AIAA 2006-5515

HASI Engineering Operations at Titan

F. Angrilli[1] , A. Aboudan[2], C. Bettanini[3], G. Bianchini[4], G. Colombatti[5], S. Debei[6], G. Fanti[7], F.Ferri[8], P.F.Lion Stoppato[9]

CISAS- Univeristà di Padova, Padova, Italy

E.Flamini[10]
ASI Agenzia Spaziale Italiana, Roma, Italy

and
M Fulchignoni[11]
LESIA Observatoire Paris Medon, Paris, France

On the 14th of January 2005 the Huygens probe entered the mysterious previously quite unknown atmosphere of Titan. One of the six instruments on board the Huygens probe was the Huygens Atmospheric Structure Instrument (HASI) devoted to the analysis of the atmosphere of Titan and to the study of its surface. A big effort was put to implement the automatic sequence to avoid any loss of scientific data. The HASI instruments, within the Huygens probe, was powered-ON before all the other instruments and started its measurements at an altitude of around 2800km, when the telemetry link with the Cassini probe was not yet set or established. In this phase of the mission 44kbts of housekeeping and acceleration data had to be stored inside the experiment memory and a specific saving sequence was implemented with several copies of each packet of data. In the successive descent phase, triggered by the 10m/s^2 deceleration threshold, temperature and pressure measurements sampling sequence was added to the accelerometer sequence; the starting of the sampling was anticipated as much as possible compatibly with the storage capability of the system and before the front shield separation (which occurred 32s after the threshold passing). The critical sequence of the deployable booms with the electric package instrument was implemented in the software in order to have execution in a 40 seconds window and a backup deployment sequence 80 seconds later. Due to the distance of the probe from the Earth and the configuration of the mission no real-time sequence operation could be executed during the 2.5 hours of the mission. Furthermore the link with the Cassini spacecraft did not allow a downlink to the probe during the mission phase, for this reasons all the operations have been programmed before the probe release which was performed the 25th of December 2004. The flexibility of the onboard software allowed the instrument to perform exactly as planned. The implementation of the Preheating phase on board the Huygens probe required a significant upload in the onboard software of the probe itself and on the software of most of the instruments. The HASI on board software had to be reprogrammed to run within this new scenario. Tests where conducted during the last part

[1] Prof, CISAS, via Venezia 1 Padova, Italy
[2] PhD, CISAS, via Venezia 15 Padova, Italy
[3] PhD, CISAS, via Venezia 1 Padova, Italy
[4] Prof, CISAS, via Venezia 1 Padova, Italy
[5] PostDoctoral Research Assistant, CISAS, via Venezia 15 Padova, Italy,
[6] Prof, CISAS, via Venezia 1 Padova, Italy
[7] Prof, CISAS, via Venezia 1 Padova, Italy
[8] PostDoctoral Research Assistant, CISAS, via Venezia 15 Padova, Italy
[9] PostDoctoral Research Assistant, CISAS, via Venezia 15 Padova, Italy
[10] Solar System Exploration Manager, ASI, via di Villa Grazioli, Roma
[11] Prof, Univ. Paris VII & Lesia, Observatoire Paris Medon, Paris

of the cruise phase to develop and verify all the changes made on the onboard software. This mission may be considered as an extreme case from the operations point of view due to the scenario of events that could have been achieved only via a completely automatic sequence. Furthermore, all the instruments had been designed to cope with this constraint. This paper describes the automatic operations that had to be implemented onboard the HASI DPU (Data Processing Unit) before launch and the ones implemented during cruise phase in order to perform the revised Preheating scenario and all the tests that where conducted.

I.Nomenclature

NASA = National Aeronautics and Spacecraft Agency
ESA = European Space Agency
ASI = Agenzia Spaziale Italiana
PWA = Permittivity, Wave, and Altimetry instrument.
PPI = Pressure Profile Instrument.
TEM = Temperature sensors.
ACC = Accelerometers.
DBS = Deployable Boom System
STUB = Fixed stem
DPU = Data Processing Unit
CDMS = Command Data and Management System
CPU = Central Processing Unit
PROM = Programmable read only memory
RAM = Random access memory
EEPROM = Electrical Erasable PROM
DDBL = Descent Data Broadcast List
BCP = Broadcast Pulse
TC = Telecommand
CO = Check Out
CRC = Cyclic Redundancy Code
FS = Flight Spare
EM = Engineering Model
SEU = Single event upset

II.Introduction

The Huygens probe is part of the joint NASA/ESA/ASI Cassini/Huygens mission to Saturn and Titan (Lebreton, Matson 2002). Huygens probe goals were to make a detailed in situ study of Titan's atmosphere and to characterize the surface of the satellite along the descent ground track and near the landing site. The probe was separated from Cassini spacecraft on 25 December 2004. After a coast phase of approximately 25 days the probe arrived at the interface point (defined as an altitude of 1270 km above Titan’s surface) on 14 January 2005 and started its atmospheric entry and descent to the surface. The Huygens mission sequence is schematically depicted in Figure 1 ; the whole probe operations timeline is referred to the so called T0 time that corresponds to the first parachute opening and can be divided into several different phases:

- Entry phase: from interface point T0 (about 160 km of altitude).
- Descent phase: from T0 to surface impact.
- Surface phase: from surface impact to link loss.

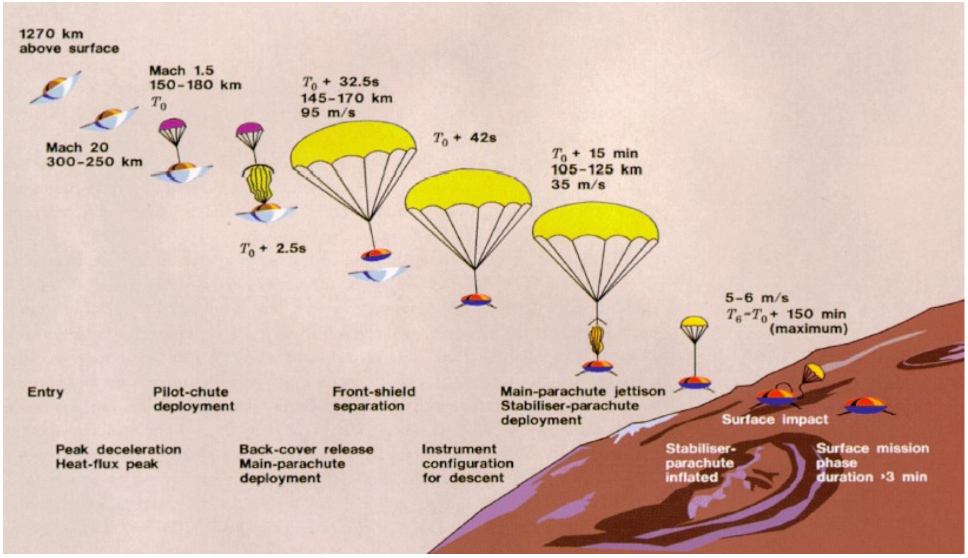

Figure 1: Huygens probe entry and descent sequence

Several Automatic pre-programmed operations where foreseen during the mission after the opening of the first parachute and the release of the back heat shield release. After 32s from T0 the frontshield was released and all the instruments where exposed to the atmospheric flux. The Main parachute (opened at T0+ 5s) was release at T0+900 and a smaller parachute was used in order to reach ground after a 2:30 gently descent (Lebreton, J. P. et al., 2005).

A.Huygens probe

The Huygens probe carries six instruments that performed scientific measurements of the physical and chemical properties of Titan’s atmosphere, measure winds and global temperatures, and investigated energy sources important for the planet’s chemistry throughout the descent mission.

The instruments on-board Huygens are:

- Aerosol Collector and Pyrolyser (ACP) (Israel *et al.*, 1997) to collect aerosols that have been analysed by the Gas Chromatograph and Mass Spectrometer experiment.
- Atmospheric Structure Instrument (HASI) (Fulchignoni *et al.*, 1997) is a multi-sensor instrument that measured the physical and electrical properties of Titan's atmosphere
- Descent Imager/Spectral Radiometer (DISR) (Tomasko *et al.*, 1997) was an optical remote sensing instrument
- Doppler Wind Experiment (DWE) (Bird *et al.*, 1997) was designed to determine the direction and strength of Titan's zonal winds
- Gas Chromatograph and Mass Spectrometer (GCMS) (Niemann *et al.*, 1997) is designed to measure the chemical composition of Titan's atmosphere from 170 km to the surface and determine the isotope ratios of the major gaseous constituents
- The Surface Science Package (SSP) (Zarnecki *et al.*, 1997) is a suite of sensors for determining the physical properties of the surface at the landing site and for providing information on the composition of the surface material.

All of Huygens’ entry and descent science and engineering data have been transmitted to the Cassini Orbiter, targeted to flyby Titan at a periapse distance of 60,000 km, recorded on board on the Solid State memory for later transmission to Earth.

B.HASI Instrument

The Huygens Atmospheric Structure Instrument (HASI) was designed to measure the physical quantities characterizing Titan's atmosphere. During the descent phase HASI measures directly profiles of atmospheric pressure and temperature as well as the electrical properties of the atmosphere.

HASI comprises several subsystems :

- PWA: Permittivity, Wave, and Altimetry package.

- PPI: Pressure Profile Instrument.
- TEM: Temperature sensors.
- ACC: Accelerometers.
- DBS: Deployable Boom System with the PWA electrodes.
- STUB: fixed stem with the TEM sensors, PPI Kiel probe and acoustic sensor.
- DPU: Data Processing Unit.

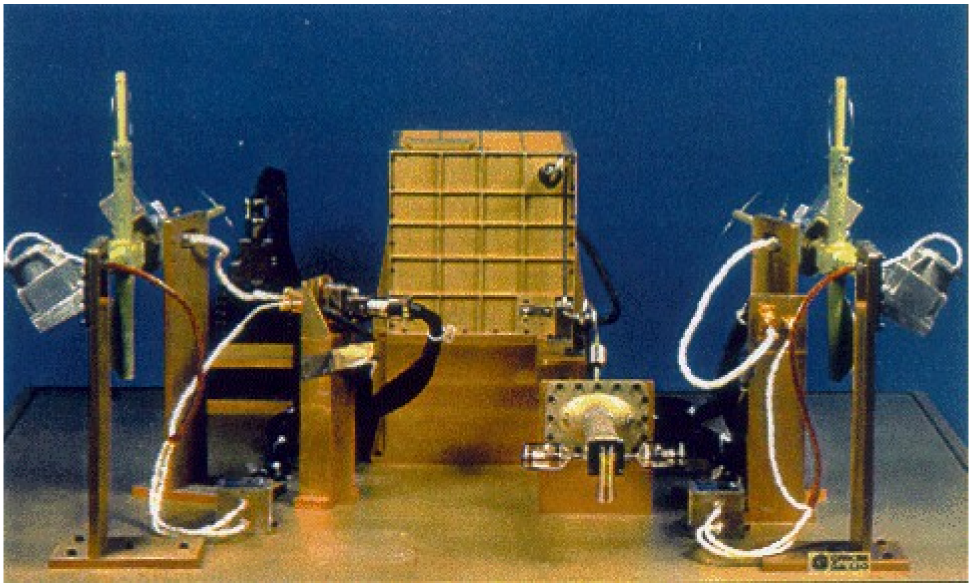
Figure 2. HASI FS model on its ground support equipment

C.HASI On board DPU system

All the operations performed by the HASI instrument are controlled by the HASI on board Software, the core of the engineering operations of HASI. The HASI on board software is executed by one microprocessor that is part of the DPU. It is linked to the Huygens CDMS and collects science data measurements from the connected sensors by means on an ADC converter plus several other dedicated interfaces. A digital Signal Processor performed and controlled, via a parallel interface, the measurements and the sessions of the PWA.

The collected science data were transferred to CDMS via ESA Standard Telemetry packets.

The CPU architecture was based on a 16 bits 80C86 microprocessor system with a 16KB words of programmable read only memory (PROM) and 32KB words of read/write random access memory (RAM). The system was clocked at 4.5MHz.

An 8KB EEPROM memory area was provided to store software patches and uploadable parameters. The use of the device was controlled by the HASI-SW which powered it on during the Memory Load and Dump sequences.

A watch dog circuit generates a reset signal in case of problems.

1. Software operative modes

According to the mission events and phases and to the DDBL information (containing all relevant informations for the instruments, i.e. spin, time, valid CDMU, etc.), the HASI Software addressed different operational modes, submodes and states as listed in Table 1.

The selection of the operative mode is governed by the following events that control the software:

- Power ON and Reset
- during STARTUP if an error in the DDBL reception happens
- Executable Telecommands
- Reset Telecommands

TABLE 1. HASI DPU Software execution mode

MODE	***SUBMODE***	***STATE***
STARTUP	not available	not available
TITAN DESCENT	Nominal / Backup	Entry / Descent1 / Descent2 / Descent3 / Impact / Surface
CHECKOUT	Nominal / Backup	Entry / Descent1 / Descent2 / Descent3 / Impact / Surface
TELECOMMAND EXECUTION	Nominal / Backup	Entry / Descent1 / Descent2 / Descent3 / Impact / Surface

The following events cause the Software to change the submode in the operational mode:

- DDBL reception errors
- BCP (pulse sent to the instruments from the Probe software for the timing) timeouts

The backup mode is a mode governed by HASI internal software which increments the time with a simulated pulse every 180 ms.

The selection of the state inside each mode is controlled by:

- The Mission Time Evolution; according to the time information sent to the Instrument the various phases and events are performed;
- The Altitude Information are derived from predicted values contained in the onboard software (table format); in the last kilometers the successive events are governed by the altitude information derived from the Huygens altimeters
- The Impact detection; the internal algorithm controlling the impact detection instant has high priority in the last km of the descent.

2. Software Planned operations

At the startup there are several operations performed by the CPU in order to enter in the operational mode; these are:

- check the possible cause of reset (reset TC, watch dog, self reset due to program failure condition)
- load in the RAM the PROM default values of each of the Uploadable items
- EEPROM test sequence (see below)
- clear all HW interfaces
- set ACC range to Fine (highest possible resolution)
- initialise internal Mission Time

The EEPROM test sequence is performed as follows:

- check the DDBL presence in both the CDMU lines
- check the received DDBLs
- switch On the EEPROM
- search for parameter update block information and verify the CRC for each block
- if the CRC is correct fill the RAM with the image contained in the EEPROM
- send a report
- switch off the EEPROM

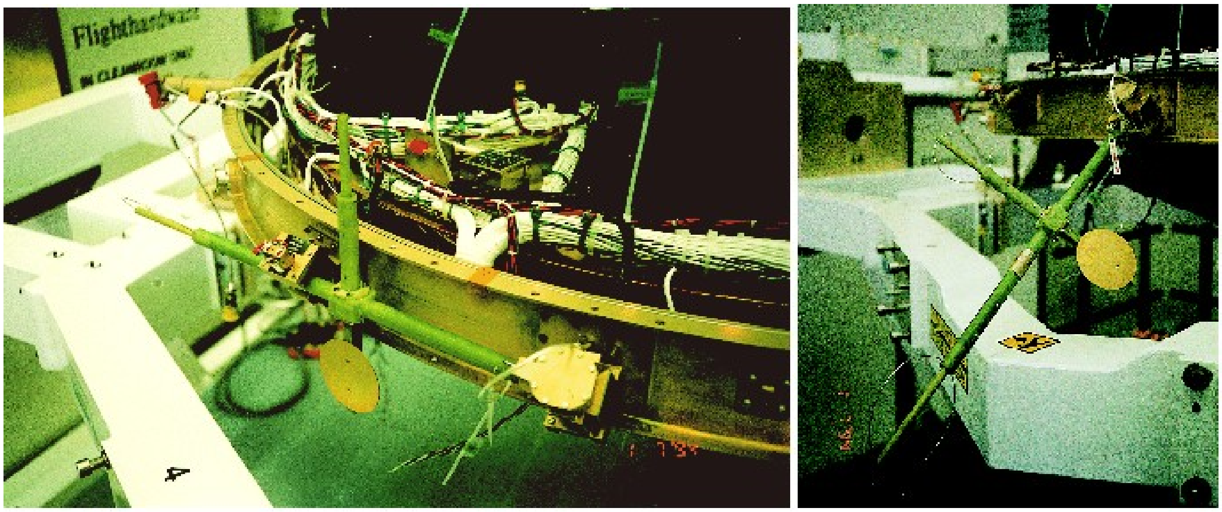

Figure3. HASI PWA BOOM Configurations.

On the Left the HASI boom in stowed position; on the right the Boom in the deployed position on the EM Huygens model

3. The Boom release Operation

During the cruise phase the booms carrying the electrical devices for the PWA experiment were stowed in a rest position on the Huygens external ring. In order to inhibit the opening of the booms during the cruise phase a second power line was designed for the booms opening and the HASI SW performed the commanding operations during this phase. This second line could be activated only during the Titan Mission phase. The booms function was to carry the electric devices as far away as possible respect to the Huygens probe in order to have the minimum interference as possible with the electric flow and in a fixed geometric configuration respect to the Huygens probe.

The deployment of the Booms was a critical task for the HASI experiment and was planned to be executed, for the first time, 100 seconds after the T0 event.

There were three operations that were required for the deploying of the booms:

1. HASI experiment must be switched ON
2. the Protected Power line must be activated
3. the HASI SW must command the boom deployment in the correct timing window

When reaching the Td1 event (T0+60s) the HASI SW performed the operations necessary for retaining the pin that blocked the release and the boom release started with the initial push given by a spring at the base of the retaining cavity.

A second attempt was performed when the DDBL time shows the predetermined time Td2 (T0+140s). Both the Td1 and the Td2 are uploadable parameters.

During the Boom operation the HASI SW recorded the status of the Protected Power and the commands sent to the opening device and were reported into the EVENT log packet for telemetry.

D.CheckOuts and Telecommands

During the Cruise phase sixteen Checkouts (CO) were performed. The Checkout was a simulated descent performed during orbital transfer in order to test all the Instruments and the Probe subsystems. During the COs HASI could receive also telecommands coming from ground via the CDMS and did not execute the Boom release sequence.

1. Telecommand sequence

HASI could accept telecommands in CheckOut mode. At BCP rate the HASI SW examines the Memory Load (ML) buffer to check the presence of the DDBL and or a Telecommand (TC); first it was checked if the DDBL was received and after if a TC was present. Several different cases could happen:

- case1: both DDBL and TC are accepted
- case2 : only DDBL is discarded

- case3 : only TC is discarded
- case4 : both TC and DDBL are discarded

In both the second and forth case the HASI SW switches to the not selected CDMU channel.
When a TC is recognised several checks will be executed to establish its correctness.

- TC congruence according to the selected CDMU (A or B)
- TC sequence count must be greater than the sequence count of the last TC received
- Tc length must be as specified
- TC CRC correctness

If one of the above conditions is not satisfied the TC is considered wrong and is disregarded. An information message is set in the EVENT LOG packet. The TC check takes about 0.2 seconds.
Each TC must be sent on both the CDMU channels at the same time because the CDMU could change during normal operation; every CDMS cycle (16 seconds) HASI could receive only 1 TC; furthermore each telecommand must be sent three times in order to have a high level of confidence that the TC is received .
After the TC is correctly received a TC echo packet, which contains all the packet data bytes as they are received, is sent to the probe.
Then the TC content is verified and if meaningful it is executed. When the TC is not in the list of those allowed for HASI (as specified in the Command Header) the TC is discarded.

TABLE 2. Nominal Mission Timeline

DDBL or ALTITUDE	***EVENT NAME***	***HASI EVENT DESCRIPTION***
17:46	Thasi	HASI power-ON **START UP** mode start
18:06		**TITAN DESCENT** mode start **ENTRY** state
21:30	TaccSample	ACC sampling start
28:00 00:00	T0 ---------	Mortar firing DDBL time reset
00:10 01:00	Tdata Td1	TEM sampling start Low pressure measurement start 1st BOOM release attempt window opens **DESCENT1** state
02:20	Td2	2nd BOOM release attempt window opens
02:30	TdataH	Probe relay link is established PWA sampling start **DESCENT2** state
32:00	Tradar	PWA proximity sensor sampling start **DESCENT3** state
1:15:00	Tmid	Medium Pressure measurements starts
1:45:00	Thigh	High Pressure measurements starts
7 km	---------	PWA mode D
1km	---------	ACC TM data stops **IMPACT** state
200m	---------	PWA mode D, with relaxation probe stops
Impact detected by ACC SERVO	Timpact	ACC impact trace PWA mode G ACC TM data restart **SURFACE** state

No TC is accepted in Titan mode.

When HASI receives an executable TC the CheckOut mode is suspended and the TC EXECUTION mode is entered. The TC is executed with higher priority respect to the science acquisition loop. At the end of the TC EXECUTION mode HASI reenters in the CO mode and is ready to receive a new TC.

Uploadable Parameters

HASI SW was design in such a way that there are several parameters that can be changed and updated during the Cruise phase; this is a fundamental operational characteristic that helped the understanding of the HASI experiment during the 7 years cruise phase and that allowed experimenters to set up the best HASI SW to be executed during Titan Mission phase.
The uploadable parameters refered to both the HASI general SW or more specifically to some fundamental parameters in the Sub system SW execution (ACC, TEM and PPI).
The HASI General parameters uploadable in the Timeline were:

- **Thasi**: Time when HASI should be switched ON during Titan descent. Used to perform the Time tag
- **Tdata**: Time when HASI enters in the Descent 1^{st} state
- **Td1**: Time when HASI starts the window to perform the first attempt of Boom deployment
- **Td2**: Time when HASI starts the window to perform the second attempt of Boom deployment
- **TdataH**: Time when HASI enters in the Descent 2^{nd} state
- **Tradar**: Time when HASI enters in the Descent ^{3rd} state
- **Predicted T0**: HASI mission Time when HASI recognises the T0 transition in Back-up sub mode. It is not used in the Nominal mode
- **Tproximity**:Time when HASI enters in the Impact state

The HASI PRE parameters are the following:

- **Tmid**: HASI Mission Time when HASI changes from LOW to MEDIUM pressure Session
- **Thigh**: HASI Mission Time when HASI changes from MEDIUM to HIGH pressure Session
- **Norm SessMap**: stores the session tables in which is indicated the sequence of the PPI channels to be read by the HASI SW
- **HC SessMap**: stores the session tables in which is indicated the sequence of the PPI channels for the Health Check session to be read by the HASI SW
- **RefChannelMap**: it stores the Reference channel number

The HASI ACC parameters are:

- **TaccSample**: it is the HASI Mission Time when HASI starts to sample the ACC.
- **TabXservo**: it defines the two threshold values to select which Xservo channel has to be transmitted in the TM packets. The best channel is selected n the following way
  - case Xservo = LOW gain: if the value is lower than the threshold parameter (7% of the 10 Volt Full Scale) then select and transmit the HIGH gain channel
  - case Xservo = HIGH gain: if the value is higher than the threshold parameter (90% of the 10 Volt Full Scale) then select and transmit the LLOW gain channel
- **RangeThr**: this defines the threshold value to change the Xservo range
- **ScdsRTab**: the tables changes the Xservo production rate and consequently the HASI data rate
- **Qft**: threshold used to detect the Impact.

The TEM parameters are:

- **TemThreshold**: threshold to pass from HIGH to LOW gain and vice versa. Default value is 105K.
- **TemSequence**: sampling sequence of the four Tem sensors from the start of TEM acquisition till the end of the mission. A complete readout is composed by four sensor readings in 5 seconds.

E.Titan DESCENT Mode

In this mode HASI behaves according to the Mission Timeline reported in TABLE 2. Nominal Mission Timeline is defined when HASI is driven by the BCP pulse (every 125 ms) and by the DDBL information (time and altitude). The Backup timeline, similar to the nominal, is driven by the BCP (if present) or by the internal HASI BCP.

When HASI is in NOMINAL state the HASI mission time is incremented after every BCP reception and it is loaded with the DDBL time. Therefore the internal states change using the DDBL information (time and altitude) and the ACC SERVO data (for the impact detection). In the Backup mode no altitude reconstruction is performed but the mission time is substituted by the internal clock incremented after every BCP simulated reception (~180 ms).

The HASI ENTRY phase starts after the Start-up procedure completion, just before the entry of the Probe into Titan atmosphere and ends at Tdata, 10 seconds after activation of the descent device. HASI DPU SW shall execute the following scheme:

- start the ACC sampling after TaccSample
- routing DDBL information to PWA
- continuous acquire and buffer of time stamped ACC data
- housekeeping functions:
  - measure the DPU box internal temperature
  - health check of the DPU housekeeping voltages
  - update bits in the STATUS WORD parameter
  - health check of Subsystems
  - health check of BCP pulse rate

In the DESCENT phases, that starts after the nominal activation instant, HASI performs the following operations:

- sampling of ACC; TEM, and PPI science and HK data
- perform 1st and 2nd boom release attempts
- housekeeping functions
- routing DDBL informations to PWA
- create and enqueue time-stamped TM packets with data from the above activities
- preliminary transmission of TM packets without discarding from the queue (in Descent 1st phase)
- restart transmission of TM packets (acquired during ENTRY and DESCENT 1st phase) according to CDMS

Titan Mode evolution activities are as follow:

- From **Thasi** to **TaccSample (ENTRY STATE)**

The telemetry starts about 112 seconds after the START-UP sequence is completed. The telemetry rate is in accordance with the CDMU polling scheme. The reading of the health check and of the housekeeping parameters starts (particularly the DPU box temperature). No scientific measurements are performed.

- From **TaccSample** to **Tdata (ENTRY STATE)**

At this point HASI SW starts to sample the ACCelerometer sensors (Xservo and the X, Y, Zpiezo sensors); in the meanwhile also the ACC housekeeping data are stating to be acquired (the temperature heads of both the servo and the piezos). All the HASI health checks are performed.

In this phase no telemetry link is established with the Cassini orbiter, this forces the HASI SW to store the acquired data in the RAM for later transmission.

Data are saved both in original packet formats and in copy formats; copy telemetry packets are transmitted to the Huygens CDMS in order to satisfy the polling rate.

- From **Tdata** to **TdataH (Descent 1st STATE)**

At Tdata HASI SW starts to read the PREssure and TEMperature sensors, while the ACC are sampled with a lower rate. Until TdataH all the HASI original data remain stored in the RAM memory. Moreover the first and second BOOM release attempts are executed. The PWA continues in entry mode.

- From **TdataH** to **Tradar (Descent 2nd STATE)**

HASI starts to re-transmit the real stored data. HASI continues to acquire PREssure TEMperature and ACC measurementsPWA changes mode of operation and starts the Mutual Impedence and the Relaxation Probe experiments. At TdataH the telemetry queues become empty.

- From **Tradar** to **Last km (Descent 3rd STATE)**

HASI continues to acquire and transmit the PRE, TEM, PWA and ACC sensor data and the housekeeping data. PWA changes into mode C and at 7km altitude switches to mode D.

- From **Last km** to **Probe Impact detection (IMPACT STATE)**

HASI recognizes the Last Km reading in the DDBL content and records the event in the EVENT LOG. HASI SW acquires and transmits PRE, TEM and PWA data.. The ACC sensors data are sampled to trigger the Probe Impact event, but data are not telemetered. The TEM changes polling rate also (only the Fine sensors are sampled). At 200m from ground the PWA stops the relaxation probe experiment

- From **Probe Impact detection** to **Tloss (SURFACE STATE)**

When HASI recognizes the Probe Impact using the Xservo data the Impact time is recorded in the EVENT LOG message and immediately transmitted. Afterwards the ACC traces (Xpiezo, Ypiezo, Zpiezo) is transmitted and then the HASI SW restarts to acquire and transmit the PWA, PRE, TEM and ACC sensors as in DESCENT3rd STATE.

F.Preheating scenario

The link problem between Huygens and Cassini Spacecraft, which was found during EM test campaign, has outlined the necessity to change the mission scenario of the Probe approaching Titan and a new mission profile of the Probe itself. In particular, to make more stable the On-board Probe clock an early wake-up of Probe has been considered leaving the Experiment switch-on timeline equal to the original. For HASI, which was switched-on about 17 minutes after Probe turn-on, it means it will be switched-on 4 hours earlier than the nominal switch-on time.

The early wake-up of the Probe will be achieved by software patches of the Probe System onboard software (POS-SW), which are under responsibility of ALCATEL Space (ex Aerospatial – Prime Contractor of Huygens). In the nominal case, the two CDMU units would work in parallel.

In failure case, a new failure case was foreseen: the EEPROM loading fails for one of the two CDMU. In this case, even if the Probe (thus the two CDMU) was switched-on 4 hours before, the failure chain would run the original mission Timeline, and the T0 transition would happen by Timeout mechanism (28 min pre T0).

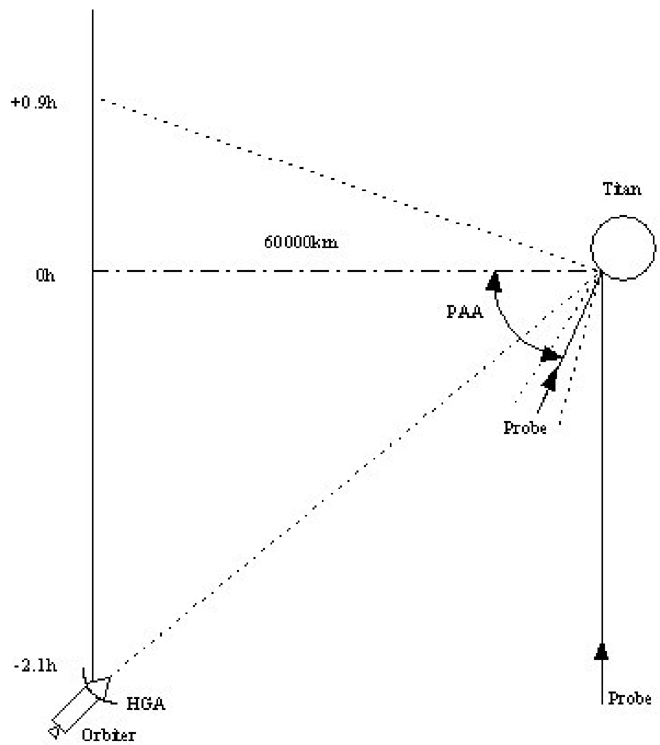

Figure 4. The new Preheating scenario

1. Implications for Huygens and HASI

In the above context, an analysis has been conduced to study the behaviour of HASI experiment and the relevant (needed) software modifications.

If HASI is listening to the VALID CDMU and running the nominal Timeline, HASI is in Entry state until **Tdata** (10s Post T0) leading ENTRY state to a nominal length of 4h 12 min; moreover, being **TaccSample** =00:21:30 in Pre T0, the ACC sampling would start much earlier than the real Titan Entry. From T0 transition, HASI follows its Timeline that is the same for nominal and preheating scenario.
Up to PostT0+2.5min (TdataH), independently from the CDMU polling rate (nominal is 14 packets for CDMU cycle = 16 sec) the acquired data shall be stored in RAM for later transmission to CDMU, when the Probe relay link to Cassini Orbiter is 'sure' (i.e. After PostT0+2.5min).
Once filled the telemetry queue (with a size for about 130 packets), HASI discards the packets after the acquisition. The TM queues are filled after about 34 minutes from the Probe power-ON. So all the packet from that instant to PostT0+2.5 min are lost; and this means all the relevant data for the entry phase.
In case HASI swaps (for DDBL or BCP error) to the CDMU whose patch has failed (i.e. NOT_VALID CDMU), which follows the original Timeline, the behavior of the system depends from the instant of swapping.
Anomalous behaviors that can be possible are:

- HASI can believe to be in a wrong state, in particular to be in IMPACT/SURFACE state @ nominal switch on.
- HASI can transmit data without recording them in nominal mission phases (the transmission mode, either direct or with packet storage, depend on HASI state).
- HASI can attempt to perform the boom release at improper instants, even if this is not a real problem being the power line protected and not enabled by CDMU when HASI try to perform this function.
- Science could be acquired in non-nominal manner since acquisition policies depends on the HASI state.

Moreover even if HASI is listening to the VALID CDMU, the failed CDMU polls its related TM queue with a wrong polling rate (it believes to be at the end of the Nominal mission when the VALID is close to the Titan Entry, so it executes related polling table at 9 Packets/cycle). A different TM budget must be considered for that TM queue. The eventual data loss must be particularly considered for the PWA, because its data are not fully redundant on the two CDMU TM queues (PWA packets are send in alternation to the two CDMUs, but both data are necessary to achieve fine resolution). For TEM, PRE and ACC this problem does not exist, because data are perfectly replicated on the two queues.

2. *Software uploading*

The patches to be applied are designed with a high level of redundancy.
The same patching information is installed three times, in three different areas of EEPROM, from which it will be later downloaded into the designated RAM areas when HASI is later reset or powered-on.

Ptch type and copy n°	***Parameter #***
Autoreset patch (1st copy)	32
Autoreset patch (2nd copy)	33
Autoreset patch (3rd copy)	34
MCA initialisation patch (1st copy)	250
MCA initialisation patch (2nd copy)	251
MCA initialisation patch (3rd copy)	255
Timeline initialisation patch (1st copy)	80
Timeline initialisation patch (2nd copy)	81
Timeline initialisation patch (3rd copy)	82
EEPROM END patch (1st copy)	2
EEPROM END patch (2nd copy)	2
EEPROM END patch (3rd copy)	3

Figure 5 . HASI Preheating patches scheme

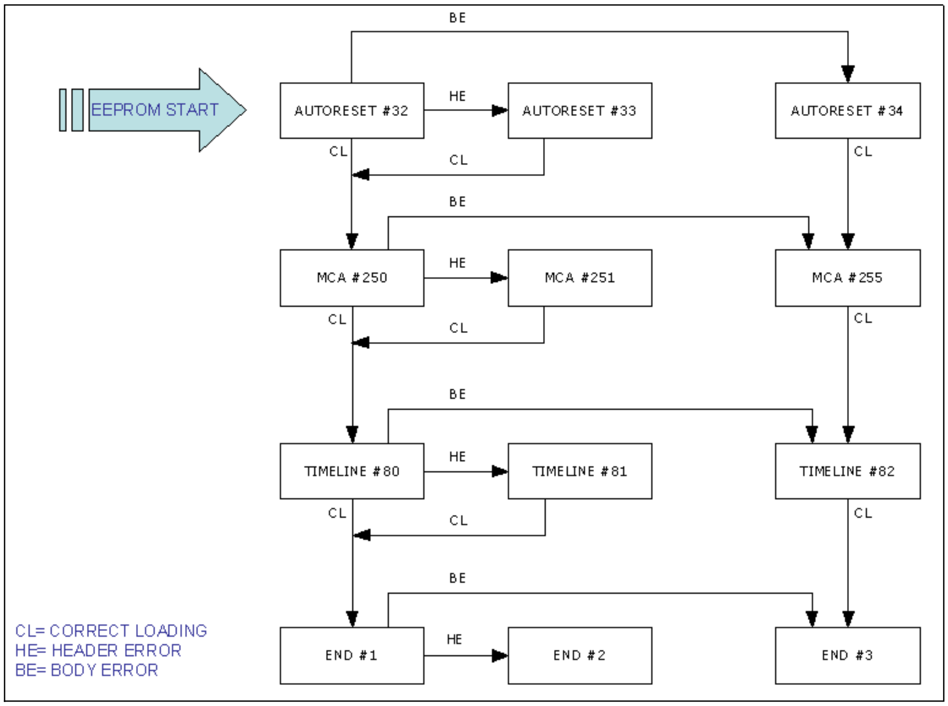

Figure6. HASI Preheating patch – SEU tolerance

The uploaded Patch

HASI has been forced to perform a reset at a precise window (4:16:00<DDB<4:19:30) time because of the ***AUTO RESET Patch*** (in Pre-T0) and the Entry data was correctly received.
Moreover in Post-T0 (in order to answer correctly to an unlikely CDMU swapping, i.e return to the valid chain) @ DDB time greater than 3:00:00 HASI would restart continuously with CDMU-A after 2nd reset window.
The ***MCA register*** initialization was originally developed before the delivery of the HASI FM model to ESA in 1996. It solved a software bug. It initialised (to 0) two consecutive words in RAM. The second word is related to the name of the first TEM sensor, which will be acquired after Tdata. The first word is the software variable, which contains the copy of the HW register that enables the MCA command.
Thasi: is the DDB Time when HASI should be switched-ON during Titan Descent (04:17:00 in PreT0). It is used in the HASI-S/W to perform the Time tag of the DPU START-UP packets and for all the data and events acquired during START-UP mode. Changed to T0+04:17:00.
Predicted T0: is the HASI Mission Time (HMT) when the HASI recognises the T0 transition in Back-up sub-mode. It is not used in Nominal mode. The back-up mode means that HASI is working by internal reconstructed DDB Time and both lines (CDMU-A and CDMU-B) are not working. Changed to T0+04:28:00.
Tdata is the HASI Mission Time (HMT) when the HASI enters in Descent 1st state and starts to sample TEM and PRE sensors. Changed to T0+00:00:10.
The ***EEPROM end*** patch closes the EEPROM. It is loaded to avoid further scanning in the EEPROM memory, so to save time in the START-UP activity of HASI.

In order to validate the software patch both at subsystm level and at system level an extensive test campaign in 2003 summer has been conducted of the FS model of HASI and on the EM model of Huygens.
The performed tests can be hereafter summarised:

- CO type; nominal Check Out during cruise phase
- Nominal mission; nominal Titan mission phase
- Failure cases (SEU and uploading Failure); possible failures due to unexpected reason
- Preheating late abort case; decision to not perform the Pre-heating mission case just before the Cassini-Huygens separation on the 25th of December 2004.

On board loading and testing on the Flight Model (FM) of HASI onboard the Huygens probe was performed in

December 2003. Only two test cases were conducted on the FM, since no decision on what type of mission Huygens would follow: the CheckOut without the Preheating and the CheckOut with the Preheating case. Both the two tests worked perfectly and the Instrument performed as expected.

G.The real mission

The telemetry link was established at T0+45 seconds allowing the HASI queues not to fill up.
Unfortunately only one of the receivers (channel B) was phase-locked and functioned properly. Channel A had an anomaly that was later identified as being due to the unfortunate omission of the telecommand to apply power to the ultra-stable oscillator driving the channel A receiver.
The actual duration of the descent following the T0 event was 2 h 27 min 50 s. During the first part of the descent, the probe followed the nominal time-based sequence with the instrument operations defined by commands in the on-board mission timeline.

TABLE 3. Output of the On board Event packet

Time respect T0	Event
-00:17:46.000	EEPROM switched ON
-00:17:46.000	EEPROM switched OFF
-00:17:46.000	EEP ROM latch-up
-04:26:13.000	ACC range coarse
-04:28:47.875	T0
03:00:02.000	AUTORESET

The Boom deployment was performed during the first allowed window attempt and occurred nominally as expected.
None of the HASI data recorded during Entry was lost and all the scientific informations where received on ground.
Unfortunately the PWA subsystem wasn't completely redundant on the two chains so the most sensible channel was lost.
All the patches uploaded on the FM worked as planned and the parameters uploaded on the RAM where the first one saved on the EEPROM showing that no problem was encountered during memory load (see TABLE 4)
The reset window starting at -04:16:00.000 was performed and evidence was found in the start up packet; below the information inside the packet:

TABLE 4. Output of the loading of the Preheating patches into the RAM

reset flag: AUTORESET		
status	**Parameter #**	**address**
OK	32	0x0040 0x000c
OK	250	0x0040 0x001e
OK	80	0x0040 0x04f6
OK	50	0x0040 0x0a60
OK	1	0x0040 0x000c

All HASI subsystems performed as expected; internal housekeeping temperatures were perfectly in the operative range of all the electronic components (see Fig. 7)

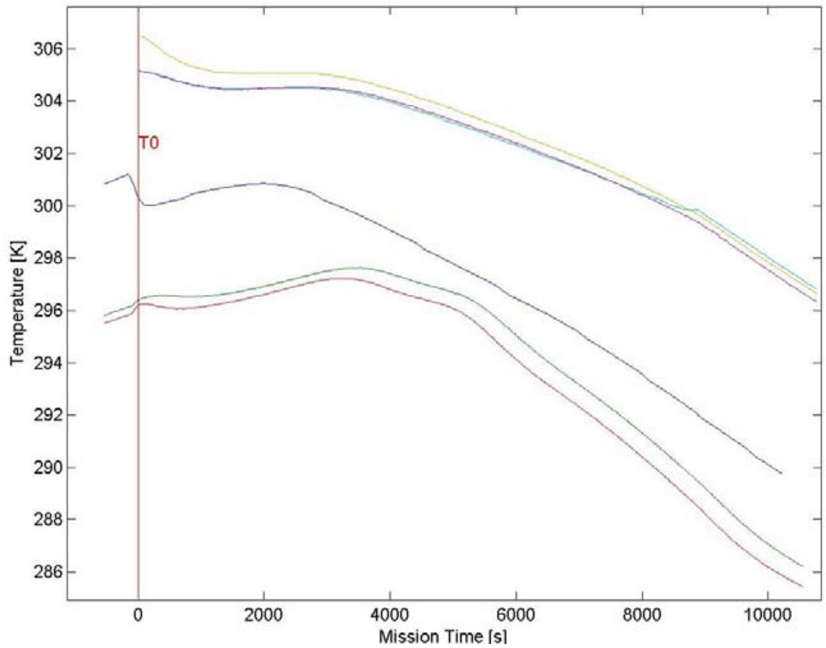

Figure 7. HASI housekeeping temperatures (1: DPU temperature; 2-3: ACC temperature;4-6: PPI temperatures)

Ⅲ.Conclusion

Huygens mission is a great success from HASI point of view. All the Housekeeping subsystems performed as expected and all the instruments worked during all the mission phases as planned.

Accelerometer servo sensor perfectly performed during entry (with the switch of gain and range performed as foreseen in the internal software sequence), descent and surface phases. ACC Piezo sensors did not perform as expected during descent phase (they where carried on the Huygens probe mainly for the impact detection and were not calibrated for the low acceleration exerted during the entry phase or the descent phase) but detected perfectly the impact on ground. TEMperature sensors correctly performed during descent and surface phases; max difference between the sensors is less than 1K. Pressure sensors correctly performed during all descent and surface phases. The PWA package sensors performed well but due to no redundancy on both CDMUs chains the higher sensitivity data where lost.

All the engineering operations that were planned before launch and updated during the cruise phase occurred as expected (i.e. Boom opening, range changes, internal mode changes, etc.)

The preheating patch, absolutely necessary for the integrity of the Instrument performance during the entry and descent Titan mission phases, was correctly uploaded and executed and all the data were correctly received.

Several lessons have been learned during the Huygens mission. Firstly that a flexible software is essential for long duration missions; the capability of having uploadable and changeable parameters inside HASI software allowed the team to have the maximum scientific return possible. Secondly that the Flight Spare and the EM models of the instruments and of the probe can have a very useful role for testing not only in prelaunch phase but also for testing and for understanding of the behavior of the instrument after launch.

Finally that on ground tests using balloon can really give the team a real data set on which understand the behavior of the instrument.

Acknowledgments

The authors thank the following people for their contributions to the realization of the HASI experiment: A. Buccheri, R. DeVidi, and M. Cosi of Galileo Avionica, A. Aboudan, S. Bastianello and M. Fabbris of CISAS, M. Chabassière of LPCE, V. Brown, J.M. Jeronimo and L.M. Lara of IAA, R. Hofe of IWF, A. Smit, L. Smit and J. Van der Hooke from RSSD-ESTEC, H. Jolly from the UK, R. Pellinen, G. Leppelmeier, T. Siili, P. Salminen from FMI, and at the Aerodynamics Laboratory of Helsinki University of Technology T. Siikonen and B. Fagerström. HASI has been realised and operated by CISAS under a contract with the Italian Space Agency (ASI), with the participation of RSSD, FMI, IAA, IWF, LPCE and PSSRI sponsored by the respective agencies: ESA, TEKES, CSIC, BM:BWK, CNES and PPARC.

We also acknowledge the long years of work by some hundreds of people in the development and design of the Huygens probe. The Huygens probe is part of the Cassini-Huygens mission, a joint endeavor of the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA) and the Italian Space Agency (ASI).

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