SCIENCE PAYLOAD
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An outer planet entry probe has two very basic science objectives. One is the determination of atmospheric structure and the other the determination of atmospheric composition.

ATMOSPHERIC STRUCTURE

With regard to structure, the general approach is that of measuring density with an accelerometer and pressure and temperature with pressure and temperature gages. This is an idea that was first advocated by Al Seiff here at Ames Research Center. It has been tested out very successfully in the Planetary Atmosphere Experiment Test (PAET) Program. It is being implemented on Viking to Mars, and the Russians used a similar procedure in their exploration of Venus.

<u>Accelerometer</u> - The objective of the accelerometer experiment is the measurement of the aerodynamically induced acceleration of the entry probe by the planetary atmosphere. The aerodynamic acceleration is directly proportional to the ambient atmospheric density. The density, ρ, is determined from the component of acceleration along the flight path, a_s:

$$\rho = \frac{-2}{V^2} \frac{M}{C_D A} a_s,$$

where M, V and $C_D A$ are the mass, velocity and aerodynamic drag area of the probe.

In the upper atmosphere, density data is available only from the accelerometer measurements. In the lower atmosphere the accelerometer measurements are enhanced by direct measurements of atmospheric temperatures and pressures. The independent data on temperature, pressure and density are combined statistically with probe trajectory data to yield the best estimate of atmospheric structure profiles.

Accelerometer data are acquired from the beginning of the sensible atmosphere to the end of the mission within the troposphere. The minimum interpretible value from the accelerometer is 4×10^{-4} G_E, which for an entry probe occurs at 656 km above the 1 atm level for the nominal atmospheric models of the Outer Planets. The probe traverses the upper atmosphere at relative velocities up to 30 km/sec; therefore, a high sampling rate is required to trace out the density profile. The analog output of each accelerometer transducer is sampled at the rate of 5 samples/sec. After peak deceleration, when the probe has slowed to subsonic velocities, the accelerometer sampling rate is reduced to 0.02 samples/sec.

The accelerometer unit is a self-contained package that consists of three orthogonally mounted accelerometers and their supporting electronics. It is a modified version of one used on the PAET vehicle. Each transducer is a single-axis, pendulous proofmass transducer which uses a capacitive bridge pickoff to detect the acceleration forces acting on the proofmass. The electromagnetic force required to maintain the proofmass in its null position is a direct measure of the aerodynamic forces exerted on the probe by the atmosphere. This type of accelerometer can measure deceleration in the desired range (.0004 to 800 G_E).

The characteristics of the accelerometer package are listed in Figure 2-47. The accelerometers are aligned orthogonally and assembled in a rigid structure. The package is mounted so that the longitudinal accelerometer lies along the center line of the probe with the proofmass as close as possible to the probe's center of gravity.

The accelerometers are energized on command of the data handling sub-system (DHS) programmer about 40 minutes before the anticipated occurrence of −0.01 G_E acceleration. The analog output of the accelerometers are sampled

by the DHS processor at 5 samples/sec until the probe experiences $-2 G_E$ acceleration after peak deceleration. From the $-2 G_E$ level to the end of the mission, the data is sampled at 0.02 samples/sec. In order to attain a high level of precision in the upper atmosphere density measurements, the longitudinal accelerometer is provided with three range scales; 0 to $-0.1 G_E$, 0 to $-10 G_E$, and 0 to $-800 G_E$. Range switching is activated by the accelerometer electronics. Two bilevel outputs are included to indicate when a range change has occurred.

The outputs of the accelerometer are 0 to 5 VDC analog signals, which are digitized by the DHS processor. The longitudinal signal is quantized into 10 bit words, the lateral signals into 7 bit words. The upper atmosphere data are stored and transmitted (interleaved with real-time science and engineering data) after radio frequency blackout.

FIGURE 2-47

ACCELEROMETER CHARACTERISTICS

RANGE: LONGITUDINAL 0 TO $-0.1 g_E$, 0 TO $-10 g_E$, 0 TO $-800 g_E$
       LATERAL: +10 TO $-10 g_E$
ACCURACY: 0.01% OF READING
SIZE: 5 x 4.5 x 4.5 CM (SENSORS PLUS ELECTRONICS)
VOLUME: 101 CM^3, (6.2 IN^3) (SENSORS PLUS ELECTRONICS)
WEIGHT: 0.3 KG, (0.66 LB) (SENSORS PLUS ELECTRONICS)
POWER: PEAK: 8.2W FOR 20 SEC; AVERAGE: 2W
DATA OUTPUT: 0-5 VDC DIGITIZED BY DATA HANDLING
       SUBSYSTEM
DATA RATE:

		WORD SIZE (BITS/WORD)	SAMPLE RATE (WORDS/SEC)	DATA RATE (BITS/SEC)
HIGH RATE	LONGITUDINAL	10	5	50
	LATERAL	7	5	35
LOW RATE	LONGITUDINAL	10	0.02	0.2
	LATERAL	7	0.02	0.14

FIGURE 2-48

PRESSURE GAGE CHARACTERISTICS

RANGE: 0 TO 20 ATM IN FOUR RANGE SCALES WITH FULL-SCALE VALUES OF 0.1, 5, 10 AND 20 ATM, RESPECTIVELY
ACCURACY: ±0.2% OF FULL SCALE
SIZE: 3.8 CM DIA x 16 CM (SENSOR + ELECTRONICS)
VOLUME: 181 CM^3, (11.1 IN^3)
WEIGHT: 0.2 KG, (0.44 LB)
POWER 1.2W AVERAGE
DATA OUTPUT: 0-5 VDC DIGITIZED BY DHS

DATA RATE: WORD SIZE (BITS/WORD)	SAMPLE RATE (WORDS/SEC)	DATA/RATE (BITS/SEC)
10	0.02	0.2

INSTRUMENT HISTORY: HARPOON

Pressure Gage - The objective of the pressure gage measurements is to obtain atmospheric pressure profiles for the troposphere of the Outer Planets. The pressure measurements are made of the stagnation region of the probe. The thermal limits of the sensor restricts the pressure measurements to the lower atmosphere where the probe velocity is subsonic. At the beginning of the measurement regime, the ambient and dynamic pressures are approximately equal in the total pressure measurement of the sensor:

$$P_T = P_\infty + \frac{1}{2} \rho_\infty V^2_\infty$$

where P_∞ is atmospheric pressure, ρ_∞ is ambient density, and V_∞ is velocity. Therefore, accelerometer data are needed to determine probe velocities and ambient densities. These parameters are required in order to derive ambient pressure from the gage data. As the probe approaches its terminal velocity, the dynamic pressure correction to the measurement becomes very small and is neglected. The properties of the pressure gage are given in Figure 2-48.

A capacitive type of sensor is employed because it monitors a wide range of pressure in a single instrument. The pressure gage is a single unit that contains four pressure transducers and a common electronics package. The transducers are in the form of pressure sensing capsules; each capsule is sensitive to a different pressure range. The full-scale values of each capsule are 0.1, 5, 10, and 20 atm, respectively. Automatic range switching occurs from one capsule to another as the pressure profile is traversed.

The circuitry for the pressure gage is given in Figure 2-49. The change in capacitance generated by a change in pressure within the sensing capsule is converted to a high level DC voltage by the signal conditioning electronics. The voltage reference circuit regulates the oscillator and other circuits.

A controlled oscillator, consisting of a control amplifier, a feedback network and an oscillator, excites the capacitive sensing capsule with a closely controlled alternating current voltage. The detector develops a low level DC signal proportional to the excitation and the capacitance of the sensing capsule. A low level signal from the detector then goes to an amplifier that develops the high level DC voltage output signal.
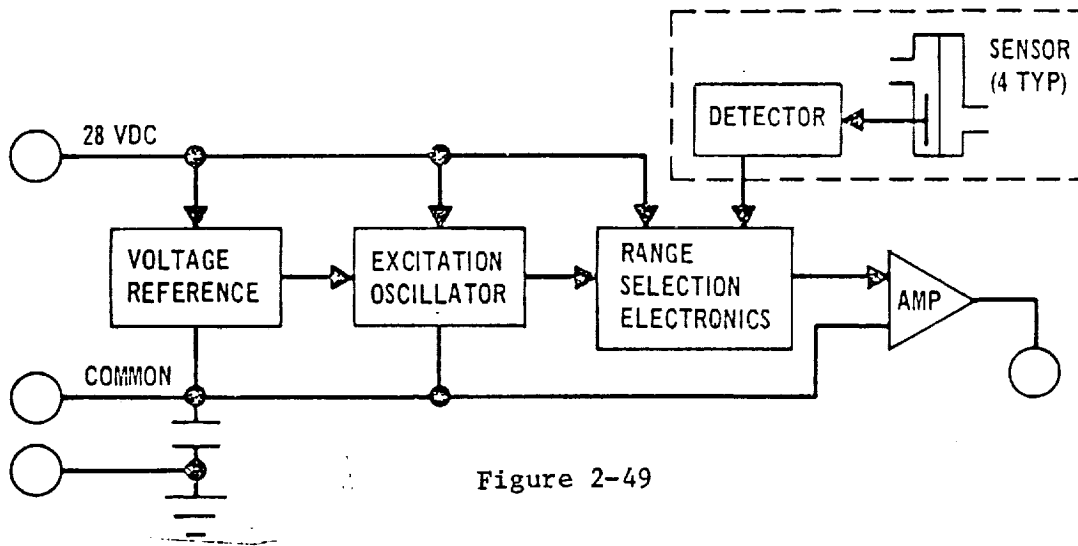
CIRCUITRY FOR THE PRESSURE GAGE

Figure 2-49

The inlet port of the pressure gage is colocated within the mass spectrometer inlet probe assembly in the sampling probe of mass spectrometer system. Pressure measurements are initiated at -2 G_E (after peak deceleration) with deployment of the mass spectrometer sampling probe in order to avoid high Mach number shock wave effects. The output of the pressure gage is an analog signal in the 0 to 5 VDC range. The output signal is sampled once every 50 seconds and is digitized into 10 bit words by the data handling subsystem.

Temperature Gage - The objective of the temperature measurement is the determination of atmospheric temperature profiles in the tropospheres of Saturn and Uranus. The atmospheric temperature measurements are made by deploying the temperature gage directly into the probe flow field. The measurement regime is therefore limited to the lower atmosphere, where local flow field conditions do not exceed the thermal limits of the gage.

The sensing element of the temperature gage is a platinum resistance wire. To provide snsor redundancy, the temperature gage contains two platinum elements in a single housing. The two elements are connected in parallel to one resistance bridge. The circuitry is designed so that, when both platinum elements are operational a 0 to 2.5 VDC output range is obtained. Should one element open, the output voltage range immediately goes to 0 to 5 VDC and the voltage output for a given temperature jumps to twice the previous value. In order to determine the appropriate scale factor, the DHS programmer sends a command to the temperature gage immediately after sensor deployment which introduces a calibrated birdge resistance in parallel with sensing elements. The change in output signal identifies the scale factor to be used in data reduction. Experimental data from similar total temperature sensors have produced a maximum response time of 0.5 seconds. The response is dependent on Mach number and pressure. The lag time decreases as atmospheric pressure increases.

The temperature gage consists of two components, the deployable sensor unit and the electronics package, and is typical of platinum wire sensors used in many space probes except for deployment technique. The physical properties of the gage are given in Figure 2-50. Before deployment, the sensor unit is positioned behind the forward heat shield in the vicinity of the probe maximum diameter. The gage deployment is accomplished by means of a preloaded spring,

which is released on command of the DHS when the probe attains the $-2\ G_E$ level (after peak deceleration). Upon deployment, the sensor unit is located in a region of high local dynamic pressure within the flow field. The sensor is extended approximately two centimeters beyond the probe boundary layer.

The output of the temperature gage is an analog signal in the 0 to 2.5 VDC range (or in the 0 to 5 VDC range on the failure of one sensor element) which is sampled once every 50 seconds. The analog signal is digitized into 10 bit words by the DHS processor prior to transmission.

ATMOSPHERIC COMPOSITION

With regard to composition, the most important instrument, in terms of probe-design impact, is the mass spectrometer. Additional correlatable data are provided by an ion spectrometer, radiometer and nephelometer.

Neutral Mass Spectrometer - The neutral atmosphere mass spectrometer and sampling system (Figure 2-50) is a self-contained unit that acquires Outer Planet atmospheric samples and determines their chemical composition. The integrated instrument package consists of three elements, the sampling system, mass spectrometer and the data control system. The function and properties of these elements are described in the subsections that follow and are summarized in Figure 2-53.

FIGURE 2-50

MAGNETIC DEFLECTION   QUADRUPOLE

II-113
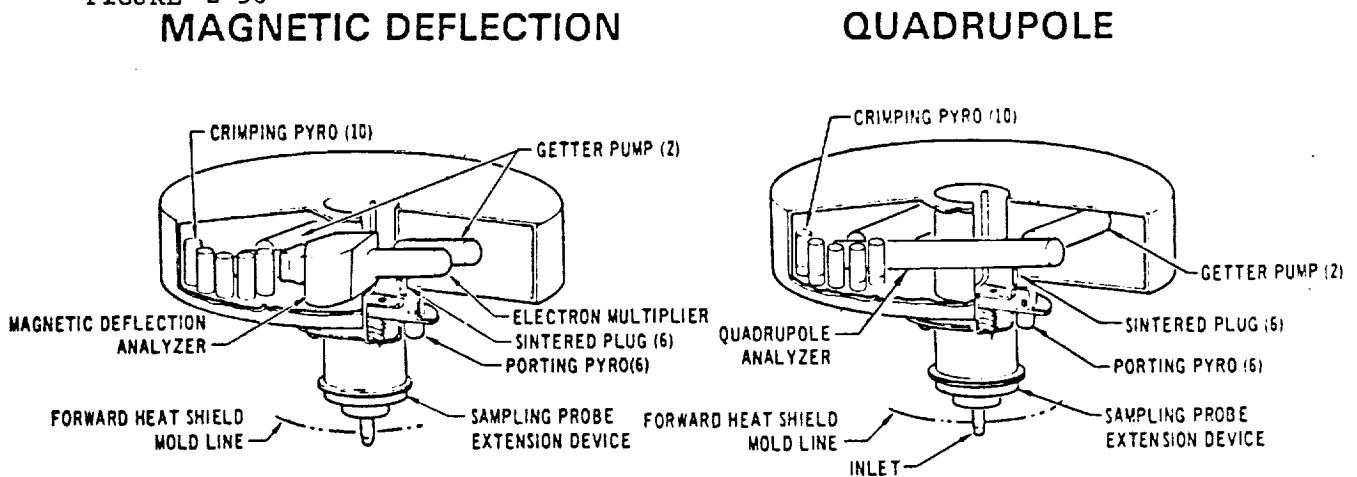
The neutral mass spectrometer analyzes six discrete atmospheric samples during the mission. The six atmospheric samples are taken at six-minute time intervals. The location of the sampling levels within the various atmospheric models is shown in Figure 2-51.

FIGURE 2-54
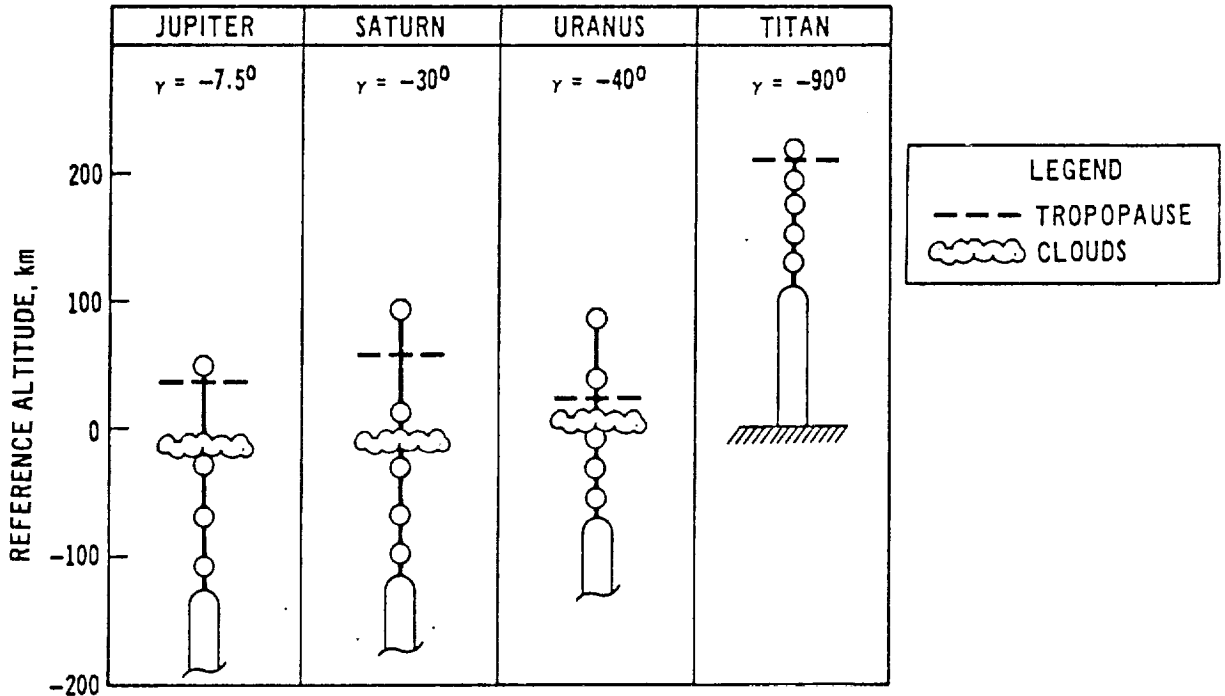
During the analysis of each atmospheric sample the mass spectrometer makes nine five-second scans of the 0 to 40 amu mass range. The first scan is digitized and transmitted directly to the probe data handling subsystem (DHS). This scan provides a detailed representation of the mass spectra of the sample. Eight additional scans are taken and averaged to remove the effect of random noise on the signal of trace atmospheric constituents. The averaged data is then transmitted to the DHS.

Sampling System - The atmospheric sampling system obtains samples of the lower atmosphere and delivers them to the mass spectrometer for analysis. The principal components of the sampling system are the atmospheric sampling probe, sampling tubes, a molecular effusive source, and pumps, Figure 2-52.

FIGURE 2-52

DETAIL OF SAMPLING PROBE ASSEMBLY IN EXTENDED POSITION
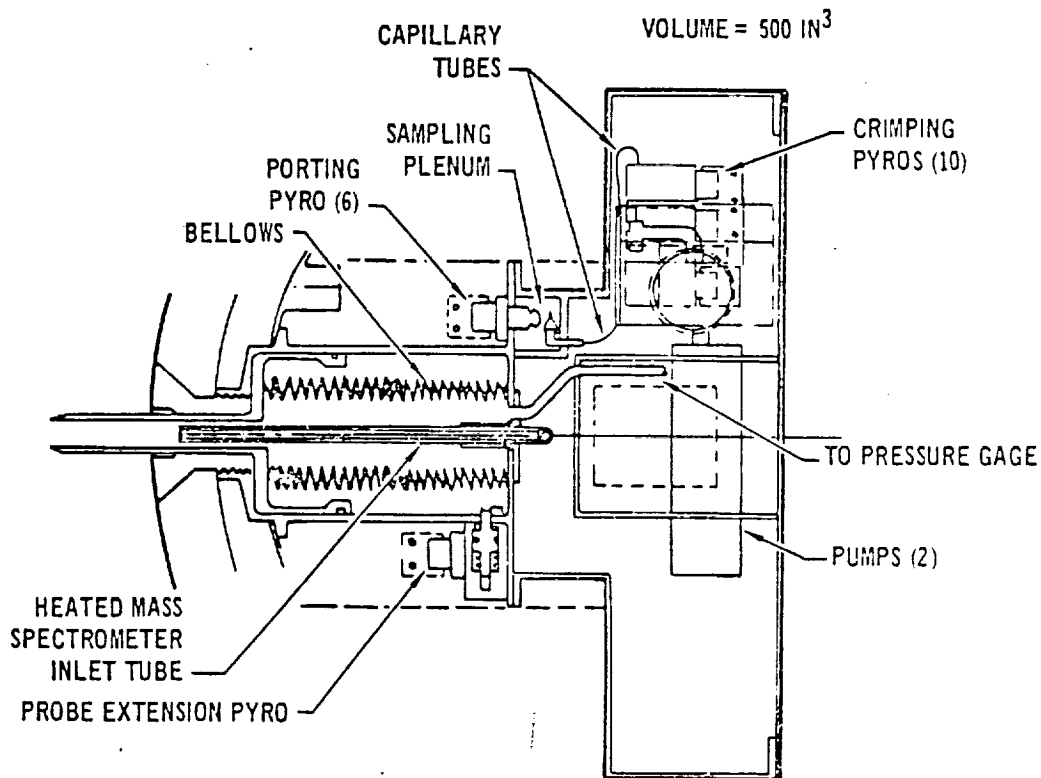
Atmospheric gas samples are obtained through a 2 cm diameter tube which is concentrically housed within a deployable tube of 3 cm diameter. Deployment is initiated through a pyro pin-puller device which releases a preloaded metal bellows. The thrust from the bellows causes the 3 cm diameter tube to push a plug out of the forward heat shield and extend 5 cm beyond the mold line into the flow field. In addition, the bellows prevents sample contamination from pyro-gases and is a plenum for the atmospheric pressure sensor.

The atmospheric samples are transmitted from the plenum to the mass spectrometer via sampling tubes. Because of the wide range of atmospheric pressures, 10^{-2} to 15 atm, over which samples are obtained, a separate sampling tube is utilized for each sample. In order to maintain near-vacuum conditions within the mass spectrometer, the sampling tubes must have an extremely small conductance. This small conductance is obtained by the combination of a porous ceramic plug and capillary tubing. Since the flow in the porous plugs and capillaries is viscuous flow, the conductance in the sampling tubes is a function of the mean pressure

difference. As the probe descends through the atmosphere, each sample is obtained at a different pressure level. Therefore, the diameter and length of each sampling tube is individually sized for the specific pressure density range over which it obtains samples.

Mass Spectrometers - The mass spectroscopic analysis of a gas sample involves ionizing the gas molecules with an electron beam. The ions that are formed are sorted by the electromagnetic fields of the mass spectrometer. The constituents of the sample are identified by the mass-to-charge ratio of ions.

Atmospheric analysis from spacecraft have been conducted with both quadrupole and magnetic deflection mass spectrometers. Both types of mass spectrometer can be accommodated into the integrated instrument package as shown in Figure 2-50 and the table below.(Figure 2-53)

FIGURE 2-53

NEUTRAL ATMOSPHERE MASS SPECTROMETER AND SAMPLING SYSTEM PROPERTIES

QUADRULOPE MASS SPECTROMETER					MAGNETIC DEFLECTION MASS SPECTROMETER				
	WEIGHT		VOLUME			WEIGHT		VOLUME	
	KG	LB	CM^3	IN^3		KG	LB	CM^3	IN^3
MASS ANALYZER	2.3	5.0	1482	90.4	MASS ANALYZER	2.3	5.1	2433	148.4
SAMPLING SYSTEM	1.8	3.9	1188	72.5	SAMPLING SYSTEM	1.8	3.9	1188	72.5
DATA CONTROL SYSTEM	1.3	2.9	1033	63.0	DATA CONTROL SYSTEM	1.3	2.9	1033	63.0
STRUCTURE AND TUBING	1.0	2.1	3543	216.1	STRUCTURE AND TUBING	1.0	2.1	3543	216.1
TOTALS	6.4	13.9	7246	442.0	TOTALS	6.4	14.0	8197	500.0

Data Control System - The mass spectrometer data control system consists of two components, the sampling programmer and the data processor.

The mass spectrometer sampling programmer performs power conditioning and controls the sequencing of the atmospheric sampling events. The programmer is energized by an enabling signal from the data handling subsystem five seconds after the deployment of the atmospheric sampling probe. The enabling signal also activates the programmer clock, which times the sequence of sampling events.

The mass spectrometer data processor samples the analog output of the mass spectrometer, formats and stores the data, and transmits the processed data to the probe data handling subsystem at a clock rate provided by that subsystem.

During the mass spectroscopic analysis of a given atmospheric sample, the mass spectrometer makes nine 5-second scans of the 0 to 40 amu mass range. The data is processed into two forms. On the first scan the analog voltage of the mass spectrometer is sampled at 10 samples per amu. These data are encoded as nine-bit binary word by the analog-to-digital converter. The data are stored in a 634 9-bit word unit of the mass spectrometer memory and are transmitted to the probe data handling subsystem on a first-in first-out basis at the rate of 16 bits per second.

The second data sample consists of the eight additional 5-second mass spectrometer scans, sampled at 5 samples per amu. These data are accumulated in a 24 bit/word random access memory for data averaging to remove the effect of random noise on the signal of trace atmospheric constituents. Each 24-bit word location in the random access memory has 12 bits allocated for data summation and 8 bits for address. The averaging process is accomplished in binary code by summing the eight sets of data at each memory location and then discarding the last three bits of the summation. The processed data is transferred to the 634-word memory unit for transmission to the data handling subsystem.

Radiometer - The objective of the radiometry measurement is the vertical distribution within the atmosphere of absorbed solar energy. Measurements are obtained in the visible and infrared region of the spectrum. Both the downward flux of sunlight and the upward flux of planetary emission are determined.

The radiometer obtains narrow band data in three channels in the visible and near infrared and broad band data in two infrared channels. The channel assignments and corresponding spectroscopic features are as follows:

0.5μm	H_2 pressure-induced dipole
1.0	CH_4 absorption
1.1	CH_4 absorption
14-25	H_2 rotational temperature
30-55	H_2 translational temperature

The detectors for the radiometer are solid state detectors in the visible and thermopiles in the infrared.

The radiometer measurements are made in the probe free stream in the vicinity of the probe beltline. The detectors are deployed from the probe by a solar panel deployment mechanism that is spring-released. The detectors are

deployed when the probe reaches the lower atmosphere; i.e., at the $-2G_E$ level. The detector housing is alternately oriented in an upward and downward looking position.

FIGURE 2-54

RADIOMETER CHARACTERISTICS

Range:	0.5 to 55 μm in 5 channels		
Size:	656 cm^3 (40 in.^{3})		
Weight:	3 kg (6.6 lb)		
Power:	3 watt		
Date Rate:	Word Size (bits/word)	Sample Rate (words/sec)	Data Rate (bits/sec)
	9	0.33	3

Nephelometer – The objective of the nephelometer experiment is the detection of cloud layers in the lower atmospheres of Saturn and Uranus. The light-scattering properties of atmospheric condensates are exploited in detecting the clouds. The condensates scatter the incident light originating from the nephelometer light source. A portion of the incident light is scattered back into the nephelometer collection lens.

A forward scattering nephelometer consists of a light source, lenses and optical detectors. Characteristics are defined in Figure 2-55. The light source is a light emitting diode, which illuminates a portion of the atmosphere within the field of view of the detectors. Three photodiode detectors are used, one to measure the backscattering by the atmospheric condensates, the other two to monitor the background atmospheric emission. These components together with the power supply and the data processing electronics are packaged into a single unit. The nephelometer is located in the aft hemisphere of the probe near the maximum diameter and looks out perpendicular to the spin axis of the probe. The nephelometer is recessed within the probe to prevent the accumulation of atmospheric condensation or dust particles on an exterior window. A viewing port is opened in the heat shield at $-2G_E$ just prior to the initiation of nephelometer measurements.

The data output from the nephelometer consists of four channels of photo-detector data at 10 bits/word and three channels of instrument status data at 6 bits/word. The analog output of the nephelometer is sampled once every 30 sec. A data processor within the instrument digitizes these data and transfers them to the DHS at 2 bits/sec using a clock furnished by the data handling subsystem.

FIGURE 2-55

NEPHELOMETER CHARACTERISTICS

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SIZE: 10 x 5.7 x 7.5 CM, SENSOR PLUS ELECTRONICS
VOLUME: 427 CM3 (26 IN3)
WEIGHT: 0.5 KG (1.1 LB)
POWER: 1.2 W PEAK, 1W AVERAGE
DATA OUTPUT: 1 NEPHELOMETER OUTPUT  1 x 10 BITS
             3 BACKGROUND LEVEL      3 x 10 BITS
             3 INSTRUMENT STATUS     3 x 6  BITS
DATA DIGITIZED INTO A SINGLE STREAM BY THE IN-
STRUMENT'S DATA PROCESSOR
DATA RATE: SAMPLE SIZE   SAMPLE RATE     DATA RATE
           (BIT/SAMPLE)  (SAMPLE/SEC)   (BITS/SEC)
              58            0.033            2
INSTRUMENT HISTORY: ARC CONCEPT
FOR PIONEER VENUS PROBE
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Ion Mass Spectrometer – The ion mass spectrometer makes ion identity and relative abundance measurements in the outer regions of the atmospheres. The instrument operates between 10^{-14} and 10^{-7} atm. On the low pressure side of the ionosphere measurements are limited by the instrument sensitivity. On the high pressure side, the instrument fails due to RF breakdown within the analyzer section. These pressure limits correspond approximately to 1100 and 500 km, respectively, in the nominal atmospheric model of Saturn.

The method of operation of an ion mass spectrometer is very similar to that of a neutral gas mass spectrometer. The primary difference between the two types of instruments is a consequence of the kind of atmospheric sample that is to be analyzed. For analyzing the ionic components of the atmosphere, there is no need for an electron gun to ionize the sample prior to mass analysis as required in the neutral mass spectrometer. The atmospheric ions are drawn into the ion mass spectrometer by the action of an electrical grid behind the inlet orifice. The ions are directed into the analyzer section by an accelerating grid. Within the analyzer section the ions are mass sorted by the action of a quadrupole field. The mass resolved ions then impinge on an ion collector. The ion current is amplified by an electron multiplier and converted to voltage by an electrometer. The characteristics of the ion mass spectrometer are given in Figure 2-56.

The positive ions anticipated in the upper atmospheres of Saturn and Uranus are those that result from the solar photoionization of hydrogen and helium: H^+, H_2^+ and He^+. Additional ion species are formed from the reaction of the primary ions with the neutral species present, resulting in H_2^+ and HHe^+. The mass range represented by these ions is 1 to 5 amu. The ion mass spectrometer scans this mass range in 0.6 seconds. The output of spectrometer is sampled at 1.66 samples/sec and quantized into five 5-bit words by the spectrometer data processor. The ion spectrometer data is transmitted at 66.6 bits/sec to the probe data handling subsystem, where it is stored until radio transmission begins, in the vicinity of the tropopause.

Figure 2-56

ION MASS SPECTROMETER
CHARACTERISTICS

RANGE: 1 - 5 AMU
OPERATING RANGE: 10^{-14} TO 10^{-7} ATM
SIZE: ANALYZER: 3.8 DIA x 12.7 CM
  ELECTRONICS: 12.7 x 12.7 x 7.6 CM
VOLUME: ANALYZER: 145 CM^3 (8.8 IN^3)
  ELECTRONICS: 1230 CM^3 (75 IN^3)
WEIGHT: ANALYZER: 0.9 KG, (2 LB)
  ELECTRONICS: 0.9 KG, (2 LB)
POWER: 3W
DATA OUTPUT: DATA DIGITIZED INTO FIVE 8-BIT WORDS
        BY THE INSTRUMENT'S DATA PROCESSOR.

DATA RATE	SAMPLE SIZE (BITS/SAMPLE)	SAMPLE RATE (SAMPLES/SEC)	DATA RATE (BITS/SEC)
	40	1.666	66.6

INSTRUMENT HISTORY: ATMOSPHERIC EXPLORERS, SOUNDING ROCKETS.

SUMMARY

The representative science payload of an outer planet atmospheric entry probe has been described. The instrumental details are based on experiments that have been successfully flown in the atmospheres of Earth and Venus. The incorporation of these instruments into an outer planet probe requires a strong interaction between instrument designer and probe designer. The installation of the instruments into a 250 lb entry probe is depicted in Figure 2-57.

Saturn Atmospheric Entry Probe

EQUIPMENT COVER

HEMISPHERICAL HEAT SHIELD (ABLATOR-R.F. TRANSPARENT)

ACCELEROMETERS

MICROSTRIP ANTENNA

PIONEER ATTACH (3)

TEMPERATURE SENSOR (EXTENSIBLE)

MASS SPECTROMETER AND PRESSURE PROBE (EXTENSIBLE)

NEUTRAL MASS SPECTROMETER

NEPHELOMETER

SANDWICH STRUCTURE

CARBON PHENOLIC ABLATOR

Figure 2-57

II-121
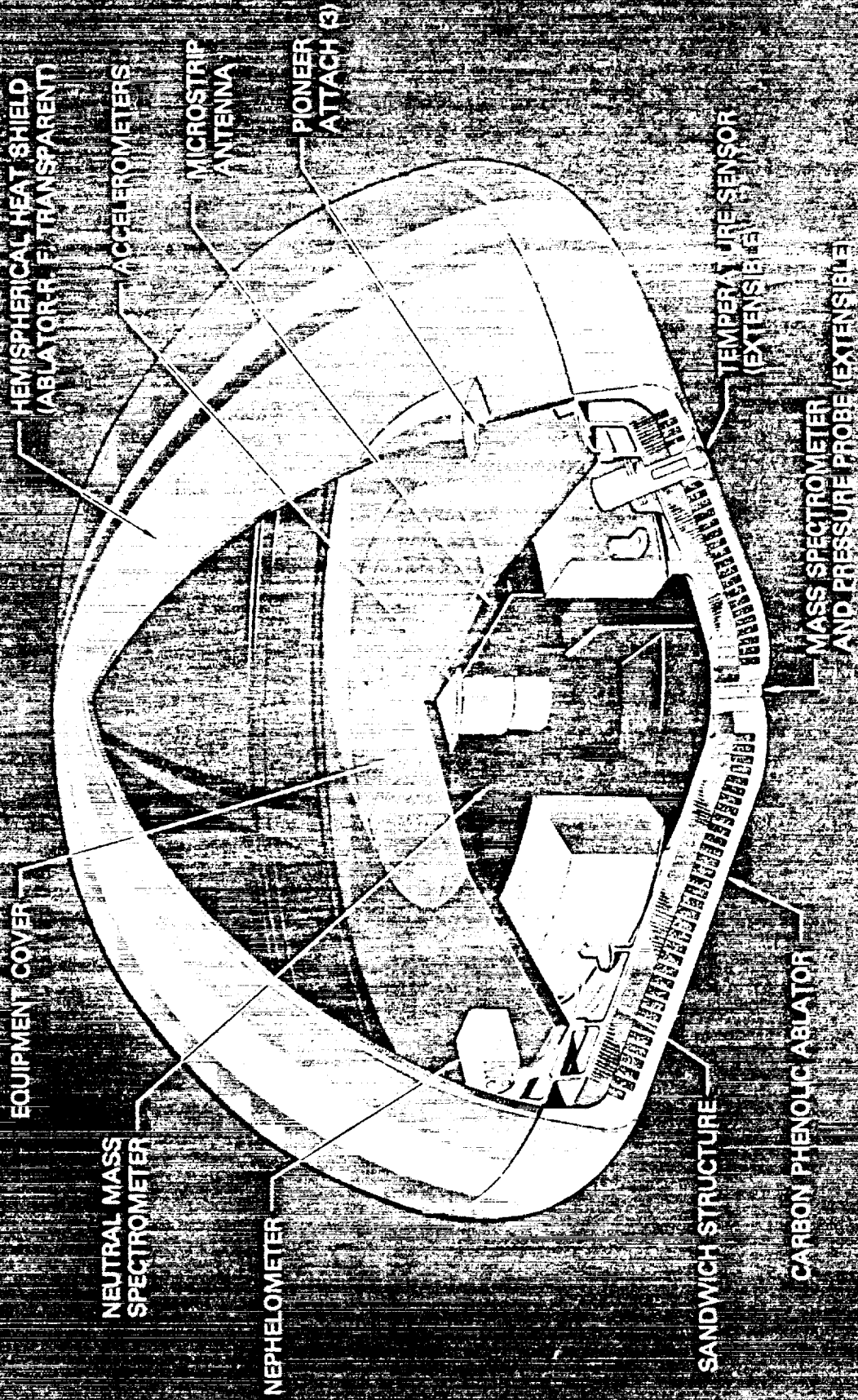
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MISSION AND SPACECRAFT DESIGN CONSTRAINTS - 21 May 1974

Chairman: Byron L. Swenson
System Studies Division
NASA Ames Research Center

MR. SWENSON: The title of this afternoon's session is Mission and Spacecraft Design Constraints. In the next two hours, we will be discussion the constraints imposed upon the spacecraft and the probe by the mission and some of the constraints that the spacecraft imposes upon the mission.

I would like to spend about the next ten or fifteen minutes on an overview of the missions under consideration to try to provide a backdrop for the more detailed presentations to follow.