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

R. D. Lorenz[1] [1] Space Department, Johns Hopkins University Applied Physics Lab, Laurel, MD 20723, USA (see full abstract - # 1326)

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 missions which might include balloons and landers. Here I summarize some recent results from the simple 'engineering' sensors on the probe: 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 – much like the devices used to actuate airbags in cars - in the SSP and HASI experiments [3,4]. The peak deceleration was ~15g (actually not much larger than the deceleration encountered entering the atmosphere), indicating a fairly soft surface, consistent with moist sand or lightly packed snow. The probe therefore kept moving about 15cm into the ground before coming to rest, although it is not clear whether the probe may have afterwards bounced or slid out of a hole, or rather if the probe pushed cobbles into the finer-grained, softer material underneath.

For a 15cm depth of penetration, the fore-dome of the probe would have a contact area of $\sim 1 m^2$, 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 about the same pressure under a human boot on Earth . This average value under the probe is ~10x smaller than the 350 kPa indicated on a specific spot by the penetrometer, a finger-sized force sensor projecting from the bottom of the probe (actually built by the author while a PhD student!). 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 interferometry measurements to monitor the motion during descent by radio, the variations in the signal strength of the transmission from Huygens facilitated the reconstruction of its spin rate [1,6,7] because the flower-petal-like pattern of power from the antenna makes a ‘heartbeat’ variation as the probe and the antenna on it spin. An interesting non-spin-related 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).

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 in the unseen western direction, consistent with the cobbles observed by the Huygens DISR camera towards the south of the lander. Further, this interferometric measurement confirms the probe to be sitting ‘on’ the surface, rather than being embedded in it, again supporting the rock-push impact paradigm.

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 must 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 (in the lowest ~0.5m of the atmosphere) was of the order of ~0.2m/s or less. These heat transfer measurements are useful for predicting the performance of montgolfiere ('hot air') balloons on a future Titan mission.

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 careful study of the tilt sensors has recently noted that around 4500s after the start of descent, the statistical properties of the record show features that are characteristic of those recorded on terrestrial balloons in cloud. Frequent flyers may also be familiar with the frequent association of clouds and turbulence.

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 insitu data from Huygens cannot be universally applied. However, it is important ground truth, and shows that engineering systems can perform well in the Titan environment. While not a subsititute for sophisticated science instruments, it is notable that the environment can be characterized to a large degree by small, simple sensors, usefully accessible via the public archive.

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Contact : Ralph Lorenz ralph.lorenz@jhuapl.edu tel: 443-778-2903. Dr Lorenz will be speaking in the Monday afternoon Titan session.