An Overview of the Jupiter Icy Moons Orbiter (JIMO)
Mission, Environments, and Materials Challenges

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Project Overview

- Congress authorized NASA’s Prometheus Project in February 2003, with the first Prometheus mission slated to explore the icy moons of Jupiter with the following main objectives:
  
  - Develop a nuclear reactor that would provide unprecedented levels of power and show that it could be processed safely and operated reliably in space for long-duration.
  
  - Explore the three icy moons of Jupiter – Callisto, Ganymede, and Europa – and return science data that would meet the scientific goals as set forth in the Decadal Survey Report of the National Academy of Sciences.
The JIMO launch campaign was to open in May 2015 and required 3 separate launches.

The Earth orbit operations was planned for approximately 5 months and the Interplanetary transfer was planned for approximately 5 years and 4 months.

The JIMO Mission shall maintain a science orbit around Callisto for at least 60 days, Ganymede for at least 60 days, and Europa for at least 30 days.

The end of mission was planned with the spaceship in science orbit at Europa.
Spaceship Overview

Conceptual

- High Power Electronics Radiator
- Bus Radiator
- Bus Compartment
- Xenon Tank Structure
- High Gain Antenna
- Electric Propulsion Thruster Pods
- Spacecraft Docking Adapter
- Main Boom Assembly
- Boom Hinge (3)
- Brayton Power Conversion
- Radiation Shield
- Reactor
- Heat Rejection Subsystem radiator panels
- Shunt Radiator panels
- Stowed Spaceship

Deep Space Vehicle

Science
Mission Environments

- **Radiation**
  - Natural Space
  - Planetary
  - Plasma
  - Onboard radiation

- **Meteoroids and Orbital Debris**
  - Sporadic Meteoroids
  - Jovian Meteoroids
  - Orbital Debris in Earth Orbit

- **Atomic Oxygen**
- **Contamination**
- **UV**
- **Thermal Vacuum**
- **Thermal Atmosphere**
- **Thermal Cycle**
- **Electromagnetic Compatibility (EMC)**
Mission Fluence as of PMSR

- Mission Fluence includes
  - Spiral out from Earth
  - Inter planetary transit
  - Science Orbits at Callisto, Ganymede, and Europa
- Transport codes not verified for these energies
- Testing
  - Accelerated testing
  - Charged particle vs gamma
  - Air vs vacuum
Trapped Belt Energy Distributions

Jupiter and Earth

- **Electrons, Jupiter**
- **Protons, Jupiter**
- **Electrons, Earth**
- **Protons, Earth**

- **Jupiter: hard electron spectrum**
- **Earth: hard proton spectrum**

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Radiation Environment Comparison

- Europa energies higher by approx. 2 orders of magnitude.
- Electron Integral flux higher by approx. 1 order of magnitude
- Proton Integral Flux higher by approx. 3 orders of magnitude
The Jovian Meteoroid Environment Overview

- Not much known – very few spacecraft measurements.
- Need lots of study, especially in identifying sources of meteoroids; possible new ones are Io, Kuiper Belt Objects, and the Jupiter Trojan asteroids.
- Electrodynamical forces may be important.
- The JPL Divine meteoroid model (METEM) was used to calculate meteoroid fluxes for all phases of the mission.
- The following calculations are based on METEM results for 5.2 AU.
- “Distance from Jupiter” is the distance from the center of Jupiter, not the cloud tops.
- Correction for Jupiter shielding (same expression as for Earth save that \(r_e\) is replaced with the Jovian equatorial radius of 71492 km).
• Grün model was scaled to (distance from Sun)$^{-1.3}$ and used to provide “sanity check”.
• Meteoroid environment was assumed isotropic (meteoroids come from all directions)
• Spacecraft was assumed to be traveling in the ecliptic plane.
• Fluxes were provided for a “randomly tumbling” spacecraft (*Note: JIMO will not be “randomly tumbling”*) and are for circular orbits from 1.0 to 5.2 AU, in 0.5 AU steps.
• Fluences (flux integrated along trajectory) were not provided due to lack of a definitive trajectory.
• *These are first order estimates only – refinements will be required, especially in Jovian space, to assure survivable design.*
• A first-order attempt at gravitational focusing is also performed.
• LOTS of work needs to be done in this region.
Near-Earth Meteoroid Flux

- Meteoroid flux at Earth = Interplanetary Flux at 1 AU X Gravitational Focusing Factor X Earth Shielding Factor.
- Gravitational focusing factor given by
  \[ G = 1 + \frac{r_e}{r} \]
  - where \( r_e \) is radius of the Earth at the top of the atmosphere (6478 km) and \( r \) is the distance from the geocenter.
- Earth shielding factor given by
  \[ \eta = \sin^{-1}\left(\frac{r_e}{r}\right) \]
  \[ S = \frac{1 + \cos \eta}{2} \]
- Average meteoroid speed ~ 20 km s\(^{-1}\).
- Average meteoroid density ~ 1 g cm\(^{-3}\) (ice).
Gravitational Focusing at Jupiter

- Based on expression derived by Don Kessler:

\[ G = 1 + \left( \frac{Rv_{esc}^2 r_p}{v_{earth}^2 r} \right) \]

- where \( R \) is the heliocentric distance of the planet, \( v_{esc} \) is the planet’s escape velocity at the surface, \( r_p \) is the planet’s radius, \( v_{earth} \) is the escape velocity from the surface of the Earth, and \( r \) is the distance from the center of the planet.

- In the case of Jupiter, this results in

\[ G = 1 + 147.2 \left( \frac{r_j}{r} \right) \]

- A more complicated numerical procedure is needed to handle focusing by Jupiter and its satellites.
• Jupiter’s gravity greatly enhances speed of meteoroids (by a factor of 5 at the cloud tops) as they “infall” to the planet.

• A mission to Io will encounter meteoroid speeds at least 1.5x that of those in LEO.
Jovian Meteoroid Flux

Flux (\# m\(^{-2}\) yr\(^{-1}\))

Distance from Jupiter (\(r_j\))

Meteoroid Mass (g)

Distance from Jupiter (\(r_j\))

Flux (\# m\(^{-2}\) yr\(^{-1}\))

Meteoroid Mass (g)

Distance from Jupiter (\(r_j\))

Flux (\# m\(^{-2}\) yr\(^{-1}\))
Materials Challenges

- In general the material radiation tolerance in a high energy electron environment is not well known.
- Cables – specifically the polymers in the cables
  - Dielectric constant change
  - Gas generation from breakdown mechanical breakdown
  - Internal charging
- Long Mission Life (approx. 20 years)
- Verification in relevant environment
- Radiation testing and characterization
  - Locating facilities
  - Test design
- Component life test requirements
- Design Margins
- System design and shielding for meteoroids
- ElectroStatic Discharge (ESD) is a Concern
  - Jovian Energetic plasma environment
  - Emphasize design to mitigate ESD
- 2 of the top risk items identify concerns of radiation effects on electronic parts and material performance
Summary

• The Prometheus Project / JIMO Mission successfully completed phase A and was indefinitely postponed after successfully completion of the Project Mission and Systems Review (PMSR)

• Much work was accomplished during phase A pertaining to Environment definitions and identification of materials and systems susceptible to degradation by the space environment

• Work initiated during JIMO was leveraged to help design and develop JUNO and follow-on missions

• Additional information may be obtained by contacting NASA Headquarters or the JPL Librarian. Library@hq.nasa.gov

• The Project Prometheus Project Final Report is available on-line at: http://en.wikipedia.org/wiki/Jupiter_Icy_Moons_Orbiter