A Venus Rover Capable of Long Life Surface Operations

Michael Evans, James H. Shirley, Robert Dean Abelson
Jet Propulsion Laboratory, California Institute of Technology

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Objectives

- The goal of this Venus Rover mission study is to examine a long-lived (weeks to months) mission that could meet the science goals of the Solar System Exploration Roadmap and Decadal Survey.

- Examine the feasibility of using a novel thermoacoustic Stirling system (TASHE) to provide electrical power and cooling.

Challenges

- Hostile Venus environment: 460°C, 90 bar
- Difficult to provide long-life electronics/systems environment (low temp & pressure)
- Difficult to provide long-life electric power

Scope

- Short study focused on: feasibility of using TASHE, identifying technology requirements, including sufficient thermal loads consistent with a minimal roving capability
- Many assumptions made regarding mobility system and technology readiness
Conceptual Rover Configuration

5 S-band horn antennas with 30-deg beamwidth provide full sky visibility with medium gain for 0.5 kbps return @ 10-W RF

53 GPHS Modules serve as TASHE heat source

TASHE acoustic wave chamber

0.5-m diameter x 1.5-m length pressure vessel is the smallest outside area that can fit all subsystems and wheel motors

High-temperature secondary battery kept outside pressure vessel

Conical wheels provide flexibility to terrain without the need for any mechanism outside the pressure vessel

Instruments are designed to occupy a small volume and require a minimum number of feed-trough’s
NRC Decadal Survey

- Specifically mentions a future Venus In-Situ Explorer
- Science Objectives
  - What global mechanisms affect the evolution of volatiles on planetary bodies?
  - Why have the terrestrial planets differed so dramatically in their evolutions?
  - How do the processes that shape the contemporary character of planetary bodies operate and interact?

Science Objectives for This Study

- Characterize the elemental and mineralogical composition of the surface
- Characterize the atmospheric composition, especially isotope ratios of key species
- Characterize planetary volcanism (activity, emissions to the atmosphere, composition)
- Characterize surface meteorology
- Characterize surface geology and morphology
Candidate instruments chosen to characterize system requirements (mass, power, data rate). Total instrument mass of 23.6 kg (w/o contingency).

All instruments packaged inside pressure vessel. Raman uses fiber optics port in hull.

NMS samples atmosphere via tiny inlet port using ambient pressure to fill one of multiple sampling containers.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Function</th>
<th>Data Rate (kbps)</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raman Spectrometer</td>
<td>Surface composition &amp; minerology</td>
<td>1</td>
<td>2.5</td>
<td>18</td>
</tr>
<tr>
<td>Neutral Mass Spectrometer</td>
<td>Atmospheric composition</td>
<td>5</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Navigation Cameras (4)</td>
<td>Navigation, Geology</td>
<td>100</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>IR Sun Sensor</td>
<td>~1 micron, Sun location for telecom</td>
<td>10</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Ground Penetrating Radar</td>
<td>Subsurface stratification</td>
<td>65</td>
<td>1.1</td>
<td>5</td>
</tr>
<tr>
<td>X-Ray Fluorescence</td>
<td>Surface elementals via alpha scattering</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Meteorology Station</td>
<td>Temperature, pressure, wind speed</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Landing Sequence

- Earth-Venus-Venus trajectory with direct entry at Venus
- Spherical inflatable ballute (64m diameter) helps reduce entry loads

1. Ballute Entry:
   - t = 0
   - Z = 140 km
   - V = 11 km/s
   - g = -4.5 deg
   - Q = 0 W/cm²
   - B = 0.3 kg/m²

2. Ballute Peak Heating:
   - t = 42 sec
   - Z = 114 km
   - V = 9.5 km/s
   - g = -2.2 deg
   - Q = 3.3 W/cm²

3. Ballute Peak Deceleration
   - t = 51 sec
   - Z = 111 km
   - V = 7.1 km/s
   - g = -2.0 deg
   - G = 34g

4. Jettison Ballute:
   - t = 150 sec
   - Z = 94 km
   - V = 128 m/s
   - g = -75 deg
   - Q = 10⁻³ W/cm²
   - B = 100 kg/m²

5. Rover Entry Module Peak Heating:
   - t = 218 sec
   - Z = 71 km
   - V = 308 m/s
   - g = -88 deg
   - Q = 0.018 W/cm²

6. Landing:
   - t = 4700 sec
   - Z = 0 km
   - V = 6.2 m/s
   - g = -90 deg
   - Q = 0 W/cm²

Legend
- B = Ballistic Coefficient
- g = Entry Angle
- G = G-Load
- Q = Heat Loading
- t = Time from Entry
- V = Velocity
- Z = Altitude

This information is pre-decisional and for discussion purposes only.
Rover Design Features

• Rover mass estimated at 680 kg (incl. 30% contingency).

• Power would be generated by a Thermal Acoustic Stirling Heat Engine (TASHE) using ~53 GPHS modules as the heat source.

• The Mobility system is assumed to use 4 conical wheels.
  – Each wheel is assumed to be a conical wire frame having a maximum diameter of approximately 80 cm and driven by its own motor.
  – The wheels do not articulate; steering is controlled by skid steering as on a tracked vehicle.

• Direct-to-Earth telecom
  – 500 bps downlink at 0.6 AU max range to a 70m DSN station
  – S-Band used to minimize atmospheric attenuation (1 dB loss vs 10 dB @ X-band)

• High temperature batteries (Na-NiCl₂) are mounted on the exterior.

• The Rover has no externally deployed parts. Only the wheels move.

• Rover surface area minimized and electronics kept in vacuum to minimize thermal load from Venus atmosphere.
Surface Operations

- Nominal operations scenario of 24 hour cycles
- Roving draws the most power (261 W)
- Four 60-minute telecom sessions, each follows stationary data collection periods
  - 30 min drives include 15 stops for nav images and GPR operation
  - Compositional science instruments operate when stationary
  - 6.9 Mbits returned per 24 hours

![Energy Balance Graph](image-url)
The TASHE produces acoustic power directly from a heat source without using any moving parts.

Electrical power is produced from a portion of the acoustic power using a linear alternator.

A Pulse Tube Refrigerator (PTR) is directly coupled to the TASHE to convert the acoustic power into thermal power, providing refrigeration with no moving mechanical parts.

Current functioning prototypes (NGST & LANL) are not designed to function on Venus.
Power and Cooling Calculations

GPHS Module

T = 1200 °C

13293 Wth

0.24 W/W

heat input from GPHS

T = 1473 K

themoacoustic eff Wpv/Qth

Environment

T = 500 °C

10134 Wth

3159 Wpv

T = 773 K

thermoacoustic reject

PV power

PV power to cooler

3044 Wpv

0.14 W/W

114 Wpv

0.70 W/W

PV power to alternator

Cooler eff Wc/Wpv

Cooling Side

thermal parasitics

300 Wth

414 W

34 Wth

80 We

T = 40 °C

T = 313 K

alternator reject

Electrical dissipation

total cooling required

JPL M. Evans 12/09/2005

This information is pre-decisional and for discussion purposes only.
The thermal control system must reject thermal energy from the atmosphere on the hull and penetrations (300 Wth total)

- The thermal load through the hull is about 133 watts.
- There are 4 drive motors with a total thermal load is 130 watts (4 x 32.5 watts).
- There are 6 optical penetrations (0.5 cm in diameter) with a total load of 3 watts.
- There is a Neutral Mass Spectrometer with a thermal load of 2 watts.
- There are 8 wire penetrations (assumes Manganin wire) with a total thermal load of 2 watts.
- There are 5 wave-guide penetrations with a total thermal load of 30 watts.

Thermal control design features

- Maintain a vacuum on the interior of the Rover (10^{-6} torr) to minimize convection. Getter material used to maintain vacuum in the pressure vessel.
- High temperature MLI on the rover interior (Gold plated Titanium with metal salt crystals as separators).
- Cooling is performed by the PTR integrated with the TASHE.
- Drive Motors are isolated from the Venus temperature environment with conduction isolation. Will be exposed to the Venus pressure (92 Bar).
- The cooling system must absorb the parasitic thermal energy.
Venus Rover Summary

• A long-lived Venus explorer is a high priority of the Solar System Exploration Roadmap.

• Increasing the mission lifetime and including mobility opens up numerous new scientific options. Scientists can now trade, e.g., between:
  – Stationary lander with full instrument suite versus Rover with limited instrument suite.
  – Increased measurement capabilities versus lifetime (for example, sample acquisition might limit lifetime through thermal problems).

• A TASHE system (or other advanced RPS concept) capable of providing electrical power and thermal cooling in a Venus environment could be enabling for a long duration surface mission.