The Huygens Probe at Titan
Ralph D. Lorenz
ralph.lorenz@jhuapl.edu

ESA Huygens Project Team 1990-1991
University of Kent (SSP) 1991-1994
University of Arizona 1994-2006
JHU Applied Physics Lab 2006-
Lifting Titan’s Veil

CUP, 2002

Saturn’s Mysterious Moon Explored

Titan Unveiled

PUP, 2008
Revised paperback 2010
Outline

Huygens Project
Probe Design

Descent Dynamics and Spin

Impact

Thermal Behaviour

( RF multipath ; Receiver Anomaly and Resolution )
Cassini Spacecraft Specs
- Height: 6.8 m (22 ft)
- Diameter: 4 m (13 ft)
- Mass: 2500 kg (2.8 tons)
  (fueled): 5600 kg (6 tons)
- Power: 700 Watts at SOI

Huygens Probe Specs
- Diameter: 2.7 m
- Mass: 320kg inc. Heat shield. ~200kg at landing
- ~1500 W-hr Lithium primary battery
- 2 S-band telemetry links @ 8kbps
~6.5 year development schedule (NB pacing re: orbiter)
7 year flight time. Implications for knowledge retention, software/hardware maintenance.
NB change in working methods/tools (electronic documents etc.)
ESA ‘juste retour’ system for geographical allocation of contracts in proportion to overall budget contribution.

Institutionally essential, perhaps, but programmatically inefficient.

NB Payloads on ESA missions paid for by member states.
Huygens Probe Descent

1270 km Above Surface

Mach 20
300–250 km

1.5
150–180 km

$T_0$

$T_0 + 2.5s$

$T_0 + 32.5s$

145–170 km

95 m/s

$T_0 + 42s$

$T_0 + 15\text{ min}$

105–125 km

35 m/s

5–6 ms

$T_s - T_0 + 150\text{ min}$

(maximum)

Entry

Pilot-chute Deployment

Front-Shield Separation

Main-Parachute Jettison

Stabilizer-Parachute Deployment

Peak Deceleration
Heat-Flux Peak

Back-Cover Release
Main-Parachute Deployment

Instrument Configuration
for Descent

Stabilizer-Parachute
Inflated

Surface Impact

Surface Mission Phase
Duration 3 min
SM2 - Parachute drop test from 40km balloon over northern Sweden, 1995
Successfully demonstrated heat shield separation/parachute sequence. Deviant rotational behavior not noticed at the time.
2.59m Pilot chute for transonic stability deployed by mortar through break-out patch.

Pulls off back cover and deploys main chute via lanyard. 8.3m main chute needed for safe front shield separation

3.3m Stabilising drogue to achieve descent fast enough to reach surface within telecom & energy window

All parachutes nylon DGB with kevlar bridle, riser & lines
Huygens Descent Configuration
Layout of systems and payload on 1.2m 'experiment platform'

Thin metal shell acts as Faraday cage; foam insulation.

Impact not a driver for structural design
Redundant CDMS and telecom architecture.
Launched on October 15, 1997 from KSC

7 Year cruise on VVEJGA trajectory
Early orbit sequence and delivery modified after radio flaw discovered in 1999

Cassini Saturn Approach through Huygens Probe Mission

- OTM-2: Ta=3d 2004 Oct 23
- OTM-1: SOI+2004 Jul 02
- OTM-1: SOI+2004 Jul 03
- OTM-1: SOI+2004 Dec 23
- OTM-1: SOI+2004 Jul 17
- OTM-6: APO 2004 Nov 21
- OTM-7: PRM 2004 Aug 23
- OTM-8: PRM 2004 Sep 07
- OTM-7: PRM 2004 Sep 07
- OTM-8: PRM 2004 Jul 02
- OTM-8: PRM 2004 Oct 23
- OTM-8: PRM 2004 Oct 29
- OTM-8: PRM 2004 Nov 15
- OTM-8: PRM 2004 Dec 10
- OTM-8: PRM 2004 Dec 17
- OTM-8: PRM 2004 Dec 24
- OTM-8: PRM 2004 Dec 29

Range from Saturn (along Saturn's direction of motion), Rs

Rev 0
Rev A
Rev B
Rev C

nominal tour

probe delivery on T1, backup on T2

prime probe delivery

returns to nominal tour on T3

probe release Nov. 6, 2004

Orbit Insertion July 1, 2004

Titan Orbit

Perigee Raise Sept. 12, 2004

Gybe Deflection Nov. 8, 2004

Huygens Probe Entry/Titan Flyby Nov. 27, 2004
Separation Performed Dec 24, 2004

Probe Imaging ORT: Estimated Rate in Body Frame

Huygens from 52km away (Dec 26, 2004)
Landing site chosen largely by geometric constraints (entry angle, solar zenith, doppler wind projection)
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 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 (image overlap), 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.
Cassini VIMS Titan Ta Base Map and Predicted Huygens DISR Image Coverage
(Combined HRI and MRI coverage for nominal wind model)
Cassini VIMS Basemap with Guesstimate of Location of DISR Mosaic of Huygens Landing Site (~ error +/- 1 deg)
Descent groundtrack fortuitously crossed bright/dark boundary.

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

Flatter, lower, but not smooth dark terrain.
Gas Chromatograph/Mass Spectrometer

Atmospheric mass spectrum rather sparse

Radiogenic $^{40}$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 $^{36}$Ar - suggests $N_2$ was brought to the system as a less volatile species, probably $NH_3$.

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

Suggests Nitrogen is fractionated (although fractionation in $N_2$ is much less than in HCN measured from Earth), carbon is not (Early loss of $N_2$ during T-Tauri winds; methane was still sequestered in interior ?)
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

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)

Useful to have independent means of measuring crucial parameters
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. and greatly improve interpretation of Cassini orbiter spectra
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
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
near-constant force, plus spike at onset (‘creme brulee’) 50N/2cm² ~ 250kPa. Not consistent with dry sand.

Penetrometer struck a pebble?

Note shallow onset – few mm of soft material on pebble? (See Atkinson et al., submitted)
Two Similar Datasets?
Both datasets rendered useful by subtraction of running mean (cf ‘unsharp mask’)

Moonquake 1971 / 187
Apollo 14 Seismometer
Bulow et al, JGR, (2005)
TILT SENSOR DATA FROM SSP EXPERIMENT

Y-TIL data is obviously rich in content. But how to extract/interpret?

Evident changes in character at 900s and after ~5200s. Maybe also a change around 4500s?

Actual tilts of probe to Titan reference frame are much smaller than this indicated tilt, which includes a dynamic component.
Statistical moments of probe motion from tilt sensor show pronounced excursion around 5000s

Motions substantially self-excited during descent (not very turbulent – 0.15 m/s)

See Planet. Space. Sci., 55, 1936

Frequency spectrum shows distinctive peak close to pendulum period during this interval.

Similar spectrum seen in instrumented balloon data on Earth - peaked spectrum seen in freezing/precipitating cloud layer
Probe Transmitter signal strength varies slightly with azimuth as well as elevation: some fluctuations expected due to probe spin.

Probe Transmitter Antenna FM
RCP 2098 MHz

Antenna Pattern [dB]

θ * sin φ [Deg]

θ * cos φ [deg]

θ = Elevation Angle [0°, 90°]
φ = Azimuth Angle [0°, 360°]
Periodic Spin modulation of AGC allows diagnosis of spin rate and direction

Signal strength history recorded on Cassini proved to be very rich and useful diagnostic of probe motion
Mission did not follow expected profile

Reason for spin reversal still not fully understood, but suspected to be due to torque from attach fittings. See also J. Brit. Interplan. Soc., 59, 273, 2006
Huygens probe at KSC (Cassini in background). Note cold-air hose to remove heat from probe inside.  

KSC photo
Huygens Thermal Budget

See Icarus, 182, 559-566, 2006

Radiative transfer \( \sim 10 \, \text{W} \) not considered
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 $h \sim 0.37(k/D) \text{Re}^{0.6}$ where Re is Reynolds #, increasing throughout descent. Reaches ~ 30 Wm$^{-2}$K$^{-1}$ prior to impact.
- Cooling of 0.002K/s means a net loss of 600 W or 150 Wm$^{-2}$, thus air:skin $\Delta T \sim 5$ K; $T_{\text{skin}} \sim 100$ K
- On ground 350 W or ~90 Wm$^{-2}$. Taking change in internal heat transfer into account requires $h < 4$ Wm$^{-2}$K$^{-1}$ so to get coefficient $h$ 8x lower than during descent at 5 m/s requires surface winds $< \sim 0.2$ m/s
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)
3.5 node model needed to reconstruct the temperature history

Free parameters in model can be tuned to reproduce descent history of inlet heater temperature.

Asymptotic inlet temperature (and thus effective surface thermal conductivity) is the result

Inferred 1-2 Wm$^{-2}$K$^{-1}$ conductivity is too high for dry granular material – implies heat loss was enhanced by ethane/methane moisture causing convection/evaporation (ground was damp)

Note clathrate decomposition temperature is not reached – evolved methane must have been present as a liquid.
Coordinated Huygens Publications

- Planetary and Space Science, Titan as seen from Huygens, Volume 56, Issue 5, April 2008, Pages 573-585
- Huygens archived data set on ESA’s PSA (http://www.rssd.esa.int/PSA) mirrored to NASA PDS atmospheric node: http://atmos.nmsu.edu/
But indeed all the whole story of Comets and Planets, and Production of the World, is founded upon such poor and trifling grounds, that I have often wonder'd how an ingenious man could spend all that pains in making such fancies hang together. For my part, I shall be very well contented, and shall count that I have done a great matter, if I can but come to any knowledge of the nature of things, as they now are, never troubling my head about their beginning, or how they were made, knowing that to be out of the reach of human Knowledge, or even Conjecture.

Christiaan Huygens, 1698