TITAN'S NEW POLE: IMPLICATIONS FOR THE HUYGENS PROBE IMPACT COORDINATES

B. Kazeminejad[1], D. H. Atkinson[2] , and J.-P. Lebreton[1]

[1] European Space Agency (ESTEC), 2200 AZ Noordwijk, The Netherlands (Bobby.Kazeminejad@esa.int)
[2] University of Idaho, Dept. of Electrical and Computer Engineering, Moscow, ID 83844-1023, USA (atkinson@uidaho.edu)

Abstract: The European Space Agency's Huygens probe separated from the NASA Cassini spacecraft on 25 December 2004, after having been attached for a 7-year interplanetary journey and three orbits around Saturn. The probe reached the predefined NASA/ESA interface point on 14 January 2005 at 09:05:52.523 (UTC) and performed a successful entry and descent sequence. The probe softly impacted on Titan's surface on the same day at 11:38:10.77 (UTC) with a speed of about 4.54 m/s. The official probe entry and descent phase reconstruction based on the estimated initial state vector provided by the Cassini Navigation team at JPL, the probe housekeeping data, and measurements from the scientific payload was performed by the Huygens Descent Trajectory Working Group (DTWG) and is published in Kazeminejad et al. (1997) [1]. A brief summary of the DTWG trajectory reconstruction results is presented and compared to other published reconstruction efforts. The impact of the recently updated and published Titan pole coordinates on both the entry and the descent trajectory is then analysed and presented: the main impact is a southward relocation of the Huygens landing site by about 0.3 degree. No major impact in the zonal direction is found (i.e., less than 0.01 deg). The new planet pole coordinates provide a new estimation of the probe impact coordinates, 10.57 deg S and 167.68 deg W. A comparison of these coordinates to corresponding values resulting from estimations of reconstruction efforts based on visual and radar images of the Cassini instrument suite (C. Sotin, private communication) show excellent agreement of the two independently derived impact coordinates.

Reconstruction Efforts

DTWG Trajectory

This is the official project reconstruction of the entry and descent trajectory performed in the framework of the Huygens Descent Trajectory Working Group comprising representative of all instrument Principal Investigators (PIs) as well as the Project Team [2]. This 3 Degree of Freedom (DoF reconstruction effort is based on science payload data from 5 of the 6 instruments and probe engineering house-keeping data and provides both a vertical (i.e., altitude and descent speed profile) as well as horizontal (longitude/latitude profile) trajectory including impact coordinates. The input data used for that effort (see middle panel), the applied reconstruction methodology (see right panel), and results are summarized in [1]. The resulting entry and descent trajectory is considered the official project trajectory and archived in the ESA Planetary Science Archive and the NASA Planetary Data System [3].

HASI Trajectory

This reconstruction effort was performed by the PI of the Huygens Atmospheric Structure (HASI) Instrument using only the HASI instrument data in both 3DoF and 6DoF reconstruction efforts [4], [5]. The reconstructed attitude profile in [5] indicates that the Angle-of-Attack remains below 3.5 deg during the entry phase. Sensitivity tests from [4] furthermore confirmed that a small AOA (< 4 deg) would have a negligible impact on the simulated trajectory, thereby supporting the simplification of an assumed AOA = 0 deg in [1]. The vertical trajectory is in good agreement with the DTWG trajectory. The horizontal trajectory is only provided for the entry phase (1250 – 150 km altitude) and show differences to the DTWG values lower than 0.244° in longitude and 0.079° in latitude (at 150 km altitude). No impact coordinates are published.

NASA Langley Trajectory

The NASA Langley reconstruction effort used the "Traditional Method" based on the atmospheric measurements and a 6DoF entry and 3DoF parachute trajectory simulator (POST2) with an Extended Kalman Filter (EKF) to filter the flight data [6]. Only vertical trajectory profiles are provided (i.e., no longitude and latitude profiles), therefore no official impact coordinates were published from this reconstruction effort.

Instruments and Datasets Contributing to the Trajectory Reconstruction

Entry Phase:

- Huygens Atmospheric Structure Instrument (HASI) Accelerometers, Central Accelerometer Sensor Unit (CASU): Entry Accelerations
- Cassini Navigation Huygens probe state vector at the NASA/ESA Interface

Descent Phase:

- HASI Pressure & Temperature Sensors: Atmospheric Pressure & Temperature
- Descent Imager/Spectral Radiometer (DISR): Integrated Wind drift
- Doppler Wind Experiment (DWE): Zonal Wind drift
- Radar Altimeter: Altitude and Descent Velocity
- Surface Science Package (SSP) Acoustic Sounder: Near-Surface Altitude and Descent Velocity
- Gas Chromatograph / Mass Spectrometer: Atmospheric Mean Molecular Weight

Surface

- Surface Science Package Accelerometer

The reconstruction strategy using the listed input data is schematically shown in Fig. 2

New DTWG Trajectory with New Pole Coordinates

More recently images from the Cassini Radar instrument from two different flybys were used to reconstruct Titan's Pole position and spin rate [8]. The new pole differs significantly (ca. 3.07 deg in RA and 0.51 deg DEC) from the one used for the DTWG reconstruction in (see Table 1).

The new parameters mainly affect the horizontal trajectory as shown by the residual longitude/latitude profiles of both entry and descent phase (see Fig. 3).

A comparison of impact coordinates is provided in Table 2.

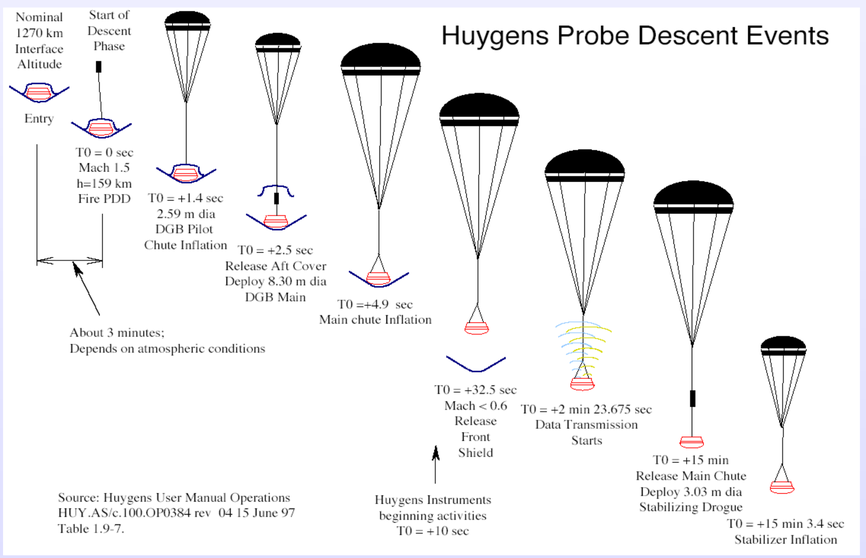

Fig. 1: The Huygens probe entry and descent sequence is divided into the pre-T0 timeline (entry phase) and the post-T0 timeline (descent phase). During the entry phase only the probe deceleration is measured by engineering and science accelerometers. During the descent phase 3 parachutes are deployed (pilot chute, main chute, and stablizing drogue) and all scientific instruments are switched on.

Reconstruction Strategy

Interface Altitude: 1270 km (~30 km radial error, 1σ)

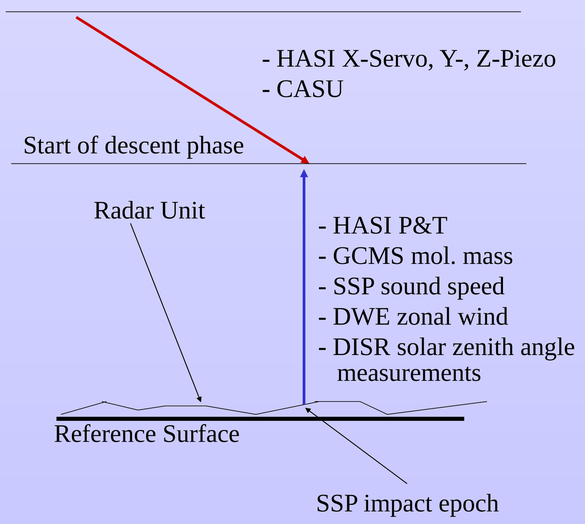

Fig. 2: Huygens probe entry and descent trajectory reconstruction strategy. The entry phase reconstruction is based upon the initial state vector and the measured probe decelerations and proceeds from the interface altitude in a downward direction. The descent phase reconstruction starts from the time of surface impact and proceeds upwards to the first measurements of pressure and temperature under the parachute.

Huygens Reconstructed Entry Trajectory

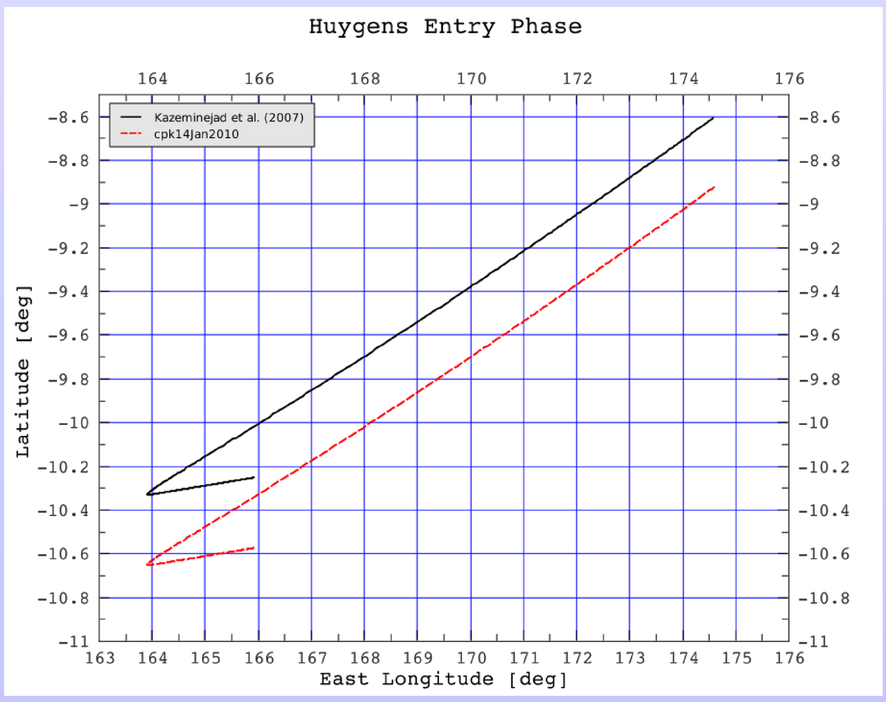

Fig. 3, Left panel: Horizontal difference of reconstructed probe entry phase altitude profile from [1] (black solid line) compared to the new reconstruction based on the updated Titan pole coordinates and dynamics (red dashed line).

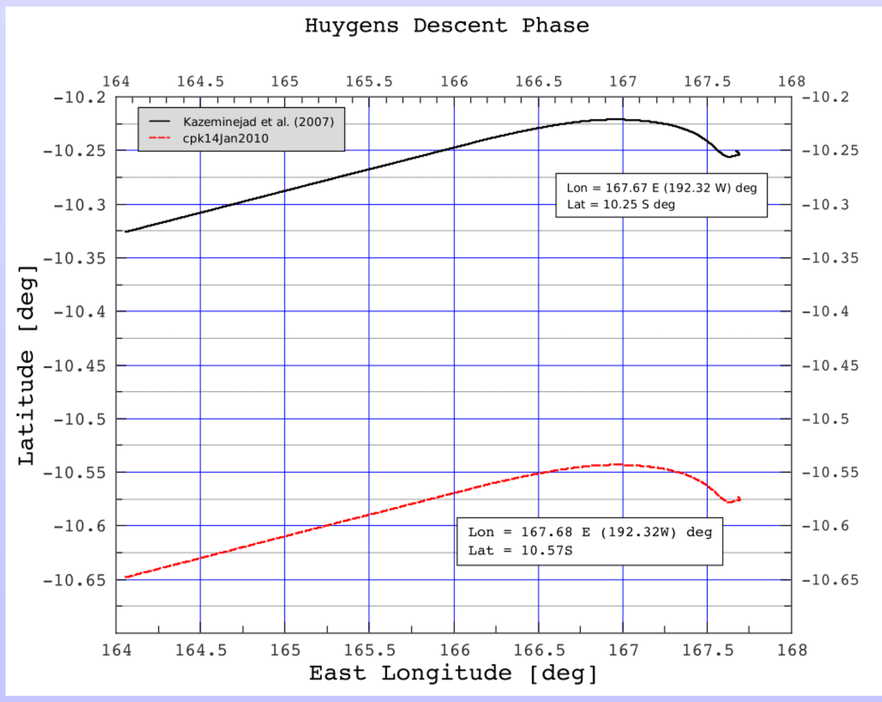

Fig. 3, Right panel: Horizontal difference of reconstructed probe entry phase altitude profile from [1] (black solid line) compared to the new reconstruction based on the updated Titan pole coordinates andy dynamics (red dashed line).

Summary of Input Parameters & Reconstructed Impact Points

Parameter	Unit	DTWG Trajectory [1]	DTWG Value Reference [1]	New NAIF PCK file: cpk14Jan2010.tcp
Titan GM	km3/s2	8978.142297854900	CPCK052005_NAV.tpc	8978.139773741360
Saturn GM	km3/s2	37931137.6508000	CPCK052005_NAV.tpc	37931207.656900
Titan Pole RA (alpha0)	deg	36.41	050214 Cassini Nav delivery consistent with IAU Report 2000	39.482700
Titan Pole RA: time derivate	deg/day	-0.036	as above	0.0
Titan Pole RA: SIN S7 coeff.	deg	0.0	as above	0.0
Titan Pole DEC (delta0)	deg	83.9400	as above	83.4279
Titan Pole DEC: time derivate	deg/day	-0.004	as above	0.0
Titan Pole DEC: SIN S7 coeff.		0.0	050214 Cassini Nav, different from IAU Report 2000	0.0
Titan Pole PM (W)	deg	189.6400	050214 Cassini Nav delivery **consistent** with IAU Report 2000	186.5855
Titan Pole PM: time derivate	deg/day	22.5769768	050214 Cassini Nav delivery **consistent** with IAU Report 2000	22.5769768
Titan Pole PM: SIN S7 coeff.	deg	0.0	050214 Cassini Nav, **different** from IAU Report 2000	0.0
Titan Nutation-Precision Series Coeff. - RA		(0. 0. 0. 0. 0. 0. +2.66 0. 0.)	050214 Cassini Nav	(0. 0. 0. 0. 0. 0. 0.0 0. 0.)
Titan Nutation-Precision Series Coeff. - DEC		(0. 0. 0. 0. 0. 0. -0.30 0. 0.)	050214 Cassini Nav	(0. 0. 0. 0. 0. 0. 0.0 0. 0.)
Titan Nutation-Precision Series Coeff. - PM		(0. 0. 0. 0. 0. 0. -2.64 0. 0.)	050214 Cassini Nav	(0. 0. 0. 0. 0. 0. 0.0 0. 0.)

Table 1:Comparison of physical input parameters used for the DTWG Trajectory [1] and the new reconstruction.

Reconstruction Effort	Impact Longitude [deg]	Impact Latitude [deg]
DTWG Published [1]	192.32 W	10.25 S
DTWG with new Pole	192.32 W	10.57 S
Cassini VIMS [7]	192.37 W	10.58 S

Table 2: Comparison of probe impact points. The CASSINI VIMS coordinates results from high resolution images of the Cassini Visual and Infrared Mapping Spectrometer and a comparison from DISR images [7].

Summary

The new trajectory based on the DTWG algorithm and adjusted physical constants as shown in Table 1 provide an impact point which is slightly shifted to the south with no significant change in longitude. A comparison of the impact site determined from Cassini VIMS and DISR images [7] to the DTWG landing site based on the new Titan physical constants shows excellent agreement, with a difference of less than 0.5 km in latitude and 2.2 km in longitude.

References

[1]: B. Kazeminejad et al., "Huygens' entry and descent through Titan's atmosphere – Methodology and results of the trajectory reconstruction", PSS 55, p.1845-1876, 2007.

[2]: D. Atkinson et al., "The Huygens Probe Descent Trajectory Working Group: Organizational framework, goals, and implementation", PSS 55, p. 1877-1885, 2007.

[3]: NASA/PDS, ESA/PSA Data Set ID: HP-SSA-DTWG-6-TRAJECTORY-V1.0

[4]: G. Colombatti et al., "Reconstruction of the trajectory of the Huygens probe using the Huygens Atmospheric Structure Instrument (HASI)", PSS 56, p. 586-600, 2008.

[5]: G. Colombatti et al., "Huygens probe entry dynamics and accelerometer data analysis", PSS 56, p. 601-612, 2008.

[6]: S. Striepe et al., "Huygens Titan Probe Trajectory Reconstruction Using Traditional Methods and the Program to Optimize Simulated Trajectories II", AAS 07-226.

[7]: C. Sotin, NASA-JPL, Private Communication

[8]: B.W. Stiles, et al., "Determining Titan's Spin State From Cassini Radar Images", The Astronomical Journal, 135, p1669-1680, 2008. (Values from NAIF PCK Kernel: cpk14Jan2010.tpc used).