**Rocket Lab Venus Probe Thermal Protection System – Design, Development, and Future Applications**

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**Presenter Biography:** Lyle Campbell is a development engineer at Rocket Lab, whose work is currently focused on thermal protection systems for the upcoming Neutron re-usable launch vehicle. He received his Bachelor of Mechanical Engineering and Master of Space Engineering from the University of Western Australia and Politecnico di Milano, respectively.

**Abstract:** Rocket Lab’s mission to Venus [1], launching in January 2025, aims to demonstrate that small launch vehicles, such as Electron, and high-energy small spacecraft, such as Photon, can enable a new paradigm of regular, low-cost interplanetary missions. The Electron launch vehicle will deliver the Photon spacecraft carrying the entry probe into low earth orbit, at which point Photon will take over and put both itself and the attached probe on an Earth-Venus transfer trajectory, with assistance from a Lunar flyby.

 The primary science objective of the mission is to sample the Venusian cloud layers between atitudes of 45 and 60 km above the surface with an autofluorescing nephelometer. The ~1kg scientific instrument will be carried by a small ~17 kg direct entry probe which will separate from the Photon spacecraft approximately 30 minutes prior to atmospheric entry.

The probe outer mould line is a scaled down version of the Deep Space 2 probes [2]. NASA’s newly developed 3D Woven Carbon Phenolic, a derivative of the Heatshield for Extreme Entry Environment Technology (HEEET) material [3], is an enabling technology for this mission, and it will comprise the probe forebody heat shield.The probe will communicate directly back to the Earth during its descent via a small on-board radio frequency (RF) antenna.

The hyperbolic Venus encounter will see the probe enter the Venusia atmosphere at approximately 11 km/s with an entry flight path angle (EFPA) of about 10°. This relatively low entry angle was selected to increase the duration of the descent phase, reduce the peak deceleration, and reduce the sensitivity of the nominal entry environments to navigational errors. For reference, the Pioneer Venus probes entered at EFPAs varying from about 25° to 70°, resulting in peak decelerations between around 220 and 450 g’s and peak stagnation point heat fluxes ranging from about 40 to 75 MW/m2 [4]. In comparison, the Rocket Lab Venus probe will experience a lower preak deceleration of around 60 g’s and a lower peak stagnation point heat flux of about 15 MW/m2, at the cost of a greater total heat load and correspondingly higher thermal protection system (TPS) mass fraction.

This paper recounts the development history of the TPS for the Rocket Lab Venus probe, with a focus on the unique requirements of the mission. In particular, the effect on the TPS design of the mission’s tight budget, short development timeline, slim mass and RF link margins, and mild but long duration entry heating. Rocket Lab’s initial investigations into a ‘hybrid’ TPS [5] based on a scaled version of the Pioneer Venus full-density carbon phenolic forebody shield, and the abandonment of this approach in favour of NASA’s 3D Woven Carbon Phenolic is presented. Additionally, the leveraging of previous testing under the HEEET project at higher conditions and the associated TPS margining strategy that was adopted to avoid the need for extensive mission-specific arc jet testing is discussed. Finally, this paper concludes with a brief consideration of the feasibility of a future low-cost aerocapture technology demonstrator mission based on the 2025 Rocket Lab Venus mission and entry probe.

**References:**

[1] French R. et al. (2022) “Rocket Lab Mission to Venus”, *Aerospace* 9(8):445. [2] Smrekar S. et al. (1999) “Deep Space 2: The Mars Microprobe Mission”, *JGR,* 104, 27013-27030*.* [3] Gash M. (2019) “HEEET TPS”, URL: https://ntrs.nasa.gov/api/citations/20190031968/downloads/20190031968.pdf [4] Pitts W. and Wakefield, R. “Performance of Entry Heat Shields on Pioneer Venus Probes”, *JGR*, 85, 8333-8337 [5] Triantou et al. (2015) “Novel Hybrid Ablative/Ceramic Layered Composite for Earth Re-Entry Thermal Protection”, *JMEP*, 24, 1452-1461