALL MISSIONS
  - WE RE-IMPLEMENT IT FOR EACH NEW PROJECT
  - WITH LARGER, FASTER COMPUTERS AND USE OF MODERN
    PROGRAMMING LANGUAGES, WE NEED TO DEVELOP THE
    SOFTWARE FOR THIS CAPABILITY THAT WILL WORK ACROSS
    SEVERAL SPACECRAFT COMPUTER PLATFORMS AND BE
    COMPATIBLE WITH CURRENT GROUND SYSTEMS
A LOOK TO THE FUTURE

- Missions that spend the project money on new instruments and processing of data as opposed to re-implementing data functions again

- Incorporation of new capabilities into an integrated set of tools that are easy to use by any person participating in operations

- Cross-training individuals, as opposed to creating a multitude of specialists

WHAT IS THE NEXT STEP?

Several possible ways to interact with us after this workshop

- Unsolicited proposal

- Letter of interest

- Describe sources of more cost-effective capabilities or approaches

- Give information about capabilities we should be aware of prior to entering into further dialog

- Demonstration of existing capabilities that would offer cost savings to NASA
Low Cost Mission Operations Workshop

Panelists

Tuesday, April 5

Michael Ebersole
Norman R. Haynes
William Kurth
T.D. Linick
Gael Squibb

Wednesday, April 6

Esker K. Davis
Ray Goldstein
Norman R. Haynes
William Kurth
T.D. Linick
Gael Squibb

Tuesday, April 7

John Casani
Norman R. Haynes
Ed Kieckhefer
T.D. Linick
Steve Proia
Gael Squibb
### Low Cost Mission Operations Workshop

#### Panelists

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Title</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casani, John R.</td>
<td>JPL</td>
<td>Assistant Laboratory Director</td>
<td>Office of Flight Projects</td>
</tr>
<tr>
<td>Davis, Esker K.</td>
<td>JPL</td>
<td>Manager</td>
<td>Discovery Office</td>
</tr>
<tr>
<td>Ebersole, Michael M.</td>
<td>JPL</td>
<td>Assistant Manager</td>
<td>Mars Pathfinder Project</td>
</tr>
<tr>
<td>Goldstein, Dr. Raymond</td>
<td>JPL</td>
<td>Manager</td>
<td>Space Physics &amp; Astrophysics</td>
</tr>
<tr>
<td>Haynes, Norm R.</td>
<td>JPL</td>
<td>Assistant Laboratory Director</td>
<td>Telecommunications &amp; Data Acquisition</td>
</tr>
<tr>
<td>Kieckhefer, Edward H.</td>
<td>JPL</td>
<td>Contract Negotiation Specialist</td>
<td>Procurement</td>
</tr>
<tr>
<td>Kurth, William S.</td>
<td>University of Iowa</td>
<td>Consultant</td>
<td>Advanced Information Systems</td>
</tr>
<tr>
<td>Linick, T.D.</td>
<td>JPL</td>
<td>Manager</td>
<td>Multimission Operations Systems Office</td>
</tr>
<tr>
<td>Proia, Stephen L.</td>
<td>JPL</td>
<td>Manager</td>
<td>NASA Prime Contract Section</td>
</tr>
<tr>
<td>Squibb, Gael F.</td>
<td>JPL</td>
<td>Manager</td>
<td>Mission Operations Development Program Office</td>
</tr>
</tbody>
</table>
1. **Science Data Processing and Analysis**

   - AESOP - Advanced End-to-End Simulation of Onboard Processing
   - VICAR - Instrument Data Processing Software
   - LinkWinds - Science Analysis Support System
   - PLATO - Processing and Display of Image Data from PDS Data Sets
   - DBVIEW - Science Data Management System Client Software

2. **Mission Design, Planning and Sequencing**

   - SEQ_POINTER - Remote Sensing Observation Generation and Design
   - PLAN-IT-II - Activity Generation and Integration
   - SEQ_GEN - Sequence Generation and Integration
   - SEG Shell and SEG - Sequence of Events Generator and its Operational Shell
   - Command Translation Tool Kit - Command Mnemonic, Bit Pattern, and Corresponding Telemetry

3. **Data Transport and Delivery**

   - Telemetry Data Processing Demonstration
   - Data Query Demonstration
   - Mars Pathfinder Demonstration

4. **Mission Coordination and Engineering**

   - **Navigation**
     - Optical Navigation
     - Real-Time (Radiometric) Monitoring
     - XMIRAGE - Orbit Determination Software

   - **Spacecraft Analysis**
     - Flight Software Memory State Track
     - Mission Control Analysis
     - MARVEL
     - VULCAN

5. **Summary**

   - IMOS - Integration Mission Operations System
     - Small Mission Prototype
Low Cost Mission Operations Workshop

For More Information

If you would like more information about low cost mission operations at JPL, you may contact these people:

Low Cost Mission Operations at JPL

Gael F. Squibb
Manager: Flight Projects Mission Operations Development Program Office
The Jet Propulsion Laboratory, m.s. 180-401
(818) 354-4086 FAX (818) 393-6800
Email: GAEL_F_SQUIBB@CCMAIL.JPL.NASA.GOV

Mission Operations for NASA Discovery Missions

Esker K. Davis
Manager: JPL Discovery Office
Office of Space Science and Instruments
The Jet Propulsion Laboratory, m.s. 180-701
(818) 354-4343 FAX (818) 354-0712
Email: ESKER_K_DAVIS@CCMAIL.JPL.NASA.GOV

Multimission Operations Systems Office (MOSO)

Al Beers
Manager: Flight Projects Interface Office
The Jet Propulsion Laboratory, m.s. 171-250
(818) 354-3416 FAX (818) 393-4267
Email: AL_BEERS@CCMAIL.JPL.NASA.GOV

Office of Telecommunications and Data Acquisition and the Deep Space Network

Ray Amorose
Manager: TDA Mission Support and DSN Operations Office
The Jet Propulsion Laboratory, m.s. 303-404
(818) 354-0052 FAX (818) 393-1692
Email: RAY_J_AMOROSE@CCMAIL.JPL.NASA.GOV
For more information about specific presentations and demonstrations, you may contact these people:

**Science Data Processing and Analysis**

William Green  
Functional Area Manager: Operational Science Analysis  
The Jet Propulsion Laboratory, m.s. 168-527  
(818) 354-3031 FAX (818) 393-6962  
Email: Bill_Green@iplmail.jpl.nasa.gov

**Mission Design, Planning and Sequencing**

Robert K. Wilson  
Functional Area Manager: Planning and Sequencing  
The Jet Propulsion Laboratory, m.s. 301-250D  
(818) 354-1128 FAX (818) 393-5074  
Email: ROBERT_K_WILSON@CCMAIL.JPL.NASA.GOV

**Data Transport and Delivery**

Robert Edelson  
Functional Area Manager: Telemetry  
The Jet Propulsion Laboratory, m.s. 525-3600  
(818) 306-6279 FAX (818) 306-6925  
Email: REDELSON@DEVVAX.JPL.NASA.GOV

**Mission Coordination and Engineering**

Michael Hill  
Functional Area Manager: Spacecraft Analysis  
The Jet Propulsion Laboratory, m.s. 301-445  
(818) 354-3414 FAX (818) 393-6871  
Email: MHILL@CCMAIL.JPL.NASA.GOV