TECHNOLOGIES FOR EXPLORING THE VENUS CLOUD ENVIRONMENT: J. A. Cutts[1], A-M Azad[1], K. Baines[1], P. K. Byrne[2], S. Dawson[1], L. Dorsky[1], R. C. Flagan[3], J.L. Hall[1], J. S. Izraelevitz, C. MacFarland[1], M. Pauken[1], J.Salazar[1], J. Schwartz[1], J. A. Sinclair[1], B.M. Sutin[1], W. West[1], [1]Jet Propulsion Laboratory, California Institute of Technology, MS 183-602, 4800 Oak Grove Drive, Pasadena, CA 91109, [2]Dept. of Earth and Planetary Sciences, Washington University, St Louis, MO [3]Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, CA. James.A.Cutts@jpl.nasa.gov

Introduction: Aerial missions that can operate for 100 Earth days or more in and below the Venus cloud layer [1], [2] create new opportunities for investigating the planet with in situ observations of cloud and atmospheric chemistry and astrobiology, atmospheric dynamics, geophysics, and surface geology. The cloud environment is relatively benign compared to the Venus surface, where temperatures are 460°C, 90-bar pressure, and highly corrosive supercritical CO_2 (with SO_2 as a minor constituent). Nevertheless, there are environmental issues that an aerobot circling Venus every 5 to 7 days in and below the cloud layer must contend with. For the last several years, JPL has been engaged in characterizing these environmental challenges and developing technology solutions to address them.

Venus Cloud Environment: The Venus Cloud layer extends from 47 km to 75 km altitude (Figure 1). Missions currently under consideration will operate primarily in the lower/middle cloud layer, potentially operating below the clouds where high-resolution near infrared imaging of the surface is possible [3].

Temperature/Pressure: Although temperatures in the Venus cloud layer are roughly comparable to those in a similar pressure region on Earth, at the base of the cloud layer they increase to 100°C or higher. Moreover, during the daytime, solar radiation can elevate the temperatures significantly higher. Pressures across the cloud layer range from 20 mbars to about 2 bars [4].

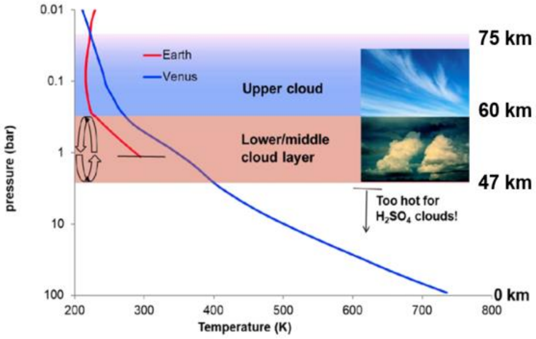

Figure 1. Venus cloud environment compared to conditions on Earth. Although there are temperature and pressure conditions that are benign relative to the surface, temperature in the lower cloud are much higher than on Earth and the corrosive sulfuric acid must also be contended with.

Solar Radiation: Scattering by cloud particles progressively attenuates solar radiation at greater depths within the cloud layer. Because of multiple scattering the intensity of radiation is almost independent of direction, with the downward flux only 10–20% higher than the upward flux. Accordingly, it is not possible to shield components from sunlight without totally enclosing them. The spectral content of the radiation (Figure 2) varies with depth and, because of scattering, depends strongly on the zenith angle of the Sun dropping sharply as the terminator is approached.

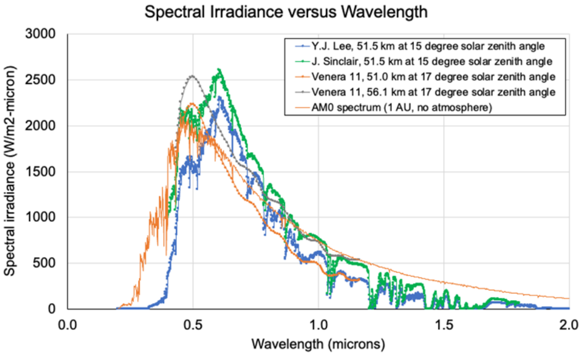

Figure 2. Spectral content of radiation in the Venus cloud layer for two models, and a comparison with Venera 11 lander measurements during its descent. The spectrum in Earth orbit is shown for comparison.

Cloud Particle Composition: The mass concentration of cloud particles is thought to range from 1 mg/m^3 in the upper cloud to 100 mg/m^3 near the cloud base [5]. The H_2SO_4 concentration likely varies from 98.4% at the cloud base at 47 km, to 95% at 52 km where the temperature is 60°C, to 80% at 60 km and remaining roughly constant above that. Larger particles >1 µm become dominant in the lower clouds.

Technical Challenges: Operating in the Venus environment presents a number of challenges that are being addressed.

Balloon Material: A laminated balloon material (Figure 3) has been selected with an outer Teflon layer to provide protection from the acid environment [6]. The high-emissivity/low-absorptivity of the film material limits the temperature difference between the balloon and the ambient atmosphere during the day. As well as contributing to the solar-optical properties, the metallic film also acts as an effective gas barrier to extend the lifetime of the balloon in the Venus atmosphere.

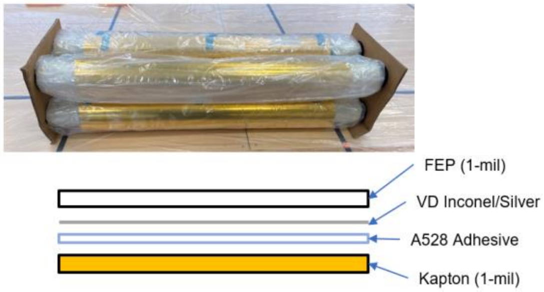

Figure 3. A laminated balloon design has been developed that is resistant to sulfuric acid, reflective to solar radiation (VD Inconel/Silver), and which includes a substrate (Kapton) to enhance mechanical strength. The metal layer augments the gas barrier properties of the Kapton.

Gondola Temperature Control: Recent advances in white, high-emissivity/low-absorptance paints (e.g., $BaSO_4$ and Z93-C55) create new opportunities for thermal control. Stability of these paints at elevated temperature (80°C for 7 days), has been demonstrated. These paints have also been coated with 25 µm-thick Parylene, which provides complete protection from acid attack and permits the retention of solar-optical properties.

Power Generation: The solar energy available during the Venus day is ample for power generation, but can be optimized for the spectral content in the cloud layer (Figure 2). Solar cell assemblies tolerant of the effects of sulfuric acid with modest impacts on efficiency of conversion are being developed (Figure 4).

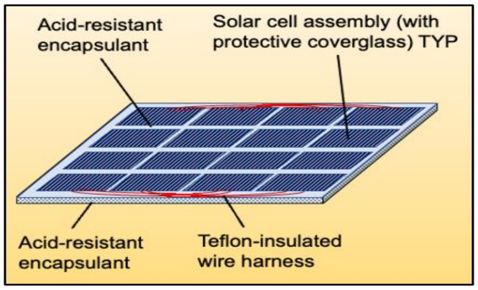

Figure 4. A concept for protecting solar panels from exposure to sulfuric acid in the Venus clouds. Encapsulents have a very small effect on transmission and hence efficiency.

Energy Storage: Although there is plenty of sunlight in the Venus cloud layer when the Sun is high, there are periods of up to three days when an aerobot operates on the nightside of Venus where photovoltaic power is low, and thus requires batteries to provide supplemental power. However, a major limitation on the ability of an aerobot to descend deep into the atmosphere is energy storage. Batteries experience severe capacity loss at elevated temperatures and, if those temperature are high enough, the batteries will fail completely. JPL has been developing wide-temperature electrolytes that will enable batteries to operate at both low and high temperatures. There has been steady progress towards a goal of 150 charge–discharge cycles at 100°C without significantly compromising battery specific energy.

Testing for Exposure to Venus Cloud Particles: Initial tests of the effects of exposure to sulfuric acid in the Venus clouds have involved immersion of material coupons in concentrated sulfuric acid. But such testing is not representative of the effects of a tenuous haze of particles. A Venus Cloud Simulator (VCS) has been constructed that generates aerosols with a nebulizer. The particle distribution (Figure 5) is flatter than observed in the Venus atmosphere, where it is established by photochemical processes, but is a closer approximation to the actual Venus environment for engineering purposes. Tests of solar panels, balloon materials, optical components, and pressure sensors are underway and preliminary results will be reported.

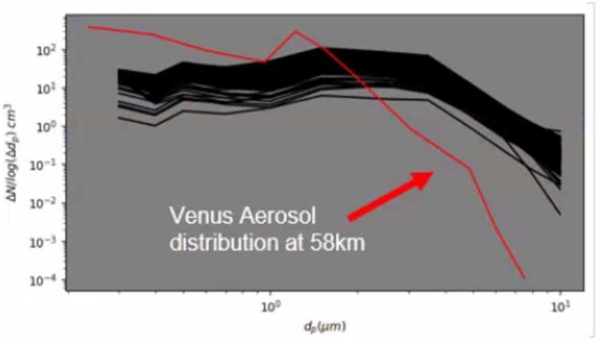

Figure 5. Size–frequency distribution of aerosol particles generated in the VCS compared with the actual distribution on Venus. The different curves are for different locations in the test chamber. The shape of the distribution in the chamber is invariant with particle concentration.

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