Operations Concepts for Deep-Space Missions: Challenges and Opportunities

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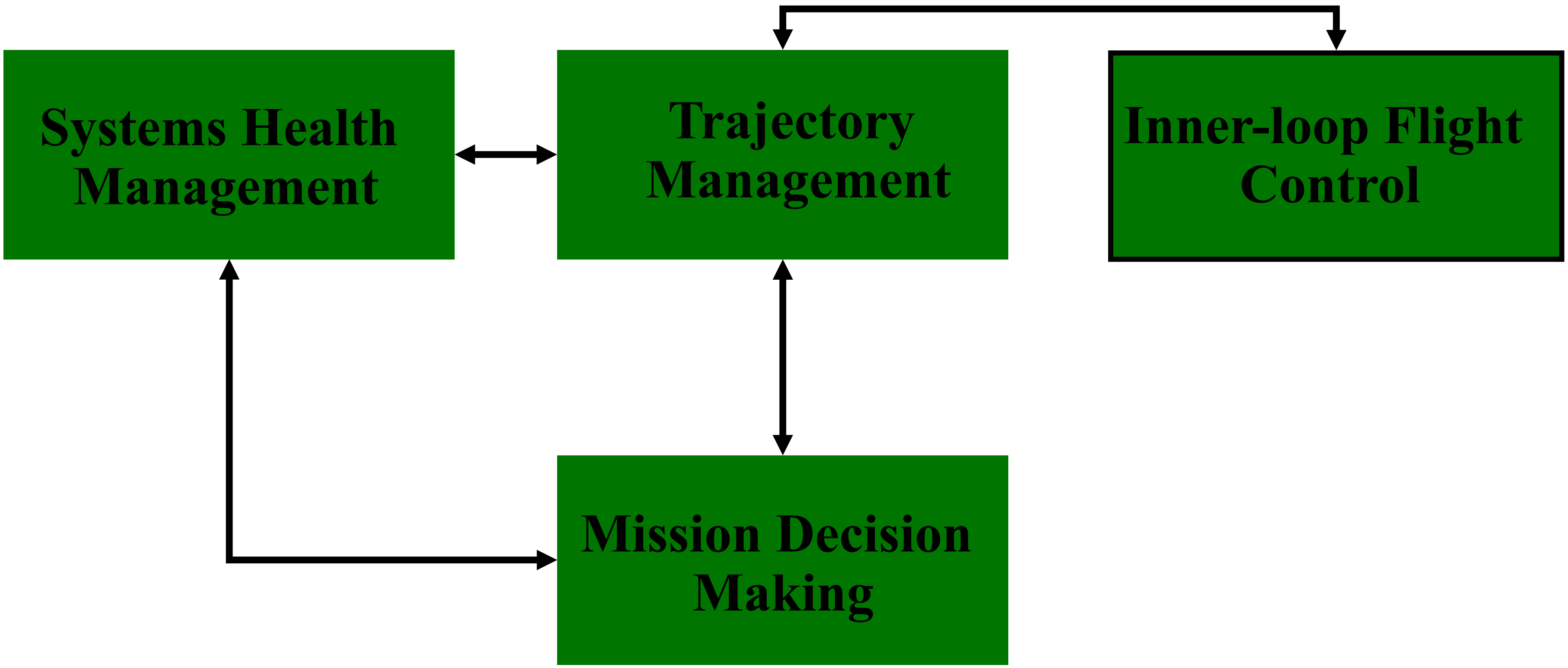
Overview

- Brief History Lesson in Spacecraft Operations:
    - Where we've been (Apollo)
    - Where we are (Shuttle)
    - Where we *were* headed (Constellation)

- Where we're going now
    - Operations Requirements for Deep Space Missions

- Roadmap
    - How do we get there

Spacecraft Operations during Dynamic Phases of Flight



Apollo 12 Ascent Operations: Systems Management

- 36.5 seconds after lift-off from Kennedy Space Center, the vehicle triggered a lightning discharge through itself.
- Protective circuits on the fuel cells in the service module falsely detected overloads and took all three fuel cells offline
- Power supply problems lit nearly every warning light on the control panel and caused much of the instrumentation to malfunction.
- The telemetry stream at Mission Control was garbled nonsense.

Apollo 12 Ascent Operations: Systems Management

- Pete Conrad:

  "Although I was watching the gauges I was aware of a white light. The next thing I noted was that I heard the master alarm ringing in my ears and I glanced over to the caution and warning panel and it was a sight to behold."

- Almost every warning light that had anything to do with the electrical system was on.

- The telemetry stream at Mission Control was garbled nonsense.

Apollo 12 Ascent Operations: Systems Management

- EECOM John Aaron remembered the telemetry failure pattern from an earlier test
- Aaron made a call:

  "Try SCE to aux".

- This switched the SCE to a backup power supply

- Aaron's quick thinking prevented an abort

Apollo 11 LEM Descent and Landing Operations: Systems Management

- 102:38:**26** Armstrong: (With the slightest touch of urgency) Program Alarm.
- 102:38:**30** Armstrong: (To Houston) It's a 1202.
- 102:38:**32** Aldrin: 1202. (Pause)
- 102:38:**42** Armstrong (on-board): (To Buzz) What is it?
- **(To Houston) "*Give us a reading on the 1202 Program Alarm*"**
- 102:38:**53 Duke: "*Roger. We got you*"...(With some urgency in his voice)

"We're Go On That Alarm."

Lessons Learned from Apollo 11
Operations: Workload

"The most difficult part [of the entire mission] from my perspective, and the one that gave me the most pause, was the final descent to landing"

"far and away the most complex part of the flight"

"systems were very heavily loaded at that time"

"the unknowns were rampant"

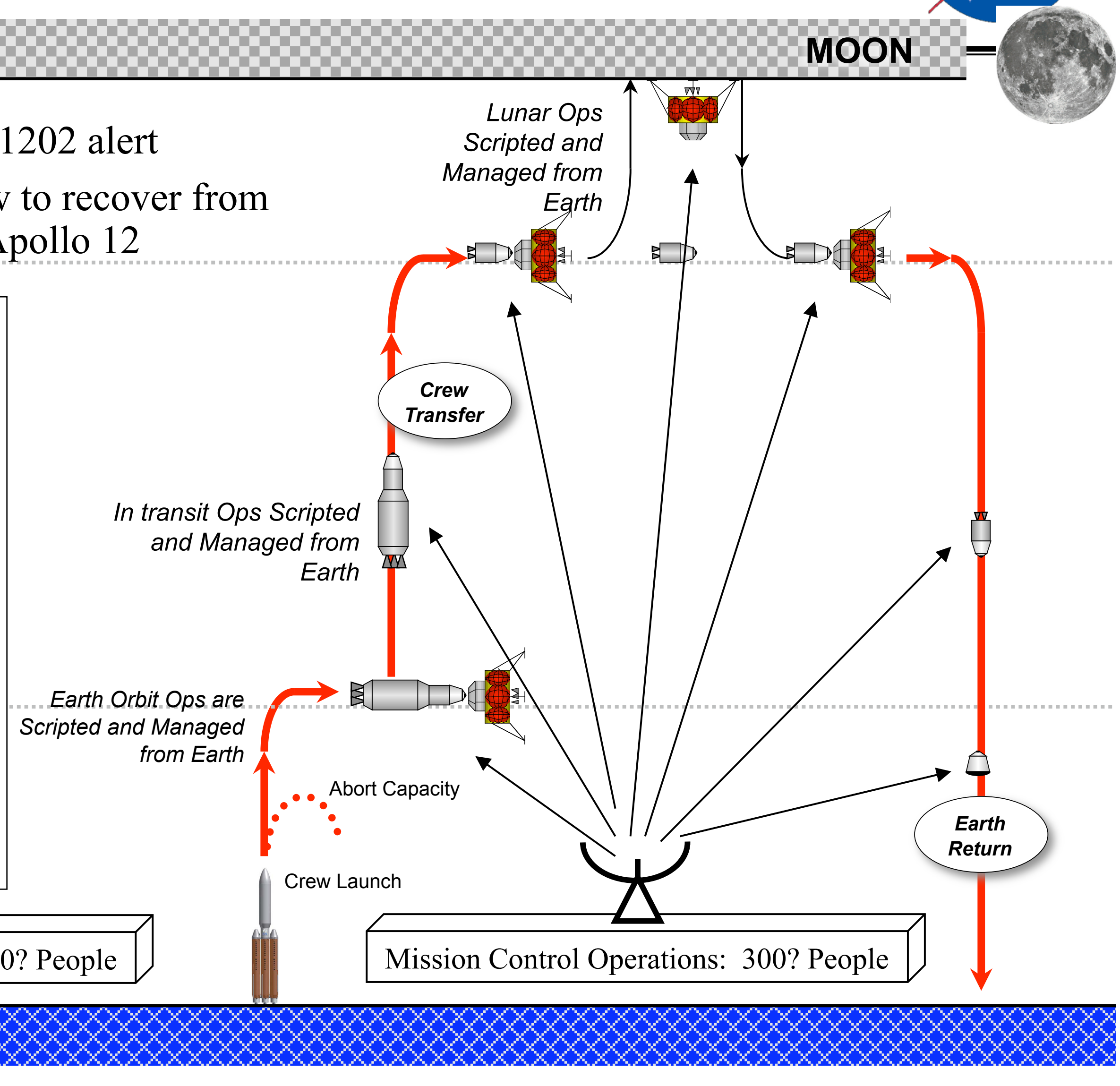
"there were just a thousand things to worry about… It was hardest for the system and it was hardest for the crews to complete that part of the flight successfully"

- Neil Armstrong, September 2001

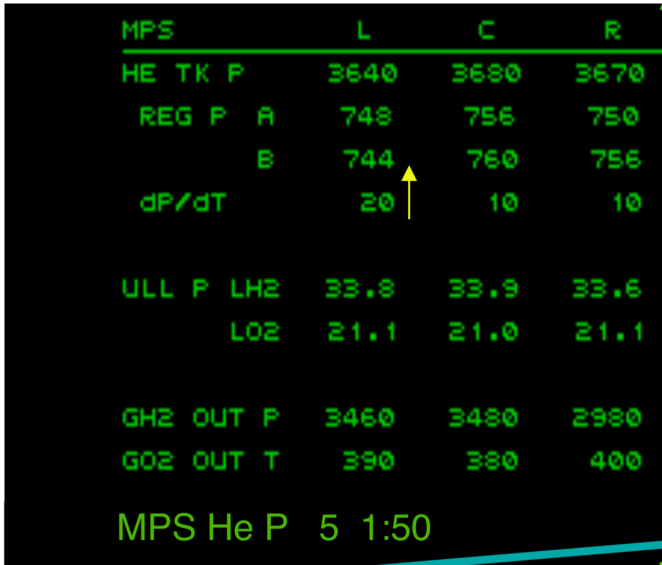
Ground-Centered Concept of Operations

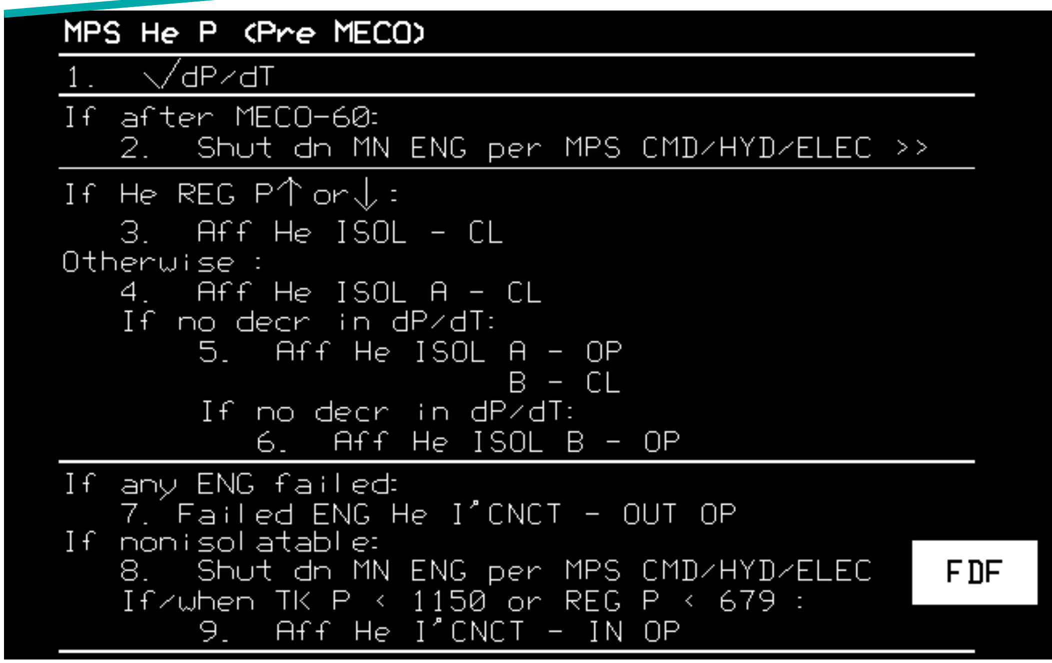
- Ground made the call on the 1202 alert
- Ground made the call on how to recover from the ascent lightning strike on Apollo 12

- On-orbit Activities Managed by Ground Control
- CapCom in the loop on every decision
- On-board mission re-planning Limited to None
- Voice-loops to Earth critical
- Life-support, Spacecraft Health, Navigation managed from Mission Control
- Launch, Mission Control, and Science Team are "Standing Teams", this is their sole job.
- Ground Operations Collocated by Areas in one spot



Shuttle Fault Management Interfaces




MPS He P (Pre MECO)

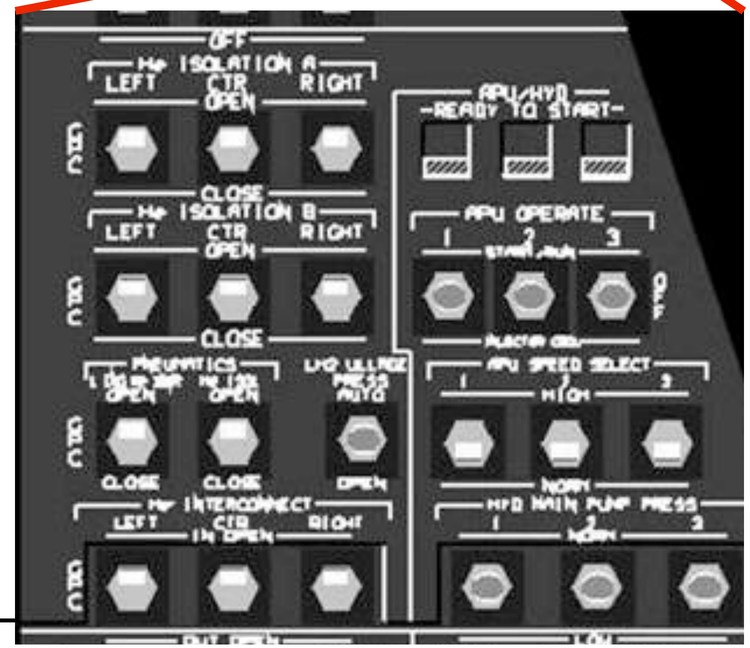
1. √dP/dT

If after MECO-60:
2. Shut dn MN ENG per MPS CMD/HYD/ELEC >>

If He REG P↑ or↓:
3. Aff He ISOL - CL
Otherwise :
4. Aff He ISOL A - CL
If no decr in dP/dT:
5. Aff He ISOL A - OP
B - CL
If no decr in dP/dT:
6. Aff He ISOL B - OP

If any ENG failed:
7. Failed ENG He I'CNCT - OUT OP
If nonisolatable:
8. Shut dn MN ENG per MPS CMD/HYD/ELEC
If/when TK P < 1150 or REG P < 679 :
9. Aff He I'CNCT - IN OP

FDF



Lessons Learned from Apollo 11 Operations

- Project Constellation Vehicles
- Severe weight limitations
- very limited onboard computing capability
- severe funding starvation
- focus quickly devolved to shuttle replacement (station servicing) ops

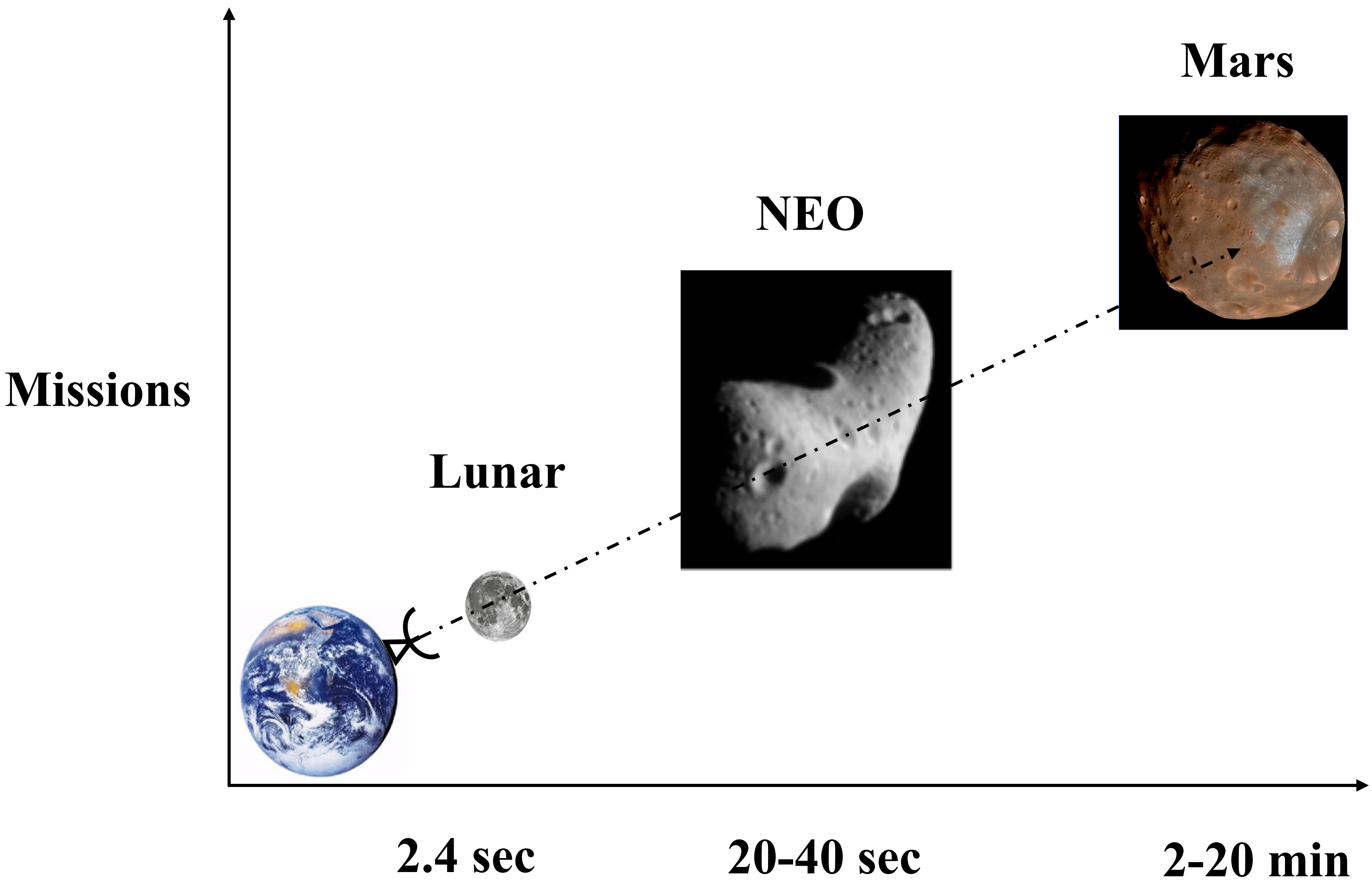
The Big-Picture Scenario

Today we are launching a bold and ambitious new space initiative to enable us to explore new worlds, develop more innovative technologies, foster new industries, increase our understanding of the Earth, expand our presence in the solar system, and inspire the next-generation of explorers…

…the President has laid out a dynamic plan for NASA to invest in critical and transformative technologies. These will enable our path beyond low Earth orbit through development of new launch and space transportation technologies, nimble construction capabilities on orbit, and new operations capabilities. Imagine… people fanning out across the inner solar system, exploring the Moon, asteroids and Mars nearly simultaneously in a steady stream of "firsts;"…

- Dr. Charles Bolden, NASA Administrator, NASA Budget Press Conference, February 1, 2010

Speed-of-Light Communications Delays beyond LEO



Distributed Crew-Ground Operations Concepts

Remote Object Surface

Remote Object Orbit

Earth Orbit

Earth Surface

- Life-support, Spacecraft Health, Navigation managed locally with support from Mission Control
- Destination Activities Managed by Crew
- CapCom is informed of decisions after the fact
- On-board planning and anomaly recovery
- Strategic Activities Managed by Ground Control
- Mission Control is a “Small Team” with on-call experts. More like “Mission Support Line”
- Constant voice-loops to Earth non-critical
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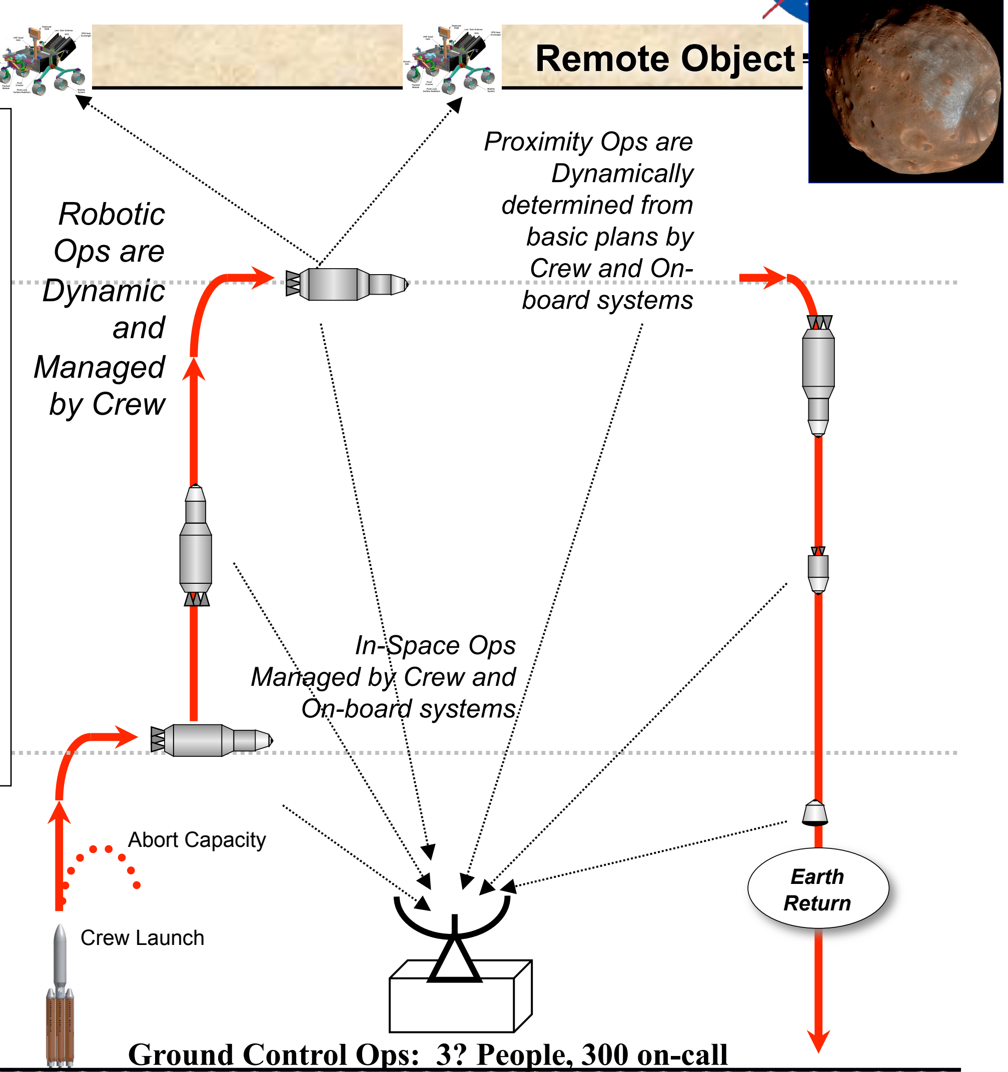


Launch Operations: 30 People

EARTH

Science Operations: 3000+ Distributed People

Operations Concepts for Deep-Space Missions

- ***Distributed crew-ground mission management***
  - **Brings broad new requirements to**
    - Migrate key capabilities onboard to reduce dependency on the ground for tactical off-nominal situation response and mission replanning
    - Enhance onboard capability to process and integrate mission-relevant information
    - Enhanced onboard capability to make time-critical decisions
    - Enhanced onboard capability to plan and replan destination-based mission activity schedules with delayed ground involvement.
    - Develop New Crew-Ground collaboration concepts over all mission phases

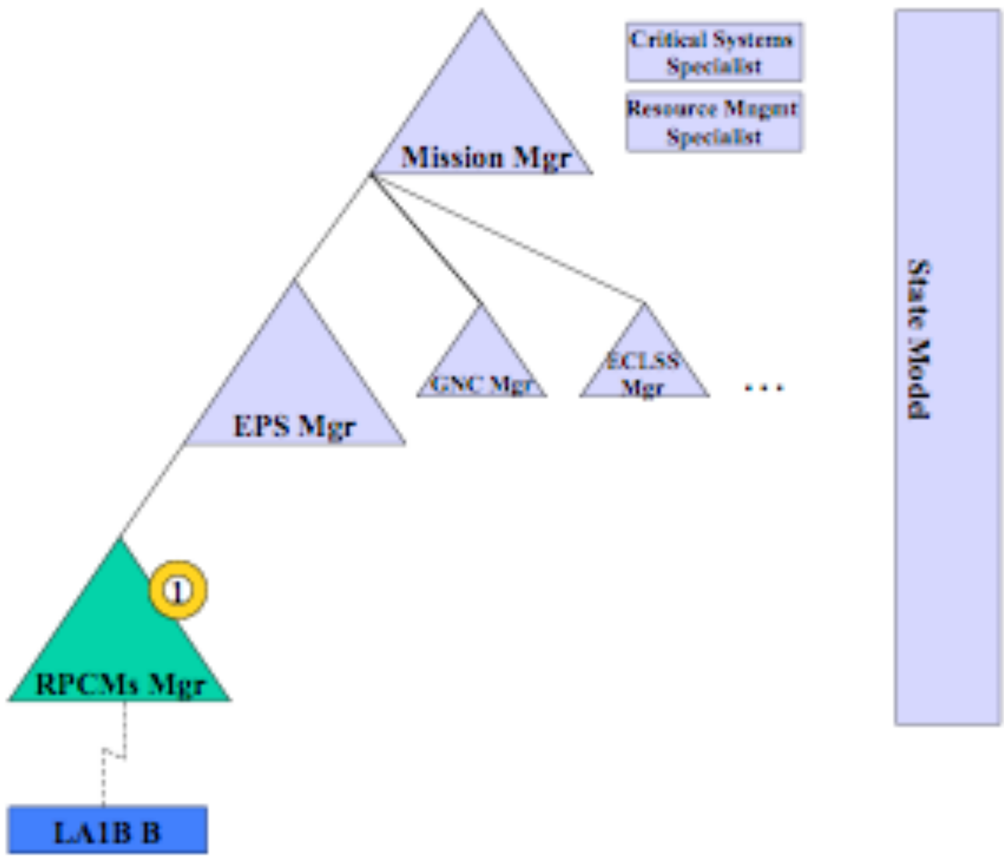
Operations Concepts for Deep-Space Missions

Critical Enabling Technologies

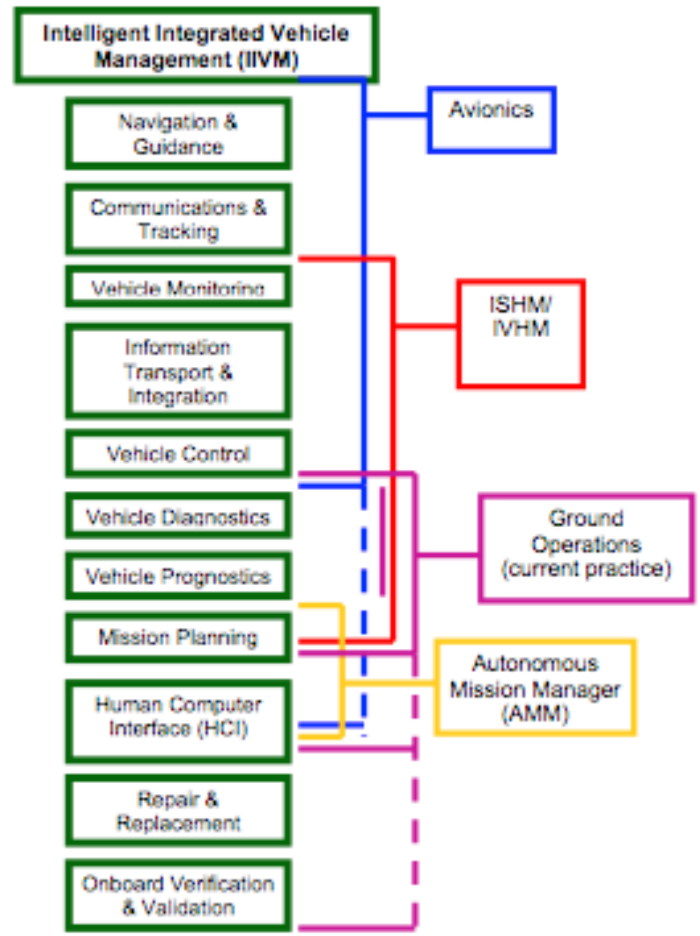
Software Development

- Enhanced vehicle/habitat mission operation automation:
    - In-flight trajectory planning and re-planning
    - Anomaly detection, fault isolation, and fault recovery
    - Embedded VR environments for JIT training
    - Procedure generation and execution
    - Multi-crew activity scheduling and rescheduling tools
    - Information organization and presentation to support task-oriented displays

Intelligent Integrated Knowledge Engineering Architectures

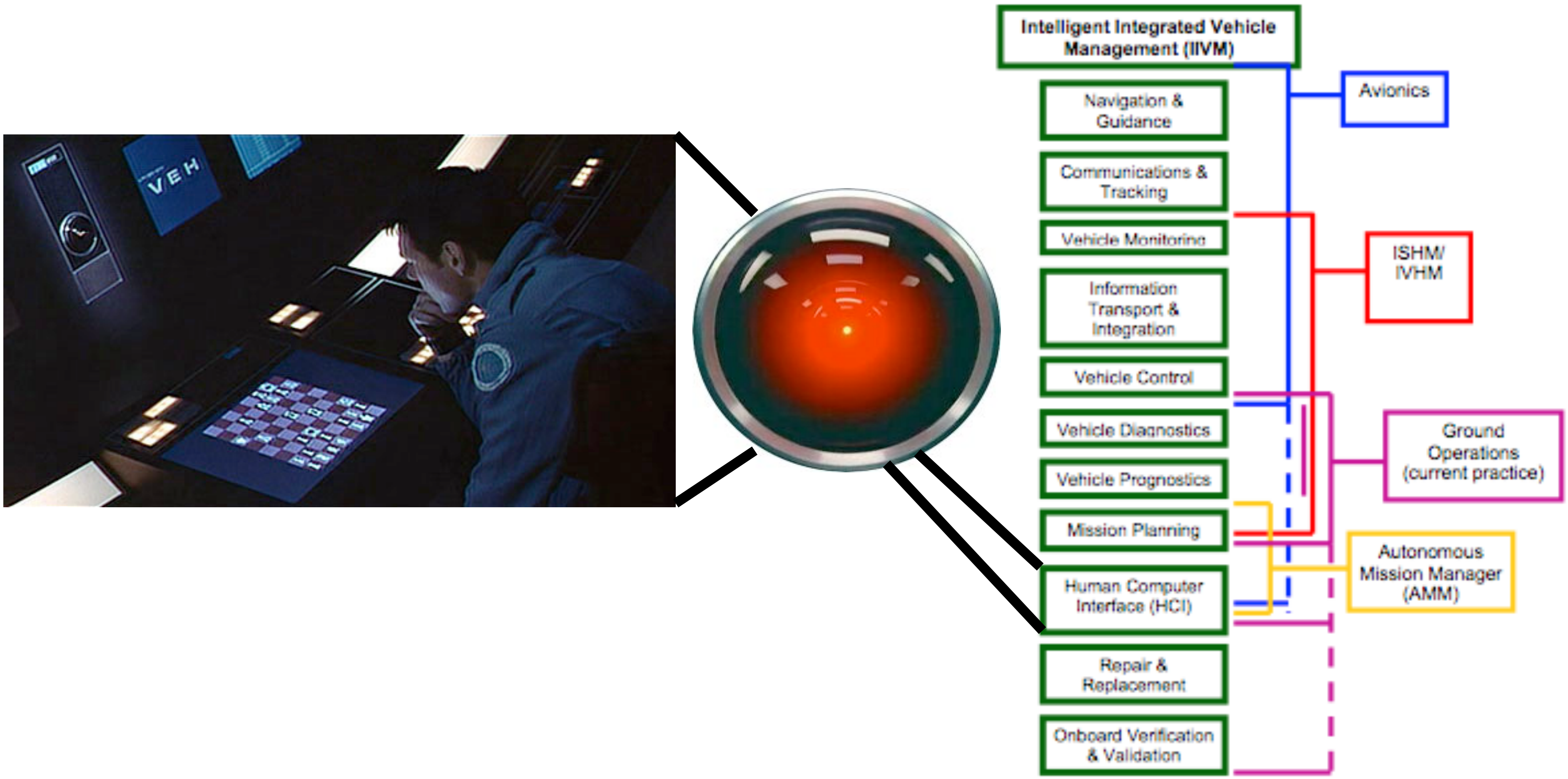


JSC Concept for SLI (2002)



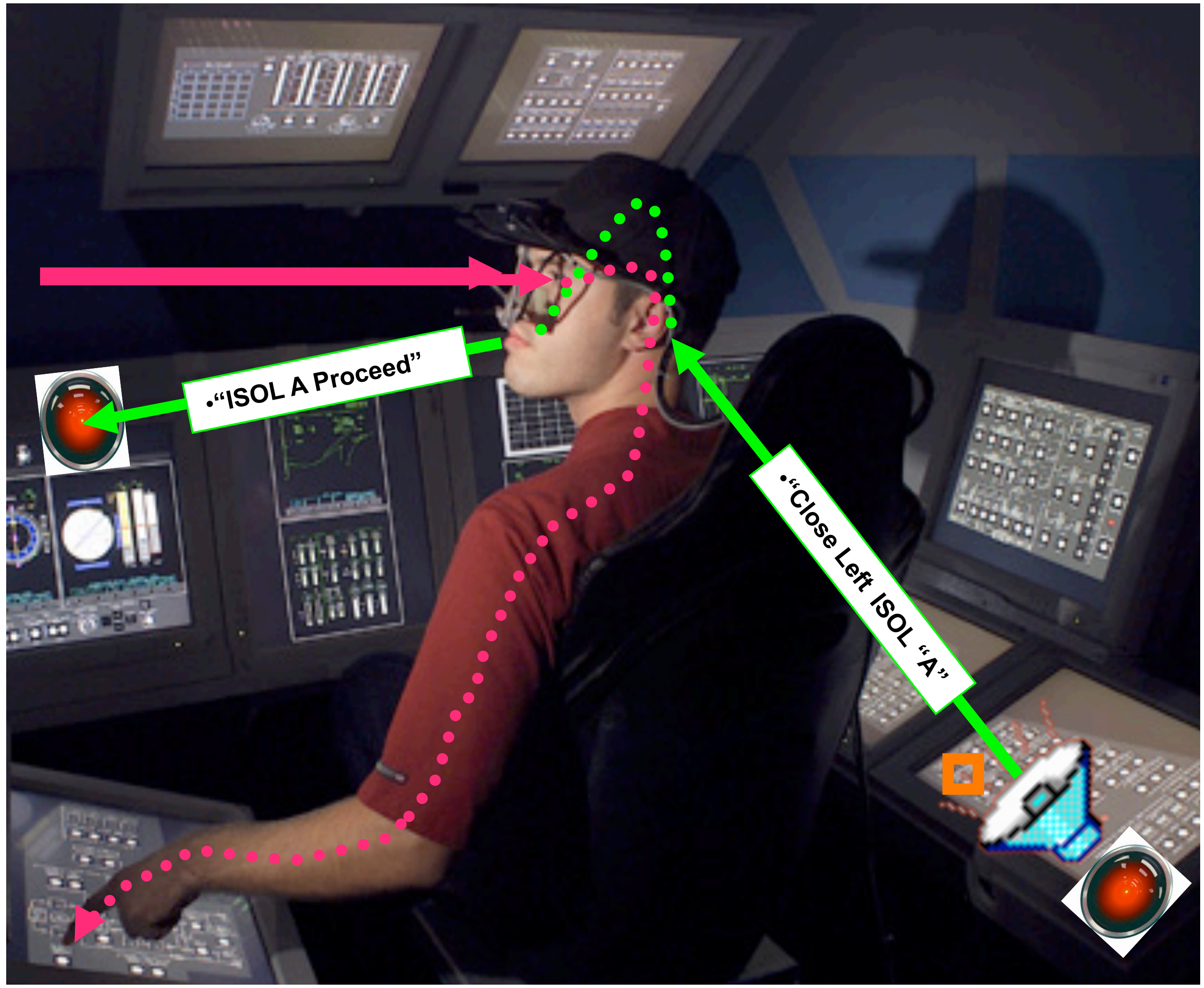
MSFC Concept (2005)

•Requirement: Replace today's "standing army" of ground-based subject matter experts with three or four crewmembers and delayed ground support



Enhanced Crew Operational Capabilities

- **Existing crew-vehicle interfaces almost exclusively visual-manual**
- **Other human information processing channels (auditory-vocal, haptics) are underutilized**
  - Integrated Natural-Language based and manual crew-vehicle communication and commanding interfaces
  - Real-time analysis of crew information acquisition and commanding activities
    - Activity-based information display
  - Adjustable human-machine function allocation based on behavior-based



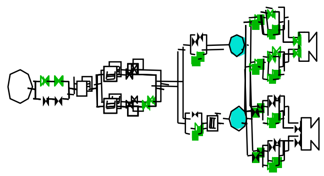
Enhanced Crew Operational Capabilities

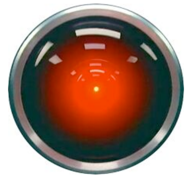
- Information presentation and display schemes to filter and provide crew with critical mission management information
  - avoid crew overload

- Flexible, adjustable crew-machine function allocation (adjustable automation) schemes
  - Real-time analysis of crew information acquisition and commanding activities
  - Adjustable human-machine function allocation based on
    - behavior-based assessments of performance readiness
    - system knowledge of crew roles and procedures

- Support tools for distributed mixed crew/automation teaming
  - Surface ops: Crew-robotic teaming
  - Habitat and Vehicle ops: Crew-immobotic teaming

Ops Concept Development Roadmap





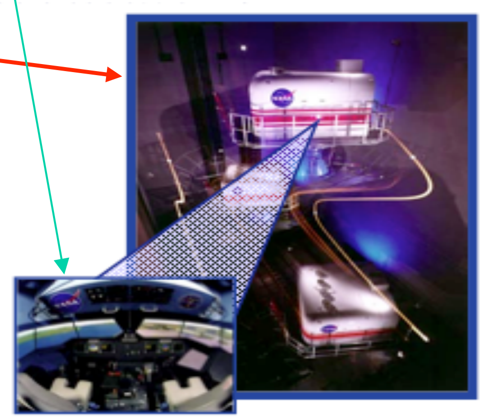
IISM **Crew-IISM Interfaces**

- Rapid, quantitative development and usability testing of candidate IISM architectures , crew-IISM user interfaces and crew-automation interactions
- Development of real-time human performance analysis and augmented cognition tools
- Development of Crew-centered machine-based agents for Distributed Collaborative Interactions
- Evaluation of Crew-System performance under accurate environmental stressors

ISE

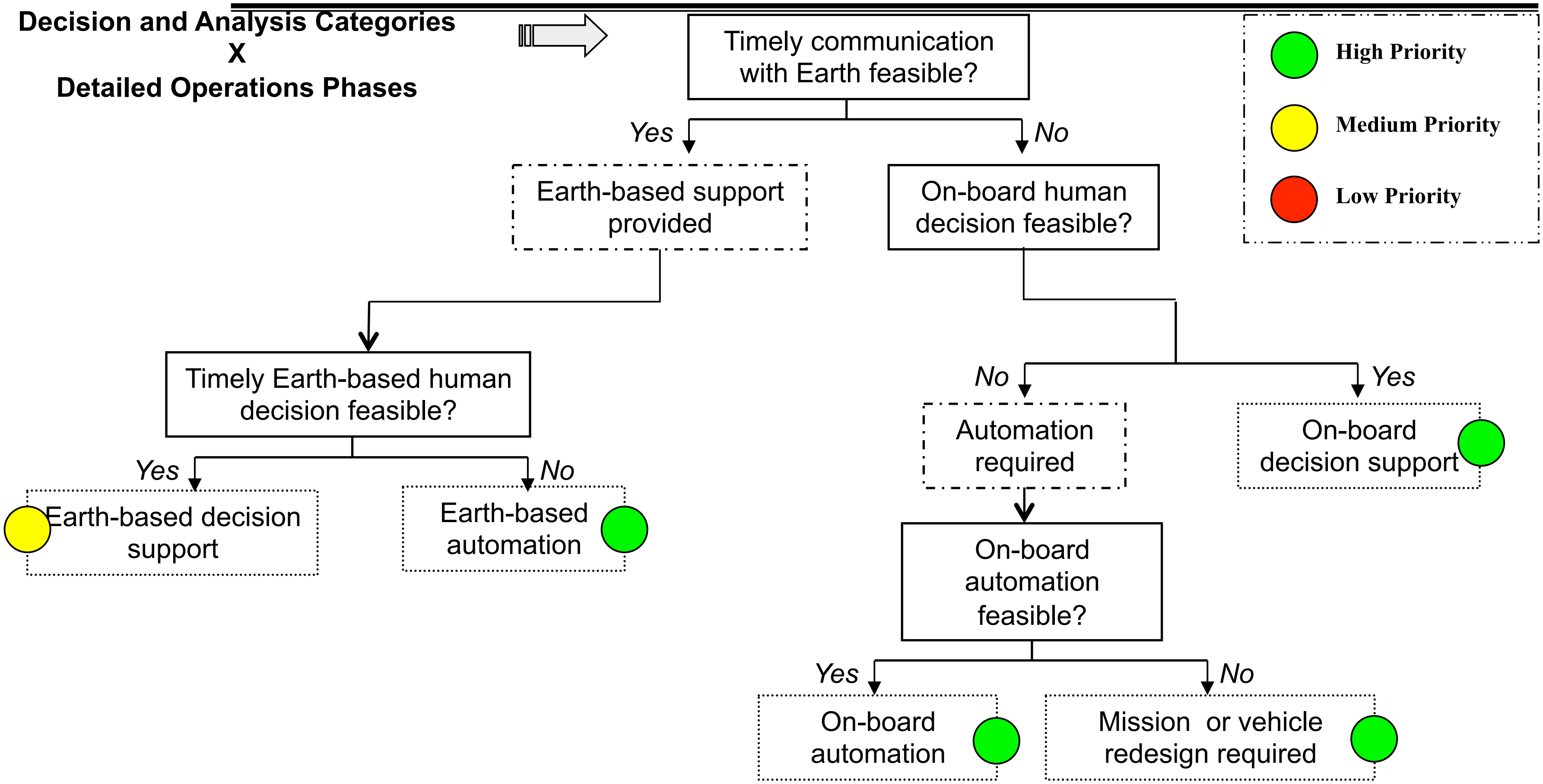
Mission Control Center

- Ops concept evaluations for mixed (crew-robotic) multi-agent surface operations and surface habitat management

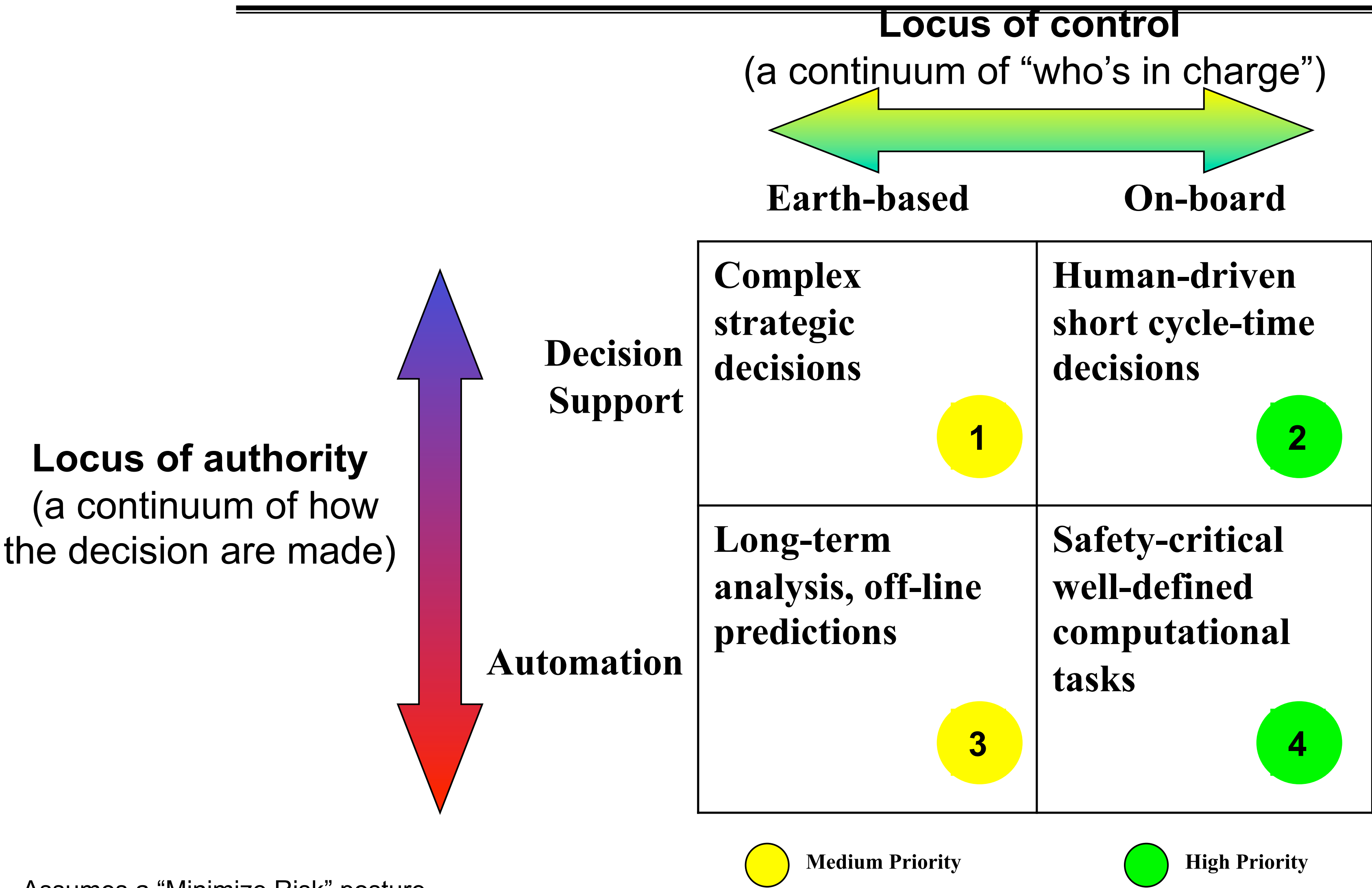


- Ops Concept Evaluations in Full-Mission Simulation w/6DF Motion
- Test, Evaluate, and Mature Distributed Asynchronous Crew-Ground Collaborative concepts with light-speed delays

Perform Mission Operations Element Trades



Complete Operations Trade-space Analyses



Assumes a "Minimize Risk" posture

Complete Operations Trade-space Analyses

- Develop and evaluate Ops concepts with varying:
  - Failure propagation latency and criticality
  - Communication latencies between crew and ground, crew/crew, and crew-robotic agents
    - Identify human-interface issues early in the design cycle

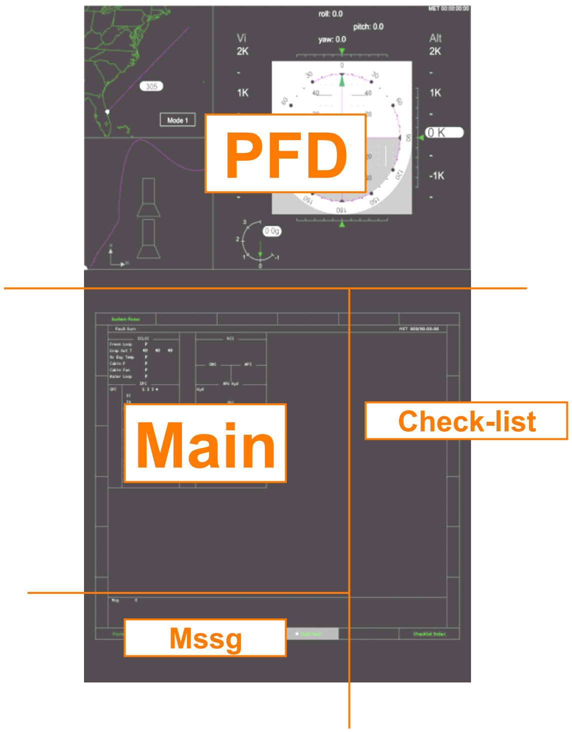
- Develop Agent-based architectures for distributed collaborative activities across all flight phases

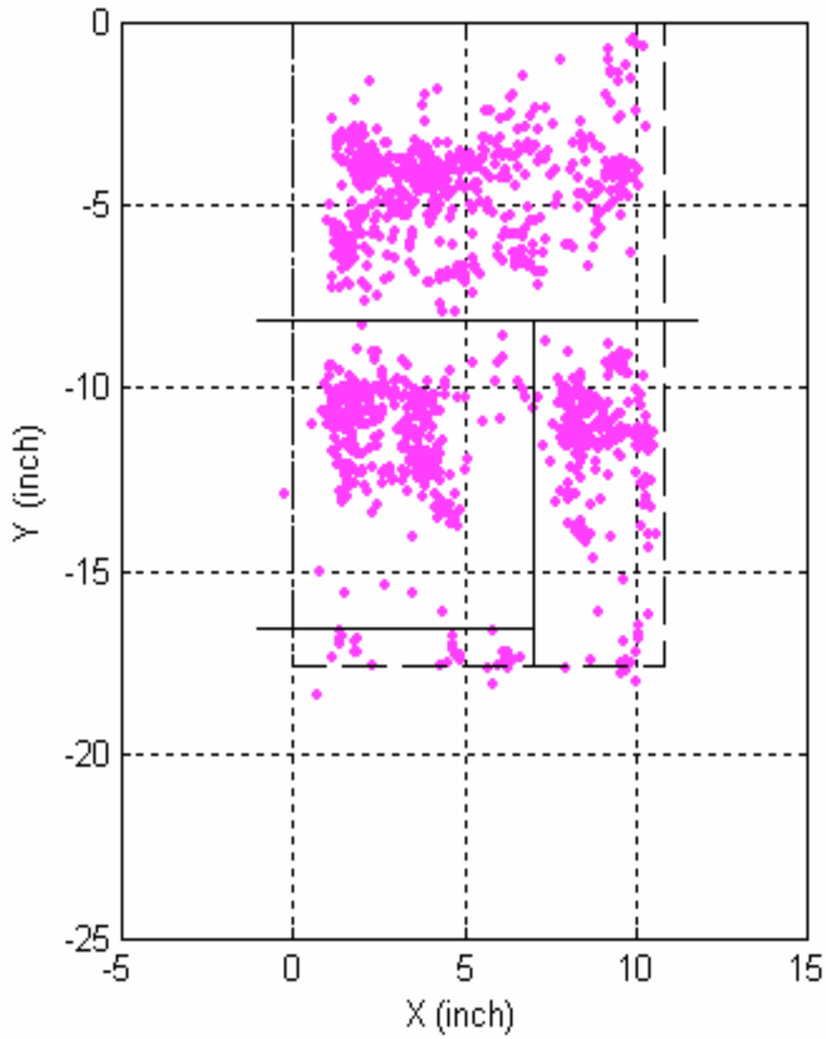
- Standardize crew-machine interfaces for vehicle and surface habitat/EVA operations

Integrated Model-based Development Uses

- Develop, test, and evaluate intuitive, flexible data-mining and information-querying methodologies
  - Natural Language understanding in noisy environments
  - Information Display and Information Filtering
  - Advanced Caution and Warning systems
  - Distributed, collaborative operations concepts with asynchronous communications between agents

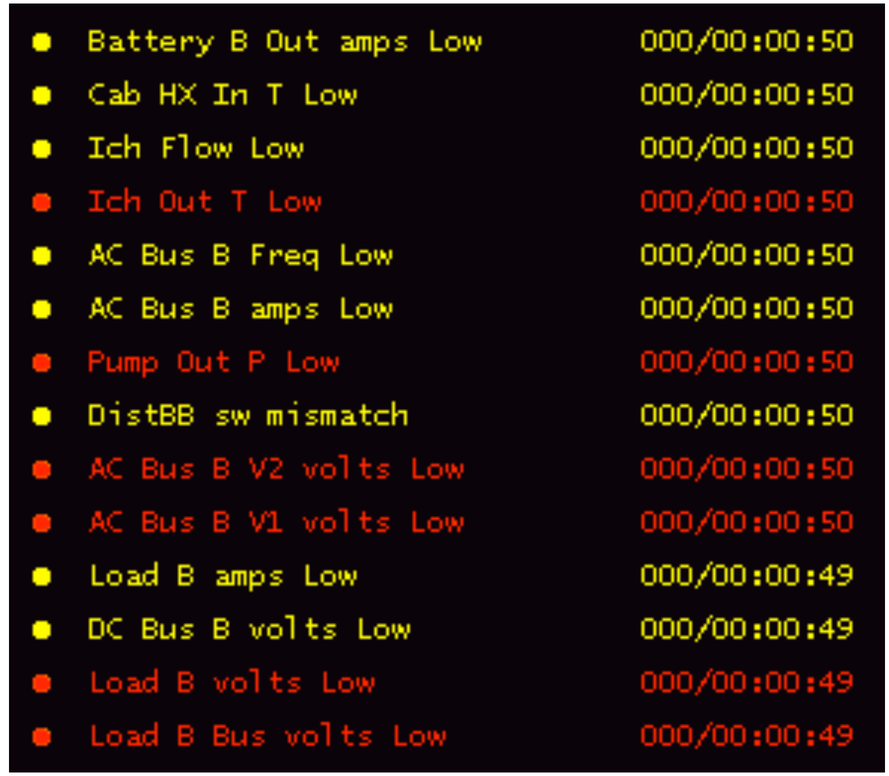
Fixation Clusters and region of interest (ROI) determination



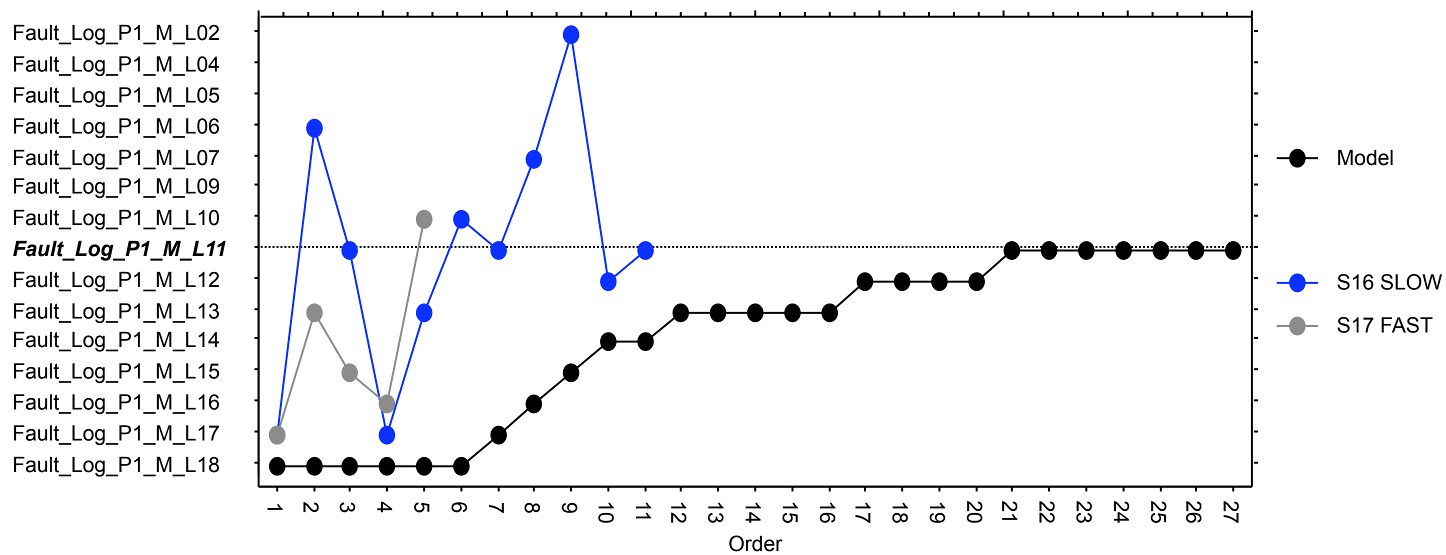


Four ROI

Root Cause



ROI=Fault_Log	5.77 sec	5.00 sec	10.73 sec	3.86 sec	17.39 sec



Complete Operations Trade-space Analyses

- Model V&V via truth-testing against telemetry derived from ground-based hardware-in-the-loop tests and flight tests
- Real-Time Mission Support Tool
  - Run ISE in real-time once mission commences
  - Perform continuous comparisons between model-generated telemetry values and actual telemetry values
  - Provide enhanced capabilities to carry out very high-fidelity, faster-than real time ground-based testing and simulation to support off-nominal mission troubleshooting a la Apollo 13

Distributed Crew-Ground Operations

Distributed Crew-Ground Operations Model

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