Huygens Probe - One Year Later
Dr Ralph D Lorenz

ESA Huygens Project Team 1990-1991
University of Kent (SSP) 1991-1994
University of Arizona 1994-
Sequel to Lifting Titan’s Veil is being written......
Huygens Descent 14 January 2005
First results within hours
Principal results papers published in Nature, December 8, 2005 (the Dog Genome special issue!)
Many more papers in work, including groundbased observations contemporaneous with probe entry (JGR); correlative analyses ongoing (Nitty-gritty details like datation of engineering and science data offset by 375ms)
Landing site imaged by Cassini RADAR on T8 (26 October 2005)
VLBI results expected soon.
Data available on ESA archive (echoed on PDS) July 2006
At least in Europe, the Huygens encounter even caught the attention of higher echelons....Tony Blair visited The Open University - meets John Zarnecki (SSP PI). Prominent French participants in Huygens welcomed by Chirac at the Elysee Palace.
Topics Today

Earth-based observations

Quick results overview (Nature papers)

Radio Signal Strength - probe spin, surface dielectric properties  (Perez et al, IPPW3 Athens, JGR-E submitted and Lorenz, Servo)

Probe Thermal Behaviour - surface winds (Lorenz, Icarus, in press)

Probe location on surface with RADAR
First detection by Green Bank; Parkes took over. Supplemented by smaller telescopes (e.g. Kitt Peak). Probe probably transmitted for >15 minutes after last detection.

NB two distinct observing campaigns (same dishes, different receivers)

1. Real-time doppler (intended as supplement to Cassini on-board doppler recovery)

2. VLBI to monitor position on the sky
Huygens as an artificial meteor - attempts to observe entry with Earth-based telescopes

- Hawaii: IRTF and Keck telescopes in the infrared window. Gemini cancelled due to bad weather conditions.
- California: Hale telescope in the violet part of the spectrum. Clouds.
- HST - STIS instrument failed in orbit in August - observation cancelled
- Only upper limits established on emission

Simulated spectrum →

![Simulated spectrum graph](image)
Huygens Atmospheric Structure Instrument

High-altitude temperature profile derived from aerodynamic deceleration (in fact, the accelerometer was the most sensitive used on a planetary mission - a few micro-g, picked up the atmosphere at 1500km!)

Mesosphere (minimum in dotted line) was basically absent! Lots of small-scale structure due to gravity waves and possibly tides.
Doppler Wind Experiment (using groundbased rather than Cassini data!) showed zonal winds to be somewhat weaker than expected, with a slightly surprising reversal near the surface. Also somewhat unexpected was a layer of strong wind shear, with winds falling to near zero at about 80km altitude.
Two Similar Datasets?
Both datasets rendered useful by subtraction of running mean (cf ‘unsharp mask’)

Huygens Probe Titan Descent
Radial Accelerometer B

Work is still underway to determine how much of this motion is self-excited and how much is due to turbulent winds

Moonquake 1971 / 187
Apollo 14 Seismometer
Bulow et al, JGR, (2005)
Huygens Atmospheric Structure Instrument

Pressure/Temperature profile was in fact very close to nominal Voyager-based models (which had large uncertainties)

Surface temperature 93.65K, 1467 hPa

Temperature minimum (tropopause) of 70.25K at 44km

Detected layer of enhanced ionization at 60-100km. Such an enhancement, due to Galactic Cosmic Rays, was predicted. No obvious lightning.
Haze particles have substantial nitrile component: not just hydrocarbons. Haze may have been a substantial nitrogen sink over time.

Peak at molecular mass 27 is well above background - attributed to HCN.

Aerosol Collector / Pyrolyzer

Instrument sucks in aerosol particles, trapping them on a filter. Filter is then ‘cooked’ and products passed to GCMS instrument for analysis.

Peak at molecular mass 27 is well above background - attributed to HCN.

Haze particles have substantial nitrile component: not just hydrocarbons.

Haze may have been a substantial nitrogen sink over time.
Radiogenic $^{40}\text{Ar}$ was detected at a mole fraction of $4.3 \times 10^{-5}$.

No other noble gases. Trace ($\sim 2.8 \times 10^{-7}$) of $^{36}\text{Ar}$ - suggests $\text{N}_2$ was brought to the system as a less volatile species, probably $\text{NH}_3$.

Isotopic ratios $^{12}\text{C}/^{13}\text{C}$ is 82.3; $^{14}\text{N}/^{15}\text{N}$ is 183; $\text{D}/\text{H}$ is $2.3 \times 10^{-4}$

Suggests Nitrogen is fractionated (although fractionation in $\text{N}_2$ is much less than in HCN measured from Earth), carbon is not (Early loss of $\text{N}_2$ during T-Tauri winds; methane was still sequestered in interior?)
Descent Imager / Spectral Radiometer

Detection of thin cloud layer at 21km altitude (side-looking images ‘collapsed’ onto a line to improve signal-to-noise)
DISR derivation of methane mole fraction. Lamp-only downward looking spectrum from altitude of 21m (black data points). This spectrum is compared to three models: 3% (blue), 5% (green), and 7% (red) methane mole fractions. These models make use of surface reflectivity at seven wavelengths (blue dots in inset).

GCMS data show rise in CH4 mole fraction (cf water on Earth) towards surface. Abundance ~1.4% at tropopause cold trap; ~5% (~50% relative humidity) at surface.
Descent Imager / Spectral Radiometer

example - upward looking spectrometer (looking away from sun) As probe descends, sky gets brighter, as on Earth, but methane bands get deeper. These data will allow recovery of haze abundance with altitude, haze particle size, etc.
Descent groundtrack fortuitously crossed bright/dark boundary.

Brighter terrain elevated by ~100m; pluvial and sapping networks.

Flatter, lower, but not smooth dark terrain.
Surface Images

(Roughly pointed due south, judging from shadows and extrapolation of pre-impact spin rate)

Rounded cobbles. Small pebbles carried away - evidence of fluvial transport
Descent Imager / Spectral Radiometer

Surface composition still being worked - no completely satisfactory spectrum fit yet. Data (red) seems compatible with mix of ice (blue curve) and organics like tholin (black solid and dashed lines)
Hit Soft solid surface. (Like wet or dry sand; wet clay; packed snow)

Delta Vel = 4.63 m/s for ACC-I.

Delta Vel = 4.33 m/s for PZR-X.

Possible slight ‘bounce’ (few cm)

Peak deceleration ~15g, implies bearing strength of ~50 kPa. Rapid onset suggests material did not need to be compacted before resisting - i.e. not fluffy. Analogs - damp sand, clay, packed snow
The Penetrometer on the Huygens Probe

Data taken in the lab in 1994 – (a) dry sand (b) wet clay (c) fine gravel (d) coarse gravel (from R. D. Lorenz, et al. 'An Impact Penetrometer for a Landing Spacecraft', Measurement Science and Technology, vol.5 pp.1033-1041, 1994 also at http://www.lpl.arizona.edu/~rlorenz
The Penetrometer on the Huygens Probe

SSP Penetrometer

The raw data from Titan!
(prelim. Calibration)

near-constant force, plus spike at onset
(‘creme brulee’)  50N/2cm² ~ 250kPa
Penetrometer struck a pebble?
Ralph’s Pilgrimage to the FM Penetrometer,
London Science Museum  January 2005

Unit on Titan is actually a flight spare. The ‘original’ Flight model was torqued incorrectly during final assembly of SSP and the PZT ceramic cracked.....

Lesson - always treat your flight spare as if it might have to step up.....
GCMS Heated inlet - volatilized surface materials. Jump in methane abundance - plus rich spectrum for surface material.

Analysis is underway to determine temperature history of inlet (not measured directly)
Probe Transmitter signal strength varies slightly with azimuth as well as elevation: some fluctuations expected due to probe spin.
PSA Housekeeping includes AGC voltage record: can be used to reconstruct received signal strength. Rapid variations during descent indicate variations in antenna gain pattern as probe spins/swings. (AGC data was used to confirm anomalous rotation of probe). Only slow variations post-impact.

A 1-min sound file of this AGC signal is at http://www.lpl.arizona.edu/~rlorenz/
Periodic Spin modulation of AGC allows diagnosis of spin rate and direction
Mission did not follow expected profile

Model spin rate with correct spin vanes only

chute release - increase in ‘demanded’ speed + torque

Reconstructed spin rate from flight data

Reason for spin reversal still not understood.
Post-impact variations are too deep and sharp to be explained with free-space antenna gain pattern alone.
In effect the receiver aboard Cassini is flying through an interference pattern generated by the Huygens transmission and its reflection from the surface!
NB signals detected after setting below optical horizon.
Multipath Interference

Gain pattern

$G_{direct} > G_{reflected}$

$\Delta$-path

Elevation = 90

If $\Delta$-path = $n^*\lambda$  $\rightarrow$ **destructive** interference*
If $\Delta$-path = $(2n-1)^*\lambda/2$  $\rightarrow$ **constructive** interference

*N.B. $\pi/2$ at reflection
Simple reflectance model with expected parameters seems to capture main features of observation.

Transmitter height controls position of nulls (very sensitive); reflectance determines depth of nulls (more sensitive to roughness than composition).

Pérez-Ayúcar M., Lorenz R. D., Floury N., Prieto-Cerdeira R., Lebreton J.-P.

JGR - submitted
Best single-parameter fit: dielectric constant ~ 2, rms roughness ~ 5 cm, (could improve fit by 2 sets of parameters)

Roughness suggests cobbled terrain also lies to the West.

Height of antenna phase center = 75 cm - suggests probe is resting on surface
You can reproduce this effect (in ultrasound) with ~$10 of electronic parts (Circuit details to be published in Servo magazine next month?)
see also animation at http://www.lpl.arizona.edu/~rlorenz
Huygens probe at KSC (Cassini in background). Note cold-air hose to remove heat from probe inside. KSC photo
Huygens Thermal Budget

**DESCENT**

```
P_{int} \sim 250W \quad T_{int} \quad T_{skin}
```

Forced Convection $V_{\text{desc}}$

**SURFACE**

```
P_{int} \sim 250W \quad T_{int} \quad T_{skin}
```

Conduction into surface (plus evaporation?)

Radiative transfer $\sim 10$ W not considered
Pre-impact Cooling Rate
~0.002 K/s

Post-impact Cooling Rate
~0.0006 K/s
Wind-Chill during and after Descent

- Interpretation needs foam insulation and internal heat generation to be taken into account.
- Total area ~ 4m². Heat transfer coefficient given by $h \approx 0.37(k/D) \text{Re}^{0.6}$ where Re is Reynolds #, increasing throughout descent. Reaches ~ 30 Wm⁻²K⁻¹ prior to impact.
- Cooling of 0.002K/s means a net loss of 600 W or 150 Wm⁻², thus air:skin $\Delta T \approx 5$ K ; $T_{\text{skin}} \approx 100$ K
- On ground 350 W or ~90 Wm⁻². Taking change in internal heat transfer into account requires $h < 4$ Wm⁻²K⁻¹ so to get coefficient h 8x lower than during descent at 5 m/s requires surface winds $< \approx 0.2$ m/s
DISR scratches first noticed in amateur mosaics

‘amateur’ mosaic by Rene Pascal
http://www.beugungsbild.de/huygens/huygens.html
Detailed correlation of Cassini RADAR and Huygens DISR images suggests landing site

Longitude 192.4 degrees W (167.6 degrees E)
(+/- 0.05 degrees 1 sigma or about 2.2 km)

Latitude 10.2 degrees S
(+/- 0.1 degrees 1 sigma or about 4.5 km).

(This is only about 7km from the Descent Trajectory Working Group estimate based on combined analysis of Doppler Wind data, DISR, Navigation data etc.)
characteristic of energetic flows - heavy but rare downpours? cf SW desert

Some theoretical work (Lorenz et al., GRL, 2005) suggests this is consistent with a hydrological paradigm of a relaxation oscillator - Titan’s weak sunlight, coupled with large holding capacity of atmosphere gives infrequent but large events - ‘The Methane Monsoon’
Analog Site - near Parker AZ
(first identified from airplane window, TUS-LAX circa 730am)

photo: R Lorenz
A Historic Event in Planetary Exploration

An outstanding international collaboration.

A rich and unique dataset with many surprises.

Leverages measurements by Cassini - will be particularly important for optical remote sensing.

‘Forensic’ analyses ongoing; correlation with other datasets.

Sets the stage for a return to Titan - with a mobile platform like a balloon
Thanks for your interest.