HUYGENS AT TITAN : A SUMMARY OF SCIENCE RESULTS FROM ENGINEERING MEASUREMENTS.

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Introduction: The unique data generated by the ESA Huygens probe [1] are the only in-situ measurements at Titan and thus will be key factors in interpretation of Cassini orbiter data and in design of future spacecraft. Here I summarize some recent results from 'engineering' data: these include the constitution of the Titan surface from impact measurements and the temperature history of heated components embedded in the ground, surface roughness from reflection of the Huygens radio signal post-impact, and constraints on turbulence and near-surface winds. These results underscore the importance of making even simple housekeeping measurements [2] available, with their documentation, in the public archive.

Impact Measurements: Impact dynamics were recorded with accelerometers in the SSP and HASI experiments [3,4] : the peak deceleration was ~15g, indicating a fairly soft surface, consistent with moist sand. The deceleration stroke was therefore about 15cm, although it is not clear whether the probe may have bounced or slid out of a hole, or rather if the probe pushed cobbles into the finer-grained substrate.

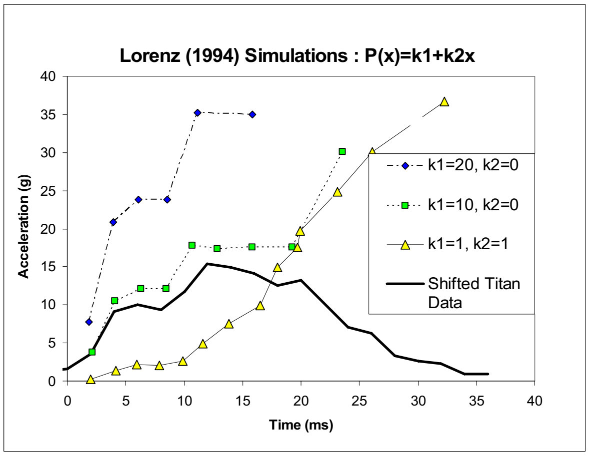

Figure 1. Impact deceleration record shows rise time more compatible with models of constant bearing strength than dry unconsolidated material.

For a 15cm depth of penetration, the fore-dome of the probe would have a contact area of ~1m^2, thus to decelerate the 200kg probe requires a bearing strength of ~30 kPa [5] (a similar result derives from energy/swept volume considerations). This is ~10x smaller than the 350 kPa indicated by the penetrometer. A leading interpretation that reconciles these divergent hardness estimates is thus that the impact pushed a number of ice 'rocks' into the softer material.

Radio Signal: In addition to Doppler and VLBI measurements to monitor the motion during descent, the signal strength of the transmission from Huygens facilitated the reconstruction of its spin rate [1,6,7]. An interesting variation in signal strength occurred as Cassini (carrying the receiver) set over the western horizon as seen from the landing site. This strong fading pattern results from the intereference of the direct ray to Cassini with radio energy reflected from the Titan surface (Fig.2).

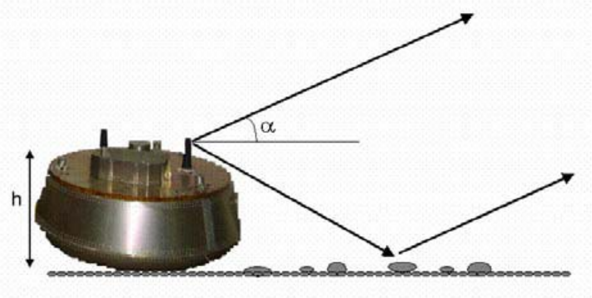

Figure 2. Antenna height and elevation angle of Cassini define the geometry by which the direct and reflected rays interfere.

This effect is strightforward to model (and indeed, to reproduce in a classroom setting with cheap ultrasound transducers [8}) and yields [Fig.3; 9] a surface roughness of ~12cm, consistent with the images of cobbles towards the south of the lander. Further, this interferometric measurement confirms the probe to eb sitting 'on' the surface, rather than being embedded in it, again supporting the rock-push impact paradigm.

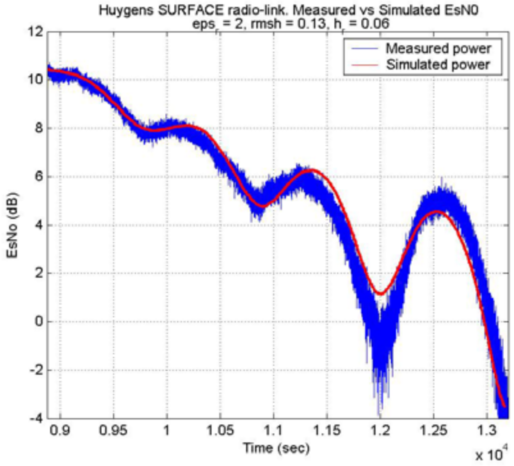

Figure 3. The signal level history requires the antenna height to be ~70cm and a surface roughness of ~12cm.

Thermal Measurements: Atmospheric temperatures were recorded by the HASI sensors during descent.[4]. However, several housekeeping sensors give insight into heat transfer to the environment from the warm probe and heated elements such as the inlet of the GCMS. The latter instrument recorded [10] complex compounds evolved from the surface, suggesting the inlet was embedded in the surface and volatilized materials from it. A detailed thermal model [11] of the heater and inlet suggests that the inlet mush have been embedded in an environment that efficiently wicked heat away. Just as damp sand at the beach 'feels' colder to a warm hand than dry sand, the estimated ~145K temperature of the inlet suggests that the ground was physically damp with liquid methane which removed heat by convection and evaporation.

A second result relates to the overall loss of heat from the probe after landing. Comparing the cooling of the probe (net heating by the ~300W of power dissipation on board was more than offset by cooling by the cold dense atmosphere) during descent [12], together with models of forced and free convective heat transfer suggests that the wind speed experienced by the probe on the surface (thus applying to the lowest ~0.5m of the atmosphere) was of the order of ~0.2m/s or less.

Turbulence: It is often stated that Huygens had a 'rough ride'. This is somewhat misleading – in fact most of the descent was fairly quiescent, although the rapid descent of the probe did excite a perhaps unanticipated amount of short-period motion, independent of atmospheric turbulence. This 0.6-1.1Hz buffeting, probably related to vortex shedding from the bluff probe, dominates the motion measurements, which include several accelerometers on the probe, a density sensor intended for ocean measurements, tilt sensors as well as Doppler recordings. A further complication to dynamics measurements is the rapid evolution of spin period [7] and the spin reversal soon after the beginning of descent.

Amidst this background, variations in the dynamical environment with altitude are difficult to discern. However, a statistical study of the tilt sensors (and comparable results can be found in the accelerometer record) has recently noted some anomalies in the mid-troposphere. Specifically [13], around 4500s after the start of descent, the power spectrum of variations recorded in the tilt data shows a change of slope (away from the low-pass-filtered white noise typical of suspended objects without particular excitation) that is characteristic of that recorded on terrestrial balloons in cloud. This anomalous turbulent episode is supported by changes in other statistical properties of the signal (such as the kurtosis, a measure of Gaussianity). It may be noted that these distinct changes occur for a limited period, while the mean deviation of the tilt record monotonically declines (along with the descent speed). These observations lend some support to the contention [14] on the basis of humidity and atmospheric structure that the probe descended through a layer of thin cloud in the 15-30km altitude range. It should be noted that it was only with the help of recent dynamical measurements recorded by meteorological balloons with simultaneous remotely-sensed cloud turbulence that a convincing signature of such turbulence could be identified in the Huygens dynamical data. It may be that dynamics data recorded on other probes such as Pioneer Venus and Galileo could yield comparable insight.

The turbulent air motions in the lowest 10km of descent are only of the order of 0.1 m/s or less, but perhaps a couple of m/s in the turbulent layer : further analysis is underway. These data will be of key importance in the design of future balloon vehicles at Titan.

Conclusions: We know from Cassini orbiter data that Titan is a remarkably diverse body, with dunes at low latitudes and lakes at high latitudes. Thus the in-situ data from Huygens cannot be universally applied. However, while not a subsititute for sophisticated science instruments, it is notable that the environment is characterized to a large degree by small, simple sensors, usefully accessible via the public archive.

References: [1] J.-P. Lebreton et al., *Nature*, **438**,.758-764, 2005. [2] R. D. Lorenz, Science from small sensors *International Conference on Low Cost Planetary Missions*, Kyoto, Japan, October 2005. [3] J. C. Zarnecki, J C et al. *Nature* 438, 792–795(2005) [4] M. Fulchignoni et al., *Nature* 438, 785–791 (2005) [5] R. D. Lorenz, *Intl. Workshop on Penetrometry in the Solar System* IWPSS2, Graz, Austria, October 2006 (iwpss2.oeaw.ac.at) [6] M. Perez-Ayucar et al., *Intl. Planetary Probes Workshop*, Anavyssos, Greece, June 2005. (http://www.ims.demokritos.gr/IPPW-3/) [7] R. D. Lorenz, *J. Brit. Interplan. Soc.*, 59, 273-282 (2006). [8] R. D. Lorenz, Servo, 35-38, (May 2006) [9] M. Perez-Ayucar et al., J. Geophys. Res., 111, E07001, doi:10.1029/2005JE002613 (2006) [10] H. B. Niemann et al. *Nature* 438, 779–784 (2005) [11] R. D. Lorenz, *Meteoritics and Plan. Sci.* 41, 1705-1714 (2006). [12] R. D. Lorenz *Icarus*, 182:559–566 (2006) [13] R. D. Lorenz, *Plan. Space Sci.*, submitted. [14] T. Tokano et al., *Nature*, 442, 432-434 (2006)

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