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

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Outline

- Project Overview
- Environments
- Materials Challenges
- Summary
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

Deep Space Vehicle
Science

Spaceship

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

- Protons, Jupiter
- Electrons, Jupiter
- Protons, Earth
- Electrons, 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.
- Electrodynamic 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.

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Near-Earth Meteoroid Flux

• Meteoroid flux at Earth = Interplanetary Flux at 1 AU \times Gravitational Focusing Factor \times 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 Icy MOONS ORBITER

Gravitational Enhancement of Meteoroid Speed

- 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.
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Interplanetary Meteoroid Flux

Mass (g)

10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0}

Heliocentric Distance (AU)

1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

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

10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1

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Jovian Meteoroid Flux

Distance from Jupiter ($r_J$)

Meteoroid Mass (g)

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

$10^{-6}$ $10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $1$ $10$
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