Exploration of Jovian Atmosphere Using Nuclear Ramjet Flyer

by

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Presentation Contents

! Results of Phase I Study  
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! Outline of Phase II Tasks and preliminary findings
Galileo Probe

- To date, only direct measurement of Jovian atmospheric properties.
- Launched: 1989
- Entered Jovian atmosphere: December 7, 1995
- \( V = 47.4 \text{ km/s} \)
- \( T_0 = 15,000 \text{ deg C} \)
- Decel. = 230 g

Eject Heat Shield

Data

- 0.08 bar
- 25 bar
Characteristics of Nuclear Ramjet Flyer:

- Jovian atmosphere is an unlimited source of propellant.
- MITEE compact nuclear reactor is (nearly) unlimited source of heat.
- With few moving parts mechanical wear should be minimal.
Nuclear Ramjet Flyer
MITEE Nuclear Engine

- MITEE (MIIniature ReacTor EnginE)


- MITEE is lighter and more compact than PBR.
MITEE Nuclear Engine (Contd.)

• Have Proposed MITEE-Based Rocket Engine for Solar System Exploration Missions:
  – Jupiter Orbiter:  2 Years
  – Europa Lander/Sample Return:  5 Years
  – Pluto Fly-By:  7 Years
  – Gavitational Lens at 550 AU:  30 Years
MITEE Nuclear Engine (Contd.)

• MITEE can be adapted for ramjet application:
  – Replace H$_2$ propellant supply system by inlet and diffuser.
  – Reduce power density from 10 MW/liter to 2 Mw/liter
  – Reduce outlet temperature from 3000 K to 1500 K
  – Increase operating life from ~1 hr to months.
THE MITEE REACTOR ASSEMBLY

MITEE FUEL REGION

- Multi-layer Roll of Metal Sheets
- Cold H₂-He Inward Flow
- Hot Gas Exit Channel

FUEL ELEMENT

- Metal Matrix Fuel Region
- Cold Frit
- Beryllium Moderator

REACTOR

MULTIPLE SHEET LAYERS

- Depressed Zones on Sheet
- Gas Flow Holes Through Sheet
- Metal Matrix Sheets
Cross Section of Single Fuel Element

Pitch

Outlet Duct

Inlet Plenum

\(^{7}\text{LiH/Be Moderator}\)

Cermet Fuel Region

Inner: \(^{184}\text{W/\text{UO}_2}\)

Outer: \(\text{Mo/\text{UO}_2}\)
Cross Section of Core

3 Shutter-Type Control Rods

$^7$LiH/Be Reflector
Radiation Safety

• Before reactor startup nuclear fuel is not hazardous.
• Reactor will start operation after Jovian entry.
• During launch phase (from Earth) safety systems prevent criticality for all conceivable accidents.
Ramjet Flight Envelope

Altitude Range of Flyer

NH$_3$ Ice?

Lightning

NH$_4$HS Ice?

H$_2$O Ice?

Altitude (km)

Ref.: Morrison and Owen 1996
Mission Characteristics

• Payload of 640 kg, comprised of
  – Ramjet Flyer 220 kg
  – Thermal Shield 220 kg
  – Companion Orbiter 200 kg
• Launch into LEO w. chemical rocket (Atlas IIAS).
• From LEO, fly to Jupiter using:
  – Chemical rocket with GA’s: ~ 6 years
  – MITEE Nuclear rocket (if available): 2 years
Mission Characteristics (Contd.)

• Deployment of Companion Satellite. Jovian entry profile similar to Galileo.

• When entry package has slowed to Mach ~1.5, flyer separates from thermal shield. Nuclear engine starts.

• Flyer commences atmospheric mapping operation.
Packaging of Ramjet Flyer in Entry Capsule
Separation of Flyer from Entry Capsule

(a) 

(b) Drogue Parachute

(c)
Atmospheric Properties Measured

- Pressure
- Temperature
- Chemical Composition
- Wind Velocity
- Cloud Particles and Size Distribution
- Lightning Frequency and Energy
- Energy Flux From Sunlight
- Energy Flux from Deep Interior
Phase I Conclusions

• Ramjet flyer provides unique tool for mapping in detail Jovian atmosphere.
• Detailed data should help explain poorly understood features of Jovian atmosphere, e.g., the Great Red Spot.
• Concept applicable to other planetary atmospheres.
Phase II Tasks

1. Integration of Reactor/Ramjet/Airframe
2. Platform Stability
3. Radiation Shielding
4. Data Transmission and Vehicle Control
5. Mission Analysis
6. Development Plan and Cost
7. Ramjet Flyer Workshop
Task 1
Integration of Reactor/Ramjet/Airframe

! Subcontract with GASL (General Applied Sciences Laboratory) for CFD analyses and for integration of ramjet/airframe.

! Neutronic and thermal/hydraulic analysis of MITEE nuclear engine proceeding in-house.
Task 2
Platform Stability

1. Characterize turbulence and gusting in Jovian atmosphere, based on most recent findings.

2. Apply the resulting loads on the Nuclear Ramjet Flyer and determine stability characteristics.

3. Develop autonomous control system.
Task 3  
Radiation Effects on Instruments

! Potential sources of radiation:

1. Background radiation in Jovian atmosphere
2. Radiation from exhaust plume
3. Radiation from nuclear engine

Radiation from unshielded nuclear engine is by far the overriding contributor.

! First approximation: Same instruments as Galileo
<table>
<thead>
<tr>
<th>Science Instrument</th>
<th>Properties Measured</th>
<th>P (W)</th>
<th>M (kg)</th>
<th>Temperature, pressure, density and mean molecular weight</th>
<th>Chemical composition of atmosphere</th>
<th>Clouds, solid/liquid particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere Structure Instrument</td>
<td></td>
<td>6</td>
<td>4.1</td>
<td></td>
<td>13.3</td>
<td>4.7</td>
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<tr>
<td>Neutral Mass Spectrometer</td>
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<tr>
<td>Nephelometer</td>
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</tbody>
</table>
## Instruments on the Galileo Probe (Contd)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightning and Radio Emissions Detector/Energetic Particles Instrument</td>
<td>Lightning and energetic particles</td>
<td>2.9</td>
<td>3</td>
</tr>
<tr>
<td>Helium Abundance Detector</td>
<td>Accurate measurement of helium/hydrogen ratio</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Net Flux Radiometer</td>
<td>Thermal (from interior) and solar energy</td>
<td>3.4</td>
<td>13</td>
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<tr>
<td><strong>Total:</strong></td>
<td></td>
<td><strong>33.4</strong></td>
<td><strong>59</strong></td>
</tr>
</tbody>
</table>
Task 3
Preliminary Findings

- Radiation dose for instrument design: $10^6$ RAD
- Galileo instruments built using 1970's electronics.
- Great strides in miniaturization and radiation hardening. (E.g., nephelometer volume $\sim 1800 \text{ cm}^3 \div \sim 50 \text{ cm}^3$)
- Using Galileo instruments leads to unrealistically conservative design.
- Obtain design characteristics for state-of-the-art instruments with radiation-hardened electronics.
Current Status of Program

! Phase II effort ongoing.

! Use of Galileo instruments inappropriate even for flyer preliminary design. Need state-of-the-art information on current scientific instruments.