OUTER PLANET PROBE MISSIONS, DESIGNS AND SCIENCE

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ABSTRACT

This paper reviews the similarities and differences of atmosphere entry probe missions, designs and science appropriate to certain solar system objects. In particular, the evolution of techniques and concepts from the Pioneer Venus Multiprobe Mission to the Galileo Jupiter Probe leading to Saturn and Titan probe concepts is traced. Candidate payloads for Saturn and Titan probes are suggested such that maximum inheritances from the earlier programs may be realized. It is clear, however, that significant Supporting Research and Technology efforts are required to develop mission-peculiar technology for probe exploration of the Saturnian system.

INTRODUCTION

Outer planet atmospheric probe missions have been accorded serious study since the early 1970's. A "common" probe design for application both to Jupiter and Saturn/Uranus has been emphasized. To a great extent these studies were stimulated by the Ames Planetary Atmospheres Entry Test (PAET) mission and have benefited from the development efforts of the Pioneer Venus Multiprobe mission. (There is a certain amount of spillover from the Viking Entry Probe and Lander program, but this has been minimal due to the relatively benign Mars entry environment.)

To a lesser extent, atmospheric probes and landers on Titan have also been studied. Surface penetrators which have been studied mainly for application to Mars have also received preliminary study for Titan and the Galilean satellites. All of the contemplated missions--Pioneer Venus (PV) Multiprobe, Jupiter Orbiter Probe (JOP) (recently designated "Galileo"), Saturn Orbiter with Probes to Saturn and Titan (SOP^2)--are severely constrained, particularly with regard to probe weight (thus scientific payload weight) and cost. "Combined" missions, e.g., an all-purpose atmospheric probe-lander-penetrator concept or even a combination of two of the three alternatives, may not be realizable. This is not to say that combinations or very ambitious missions would not actually be cost-effective and it is strongly recommended that such approaches be studied seriously and the required compromises elucidated at an early stage. It is clear that even the simplest mission to Saturn/Titan severely pushes the Shuttle/IUS capabilities; therefore new propulsion systems, orbital assembly techniques, or PV type missions, i.e., separate Orbiter and Probe launches, will need to be developed to evolve a cost-effective, scientifically valuable program. In fact, Solar Electric Propulsion is currently being considered for this purpose.

The purpose of this paper is to summarize existing programs and studies as they pertain to an SOP^2 mission. The results of this Saturn Workshop, particularly the feasibility of candidate payloads, will thus have a basis in reality appropriate to NASA's current technological base and anticipated resources for exploration of the Saturnian system beyond Pioneer and Voyager.

GALILEO

The Galileo mission was approved by Congress as a FY 78 new-start in the Summer of 1977. Shortly thereafter tentative scientific payloads were announced by NASA Headquarters. (The Galileo program is managed by JPL and they are also developing the Orbiter which will carry the Probe to Jupiter. ARC is managing the Probe portion of the mission including development and integration of the Probe experiments. Only the Probe-related features are discussed in this paper.) Two competitive Probe system design studies were completed by McDonnell Douglas and Hughes Aircraft/General Electric in December 1977; an RFP for the Probe development and execution phase was issued in January 1978; hardware proposals were received in March 1978 leading to selection of the Hughes/GE team in June 1978. The Probe design, Probe experiments and Probe mission strategy are currently in a state of conceptual design. Thus, we are only able to describe a "baseline" or "strawman" picture at this point.

Probe Mission Strategy

Key elements of the Galileo Probe mission are listed in Table 1, which also contains a comparison with the PV Multiprobe program. After about 1000 days in transit (from a January 1982 launch to September 1984 arrival), the Orbiter will release the Probe some 100 days prior to encounter with Jupiter. The Probe will enter the Jovian atmosphere (the entry is defined to begin at 450 km above a pressure level of 1 bar; all altitudes below are referenced to this level) near the evening terminator with a relative velocity of 48 km/s (>100,000 mph) at a shallow relative entry angle of -9.35 at a latitude of 5.5° S (South Equatorial Zone). Inertial values are 60 km/s and -7.5° respectively. After the Probe experiences enormous aerodynamic braking forces and heating during which the heatshield will ablate about half its weight, the Probe will deploy a parachute near Mach 1 to slow the Probe rapidly. The forward and aft heatshields (i.e., deceleration module) will then be ejected exposing the descent module (currently containing six experiments: see below) to the environment. Scientific measurements will be made in the pressure range 0.1-10 bars (~50 km to -100 km) during the next 30 min. The Probe may free-fall below 10 bars continuing to make scientific measurements for another 15 minutes to about 20-30 bars (-160 km) where the Probe mission will terminate. (Termination will occur due either to thermal failure or insufficient Orbiter-to-Probe communications margins.) The main parachute size (~2 m) and its jettison time will be selected to ensure this pressure range-time goal (based on a "nominal" atmosphere defined by the Galileo Project Science Group). Certain limited experimental data will also be collected prior to entry and during entry into the sensible atmosphere above 0.1 bar. These data will be stored on the Probe to be transmitted together with the lower atmosphere data back to the overflying Orbiter (~4 R_J range) for tra nission to Earth.

Probe Design

Key elements of the Galileo Probe design are listed in Table 2, which also contains a comparison with the PV Probe's features. The Galileo Probe consists of a quasi-spherical descent module of 80-90 cm base diameter containing the scientific instruments, encased in a deceleration module consisting of a conical forward and spherical aft heatshield. The forward shield will be about 120 cm base diameter and

Table 1. Comparison of Mission Factors

	Pioneer Venus Large Probe		Pioneer Venus Small Probe	Galileo Probe
Launch Date		August 1978		January 1982
Launch Vehicle - Type		Atlas/Centaur		Shuttle/IUS
- Capability, kg		910		1500*
Trajectory Type		I		II
Transit Time, Days		125		1049*
Encounter Date		December 1978		September 1984*
Entry Speed, km/s		11.6		48.3**
Entry Angle, deg	-25 to -45		-20 to -75	-9.35
Maximum Deceleration, G_E	315		190 to 550	320
Descent Regime - bars		0.07 to 100		0.1-10 (20-30)
- K		232 to 750		110-350 (400-450)
Descent Time, min	55		57	30 (45)
Descent Velocity, m/s	55 - 10		70 - 10	400 - 50

*1800 KG, 1275 days and November 1984 for a Mars gravity-assist strategy (recently determined to be required to meet total mass constraints)

**relative to atmosphere; inertial velocity is 60 km/s

Table 2. Comparison of Probe Designs

		Pioneer Venus Large Probe	Pioneer Venus Small Probe	Galileo Probe
Mass	- Total, kg	314	90	250
	Science, kg	29.3 (34 max)	3.5 (4 max)	21 (25 max)
Science Volume, cc		31625 (40000 max)	3110	24400 (27000 max)
Science Power, W		92.8 (106 max)	9.8 (10 max)	48
Science (and s/c) Data, b/ps		256/128	64/16	150
Store, bits		3072	3072	32000
Heatshield	- Type, Fore	Carbon Phenolic	Carbon Phenolic	Carbon Phenolic
	Aft	low dens. elastomeric	low dens. elastomeric	phenolic nylon
	- Mass, kg	33	9	100
Pressurized, psia		8 - 30	4 - 30	No
Staged		Yes	No	Yes
Base Dia, cm		142	76	120
Half-Cone Angle, deg		45	45	45
Radiation Protection Requirements		No	No	Yes
Communications Link		Direct	Direct	Relay thru Orbiter

will be a spherically tipped cone some 45° half-angle. The height of the Probe is about 90 cm. The total Probe weight is 250 kg (maximum) accommodating some 21 kg (25 kg max) of scientific instruments. The heatshield itself weighs about 100 kg (total) and is ablated significantly by the severe heating peculiar to Jupiter entry. The descent module is vented in a controlled fashion to the ambient environment.

Scientific Instruments and Objectives

There are six experiments selected tentatively for the Galileo Probe. These are listed in Table 3 and compared with those being flown on PV. Key instrument

Table 3. Probe Experiments

	Pioneer Venus Large Probe	Pioneer Venus Small Probe	Galileo Probe
Temperature, Pressure, Acceleration (Single Experiment)	X	X	X
Neutral Mass Spectrometer	X		X
Gas Chromatograph	X		
Helium Abundance Detector			X
Solar Flux Radiometer	X		
Infrared Radiometer	X		X
Net Flux Radiometer		X	
Nephelometer	X	X	X
Cloud Particle Size Spectrometer	X		
Lightning Detector			X
	7	3	6

characteristics are listed in Table 4. The major features and scientific objectives are discussed below. Final confirmation of the experiments is expected in October 1978.

Temperature, Pressure, Acceleration (PI: Alvin Seiff/Ames Research Center) - Together these measurements comprise the Atmospheric Structure Experiment. The experiment consists of a temperature sensor and pressure transducers exposed to the ambient flow during the descent regime (below 0.1 bars), a 3-axis accelerometer located at the descent module center-of-gravity operating during both entry and descent, and associated electronics. The primary objective is to reconstruct atmospheric state profiles (pressure, temperature, density) from the point where the sensible atmosphere is detectable ($\sim 10^{-6}\ g_E$) to end of mission. Secondary objectives include determination of atmospheric mean molecular weight, horizontal wind velocity and wind shear (requires Doppler tracking), neutral flow velocity and turbulence intensity and scale.

Neutral Mass Spectrometer (PI: Hasso Niemann/Goddard Space Flight Center) - The instrument consists of a quadrupole mass spectrometer operating over the mass range 1-52 AMU plus two higher mass numbers (probably 84 and 131 AMU (Kr and Xe)). The primary objectives are to determine vertical variations of the

Table 4. Key Galileo Probe Science Instrument Characteristics

Instrument	Mass KG	VOL cm^3	Avg Pwr w	Descent Data Rate BPS
Atmosphere Structure (T, p, g)	3.0	3600	6	20.5*
Neutral Mass Spectrometer	9.5	9400	18	28
Helium Abundance Detector	1.2	2400	1	2
Net Flux Radiometer	3.0	3500	6	16
Nephelometer	2.5	3000	5	8
Lightning, Radio Emissions	1.8	2000	2	5*

*Does not include pre-entry/entry requirements.

chemical composition of the Jovian atmosphere within the above mass range with a threshold of about 10^{-8} or 10 ppb mixing ratio. An enrichment cell system is used to increase the ratio of minor to major constituents for analysis of trace constituents and the determination of some isotope ratios in a few samples. Noble gas concentration and isotope ratios are also to be obtained through the use of scrubbers. Samples are ingested into the system through direct glass-capillary pressure-reducing leaks connected to an inlet system located near the Probe stagnation point.

Helium Abundance Detector (PI: Ulf von Zahn/Univ. of Bonn) - This is another composition device dedicated to precise (0.1%) determination of the He/H_2 ratio in the Jovian atmosphere. A Jupiter atmosphere sample is ingested into a cell contained within the Probe. A miniature optical interferometer is used to compare the refractive index of this sample to that of a reference gas mixture contained within the Probe. Measurements are made in the range 3-8 bars only.

Net Flux Radiometer (PI: Robert Boese/Ames Research Center) - This experiment consists of a multichannel radiometer (0.3-30, 0.3-2000, 20-30, 30-40, 40-60 micrometers plus possibly two other channels) measuring ambient radiation in 50° cones alternately centered ±50° from the Probe horizontal. The primary objectives are to measure the net flux of solar energy (assuming a dayside entry) and planetary emission, determine location of cloud layers, measure mixing ratios of selected constituents and to study the opacity of clouds and aerosols.

Nephelometer (PI: Boris Ragent/Ames Research Center) - This experiment consists of a single-wavelength, multiple-angle (5) scattering nephelometer. The primary objectives are to determine the vertical extent, structure and microphysical characteristics (particle size distribution, number density, physical structure) of the Jovian clouds.

Lightning and Radio Emission Detector (PI: Louis Lanzerotti/Bell Labs) - This experiment consists of both electromagnetic and optical sensors. The former operate in the frequency domain (3, 15, 100 kHz narrow band) and the time domain (1 Hz-100 kHz; 16 s resolution). A ferrite core coil is used as an antenna. The optical sensor is a photodiode connected to a lead-glass fisheye lens. The primary objectives are to determine if lightning exists on Jupiter and measure basic physical characteristics; determine scale size of cloud turbulence; study electrification; look for evidence of precipitation, sources of heat and acoustic shock waves; measure RF noise levels. As a secondary objective, the electromagnetic sensor will be operated pre-entry, below 3 R_J altitude, to measure the component of Jupiter's magnetic field perpendicular to the Probe spin axis.

This brief summary of experiments on the Galileo Probe is provided as background to aid in selection of candidate payloads for Saturn and Titan atmospheric Probes. There are other potential experiments of course, some of which have already been proposed. A listing of both Category 1 experiments and non-Category 1 experiments proposed for Galileo is given in Table 5 and some are discussed briefly below.

Gas Chromatograph

This potentially very valuable composition experiment (particularly for the study of heavy organic molecules at sensitivities of about 1 ppb) was not chosen for Galileo primarily because of resource constraints (mass and dollars).

Table 5. Galileo Proposed Probe Experiments Not Selected

Catetory I	Mass, kg
Gas Chromatograph*	4-6
Energetic Particle Detector	1-2
Ion Mass Spectrometer*	3-4
Neutral Mass Spectrometer (Aeronomy)*	4-5
Electron Temperature Probe*	2-3
Non-Category I	
Alpha-Scatter Composition Detector	
Microwave Radar Precipitation Detector	
Cloud Imager	
Magnetometer*	
Retarding Potential Analyzer*	
Ortho/Para H_2 Ratio	

*PV derivatives

Energetic Particle Detector, Ion Mass Spectrometer, Neutral Mass Spectrometer, Electron Temperature Probe

These very valuable radiation and aeronomy instruments would operate in the pre-entry regime (ionosphere and magnetosphere). One or more of these may yet be added to the Galileo payload prior to payload confirmation.

Pioneer Venus Comparisons

Tables 1, 2, 3 and 4 contain some useful data comparing PV and Galileo with regard to mission factors, Probe designs and experiments. The inheritances provided to Galileo by PV have been important and we are certain those provided to the Saturn and Titan Probes by Galileo will also be.

Major mission factor similarities and differences are highlighted in Table 1. Although the Shuttle/IUS launch capability (1500 kg, or 1800 kg with a Mars gravity assist) is significantly greater than that of the Atlas/Centaur (910 kg), the additional mass plus a good deal more, is consumed by Galileo *Orbiter* requirements compared to the PV bus (Fly-by) because of the orbit insertion/operations requirements. The order-of-magnitude longer transit times (1049 or 1275 vs 125 days) for Galileo translate into more stringent reliability requirements for the experiments and Probe subsystems. However, the most significant difference between the two Probe missions results from the tremendous entry speeds of the Jupiter Probe (48.3 km/s) in a H_2-He environment versus the Venus Probes (11.6 km/s) in a CO_2 environment. Note that the difference lies not in the structural requirements for survival (g-loading is similar) but in the entry heating or thermal protection requirements. This will be further discussed subsequently. Note also that although the *entry* requirements are more severe at Jupiter, operation in the *descent* regime is more benign. Galileo Probe operation will terminate at about 30 bars and 450 K after 45 mins, whereas the PV Probes will operate for about 60 minutes reaching 100 bars and 750 K.

Referring to Table 2, the Galileo Probe mass (250 kg) is between the PV Large Probe (314 kg) and Small Probe (90 kg), the increase in heatsheld being offset by no pressure vessel penalty. The same is true for the pertinent science parameters (mass, volume, power, data rate). The much more severe entry requirements for Galileo are reflected in the much higher required heatshield weights (100 kg or 40% of Probe mass compared to 33 and 9 kg for the PV LP and SP respectively). The design of the heatshield is the single most important concern of the Galileo program. On the other hand, the more benign descent environment on Jupiter permits the use of a vented probe, with attendant savings, hopefully, in instrument design and possibly simpler thermal control considerations. Added difficulties at Jupiter, not thought to be of the same magnitude as entry heat protection, are the requirement for survival through the radiation belts of Jupiter, and design of the probe-to-orbiter RF link sufficient to perform satisfactorily in the poorly understood absorbing atmosphere and cloud environment.

Referring to Table 3, one sees the experiment inheritance provided to Galileo by PV. The Gas Chromatograph and Cloud Particle Size Spectrometer were the only PV experiments not carried over to Galileo; however, two new Jupiter-oriented experiments were added to Galileo. The multiple-scattering-angle nephelometer on Galileo, compared to the backscattering only nephelometer on PV, will provide much of the types of data potentially available from the Particle Size Spectrometer; as mentioned earlier there is no true counterpart on Galileo of the PV Gas Chromatograph.

SATURN/TITAN PROBES

Only very preliminary studies of Probe missions to Saturn and its satellite, Titan, have been performed. There are, of course, many options and all must be given adequate study to determine an optimum strategy for exploration of the Saturnian System. The options range from a simple flyby bus that would carry a simple atmospheric probe to Saturn and/or Titan to a sophisticated orbiter that targets a sophisticated atmospheric probe to Saturn and a combination atmospheric probe-lander to Titan. From a *Probe* standpoint, this range of options allows a broad spectrum of possibilities. For the purposes of this paper, we have adopted a middle ground within the range of options and focus on a SOP^2-type mission which is derived from and thus benefits directly from the Galileo experience. However, scientific payload options are suggested for a more sophisticated mission as well.

A Candidate "Baseline" SOP^2 Mission Strategy

The "baseline" SOP^2 mission encompasses atmospheric Probe exploration of both Saturn and Titan and a Saturn Orbiter with multiple satellite encounters, with launch in 1986. The mission can be accomplished by the addition of a Titan Probe to the Galileo Orbiter, which, we believe, can be added without extensive alteration to the Orbiter, and by the use of the Galileo Probe with a lighter weight heatshield and associated structure as the Saturn Probe. Therefore costs should be held to a minimum through extensive inheritance of Galileo Orbiter and Probe and perhaps the scientific instrumentation aboard at least the Saturn Probe. One possible SOP^2 mission sequence is listed in Table 6.

Probe Design Requirements

For the SOP^2 mission described above, typical entry conditions for the Probes are listed in Table 7, compared with the Galileo Probe. Note that whereas the Galileo Probe must be targeted to a shallow entry angle to minimize peak heating while still avoiding skip-out, the greater ephemeris uncertainties associated with Saturn and Titan require much steeper entry angles. Despite this, requirements for structural survival and entry heat protection are much simpler for Saturn than Jupiter and are trivial for Titan. Table 8 lists the potential Probe, Science and Heatshield masses and compares these with the PV and Galileo Probes. The differences in Saturn and Titan Probe masses are illustrative only. Other mixes are indeed feasible.

Candidate Payloads

<u>Saturn Probe</u>

At this point it seems plausible to consider the PV and Galileo Probe instruments as reasonable candidates for the Saturn Probe (see Tables 3, 4 and 5). Note that the 20 kg capability for the latter compares well with the Galileo payload of 21-25 kg (Table 8).

Table 6. Nominal SOP^2 Mission Sequence at Encounter

- Target spacecraft for Saturn atmosphere entry point
- Separate Saturn Probe
- Retarget for near-equatorial Saturn orbit with $R_p = 3R_s$ (outside rings)
- Transmit Saturn Probe entry and descent data to orbiter for transmission to earth
- Perform Saturn-orbit injection to apoapsis for Titan-commensurate period (~144 days)
- Raise periapsis radius R_p for Titan encounter
- Separate Titan Probe (ΔV on probe for entry)*
- Transmit Titan-Probe entry and descent data to orbiter
- Pump down to 32 day orbit
- Perform orbital maneuvers as required for remainder of mission

*May follow pump-down to 32-day orbit

Table 7. SOP^2 and Galileo Probe Entry Conditions

	Saturn	Titan	Jupiter
Entry Velocity (Rel) - km/s	29	6	48
Entry Angle (Rel) - deg	-30	-60	-9.35
Maximum Decel - g_E	365	11	300
Peak Heating Rate - KW/cm^2	5	0.1	40

Table 8. Comparison of Probe Designs

	Saturn Probe	Titan Probe	Pioneer Venus Large Probe	Pioneer Venus Small Probe	Galileo Probe
Total Mass, kg	143	110	314	90	250
Science Mass, kg	20	20	29.3	3.5	25
%	14.0	18.0	9.3	3.9	10.0
Heatshield Mass, kg	37	9	33	9.5	100
%	26	8.2	10.5	10	40

Titan Probe

The Ames Research Center has embarked on a six-month Phase A study of a Titan "Probe" applicable to a potential SOP^2 mission. The options to be studied are listed in Table 9. The minimum Probe (~175 kg) would be an atmospheric probe only (note that this minimum weight is now thought to be more realistic than the 110 kg shown in Table 8 considered by Martin-Marietta earlier). A somewhat more complex probe (~215 kg) would permit several hours operation at the surface after completing the atmospheric phase. Finally, a fully combined atmospheric and surface-oriented probe (400 kg) might survive for several months. The candidate payloads are suggestive only, but are hopefully representative and compatible with the total payload weights. The actual candidate payload list for the study will be selected as a result of the Workshop.

The most recent, in-depth study of a Titan Probe mission was performed by Martin-Marietta (A Titan Exploration Study - Science Technology and Mission Planning Option, Vols. I and II, Final Report, NASA CR 137847, Contract NAS 2-8885, June 1976). The following candidate payloads are abstracted from that study and are based on significant personal interactions of Martin-Marietta personnel with the scientific community. Table 10 lists candidate Titan atmospheric probe instruments. The blocked list is basic and fits reasonably well the capability given in Table 8. Table 11 lists a candidate Titan lander payload and Table 12 a Titan penetrator payload.

Table 9. Titan Probe Matrix

Element	Scope: Approach and Atmosphere	Scope: Approach, Atmosphere and Short Surface Operation	Scope: Approach, Atmosphere and Long Surface Operation
Mass, kg	≤175	≤ 215	≤ 400
Operation	Can "die" at impact	Impact plus several hours	Impact plus several months
Payload			
Atmosphere	P, T, Accelerometer Neut. Mass Spec. Gas Chromatograph Cloud Sensor Net-Flux Radiometer	P, T, Accelerometer Neut. Mass Spec. Gas Chromatograph Cloud Sensor Net-Flux Radiometer	P, T, Accelerometer Neut. Mass Spec. Gas Chromatograph Cloud Sensor Net-Flux Radiometer
Surface		Impact Accelerometer α P, X, Neutron, γ Spectrometer	Impact Accelerometer α P, X, Neutron, γ Spectrometer
Environment			Meteorology Pictures Active Sampler DTA GCMS

Recommendations

Given the current state of knowledge of the Saturnian system, and the extra knowledge expected from the Pioneer and Voyager fly-bys, and given our current spacecraft, Probe and scientific instrument technological capabilities a few general observations suggest themselves. The major scientific questions associated with the Saturn atmosphere and Titan atmosphere closely parallel those associated with Jupiter and Venus. Thus the Galileo Probe payload should match nicely the payload required of a Saturn Probe and a Titan Atmospheric Probe. The major deficiency is a Gas Chromatograph. It is recommended that SRT studies be supported to develop and maintain our GC competence.

Table 10. Titan Atmospheric Probe Science Payload

Instrument	Characteristics
Atmospheric MS	1-50 AMU, 3 measurements/scale height
Organic MS	50-250 AMU, 1 measurement/scale height
GC	1-3 analyses, up to 3-carbon
UV Photometer	Solar Pointing, 220, 260, > 280 nm bands
Accelerometer	Entry
T, P Transducers	3 measurement/scale height
Impact Transducer	Surface location, penetrability
Expanded Organic Analysis	
IR Radiometer	IR balance
Visible Light Monitor	Solar pointing
Nephelometer	Galileo
Cloud Particle Size Analyser	Pioneer Venus
Ion MS	Ionosphere Measurement
RPA or Plasma Probes	Charged particles in ionosphere
X-ray Fluorescence Spectrometer	P, S, Cl, Ar Detection

With regard to Titan *surface* measurements, unique problems exist. Firstly, knowledge of surface characteristics is so poor that it is probably unwise to plan, in a first mission, for a penetrator payload or even a very sophisticated lander payload. The best compromise appears to be a Titan Probe that is primarily atmospheric-oriented yet incorporates a minimum of surface observations intended to facilitate design of the next exploratory effort (i.e., the mid-range probe shown in Table 9). Again the Galileo-derived scientific instruments should apply well to the atmospheric portion of the payload. SRT studies are required to develop the surface-oriented payload.

Examination of the Titan Probes will doubtless turn up a few significant features which do not derive from PV or Galileo. In the case of the long duration Probe, in particular, truly severe thermal control problems will arise because of the temperature (and winds ?) uncertainty. Also electrical power requirements will differ greatly.

Table 11. Titan Lander Science Payload

Instrument	Characteristics
Combined GCMS/Life Detection	Viking GCMS + Kok experiment
Meteorology	T, P, wind
Sunlight Monitor	Visible, UV?
Imagery	One panorama
Surface Sampler	Scoop/Chisel (viscid surface?)
Wet Chem. Amino Acid Analysis	ABLDI
Expanded Organic Analysis	
Seismometer	Passive, Active?
Neutron Activation, Scatter	Elements, Isotopes
Passive Gamma-ray Spectrometer	K, U, cosmic ray, nuclides
XRFS, X-ray Diffraction	Heavy elements, crystal structure
Heat Flow	Temperature, gradient, thermal conduction
Microwave Radiometer	Subsurface temperature profile
Sonar Sounder	Layer detection
Drill Sampler	1-10 m
Particle Size Analyzer	Regolith characteristics
Age Dating	Ices, organics?
Upper Atmosphere Life Detect.	Sampler
Listening Devices	Audio, EM, lightning, thunder

A major requirement at an early date is for an in-depth tradeoff analysis of SOP^2 mission options given a Shuttle/IUS propulsion system and advanced propulsion systems, e.g. Solar Electric. At this point it is impossible to intelligently "size" the mission, i.e., allocate mass between Orbiter, Saturn Probe and Titan Probe spacecraft and science instruments.

Table 12. Titan Penetrator Science Payload

Instrument	Characteristics	Mass (Kg)	Power (Watts)
Accelerometer	Physical Properties of Surface Material	0.3	1.0
Temperature Array	Soil temperature, thermal conductivity	2.0	0.1
MS	10-300 AMU	6.5	27.5
Expanded Organic Analysis*		8.8 kg	28.6 W
Passive Seismometry	Viking		
Active Seismometry	Explosive Charges		
Neutron Activation	Elements, Isotopes		
Passive Gamma-ray Spectrometer	K, U, Activated Nuclides		
XRFS	Elements		
X-ray Diffractometer	Crystal Structures		
Heat Flow	Temperature Profile		
Magnetometer	Sensitivity?		

*The following instruments are optional