The Huygens Atmospheric Structure Instrument (HASI)

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1. Introduction

The Huygens Atmospheric Structure Instrument (HASI) is a multi-sensor package designed to measure the physical quantities characterising Titan's atmosphere. HASI's scientific objectives are:

- determine the density, pressure and temperature conditions of the atmosphere's higher regions during entry. Of particular interest is determining the physical conditions in the region where the 'detached' haze, observed by Voyager, is formed
- measure the stratospheric density, T and p profiles during the descent phase; identify the trace constituents that condense in this part of the atmosphere. Interpret any data that may suggest the existence of clouds in the upper troposphere
- measure the T and p conditions in the lower troposphere and determine the existence and the extent of a convective zone
- determine the nature of the surface
- determine atmospheric electrical conductivity and investigate ionisation processes, wave electric fields and atmospheric lightning. Detect acoustic noise due to turbulence and thunder storms. Characterise electrical properties, conductivity and permittivity of the surface material
- determine the surface's large-scale and small-scale topography and the surface's dielectric properties to distinguish remotely, in particular, between a liquid and a solid surface before impact. If liquid, information on surface winds may be obtained. All data are measured along the ground track of the descending Probe because of horizontal winds during the last 60 km of altitude.

2. HASI Management Structure and Scientific Team

The HASI experiment was proposed by an international consortium of 17 institutions from 11 countries. The industrial contractor is Officine Galileo (Firenze, Italy). The experiment's management structure of the experiment is shown in Fig. 1. The Principal Investigator (Prof. M. Fulchignoni) has full responsibility for the experiment, reporting to ESA and the Italian Space Agency (ASI). Coordination of hardware activities is managed by the Project Management Office (PMO) under the responsibility of the Project Manager (Prof. F. Angrilli) and the Instrument Manager (Prof. G. Bianchini), who report directly to the PI.

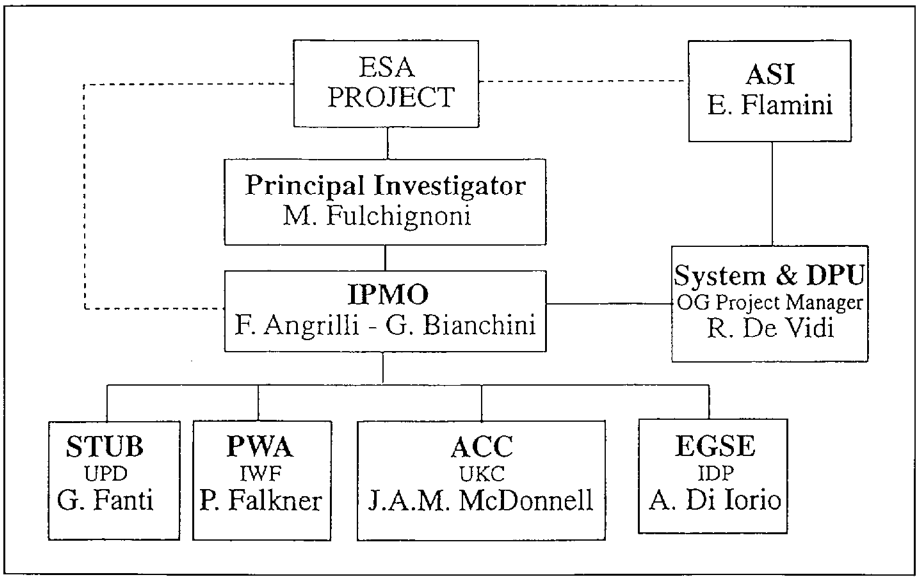


Fig. 1. HASI management structure. ASI: Italian Space Agency; IDP: Image Data Processing; OG: Officine Galileo; SSD: ESA/ESTEC Space Science Department; UKC: University of Kent at Canterbury; UPD: University of Padova.

HASI's cost is shared between ASI (70%) and the other European institutions (30%) who provide hardware elements. Officine Galileo also has responsibility for the Assembly, Integration and Verification (AIV) activities up to launch.

3. HASI Subsystem and Sensor Packages

HASI is divided into four subsystems: the accelerometers (ACC); the deployable booms system (DBS); the stem (STUB) carrying the temperature sensors, a Kiel probe for the pressure measurements and an acoustic sensor; the data processing unit (DPU). The Electric Ground Support Equipment (EGSE) completes HASI's subsystem set. HASI's subsystems, their acronyms, the institutions responsible for management (together with the providers) and the elements are summarised in Table 1.

Table 1. HASI subsystems.

Subsystem (Acronym)	*Responsible Institutions (Providers)*[1]	*Elements*
Deployable Boom System (DBS)	SSD (LPCE/SSD)	PWA[2] electrodes, Booms Magnetic Actuators, PWA pre-amplifiers (HASI-I)
Fixed stem (STUB)	UPD (UFT/FMI/IWF)	Temperature sensors, PPI[3] Kiel probe, acoustic sensor
Accelerometers (ACC)	UKC (UKC)	Three accelerometers
Data Processing Unit (DPU)	OG (FMI/IWF/IAA/OG)	Boards
Electrical Ground Support Equipment	OG (UPD/OG)	EGSE

1: refer to author affiliations for institute acronyms; 2: Permittivity, Wave and Altimetry; 3: Pressure Profile Instrument

The scientific measurements are performed by four sensor packages: the accelerometers (ACC), the Pressure Profile Instrument (PPI), the temperature sensors (TEM), and the Permittivity, Wave and Altimetry package (PWA). These packages, their acronyms, the provider institutions and the measured parameters are summarised in Table 2. TEM, PWA and PPI's Kiel probe are mounted externally and ACC is attached to Huygens' experiment platform at the Probe's centre of gravity in the entry configuration. HASI's block diagram is given in Fig. 2.

Table 2. HASI sensor packages.

Sensor package (Acronym)	*Institution*	*Measured parameters*
Accelerometers (ACC)	UKC	Atmospheric deceleration; descent monitoring; response to impact
Pressure Profile Instrument (PPI)	FMI	Atmospheric pressure profile
Temperature (TEM)	UPD	Atmospheric temperature profile
Permittivity, Wave and Altimetry (PWA)	IWF, SSD, LPCE, IAA	Atmospheric electric conductivity and DC electric field; wave electric fields and lightning; acoustic noise due to turbulences or storms; radar echoes below h=60 km

3.1 The HASI subsystems

3.1.1 The Deployable Boom System (DBS)

The DBS carries the PWA sensors outside of Huygens. The DBS subsystem is composed of two deployable booms, the PWA sensors (including wiring), two HASI-I box interfaces and two release mechanisms. The booms are stowed under Huygens'

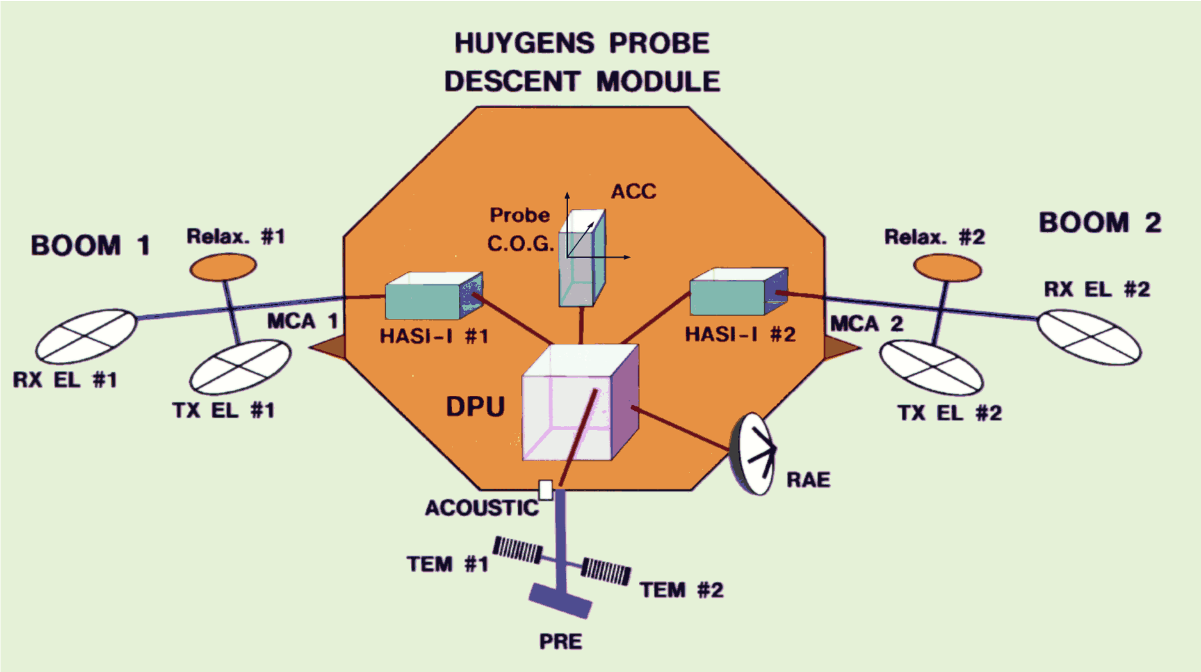


Fig. 2. HASI block diagram. The single sensors are shown as described in section 3.2.

thermal shield during cruise and released at the beginning of atmospheric entry to position the sensors for measurement. They are released from their stowed configuration (see Fig. 3) by an electromagnetic actuator (MCA) and deployed (see Fig. 4) by a coil spring.

Each boom, fixed by a hinge bracket screwed to Huygens' ring, carries three PWA sensors: mutual impedance receiver (MI RX), mutual impedance transmitter (MI TX) and a relaxation sensor. The PWA MI RX and relaxation sensor are linked to a HASI-I box via cable. The PWA TX sensor is linked to the DPU sub-assembly via two pieces of harness. They are joined through a pair of male/female connectors: the male connector is fixed on a bracket.

Each boom with sensor wiring and related HASI-I box is considered to be a single set. Each HASI-I box, containing the PWA pre-amplifiers, is linked to the DPU sub-assembly via a single connector. Each MCA is attached to the release mechanism mounted on Huygens' ring through a screwed bracket. The MCA is linked to the DPU subsystem in the same manner as the PWA TX sensor.

3.1.2 The fixed stem (STUB)

The STUB carries the TEM sensors, the Kiel probe and the PWA's ACU sensor externally (see Fig. 5). The STUB sub-assembly comprises the stem, the Kiel probe, its routing tube (divided into two sections), two pressure tube supports and two TEM sensors (including cable). The STUB is housed under Huygens' thermal shield during cruise, its flange screwed to Huygens' ring. The stem ensures that the sensors (two TEM sensors and Kiel probe) are appropriately positioned and oriented in the gas flow during measurement.

The TEM sensors' cabling passes through the stem and emerges from the flange inside Huygens. This cable is connected to the DPU box; the Kiel probe is at the stem end, held by four flange screws. Two sections of tube (the pressure tube was connected after integration in Huygens), joined by a fitting near the experiment platform inside Huygens' ring, bring the atmospheric flow to the DPU, where the transducers and the

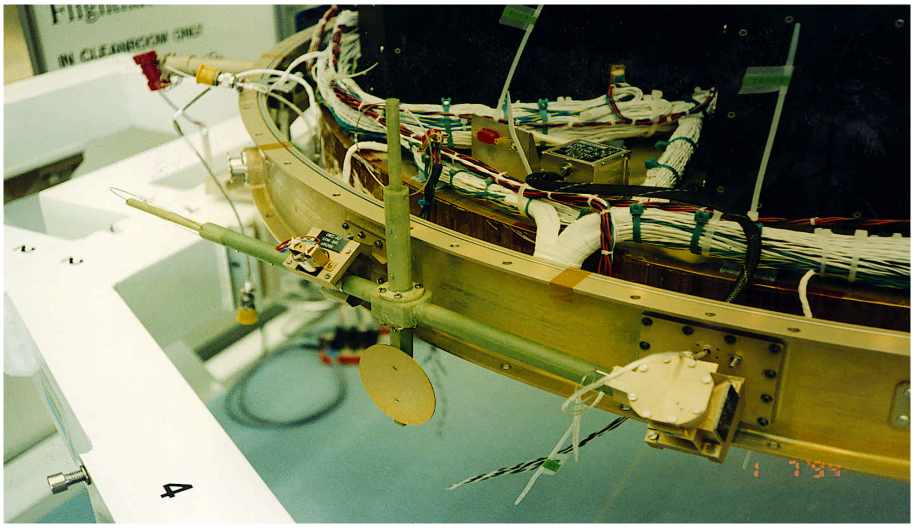


Fig. 3. The booms in stowed configuration, integrated in Huygens' Structural-Thermal-Pyro Model (STPM).

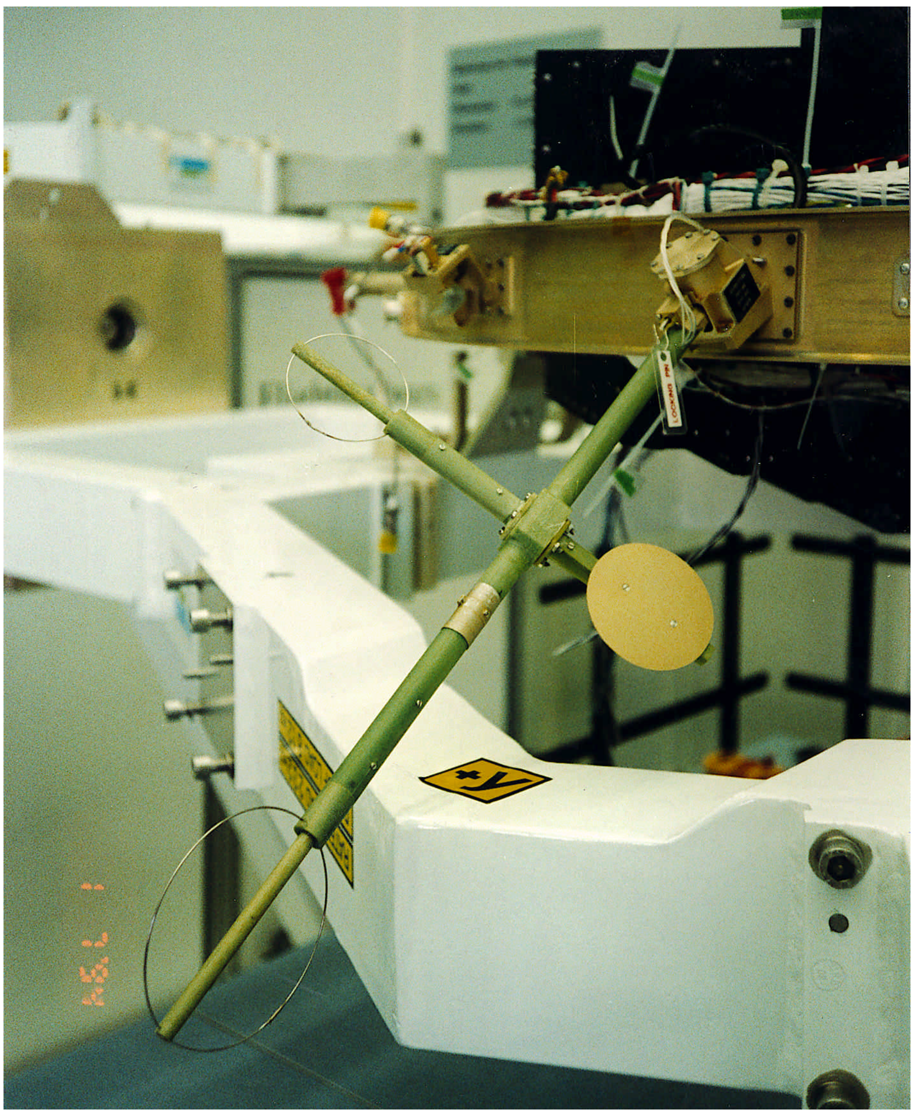


Fig. 4. The boom deployed during an STPM model test.

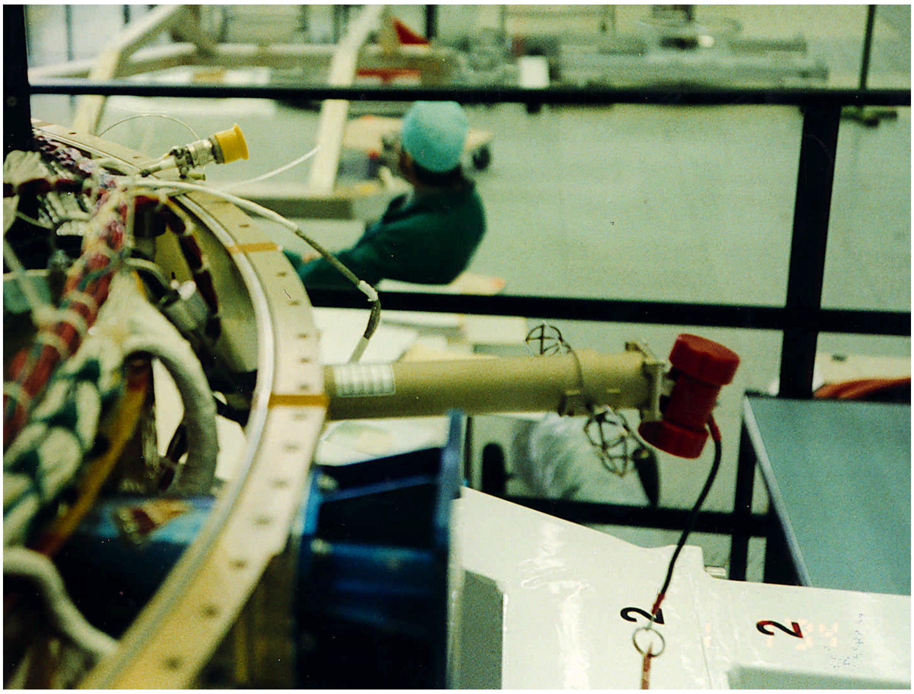


Fig. 5. The STUB with the TEM units and the PPI Kiel probe mounted on Huygens' STPM model.

electronics are located. The ACU sensor is fixed on the STUB flange and connected via a cable to the DPU box.

3.1.3 The accelerometer box (ACC)

The ACC is a small box located at Huygens' centre of gravity. The subsystem includes four accelerometers, two temperature sensors and their proximity electronics. A cable connects it to the DPU box. The ACC box is attached to Huygens' experiment platform with four cap head bolts. Its footprint, for mounting purposes, is a 60x80 mm rectangle centred on, and orthogonal, to Huygens' x-axis. The 45x45 mm area directly below the box's centre was hollowed out to allow for the heads of the sensors' mounting block bolts.

3.1.4 Data Processing Unit (DPU)

The DPU, an electronics box located on the experiment platform near the STUB, comprises four functional blocks:

- the PPI electronics board, which contains the pressure heads and electronics. A fitting on the DPU box wall connects the pressure tube from the STUB to a pressure distributor
- the Radar Altimeter Extension (RAE) board is mounted on the PPI board as a small piggyback board. It shares the backplane connector with PPI, but there are no other electrical connections between them
- the PWA block of two electronics boards handles all PWA sensors: analogue signal conditioning and data conversion; PWA data processing and data handling to the Experiment Power Data Handling (EPDH) block
- the EPDH block of four electronics boards and a motherboard provides:
  - power supplies for the DPU electronics and for the other HASI subsystems;
  - interconnection between the electronics boards;

— experiment data handling to the Command and Data Management Subsystem (CDMS);
— sensors' conditioning and data conversion from TEM and ACC sensors;
— data acquisition from the PPI and electronics blocks;
— data processing.

3.2 The HASI sensor packages

3.2.1 Accelerometers (ACC)

The Accelerometer subsystem contains one servo accelerometer with switchable range (by means of its conditioning circuitry) sensitive to acceleration in the x-axis (Huygens' spin axis) and three piezoresistive accelerometers, each sensitive to the acceleration in one of the x/y/z-axes.

The piezoresistive accelerometer (ENDEVCO 7264A-2000T) consists of a suspended silicon seismic mass supported by two strain-dependent resistances (Fig. 6). The accelerometer is incorporated in a Wheatstone bridge; a small output voltage dependent on acceleration is produced when an external voltage is applied. Temperature variations are measured by an AD 590 sensor fixed on the mounting structure.

The servo accelerometer (Sundstrand QA-2000-030) senses the displacement of a seismic mass and drives it back to a null position. The required current is a direct

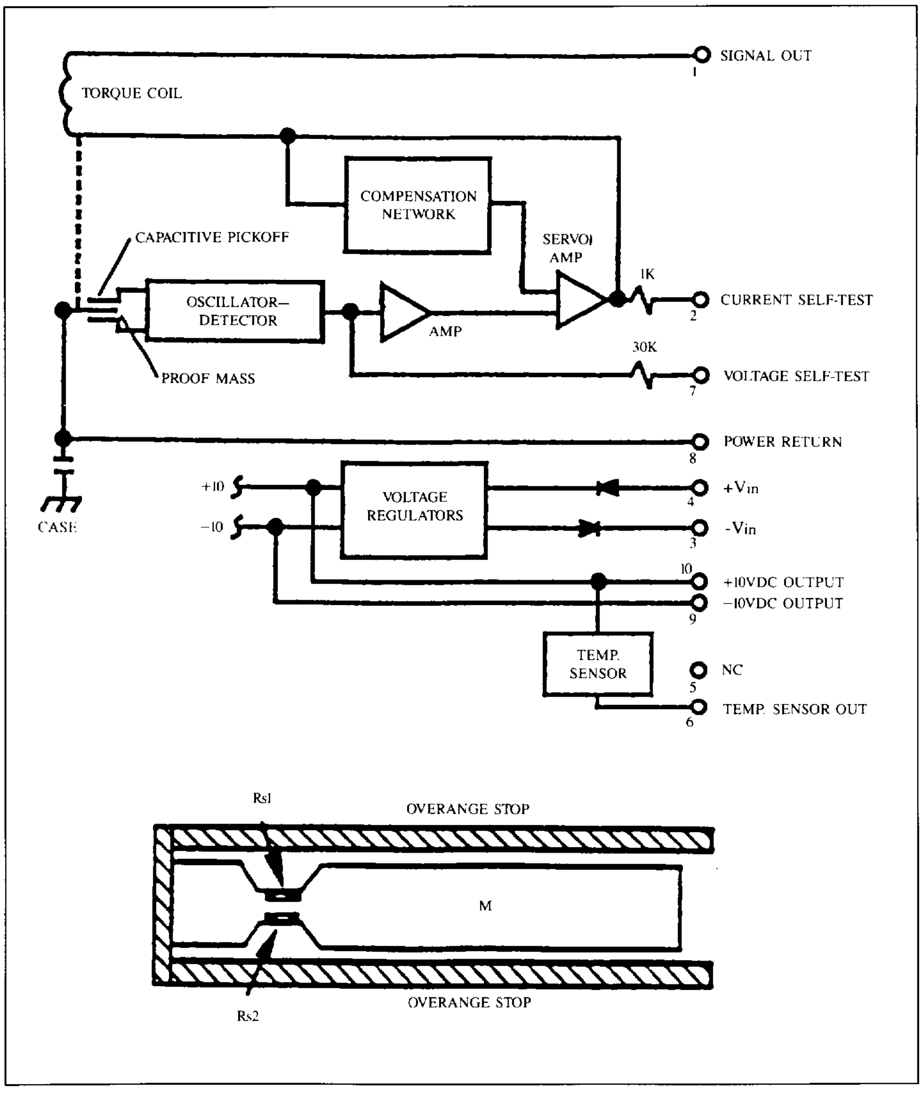


Fig. 6. Schematic of the servo (top) and piezoresistive (bottom) accelerometers.

Table 3. ACC characteristics and performances.

x-axis servo accelerometer	(along Probe path)
High resolution setting	
Range: 2-20 mg	
Resolution: 1-10 μg	
Low resolution setting	
Range: 1.85-18.5 g	
Resolution: 0.9-9 mg	
Relative accuracy: 1% of full scale	
x/y/z-axis piezoresistive accelerometers	
Range: ±20 g	
Resolution: ±50 mg	

measure of acceleration. Temperature is measured by an AD 590 sensor included in the servo package. The x-axis servo accelerometer's output is conditioned and amplified by two non-inverting amplifiers, one with a gain of 1 and the other with 10. They provide the two x-axis servo channel outputs. Besides these two channels, the servo's range is switchable between high resolution and low resolution ranges, achieved by switching the output of the servo accelerometer (a current) between two load resistors by using a single analogue switch.

The ACC characteristics and performances are summarised in Table 3.

3.2.2 Pressure Profile Instrument (PPI)

The transducer on the PPI board is a variant of the silicon capacitive absolute pressure sensor (Barocap) produced by the Vaisala Co, Helsinki, Finland, for radiosondes flown on stratospheric balloons up to 40 km (Fig. 7). The standard operating range of a sensor is 0-2 bar. The Barocap consists of a very small sensor head with associated transducer electronics. The varying ambient pressure bends a thin silicon diaphragm in the sensor head, causing changes in the head capacitance. That variation is converted into frequency in the PPI electronics. Two types of Barocap, characterised by different thicknesses of silicon diaphragm, are used. The thinner diaphragm is suitable for 10^{-3}-10^{2} mbar. The thicker diaphragm of the other Barocap completes the required range. The temperature is measured by a Thermocap sensor for compensation. The sensor heads are located inside the DPU on the PPI board. On the STUB stem there is a Kiel-type total pressure Pitot tube inlet and a sectioned tube conveys the external pressure to the sensor heads inside Huygens.

The PPI characteristics and performances are summarised in Table 4.

Table 4. PPI characteristics and performances (pressure profile with altitude).

Range:	0-2000 mbar
Resolution:	<0.04% or ±0.005 mbar
Absolute accuracy:	1%

3.2.3 Permittivity, Wave and Altimetry (PWA) sensors

The PWA analyser consists of six electrodes and an acoustic sensor. Four electrodes form, after deployment, a trapezoid in the plane containing Huygens' x-axis. The

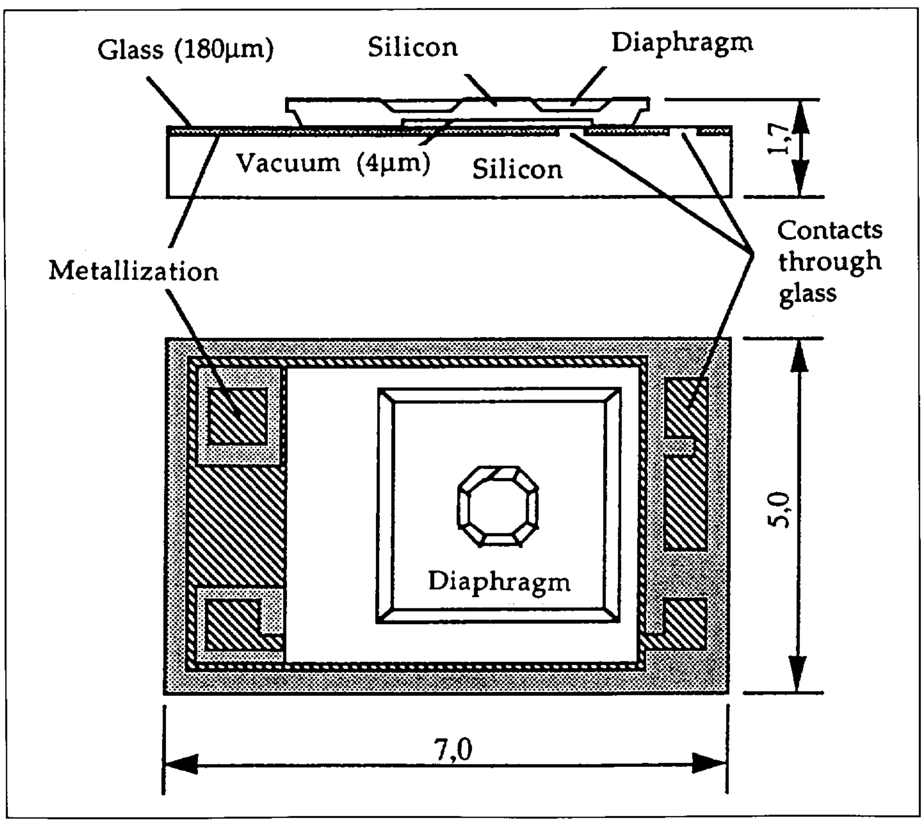


Fig. 7. Schematic of the Barocap sensing head.

trapezoid has bases of 205 cm (TX electrodes) and 166 cm (RX electrodes) and a height of about 12 cm (see Fig. 2). The two remaining electrodes (relaxation sensors) are mounted on the two booms' inner sections.

The mutual impedance is measured by applying sine wave pulses of 0.2-20 V at fixed frequencies (from 100 Hz up to 6 kHz after impact) on two TX electrodes. The modulus and phase of the impedance are computed after analysis of the RX electrodes' signal (with intelligent choice of TX driver range and RX amplifier gain). The signal received by the dipoles is sampled at a rate of 12 800 Hz; a statistical analysis and a Fast Fourier Transform can be performed every 20 ms, yielding a 50 Hz spectral resolution in a 6.4 kHz bandwidth. The receiving dipole and signal analyser will detect wave emissions in the atmosphere. It is also intended to detect quasi-static electric fields with amplitudes of up to several V/m using the two relaxation sensors.

The conductivity due to positive and possibly negative ions will be measured in parallel with the relaxation sensors. Potentials will be applied between the descent module and the sensors for 1 s every minute by closing switches; the sensors and the vehicle return independently to their equilibrium potentials when the switches open. Measuring these potentials as a function of time (64 words in 59 s) will confirm or disprove the existence of free electrons and yield the ion conductivity. The relaxation electrodes are grounded at the end of the measurement sequence.

A microphone is mounted on the STUB for detecting acoustic events.

Huygens' Radar Altimeter proximity sensor is a redundant FMCW radar with redundant channels at 15.4 GHz and 15.8 GHz, and operating in servo mode, keeping the first intermediate frequency (IF) constant at 200 kHz. This IF signal, containing information on the surface properties and descent velocity, is, in addition to being processed internally, buffered and sent to the Radar Altimeter Extension (RAE) in the HASI experiment. In the RAE, the signal is converted to a second IF at 10 kHz and filtered before it is passed on to the PWA A/D-converter and signal processor. The signal processor performs Fourier transformation, digital integration and data packetising and controls the data acquisition.

The PWA characteristics and performances are summarised in Table 5.

Table 5. PWA characteristics and performances.

AC field	
Natural wave phenomena, e.g. lightning	
Threshold:	$>2\ \mu$V/m/Hz
Dynamic range:	80 dB
Frequency range:	0-10 kHz
DC field	
Atmospheric electricity, Schumann resonances	
Threshold:	1 mV/m
Range:	1 mV/m - 30 V/m
Dynamic range:	16 bit
Mutual Impedance	
Electron conductivities, ground conductivity	
Conductivity range:	10^{-11}-10^{-7}/Ωm
Relative permittivity range:	1-100
Time resolution:	2-3 s
Relaxation probe	
Ion-electron conductivities	
Conductivity range:	10^{-15}-10^{-11}/Ωm
Accuracy time constant:	0.1 s
Time resolution:	1 min
Acoustic	
Natural acoustic phenomena, e.g. thunder, rain, hail, surface waves	
Threshold:	10 mPa
Dynamic range:	90 dB
Frequency range:	0-6 kHz
Resolution, amplitude:	3%
frequency:	50 Hz
time:	1 s
Altimetry	
Surface structure, roughness	
Maximum range:	60 km
Range resolution:	40 m @ 24 km
S_0 minimum:	-10 dB @ 60 km
S_0 accuracy:	1.5 dB

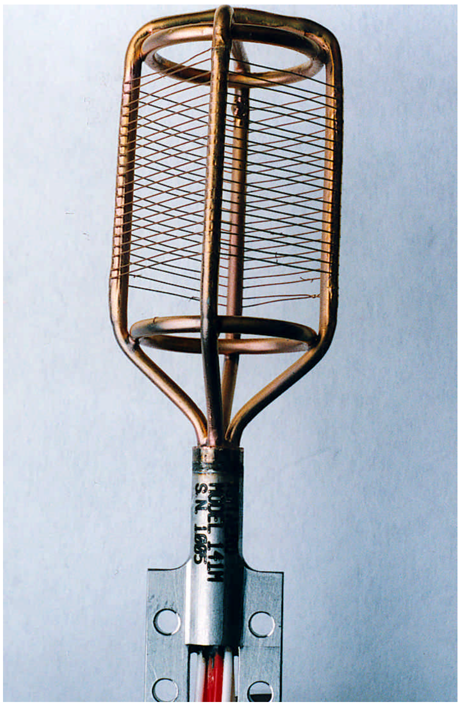
3.2.4 Temperature sensors (TEM)

A dual-element (S1+S2) platinum resistance thermometer was designed to meet the mission goals. TEM's main sensing element, designated S1, is a fine-wire platinum resistance thermometer, 0.1 mm in diameter. The temperature sensor is presented in Fig. 8. S1 is wound around a platinum (Pt) support frame ~6 cm long and ~3 cm wide, configured as a double coil of 19 turns directly exposed to the atmosphere. The wire is approximately 1.2 m long, with 16 Ω resistance at 0°C. S1 is insulated from the frame by covering the outer posts with a thin layer of a lead glass, while a second layer of the same glass holds the windings in their proper position. The S2 secondary sensing element, which will guarantee temperature measurements even if S1 is damaged, is attached to the top (windward) of the support frame (see Fig. 9). It is a 40 cm-long insulated wire platinum resistance thermometer, 0.05 mm in diameter, with a ~19 Ω resistance at 0°C. In order to include the TEM units in the global Huygens Faraday cage, the sensors are coated with 25 μm of paralyne and 0.1 μm of gold.

Huygens is provided with two TEM units mounted on the STUB. They are located outside Huygens' boundary layer, in a region where local flow velocity around Huygens is high, in order to avoid thermal contamination and promote very fast response. The TEM characteristics and performances are summarised in Table 6.

Table 6. TEM characteristics and performances (temperature profile with altitude).

Range (60-110K)	
Resolution	<0.02K
S1 absolute accuracy	<0.5K
S2 absolute accuracy	<0.8K
Range (90-330K)	
Resolution	<0.07K
S1 absolute accuracy	<2K
S2 absolute accuracy	<2K



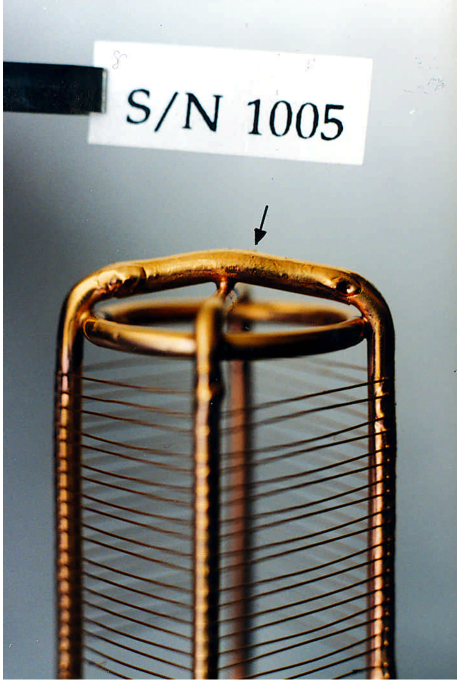


Fig. 8. The HASI temperature sensor (TEM).

Fig. 9. The S2 secondary temperature sensing element (arrowed) is attached on top of the support frame.

4. Electrical Ground Support Equipment (EGSE)

The Electrical Ground Support Equipment (EGSE) permits the control of HASI at experiment Probe system and Cassini spacecraft test levels. The EGSE is designed for checkout and verification of HASI operations during the experiment and Huygens' AIV tests.

The EGSE provides two different types of configuration and control software versions, matching the requirements and reproducing the environments of AIV test phases for both the experiment and Huygens. At experiment test level, two main SCOE computers are supplied to the EGSE: data analysis and main control equipment (Instrument Workstation, IWS: VAX station 4000) and a Stimuli Monitoring Unit (SMU: IBM 80486 PC) to control the stimuli subsystem equipment. At Huygens AIV test level, stimuli to the experiment is not supplied and the SMU is not used except on verification tests during HASI integration in Huygens. The instrument workstation controls HASI's EGSE subsystem, executes the test and checkout operations of HASI instrumentation and handles the interfaces with the EGSE subsystems. It collects and processes the scientific and housekeeping data incoming from the Probe InterFace Simulator (experiment AIV test level) or Master Test Processor (Huygens AIV test level).

5. Telemetry

Two telemetry channels carry HASI's data to Earth via the Orbiter. A double data packet is transferred to HASI-DPU every 2 s. Each double packet consists of 2x112 byte data. In total, about 10 000 data packets will be transmitted from HASI during the Probe's mission.

6. Anticipated Results

HASI's data will be analysed and inverted when Cassini's DPU transmits all the data to Earth stored during Huygens' mission in Titan's atmosphere. Interpreting these data will allow the HASI team to answer the questions concerning the physical nature of Titan's atmosphere.

6.1 Pressure, temperature and density profiles

6.1.1 Entry phase

HASI will be the only instrument operating during the entry phase. This upper part of the atmosphere (H>40 km), where the photodissociation of methane into more complex organics (C_2H_2, C_2H_4, HCN) takes place, is not well known and the energy balance of the thermosphere needs to be profoundly investigated. HASI will determine the density profile in the upper atmosphere and, ultimately, the temperature profile in this region. Of particular interest is the determination of the physical conditions in the region where the haze seen on the Voyager images is formed. The typical scale height during this phase is 40 km; Huygens' speed will reach 400 m/s at 200 km.

Information on density, pressure and temperature in Titan's atmosphere, from an altitude of about 2000 km down to about 190-170 km, during the high-speed entry phase, relies primarily on the data collected by HASI's 3-axis accelerometer; at least 3-4 measurements per scale height are needed. The atmosphere's density profile, $\rho(z)$, is proportional to the acceleration along the flight path $-a_s$, through the equation:

$$\rho(z) = -\frac{2ma_s}{C_d A V_r^2} \qquad (1)$$

The vehicle mass m, the aerodynamical drag coefficient C_d and Huygens' cross sectional area (A) are constants known from ground tests. $V_r = V_i + V_{atm}$, where V_i is the Probe's velocity in the inertial frame, V_{atm} represents the contributions of the wind and atmospheric corotation, and V_r is the vehicle velocity relative to the ambient atmosphere.

6.1.2 Descent phase

Following the maximum deceleration near 270 km, the descent phase begins in the stratosphere at 170 km altitude, where the scale height is 37 km. Full measurement (4-5 values) is required every 4 km or so (about 10 points per scale height).

HASI's precise measurements of the T-p stratospheric profile will help to define layer by layer the nature and composition of this part of the atmosphere, where the organic chemistry is most active and a number of species are formed that condense at the tropopause, in the lower part of the stratosphere.

A comparison between the thermal flux F_{IR} determined from HASI measurements, via the thermal gradient, and the absorbed solar flux obtained from the Descent Imager/Spectral Radiometer (DISR) will give the radiative balance of the atmosphere. Furthermore, by combining the HASI data (p, T, ρ) with those from the mass spectrometer (GCMS), we should be able to retrieve the atmosphere's chemical composition as a function of altitude and provide vertical concentration profiles of organic and inorganic compounds. HASI will also a key role by very accurately measuring the local temperature and pressure which are needed, with an estimate of the mixing ratios, for the identification of the condensates. Indeed, in order to determine whether the partial pressure of a compound is equal to its vapour pressure (and therefore whether it condenses at a certain level), we need to know the temperature accurately. If condensates other than methane exist (ethane or acetylene, for example, which are the most abundant molecules after methane, or water ice, which is seen in the Voyager data) the vapour pressure of these gases must be compared with their local partial pressure at 60 km for ethane and 75 km for acetylene. The aerosol collector (ACP) will sample the stratospheric particles during the descent and thus will help to identify the chemical composition of the aerosols, which include polymers formed in the upper atmosphere by photodissociation of methane, acetylene and HCN. At these altitudes, the scale height is ~20 km and velocity ~17 m/s.

The same procedure applied at the 'cold trap' level near the tropopause should contribute to the detection of methane clouds, if any. Again, HASI T-p measurements combined with data obtained from the particle and gas analysis instruments will provide information on this region. At this point, Huygens will fall at a moderate 10 m/s, which is compatible with good spatial resolution over the 16 km scale height. In order to confirm the existence and define the extent of a possible convective zone in the region just above the surface, HASI should measure as accurately as possible the T-p profile in the lowest part of the atmosphere and determine the temperature lapse rate, which should be less than the dry adiabatic rate (dT/dz = 1.4K/km) if methane condensation does occur. Voyager radio science measurements of the temperature gradient show that Titan's atmosphere is in radiative equilibrium and that, if a convective zone does exist, it should be confined to the first few kilometres above the surface.

During the parachute descent, nominally beginning at 170 km, pressure and temperature will be measured directly by pressure and temperature sensors with access to the unperturbed field outside of Huygens' boundary layer. Both the measured temperature and pressure, T_{meas} and p_{meas}, need dynamic corrections:

$$T_{corr} = T_{meas} - \frac{rV_r^2}{2c_p} \quad (2)$$

$$p_{corr} = p_{meas} - \frac{\rho V_r^2}{2} \quad (3)$$

where c_p is the specific heat constant pressure, $V_r^2/2c_p$ is the temperature increment from conversion of the kinetic energy to thermal energy in the gas flow approaching the sensor, and r is the recovery factor (related to the fraction of thermal energy actually experienced by temperature sensors in laboratory calibrations).

The pressure correction can be determined with an iterative procedure starting from the density $\rho_0(z)$ defined from uncorrected pressure $p_0 = p_{meas}$ through the mean molecular weight:

$$\mu = \frac{RT_{corr}}{\rho_0 g(z)} \frac{dp_0}{dz} \quad (4)$$

with $g(z) = g_s R_{Titan}^2 / R_{Titan+z}^2$ (g_s is the surface gravitational acceleration, z the altitude, R_{Titan} the Titan radius), and the equation of state: $\rho = \rho(\rho_0, T_{corr}, \mu)$.

From the calculated $\rho(z)$ we get a first correction p_{1corr} to p_0, with ρ replaced by ρ_0. Repeating the procedure, we reach satisfactory profiles step-by-step for ρ, μ and p.

6.2 Turbulence and gravity wave activity in Titan's atmosphere

In addition to providing exact information about the density, pressure and temperature structure of Titan, measurements of winds, waves and turbulence will be conducted by HASI. The last three are important for transport of constituents, energy and momentum.

We have estimated the minimum intensity of turbulence in Titan's atmosphere, assuming that turbulence is important only when turbulent diffusion is stronger than molecular diffusion. In order to detect the length scales associated with turbulence, HASI's accelerometers must be able to measure scales decreasing from about 50 km at an altitude of 1000 km down to 0.5 m in the troposphere. Turbulence can also be detected below 600 km altitude if it is very strong. Even if we do not detect turbulence in the lower atmosphere, we will still not able to conclude that it does not exist. Nevertheless, we will be able to observe whether conditions that lead to turbulence are present: we can estimate the atmosphere's stability from wind and temperature profiles, and we can observe waves in the wind, density and temperature. Titan's gravity and temperature structure determine the spectrum of gravity waves that are possible in this atmosphere.

6.3 Titan's atmospheric electricity, electron and ion conductivities and wave activity

The investigation of the electric properties of Titan's atmosphere and surface will be conducted principally by the PWA. The issues raised by atmospheric electricity are: production and transport mechanisms of the electrical charges; altitude profiles of charge densities (electrons, positive and negative ions), electric field and conductivities related to each particle species; existence of discharges, corona effects and lightning, conductivity of the ground. In order to answer to these questions, PWA will derive the following parameters:

- Ion conductivity: measured with the relaxation sensors. Ion conductivities are expected to be in the range 10^{-15}-$10^{-11}/\Omega m$ according to the theoretical models.
- Electron conductivity: measured by the Mutual Impedance (MI) sensors. This parameter will be measured precisely over the whole altitude range, from 170 km to 0 km and is believed to vary over 10^{-11}-$10^{-7}/\Omega m$. The electron densities can be derived from the conductivities when neutral density and temperature are known. There is also a probability that there are electronegative species, which would reduce the free electron density.
- Lightning discharges: associated electromagnetic waves can be detected by the AC field sensors.
- Static electric field: measured with the DC field sensors. The objective is to measure the altitude profiles of the atmospheric electric field. Although the conductivity of Titan's ground is unknown and might be very low, thus enabling inhomogenous charging and non-vertical electric field in the atmosphere's lower levels, most probably due to the vertical gradient conductivity, the large-scale 'fair' weather electric field will be close to vertical and, hence, the experiment will emphasise measurements of the vertical component. By measuring the voltage of these two sensors with respect to the main body, it will be possible to determine the horizontal component as well, with less precision.
- Ground conductivity: if Huygens survives impact without loss of the radio link, the PWA (and the pressure and temperature sensors) will measure the surface conditions. The PWA quadrupolar probe of the MI experiment will provide data that allow characterisation of the electric properties, conductivity and permittivity, of the surface material whatever its phase, solid or liquid, and yield information on the dynamics of the surface if it is liquid.
- Acoustic noise: the ACU sensor will detect sound waves and provide a correlation between acoustic and lightning events.
- Surface properties: large- and small-scale surface structure (roughness) and a spatially integrated value of the surface permittivity will be derived from the Radar Altimeter Extension unit data. Surface differentiation along the descent ground track will be investigated.

6.4 Lightning on Titan

Titan's lower atmosphere, where, as on Earth, there are clouds and convective motion, is probably subjected to various electrification processes that will ultimately lead to the development of significant vertical electrical fields and, hence, thunderstorm conditions. Lightning activity is of crucial importance for the formation of some atmospheric constituents such as hydrocarbons and HCN.

Detecting atmospheric electromagnetic emissions would provide evidence of lightning activity that was not observed during the Voyager flybys. However, lightning has been detected on planets such as Jupiter and Neptune, where whistlers have been found. Owing to the absence of a substantial magnetic field on Titan, wave propagation is not possible in the whistler mode. Furthermore, high density layers may prevent propagation from the lower atmosphere to space. Current models predict peak electron densities in Titan's atmosphere of up to $10^3/cm^3$ at 100 km altitude. This layer is created by galactic cosmic ray and Saturn electron precipitation. Meteoroid impact is believed to contribute to an ionosphere layer with densities of up to $10^5/cm^3$ around 500 km altitude, whereas an upper layer (1200 km) with densities of the same order is induced by solar photons.

The situation on Titan, however, is unfavourable to lightning production. The main atmospheric constituents (N_2, CH_4) have low dielectric constants and the solar input at Titan is only 1% that of Earth's.

The detection of lightning, if it does exist, will also depend on the descent's geographic location, the average discharge rate and the typical discharge energy.

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