HIGH SPATIAL RESOLUTION IMAGING OF THE SURFACE OF VENUS VIA A BALLOON-BORNE TOW-BODY CAMERA SYSTEM.

K. H. Baines[1], J. A. Cutts[1], P. Mcgarey[1], B. M. Sutin[1], A. B. Davis[1], [1]Jet Propulsion Laboratory, California Institute of Technology, MS 183-602, 4800 Oak Grove Drive, Pasadena, CA 91109, Kevin H.Baines@jpl.nasa.gov

Introduction: Since the first near-infrared images and spectra of Venus' nighttime surface were obtained by the Near Infrared Mapping Spectrometer (NIMS) during the Galileo flyby in 1991 [1,2], hundreds of near-infrared images and spectra have been obtained by other flyby and orbiting spacecraft, including Cassini [3], Venus Express [4,5,6] and Akatsuki [7]. In these observations, thermal radiation in the 0.85-1.18 μm wavelength range upwelling from the hot (~740 K) surface is scattered by the optically-thick yet conservatively-scattering cloud deck, resulting in rather dramatic degradation of the spatial resolution of the imagery to about 100 km. However, apart from atmospheric seeing, the spatial resolution of such thermal surface imagery obtained below the cloud deck, at near the 47-km (~ 100C) level, should be able to achieve any value desired, dependent only on the design of the instrument and its platform (e.g., aperture and pixel size, and camera platform stability [8,9]). For example, if seeing is on the order of 45 arc secs (the apparent maximum size of Jupiter in Earth's skies), then the surface spatial resolution can be as good as 10 meters from an altitude of 47 km. Assuming the optics are designed to achieve this resolution, then the actual spatial resolution obtainable largely depends on camera stability (e.g., jitter; spatial and angular drift of camera pointing during the exposure). Such high resolution imaging in the near infrared in several spectral bands provides a means to characterize rock composition in geologic features such as tessera and coronae, and to identify and characterize volcanic phenomena such as hot magma flows and water vapor enhancements [10].

Possible High-Resolution Imaging Platforms: Relatively stable observations are theoretically possible from a balloon platform. However, the high temperature encountered at 47 km altitude and below presently precludes the use of a constant-altitude (super pressure) balloon as beyond typical spacecraft/aircraft temperature design limits, although such design issues may be overcome in the next decade [10]. Variable-altitude balloons may find a way to briefly dip to sub-cloud altitudes [10], but at increased risk to the balloon and increased overall operations costs.

One technique for sub-cloud nighttime surface imaging would be to image during descent from a phase-change-material-cooled probe or lander. In particular, from a balloon platform situated near the relatively benign environmental altitude of 55 km, the deployment of an imaging probe would seem to be a good solution. However, this limits imagery to a short time period (less than an hour) during descent, providing relatively little territorial coverage. Moreover, probes may spin and nod as they descend, severely degrading the observed resolution and obtaining images at uncertain azimuth and elevation angles (à la the Huygens probe [11]).

The Tow-Body Concept: A more promising solution may be to use a tethered platform that is repeatedly raised and lowered from the balloon. The platform would incorporate a phase-change material for repeated cooling. For sub-cloud excursions of ~1-2 hours, the platform would be lowered to the 47-km level from the balloon. Flying over the surface at the speed of the winds near 55-km altitude, the platform would view changing scenery at a rate of ~60 m/s, or ~220km/hr [12]. Thus, exposure times would be < 0.16 sec to limit the lateral smear to 10 meters. Over the 8km range difference in altitudes between the tow-body and the balloon, the zonal wind typically varies by ~3 m/s [13]. The tow-body would thus be dragged behind the balloon at this relative airspeed, providing the opportunity to use aerodynamic forces, such as a tail appendage, to maintain a relatively stable platform pointing into the relative wind. As well, pitch stability could be reasonably maintained using a stabilator/elevator and/or a canard, a common design implementation for underwater tow vehicles on Earth.

Current estimates for tow-body mass, incorporating the phase-change material, rechargeable battery power, pressure/temperature sensors, airspeed sensor, accelerometer, the near-infrared imager and a top-mounted CCD camera for balloon and sky/cloud viewing on deployment and retraction, is ~2-3 kg. The tether, comprised of high-strength tensile fibers, a Gb-speed optical comm link, and a protective coating for the abrasive atmosphere, is planned to extend ~ 9 km to account for its downwind drift in the prevailing relative wind. The estimated tether mass is 3.6 kg, while the deployment/retraction system on the balloon gondola has an estimated mass of ~ 1 kg.

We find that while the tow-body technique is feasible for nighttime high-resolution thermal surface imaging from the 47-km altitude level just beneath the clouds, it is not a solution for imaging the surface in reflected sunlight. For that purpose, the tow body needs to be within 10 km of the surface which we consider to be impractical.

Near-Infrared Imaging Tow-Body Camera: As currently planned, the camera will image at three near-IR surface-emission wavelengths - 1.01, 1.10, and 1.18 μm - that have reasonably large fluxes that - given the volume and mass limitations of the camera system - can achieve a sensor SNR of > 10 on a 10-m scale from 47 km in less than the 0.16 sec image-smear time noted earlier. Two other possible wavelengths - 0.85 and 0.90 μm observed by the Visual-Infrared Mapping Spectrometer (VIMS) on Cassini [3] - have an order of magnitude lower surface thermal emission flux, thus precluding their use for achieving 10-m resolution imagery from a fast-moving aerial platform.

The current design calls for images to be acquired by all three wavelengths simultaneously, using 3 imaging arrays of 1280 x 1024 pixels, covering 10.24 km east-west and 12.8 km north-south. It is expected these arrays will be cooled by the phase-change material to 35°C degrees. Three images - one for each wavelength - will be acquired every one-third of a frame downwind, corresponding to an image set every 56 sec assuming a tow-body groundspeed of 60 m/s. Over a 1-hour excursion, a total of 192 near-IR images are expected to be collected for the three wavelengths, covering contiguously a region spanning 216 km east-west and 12.8 km north-south at near 10-m resolution.

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