HUYGENS DESCENT TRAJECTORY WORKING GROUP

Experimenter to DTWG Interface Control Document

HUY-DTWG-IF-0001

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CHANGE LOG

The change log section summarizes the modifications to the DTWG interface document with respect to the officially signed Ver. 8.0

Location	Date	Description of Modification
Sec. 4: Subsection 4.8 was added	August 2004	ACP pressure data was added as an official DTWG delivery; A dedicated file name and a description of the ACP delivery are provided.
Sec. 6.4	August 2004	The DTWG product file HUY_DTWG_ENTRY_POS.DAT was renamed HUY_DTWG_ENTRY.DAT and contains additionally the probe inertial velocity as column 7.
Sec. 6.2	August 2004	The words “consolidated validated” were removed in the description of the various DTWG deliveries;
Sec. 7	October 2004	Added statement regarding restricted experiment team/IDS access to other team directories on Sci Ops FTP server.
Sec. 4.5 / Sec 4.8	November 2004	Corrected inconsistency re ACP data. Removed Section 4.8 re ACP data; Moved ACP Pressure data to Section 4.5
Sections 3.1, 3.2, and 3.4	November 2004	Time Reference for Experiment Team Data deliveries changed from ET (J2000) to UTC
Section 1.5 / Section 5	November 2004	Removed reference to SCLK

1. Introduction

1.1 Background

The Huygens Probe – ESA's contribution to NASA's Cassini mission to Saturn – was launched on October 15, 1997 and is scheduled to enter the atmosphere of Saturn's largest moon Titan on January 14, 2005. To correctly interpret and correlate the results from all probe science experiments, and to allow a synergistic interpretation of the remote sensing measurements from the orbiter instruments, an accurate reconstruction of the probe trajectory is needed [REF. 1]. If a common and consistent descent profile is not available, each probe experiment team would need to independently develop a profile, thereby causing not only a significant duplication of effort and expenditure of resources, but also making correlation and comparison of results from different experiments somewhat suspect and therefore less meaningful. Furthermore, direct (*in situ*) atmospheric sampling by the probe will provide ground truth verification of orbiter observations of the atmosphere and surface of Titan. The value of the ground-truth support for orbiter science at Titan will be significantly compromised if the probe altitude, location, and velocity as a function of time are not precisely known. The responsibility of developing analysis techniques by which the Huygens Probe entry descent trajectory can be reconstructed from the interface altitude of 1270 km (this represents the official NASA/ESA hand-off point) to the surface is given to the Huygens Descent Trajectory Working Group (DTWG), chartered in 1996 as a subgroup of the Huygens Science Working team (HSWT). The membership of the DTWG includes the Huygens and Cassini project scientists and representatives from each of the probe and orbiter science instrument teams contributing the entry and descent trajectory reconstruction. The primary goals of the DTWG are to

- develop a framework between experiment teams and project for sharing and exchanging data relevant to the descent trajectory analysis and modelling.
- develop methodologies by which the probe descent trajectory and attitude can be accurately reconstructed from the probe science and engineering data.
- provide a single, common descent profile that is consistent with all the available probe and orbiter engineering and science data, and can be utilised by each instrument team for analysis of experiment measurements, and correlation of results between experiments.

1.2 Scope

The purpose of this document is to define and control the mechanisms and format by which Huygens experiment and engineering data will be made available to the DTWG for the purpose of performing the reconstruction of the Huygens Probe entry and descent trajectory, and by which the reconstructed entry and descent trajectory data will be made available to the Huygens Project Scientist Team (PST) and HSWT. This document comprises

- a specification of the parameters and format of each experiment and housekeeping data set made available to the DTWG (input data);
- a specification of the parameters and format of the reconstructed entry and descent data provided by the DTWG (output data);
- the transfer mechanism used to deliver the input and output data sets, including trajectory medium and location;
- the schedule governing the availability of the input and output data sets; and
- the rules governing the use and publication of input and output data sets.

1.3 Intended Readership

All the Huygens instrument teams and the Huygens Engineering Team that will provide data to the DTWG for the reconstruction of the Huygens entry and descent trajectory.

1.4 References

[REF.1] "Report of the Huygens Descent Trajectory Working Group'', Atkinson D. H. 2003 (Rev. 3)

[REF.2] "Huygens DTWG to Archive Interface Control Document ", HUY-DTWG-IF-0002, Issue 2, Rev. 1, May 2004.

[REF.3] "Mars Pathfinder EDL Derived Profiles – Dataset Description", available at http://atmos.nmsu.edu/PDS/data/mpam_0001/document/edlddrds.htm

[REF.4] Davies, M. E., et al., "Report of the IAU/IAG/COSPAR Working Group on Cartographic Coordinates, and Rotational Elements of the Planets and Satellites: 1994", Celestial Mechanics and Dynamical Astronomy, Vol. 63, 1996, pp. 127-148.

[REF.5] "DTWG Phase-A Report, Proposal for an Algorithm to Reconstruct the ESA Huygens Entry and Descent Trajectory", Kazeminejad B. and Atkinson D. H. Ver. 4, 2003-04-11.

[REF.6] "DTWG Rules of the Road'', Rev. April 2004, Atkinson, D.H.

[REF.7] Huygens Data Analysis and Data Management Plan

[REF.8] NAIF SPICE Toolkit Time required reading file "TIME.REQ" available as part of the NAIF SPICE toolkit from ftp://naif.jpl.nasa.gov

1.5 Acronyms & Abbreviations

ACP	Aerosol Collector & Pyrolyser
ASCII	American Standard Code for Information Interchange
DDS	Data Distribution System
DISR	Descent Imager & Spectral Radiometer
DTWG	Descent Trajectory Working Group
DWE	Doppler Wind Experiment
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Research & Technology Centre
ET	Ephemeris Time
FDF	Fast Delivery Format
GCMS	Gas Chromatograph & Mass Spectrometer
HASI	Huygens Atmospheric Structure Instrument
HPOC	Huygens Probe Operations Centre
IDS	Interdisciplinary Scientist
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
PDS	Planetary Data System
PI	Principal Investigator
PSA	Planetary Science Archive
PST	Project Scientist Team

REF	Reference Document
SFDU	Standard Formatted Data Unit
SSP	Surface Science Package
TL	Team Leader
UTC	Universal Time Coordinated

2. Interface Specification

The file exchange interface comprises three sets of data files:

1. The ***DTWG Input Data***, including the format and content of all data sets from the various instruments and probe housekeeping that will be made available to the Huygens DTWG to perform the reconstruction of the probe entry and descent trajectory.

2. The ***Huygens Probe Initial Conditions and Event File*** will be provided by the PST to the DTWG and comprises the epochs of important events during the probe mission.

3. The ***DTWG Product*** comprising the format and content of all data sets describing the reconstructed entry and descent trajectories and entry attitude that will be made available to the DTWG, the PST, and the HSWT.

The first two sets of data files will be used by the DTWG to reconstruct the Huygens Probe entry and descent trajectory. Note that the archiving plans for the DTWG product is detailed in [REF.2]. A description of the various DTWG product files and their content will be provided in this document.

3. DTWG Input Data Format and Conventions

3.1 Data Format

All files should be in ASCII format. As the various instrument measurements will have different sampling rates each parameter should be provided in a separate file with the following header

INSTRUMENT NAME: HASI
SENSOR/MEASUREMENT: X-AXIS ACCELERATION
DATE OF DELIVER TO THE DTWG: 15-JAN-2005
UNIT OF SENSOR MEASUREMENT: M/S**2
START COUNT: 1246725418.00000 (in ET/J2000 decimal sec.)
STOP COUNT: 1246726677.84375 (in ET/J2000 decimal sec.)
INTERCHANGE FORMAT: ASCII
TOTAL NUMBER OF INSTRUMENT MODES: 3

Note that the time references are always in Universal Time Coordinated (UTC). The header will also provide basic information on the preprocessing/calibration of the raw data. One example is given here for the HASI TEM sensor measurement.

PREPROCESSING INFORMATION AND NOTES:
THE HASI ATMOSPHERIC TEMPERATURE MEASUREMENT WAS CORRECTED FOR
DYNAMIC EFFECTS ETC.
#

The quality of the provided data set is expressed by the DATA_QUALITY_ID which can take the following values:

DATA_QUALITY_ID = 1 … highly reliable and consistent data set
DATA_QUALITY_ID = 2 … data set is quite reliable with minor inconsistencies
DATA_QUALITY_ID = 3 … data set has some inconsistencies but is overall still valid
DATA_QUALITY_ID = 4 … data set is not reliable, needs further pre-processsing

The header input for a good dataset would therefore be

#DATA_QUALITY_ID = 1

The final part of the header should provide any relevant information on data dropouts and invalid data points, and other important notes.

ALL RELEVANT INFORMATION CONCERNING DATA QUALITY AND OTHER NOTES
FOR EXAMPLE:
THE FOLLOWING DATA DROPOUTS HAVE BEEN IDENTIFIED:
RECORD NR: 255 AT EPOCH: XXXX.XXX
#

The end of the file header is designated by:

END OF HEADER

and the data should always start after the end of the file header. The data should be provided in five SPACE separated columns, where

Column 1 = time in Universal Time Coordinated (UTC) (see Appendix C)
Column 2 = Measurement value (in units specified in header)
Column 3 = Absolute measurement error given as 1 sigma standard deviation
Column 4 = Integer number of instrument mode as designated in the header information
Column 5 = Dropout Flag: 1 if measurement is valid, 0 if measurement values is an outlier

Notes: If the measurement error is not known at the time of the file delivery, column 3 should have the value -1.

3.2 Input Data Time System and Format Specification

All the DTWG input data should be timed in Time Coordinated (UTC) (see Appendix C). The time format is

yyyy-mm-ddThh:mm:ss.sss

As an example, in UTC the JPL030312 delivery interface epoch 9:00:00.000 on January 14, 2005 (ET/TDB) = 158,965,200.000 (ET seconds past J2000) is:

2005-01-14T08:58:55.816

3.3 Units

Unless otherwise noted, SI units are to be used throughout. Specific exceptions include X, Y, and Z (altitude) positions, and Xdot and Ydot velocities which are to be in km and km/s, respectively. Probe descent velocities are to be in meters per second, and input pressure data will be provided in mbars. Temperatures will be provided in degrees Kelvin. Units for specific parameters are listed in the DTWG input file format definitions in Section 4.

3.4 Data File Names

All files should have the extension *.DAT. The name of the file should be of the form

<instrument>_<sensor>_<parameter>_DDMMYYYY.DAT

with the field <instrument> one of the following

- HK for housekeeping data
- HASI for Huygens Atmospheric Structure Instrument
- DWE for Doppler Wind Experiment
- SSP for Surface Science Package
- DISR for Descent Imager and Spectral Radiometer
- GCMS for Gas Chromatograph & Mass Spectrometer

The <instrument> field will be followed by fields for <sensor> and <parameter> (if applicable), and the production date of the data file in the time format DDMMYYYY (i.e., Day, Month and Year). Each field is separated by a single underscore. Example of properly named data sets are provided below.

- HASI_XSERVO_DDMMYYYY.DAT
- HASI_XPIEZO_DDMMYYYY.DAT
- HASI_YPIEZO_DDMMYYYY.DAT
- SSP_APIV_DDMMYYYY.DAT
- HK_CASU1_DDMMYYYY.DAT (Housekeeping Central Acceleration Unit 1)
- HASI_PPI_DDMMYYYY.DAT (HASI pressure measurement)

The following sections list the expected data deliveries from the various instruments and the probe housekeeping data sets for the reconstruction of the probe entry and descent trajectory (i.e., probe position and velocity). Note that each of the listed instrument measurement should be provided in a separate file with the proper naming convention and format. All trajectory data sets should be provided as a function of UTC time in the format provided in 3.2.

4. Specification of DTWG Input Data

4.1 Housekeeping Data

The following housekeeping data will be required for the trajectory reconstruction and will be provided by the Project Scientist Team (PST)

- Central Acceleration Sensor Unit Measurement (x-axis) CASU Unit [m/s²]
- Radar Altimeter Unit 1 altitude above surface measurement [km]
- Radar Altimeter Unit 2 altitude above surface measurement [km]

Note that there are three CASU units, i.e., CASU1, CASU2, and CASU3. The PST will choose the best profile and provide it to the DTWG.

Note that after accelerometer gain state changes, very brief transients can be produced in the accelerometer data (e.g., [REF. 3]), which produce sudden jumps in the normal or axial acceleration values. To eliminate this error in the reconstruction procedure an inspection and pre-processing is needed to filter out these spurious peaks. The accelerometer measurements tables therefore require an exact identification of any instrument gain range change (e.g., as part of the identification of the various instrument modes).

The following file names are proposed for the various measurements respectively:

HK_CASU_DDMMYYYY.DAT

HK_RAU1_DDMMYYYY.DAT

HK_RAU2_DDMMYYYY.DAT

4.2 Huygens Atmospheric Structure Instrument (HASI)

The following HASI instrument measurements are required for the trajectory reconstruction:

- X-Servo Acceleration [m/s²]
- X-Piezo Acceleration [m/s²]
- Y-Piezo Acceleration [m/s²]
- Z-Piezo Acceleration [m/s²]
- Surface Impact Time [ET seconds]
- Atmospheric pressure profile: PPI [mbar] (uncorrected for dynamic effects)
- Atmospheric pressure profile: PPI [mbar] (corrected for dynamic effects)
- Atmospheric temperature profile: TEM [K] (uncorrected for dynamic effects)
- Atmospheric temperature profile: TEM [K] (corrected for dynamic effects)

Notes:

1. Surface impact time will be provided based on HASI team analysis of 3 Piezo accelerometers.
2. One pressure dataset will be provided. Data provided will be determined by HASI team to be the highest quality dataset. Column 4 will provide information on measurement sensor and range. Corrected/calibrated or uncorrected/uncalibrated (including temperature compensation and dynamical effects) will be noted for each measurement.
3. One temperature data set will be provided from Fine Sensor temperature data. Data provided will be determined by the HASI team to be the highest quality dataset. Column 4 will provide information on measurement sensor and range. Corrected/calibrated or uncorrected/uncalibrated (including temperature compensation and dynamical effects) will be noted for each measurement.
4. The first pressure and temperature data delivery will comprise only the dataset uncorrected for dynamical effects. All subsequent HASI data pressure and temperature dataset deliveries will comprise both corrected and uncorrected for dynamical effects.

Note that after accelerometer gain state changes, very brief transients can be produced in the accelerometer data (e.g., [REF. 3]), which produce sudden jumps in the normal or axial acceleration values. To eliminate this error in the reconstruction procedure an inspection and pre-processing is needed to filter out these spurious peaks. The accelerometer measurements tables therefore require an exact identification of any instrument gain range change (e.g., as part of the identification of the various instrument modes).

5. The HASI team will be responsible for removing (filtering) transients associated with range changes in the ACC and TEM measurements as part of the experiment data processing and calibration. Values possibly affected by state change (e.g. unreliable measurements) will be marked and/or removed.

The following file names are proposed for the various measurements respectively:

- HASI_XSERVO_DDMMYYYY.DAT
- HASI_XPIEZO_DDMMYYYY.DAT
- HASI_YPIEZO_DDMMYYYY.DAT
- HASI_ZPIEZO_DDMMYYYY.DAT
- HASI_ACC_IMPACT_DDMMYYYY.DAT
- HASI_PPI_CORR_DDMMYYYY.DAT
- HASI_PPI_UNCORR_DDMMYYYY.DAT
- HASI_TEM_CORR_DDMMYYYY.DAT
- HASI_TEM_UNCORR_DDMMYYYY.DAT

4.3 Surface Science Package (SSP)

The following SSP instrument measurements are required for the trajectory reconstruction effort:

- Speed of sound measurement from API-V [m/s]
- Probe altitude above surface measurement from API-S [km]
- Time of surface impact from ACC-I [ET seconds]

The following file names are proposed for the various measurements respectively:

SSP_APIV_DDMMYYYY.DAT

SSP_APIS_DDMMYYYY.DAT

SSP_ACCI_IMPACT_DDMMYYYY.DAT

4.4 Descent Imager and Spectral Radiometer (DISR)

The following DISR instrument measurements are required for the trajectory reconstruction:

- X position [km from surface landing location]
- Y position [km from surface landing location]
- Altitude (DISR Z position) [km]
- Solar Zenith Angle (SZA) [deg]

Note: the X, Y and Z coordinate axes are directed parallel to the equator (positive east), the local meridian (positive north), and the local vertical (positive up). The origin is defined to be at the location of the probe landing site.

The following file names are proposed for the various measurements respectively:

DISR_XPOS_DDMMYYYY.DAT

DISR_YPOS_DDMMYYYY.DAT

DISR_ZPOS_DDMMYYYY.DAT

DISR_SZA_DDMMYYYY.DAT

4.5 Aerosol Collector and Pyrolyser (ACP)

The following ACP instrument measurement is required for the DTWG reconstruction:

- Atmospheric pressure (mbar)

The following file name is proposed:

ACP_PRESS_DDMMYYYY.DAT

4.6 Doppler Wind Experiment (DWE)

The following DWE instrument measurement is required for the DTWG reconstruction:

- Zonal wind speed [m/s]

The following file name is proposed for the wind speed measurement:

DWE_ZWIND_DDMMYYYY.DAT

The DWE data will be provided as a function of either SCET = UTC, or Ephemeris Time (ET). The proper time convention will be noted in the data header.

4.7 Gas Chromatograph Mass Spectrometer (GCMS)

The following GCMS instrument measurement is required for the DTWG reconstruction:

- Mole fractions of main atmospheric constituents (percent: mole fraction * 100.0)

Note that the mole fraction should be given as a percent: mole fraction * 100.

The following file names are proposed for the various measurements respectively:

GCMS_MOLFRACT_N2_DDMMYYYY.DAT
GCMS_MOLFRACT_CH4_ DDMMYYYY.DAT
GCMS_MOLFRACT_AR_DDMMYYYY.DAT
GCMS_MOLFRACT_XX_ DDMMYYYY.DAT

The placeholder file GCMS_MOLFRACT_XX_ DDMMYYYY.DAT will be used only in the event that a 4th atmospheric constituent is found to have a major abundance. If no 4^{th} constituent is found then this file will contain zeros in the measurement column.

5. Huygens Probe Initial Conditions and Event File

The Probe Event File will be provided by the PST to the DTWG in the form of a NAIF text kernel (see template in Appendix A) with the file name

EVENT_FILE_DDMMYYYY.DAT

This file comprises

- A short identification string of the event file;
- The probe interface epoch [in ET seconds] as provided by the Cassini NAV team;
- The state vector of the probe at the interface epoch in Titan-centred EME2000 coordinates;
- The Saturnian system gravitational constant (GM) [km^3/s^2];
- The Titan gravitational constant (GM) [km^3/s^2];
- The full 14 x 14 knowledge covariance matrix mapped at the reconstructed interface time, ordered as probe state (Xp, Yp, Zp, DXp, DYp, DZp) and orbiter state (Xo, Yo, Zo, DXo, DYo, DZo), Saturnian system GM, and Titan GM. Note that for the trajectory reconstruction effort only the probe state and the GMs are needed (the 8 x 8 sub-matrix).

Furthermore the following Titan-related physical constants are needed for the algorithm internal frame conversion procedures:

- Pole right ascension [deg]
- Pole declination [deg]
- Pole prime meridian
- Pole Longitude Axis
- Titan radius [km]
- Titan J2 harmonic coefficient (assumed to be 0)

The following important events are required for quality control and consistency check of the reconstructed trajectory (all provided in ET):

- S0 detection
- T0 detection
- G-switch epochs
- Heat shield release
- Stabilizing drogue deployment
- DISR cover ejection
- HASI boom deployment
- GCMS cover ejection
- ACP cover ejection
- All RAU lock/unlock events

6. The DTWG Product and Deliveries

6.1 Format

The DTWG product will be provided in 2 formats:

- **Fast Delivery Format (FDF)**, comprising simple ASCII files with space separated columns and file names as specified below.
- **PDS format**, which will be provided to the PSA and the PDS.

Only the FDF format will be described in this document. The PDS format and data products are described in detail in [REF. 2].

6.2 DTWG Product Deliveries

Several DTWG trajectory deliveries are planned. Deliveries 1 through 4 are outlined in the Rules of the Road (see Appendix E):

- **Delivery Nr. 0:** A probe entry and descent trajectory predict will be made available five days prior to probe arrival. The trajectory predict will be based upon the most recent JPL probe delivery file and will be made available in the Fast Delivery Format.
- **Delivery Nr. 1:** 2 days following the probe data delivery (FDF)
- **Delivery Nr. 2**: 2 weeks following the probe data delivery (FDF)
- **Delivery Nr. 3**: 2 months following the probe data delivery (FDF)
- **Delivery Nr. 4 (Final Delivery)**: 6 months following the probe data delivery (FDF and PDS Formats)

6.3 Time and Trajectory Conventions

The DTWG will provide the reconstructed entry and descent parameters as a function of Ephemeris Time (ET), time from T0, and UTC.

The Probe longitudes will be provided in **West longitudes**.

The latitude convention is:

- positive values for North latitude
- negative values for South latitude

Probe altitude will be provided in two formats:

- with respect to the reference surface (reference altitude, 2575.0 km)
- with respect to the RAU measured topography (when RAU data is available)

6.4 The DTWG Products

The DTWG Product comprises the Main Product with the actual reconstruction results, and the Auxiliary Products with information necessary to interpret, understand and use the results provided in the Main Products. The data tables will be provided at time steps of 1 second.

DTWG Main Product

The DTWG Main Product comprises the reconstructed probe trajectory information separated in entry and descent phase and consists of the following files:

HUY_DTWG_ENTRY.DAT [alt, lat, west long, AoA, inertial velocity as f(t)]

HUY_DTWG_ENTRY_EME2000_POS.DAT [entry x, y, z as f(t)]

HUY_DTWG_ENTRY_EME2000_VEL.DAT [entry xdot, ydot, zdot as f(t)]

HUY_DTWG_DESCENT_POS.DAT [alt relative to 2575 km, pressure, lat, west long as f(t)]

HUY_DTWG_DESCENT_VEL.DAT [alt relative to 2575 km, pressure, descent velocity as f(t)]

HUY_DTWG_DESCENT_RAU.DAT [alt relative to surface, pressure, topography as f(t)]

The exact content of each file is outlined in the subsequent sections:

6.4.1. HUY_DTWG_ENTRY.DAT

This file contains the probe entry altitude, west longitude, latitude, and angle of attack as a function of time in column format:

Column 1: Time in ET (J2000)

Column 2: Relative time with respect to T0 [sec]

Column 3: Time in UTC

Column 4: Probe altitude relative to the reference surface (2575.0 km) [km]

Column 5: Probe West Longitude [deg]

Column 6: Probe Latitude [deg]

Column 7: Probe Angle of Attack [deg]

Column 8: Probe inertial velocity [m/s]

6.4.2 HUY_DTWG_ENTRY_EME2000_POS.DAT

This file contains the probe EME2000 entry position as a function of time in column format:

Column 1: Time in ET (J2000)

Column 2: Relative time with respect to T0 [sec]

Column 3: Time in UTC

Column 4: Probe X-coordinate (Titan-centred EME2000 system)

Column 5: Probe Y-coordinate (Titan-centred EME2000 system)

Column 6: Probe Z-coordinate (Titan-centred EME2000 system)

6.4.3 HUY_DTWG_ENTRY_EME2000_VEL.DAT

This file contains the probe EME2000 entry velocities as a function of time in column format:

Column 1: Time in ET (J2000)

Column 2: Relative time with respect to T0 [sec]

Column 3: Time in UTC

Column 4: Probe X-coordinate velocity (Titan-centred EME2000 system)

Column 5: Probe Y-coordinate velocity (Titan-centred EME2000 system)

Column 6: Probe Z-coordinate velocity (Titan-centred EME2000 system)

6.4.4 HUY_DTWG_DESCENT_POS.DAT

This file contains the pressure, altitude, west longitude, and latitude as a function of time in column format:

Column 1: Time in ET (J2000)

Column 2: Relative time with respect to T0 [sec]

Column 3: Time in UTC

Column 4: Atmospheric Pressure at probe [mbar]

Column 5: Probe altitude relative to the reference surface (2575.0 km) [km]

Column 6: Probe West longitude [deg]

Column 7: Probe latitude [deg]

Column 8 – 11: Corresponding uncertainties in the same units as Columns 4 – 7

6.4.5 HUY_DTWG_DESCENT_VEL.DAT

This file contains the pressure, altitude, and descent velocity as a function of time in column format:

Column 1: Time in ET (J2000)

Column 2: Relative time with respect to T0 [sec]

Column 3: Time in UTC

Column 4: Atmospheric pressure at probe [mbar]

Column 5: Probe altitude relative to the reference surface (2575.0 km) [km]

Column 6: Probe vertical (descent) velocity [m/s]

Columns 7 – 9: Corresponding uncertainties in the same units as Columns 4 – 6

6.4.6 HUY_DTWG_DESCENT_RAU.DAT

This file contains the pressure, altitude, and descent velocity as a function of time in column format:

Column 1: Time in ET (J2000)

Column 2: Relative time with respect to T0 [sec]

Column 3: Time in UTC

Column 4: Atmospheric pressure at probe [mbar]

Column 5: Probe altitude Relative to sub-probe surface from RAU1 [km]

Column 6: Probe altitude Relative to sub-probe surface from RAU2 [km]

Column 7: Surface elevation relative to reference surface (2575.0 km) [km]

Columns 8 – 10: Corresponding uncertainties in the same units as Columns 4 – 6

DTWG Auxiliary Product

6.4.7 HUY_DTWG_AUX.DAT will be identical to the Huygens Probe Initial Conditions and Event File provided to the DTWG by the PST as a NAIF text kernel. See Section 5 for exact contents of this file, and Appendix A for the template.

7. Data Flow and Delivery

The physical file exchange will be done via a secure FTP site provided and maintained by the PST (ESA/ESTEC).

All the DTWG members will have access to the DTWG data site for uploading and retrieving of trajectory data. These data will be used by the DTWG team only for the purpose of the reconstruction of the probe entry and descent trajectory and entry attitude as outlined in the DTWG Rules of the Road, and will not be published or made available beyond the PST and HSWT except with approval of all DTWG members and as governed by the DTWG Rules of the Road. The applicable data rights are outlined in [REF. 7].

Each instrument providing data for the entry and descent trajectory reconstruction will have a directory for that team's trajectory input data. Within each directory, different data deliveries will be placed in subdirectories designated by date of delivery: Delivery#_DDMMYYYY. The naming conventions of individual data sets are as specified in Section 3. For example:

- Directory: HASI
    - Subdirectory: Delivery1_16012005
        - File: HASI_XSERVO_DDMMYYYY.DAT
        - Doc
    - Subdirectory: Delivery2_15022005
        - File: HASI_XSERVO_DDMMYYYY.DAT
        - Doc
    - Subdirectory: Delivery3_30032005
        - File: HASI_XSERVO_DDMMYYYY.DAT
        - Doc
- Directory: DTWG
    - Subdirectory: Delivery1_18012005
    - Subdirectory: Delivery2_30012005
    - Subdirectory: Delivery3_15032005
    - Subdirectory: Delivery4_15072005

All experiment teams (including IDS's) will have permissions set on the Huygens Science Operations FTP server such that access is restricted to that team's respective directory, the DTWG directory, and the PST directory. No experiment team will have permission to download, access, or view the directory or the contents within the directories of other teams.

The PST and the DTWG will have read access to all experiment team and IDS directories.

The final DTWG trajectory will be archived in the PSA in PDS format.

8. Simulated Data Set

The PST will provide to the DTWG a simulated set of data for the testing and validation of the trajectory and attitude reconstruction tools. The format and file names of the Simulated Data Set will conform to the convention presented in Section 3 of this document, and will comprise all the instrument and housekeeping files outlined in Sections 4 and 5.

9. Data Handling and Publication Policy

The data handling and publication policy of the DTWG will be governed by the DTWG Rules of the Road [REF.6/Appendix E] and the Huygens Data Analysis and Data Management Plan [REF.7].

Appendix A: Huygens Probe Initial Conditions and Event File

Template of Huygens Probe Initial Conditions and Event File

```
\begintext

*******************************************************
*   HUYGENS PROBE INITIAL CONDITIONS AND EVENT FILE   *
*******************************************************

\begindata

HUY_Event_File_Description = ( ' XXX +'
                      'XXX +'
                      'XXX')
\begintext

Probe entry Interface Time (ET) provided by Cassini Navigation team at JPL

\begindata

Interface_Time = ( @14-JAN-2005-09:00:00.000)

\begintext

Probe position (km) and velocity (km/s) vectors in Titan-centred, EME2000
coordinates at the probe entry interface time.

\begindata

Probe_State = (   -2.116721028D+02,
 -3.821140624D+03,
 -3.716251621D+02,
 -2.340519721D+00,
 5.540266030D+00,
 4.587518978D-01 )

 \begintext

Saturnian system gravitational constant (GM) in km3/s2.

\begindata

Estimate_Saturn_GM = ( 3.794062976D+07 )

\begintext

Titan gravitational constant (GM) in km3/s2.

\begindata

Estimate_Titan_GM = ( 8.978200000D+03 )


\begintext

Full 14 x 14 knowledge covariance matrix mapped at the reconstructed interface
time. Ordered as probe state (Xp, Yp, Zp, DXp, Dyp ,DZp), orbiter state (Xo, Yo,
Zo, DXo, DYo, DZo), Saturnian system GM, and Titan GM.

\begindata
```

```
Cov_Matrix = (
  9.70719072786313D+02, 2.09832966090401D+03, -7.16783847624714D+01,
 -8.23664443610206D-02, 2.04381796202432D-01, 3.24014345668979D-02,
 -1.61112478051899D+01, -3.79384278848334D+01, -3.96193100140521D+00,
 6.74717743722549D-06, -1.42500132390226D-04, 9.29186626962193D-05,
 4.41994134705193D+00, -2.788483112918D-01,
 2.09832966090401D+03, 5.21829282833298D+03, -2.05958207578518D+02,
 -1.87809624316756D-01, 5.12363020769872D-01, 8.26610918650051D-02,
 -8.08102921704054D+01, -6.8097846322084D+01, -4.52195254163236D+01,
 1.67153894318209D-04, -3.91701423452592D-04, 3.87788770217366D-04,
 -2.21562341488403D+01, -3.92138032388517D-01,
 -7.16783847624714D+01, -2.05958207578518D+0 …
…

[…]  )

 \begintext

 Titan related physical constants, i.e.,
 - Pole rectascension [deg]
 - Pole declination [deg]
 - Pole prime meridian numbers as defined in [REF. 1]
 - Longitude Axis
 - Titan radius [km]
 - Titan J2 harmonic coefficient


\begindata

 BODY606_POLE_RA       = (    36.41   -0.036      0.   )
 BODY606_POLE_DEC      = (   +83.94   -0.004      0.   )
 BODY606_PM            = (   189.64  +22.5769768  0.   )
 BODY606_LONG_AXIS     = (     0.                      )
 BODY606_RADII         = (  2575.    2575.     2575.  )
 BODY606_J2            = ( 0.0D0 )

\begintext
```

the following important events [all in ET sec. past J2000] are required for the quality control and consistency check of the reconstructed trajectory:

- S0 detection
- T0 detection
- G-switch epochs
- Heat shield (FRSS) release
- Stabilizing Drogue deployment

- DISR cover ejection
- HASI boom deployment
- GCMS cover ejection
- ACP cover ejection

- First RAU1 lock
- First RAU2 lock
- RAU1 unlock
- RAU2 unlock

\begindata

S0_EVENT= (158965464.9798)
T0_EVENT= (158965471.3548)
GSW_EVENT= (----)
MAIN_CH_EVENT= (158965473.8548)
FRSS_EVENT= (158965503.8548)

DISR_COV_EVENT= (158965537.6048)
HASI_BOOM_EVENT= (158965521.0098)
GCMS_INLET_COV_EVENT= (158965521.3548)
GCMS_OUTLET_COV_EVENT= (158965529.4798)
ACP_COV_EVENT= (158965504.2298)
DROGUE_CH_EVENT= (158966371.3548)

RAU1_LOCK_1= (158967386.4798)
RAU2_LOCK_1= (158967386.4798)
RAU1_UNLOCK_1= (00000.00)
RAU2_UNLOCK_1= (00000.00)

\begintext

Note that the number at the end of the RAU_LOCK and RAU_UNLOCK determines the number of lock and unlock events, e.g., if the RAU1 locks for the 3th time then use RAU1_LOCK_3 = (0.0)

Appendix B: Instrument Input Data Header Template

```
# INSTRUMENT NAME: HASI
# SENSOR/MEASUREMENT: X-AXIS ACCELERATION
# DATE OF DELIVER TO THE DTWG: 15-JAN-2005
# UNIT OF SENSOR MEASUREMENT: M/S**2
# S/C CLOCK START COUNT: 1246725418.00000 (in decimal sec.)
# S/C CLOCK STOP COUNT: 1246726677.84375 (in decimal sec.)
# INTERCHANGE FORMAT: ASCII
# TOTAL NUMBER OF INSTRUMENT MODES AND DESCRIPTION OF EACH: 3
#
# MODE 1:
#
# MODE 2:
#
# MODE 3:
#
#
# PREPROCESSING INFORMATION AND NOTES:
# THE HASI ATMOSPHERIC TEMPERATURE MEASUREMENT WAS CORRECTED FOR
# DYNAMIC EFFECTS ETC. ETC.
#
#DATA_QUALITY_ID = 1 … highly reliable and consistent data set
#
# ALL RELEVANT INFORMATION CONCERNING DATA QUALITY AND OTHER NOTES
# FOR EXAMPLE:
# THE FOLLOWING DATA DROPOUTS HAVE BEEN IDENTIFIED:
# RECORD NR: 255 AT EPOCH: xxxxxx
#
# END OF HEADER
```

Appendix C: Definition of Ephemeris Time and Conversion from UTC

Ephemeris time (ET) is the uniform time scale represented by the independent variable in the differential equations that describe the motions of the planets, sun and moon. There are two forms of ephemeris time: Barycentric Dynamical Time (TDB) and Terrestrial Dynamical Time (TDT). Although TDB and TDT represent different time systems, these time systems are closely related. Barycentric dynamical time is used when describing the motion of bodies with respect to the solar system barycentre. Terrestrial dynamical time is used when describing motions of objects near the earth.

When the DTWG refers to ET, TDB is the implied time system. ET is provided in seconds past a reference epoch. The reference epoch used by the DTWG is the epoch J2000 (January 1, 2000 12:00:00). Note that the DTWG time definition is equal to the time system definition of the NASA NAIF SPICE Toolkit [REF. 8].

During the time of the Huygens Probe mission no leap seconds occur and the time difference between UTC and ET is precisely 64.184 seconds. One can therefore convert between the two systems using:

(Step 1): [ET time] = [UTC time] + 64.184 seconds

For example

ET 2005 JAN 14, 09:00:00.0000 = UTC 2005 JAN 14, 08:58:55.816

To convert the ET time string into the number of ET seconds past J2000 (as required by the DTWG) one can use the reference point of

ET 2005 JAN 01, 00:00:00.0000 = ET 157,809,600.0000 sec past J2000

using the simple relation :

(Step 2) [ET sec past J2000] = [ET sec past 2005 Jan 01, 00:00:00.0000] + 157 809 600.0000

Example Convert the JPL030312 interface epoch in UTC to J2000 ET (TDB).

In UTC format, the JPL030312 interface epoch is

2005 JAN 14, 08:58:55.816

This can be converted to ephemeris time (ET) by adding 64.184 seconds:

JPL030312 interface epoch in ET = 8:58:55.816 + 64.184 = 9:00:00.000

This can now be converted to seconds past 2005 Jan 01, 00:00:00.0000:

9:00:00.000 2005 JAN 14 = (13 dy x 24 hr/dy + 9 hours) x 3,600 sec/hr = 1,155,600.0000 sec

and then to seconds from J2000

1,155,600.0000 + 157,809,600.0000 = 158,965,200.0000

Appendix D: Coordinate System Conventions

The DTWG output data will only be provided in Titan centred inertial reference system, i.e., the EME2000 system and a Titan body-fixed (i.e., rotating) coordinate system (R-Frame). Longitudes are provided in West Longitudes. Altitude will be given with respect to the Titan reference surface assuming a planetary radius of 2575 km.

The **EME2000 system** (also often referred to as the J2000 system) is aligned with the Earth mean equator and equinox at the reference epoch J2000 (i.e., Greenwich noon on January 1, 2000 Barycentric Dynamical Time) and has its origin at the center of the planet. The z-axis is parallel to the mean rotation axis of the Earth and the x-axis points in the direction of the mean vernal equinox, i.e. the ascending node of the Earth's mean orbital plane on the mean equator at the fixed epoch J2000. The y-axis fills out an orthogonal right-handed system. Here the term "mean" indicates that only secular (or long-periodic) changes in the orientation of the Earth's rotation axis (or its equator) and the ecliptic are considered. Note that the EME2000 is an inertial system which means that it does not accelerate or rotate with respect to the star field and so Newton's Laws of Motion apply in that frame. The Cassini Navigation team will provide the initial state vector of the probe and the corresponding covariance matrix in Titan-centred EME2000 coordinates. Note that the EME2000 coordinate system is a quasi-inertial (not perfectly inertial as the planet centre is moving) or Newtonian reference system and the formulation of the equations of motion in such a system therefore does not require the inclusion of Coriolis and centrifugal forces.

The Titan rotating system (**R-Frame**) is a Titan-centred body-fixed coordinate system used to specify a stationary point on Titan's surface. Titan's orientation is defined as a continuous function of time by the formulation in [REF. 4]. The z-axis is along Titan's pole, evaluated for 0 hours of the entry date, and is the same as for the Titan Q System. The x-axis passes through the intersection of Titan's equator with the prime meridian, and rotates with the satellite body. The y-axis fills out an orthogonal right-handed system. Both the Cassini ground system and the Orbiter Inertial Vector Propagator system (IVP) will be able to accommodate a change in the Titan orientation constants. Northern latitudes are designated as positive. For the longitude, a geodetic definition is applied, which defines the longitude as the angle between this vector and the plane of the prime meridian measured positively in the eastern direction. The radius is the modulus of this vector.

Appendix E: Huygens Mission Descent Trajectory Working Group

Rules of the Road

To ensure an orderly and efficient analysis, interpretation, and delivery of the Cassini/Huygens engineering and instrument data necessary for the Huygens probe entry and descent trajectory reconstruction, the Cassini/Huygens Descent Trajectory Working Group (DTWG) agrees to the following set of procedures and rules:

1. The DTWG membership comprises the DTWG Chair and Co-Chair, the Cassini and Huygens Project Scientists, the Huygens Operations Scientist, contributing Probe and Orbiter Instrument team representatives, Interdisciplinary Scientists (IDS), and other appointed instrument team members. **It is the responsibility of the DTWG members to ensure that these Rules-of-the-Road are known and observed by their team.**

2. **Each team member is responsible for the analysis of data from his/her instrument or investigation.** The DTWG members and their science team are responsible for the initial analysis, interpretation, and publication of their experiment data.

3. All DTWG members will provide the agreed upon processed data to the DTWG for the sole purpose of probe entry and descent trajectory reconstruction activities. The first delivery of the agreed upon experiment data to the DTWG will be made within two days of the return of the initial probe data set to the Huygens Probe Operations Centre (target date = Sunday Jan 16). Subsequent data deliveries will be made according to the following schedule (all time periods relative to the date of the return of the **consolidated** probe data set to the Huygens Probe Operations Centre):

    ii. 10 days
    iii. 6 weeks
    iv. 5 months

4. The DTWG-derived trajectory data will be made available to the Huygens Science Working Team (HSWT) and to the Project Science Group (PSG). The first delivery of the DTWG-derived trajectory data will be made within two days of the receipt of the initial instrument team data delivery defined in 3 (above). Subsequent deliveries will be made according to the following schedule (all time periods relative to the date of the return of the **consolidated** probe data set to the Huygens Probe Operations Centre):

    i. 2 weeks
    ii. 2 months
    iii. 6 months (final data product)

5. The DTWG-derived trajectory data **will not be published without the specific written authorisation of the DTWG and the HSWT**. However, with HSWT authorization the preliminary reference trajectory may be used in oral presentations addressing early experiment results. Proper credit must be provided to the contributing instrument teams and to the DTWG.

6. Each member of the DTWG entrusted with the reference trajectory data is required to see that the trajectory data is not distributed beyond the DTWG without the written permission of the HSWT.

7. Publication of the Reference entry and descent trajectory will follow the publication plan agreed upon by the HSWT.

8. Conflicts that may arrive from the usage or the interpretation of the DTWG data set will be referred to the HSWT for resolution.

DTWG Membership

- Chair and Co-Chair
- Huygens Project Scientist and Huygens Operations Scientist

- Cassini Project Scientist
- Contributing Probe and Orbiter Instrument Team Representatives and Interdisciplinary Scientists (IDS)
- Other appointed instrument team members