

THE HUYGENS ATMOSPHERIC STRUCTURE INSTRUMENT (HASI): EXPECTED RESULTS AT TITAN AND PERFORMANCE VERIFICATION IN TERRESTRIAL ATMOSPHERE

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ABSTRACT

The Huygens ASI is a multi-sensor package resulting from an international cooperation, it has been designed to measure the physical quantities characterizing Titan's atmosphere during the Huygens probe mission.

On 14th January, 2005, HASI will measure acceleration, pressure, temperature and electrical properties all along the Huygens probe descent on Titan in order to study Titan's atmospheric structure, dynamics and electric properties. Monitoring axial and normal accelerations and providing direct pressure and temperature measurements during the descent, HASI will mainly contribute to the Huygens probe entry and trajectory reconstruction.

In order to simulate the Huygens probe descent and verify HASI sensors performance in terrestrial environment, stratospheric balloon flight experiment campaigns have been performed, in collaboration with the Italian Space Agency (ASI). The results of flight experiments have allowed to determine the atmospheric vertical profiles and to obtain a set of data for the analysis of probe trajectory and attitude reconstruction

1. INTRODUCTION

The Cassini/Huygens mission, currently touring the Saturnian system, will devote particular attention to Titan, Saturn's largest moon. On the 14th January 2005 the Huygens probe [1] will descend through the thick atmosphere of this satellite down to its surface. Measurements will be performed during the entry, descent and landing phases in order to characterize the atmosphere and surface of Titan. In particular, vertical profiles of atmospheric density, pressure and

temperature will be derived using accelerometric and direct pressure and temperature measurements.

The Huygens Atmospheric Structure Instrument (HASI) [2] is one of the six instruments on board the Huygens probe that actually will provide these key measurements to investigate Titan's environment.

The HASI sensors are devoted to study Titan's atmospheric structure and dynamics measuring of acceleration, pressure and temperature and electrical properties [3].

An outline description of the HASI instrument, its subsystems and sensors, operations and expected results at Titan are reported. The actual performance of HASI is discussed especially on the basis of the results of stratospheric balloon flight experiments.

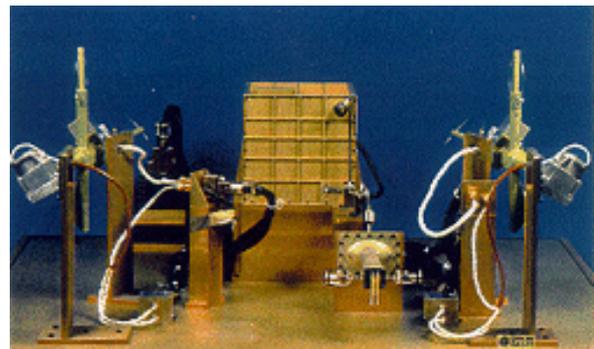


Fig.1 HASI experiment

2. HASI OVERVIEW

HASI is a multitask experiment package that has been designed to measure physical quantities characterizing Titan's atmosphere, specifically to determine the density, temperature and pressure profiles, and to study winds, turbulence and electric properties. HASI data will contribute also to the

analysis of atmospheric composition and to provide information on surface, whatever its phase: liquid or solid.

The main scientific objectives are to:

- Determine the atmospheric density, pressure and temperature profiles.
- Determine the atmospheric electric conductivity and charge carrier profiles.
- Investigate ionization processes.
- Survey wave electric fields and atmospheric lightning; analyse quasi-static electric fields leading to storm formation.
- Detect acoustic noise due to turbulence or storm.
- Characterize the roughness, mechanical and electric properties of the surface material whatever its phase, solid or liquid.

HASI will monitor the acceleration experienced by the Huygens probe during the whole descent phase and will provide the only direct measurements of pressure and temperature through sensors having access to the atmospheric flow. HASI accelerometers are the only sensors operating during the entry phase, they will allow to determine the main physical properties of the upper atmosphere of Titan. Thus HASI data will also represent the unique contribution to the Huygens probe entry trajectory reconstruction.

Electrical measurements will be performed in order to characterise the electric environment on Titan and to detect effects connected to electrical processes, such as lightning and thunders.

In situ measurements are essential for the investigation of the atmospheric structure and dynamics. The estimation of the temperature lapse rate can be used to identify the presence of condensation and eventually clouds, to distinguish between saturated and unsaturated, stable and conditionally stable regions.

The variations in the density, pressure and temperature profiles provide information on the atmospheric stability and stratification, on the presence of winds, thermal tides, waves and turbulence in the atmosphere. Moreover, the descent profile can be derived from temperature and pressure data as a function of pressure and altitude. The return signal of the Huygens altimeter radar is processed by the HASI electronics, providing an independent estimation of altitude and spectral analysis of the signal yields information on satellite's

surface.

HASI experiment (fig.1) is divided in four subsystems: the accelerometers (ACC); the

deployable booms system (DBS); the stem (STUB) carrying the temperature sensors, a Kiel probe for pressure measurement and an acoustic sensor and the data processing unit (DPU).

The scientific measurements are performed by four sensor packages: the accelerometers (ACC), the temperature sensors (TEM), the Pressure Profile Instrument (PPI) and the Permittivity, Wave and Altimetry package (PWA). PWA perform also the spectral analysis of the return signal of the Huygens radar altimeter to derive information on altitude and surface properties.

HASI has been proposed by an international collaboration including 17 institutions from 11 countries. HASI has been funded by the Italian Space Agency (ASI) and by other European institutions who provided hardware elements. HASI subsystems and elements have been designed, developed and built in the different institutes and by Galileo Avionica (GA, Firenze, Italy), the industrial contractor, which has had the responsibility for the Assembly, Integration and Verification activities.

3. HASI-ACC: ACCELEROMETER PACKAGE

The HASI accelerometer subsystem (ACC) is a three axial accelerometer consisting of a one-axis highly sensitive accelerometer (Servo) and three piezoresistive accelerometers aligned to the principal axes of the Huygens probe. ACC is mounted as close as possible to the Huygens probe's center of mass, in order to sense acceleration along the probe's descent axis (X axis).

ACC sensors could sense a wide range of accelerations from the limiting resolution (around 0.3 mg) during the high speed entry phase to a maximum up to 20 g at landing [4]. The accuracy on the acceleration measurement is of the 1% and the resolution, for the X-servo accelerometer, is of the order of 0.3 μ g in high range and 0.3 mg in low range.

The main objective is monitoring the axial and normal accelerations experienced by the Huygens probe and thus to derive Titan's atmospheric density profile, but also record the impact signature.

Moreover being the only sensors operating during the entry phase, ACC measurements will provide the unique contribution to the Huygens probe entry trajectory reconstruction.

4. HASI TEM: TEMPERATURE SENSORS

The HASI temperature sensors (TEM) are two redundant dual element platinum resistance thermometers (TEM) mounted on the STUB in order

to be appropriately located and oriented with respect to the gas flow during the measurements.

TEM design [5] derives its heritage from the *Pioneer Venus* temperature sensors [6].

Each TEM unit has two sensing elements (Pt wire): the primary sensor (FINE) is directly exposed to the air flow, while the secondary sensor (COARSE) is designed as spare unit in case of damage of the primary sensor. Temperature measurements are performed by monitoring resistance variation of TEM sensors.

Sensors can resolve 0.02 K with an accuracy of 0.2 K at best [3].

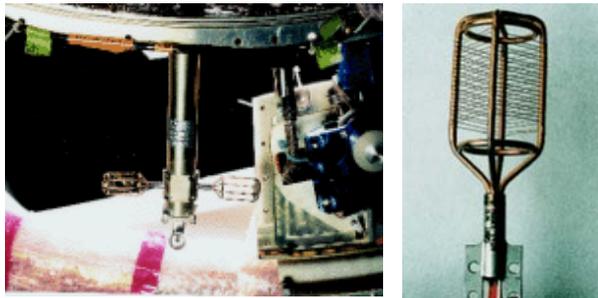


Figure 2 HASI STUB and TEM sensor

5. HASI PRESSURE PROFILE INSTRUMENT (PPI)

The Pressure Profile Instrument (PPI) includes sensors for measuring the atmospheric pressure during descent and surface phase. The atmospheric flow is conveyed through a Kiel probe, mounted on the STUB tip, inside the DPU where the transducers and related electronics are located. The PPI transducers are silicon capacitive absolute pressure sensors (Barocap) and temperature capacitive sensors (Thermocap) for thermal compensation [7]. PPI has three different pressure sensitivity ranges for low, medium, high pressure from 0 to 1600 hPa, with a resolution of 0.01 hPa.

6. HASI PERMITTIVITY, WAVE AND ALTITUDE (PWA) ANALYSER

The Permittivity, Wave and Altimeter package (PWA) [8] consists of six electrodes and an acoustic transducer.



Fig.3 PWA sensors on the Deployable Boom

The electrodes placed on the deployable booms (DBS) form a quadrupolar probe consisting of a pair of mutual impedance transmitter (TX) and receiver (RX) to measure atmospheric electric conductivity due to free electrons and detect wave emission. The two electrodes placed at the tip of the booms are relaxation probes (RP) for measuring ion electric conductivity and quasi-static electric field. The acoustic sensor (ACU) is mounted on the STUB and should detect sound waves to correlate with acoustic noise, turbulence and meteorological events.

PWA processes also the radar echo signals of the Huygens Proximity Sensor (RAU) [9] in order to derive information on surface properties and altitude.

7. HASI MISSION AT TITAN: OPERATIONS AND EXPECTED RESULTS

HASI will be the first instrument to perform measurements during Huygens entry phase in Titan's atmosphere. During the high speed entry phase, from an altitude 1300 km down to 160 km (4 min duration) acceleration data are sampled. Following the maximum acceleration near 270 km, the entry phase ends and the Probe device deployment sequence begins. In a period of three minutes pilot parachute is fired to lift off the Probe after cover and inflate the main parachute; the frontal thermal shield is released falling away. From this moment, starting from 160 km altitude, Huygens scientific instruments are exposed to Titan's atmosphere. The Probe descent continues under chute dragging. At 120 km altitude the main parachute is cut away and replaced by a smaller one. The complete descent will last 2 hours and 15 min; at least other 15 minutes are foreseen before the batteries run out and the loss of Probe relay link to Orbiter, to perform surface measurements after landing [10].

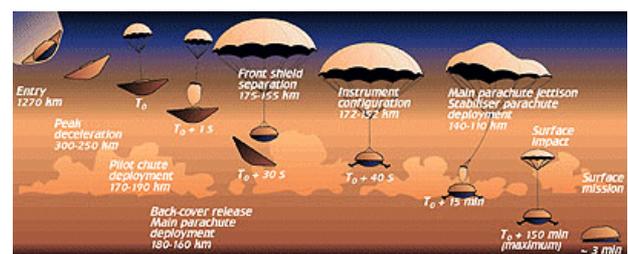


Fig. 4 Huygens mission scenario

About one minute after the frontal shield release (at about 160 km), HASI booms are deployed and direct measurements of pressure, temperature and electrical properties will be performed.

The sampling of HASI sensors is driven by timeline and triggered by environment conditions during descent. Huygens proximity sensor sampling will start from 60 km altitude level, but the Probe system will continue to use the altitude table until both the

two radars will lock (expected around 30-km level). In that part of the atmosphere PPI will switch from low to medium and then to high pressure range measurements. In the last km (HASI IMPACT state) the ACC will be triggered to impact detection, no ACC data will be transmitted until the impact. In this last part of atmosphere only TEM fine sensor will be sampled every 1.25 s to achieve a better vertical resolution; the normal sampling (4 measurements alternating fine and coarse sensors sample of TEM1 and 2 on a period of 5 s) will be selected again at surface.

8. ENTRY PHASE: THE UPPER ATMOSPHERE

HASI will be the first instrument to be operative, measuring the deceleration of the Huygens probe as function of time. ACC measurements will be used for determining the main physical properties of Titan's upper atmosphere.

Knowing the atmospheric mean molecular weight and the Probe aerodynamics, vertical profiles of density, pressure and temperature will be derived from the accelerometer data with similar techniques already used for atmospheric entry probe on Venus [11], Mars [12] and Jupiter [13]

The density profile will be derived from

$$\rho = -\frac{2ma}{C_D AV^2}, \quad (1)$$

where m and A are the mass and frontal area of the probe, a the measured deceleration, C_D the drag coefficient and V the velocity of the probe relative to the atmosphere in the direction of the descent trajectory.

Given the accelerometer sensitivity (0.3 μg in the most sensitive range) [4] and the engineering Titan's atmospheric model [14], HASI ACC should start detect the atmospheric drag at an altitude of ~1300 km (corresponding to a threshold atmospheric density of $\sim 7 \times 10^{-12} \text{ kg/m}^3$).

HASI-ACC Servo accelerometer is one of the most sensitive and stable launched to date [4], promising to deliver excellent performance during entry into Titan's atmosphere.

HASI data represent also the unique contribute to the Huygens probe trajectory reconstruction.

9. DESCENT PHASE: THE LOWER ATMOSPHERE

Starting from ~162 km direct measurements of temperature, pressure, electrical properties and acoustic recording will be performed by sensors

having access to the unperturbed field outside the probe boundary layer.

The definition of temperature and pressure profiles, also combining HASI measurements with data from other experiments, will help to define the atmospheric structure, layer by layer composition (in particular to evaluate the CH_4 mixing ratio in saturation region), the vertical concentration profile of organic and inorganic compounds, and the partial pressure of saturated gas in order to detect presence of tropospheric clouds. Quantities depending on temperature (e.g. viscosity coefficient, scale height) and the temperature lapse rate dT/dz will be derived from local temperature and pressure measurements in order to detect transition between stable and conditionally stable regions and investigate the existence and the extent of a convective zone in the lower atmosphere.

Wind gusts in the atmosphere can be observed by monitoring with the accelerometers, the period oscillations on the Probe-parachute system, and thus detecting any perturbations on these oscillations caused by wind [15]. Variations on density and pressure profile, as well as on the temperature gradient, will provide information regarding atmospheric stability, wave propagation and saturation and atmosphere layering.

The electrical properties of Titan's environment will be investigated through PWA measurements in order to study ionisation processes related to galactic cosmic radiation, Saturn magnetospheric electrons, and micrometeorites and to determine electrical charges density profiles. Electric fields and electrons and ions conductivities will be measured; acoustic noise and lightning effects connected to thunder storm, if any, will be detected.

10. LANDING AND SURFACE PHASE: THE SURFACE

HASI will contribute also to the characterization of Titan's surface partly redundant with the Huygens Surface Science Package (SSP) [16]. ACC will detect the impact and record the trace of the impact signature, yielding information on surface hardness and allowing distinguishing between liquid and solid surface. Electrical properties, pressure and temperature will be sampled as well at ground level. The spectral analysis of the Huygens radar return signals (blanking and echo signals) will allow to derive surface topography along ground track, small scale structures, dielectric properties and to contribute to discriminate between liquid and solid surface.

Moreover HASI data will be used as ground truth for calibration of remote sensing measurements (e.g. radio occultation, IR spectra).



Fig. 5 Huygens/HASI balloon experiment on the launch pad

11. HUYGENS-HASI BALLOON FLIGHT EXPERIMENTS: HASI PERFORMANCE VERIFICATION

A stratospheric balloon flight experiment campaign has been organized in collaboration with the Italian Space Agency (ASI) to verify and test HASI performance in dynamic conditions similar to the descent phase.

In order to simulate the last part Huygens probe parachuted descent on Titan and test HASI, a mock up of the Huygens probe carrying onboard HASI instrument and other instrumentation is launched with a stratospheric balloon from the ASI launch base of Trapani, Sicily. The probe is lifted up high altitude (>30 km) by means of a stratospheric balloon (see fig. 6). Once the balloon is cut away, the probe starts to descend dragged by the parachute and spinning, till impact to the ground (fig.7). The gondola and the payload are recovered after landing and, if possible, are refurbished to be flown in the next flight experiment.



Fig. 6 The flight train: balloon, parachute, ASI telemetry gondola and Huygens mock-up with onboard HASI.

The measurements carried out during the ascending and descending phases are transmitted to ground by telemetry and recorded and stored on board.



Fig. 7 Descent under the parachute and landing

The flight experiments are aimed to a better understanding of the different HASI subsystems actual performance and in preparation of the mission data interpretation, but also to the study of the physical properties of the terrestrial atmosphere.

Several balloon flight tests with onboard some subsystems composing HASI and the reference payload have been successfully performed from the ASI launch base “Luigi Broglio” in Sicily (June 2001, May 2002 [17] and again on June 7th, 2003 [18]) and from Léon, Spain in December 1995 the COMAS SOLA experiment [19].

Together with HASI instrument, other equipment of the Huygens probe, and some sensors for Mars exploration (namely UV Beagle2/MarsExpress sensor and Mars TEM) housekeeping and add-on package have been flown providing data, in some case redundant, to improve our ability in interpreting the Huygens data that will be recorded at Titan.

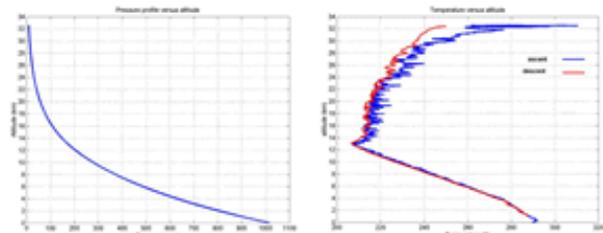


Fig. 8 Atmospheric vertical profiles as measured by HASI PPI and TEM sensors.

The results of flight experiments allow determining the atmospheric vertical profiles (fig.8) [20], to obtain a set of data for the analysis of probe trajectory [21] and attitude reconstruction [22] and to

test the algorithm developed for the Huygens trajectory reconstruction [23].

While waiting for Huygens probe arriving at Titan, we are running in parallel a balloon flight experiment from Antarctica. The scope of this experiment is to enlarge the scientific investigation and test the instrument performance in an environment more similar to that one expected at Titan. The environmental conditions in a polar region are more similar to Titan's ones, the atmosphere is drier (no of water vapour is present in Titan's atmosphere), there the thermal structure of terrestrial atmosphere is more similar to that one of Titan (temperature are lower than anywhere else on Earth), the terrestrial electromagnetic background, that could affect electrical measurements, is lower than in other more populated terrestrial zones, the fly-byed region is covered by ice/snow; the permafrost is more similar to the expected Titan's surface (e.g. for checking the radar altimeter performance).

The balloon launch is scheduled for November – December 2004 from the Italian Antarctic base of Baia Terra Nova in cooperation with ASI and the PNRA (the National Program of Researches in Antarctica).

12. CONCLUSIONS

Taking the heritage of prior atmospheric structure experiments (e.g. Pioneer Venus and Galileo ASI), HASI will provide an in-sight in Titan's atmosphere determining atmospheric profiles of density, temperature, and pressure. In addition to similar ASI experiment, HASI will measure atmospheric electrical conductivity, wave and electric fields and investigate ionisation processes. HASI data are a unique contribution to the Huygens probe entry and trajectory reconstruction. Moreover HASI will contribute also to the characterization of Titan's surface, whatever its phase, solid or liquid and to monitor the environmental conditions at ground level.

In flight data and HASI/Huygens balloon flight experiments demonstrate and assess HASI performance, promising to deliver excellent results during the descent into Titan's atmosphere.

Looking forward for the Huygens mission at Titan on 14th January 2005, we are running in parallel a new balloon experiment from Antarctica that will help for the analysis and interpretation of the data that HASI will record at Titan.

13. ACKNOWLEDGEMENTS

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