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Distributed Operations for a Large Multi-instrument Space Mission: Lessons Learned from the Cassini-Huygens Program

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Distributed Operations
for a Large Multi-instrument Space
Mission

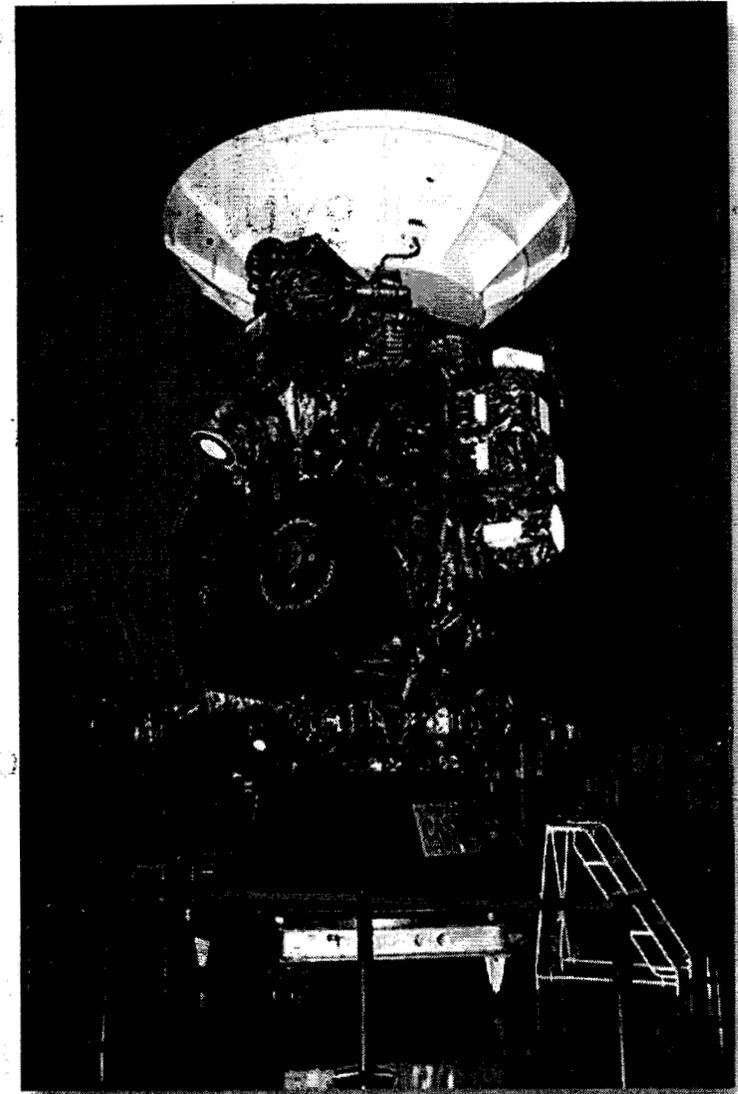


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Introduction to Cassini-Huygens Mission

- Launched in October 1997
- 7 year cruise to Saturn
- Largest Inter-Planetary Spacecraft ever built
 - 12 science instruments
 - One Titan entry probe built by ESA
- 74 orbits around Saturn
- 45 flybys of Titan
- International Mission:
 - Primary Sponsors are NASA, ESA, and the Italian Space Agency (ISA)
 - 18 other countries outside of the United States Participating



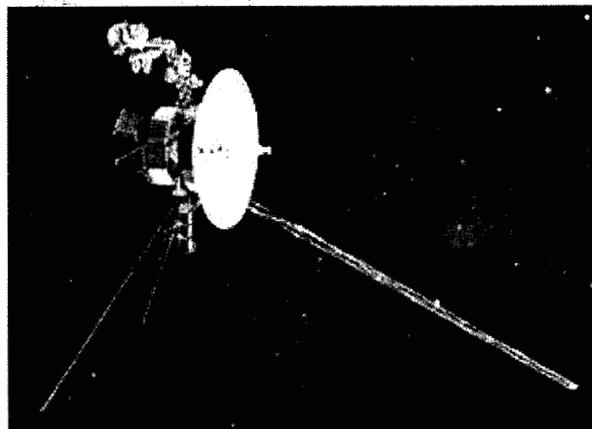


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Comparison with Other Outer Planet Missions

- **Voyager 1 & 2:**
 - 11 science investigations
 - 5 Remote Sensing
 - 5 Fields and Particles
 - 1 Radio Science experiment
 - Scan Platform for Remote Sensing Instruments
- **Galileo:**
 - 12 science investigations
 - 4 Remote Sensing
 - 7 Fields and Particles
 - 1 Radio science experiment
 - 1 atmospheric entry probe
 - Scan Platform for Remote Sensing Instruments





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Large Scale Multi-Instrument Spacecraft Complications

Conflicts between Remote Sensing Instruments and Fields and Particles Instruments





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Centralized Mission Operations for Voyager and Galileo

- **Voyager 1 & 2 and Galileo**
 - Spacecraft Bus operations performed at JPL
 - Principal Investigators located around the world
 - Principal Investigator's science teams all had "liaison teams" at JPL
 - Perform instrument commanding
 - Provide coordination between JPL and Principal Investigator team
 - Represent the interest of Principal Investigator
 - Science observation designs, in particular, remote sensing pointing designs were all performed at JPL

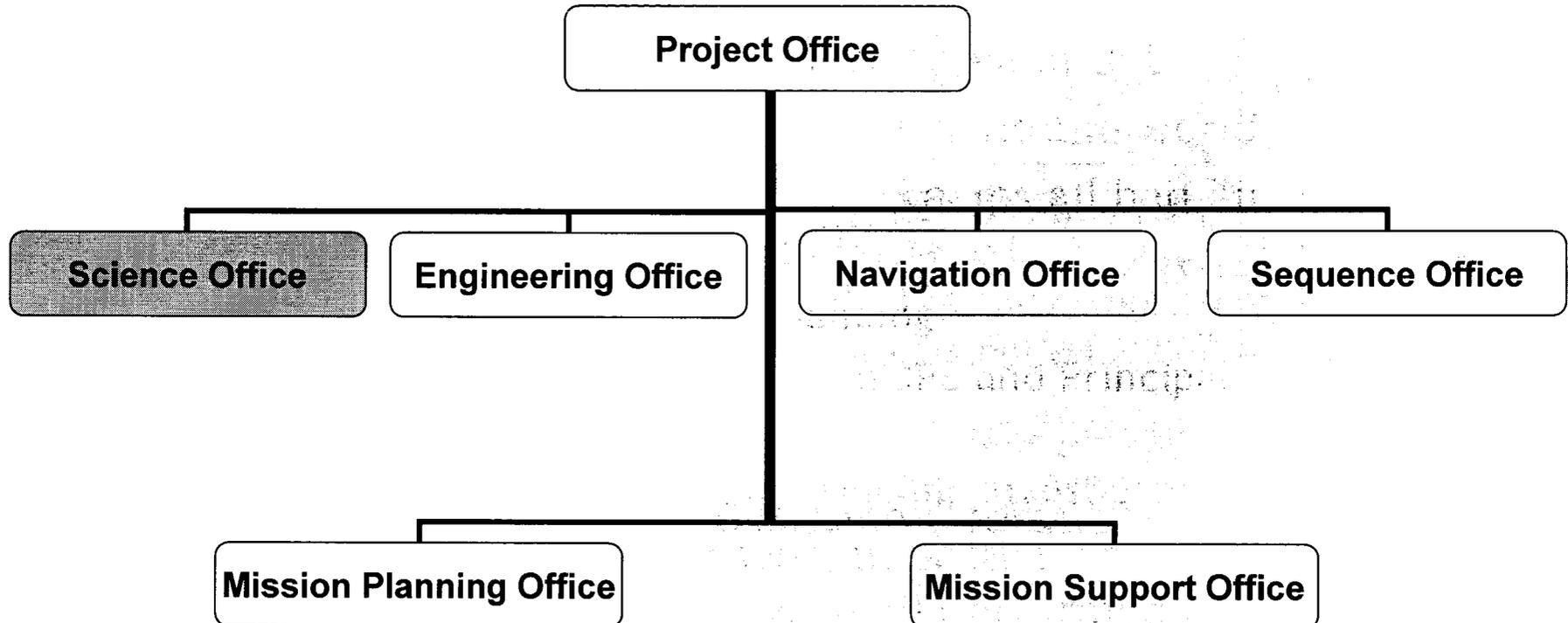
Centralized structure allows traditional "Mission Control Room" Concept of Operations to be used



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Mission Operations at JPL - An Overview



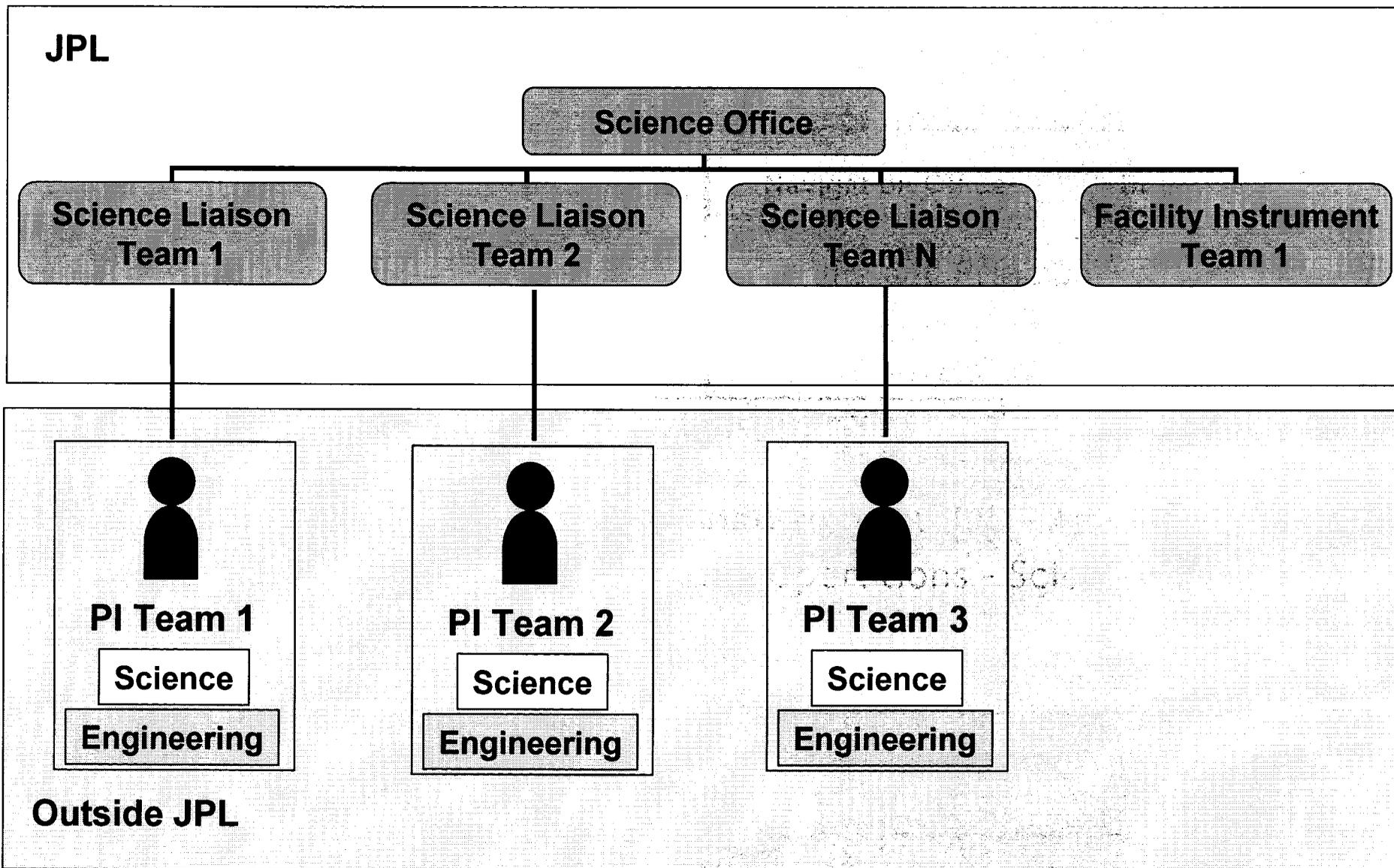


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Centralized Operations - Science Office



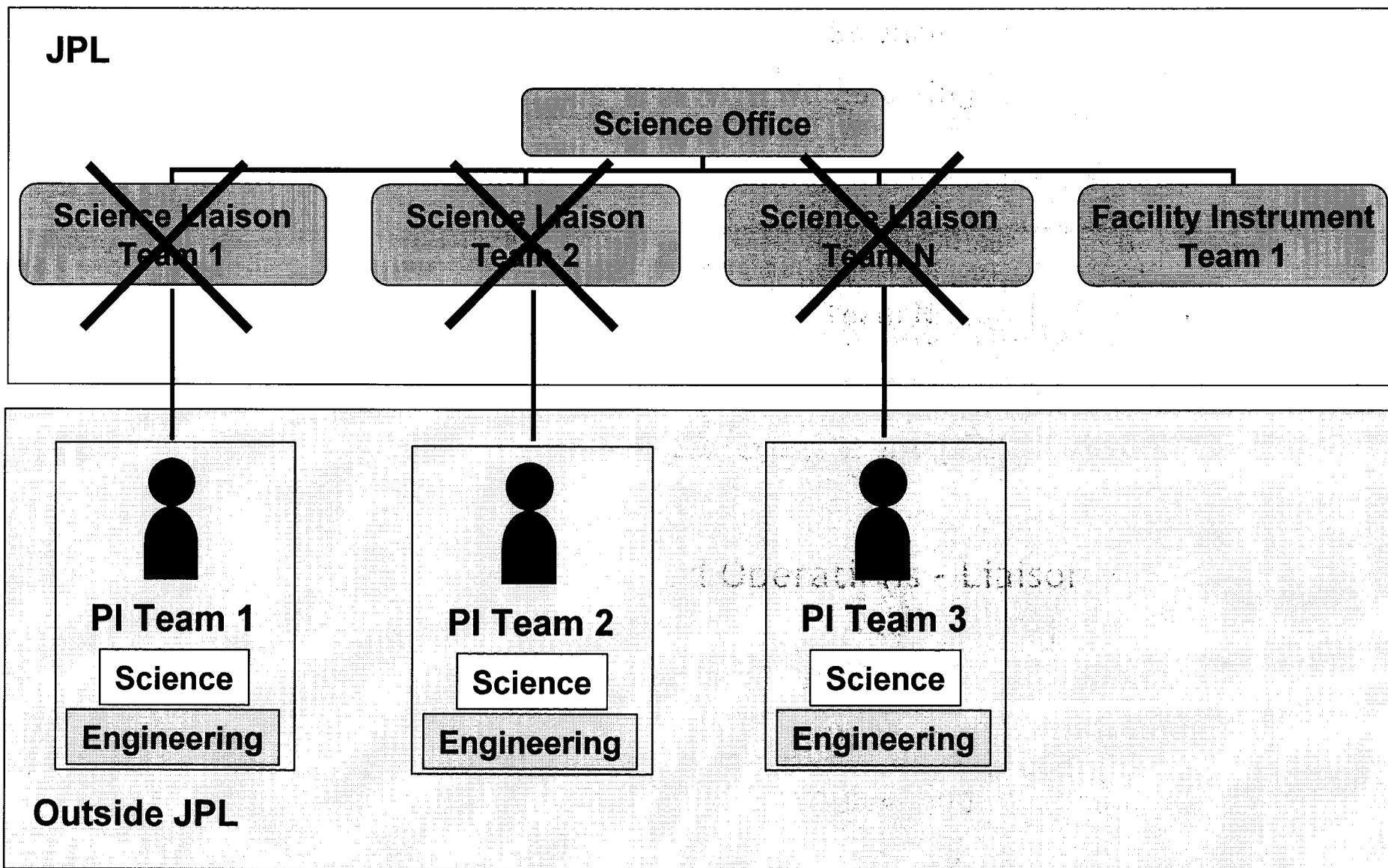


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Distributed Operations - Liaison Team Gone





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Advantages of Distributed Operations for Cassini-Huygens

- **Non-real time nature of outer planet missions allows this to be done**
- **Data architecture on-board spacecraft is distributed**
- **International nature of mission lends itself to decentralization**
- **Operations Cost can be controlled by “outsourcing” science operations to non-JPL sites**
- **Brings in educational and research institutions in the space exploration effort**

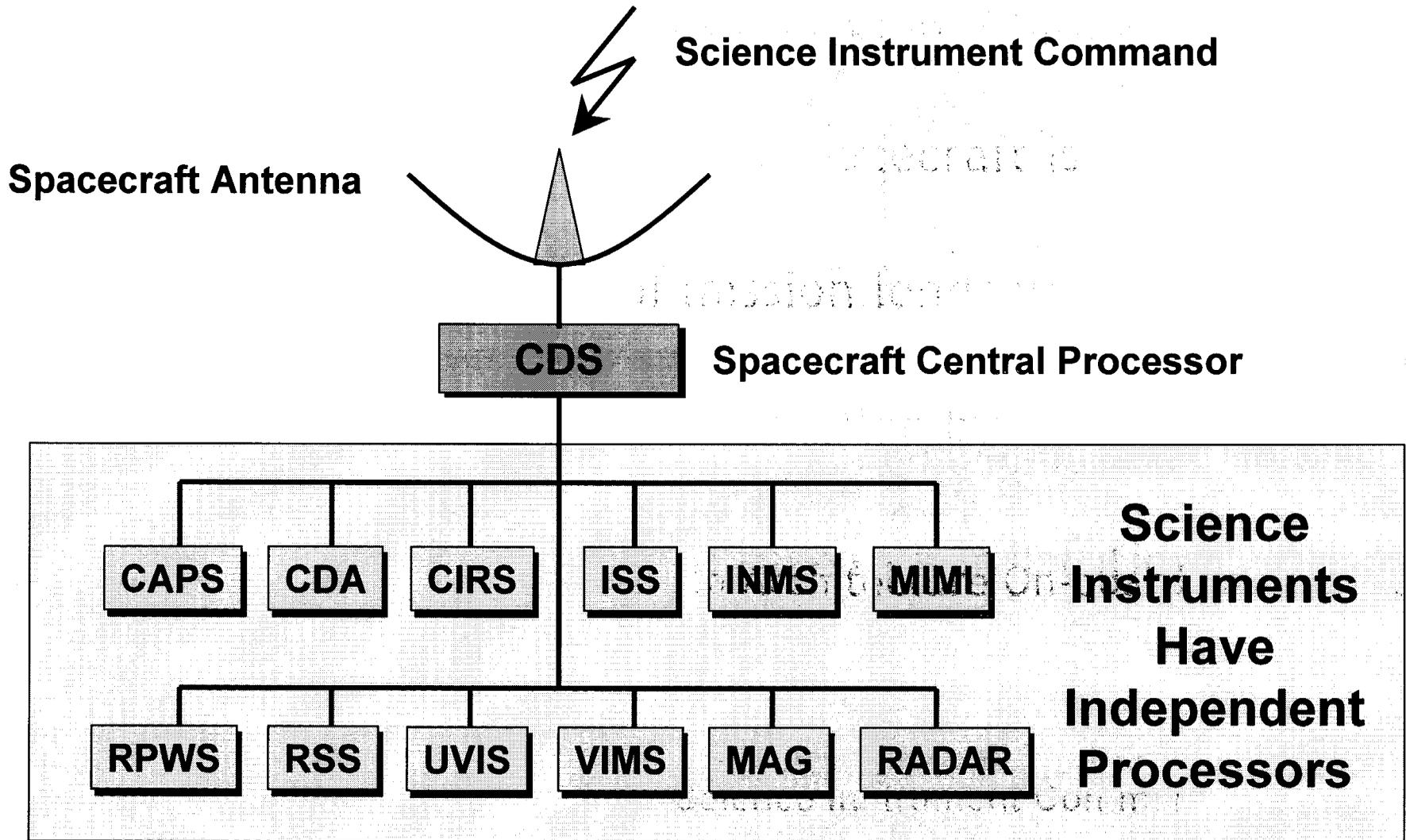


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Distributed Data Architecture On-board Spacecraft





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Case Study 1: Issue a Command Internal to Science Instrument - Successful Implementation

Science Team (Outside JPL)



Create
Instrument
command

Instr_A_trigger_1
Instr_A_trigger_2
...
...
...
Instr_A_trigger_n

Sequence

Development Process (JPL)

Merge

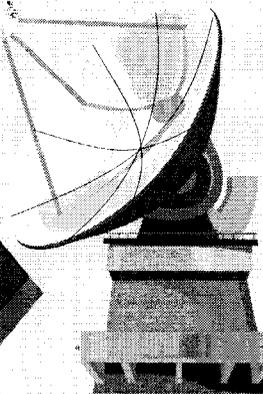
Constraint
Check (1)

Power
Mode
Ok?

Merged Cmd
Sequence

Instr_A_Cmd_File
Instr_B_Cmd_File
...
Instr_N_Cmd_file

Uplink (JPL)





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Scan Platforms on Large Multi-instrument Spacecraft

- **A scan platform for remote sensing instruments simplifies operations**
 - Remote sensing instruments can be oriented independently from fields and particles instruments to perform observations
 - Thermal exposure of remote sensing instruments can be minimized by simply moving the platform, not the entire spacecraft
- **De-couples instruments from spacecraft bus**
- **As a cost reduction measure, the scan platform was removed from the Cassini spacecraft.**

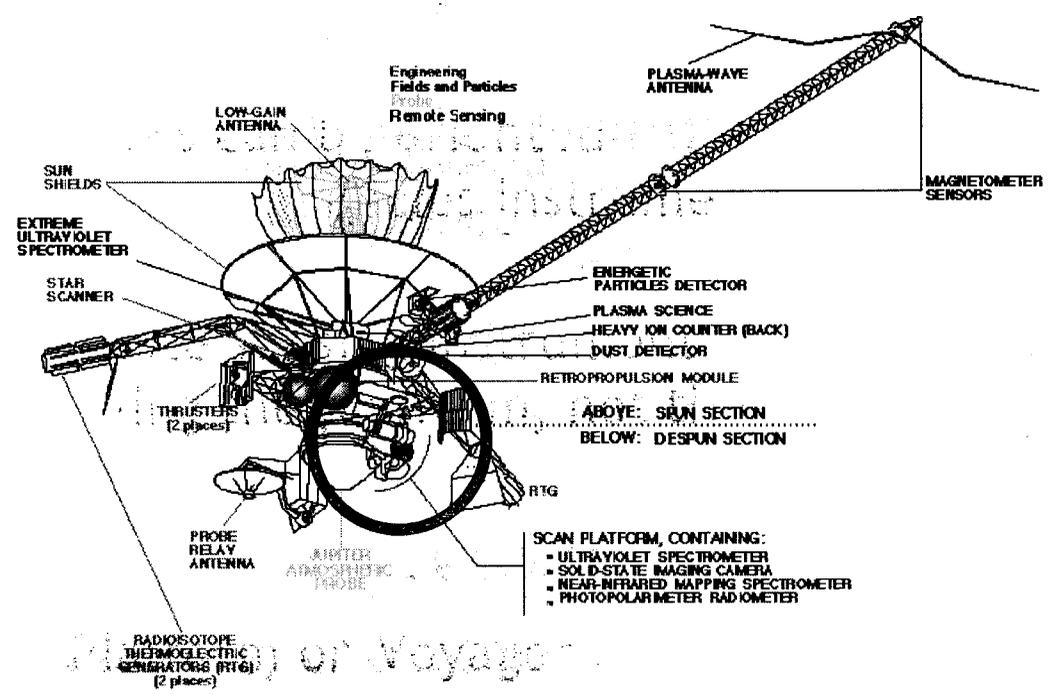
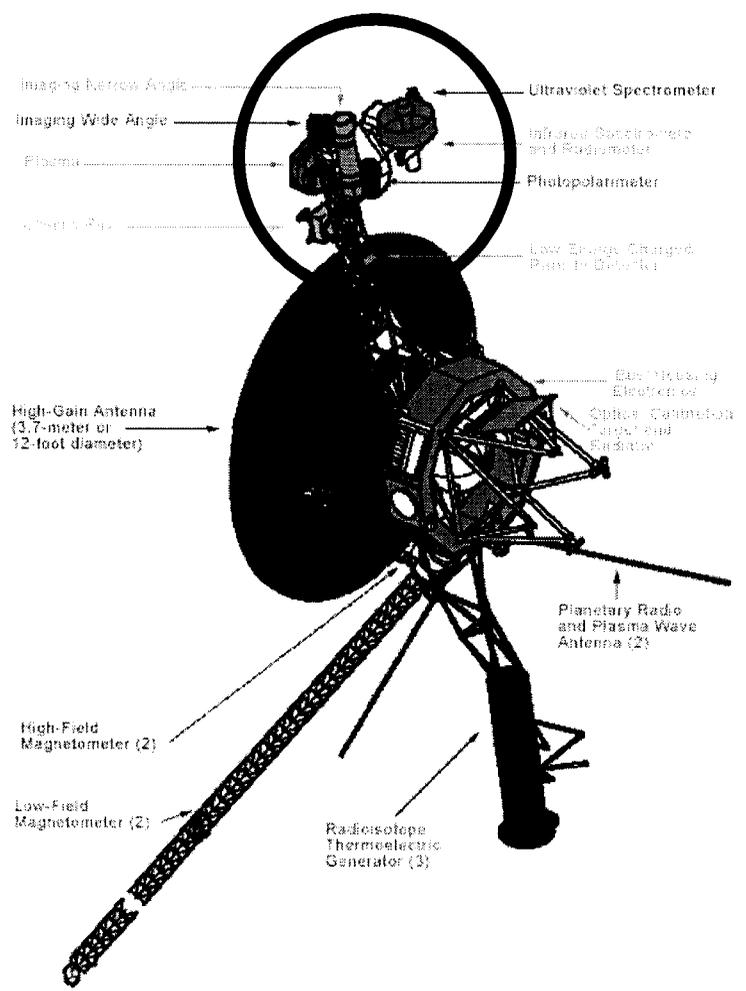


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Spacecraft Scan Platform on Voyager and Galileo

Voyager

Galileo

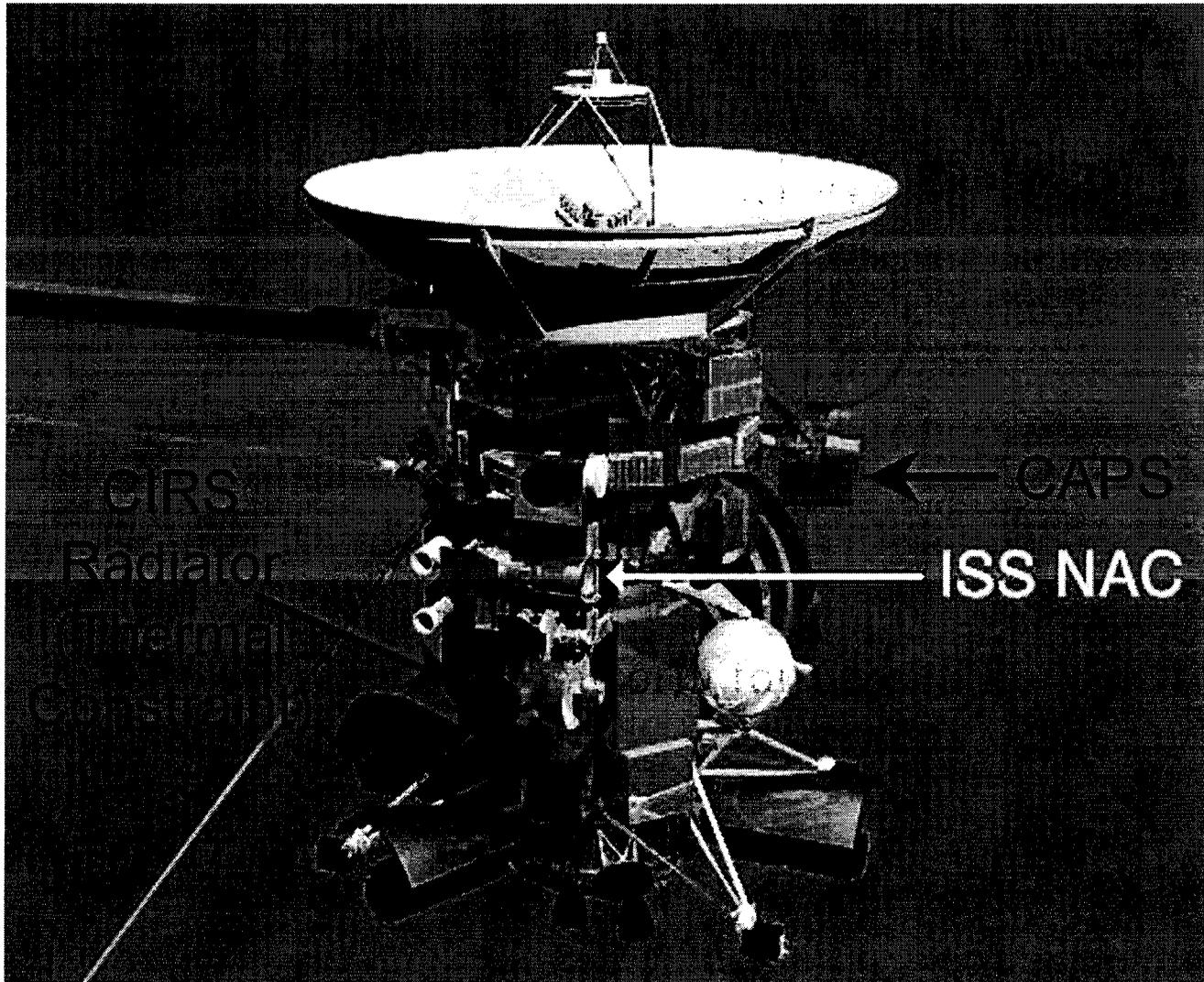




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No Scan Platform for Cassini Remote Sensing Instruments





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Case Study 2: Distributed Operations without a Scan Platform - Many Challenges

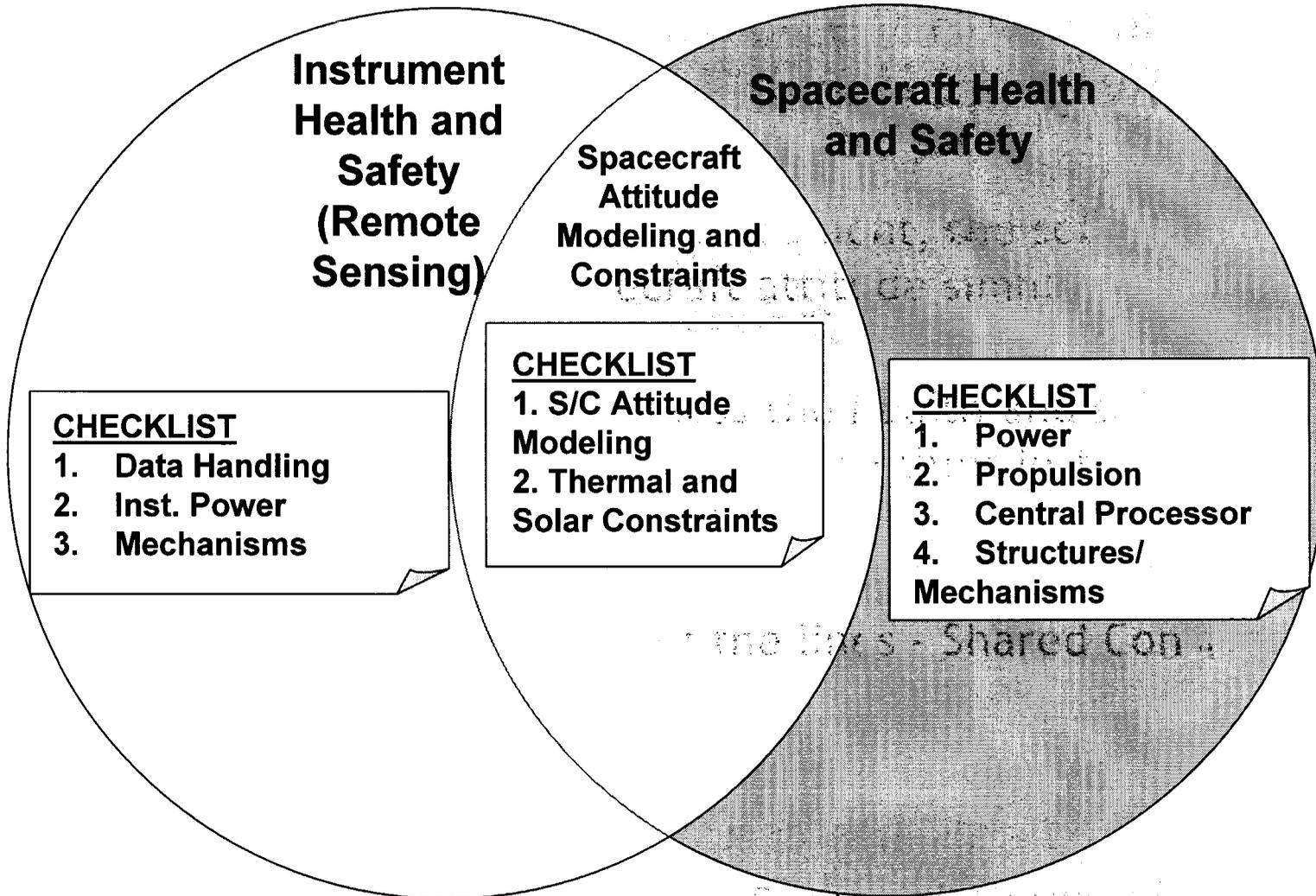
- **Line Blurred between Instrument Health and Safety and Spacecraft Health and Safety without a Scan Platform**
 - To safely point his or her instrument, the scientist has a vested interest in spacecraft attitude simulation and constraint checking
 - Scientists now have to assess the health and safety of the entire spacecraft in addition to their instruments



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Blurring of the lines - Shared Constraints





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Blurring of the lines (cont.)

- **Creative tension between Science and Engineering exists in all JPL missions**
- **Normal Science vs. Engineering conflict**
 - Scientists want to do something
 - Engineers says no because it's too risky
- **Each player knows their role**
 - **Scientists:**
 - Ensure science data is collected and returned
 - Advocate for increased science when appropriate
 - **Engineers:**
 - Ensure the spacecraft operates safely
 - Advocates for decreased operational complexity
- **In most missions, a compromise is reached and the right balance is achieved between science data collection and spacecraft risk.**



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Introduces New conflicts between Science and Engineering

- **Distributed ops allocates responsibility to science teams**
- **Science teams also performs Spacecraft Engineering health and safety functions**
- **Traditional Spacecraft Engineers also performs spacecraft health and safety functions**
- **New Conflict: Scientists and Engineers BOTH have responsibility to check spacecraft health and safety**
- **This new conflict drives the need for a Central Operations Decision Maker: The Mission Director**



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Operational Complexity is not necessarily reduced

- Number and variety of science instrument payloads drive complexity
- Distributed operations may in principal reduce complexity by delegating responsibility to science teams
- Yet, mission assurance requirements demand checks and balances in the operations environment
 - Someone still has to check their work.



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Conclusions

- **Distributed Operations for large multi-instrument spacecraft can work if subsystems are weakly coupled from spacecraft constraints**
 - Case 1: Internal Instrument Commanding
- **Distributed Operations will pose significant challenges if subsystems are strongly coupled with spacecraft constraints and resources**
 - Case 2: Remote Sensing without a Scan Platform

Conclusions (cont.)



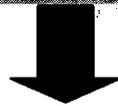
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Distributed Operations - Decentralization



**Blurs the Lines Between Instrument and Spacecraft
Health And Safety (Shared Constraint Violations)**



**Introduces New Conflicts Between Science and
Engineering**



Operational Complexity Not Necessarily Reduced



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Scan Platform and Distributed Operations

	Scan Platform Exists	Scan Platform Does Not Exist
Centralized Operations	Less constraint violations No blurring of the lines between Science and Engineering	More constraint violations No blurring of the lines between Science and Engineering
Distributed Operations	Less constraint violations Blurring of the lines between Science and Engineering	More constraint violations Blurring of the lines between Science and Engineering <ul style="list-style-type: none">• Recommend Mission Director to mediate conflicts