LEAVES – A PLATFORM FOR WIDELY DISTRIBUTED EXPLORATION OF VENUS' ATMOSPHERE

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Introduction: Progress on open questions associated with mechanisms driving Venus atmospheric processes requires simultaneous observation of the fundamental atmospheric physical properties (temperature, pressure, wind, chemical composition, etc.) over a broad range of altitudes, local solar times and latitudes as well as detailed and coincident observation of external forcings such as incoming solar radiation, solar pressure and solar wind[1, 2]. The LEAVES (*Lofted Environmental and Atmospheric VEnus Sensors*) platform, a proof-of-concept maturation effort supported by the NASA Innovative Advanced Concepts program, is a swarm approach to obtaining key Venus atmospheric data for exceptionally low cost and risk. This is made possible by an inexpensive, ultra-lightweight, passive-drifting, atmospheric sensor package that can yield valuable new, transformative information on the Venus atmosphere above, within, and below the clouds. LEAVES uniquely enables atmospheric sensing through combining miniaturized, special-purpose sensors, conventional electronics, and low-power communications on a lightweight drifting structure that generates substantial atmospheric drag. The benefits of this architecture include scalability, straightforward integration as a secondary payload, and reduced cost of obtaining high-priority science data. While LEAVES has a low TRL as an integrated system, all components comprising it are mature to the TRL 5-6 level.

Motivation: Developing a comprehensive global picture of simultaneous atmospheric conditions is beyond the scope and capabilities of conventional, single-platform missions, due to sparse lateral *and/or* vertical coverage. Leveraging a "swarm" of inexpensive, independent atmospheric sensors with high atmospheric residence times, LEAVES provides a way of obtaining comparatively dense coverage in both lateral and vertical extents.

Probe Design: Each lightweight atmospheric probe is made of a ~100 g, high-drag structure and a 30 g, single-board science payload. A spring-hinge expands the 3-sided, inverted shuttlecock structure upon deployment, which then self-stabilizes due atmospheric resistance and a low center of gravity. The remarkably low areal density of ~ 0.1 g/m^2 yields a ballistic coefficient of 0.13 while maintaining structural strength sufficient for both a direct orbital deployment (i.e. without aeroshell) and a period of extended science operations in Venus' middle atmosphere.

Each probe in the swarm is equipped with at least two highly sensitive, chemical species sensors with better than 1 ppm resolution, temperature and pressure sensors, 6-axis IMU, a microprocessor, 400 MHz radio, and hybrid high/low temperature battery. Sensor data is recorded every 30 seconds, at 8-bit resolution, and cached by the microprocessor for upload to an orbiting relay during multiple uplink opportunities.

Unprecedented Atmospheric Data: During a host spacecraft's aerobraking or orbit circularizing campaign, cohorts of a dozen or more probes are released at an altitude of ~150 km. If the carrier spacecraft is in a polar orbit, the deployment sequence can be timed to space out the probes over 10-20 degrees of latitude. Over the next several days to weeks, the LEAVES' orbits decay until they reach their target operational altitude of 100 km. For 9-10 hours, they each collect around 1 MB of data, composed of >1000 repeated sensor measurements. These data span 60 km of altitude (including the clouds) and 1500 km of lateral travel.

Ongoing work: Our work under the NIAC Phase II focuses on fabrication and demonstration of the single-board electronics/sensor payload. In addition, we are refining the structure to function as a directional glider, in contrast to the Phase I design [3, 4] shown in Figure 1 below. This work will demonstrate a functional approach to communication between LEAVES units and a relay station and address the challenge of georeferencing probe data.

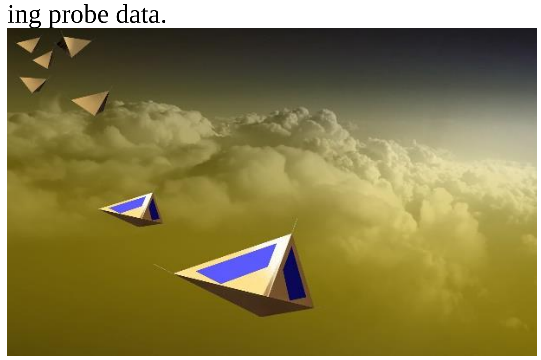

Figure 1. Multiple LEAVES units descending into Venus' clouds (Phase I design).

References: [1] A. Brecht *et al.*, "Closing the Gap Between Theory and Observations of Venus Atmospheric Dynamics with New Measurements," 2020. [2] F. P. Mills *et al.*, "Atmospheric chemistry on Venus – New observations and laboratory studies to progress significant unresolved issues," 2020. [3] J. A. Balcerski *et al.*, in *LPS*, 2018, vol. #2038. [4] J. A. Balcerski *et al.*, Planetary CubeSats Symposium, GSFC, 2019.