TO FLY OR TO FLOAT? HEAVIER-THAN-AIR AND DIRIGIBLE BALLOON TITAN EXPLORER CONCEPTS. R. D. Lorenz, Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721, USA (rlorenz@lpl.arizona.edu)

Introduction: Post-Cassini Exploration of Titan is likely to be focussed on determining the global inventory (surface and subsurface) of organics and the geological and meteorological context for their processing. Although a variety of platforms could be used, the most attractive are aeroplanes and dirigibles (airships). An aeroplane offers dramatic performance in a feasible package, due to several synergies between propulsion, power and communications systems. An aircraft powered by a Stirling engine could perform a global survey in ~1 year A less aggressive option is an airship, giving more spotty coverage and lower data return.

Science Objectives: Cassini will characterize the atmospheric composition of Titan, and the global appearance at near-IR and centimetre wavelengths. The subsurface inventory will not be well-constrained, nor will more than a tiny fraction of the surface be imaged at sub-km resolution. The CSWG for the PreBiotic Material in the Solar System Campaign of the NASA Roadmap has identified [1] Titan's subsurface and surface reservoirs as the focus of post-Cassini exploration.

Limitations of Orbital Platforms: The extended nature of Titan's atmosphere makes it impossible to sustain an orbiter for substantial (> month) durations against drag unless the orbital altitude is significantly larger than 1200 km. This is an appreciable fraction of the planetary radius of 2575km - this altitude makes subsurface radar sounding essentially impossible. Further, scattering by the thick atmospheric haze which extends to about 200km altitude makes optical remote sensing difficult. High-resolution surface and subsurface sensing therefore requires a platform beneath the haze - at a few tens of km altitude at most. Most of what can be achieved from orbit will be done by Cassini.

Limitations of Surface Platforms: The best interpretation of available data [2] is that Titan's surface has at least two terrain types, one probably ice-rich (and possibly mountainous), and another darker terrain, which may be dominated by liquid hydrocarbon lakes. Although local mobility may be possible on either of these, with the caveat that either or both may be sticky, planetary-scale mobility for a surface vehicle [not yet demonstrated anywhere] across both terrains is difficult to conceive.

Feasibility of Lighter-than-Air Platforms: Titan's cold, dense atmosphere is an easy one in which to float, and balloon missions have been suggested as far back as 1978 [3,4,5]. However, a balloon or dirigible is condemned to drift in the wind (fig.1), with the dominant wind direction being E-W (while tropospheric zonal winds are of the order of 10 m/s, meridional winds are less than 1mm/s [6]). A balloon at low latitudes and 10km altitude might circumnavigate Titan in 6-10 days, of which half would be in darkness and hidden from Earth, but even in a year will traverse only a small range of latitude.

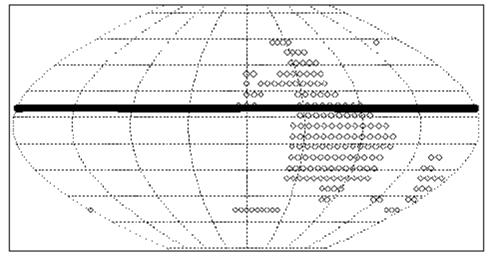

Fig.1 Sinusoidal (±70º) projection of Titan centered on 180ºW (antisaturn point): diamond-stippled area is bright terrain identified by HST [7]. Balloon trajectory over 1 year in zonal wind field with 1mm/s meridional winds is indicated by thick line. One third of the time is spent at solar zenith angles >60º.

A slowly-moving dirigible balloon can cover more ground (fig.2) and requires only modest amounts of propulsive power (~1W) for speeds of ~10cm/s. This speed allows traversing of global-scale latitude ranges, but does not allow for loitering over or circling around targets of interest. As for the balloon, zonal winds subject the vehicle to a 6-10 day diurnal cycle, with extended periods of darkness and Earth occultation.

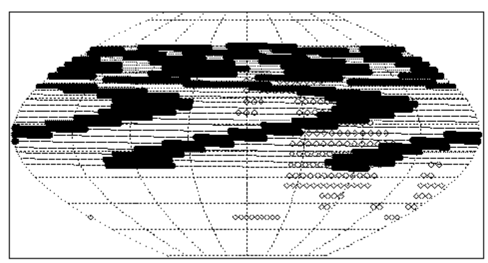

Fig2. Trajectory of a dirigible, thrusting north at 0.1m/s. Thick line segments are those intervals with solar zenith angle <60º, where solar illumination and direct-to-earth communication are available. Thin segments denote blackout periods.

Feasibility of Heavier-than-Air Platforms: Beyond the convenience of its dense atmosphere, Titan offers the added advantage that its gravity is low, reducing the lift and power requirements to stay aloft. However, helicopters and tilt-rotors still have prohibitive power requirements. Aeroplanes, on the other hand, are quite feasible without resorting to chemical propulsion. As an example, consider a 20kg vehicle (typical of small military RPVs), with a very modest lift-to-drag ratio of 10. Assuming a design flight speed of 26 m/s, the propulsive power required would only be 70W .

While this is a large number in electrical terms, a very small e.g. Stirling engine, could produce this mechanical power directly using less than 450g of $^{238}PuO_2$, ssuming a conversion efficiency of 30%. Ample electrical power could be generated by tapping some of the shaft power with a dynamo, rather than using an inefficient thermoelectric converter. Yet another advantage of Titan is that its cool dense atmosphere would efficiently cool the engine heat sink, increasing the thermodynamic efficiency.

Guidance and Communication: Although arbitrarily sophisticated terrain-following navigation systems can be devised, a simple sun-following algorithm could be very easily implemented and would produce an effective survey pattern (fig.3).

If the vehicle can fly at speeds greater than the sum of Titan's planetary rotation and its zonal winds, then it can keep pace with the sun across Titan's surface. This increases (to ~100%, except during eclipses, which will not occur in the 2010-2020 timeframe) the time that both the scene is illuminated for optical imaging, and the time that the Earth is high in the sky.

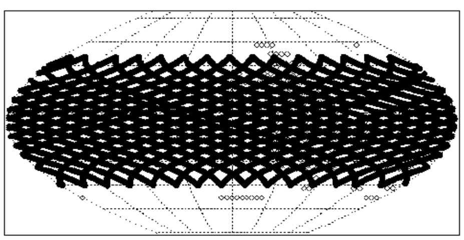

Fig.3 groundtrack (99% of time spent with solar zenith angle <60º) of an aircraft flying at 26 m/s on a heading alternating between 85º and 95º, with speed modulated by the solar zenith angle ('sun-chasing')

Radio communication might use patch antennas on the wing surface to minimize the drag penalty. Another possibility that may be worth examining is laser communication - it happens that the 1.064μ wavelength of Nd-YAG lasers lies in a clear window in Titan's atmosphere between methane bands: optical downlink might be worthwhile to avoid committing valuable DSN time. In both cases downlink data volume correlates directly with available electrical power.

Payload Side-looking optical imaging would offer a dramatic geological perspective, with metre-scale resolution over large areas possible. Such imaging would also be valuable in studying Titan's meteorology, now known to be dynamic [8], and perhaps also in oceanographic studies.

Subsurface radar sounding at metre wavelengths is an attractive technique, and is much easier to perform from a few kilometres altitude than from orbit. This would allow the detection of subsurface structures and inventory subsurface reservoirs of organics, as well as probing the depths of lakes and seas. This instrument could also supply an altitude measurement.

Small solid-state sensors would sense pressure, airspeed, temperature and methane humidity.

A final consideration is for contact measurements with the surface, in particular to explore chemical composition of deposits. This is a challenge for all vehicles, although airplanes in particular. 'Fishing line' dipping samplers, or even flying or buoyant sample retrievers are possibilities.

Delivery Titan's atmosphere is easy to enter, as well as to fly in, due to its thickness and the large scale height. Direct entry from an interplanetary trajectory is easy to achieve, even with a low entry protection system mass fraction, since Titan is well up in the Saturnian gravity well.

Conclusions For our current best guesses at the most pressing post-Cassini questions about Titan, airships and aeroplanes look like the most promising platforms. The data return from an aeroplane mission could be much higher, and scientifically more directed than that from an airship, at the cost of only modest incremental complexity. Cost differential between the concepts is unclear: an aeroplane would benefit from substantial recent advances in military and civilian RPV technology, although the combined mechanical/electrical power generation system requires some advanced technology investment. The packaging/deployment, delivery, autonomy and telecommunications challenges are common to both platforms. The deciding factor is likely to be the (political) constraints applied on power generation.

References: [1] Europa/Titan CSWG, JPL, September 1998 [2] Lorenz, R. D. and Lunine, J. I., Titan's Surface Reviewed **-** The Nature of Bright and Dark Terrain, *Planetary and Space Science* **45**, 981-982 (1996) [3] Blamont, J. in **NASA CP-2068** (1978) [4] Friedlander, A. L. Titan Buoyant Station, *J. Brit. Interplan. Soc*. **37**, 381-387 (1984) [5] Lorenz, R. D. and Nock, K. T. BETA: Balloon Experiment at Titan, IAA-L-0606, *2nd International Conference on Low-Cost Planetary Exploration*, JHU/APL (1996). [6] Flasar, F. M. and Conrath, B. J. The Meteorology of Titan, **ESA SP-338**, 89-99 (1992) [7] Smith, P. H. et al., Titan's Surface, Revealed by HST Imaging, *Icarus*, **119**, 336-349 (1996) [8] Griffith, C.A. *et al.*, Transient Clouds in Titan's Lower Atmosphere, *Nature*, **395**, 575-578 (1998)