A Venus Rover Capable of Long Life Surface Operations

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2005 AGU Fall Meeting

December 9, 2005

Study Overview

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 an novel thermoacoustic Stirling system (TASHE) to provide electrical power and cooling.

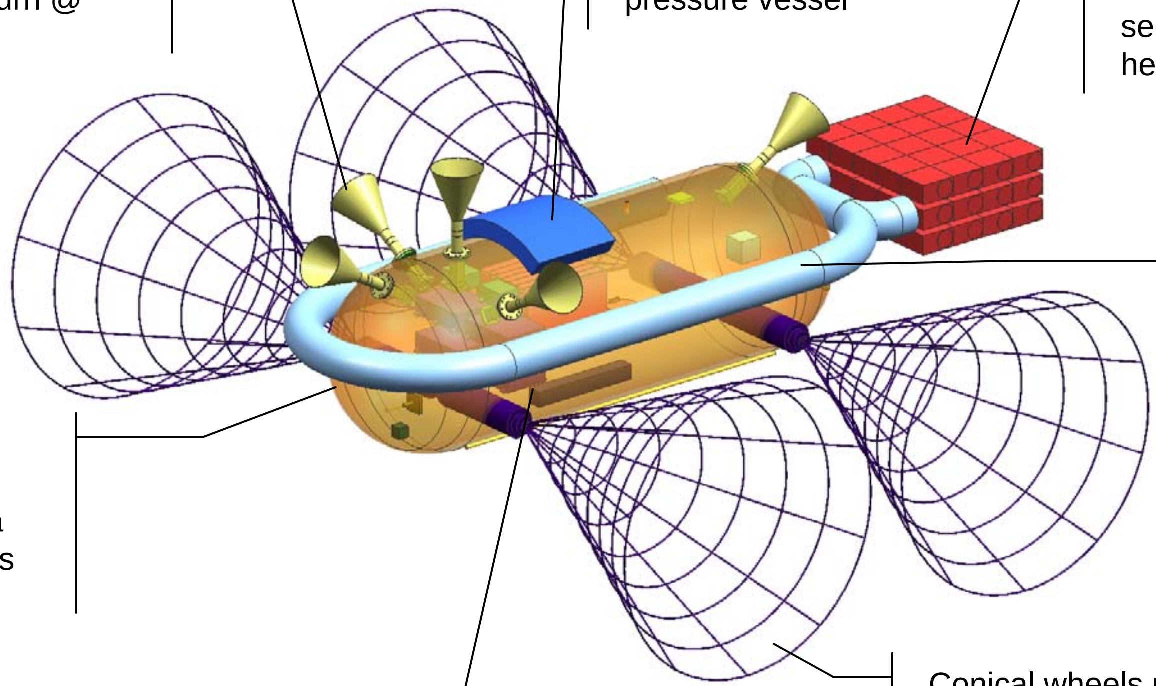
Challenges

- Hostile Venus environment: 460ºC, 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

High-temperature secondary battery kept outside pressure vessel

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

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

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

Science

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 comtemporary 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, emmissions to the atmosphere, composition)
- Characterize surface meteorology
- Characterize surface geology and morphology

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

Strawman Instruments

- 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.

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

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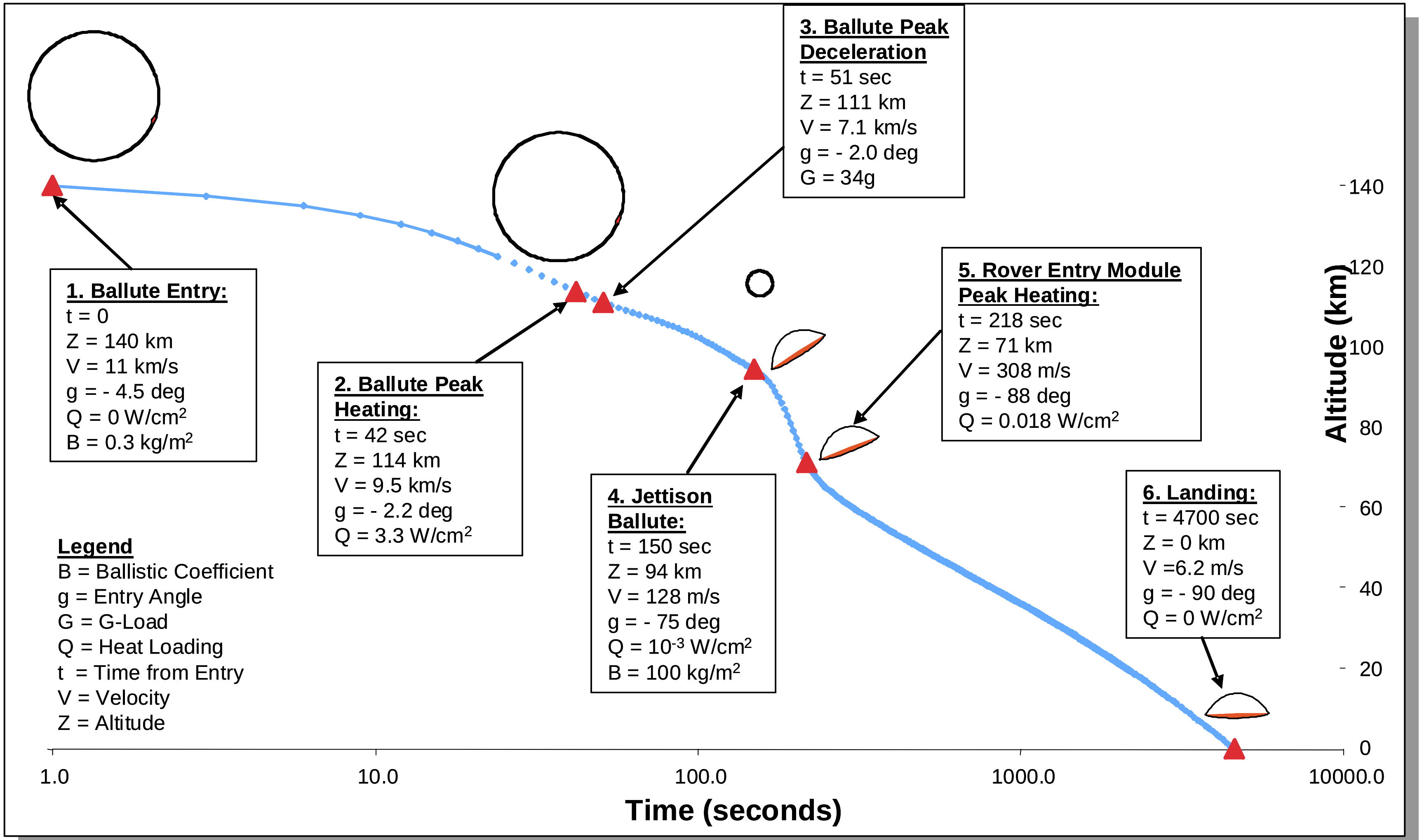
Landing Sequence

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



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 ($Na\text{-}NiCl_2$) 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.

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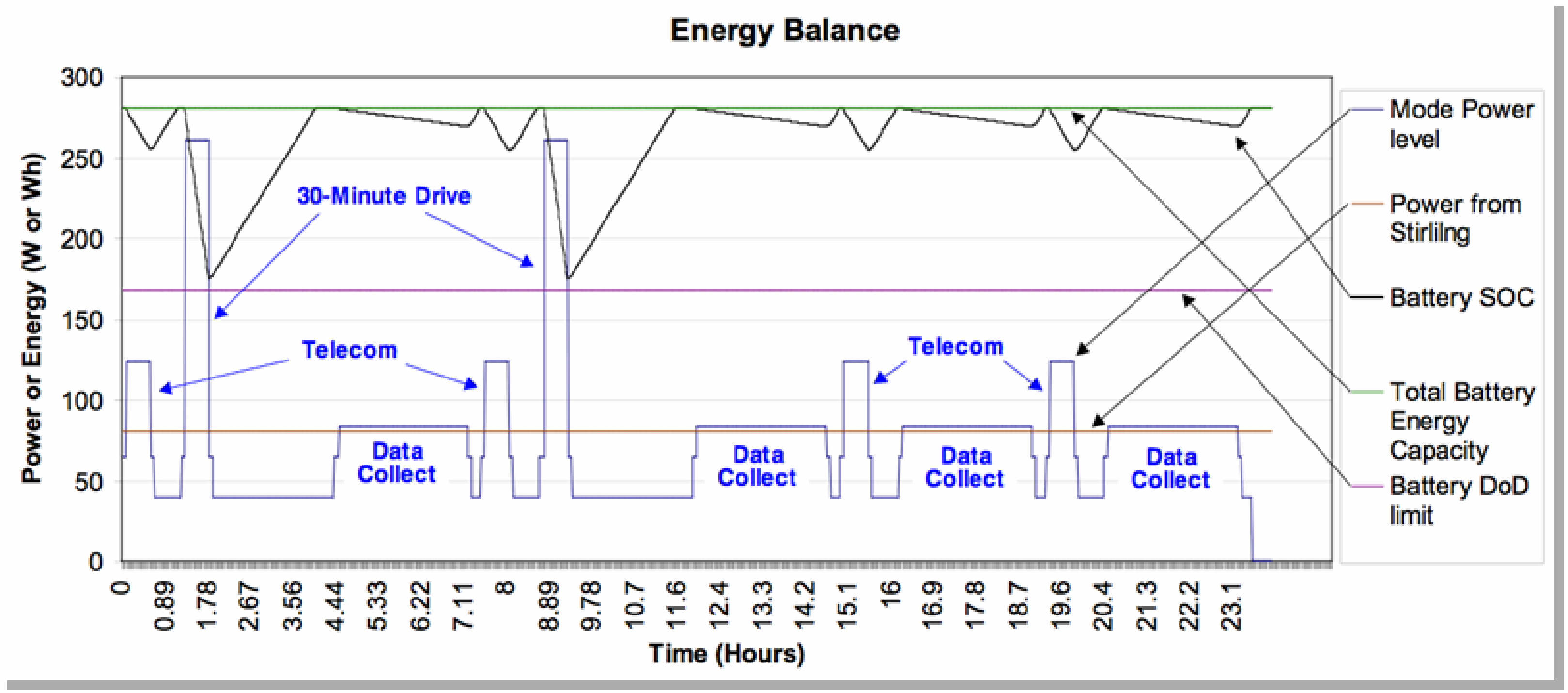
Surface Operations

- 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



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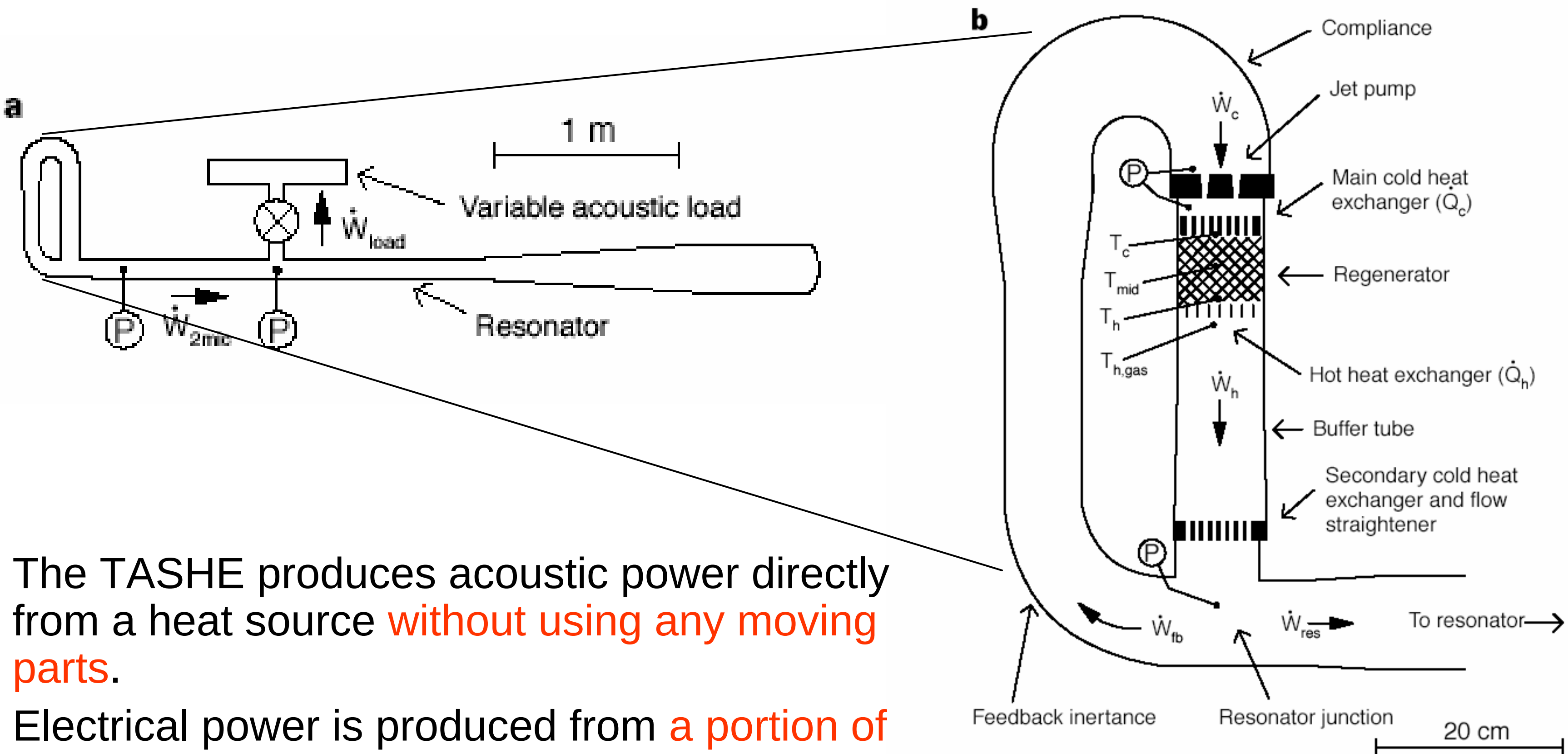
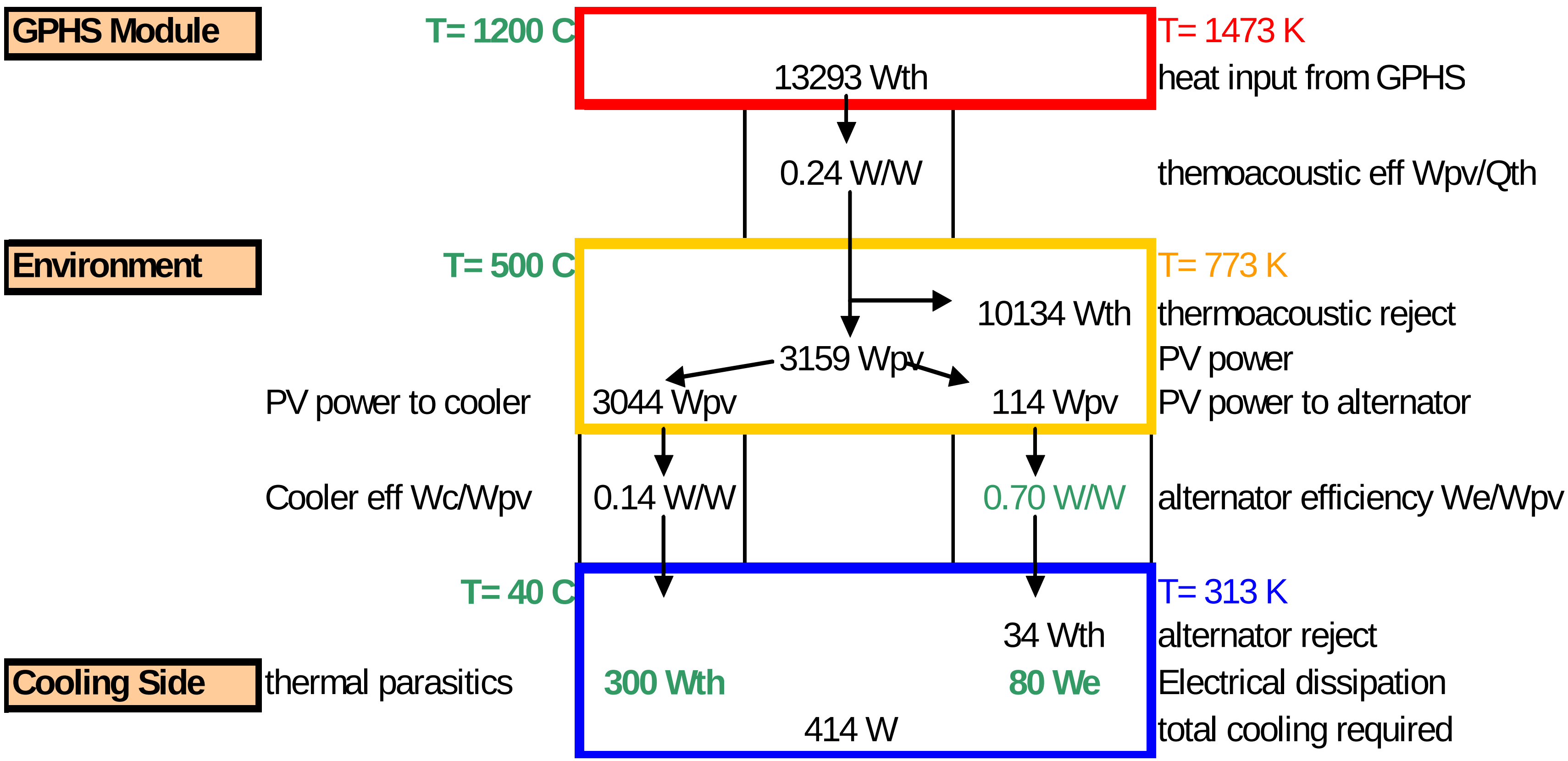
Thermoacoustic Stirling Heat Engine (TASHE)



- 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



Thermal Design

- 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 wattts).
  - 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.

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