STRATEGIES FOR SAFELY LANDING ON VENUS TESSERAE.

J. J. Knicely[1], R. J. Lynch[2], P. A. Mason[2], N. Ahmad[2], L. H. Matthies[3], C. J. Gramling[2], C. I. Restrepo[2], M. S. Gilmore[4], and R. R. Herrick[1], [1]University of Alaska Fairbanks, 2156 Koyukuk Drive, Fairbanks, AK 99775 (jknicely@alaska.edu), [2]NASA Goddard Space Flight Center, [3]NASA Jet Propulsion Laboratory, [4]Wesleyan University.

Introduction: We characterized tessera landing sites and analyzed current hazard detection and avoidance (HD&A) methods in support of the Venus Flagship Mission (VFM) concept study for the Planetary Decadal Survey. The successful and safe placement of a lander in tessera terrain is required to address many of the open questions regarding the evolution of Venus and is essential to the question of habitability. The VFM design requires the lander to avoid slopes ≥30°, boulders ≥0.5 m in diameter, and any sites with a mantling of extraneous material ≥5 cm in order for our drill assembly to access true tessera material.

Landing Site Characterization: Our highest resolution data for characterizing tessera terrains comes from a combination of Magellan and Arecibo data. Magellan-derived information, including stereo topography, imagery, and altimeter products (roughness, RMS slope) suggest generally low slopes and sufficiently smooth surfaces. Cursory analysis of stereo-derived topography indicates that >90% of tessera terrains have slopes <20°, with a median of ~5°; Figure 1 shows an example landing ellipse and slopes in Western Ovda Regio. Magellan data has previously been used to identify areas of thick mantling deposits, but these have been limited by the polarization of the Magellan SAR system; work by [1] combined the Magellan data with Arecibo data to find crater mantling layers as thin as 5 cm on tessera terrains near crater impacts. Problematically, these data represent properties over kms of scale. The stereo-derived topography and mantling maps have a horizontal footprint of ~1-2 km [1, 2]. These large footprints allow only broad-scale characterization. Although the imagery has a much higher resolution of 75-200 m, this is still far too coarse to resolve potentially hazardous regions [3]. In order to avoid excessive slopes and large boulders, the lander system must then identify and avoid meter-scale hazards autonomously.

HD&A: We identified 5 primary issues with which the lander's HD&A system must contend: a monochromatic surface, near-isotropic lighting, atmospheric scattering, atmospheric turbulence, and the need for autonomy. Several of these issues have already been partially addressed (e.g., Chang'e-3 successful landing on the monochromatic surface of the Moon's far side). The VFM lander design includes a NIR descent imager that is used at relatively high altitudes (~15 km) for broad scale hazards and a LIDAR system used at relatively low altitudes (~2 km) for small scale hazards. Early work on the problem of the near-isotropic lighting suggests that texture analysis may solve problems with reliable feature tracking [4]. If these issues can be addressed, autonomous neural networks capable of dealing with uncertainty are the best option to allow efficient prioritization and guidance to a low hazard, high science value location, as well as address unknown wind conditions in the lower atmosphere that may unexpectedly redirect the lander's descent. Identification of meter-scale hazards is only possible in the last few km of descent with avoidance maneuvers in the final 2.5 km, providing ~3-6 minutes to divert the spacecraft. Goddard LIDAR experts are working on increasing the effective range up to 9 km, which would provide ~11-20 minutes to divert the spacecraft. We considered different options for horizontally maneuvering the spacecraft in the dense atmosphere and identified using fans as the most SWaP-efficient method. A fan system with 20 cm propellers and ~17 W can divert the lander up to 50 m if activated by 2 km altitude, with larger propellers and a higher activation height resulting in larger maximum divert distances.

References: [1] Campbell et al. (2015) *Icarus* DOI:10.1016/j.icarus.2014.11.025. [2] Herrick et al. (2012) *Jrnl Geop Rsch* DOI: 10.1029/2012EO120002. [3] Ford & Plaut (1993) JPL Publication 93-24. [4] Campbell & Shepard (1997) *Geop Rsch Lttrs* DOI: 10.1029/97GL00598.

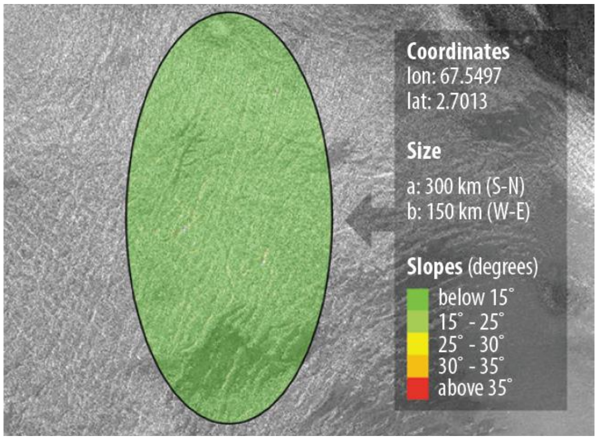

Figure 1. Slope analysis over VFM landing ellipse using radargrammetric data from [2].