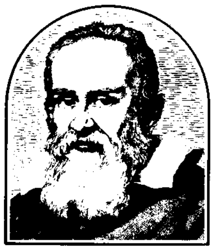
SECTION 5



THE GALILEO PROBE

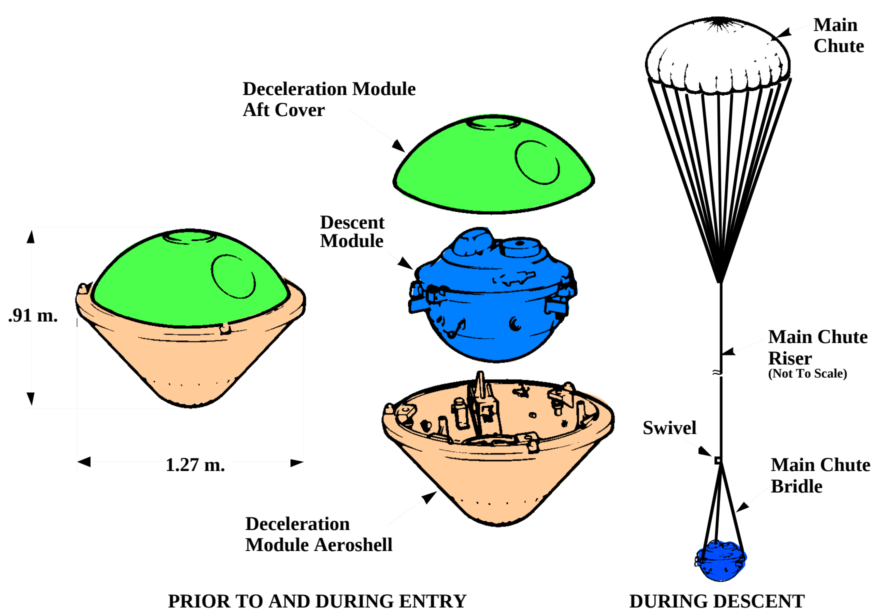
On Arrival Day, the Galileo probe achieved essentially all its mission objectives. It had been designed and built to sample and measure Jupiter's atmosphere (see Probe Science Results section). The probe, with a mass of 339 kilograms, was carried aboard the orbiter until its release in July 1995 for entry into the Jovian atmosphere on December 7, 1995. The probe carried a complement of six scientific instruments from which data were sent to the orbiter for relay to Earth.

The probe did not have an engine or thrusters so it could not change the path set for it by the orbiter. The probe was spin-stabilized, achieved by spinning the orbiter up to 10.5 rpm before release. There was no communication between orbiter and probe during the coast to Jupiter because the probe had no capability to receive radio signals. And it could only transmit after atmospheric entry.

The probe consisted of two main parts, the deceleration module and the descent module. The deceleration module was required for the transition from the vacuum and cold of interplanetary space to the intense heat and structural loads to be incurred during a hypersonic entry into a planetary atmosphere—and from a speed of tens of kilometers per second to a relatively placid descent by parachute. The descent module carried the scientific instruments and supporting engineering subsystems that collected and transmitted priceless scientific data to the orbiter flying overhead.

The probe was managed by NASA's Ames Research Center. Hughes Space and Communications Company (formerly Hughes Aircraft Company) designed and built the probe. Lockheed Martin Hypersonic Systems (formerly General Electric Re-Entry Systems Division) built the probe's heat shield.

The Galileo Probe



Deceleration Module

At entry, the probe's exterior resembled a blunt cone with a base 1.3 meters in diameter and a conical (half) angle of 45 degrees. The shape followed closely the design of the Pioneer Venus large probe.

The high-speed entry of a probe requires protection from the heat of entry. Heat shields have been used for this purpose since the early days of the space program. The materials used for the Galileo probe's two heat shields—carbon phenolic for the forebody shield and phenolic nylon for the afterbody shield—have been widely used for Earth re-entry vehicles. Temperatures of 14,000 kelvin were generated during the Galileo probe's entry into the Jovian atmosphere. For comparison, the surface temperature of the Sun is about 6000 kelvin.

The parachutes were used for two key functions, separating the deceleration and descent modules and providing an appropriate rate of descent through the atmosphere. Before deployment of the main chute, a smaller, pilot parachute was fired at 30 meters per second by a mortar to start the deployment process. The deployment occurred in less than 2 seconds, pulling away the aft cover and unfurling the main chute. The main parachute's diameter was 2.5 meters. The canopy and lines were made of Dacron and Kevlar, respectively. Once the main chute was fully deployed, the forebody shield (aeroshell) was jettisoned.

Descent Module

The Galileo descent module, carrying the six scientific instruments, was not hermetically sealed against the influx of the Jovian atmosphere (unlike those designed for Pioneer Venus). The need to save weight was a factor in this decision. However, certain equipment was hermetically sealed within housings designed to withstand pressures up to 20 bars and tested to 16 bars.

The bar is a unit of pressure approximately equal to the atmospheric pressure of the Earth at mean sea level. (The Greek word "barys" means "heavy.") One often sees terrestrial weather data expressed in millibars (1000 millibars equal 1 bar), abbreviated "mb."

Engineering Subsystems

The engineering subsystems of the probe were those systems that maintained the scientific instruments in good health; furnished their commanding, thermal, and electrical needs during descent through the atmosphere; and processed and transmitted the resultant scientific data to the orbiter. To eliminate single-point, catastrophic mission failures, the probe was designed with redundant electrical and electronic subsystems. Two simultaneous data streams flowed from the instruments to the orbiter.

Communications Subsystem	The communication subsystem provided two L-band channels. (L-band is a region of the radio spectrum that is effective for transmission through Jupiter's atmosphere.) The two channels for the probe were at 1387.0 and 1387.1 megahertz. Both channels transmitted their signals through a crossed-dipole-pair antenna. The relay radio hardware (RRH), mounted on the orbiter, provided the communications link with the probe. The RRH antenna is a 1.1-meter, steerable, parabolic dish. The RRH digital receivers tracked the highly dynamic probe signals and processed them for storage on the orbiter's tape recorder and extended computer memory.
Power Subsystem	Once free from the orbiter, the power for the probe came from chemical energy stored in three battery modules, containing lithium/sulfur dioxide ($LiSO_2$) cells. (These batteries had an energy capacity of about 700-watt hours, roughly the same as the average car battery.) Additionally, a redundant set of thermal batteries provided the high-amperage current to fire the pyrotechnic hardware required during entry deployment events. The Power Subsystem also controlled energy distribution to the engineering subsystems and scientific instruments.
Command and Data Handling Subsystem	As the name indicates, the Command and Data Handling (C&DH) Subsystem refers to the two primary information components of a space mission: commands and data. The C&DH Subsystem consisted of the data and command processor, the pyrotechnic control unit, and the acceleration switches. En route to Jupiter, it processed and interpreted commands from the orbiter during probe tests, some of which were done just prior to release. After release, the Command and Data Handling Subsystem was in charge of issuing all commands internal to the probe. However, the probe was intentionally placed in a quiescent state during its 5-month coast period. During this interval, only the coast timer circuitry and acceleration switches were powered. At the end of the coast, 6 hours before atmospheric entry, the timer wound down to zero and "woke up" the probe. During the descent through the atmosphere, a sequence of commands stored in non-volatile, read-only memory was executed. In conjunction with the design philosophy mentioned above, two electronic "strings" (or channels) were implemented in the Command and Data Handling Subsystem. Prior to entry, a self-test function was exercised. The probe's computer successfully passed this test.

The Science Instruments

The science instruments directly sampled the atmosphere and near-Jovian environment on the day of Galileo's arrival at Jupiter.

Atmospheric Structure Instrument

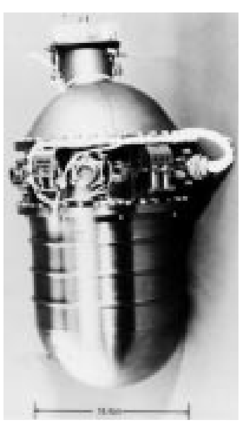
The primary purpose of the atmospheric structure instrument (ASI) was to determine how the temperature, pressure, and density of the atmosphere vary with altitude. The ASI was designed to take measurements from about 1000 kilometers above the clouds down to the end of the probe mission.

The instrument package consisted of acceleration, temperature, and pressure sensors and associated electronics. The temperature sensor had a range from 0 to 500 kelvin. (The mean temperature on Earth's surface is approximately 300 kelvin or 80 degrees Fahrenheit.) The pressure sensor was designed to cover a wide range of pressures from 0.1 to 28 bars. The pressure sensors were similar to devices used on the two Viking missions to Mars. Their reliability had been demonstrated through operation on the surface of Mars for several years.

The third type of sensor in the ASI, accelerometers, covered a wide range of measurements: from one millionth of a g to 400 g. (A "g" is the acceleration that gravity produces at the surface of the Earth and is equal to 9.8 m/s^2.) Accelerations are sensed in three dimensions so that the total acceleration of the package is known. Acceleration data yield information about the effect of atmospheric turbulence on the probe.

The experiment mass was 4.1 kilograms, and the average experiment power was 6.0 watts.

Neutral Mass Spectrometer



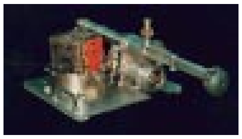
The composition of the atmosphere of Jupiter had been studied intensively with ground- and space-based observations, but many questions remained. The neutral mass spectrometer (NMS) was designed to provide a detailed analysis of the chemical composition of the atmosphere and aid in understanding the processes responsible for the complex, colorful clouds.

The Galileo probe uses a quadrupole mass spectrometer. In this device the ions are passed between four parallel rods. These rods have a combination of DC and AC voltages that allows ions of a certain mass to pass through, while rejecting the rest. During descent, the voltages are adjusted to allow different masses to pass through.

Atmospheric gases entered the mass spectrometer through two inlet ports at the apex of the probe. These ports were sealed by metal–ceramic devices and kept under a vacuum until the probe entered the atmosphere. Pyrotechnic devices then released the covers, allowing atmospheric gases to enter and be pumped to the test cells.

The instrument weighed 13.3 kilograms and consumed about 25 watts.

Nephelometer



The nephelometer (NEP) was used to investigate the structure of clouds and the characteristics of particles in the atmosphere of Jupiter. (In Greek, the word "nephele" means "cloud.") Knowledge of cloud properties allows modeling of the paths of energy balance for Jupiter.

The detailed scientific objectives of the NEP are tied to altitude, as measured by pressure, within the atmosphere. The NEP was designed to map cloud structures to a resolution of 1 kilometer from 0.1 to 10 bars. Also, the NEP measured the numbers and dimensions of particles and determined, by their shape, whether they were in the liquid or solid (ice) state.

The NEP fired a laser beam from the probe through cloud particles adjacent to the probe. A reflector on an arm extended away from the probe reflected the scattered light back into the instrument detector.

The instrument mass weighed 4.7 kilograms and operated on an average of 11 watts.

Lightning and Radio Emissions Detector/ Energetic Particles Instrument

For the lightning and radio emissions detector/energetic particles instrument (LRD/EPI) investigation, two instruments shared the electrical system that collected the LRD data—together with the scaling, data processing, and data formatting of the EPI.

The LRD searched for lightning during its descent through the atmosphere of Jupiter and also measured the radio-frequency noise spectrum of the atmosphere (the amount of radio energy as a function of frequency). In addition, the LRD made radio-frequency measurements as the probe approached Jupiter, at about 4, 3, 2, and 1 planetary radii.

The LRD hardware consisted of three basic sensors. One sensor was a radio-frequency antenna that measured in the frequency range from 10 hertz to 100 kilohertz. The lightning sensors operated in the optical range. Two sensitive photodiodes were placed behind two fisheye lenses that looked out perpendicular to the spin axis of the probe, 180 degrees apart, to give full coverage.

The EPI experiment studied the inner portion of the magnetosphere (the region within 5 radii of the planet) and the outer reaches of the Jovian atmosphere. The objects of this study were four species of particles: electrons, protons, alpha particles, and heavy ions (atomic number greater than 2). (An alpha particle is the nucleus of a helium atom, which is composed of two protons and two neutrons.)

The EPI made omnidirectional measurements of particles. Samples were taken at 5, 4, and 3 Jupiter radii, then continuously from 2 radii to entry of the atmosphere. The EPI could count up to as many as 3 million particles per second.

The EPI's silicon detectors were mounted at the end of a telescope tube. The telescope was aligned at an angle of 41 degrees to the spin axis of the probe.

The experiment mass was 2.9 kilograms, and average power was 3 watts.

Helium Abundance Detector

The atmosphere of Jupiter is composed primarily of hydrogen and helium. The helium abundance detector (HAD) had the ability to measure very accurately the abundance ratio of helium to hydrogen. The uncertainty in the ratio was expected to be 0.0015, more than 10 times smaller than the best current Voyager uncertainty.

The optical properties of a substance are a function of its composition. The HAD instrument made the measurement of the abundance ratio by determining the refractive index of the Jovian atmosphere over a range of pressures from 2.5 to 10 bars. The measurements were done using an optical interferometer.

The mass was 5 kilograms, and the instrument consumed 1 watt.

Net Flux Radiometer

Pioneer and Voyager spacecraft passing by Jupiter measured radiation leaving Jupiter's cloud tops, but we could only guess about the nature of radiation within the atmosphere. In contrast, the net flux radiometer (NFR) in the probe was designed to directly sample the local energy flows within and below the Jovian cloud layers.

As the probe descended through various atmospheric layers, observable changes in the net radiation flux were anticipated. The temperature differences that tend to arise from the radiative heating and cooling would produce buoyancy differences and, ultimately, winds. During the descent into a continuously hotter and denser atmosphere, the NFR rapidly alternated between looking upward and looking downward. Measuring the difference in radiation intensity between these two views would determine the amount and direction of the net flow of radiative energy.

Radiation from the Jovian atmosphere entered the instrument through a diamond window. The NFR had six lithium tantalate pyroelectric detectors viewing through filters extending from the visible to infrared wavelengths.

The NFR had a mass of 3.4 kilograms and used an average of 13 watts during descent.

Doppler Wind Experiment

The Doppler wind experiment (DWE) measured the winds in the atmosphere of Jupiter by using the Doppler effect. As the probe was carried by winds during the descent, the frequency of its radio signal changed, indicating the probe's velocity and providing data about the winds. Voyager data showed winds of 100 meters per second (about 200 miles per hour) at the top of the clouds. An analysis of the Doppler effect on the probe radio signal can tell us about winds deeper in the atmosphere and the source of energy that drives them. Is the source solar or does it come from heat welling up from the planet itself?

Probe Scientific Experiments

Experiment	Principal Investigator, Institution	Objectives
Atmospheric Structure	Alvin Seiff, San Jose State University Foundation	Temperature, pressure, density, molecular weight profiles
Neutral Mass Spectrometer	Hasso Niemann, NASA Goddard	Chemical composition
Helium Abundance	Ulf von Zahn, Institut für Atmospharenphysik an der Universität Rostock	Helium/hydrogen ratio
Nephelometer	Boris Ragent, San Jose State University Foundation	Clouds, solid/liquid particles
Net Flux Radiometer	Larry Sromovsky, University of Wisconsin	Thermal/solar energy profiles
Lightning and Radio Emissions/Energetic Particles	Louis Lanzerotti, Bell Laboratories, and Klaus Rinnert, Max Planck-Institut für Aeronomie	Detect lightning, measure energetic particles
	Harald Fischer, Institut für Reine und Angewandte Kernphysik, Universität Kiel	
Doppler Wind Experiment	Dave Atkinson, University of Idaho	Measure winds, learn their energy source