AERACEPT (AEROSOL RAPID ANALYSIS COMBINED ENTRY PROBE/SONDE TECHNOLOGY): ENABLING TECHNOLOGY FOR MISSIONS TO THE VENUS CLOUDS. D. M. Gentry[1], A. Borner[2], C. Dang[3], J. B. E. Meurisse[2], C. Naughton[1], J. Park[1], J. Blair[1], A. Cassell[1], S. Dhaniyala[5], L. Iraci[1], A. L. Mattioda[1], P. Sobron[4], E. Venkatapathy[1], and A. Davila[1] [1]NASA Ames Research Center [2]Analytical Mechanics Associates, Inc. [3]Bay Area Environmental Research Institute [4]Impossible Sensing [5]Clarkson University

Introduction: Aerosols (clouds, hazes, dusts) are drivers of key planetary processes, including mass and energy transfer. They can play a determining role in planetary climate evolution, such as the divergence of Venus and Earth. Clouds are even of habitability interest due to their occurrence on rocky worlds with liquid water – Earth's fog and cloud water have a substantial microbial presence. However, aerosols are highly dynamic, and once-in-a-lifetime flagship missions are not enough to fully characterize them.

AERACEPT (AErosol Rapid Analysis Combined Entry Probe/sonde Technology) is an early-stage technology combining the functions of an entry vehicle and aerosol-sampling passive descent sonde into a single aeroshell body, reducing the mass, volume, and complexity of planetary aerosol sampling. AERACEPT is particularly well suited for a Venus mission, where the particles of greatest interest are within the subsonic descent regime. It is part of the Nephele mission concept study for a small probe complementing larger missions targeting Venus atmospheric gas analysis, such as DAVINCI and Venera-D, by specifically targeting cloud and haze particles from 63 to 39 km.

Key Features: AERACEPT uses the aeroshell's own velocity to drive aerosol capture and separation. Its design uses a small aeroshell without heat shield separation, deployable parachutes, or descent control.

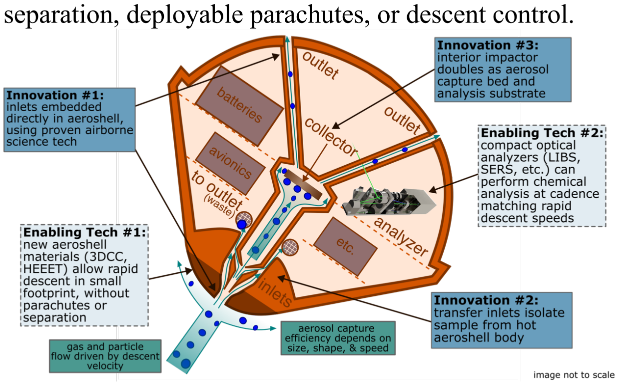

Figure 1. Probe concept modeled on the Pioneer Venus Small Probe with aerosol particle capture system and notional analysis payload.

AERACEPT combines a unique set of technologies (Fig 1): recently developed thermal protection materials including 3D woven carbon-carbon (3D-C/C) and single-layer Heatshield for Extreme Entry Environment Technology (HEEET); aerosol sampling technologies with heritage in both planetary and airborne science (high-speed inlets and particle separation); and rapid, robust optical analysis instruments (such as the VOLTR dual spectrometer). It also draws on flow-through inlet and particle capture heritage from larger probe missions and concepts, including Galileo, Huygens, Venera, and VeGa. Though self-contained small aeroshell sondes have been flown for gas sampling (Pioneer Venus, Mars Deep Space 2), they were not intended for particulate analysis beyond nephelometry. Particle sampling from a proof-of-concept aeroshell was demonstrated decades ago (the PAET), but thermal and material concerns at the time limited its potential mission application.

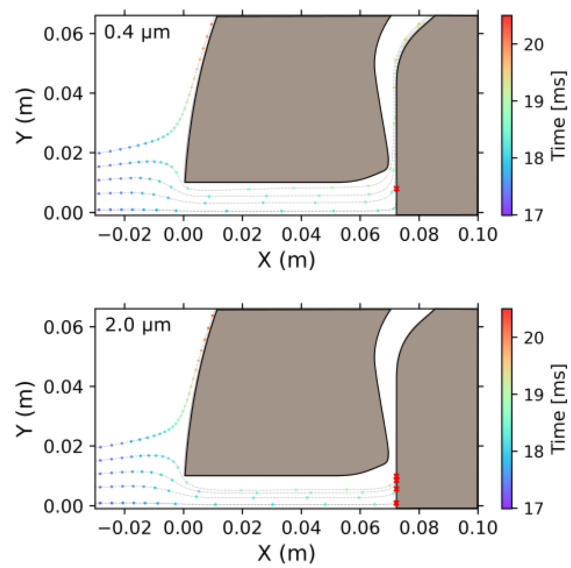

Figure 2. Representative trajectories for 0.4 and 2 μm diameter particles at 62.25 km Venus altitude.

Development Challenges & Current Status: AERACEPT creates a new mission trade space for planetary aerosol science missions. High-level questions necessary for TRL advancement include:

1. How will thermal degradation of aerosol samples, from the hot aeroshell body and high capture velocity, limit achievable science?
2. Can the reduced footprint capture enough (and not too much!) sample for science?
3. Can current analysis technology keep up with the faster descent? How is sample resolution limited?

Thermal modeling and validation. The thermal protection material (TPM) response of the nose for points along the notional Nephele trajectory was computed using Traj → DPLR → BLAYER → PATO. The aeroshell surface is predicted at ~3700 K peak, ~1300 K at start of science ops; predicted stagnation point recession is 1.1 mm after convective heating at 88 s. Outgassing (ablation and pyrolysis) products from 3D-C/C are not predicted to cross-talk with key Venus aerosol science analytes (Table 1) under these conditions. A validation test of this model using an aeroshell nose section, with and without a through-hole, was conducted in CO_2 at the UIUC Plasmatron X facility (Fig 3); preliminary analysis of the results shows that the recession rate matches well.

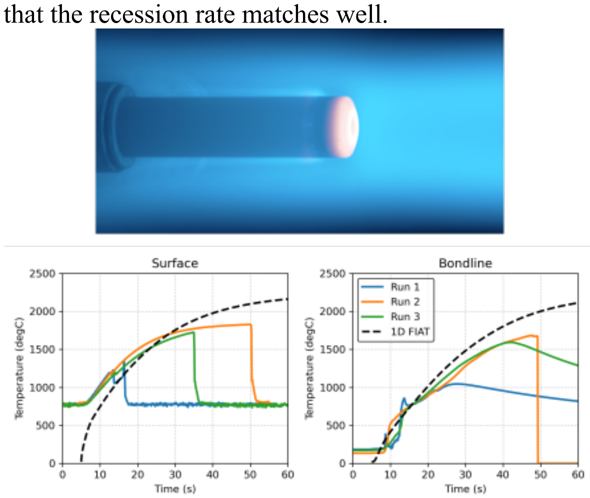

Figure 3. (t) 3D woven carbon-carbon cylindrical section of aeroshell nose with inlet under test. (b) Pyrometry for non-inlet surfaces and bondlines. Run 2 has complete data from both thermocouples.

Flow modeling and validation. A compressible flow solver (rhoPimpleFoam) was linked with a particle tracking solver (denseParticleFoam) to predict particle capture efficiency in different size bins (Fig 2). Using the standard Venus atmosphere and particle populations, predicted capture efficiency ranges from 16 to 2 % at *Stk* ~ 0.2, for a total sample volume of ~27 μL. This sample would be numerically dominated by midsize (~0.4 μm dia) particles, but by volume would consist of >95% the sparser larger particles (> 8 μm). These predictions will be empirically validated with an upcoming two-point scaled validation test at the NASA Ames Fluid Mechanics Laboratory.

Combined thermal and flow predictions. The two model outputs were combined with subsonic CFD computed in OpenFOAM to predict wall heating and kinetic heating for the internal flow path. Particle temperature delta is predicted to be <2 K through 47 km; the maximum is ~14 K, experienced by the smallest haze particles below the cloud layer. (This prediction does not include radiative transfer during science operations as it is highly sensitive to assumptions about the mechanism used to open the inlet.) Most target analytes (Table 1) will be preserved in that temperature range, though some water will be lost. Notably, these conditions can be reproduced in the lab for science testing and validation.

Table 1: Potential target analytes for Venus aerosols.

type	**target analyte**
elemental	S, C, H, P, Cl, N, O, Fe
molecular	H_2O, H_2SO_4, SO_x, PO_x, NO_x, CH_x ...
specific	organic moieties: C=C, C=O, C≡N...

Analysis sensitivity and cadence. Synthetic Venus analogs spanning the key Venus aerosol analytes in Table 1 are under test with Raman, LIBS, and UV/VIS/NIR spectroscopy. Initial optical substrates did not survive exposure to 80% w/w H_2SO_4, but complex organic features are apparent in Raman spectra on silicon, graphite, and PTFE substrates, as are UV/VIS fluorescence features in bulk (Fig 4).

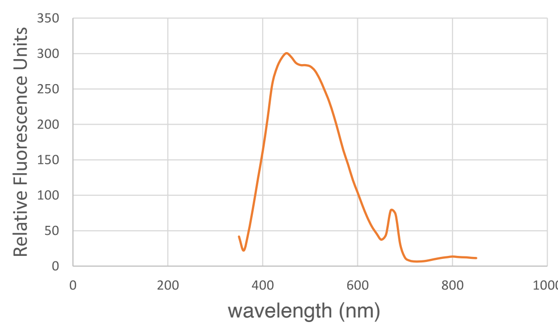

Figure 4. UV/VIS fluorescence spectra of aged Venus aerosol analog material generated from 80% w/w H_2SO_4 + propanal.

Summary: Thermal and particle capture modeling are favorable for science operations under the Nephele use case. We are using are using our newly-developed toolchains to characterize these trades. Material compatibility is a significant limitation, especially for the analytical instrument(s). While a specific mission implementation could be significantly optimized beyond these initial results, they show that AERACEPT has significant potential value in enabling small-spacecraft aerosol science.

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