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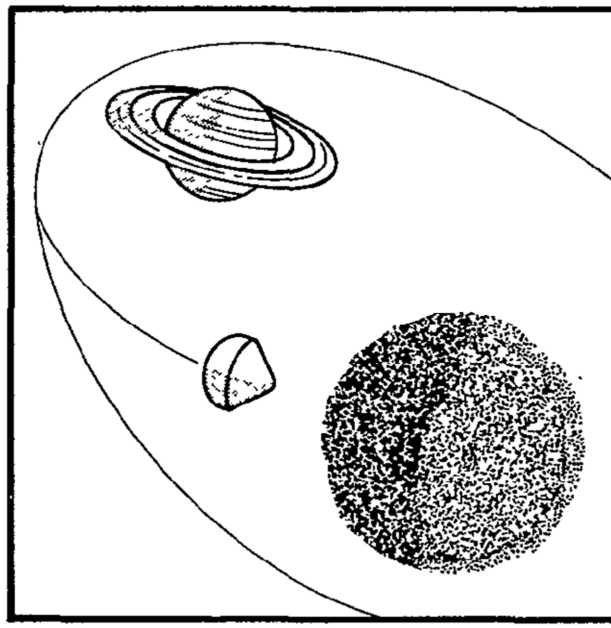
Final
Report

31 March 1979

Study of Entry and Landing Probes for Exploration of Titan



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MCR-79-512

STUDY OF ENTRY AND LANDING PROBES FOR EXPLORATION OF TITAN

March 31, 1979

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Prepared Under Contract No. NAS2-9985

by

Martin Marietta Corporation
Denver Division

for

National Aeronautics and Space Administration
Ames Research Center

FOREWORD

This final report has been prepared in accordance with requirements of NASA Contract No. NAS2-9985 to present the results of a six-month study for the Ames Research Center by Martin Marietta Corporation, Denver Division.

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EXECUTIVE SUMMARY

Saturn's largest moon, Titan, is a totally unique planetary body which is certain to yield exciting new phenomena. Titan is sufficiently cold and massive to retain a substantial atmosphere, composed largely of reducing gases which are common in the outer solar system. These volatiles provide interesting possibilities for chemical evolution of organic materials through photochemical production, and their probable fallout to the surface leads to the need for chemical characterization of both the atmosphere and surface of Titan. Although current knowledge of Titan's atmosphere is somewhat uncertain, a more accurate atmospheric definition will be possible before a program start based on new radio astronomy interferometry measurements and results of Pioneer 11 and Voyager flyby of Titan in 1979 and 1980. Current information is not sufficiently detailed to distinguish between a thin methane rich atmosphere and a thick nitrogen rich atmosphere. Therefore, both the thin and thick atmospheric models were used for the study of various Titan probe classes described in this report.

The objective of this study was to define the technical requirements, conceptual design, science return, schedule, cost and mission implications of three probe classes that could be used for the exploration of Titan. The three probe classes considered by the study were based on a wide range of exploration mission possibilities and are summarized as follows:

- Class A - Atmospheric Probe with atmospheric science only.
- Class B - Atmospheric Probe/Lander - capable of pre-entry, atmospheric, and limited surface science.
- Class C - Atmospheric Probe/Lander - capable of pre-entry, atmospheric and expanded surface science with extended mission duration.

This study shows that the Class B Probe/Lander is a very practical Titan exploration vehicle. It provides an exciting low-risk scientific mission for a total probe cost of $70-80 M (1978 dollars). No new technology developments are required, in fact considerable use can be made from hardware inherited from the Pioneer Venus and JOP programs.

The Titan probe mission will be launched in conjunction with the Saturn orbiter and Saturn probe (SOP^2). The Shuttle with the Solar Electric Propulsion Stage will launch the orbiter and probes in January of 1987 with an arrival in November of 1993. In the current mission scenario, the Saturn orbiter will release the Saturn probe on initial approach and the Titan probe will be released from Saturn orbit in a subsequent pass. After release from Saturn orbit, the probe entry velocity at Titan is about 4.5 km/s or slightly less than the Viking lander entry velocity at Mars. Because of the lower gravity on Titan and the atmosphere characteristics, the entry environment is less severe on Titan than on Mars.

Because of the large uncertainties in the Titan atmsophere and surface characteristics, many probe configuration trade offs were done which included various combinations of entry shapes, parachutes, descent shapes, and hard and soft landers. From these trades a basic hard lander configuration was selected which provides a practical design approach for both lander classes. This configuration is typified by the Class B probe/lander which is described briefly in the following paragraph.

Emphasis was placed on the Class B probe which meets the basic science requirements established by the Space Science Board (1975) and the Reston Workshop on the Saturn System (1978). The Class A and Class C probes provided basic technical, science return and cost trade data for use in future mission and program planning and in understanding the relative merits of the Class B probe. The descent sequence, science payload, and probe configuration are illustrated in Figures 1 and 2. The basic probe configuration includes a 70-degree half angle cone aeroshell with a spherical base cover. The pre-entry science toroidal module is in place in the pre-entry illustration which lists the pre-entry science payload complement. The module is jettisoned prior to entry and, after entry in the thin atmospheric model case, the parachute is deployed to slow the vehicle and allow sufficient time for descent science measurements. (No parachute is required for the thick atmospheric model case.). At parachute deployment, a nose cover is also deployed from the center of the heat shield, exposing the atmospheric sample inlets and descent camera. The sample inlet is extended slightly beyond the heat shield boundary layer to obtain uncontaminated samples. The parachute is jettisoned prior to touchdown and the probe is allowed to free fall to the surface. The crushable honeycomb aeroshell attenuates the landing impact, provides good impact stability and low penetration on hard or snowy surfaces, and flotation on a liquid surface. After touchdown the surface science implementation sequence is begun in which the imaging and meteorology mast is deployed upward and the surface sample core drill is extended downward. The primary surface science data are transmitted to the orbiter within the first 90 minutes and secondary data are transmitted until the orbiter travels to the horizon or out of range.

Study Results - A broad range of probe classes and mission alternatives were evaluated as a function of the large environmental uncertainties with the following results:

- Titan Probe Masses:

	Thick Atmosphere (30% Probable Surface)	Thin Atmosphere
Class A	114 kg	113 kg
Class B	226	227
Class C	351	355

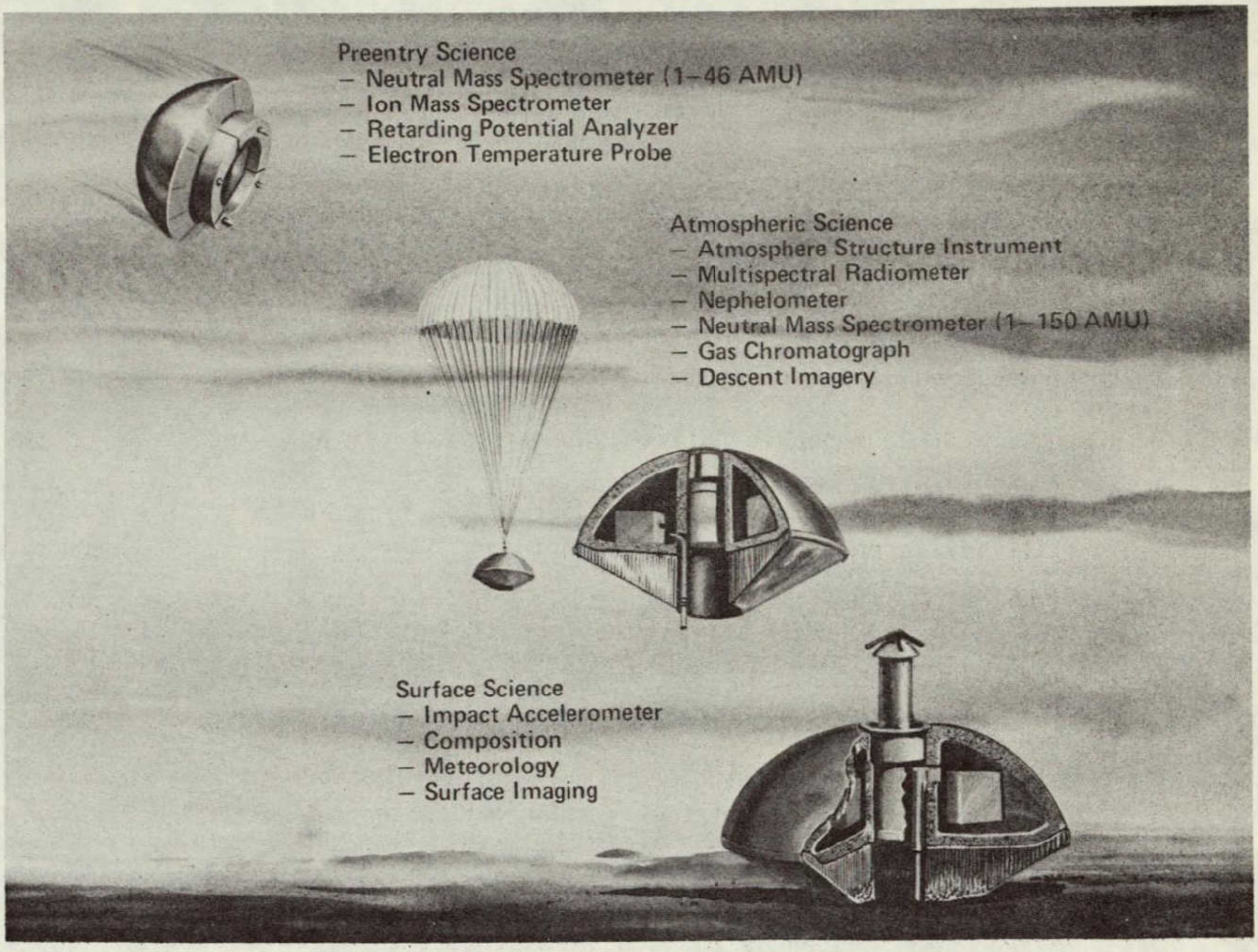


Figure 1 Class B Probe/Lander Entry and Descent Sequence

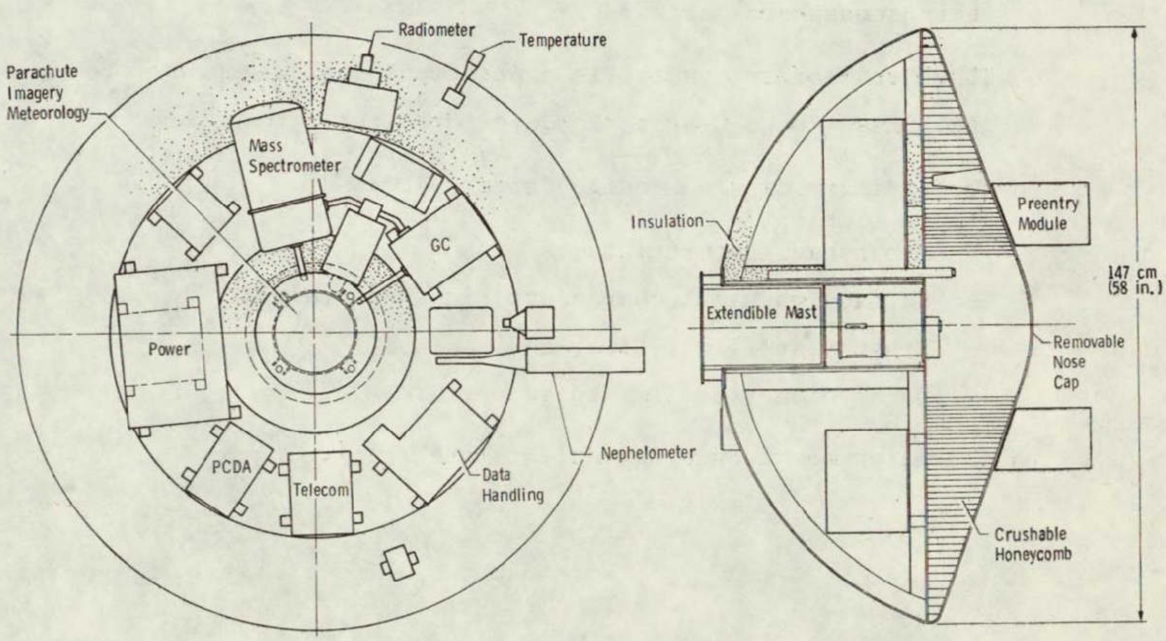


Figure 2 Class B Probe/Lander Configuration

- Titan Probe Program Costs;

Class A	\$40 - 50 M
Class B	\$70 - 80 M
Class C	\$90 -105 M

- Impact of thin versus thick (30% Probable Surface) atmosphere on design is minimal.
- Thick (10% Probable Surface) atmosphere increases Class B probe design weight by 30%.
- 32-day extended mission time increased Class B probe weight by 10%.
- Hard lander configuration provides:
  - Practical design for all lander classes,
  - Good impact stability,
  - Low penetration on ice or snow, and
  - Flotation on liquid surface.

Conclusions - Based on the study results, the following conclusions were made:

- All probe classes are feasible for both the thick and thin atmosphere cases.
- The hard lander concept is a practical design approach for the Class B and C probe/landers for either atmosphere.
- The primary mission design drivers are:
  - Atmosphere uncertainty,
  - Surface physical characteristics uncertainty,
  - Eight year flight time, and
  - Data volume required to support imaging.
- No major new technology drivers are required.

- o Major hardware uncertainties are:
  - Surface sample acquisition at low ambient temperature (70-100°K).
  - Properties of mechanical devices and materials at low ambient temperature.

Recommendations - Recommended areas for future study include:

1. Titan physical properties model including atmosphere, surface, and light level uncertainties,
2. Science sample acquisition and handling at low cryogenic temperatures,
3. Pre-entry science implementation, and
4. Impact on probe system design of direct entry rather than out-of-orbit entry as baselined in the current study.

I. INTRODUCTION

The growing interest in Saturn and its largest moon, Titan, has resulted in the definition of exploratory science objectives for Titan from the 1975 NAS/SSB Report on Space Science and from the 1978 Reston Workshop on the Saturn System. From the workshops, two extreme atmosphere models were proposed by Drs. Donald Hunten and John Caldwell as being the best candidates for describing the actual range of atmospheric parameters possible on Titan. These models provide the basis for probe system design in this study. In addition, both vehicle and mission studies of Saturn orbiter and probe systems have been completed by NASA Ames and JPL. Martin Marietta, under contract to NASA Ames, conducted a Titan exploration study in 1976 which investigated probe designs and technology requirements. JPL has completed Saturn orbiter and probe mission studies in 1975 and 1978.

This report describes the results of an evaluation of entry and landing probes for the exploration of Titan. The purpose of the study was to define technical requirements, conceptual designs, science return and schedule/cost implications of three probe classes designed for the large uncertainties in the atmosphere and surface of Titan. Greatest emphasis was placed on the intermediate type Class B design which is a combination atmospheric and lander probe. The Class A is a simple atmospheric probe and the Class C is a more complex combination atmospheric and lander probe with expanded surface science and extended mission duration.

The study responsibility was divided into three areas: NASA Ames provided program management and science definition, JPL provided mission analysis and orbiter/probe trajectories, and Martin Marietta provided probe mission and system design engineering functions.

The scope of this study did not include the resources necessary to investigate various missions and, therefore, an out-of-orbit case only was considered. However, during the course of the study other mission options were defined that are worthy of further investigation. In particular, the direct entry mission should be investigated in future studies. The Titan probe could be released during the initial encounter with a direct entry into Titan which could result in a considerable reduction in required orbiter propulsion. The Titan probe weight increase due to direct entry would be small compared to the savings in orbiter weight, however, this approach would present increased operational complexity.

II. MISSION OVERVIEW

The Titan probe mission will be launched in conjunction with the Saturn orbiter and Saturn probe (SOP[2]). The Shuttle with the Solar Electric Propulsion Stage (SEPS) will launch the orbiter and probes in January of 1987 with an arrival period of November 1993. The baseline mission scenario includes Saturn probe release on approach and orbit insertion into an initial capture orbit period of 160 days with subsequent Titan flybys which are used to pump the orbits down to a 48-day period and, finally, into a 32-day period which has an orbit resonance with Titan of 2 to 1. This portion of the mission sequence is illustrated in Figure II-1.

Optical navigation is required to obtain the necessary accuracies for these orbital maneuvers and the multiple encounters with Titan further reduce navigation uncertainties. The Titan probe is released from the 32-day period orbit about 10 days prior to encounter and entry for completion of the probe mission. The orbiter may remain in the 32-day period orbit for a series of re-encounters with the probe/lander depending on which probe class mission is being flown. The baseline Class A and B probe missions are completed on the initial encounter while the Class C probe mission requires several re-encounters to complete.

Figure II-2 illustrates the Titan probe encounter and entry geometry relationship with the orbiter. The probe and orbiter approach Titan in a retrograde trajectory and entry occurs near the subsolar region at about 10:00 AM local time. This entry condition was dictated by the science requirement for a light side entry. Titan has a very low rotational rate since it is assumed locked onto Saturn and therefore makes one revolution in 16 days. The effect of a retrograde entry on the probe entry velocity is small, i.e., an increase of about 12 m/sec above the entry velocity of 4.5 km/s.

Figure II-1 Titan Encounter Geometry (Typical)

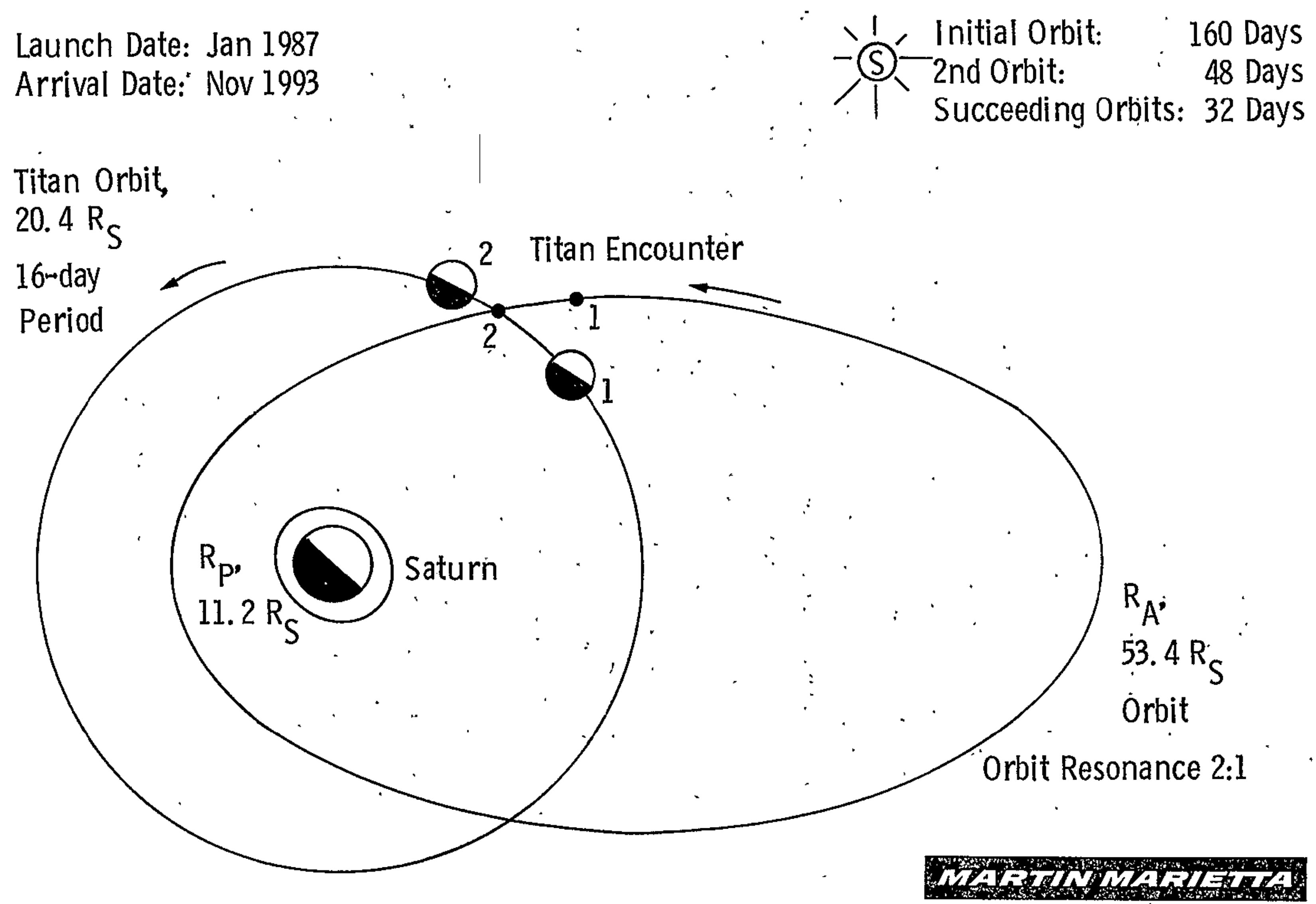
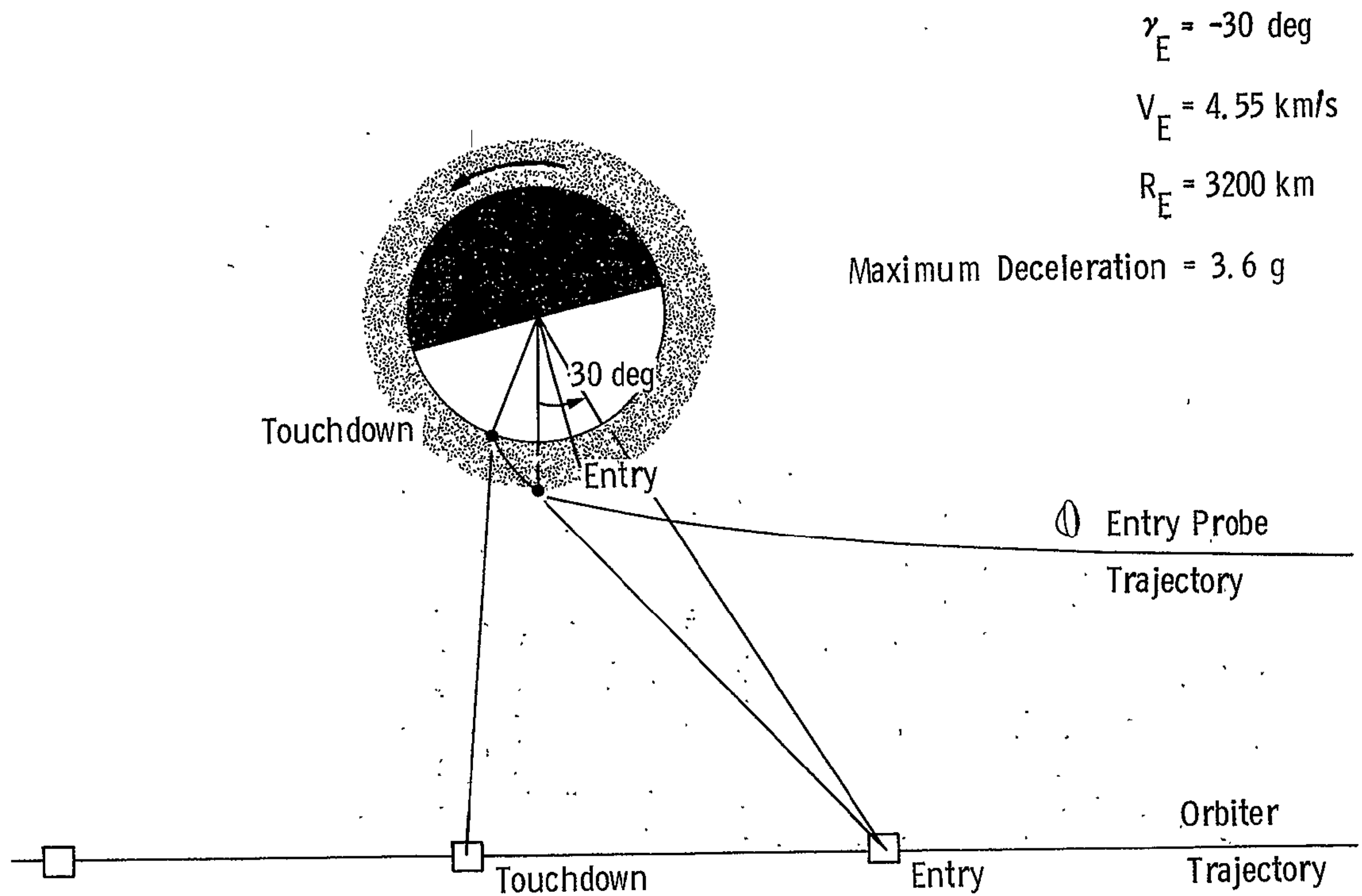


Figure II-2 Entry at Titan



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The probe is released from 5 to 10 days prior to entry and the orbiter is timed to lag the probe by about 30 degrees of longitude at probe entry in order to optimize the communication link geometry during probe descent and surface operation. At an entry radius of 3200 km, the probe enters at a nominal flight path angle of -30 degrees and a relative velocity of 4.55 km/s. The orbiter flyby radius of closest approach is a function of the atmospheric model and varies from 6.1 R_T (Titan radii) to 12.6 R_T for the thin and thick atmosphere models respectively. Figure II-3 illustrates the orbiter encounter relationship from a Saturn centered reference. Since Saturn is the system center of mass rather than Titan, the encounter relative geometries are rather unusual. The orbiter does not approach Titan on the more familiar hyperbolic trajectory but, instead, passes by on a nearly linear trajectory.

The orbiter mission analysis, orbit determination, and encounter trajectory analysis were performed by JPL and the detailed encounter data used in this study are presented in Appendix A of this report.

The probe entry and descent sequence is summarized in Figure II-4. The atmosphere model has a significant impact on the mission sequence and timing as reflected in the descent times. All three probe classes under study have identical entry and descent time histories for each atmosphere model since they have been designed with the same ballistic coefficients (m/C_DA).

A typical Titan probe entry and descent sequence of events is indicated in Figure II-4. The probe is spin stabilized and oriented in inertial space by the orbiter so that it will have a nearly zero angle of attack during the pre-entry and entry phase. The probe is then released from the Saturn orbiter about 5 to 10 days prior to entry. A warmup sequence is begun 5 hours prior to entry to assure that the reference oscillator in the communication subsystem is well stabilized. The pre-entry science

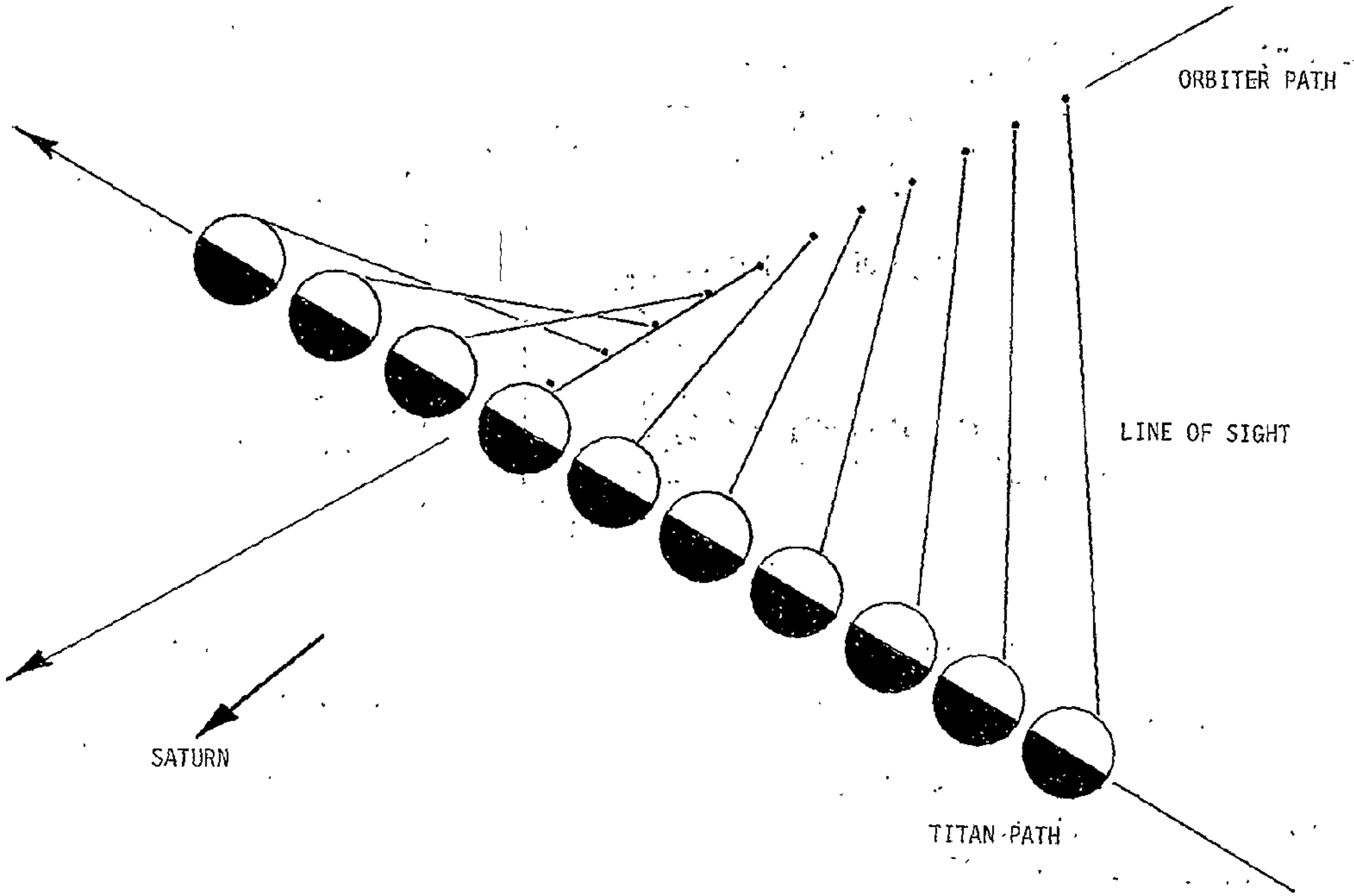
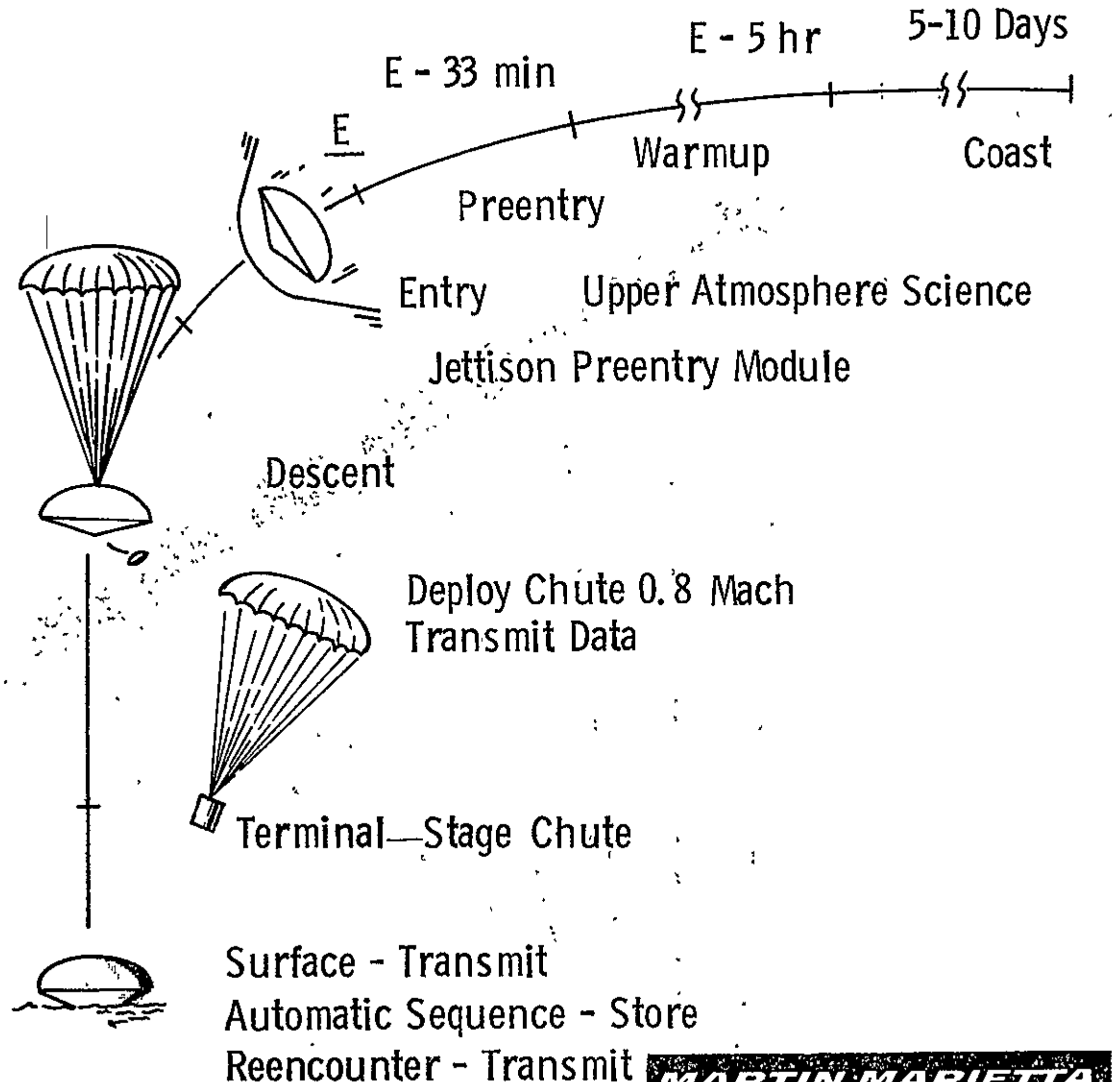


Figure II-3 Encounter - Saturn Centered Reference

Figure II-4 Mission Entry/Descent Sequence - Typical

	Atmosphere Thin	Atmosphere Thick
Entry Time	11.3 min	7.9 min
Descent Time to Surface	25 min	(60%)* 125 min (30%) 283 min (10%) 511 min



*Percent probability of surface location.

instruments (Class B and C probes) are calibrated and pre-entry science data are measured for about 33 minutes as the probe descends through the upper atmosphere. At a signal from the accelerometer triad, the pre-entry science module is jettisoned and the probe enters. After entry when the probe slows to about a 0.8 Mach number velocity, a parachute is deployed (in the case of the thin methane atmosphere) to further slow the probe to allow sufficient time for making science measurements and processing the atmospheric samples. At the time of parachute deployment the protective covers are jettisoned from the science instruments. At an altitude near the surface a radar altimeter signals release of the parachute and the probe vehicle free falls to the surface for a hard landing of nominally 300 g.

As shown in Figure II-4 the descent times are drastically affected by the atmosphere models assumed for the study. The atmosphere models are unrelated in that the thin atmosphere is nearly 100% methane and the thick atmosphere is essentially 100% nitrogen. The thick atmosphere density and extreme surface location result in a total descent time of about 8.5 hours compared to a descent time of barely 7 minutes in the thin atmosphere without a parachute and 25 minutes with the parachute.

The surface sequence depends on the probe class. Class A is a simple atmospheric probe, Class B is a combination atmospheric and lander probe, and Class C is a combination atmospheric and lander probe with expanded surface science and extended mission duration. The Class B lander transmits data from the surface only at initial encounter, while the Class C lander also measures and stores science data while the orbiter is out of sight for later transmission at orbiter re-encounter.

III. SCIENCE REQUIREMENTS

A. INTRODUCTION

Titan, the largest moon of Saturn, is a totally unique planetary body, certain to yield exciting new phenomena. Titan is sufficiently cold and massive to retain a substantial atmosphere, composed largely of reducing gases which are common in the outer solar system. These volatiles provide interesting possibilities for chemical evolution of organic materials through photochemical production, and their probable fallout to the surface leads to the need for chemical characterization of both the atmosphere and surface of Titan. The benign pre-entry environment allows study of energy sources for the formation of organic chemistry, and the radiative and dynamic state of the atmosphere will provide interesting comparative data since it is intermediate between that of Earth and Venus. Although current knowledge of Titan's atmosphere is somewhat uncertain, a more accurate atmospheric definition will be possible before a program start based on new radio astronomy interferometry measurements and results of Pioneer 11 and Voyager flyby of Titan in 1979 and 1980. For this study both a thin methane rich atmosphere and a thick nitrogen rich atmosphere model were included.

The science payload complements for each probe class were selected to give a significant spread in science return between each class in order to more clearly evaluate the impact of science return on configuration design and cost. The NASA/ARC study scientist was responsible for this selection and his recommendations were based on results from the Space Science Board (1975), the Reston Workshop on the Saturn System (1978), and on numerous discussions with planetary scientists throughout the country. As the study progressed, the initial science payload complement evolved in both definition and content.

In most atmospheric science cases, science instrument definitions were obtained from Galileo probe instruments. Additional instrument definitions were based on the Pioneer Venus orbiter and probes, on the Viking lander, or on instruments proposed for a Mars penetrator mission. Some of the more complex surface science instruments, such as the wet chemistry/ozone-analysis device included on the expanded payload Class C lander, were based on follow-on Viking rover studies performed by Martin Marietta.

The science payload complement by probe class is shown in Table III-1, the data requirements are shown in Table III-2, and the physical characteristics of weight, size and power are given in Table III-3.

The science instruments are grouped into pre-entry, atmospheric, surface, and alternate categories and discussed under these headings in the following sections.

In addition, science implementation and integration into the probe are discussed in Section V C.

Table III-1 Science Payload Complement by Probe Class

Instrument	Probes Class A	Probes Class B	Probes Class C	Heritage
Pre-entry				
1. Neutral Mass Spec (1-46 AMU)		X	X	PV (Orbiter)
2. ION Mass Spec		X	X	PV (Orbiter)
3. Retarding Potential Analyzer		X	X	PV (Orbiter)
4. Electron Temperature Probe		X	X	PV (Orbiter)
Atmosphere				
1. Atmosphere Structure Instrument	X	X	X	Galileo
2. Multispectral Radiometer	X	X	X	Galileo
3. Nephelometer with Differential Thermal Analyzer	X	X	X	Galileo
4. Neutral Mass Spec (1-150 AMU Required)*	X	X	X	Galileo, Viking
5. Gas Chromatograph	X	X	X*	ARC
6. Descent Imagery		X	X	Penetrator
7. Doppler/Wind (Stable Osc.)	X	X	X	ARC
Surface				
1. Impact Accelerometer		X	X	Penetrator
2. Composition (Mass Spec & Gas Chromatograph, 250 AMU)		X	X	Viking
3. Meteorology		X	X	Penetrator
4. Surface Imaging		X	X	MP, JPL
5. Passive Seismometer			X	Viking
6. Microscope			X	Langley, Viking, New
7. Precipitation Experiment			X	New
8. Active Wet Chemistry "Ozonanalysis"			X	Viking
9. Alpha-Backscatter			X	Turkovich
Alternate - Surface				
1. Balloon Sonde			X	Earth, Venus Studies, New

*Class B and C use Surface GCMS for Atmosphere Measurement

Table III-2 Science Payload Complement Data Requirements

Instrument	Data Requirements
Pre-entry	
1. Neutral Mass Spec (1-46 AMU)	6 BPS
2. ION Mass Spec	6 BPS
3. Retarding Potential Analyzer	18 BPS
4. Electron Temperature Probe	6
Atmosphere	
1. Atmosphere Structure Instrument	31 Bits/km
2. Multispectral Radiometer	77 Bits/km
3. Nephelometer with Differential Thermal Analyzer	60 Bits/km + 400 Bits/Scale Height
4. Neutral Mass Spec (1-150 AMU)*	25,000 Bits Total
5. Neutral Mass Spec (1-250 AMU) (B and C*)	42,000 Bits Total
6. Gas Chromatograph	10,000 Bits Total
7. Descent Imagery	1.08×10^6 Bits/Picture (2 Minimum)
8. Doppler/Wind (Stable Osc.)	N/A
Surface	
1. Impact Accelerometer	60,000 Bits Total
2. Meteorology	0.2 BPS
3. Surface Imaging	4×10^6 Bits/Picture (Color)
4. Passive Seismometer	2 BPS Low Rate, 40 BPS Event
5. Composition - GCMS* (250 AMU)	130,000 Bits/Sample, 10 Samples
6. Microscope	2×10^6 Bits/Picture
7. Precipitation Experiment	60 Bits/Sample, 100 Samples
8. Active Wet Chemistry "Ozonanalysis"	130,000 Bits/Sample X 4
9. Alpha-Backscatter	30,000 Bits/Sample, 10 Samples
Alternate - Surface	
1. Balloon Sonde	10 BPS

*Class B and C use Surface GCMS for Atmosphere Measurement with Range Restricted to 150 AMU

Table III-3 Titan Probe Science Complement Characteristics

INSTRUMENT	HERITAGE	A	B	C	WEIGHT (KG)	WEIGHT MARGIN TO BE ADDED (%)	VOLUME (CM^3)	SHAPE	POWER (W)
PRE-ENTRY									
Neutral Mass Spec (1-46 AMU)	PV-Orbiter		X	X	4.3	10	4260	--	11.2
Ion Mass Spec			X	X	2.9	10	4425	--	1.5
Retarding Potential Analyzer			X	X	2.7	10	4440	--	2.8
Electron Temperature Probe			X	X	2.0	10	2050	--	4.0
ATMOSPHERE									
Atmospheric Structure Instrument	Galileo-Probe	X	X	X	2.0	10	3100	--	5.5
Multispectral Radiometer		X	X	X	2.5	30	3500	--	4.6
Nephelometer with Differential Thermal Analyzer		X	X	X	2.5	30	3800	--	2.3
Neutral Mass Spec (1-150 AMU)		X			9.0	20	12000	-- *	12.0
Neutral Mass Spec (1-250 AMU)			X	X	13.5	20	18000	-- Class C Uses	18.0
Gas Chromatograph	Viking	X	X	X	6.6	30	6500	-- Surface GCMS	
Doppler/Wind (Orbiter Monitors Transmitter Signal)	-	X	X	X	0.0	30		--	5.0/20 Minutes, 2.0/280 Minutes
Descent Imagery	New(ARC)		X	X	0.25	10	170	--	.9
SURFACE									
Impact Accelerometer	New(ARC)		X	X	0.03	20	30	--	.03
Composition (Uses Atmospheric Mass Spec 250 and Atmospheric Gas Chormatograph)	-		X			30	--	--	
Meteorology	Viking		X	X	0.3	10	300	--	.075
Surface Imaging	Viking		X	X	3.0	30	1854	--	4.0
Active Wet Chemistry (Ozonal)	Viking			X	15.0	30	27400	Front end only - Detector is GCMS	15.0
GCMS (Viking Type)	Viking			X	18.8	30	26500	--	10.0 Heater, 60.0 GCMS
Passive Seismometer	Viking			X	2.23	20	3670	--	4.0
Microscope	LRC Study			X	1.0	30	154	1" L, 1" D	1.0 Preamp
Alpha Backscatter	New			X	2.0	20	2220	--	5.0
Precipitation Experiment	Galileo-Probe			X	2.5	30	4000	--	2.3
Totals (KG)		22.6	42.58	78.51					
ALTERNATES									
Balloon Sonde	Earth Sondes			X	21.0	30	37059	12"D (Tank), 12"D X 12" L Cylinder - for Gondola + Balloon	100/10 Minutes - Heater

B. PRE-ENTRY SCIENCE

1. Objective - The objective of the pre-entry science measurements is to characterize the structure, composition and ionization of the Titan upper atmosphere and ionosphere.

2. Requirements - The pre-entry science instruments required to meet the above objective include:

- o Neutral Mass Spectrometer
- o Ion Mass Spectrometer
- o Retarding Potential Analyzer
- o Electron Temperature Probe

The mass spectrometers are required to measure a mass range of 1-46 AMU.

The pre-entry science measurements are required from a minimum of about 5000 km altitude above the surface down to the continuum atmosphere where the entry aerodynamic bow shock forms. For Titan, the entry altitude is about 500 $\sim$ 600 km above the surface depending on the atmospheric model assumed.

The pre-entry science instrument data requirements are given in Table III-2 and the physical characteristics are given in Table III-3. The characteristics for these instruments are based on Pioneer Venus orbiter and bus upper atmosphere instruments, and the data rate requirements were scaled from previously developed requirements for a Jupiter probe. Differences in approach velocity and flight path angle were taken into account.

The weight for each instrument on Table III-3 is representative of actual weights for identical or similar devices. Note, however, that a "weight margin to be added" is listed for each instrument. This weight margin varies from 10% to 30% depending on the estimated maturity of each instrument in this future application. The margin applies more to the instrument integration and sample acquisition design than to the instrument itself.

The neutral mass spectrometer operates in the ionosphere and upper atmosphere and measures the neutral constituents up to a mass of 46 AMU for comparison with the lower atmosphere neutral mass spectrometer data to characterize the total Titan atmosphere.

The ion mass spectrometer operates in the ionosphere to determine the ionic abundances and provides distribution data as a function of altitude.

The retarding potential analyzer samples the ionic species through the magnetosphere and ionosphere to determine the ion concentrations, ion temperatures, drift velocities and energy distributions.

The electron temperature probe (Langmuir probe) obtains electron number density and temperature through the ionosphere.

C. ATMOSPHERIC SCIENCE

1. Objective - The objective of the atmospheric science measurements is to characterize the atmospheric structure, bulk composition, cloud vertical distribution and composition, and winds.

2. Requirements - The atmospheric science instruments required to meet the above objective are as follows:

- o Atmosphere Structure Instrument
- o Multispectral Radiometer
- o Nephelometer with Differential Thermal Analyzer
- o Neutral Mass Spectrometer (1-150 AMU)
- o Gas Chromatograph
- o Doppler/Wind (stable oscillator)
- o Descent Imagery (supports cloud imagery and surface science)

The data requirements and physical descriptions for these instruments are given in Tables III-2 and III-3.

The atmospheric structure instrument consists of an accelerometer triad, and pressure and temperature sensors. Deceleration and pressure data are required throughout the entry and descent phase and temperature data is required during descent.

The multispectral radiometer includes both UV and visible light channels. It requires about a 90-degree field of view out and up.

The nephelometer measures cloud particle (aerosol) reflectance and density of particles while the differential thermal analyzer provides information on the aerosol composition. The differential thermal analyzer (DTA) is a small quartz crystal with a resonance frequency which is a very sensitive function of mass loading. It is placed in or parallel to the nephelometer inlet stream, and aerosol is deposited on the crystal. The crystal is heated, and the mass loss at a given temperature is recorded. This unit must be deployed into the airstream after the entry heating period is completed and functions during subsonic descent to the surface.

The neutral mass spectrometer defines atmosphere and aerosol composition and must cover a mass range of 1-150 AMU. Its sample acquisition device is activated after entry and the spectrometer operates during subsonic descent to the surface. A second mass spectrometer is shown in the listings of Tables III-1 through -3 with a mass range of 1-250 AMU for the Class B and C probes. In the case of the landers, the mass spectrometer is used both for atmospheric descent measurements and surface composition measurements, and a mass range of 1-250 AMU is required for the surface measurements.

The gas chromatograph (GC) also provides composition measurements for atmospheric gases and complements the mass spectrometer information. The current GC designs require considerable time to obtain, process and purge samples through lengthy columns (about 30 minutes for four analyses). It has been estimated by Dr. V. Oyama of NASA/ARC that technology appropriate to the Titan mission would allow use of a GC with mass, volume, power, and sample time decreased by a factor of 4-10 over current state-of-the-art designs such as that used in this study.

The descent imagery requires a framing camera (snapshot to stop movement) with sensitive light detection. A CCD (charge coupled device) imaging camera is appropriate for this application. The estimated surface illumination at the Titan subsolar location is a maximum of about .009 W/m^2 and possibly less by a factor of 2 due to cloud layers. By comparison, Venus surface illumination was measured by the Venera lander at about 40 W/m^2 and a moonlight night on Earth is about .003 W/m^2. A minimum of two images are required with more desired.

For the Doppler/wind tracking experiment, the telemetry transmitter oscillator on the probe requires a 3×10^{-10} rms phase stability during the descent period. The orbiter receiver must be capable of detecting frequency shifts of this order of magnitude. The oscillator requires a warm-up time of a minimum of five hours of which the first 20 minutes requires 5 W of power and the remainder requires 2 W.

D. SURFACE SCIENCE

1. Objective - The objective of the surface science is to determine the composition and structure of the surface and interior, and the properties of organics and precipitants. The surface science also supports the atmospheric science through use of a meteorology experiment which measures local near surface atmospheric pressure, temperature and winds.

2. Requirements - The surface science instruments required to generally meet the above objectives are as follows:

- o Impact accelerometer
- o Composition using mass spectrometer and gas chromatograph
- o Meteorology
- o Surface imaging

The expanded surface science payload, which can provide more definitive data, but is not necessary for a basic understanding of the planet, is as follows:

- o Passive seismometer
- o Microscope
- o Precipitation experiment
- o Active wet chemistry "ozone analysis"
- o Alpha-Backscatter experiment

The data requirements and physical descriptions for these instruments are given in Tables III-2 and III-3.

The impact accelerometer must have a range from 0 - 3930 m/s^2 (400 g's). The hard lander is designed to sustain a maximum deceleration of 2945 m/s^2 (300 g's) on impact with a solid surface. The impact accelerometer stroke time history at impact should provide some information on the surface hardness. The surface may vary in consistency from solid ices to snow to liquid.

The surface composition instrument uses both a mass spectrometer and a gas chromatograph. The same instruments are also used for atmospheric composition measurements during descent. This experiment requires devices for sample acquisition and sample processing at pre-selected step wise temperatures up to 2 to 3 X 100 K in a sealed oven so that gaseous products can be carried into the detecting instruments. In addition, suitable manifolding is required to deliver the gaseous samples either to the GC and MS in parallel (separately) or in series first through the GC and then into the MS. The MS must have a mass range from 1-250 AMU in order to cover the anticipated range of surface materials which may include ices, clathrates, and organic material. A discussion of methods of implementing this sample acquisition system is presented in Section V D 1. Additional experiments for measuring composition are also discussed later in this section under the expanded science payload. These instruments include a precipitation experiment, a wet chemistry "ozone analysis", and an alpha-backscatter experiment.

The meteorology experiment includes sensors for atmospheric pressure, temperature, and wind velocity and direction. The wind detector and temperature sensors should be mounted at least 1 meter above the surface. The descent pressure sensor is also used for this experiment.

The surface imaging requires a high quality color image (three black and white with appropriate filters). The imager may be a CCD type or a facsimile type camera. With a CCD the analog data is read directly into an analog delay line buffer device just as in the descent imaging equipment and then the data is digitized and transmitted to the orbiter. The facsimile type camera is scanned at such a rate that the data is transmitted directly to the orbiter as it is generated and, therefore, a large scale buffer or data storage is not required. With appropriate filters both color data and infrared spectral information are obtained from the sensors. For the facsimile camera, imaging is accomplished by a helical scan of the field. Horizontal lines extend for a full 360° while vertical range of scan is 90°. Nine hundred (900) horizontal lines representing a field of view of 360° x 90° is divided into 0.1° increments resulting in 108,000 pixels. With a 12-bit word per pixel and three images per color picture, a data requirement of about 4×10^6 bits per color picture results. A discussion of imaging implementation and light level requirements is included in Section V C 3.

The passive seismometer will provide information on the internal structure of Titan if any events are recorded during the extended mission of the Class C lander. This period is a minimum of several months. The seismometer is based on the Viking design which features a standby low data rate mode and an event or high data rate mode which is triggered by an event. It is desirable to place the instrument in solid contact with the surface to provide effective coupling.

The microscope is a low power device which can provide useful information about ice crystallography and inorganic grains and give an indication of the "weathering" history of the surface. Accurate focusing is required since the depth of field is critically small on this type of device.

The precipitation experiment is included to determine what is precipitated, when, how much, and how often. The instrument could be turned on by a deposition sensor, or it could be periodically queried for a non-zero response. For this study a nephelometer type device with a differential thermal analyzer element was assumed for weight, power, volume, and data rate requirements. A more refined approach requires additional study and development.

The active wet chemistry "ozone analysis" experiment complements the gas chromatograph and mass spectrometer composition measurements. It is intended to provide additional composition data by inducing active chemical reactions between the surface samples and an oxidizer such as ozone introduced in a sealed container. The output gases are then fed into the inlet of the GCMS instrument for detection.

The alpha-backscatter instrument also complements the GCMS composition measurements by providing elemental analysis (H, C, N, O primarily) of the surface samples. The possibility of significant surface pressures puts additional requirements on the alpha backscatter instrument. Because of alpha particle absorption in the atmosphere, the sample must be brought into very close proximity to the alpha source and detector or the atmosphere must be evacuated from the sample and instrument. The extremely long mission duration of 7 to 8 years requires that a new alpha source be found. Current sources used in this application have half life periods that are too short. Isotopes of Californium appear to be suitable candidates.

E. ALTERNATE SCIENCE

1. Balloon Sonde - The helium filled balloon sonde was included as an alternate experiment for the expanded science payload of the Class C probe lander. This experiment provides a pressure and temperature profile with altitude at a period in the diurnal cycle which can be selected to be different from the initial descent profile. For example, the initial entry, descent, and landing target is near the subsolar region where maximum light levels are desired for both imaging and multichannel spectrometer experiements. An appropriate launch time for the balloon sonde would therefore be on the night side some 8 days after landing. A more ambitious balloon sonde might also provide information on winds if the lander were equipped with necessary tracking gear.

In the SOP² Reston Workshop (1978), a Montgolfiere type solar-powered, long-lived balloon concept was presented by J. Blamont of CNES and the concept was endorsed for further consideration in the Titan probe study. Further study of the balloon requirements in a more realistic Titan environment was done by CNES just prior to start of this study. A dust or aerosol optical depth less than three is required for successful operation of the balloon in even the "thick" atmosphere, at a pressure level of several hundred millibars. The best current estimate of the total aerosol optical depth is 6-10 at visible wavelengths, and the pressure at optical depth 2 is roughly only a few millibars even in the "thick" atmosphere. Therefore, the passively heated, long-lived balloon concept does not seem to be viable in the Titan environment. A heated balloon has been suggested by CNES, but this type of balloon would either be very heavy (~200 kg including science), or would be very short-lived. In addition, further research on balloon skin material properties is required. Therefore, as further work on this balloon concept was beyond the scope of the present study, it was recommended by NASA/ARC that no further effort be devoted to incorporation of a Montgolfiere balloon into the probe missions to Titan at this time.

TITAN ATMOSPHERE MODELS

The Titan atmosphere models used in the entry and descent analysis were based on data provided in Attachment 1 to the RFP, Reference 1. Two basic models were presented in the above reference, a thin model composed of 100% methane and a thick model composed mostly of nitrogen. The basic characteristics of the thin model as given are shown in Table III-4.

Table III-4 Thin Model Atmosphere (Methane)

T °K	Pressure (mb)	Altitude* (km)
160	0.11	226 (2900 km R_p)
78	10	0
78	17 (surface)	-16

*Altitudes are modified from the RFP values to satisfy the hydrostatic equation.

The basic characteristics of the thick (nitrogen) model are shown in Table III-5.

Table III-5 Thick Model Atmosphere (N_2)

T °K	Pressure	Altitude* (km)	
160	2.6 mb	248	
117	10.0 mb	200	(2900 km R_p)
72	85.0 mb	148	
72	480.0 mb	118	
86	1.2 bar	138	
100	1.9 bar	85	(60% probable surface temp.)
150	7.8 bar	43	(30% probable surface temp.)
200	21.0 bar	0	(10% probable surface temp.)

*Altitude scale shifted to 0. at 10% probable surface temperature to facilitate trajectory analysis.

Dispersed models for the thin (methane) model are derived by perturbed temperature - altitude profiles, based on the error bar shown in Reference 1. The thin model temperature profiles and the resulting pressure and density vs altitude plots are presented on Figures III-1 through -3. Thick (nitrogen) model temperature, pressure and density plots are shown on Figures III-1, -2, and -4. Dispersion in this model is provided by the surface temperature uncertainty and resulting surface location uncertainty.

Titan atmosphere state is shown on Figure III-2 for the thin and thick atmosphere models. It is noted that both the thin and thick nominal models are close to a state change from gas to solid or liquid.

Density scale height as a function of altitude is presented on Figure III-5.

Figure III-1 Titan Atmosphere Models

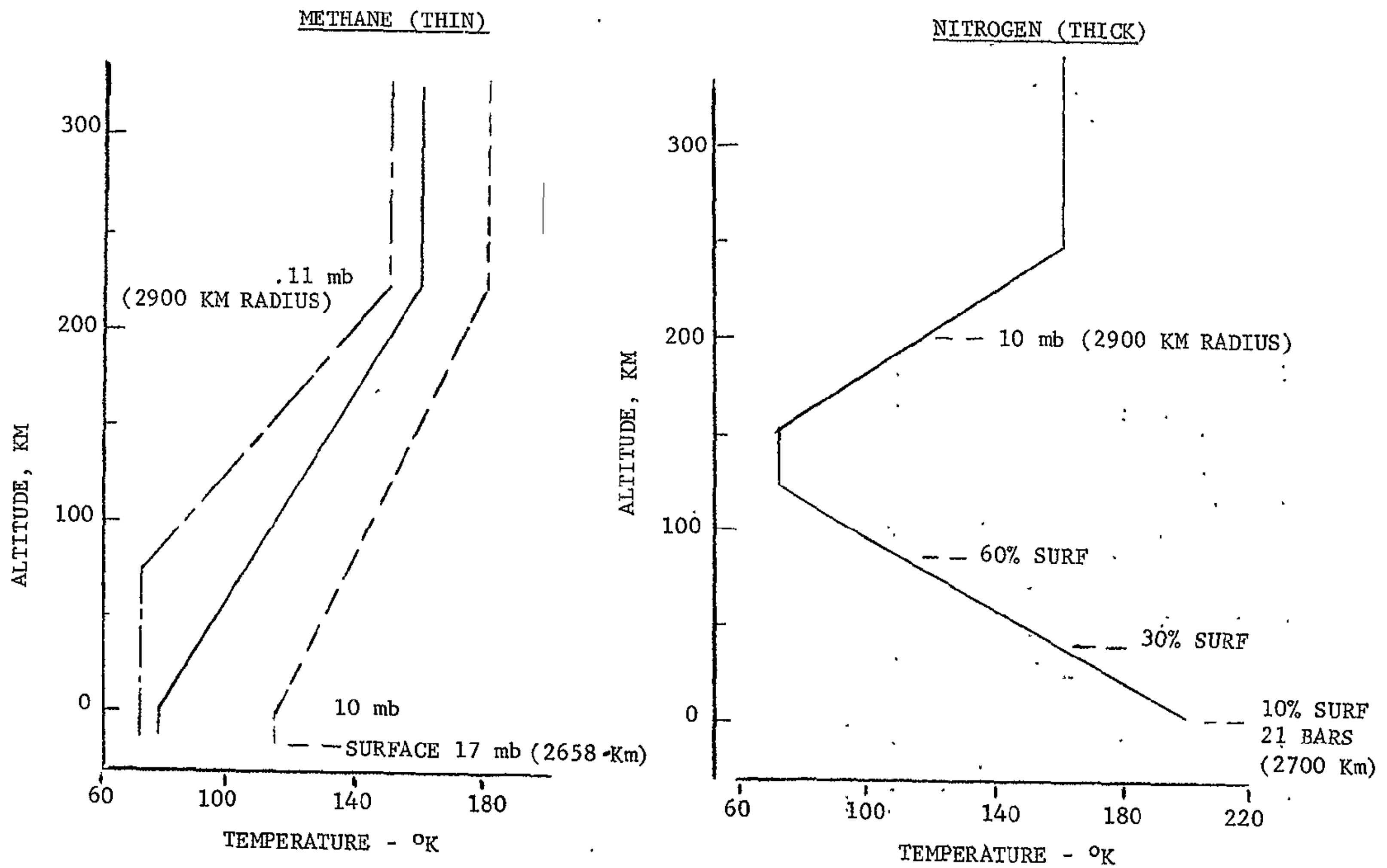


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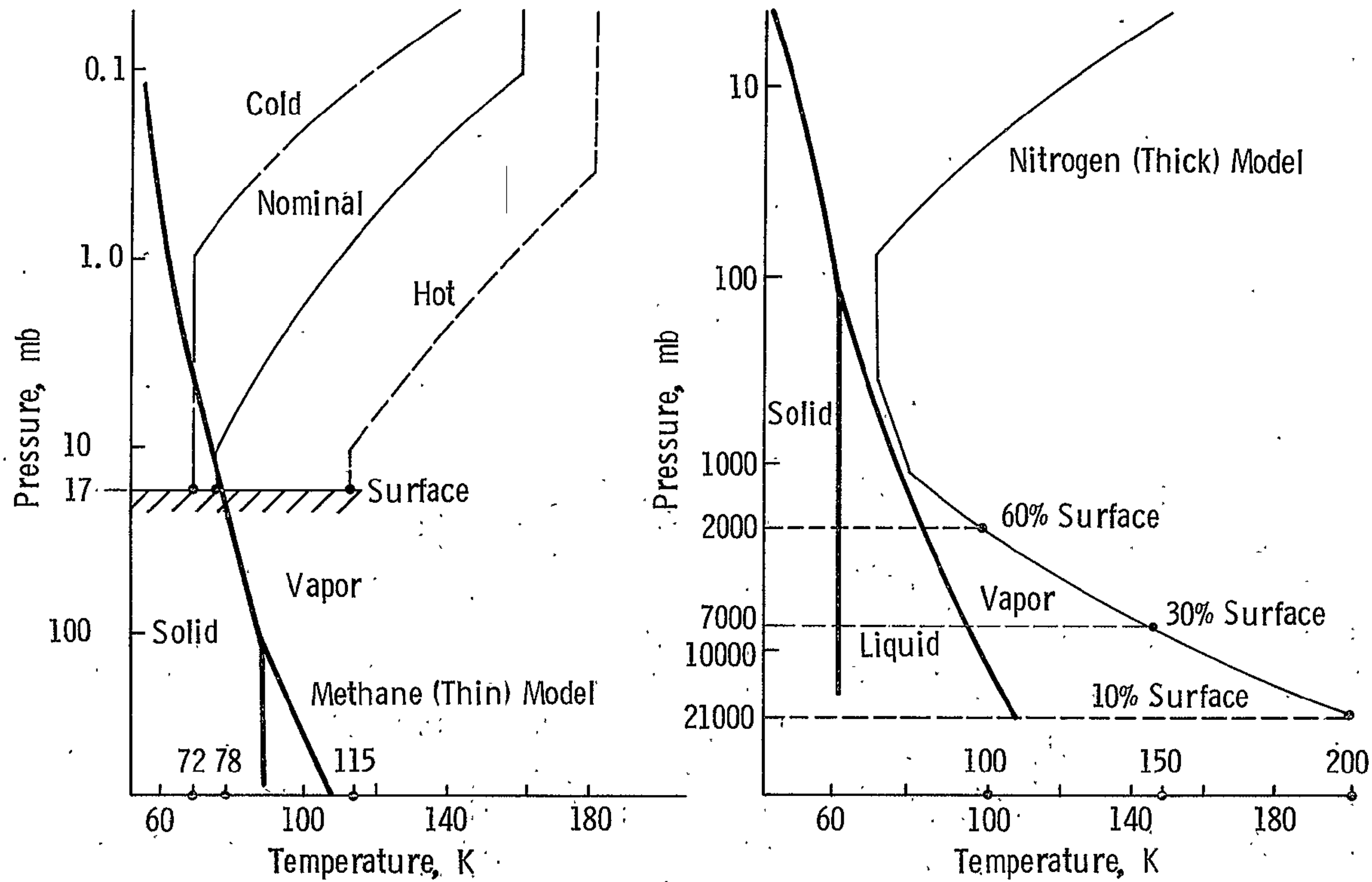
Figure III-2 Titan Atmosphere State



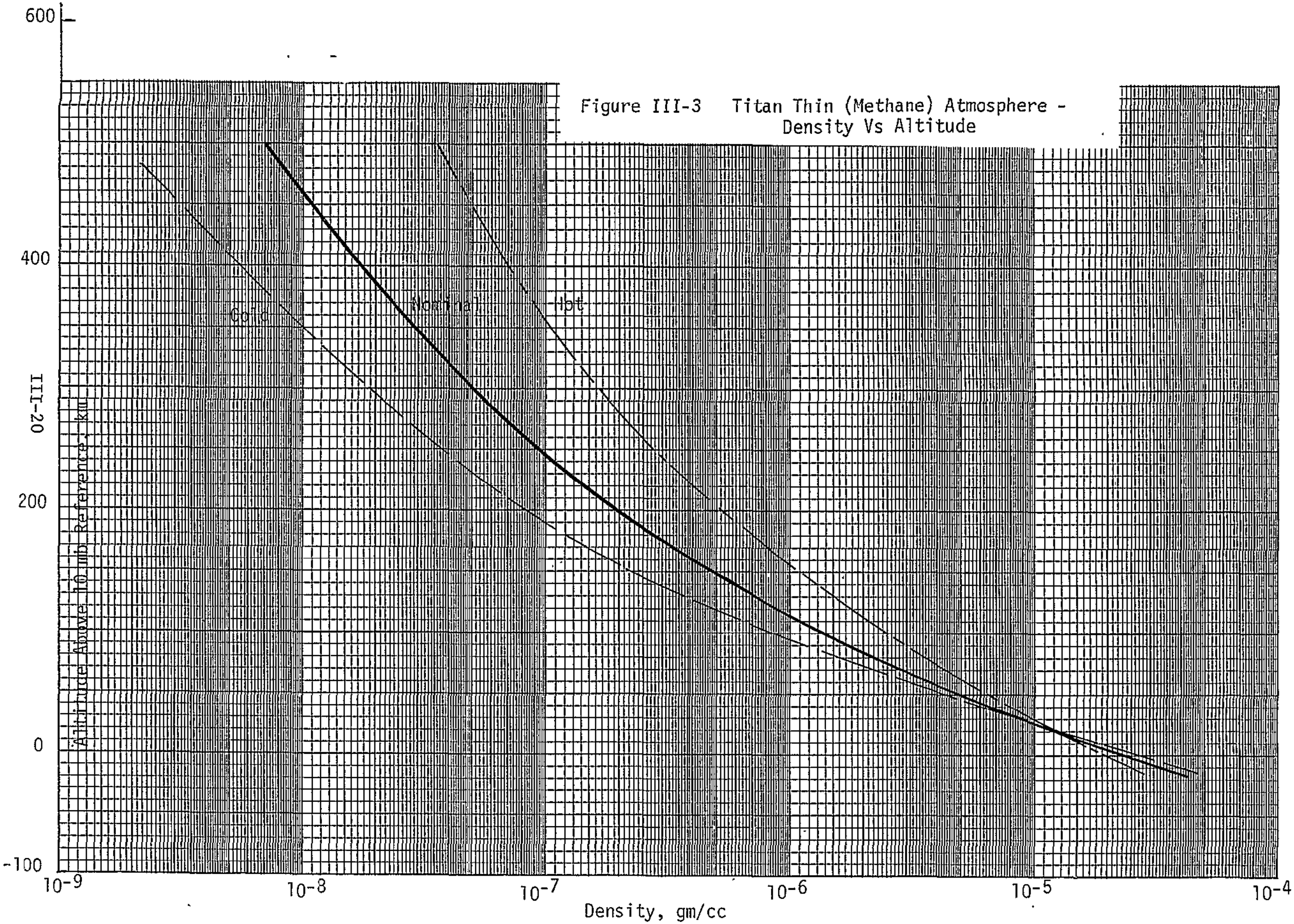


Figure III-3 Titan Thin (Methane) Atmosphere - Density Vs Altitude

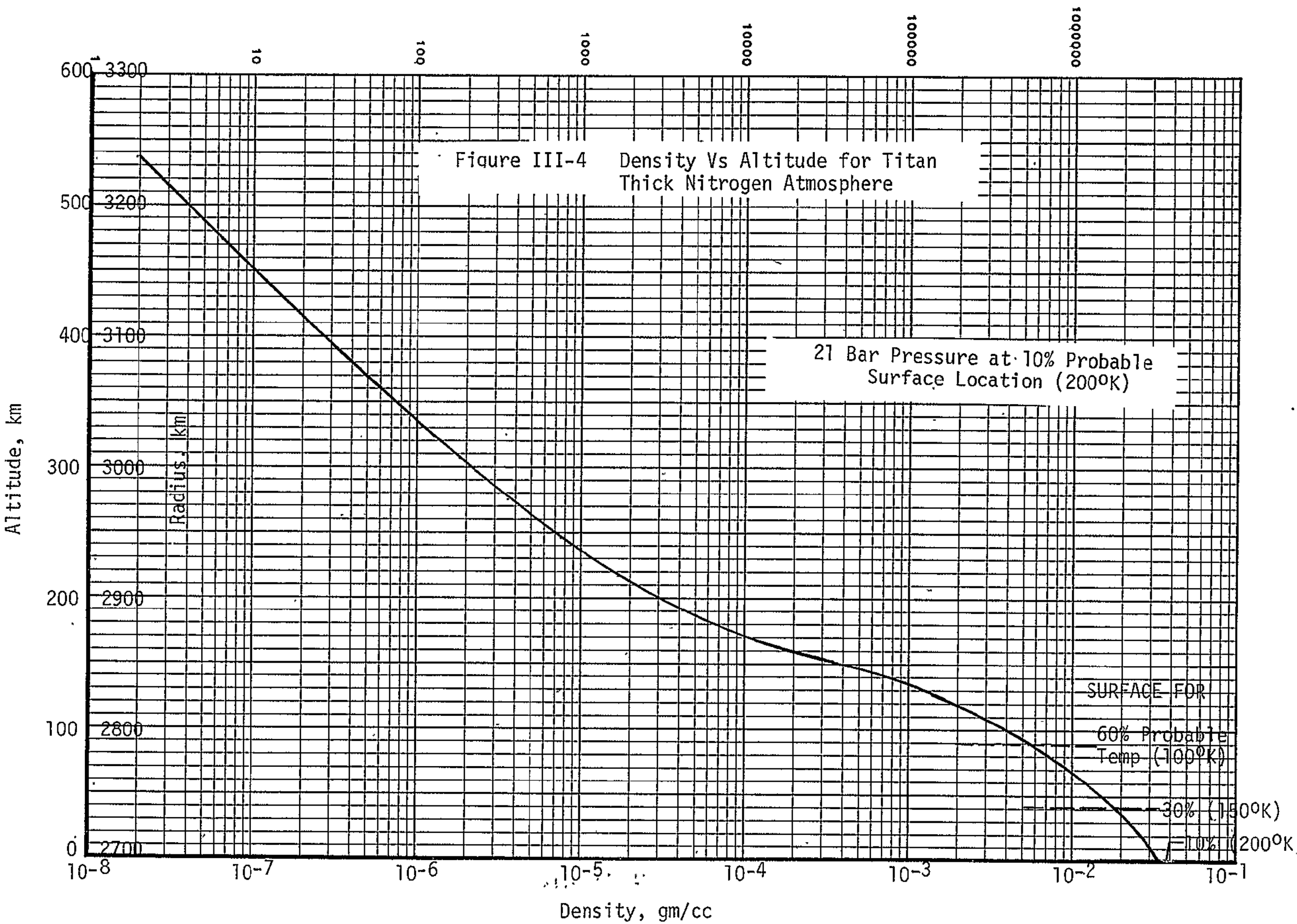


Figure III-4 Density Vs Altitude for Titan Thick Nitrogen Atmosphere

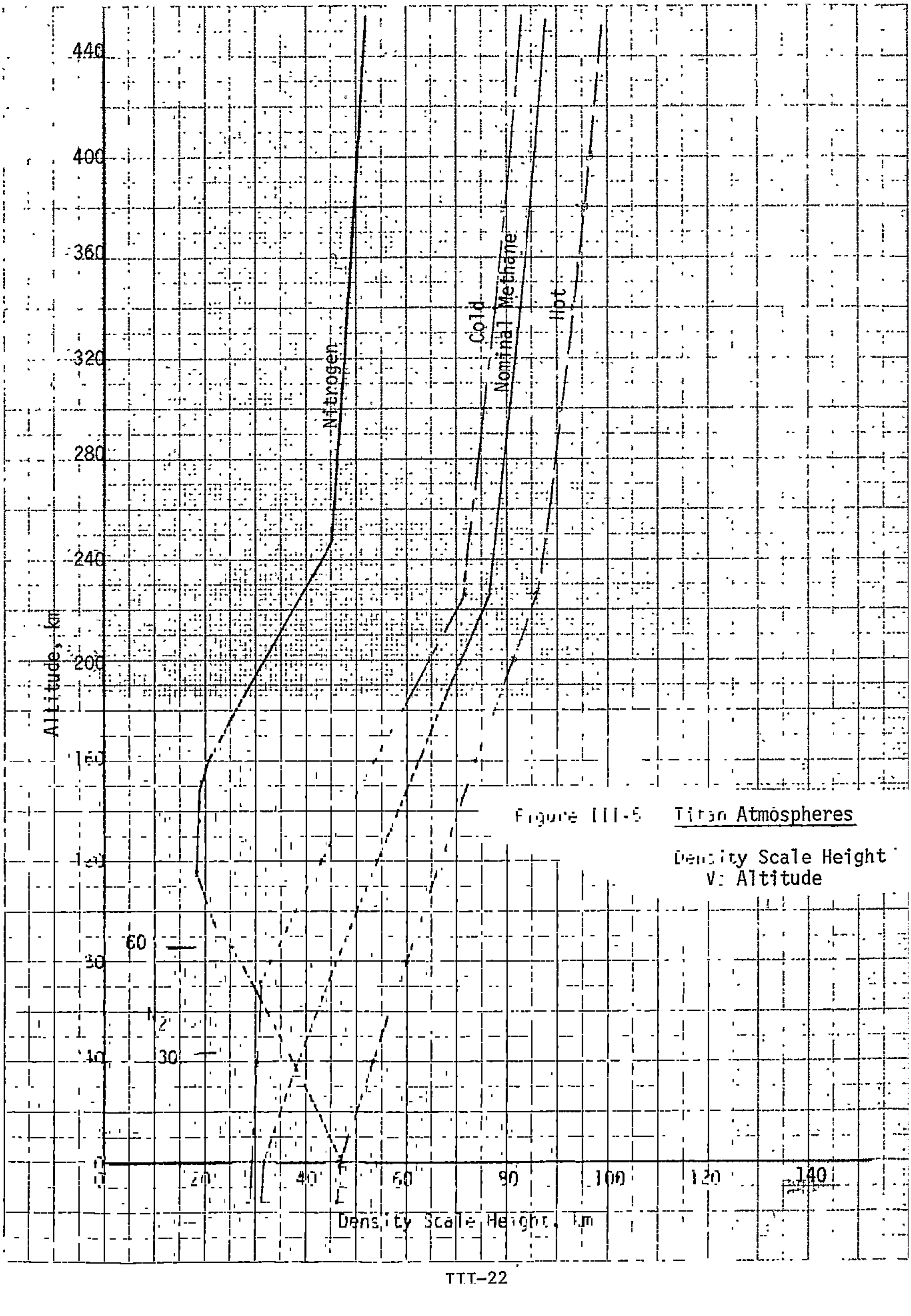


Figure III-5 Titan Atmospheres

Density Scale Height
V: Altitude

IV. TRAJECTORY ANALYSES

A. INTRODUCTION

Entry trajectories were run using the Martin Marietta atmospheric entry program UD288. Trajectories were run in the thin (methane) and thick (nitrogen) atmosphere over a range of entry flight path angles of -30 degrees, -35 degrees and -40 degrees and ballistic coefficients of 31.4, 78.5 and 157 kg/m^2. Entry altitude is defined at a Titan radius of 3200 km with an entry velocity as defined in the JPL supplied data of Appendix A. In the thin atmosphere, parachute deployment is at 0.8 Mach no. No parachute is required in the thick atmosphere.

The bulk of the entry trajectories run were for entry from Saturn orbit. The effect of the higher entry velocities associated with entering the Titan atmosphere from the Saturn approach trajectory is briefly discussed in Section IV. F.

B. ORBITER TRAJECTORIES

Saturn orbiter time histories in the vicinity of the Titan encounter and probe trajectories down to the entry interface altitude were supplied by JPL. The data in tabular form are included in Appendix A. Time histories of Titan relative altitude, latitude and longitude for the orbiter and probe are included. Sets of data have altitude of closest approach as the primary perturbing parameter. Altitudes of closest approach of the orbiter vary from 6.1 R_T (Titan radii) to 20.0 R_T.

C. ENTRY TRADES

Parametric evaluation of the effect on entry environment of entry flight path angle (γ_E), entry ballistic coefficient (B_E) and atmosphere models are presented in Figures IV-1 through 7. Maximum dynamic pressure for the nominal, hot and cold thin methane atmospheres as a function of ballistic coefficient and flight path angle is shown on Figures IV-1 and IV-2. It is noted that the cold methane model provides the highest value of peak dynamic pressure. The thick nitrogen atmosphere value at B_E = 78 kg/m^2 (0.5 sl/ft^2) and γ_E = -30 degrees is shown for comparison. The value is only 240 N/m^2 (5 psf) higher than the critical cold methane model value of 2250 N/m^2 (47 psf) and is therefore not considered to provide a significant variation for conceptual design purposes. Peak heating rates and total heat load are presented parametrically on Figures IV-3, -4, and -5. Note that the cold methane model is critical for heating rate, and over a range of the parametric parameters evaluated, total heat load is critical in either the methane nominal or hot model atmosphere depending on the values of the parameter.

Aeroshell structure and heat shield designs for the entry capsule were based on the applicable critical values from the above charts. An aeroshell structural weight design curve was developed with variables of aeroshell diameter and peak entry dynamic pressure. These data are for a blunted cone class configuration and are based on Martin Marietta and NASA Langley Research Center studies. The structural weight curve is shown on Figure IV-6.

The Titan probe entry skip-out boundary was calculated as a function of entry velocity and results are shown in Figure IV-7. The entry velocity from Saturn orbit is 4.55 km/s giving a skip-out boundary value of -27 degrees. For a direct entry at 10.6 km/s the skip-out boundary is -30 degrees.

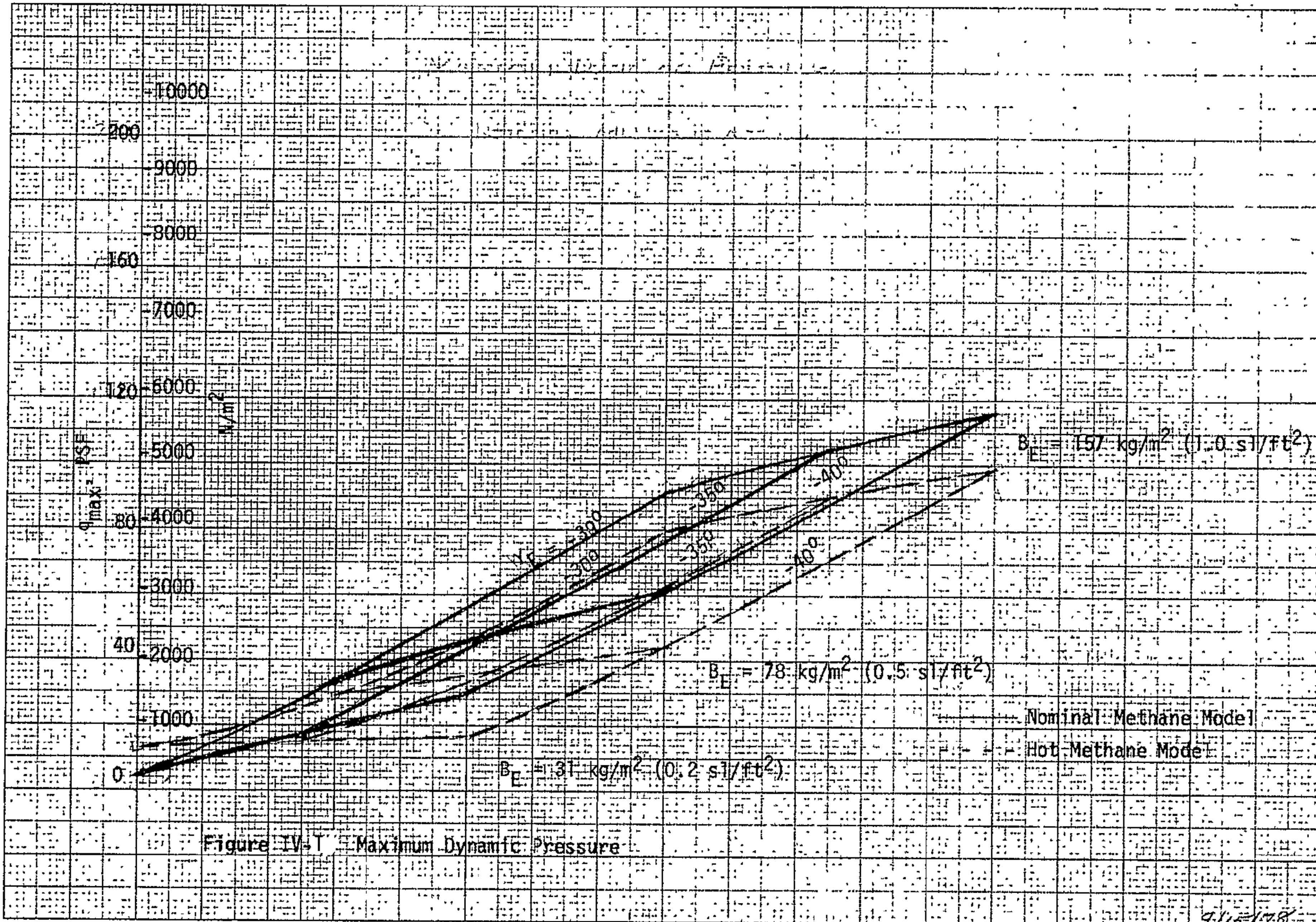


Figure IV-1 Maximum Dynamic Pressure

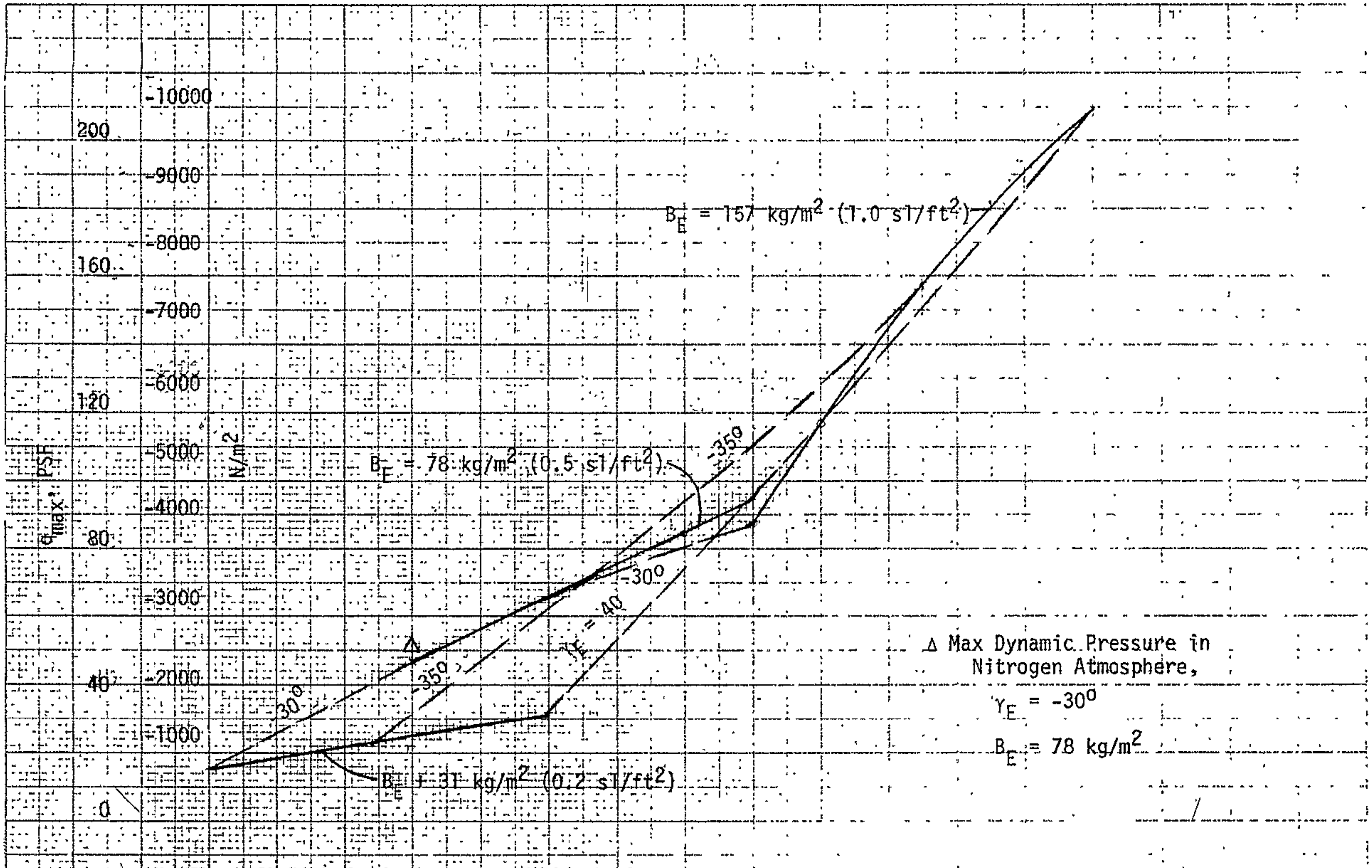


Figure IV-2 Maximum Dynamic Pressure - Cold Methane Atmosphere

9/15/78

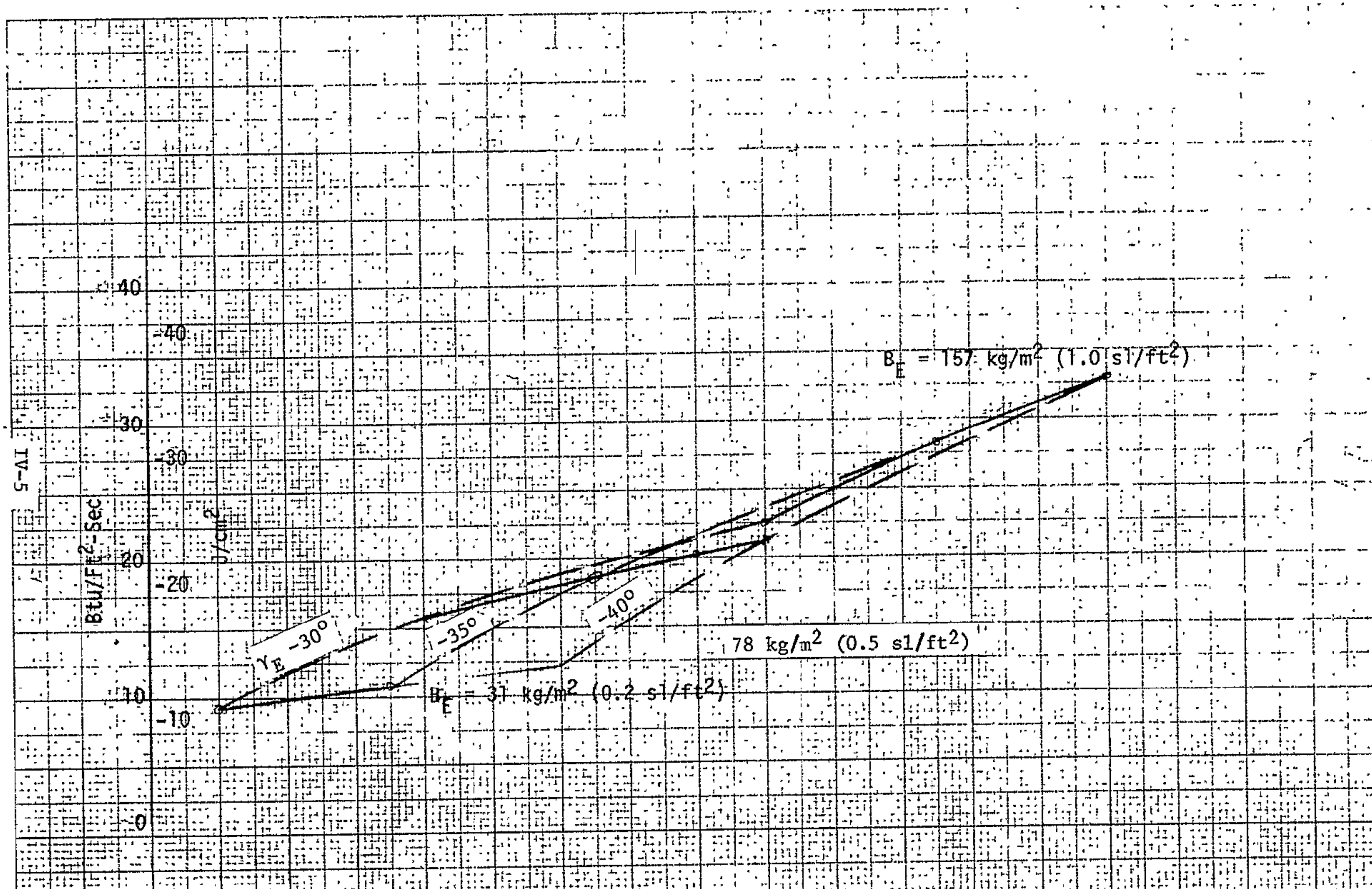


Figure IV-3 Peak Heating Rate - Cold Methane Atmosphere

R_N = 1.0 ft.

9/15/78

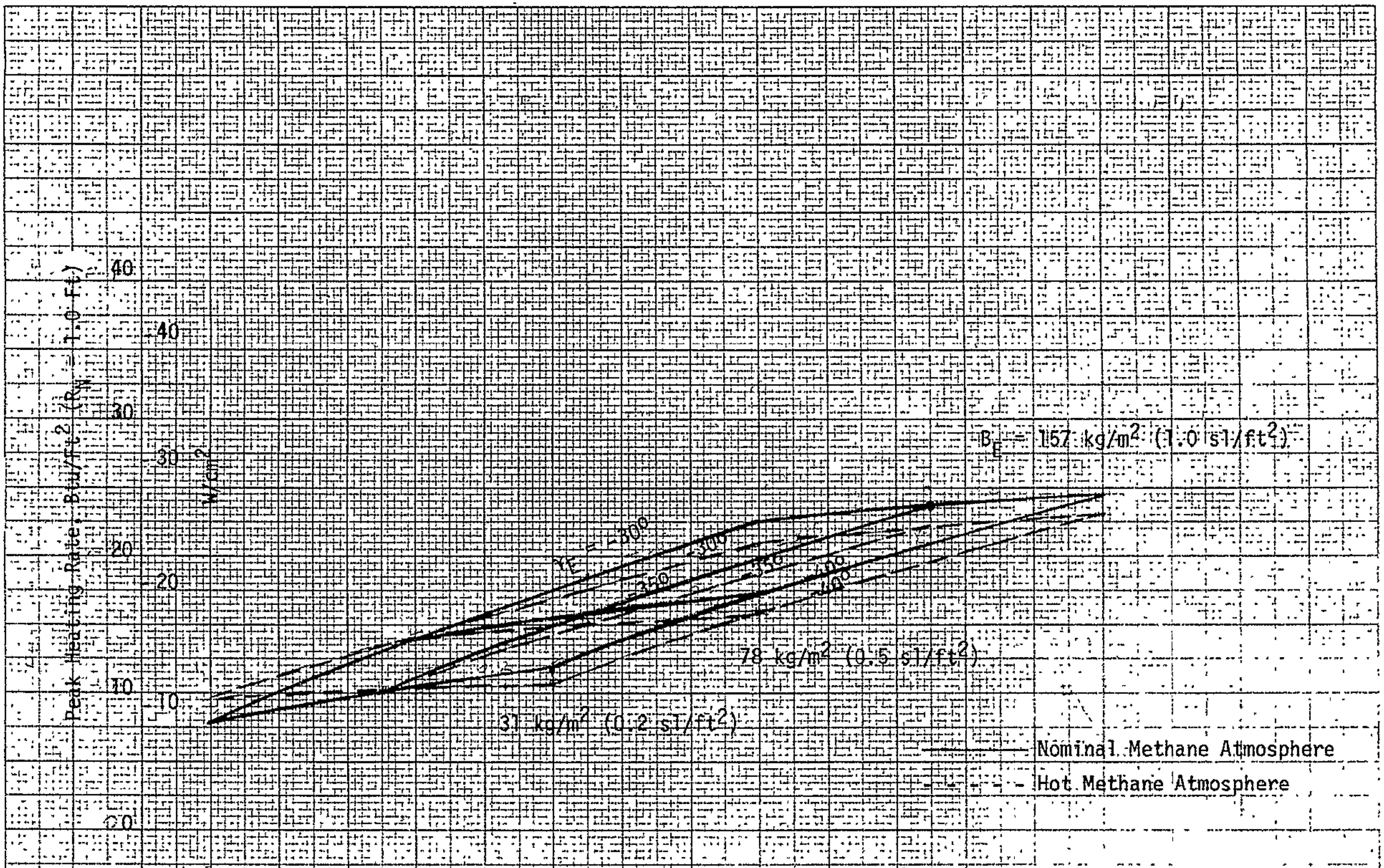


Figure IV-4 - Peak Heating Rate - R_N = 1.0 ft.

9/15/78

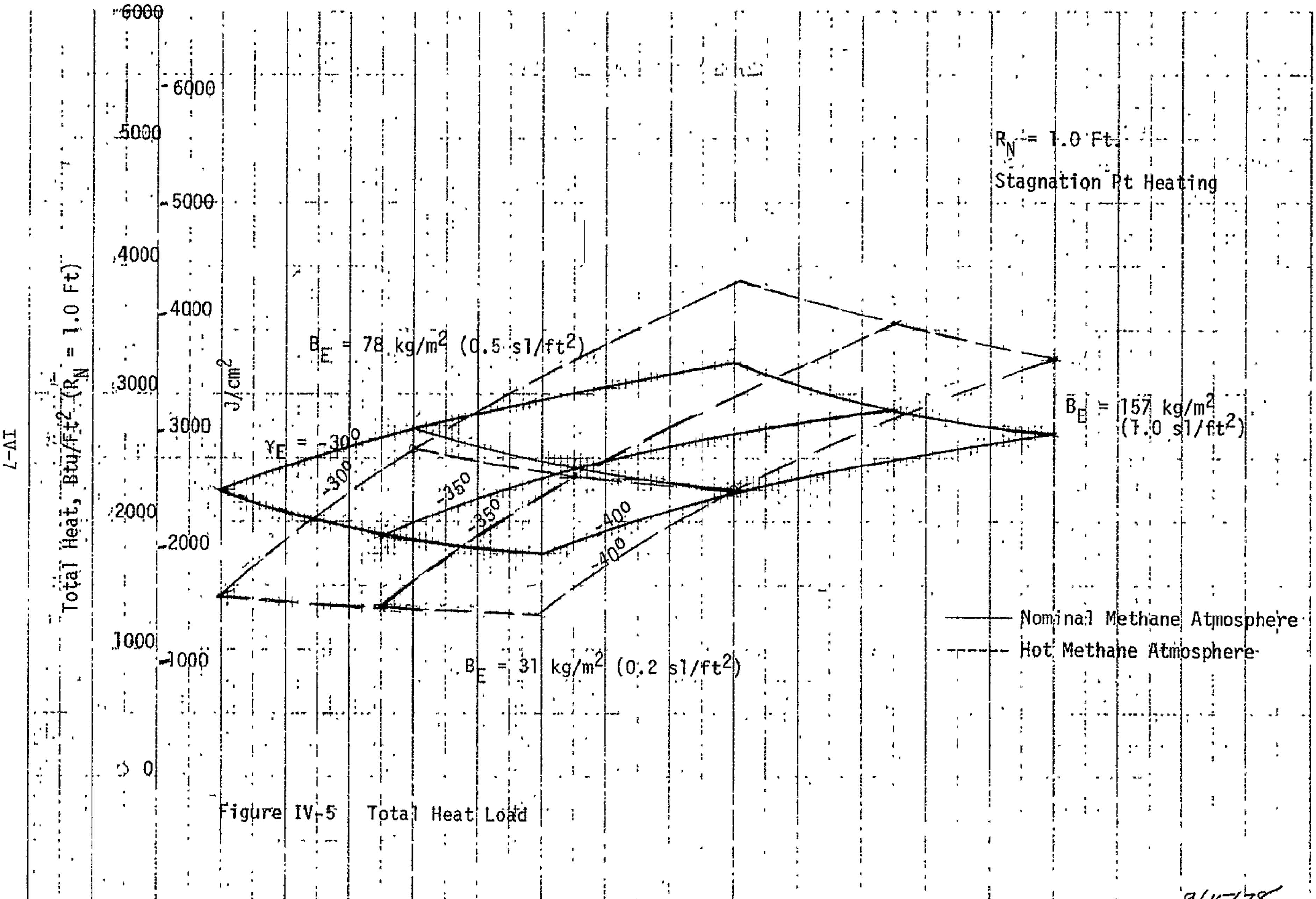


Figure IV-5 Total Heat Load

9/15/78

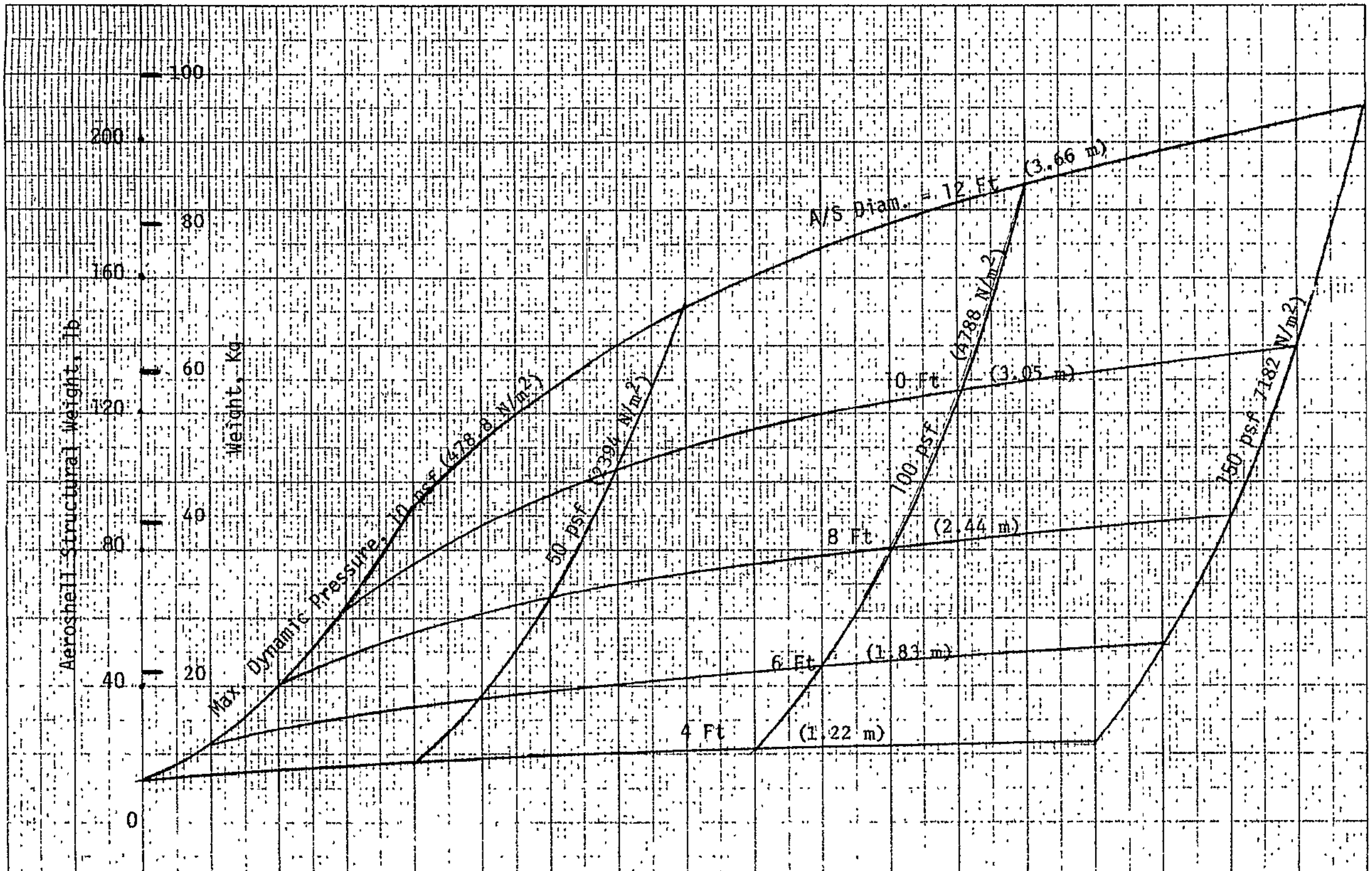


Figure IV-6   Aeroshell Structural Weight Vs A/S Diameter and Peak Dynamic Pressure

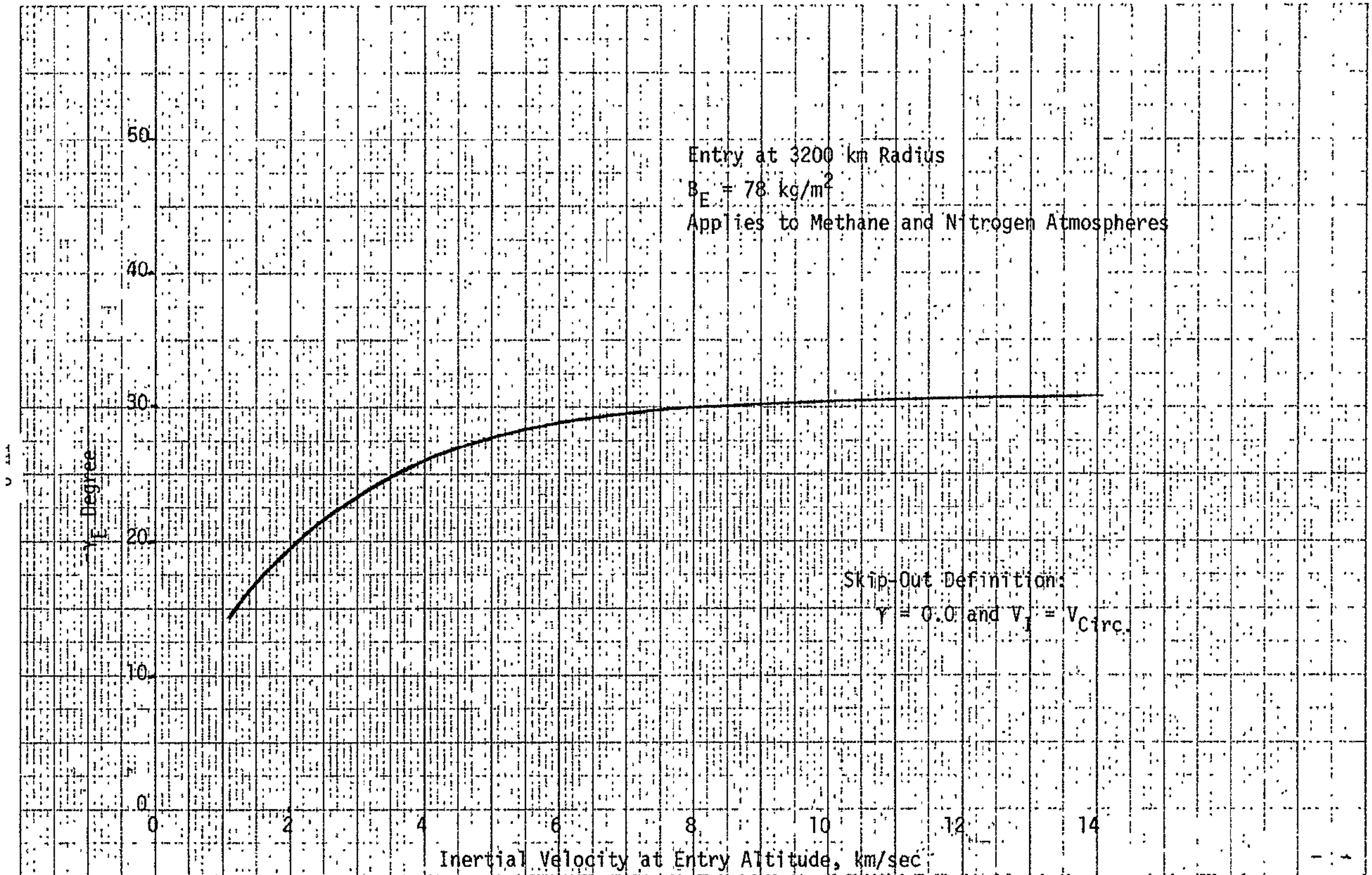


Figure IV-7 Titan Skip-Out Limit

D. DESCENT TRADES

Descent times from entry to the surface in the nominal, hot and cold methane atmospheres are presented on Figures IV-8 and -9. These times are for the unstaged, or fixed entry vehicle configuration without parachute deployment. Descent time including the parachute phase with deployment at Mach 0.8 is shown on Figure IV-10.

Descent times in the nitrogen atmosphere from entry to the 60% probability, 30% probability and 10% probability surfaces as a function of staged ballistic coefficient are shown on Figure IV-11. The times are for entry with a ballistic coefficient of 78 kg/m^2 (0.5 sl/ft^2) and staging to a subsonic ballistic coefficient (B) as shown on the curve.

Terminal velocity in the nitorgen atmosphere as a function of subsonic ballistic coefficients at the 60%, 30% and 10% probability surface is shown on Figure IV-12.

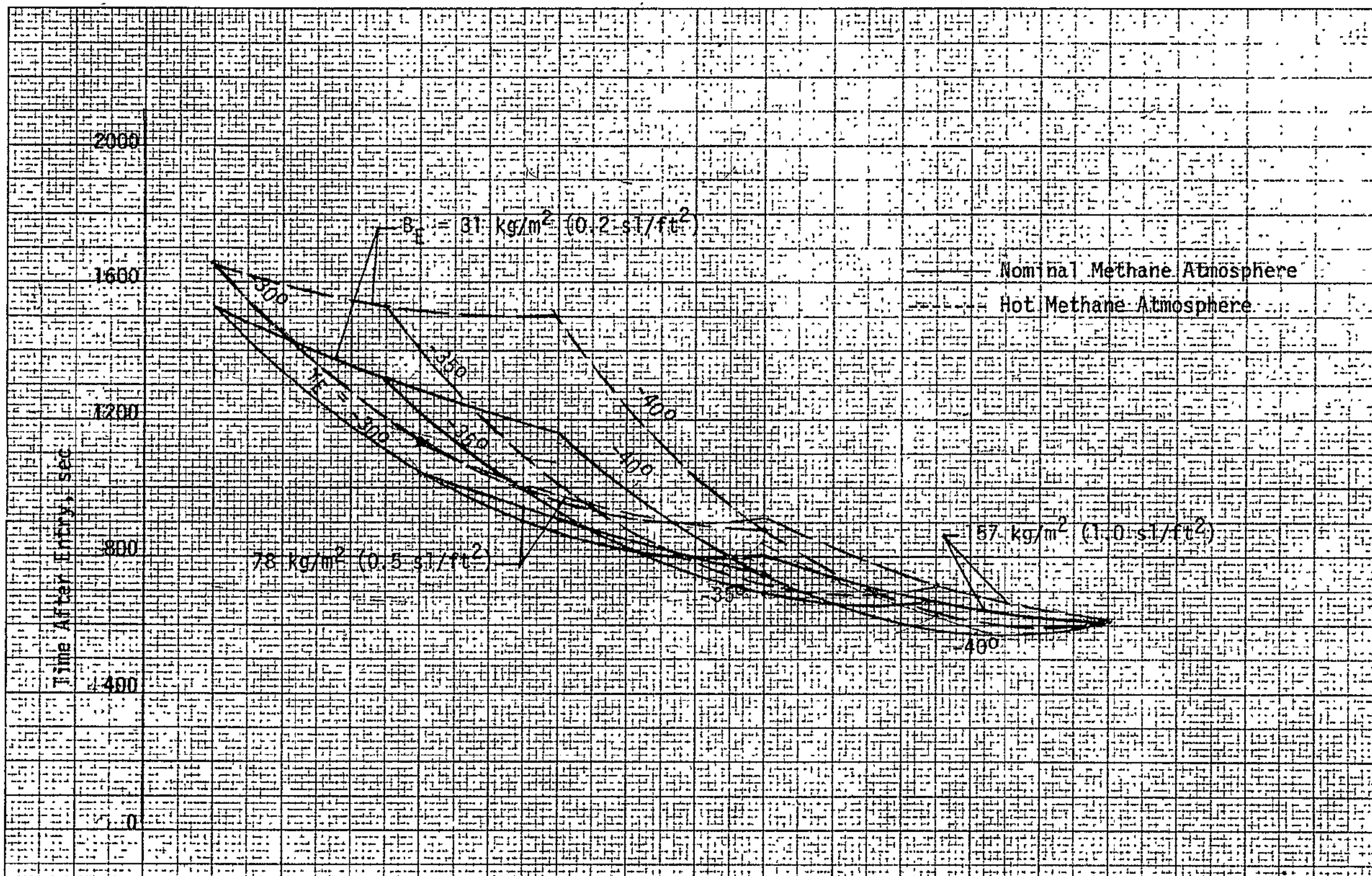


Figure IV-8 Time - Entry to Surface - Unstaged

9/15/78

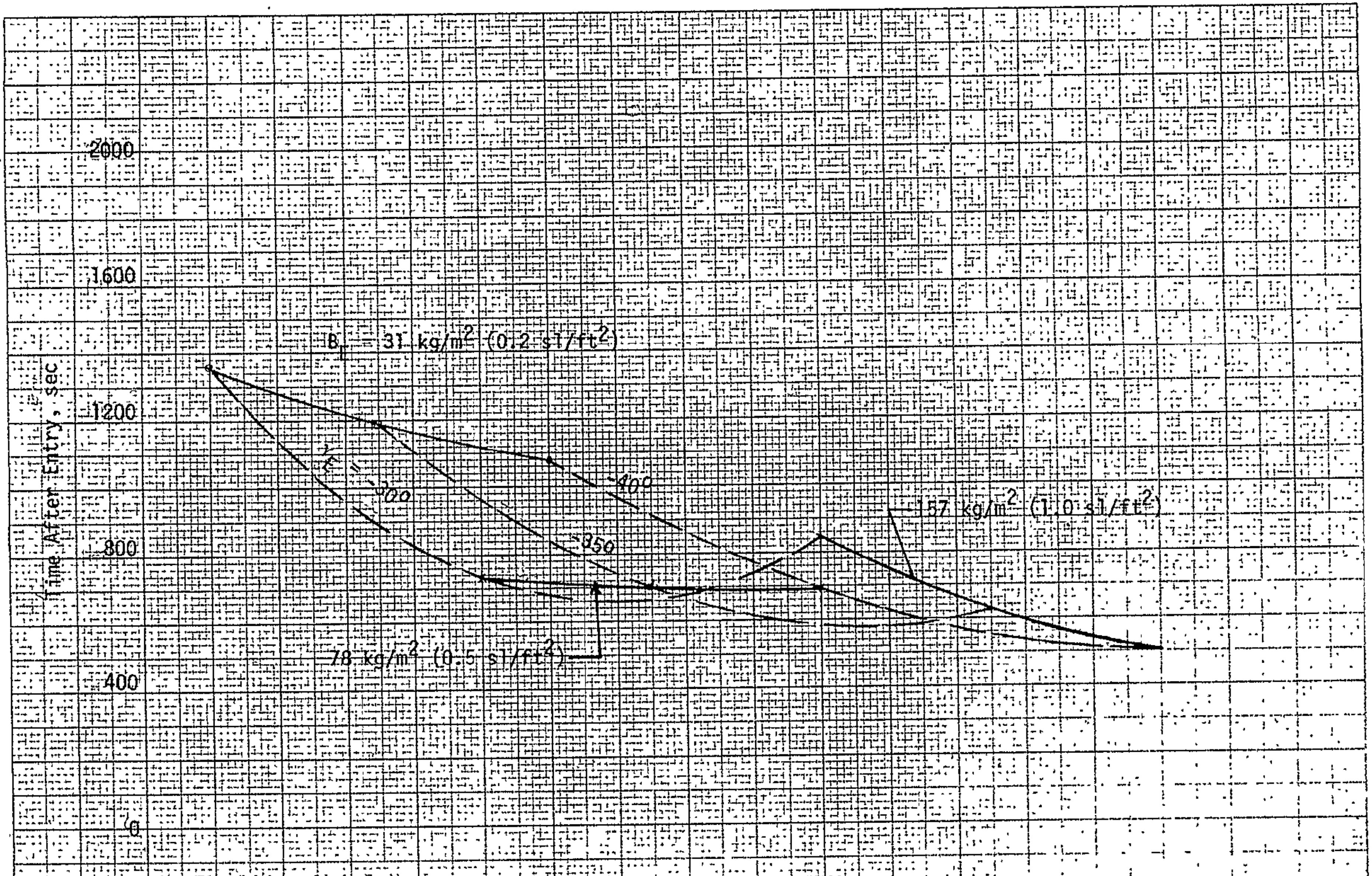


Figure IV-9. Time - Entry to Surface - Unstaged
Cold Methane Atmosphere

9/15/75

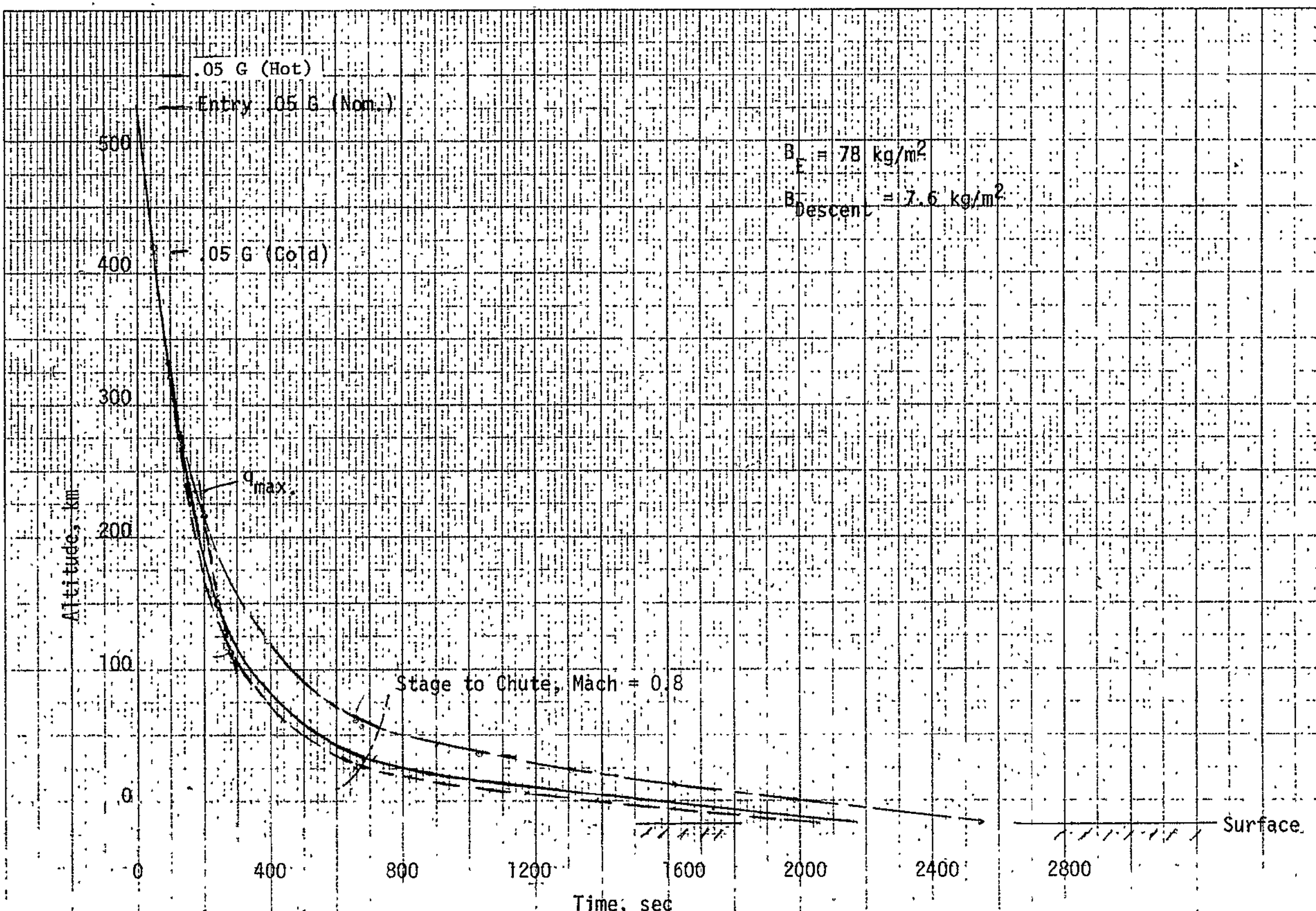


Figure IV-10 Effect of Atmosphere Model on Descent Profile - Thin (Methane) Atmosphere

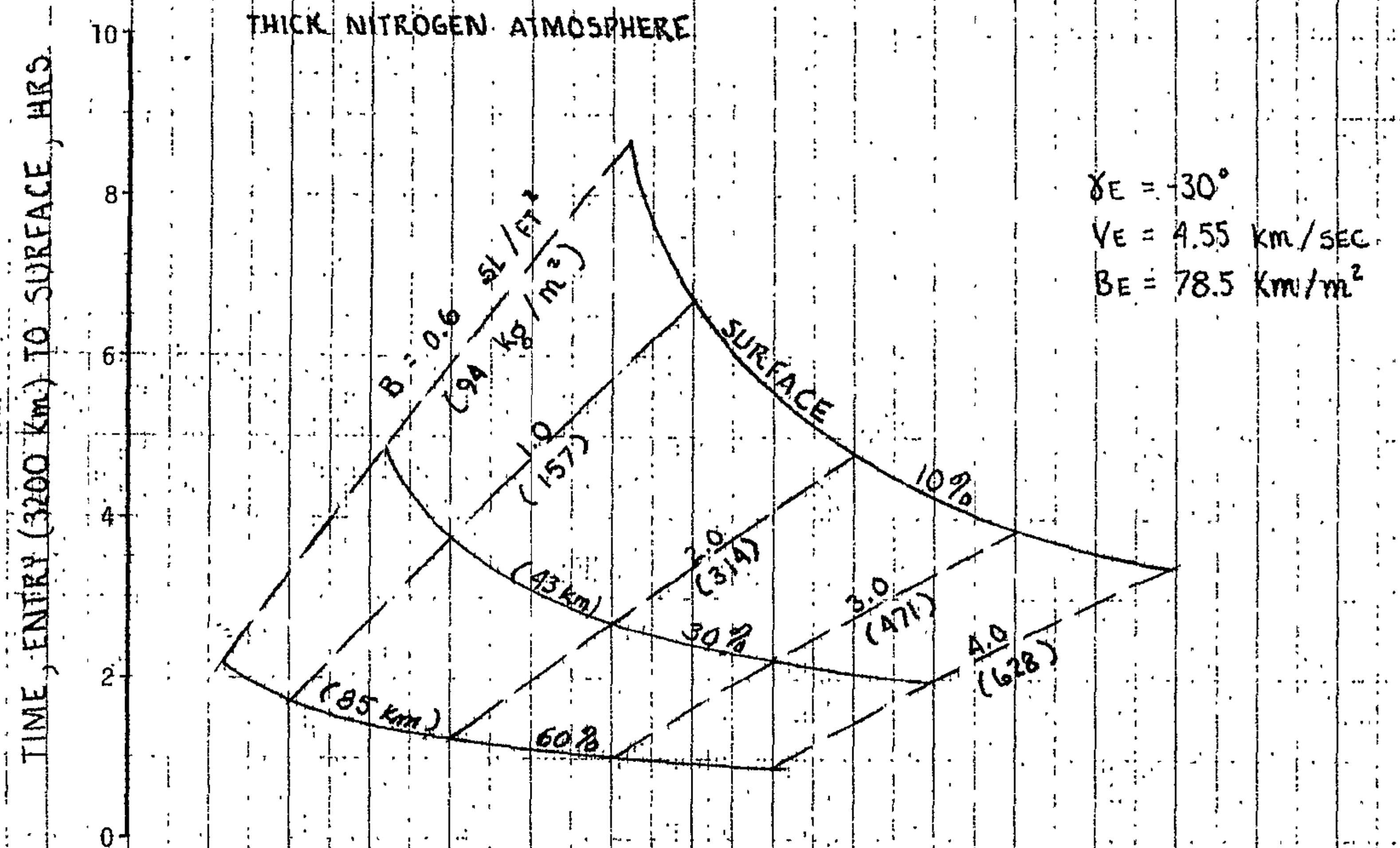


Figure IV-11 Descent Time Vs B_E and Altitude of Surface

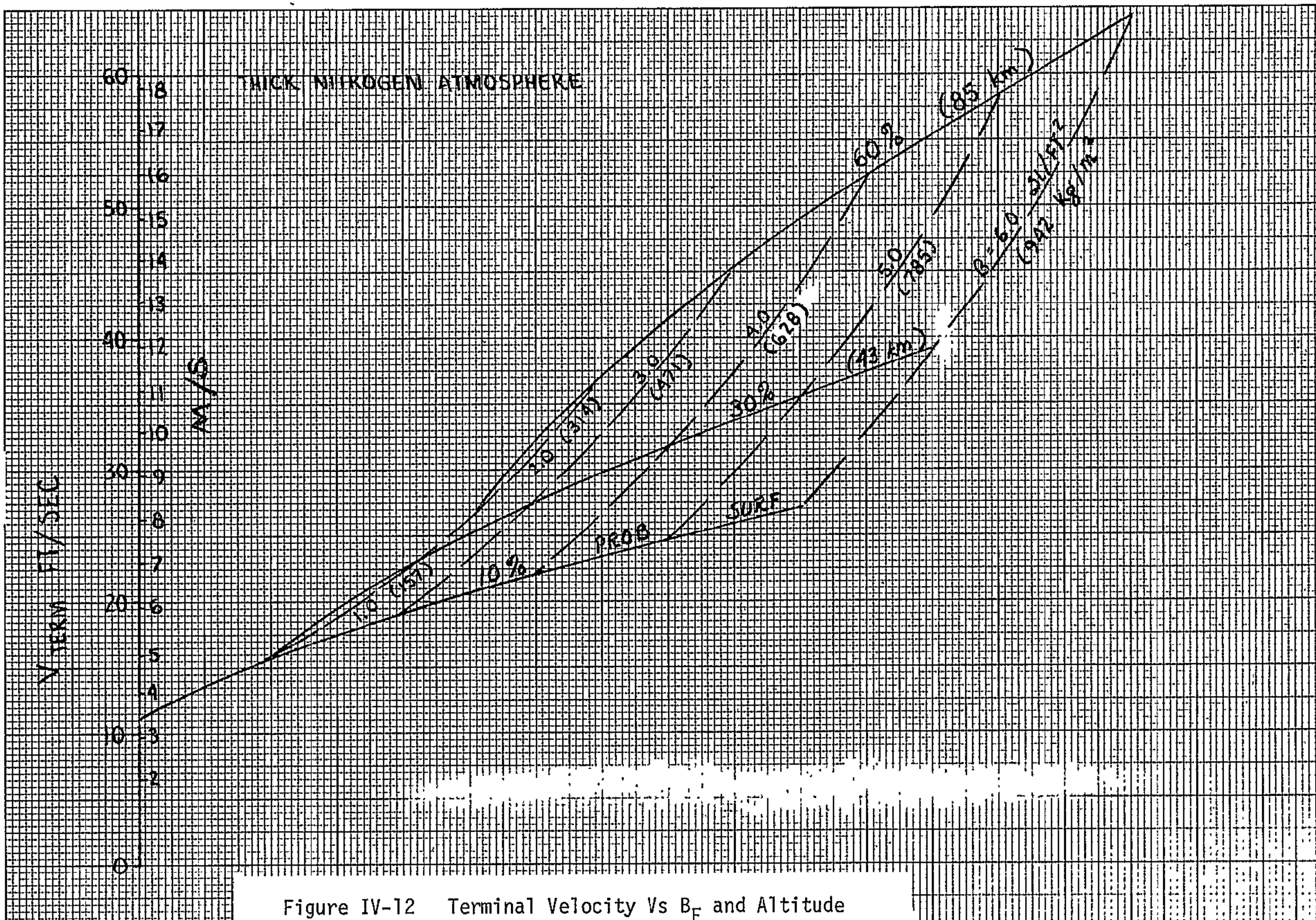


Figure IV-12 Terminal Velocity Vs B_E and Altitude

E. BASELINE ENTRY AND DESCENT TIME HISTORIES

Baseline entry and descent time histories as a function of altitude are shown for the thin methane atmosphere in Figure IV-13 and for the thick nitrogen atmosphere in Figure IV-14. These figures are for the nominal entry conditions, $\gamma_E = -30$ degrees, $B_E = 78.5$ kg/m^2, $V_E = 4.55$ km/sec in the nominal atmosphere models. Noted on the plots are significant entry events and environmental quantities. Table IV-1 summarizes the descent times and altitudes for the thick and thin atmospheres.

F. DIRECT VERSUS OUT-OF-ORBIT COMPARISON

The basic entry and descent analysis was done for velocity conditions related to entry from Saturn orbit. A brief study was done to evaluate the effect of entry into the Titan atmosphere at velocities associated with Saturn approach velocities. Results of the study are shown on Tables IV-2, -3, and -4. The tables indicate the expected severe impact on such environmental items as maximum dynamic pressure and heating rates and loads. The impact of these factors on the nominal Class B probe design is summarized on Table IV-4.

Figure IV-13 Entry and Descent Profile - Thin (Methane) Atmosphere

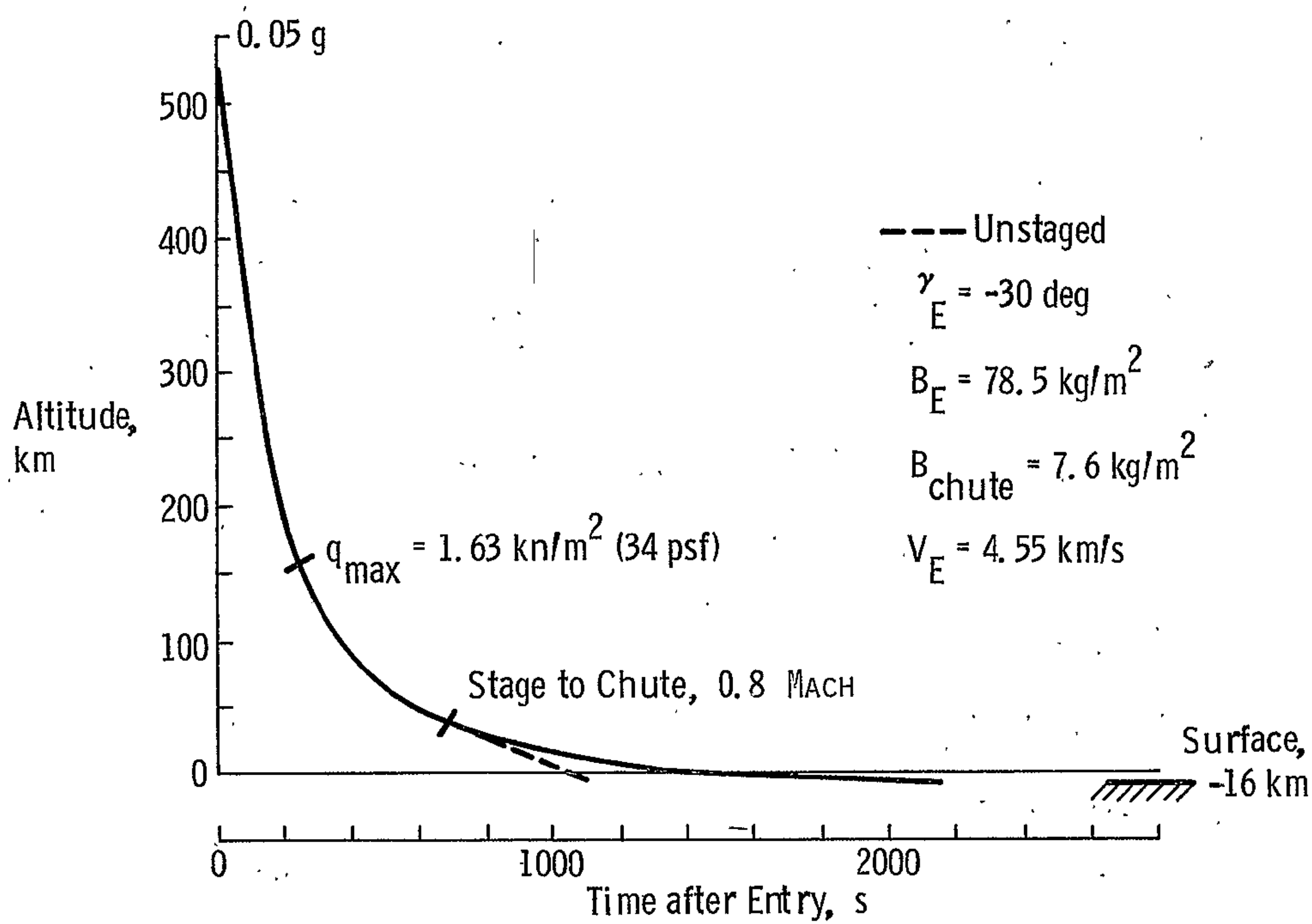


Figure IV-14 Entry and Descent Profile - Thick (Nitrogen) Atmosphere

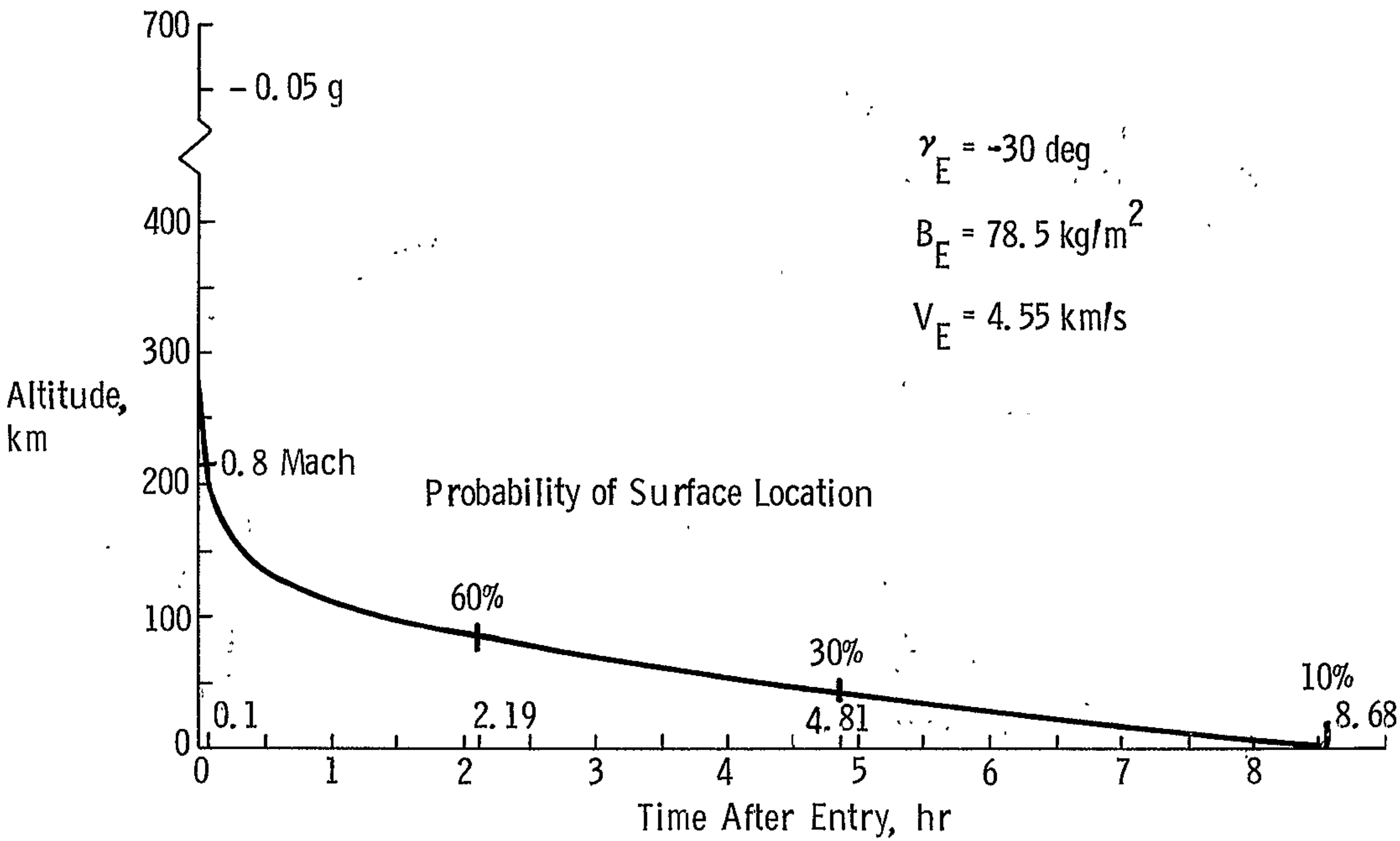


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Table IV-1 Baseline Entry/Descent Times and Altitudes -- Nominal

B_E = 78.5 Kg/m^2 V_E = 4.55 Km/Sec

$B_{SUBSONIC}$	94.2 KG/m^2		7.63 KG/m^2 (Parachute)	
	THICK ATMOSPHERE		THIN ATMOSPHERE	
CONDITION	TIME (MIN)	ALTITUDE (KM)	TIME (MIN)	ALTITUDE (KM)
0.05 g	- 2.43	648	0	526
ENTRY (3200 Km Radius)	0	502	0	526
0.8 M STAGE	5.50	230	11.31	31.1
THIN ATMOS. SURFACE (1)	---	---	36.15	-16
THICK ATMOS. SURFACE (2)				
60% PROBABLE	130.50	86		
30%	288.5	43		
10%	516.5	0		

(1) THIN ATMOSPHERE REFERENCE SURFACE 2,658 KM

(2) THICK ATMOSPHERE REFERENCE SURFACE 2,700 KM

Table IV-2 Direct Versus Out-of-Orbit Entry

	OUT-OF-SATURN ORBIT	DIRECT ORBIT	SYSTEM IMPACT
ENTRY VELOCITY, KM/SEC	4.55	10.4	—
HEAT RATES, $\dot{q}$--BTU/FT^2	17.5	215	5X HEATSHIELD
TOTAL HEAT, Q--BTU	2,513	17,028	5X HEATSHIELD
DYNAMIC PRESSURE MAX.--PSF	60	328	1.7X AEROSHELL
DYNAMIC PRESSURE, STAGE--PSF	3.6	4.1	1.14X PARACHUTE
COMMUNICATION RANGE-- $\frac{R_{DIRECT}}{R_{ORBIT}}$	1.0	GREATER	$\sim$1.5X R_{ORBIT}

Table IV-3 Comparison of Entry Conditions

	MARS (VIKING)		TITAN	
	DESIGN	ACTUAL	OUT OF ORBIT	DIRECT
ENTRY VELOCITY, KM/SEC	4.63	4.61	4.55	10.4
ENTRY FLIGHT PATH ANGLE, DEG	-17.7	-16.9	-30.0	-40.0*
MAX. DYNAMIC PRESSURE, KN/m^2	6.89	4.62	2.87	15.73
MAX. HEATING RATE, W/cm^2	29.51	24.17	19.9	244.0
TOTAL HEAT LOAD, J/cm^2	1713.7	1248.4	2852.0	19,325.0
PARACHUTE DEPLOY:				
o MACH NO.	2.1	1.1	0.8	0.8
o DYNAMIC PRESSURE, KN/m^2	0.41	0.33	0.17	0.19

*ASSUMES $\pm$ 5° γ_E UNCERTAINTY

Table IV-4 Impact of Direct Entry on Probe Design

	FACTOR
HEAT SHIELD MASS	5X
AEROSHELL MASS	1.7X
PARACHUTE MASS	1.14X
ORBITER FLYBY VELOCITY	4.50 KM/SEC COMPARED TO 8.9 KM/SEC DIRECT
COMMUNICATION RANGE	51,000 KM COMPARED TO 111,000 KM DIRECT

o IMPACT OF DIRECT ENTRY ON THE 226 KG CLASS B PROBE DESIGN COMPARED TO OUT-OF-ORBIT DESIGN

- HEAT SHIELD Δ MASS = +12 KG
- AEROSHELL Δ MASS = +5 KG (COMBINATION AEROSHELL/IMPACT ATTENUATOR)
- PARACHUTE Δ MASS = +2 KG
- INCREASED TRANSMITTER POWER
- INCREASED ELECTRICAL BATTERY POWER
- INCREASED EQUIPMENT COMPARTMENT VOLUME
- INCREASED STRUCTURE AND AEROSHELL SIZE

V. CONFIGURATION DESIGN AND INTEGRATION

A. INTRODUCTION AND CONCEPT DEVELOPMENT

This chapter discusses the approach to configuration design and examines the problems associated with integration of both science instruments and engineering subsystems into the probe vehicle designs. The objective of the study was to evaluate the design and cost impact of a number of variables in mission design, science payload, atmospheric environment uncertainty, surface definition uncertainty, and system complexity.

The mission options include the baselined probe entry from Saturn orbit at an entry velocity of 4.55 km/s and a direct entry from initial Saturn encounter at about 10.4 km/s. The entry from Saturn orbit was baselined at the study midterm meeting under recommendations from JPL since this approach was consistent with their Saturn orbiter mission design. The results of a brief analysis of the impact of direct entry on probe design are presented in Section IV, F.

The science payloads have been defined in three classes as discussed in detail in Section III:A. Briefly, Class A is a simple atmospheric probe, Class B is a combination atmospheric and lander probe, and Class C is a combination atmospheric and lander probe with expanded surface science and extended mission duration. In addition, the Class B and C probes also incorporate a pre-entry science module.

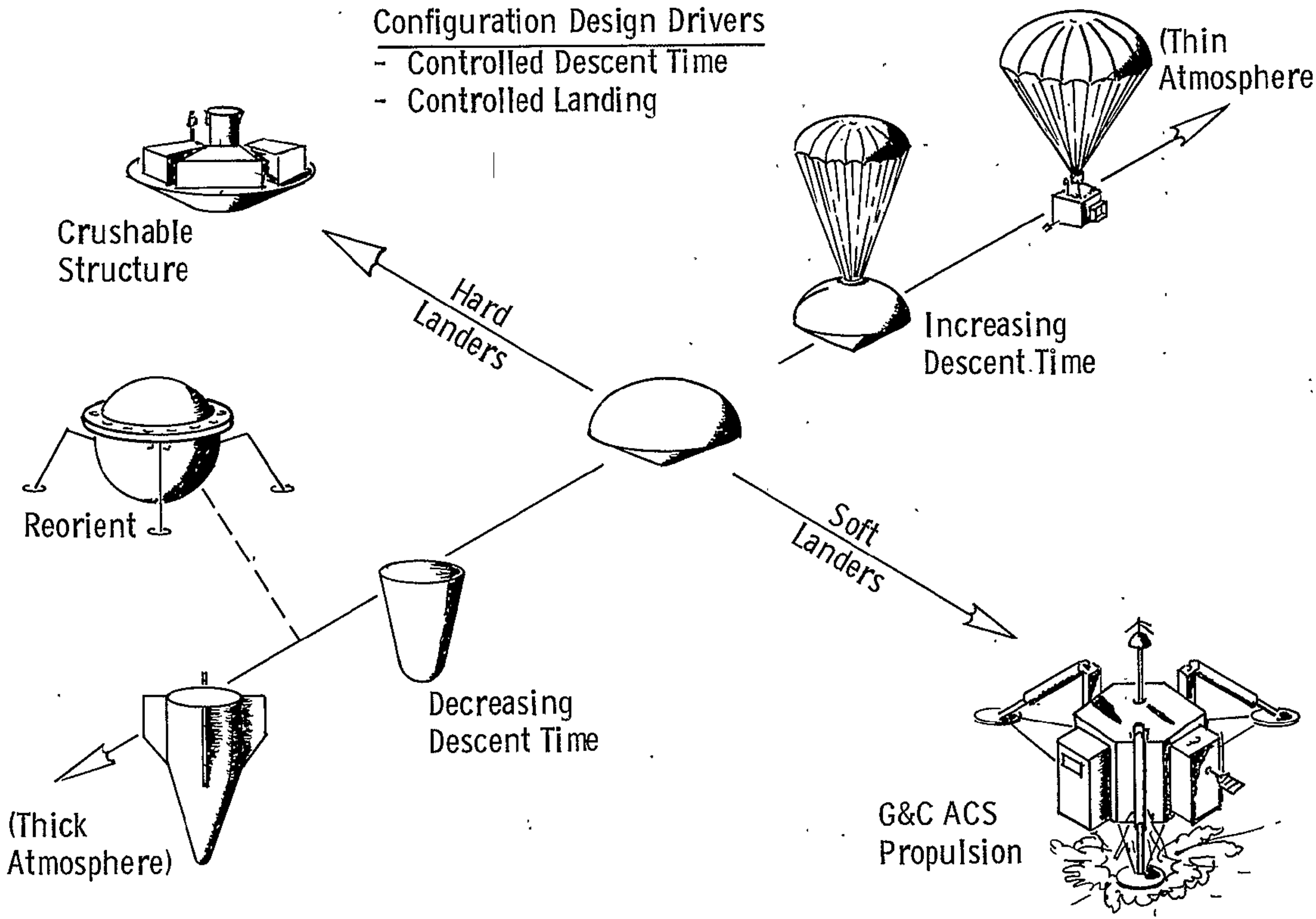
The atmosphere and surface uncertainties are defined in Section III F. There are two separate atmosphere models; a thin methane model with surface pressures of about 17 mb and a thick nitrogen model with surface pressures varying from 1.9 to 21 bars. Probe systems are designed to only the thin or thick atmosphere but not to both simultaneously. This approach was based on the assumption that the atmosphere will be more accurately defined before the actual hardware design phase starts. With the current models of Titan it is possible that the surface condition may vary from solid ices and snow to liquid and this has a significant impact on the lander configuration as well as surface sample acquisition.

In the first half of the study a broad range of configuration options was considered as illustrated in Figure V-1. During this period various concepts were being sought which could meet the system design constraints. The configuration design drivers are controlled descent time to provide sufficient time for science measurement and data transmission, and controlled landing to provide low enough impact velocity and shock attenuation to assure a safe, stable landing. As illustrated in the upper right side of the figure, the thin atmosphere required that the configuration be retarded by a parachute to allow sufficient time for the descent science measurements (the gas chromatograph requires about 25-30 minutes to obtain four samples). In the thick atmosphere, the entry probe is slowed to such an extent that either the probe configuration needed to be streamlined to increase its ballistic coefficient or the probe suffered some weight penalties to accommodate increased battery life and extended data transmission ranges. Evaluation of this trade off resulted in selection of retaining the entry aeroshell to the surface. Although this configuration had an extended descent time, it resulted in a much simpler landing system. The streamlined shapes have poor landing stability and require the addition of erection devices after touchdown. Part of this trade study included an evaluation of hard versus soft lander concepts as illustrated in Figure V-1 and further discussed in Section V D 1.

The soft lander concept, similar to the Viking lander, can provide a more precise touchdown velocity at the expense of additional system complexity. Guidance and control, attitude control, and terminal propulsion subsystems are necessary as well as landing legs to provide impact attenuation and attitude stability on the surface.

The hard lander is a less complex concept which uses a crushable honeycomb structure behind the entry heatshield for impact attenuation. It is designed to provide less than 300 g's deceleration on a hard surface with a stroke of 15 cm at a descent rate of 20 m/s. After further study, it became apparent that the hard lander concept

Figure V-1   Configuration Options Considered

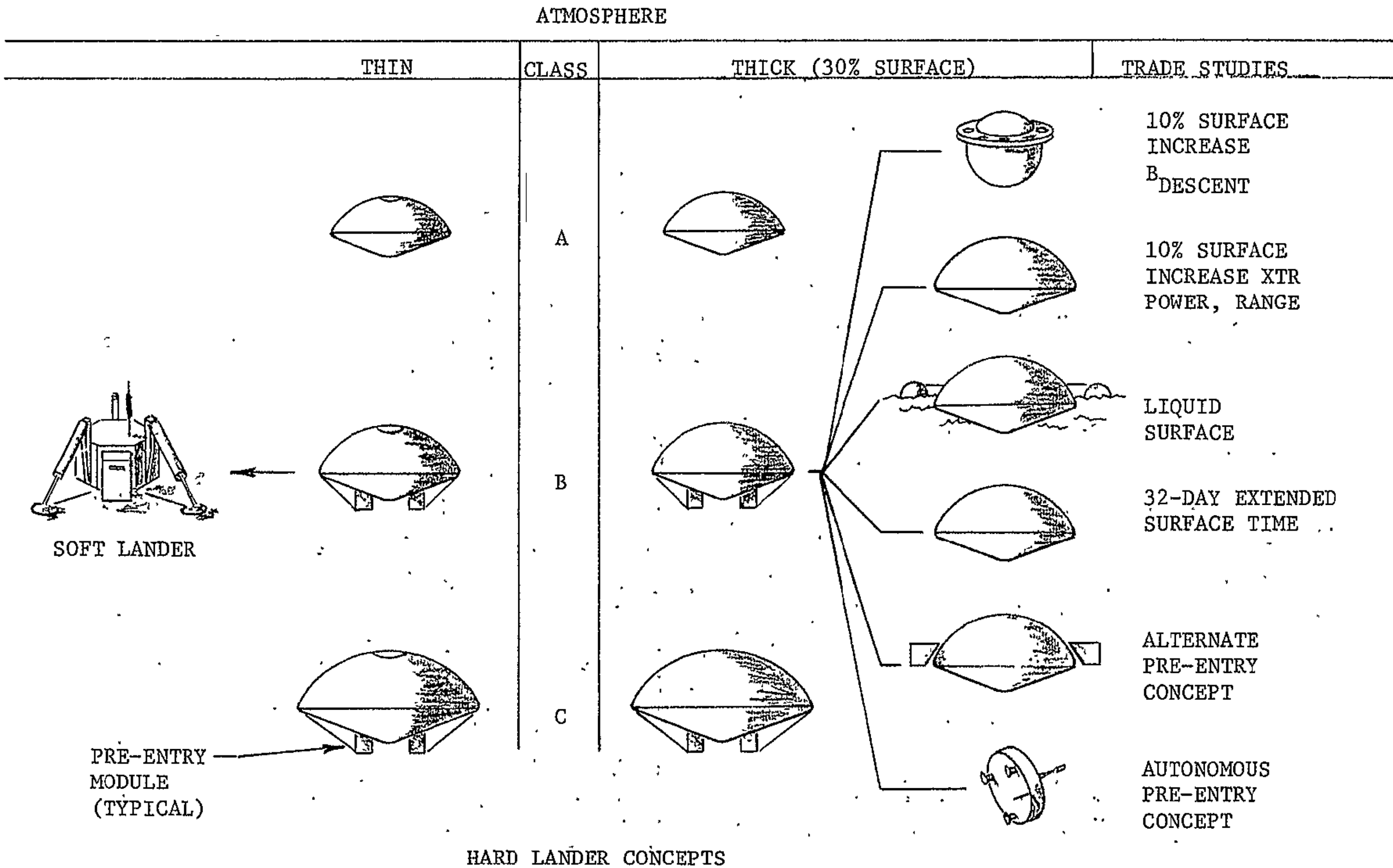


provides a practical design for all lander classes, has good impact stability, low penetration on ice or snow, and provides flotation in case of landing on a liquid nitrogen surface. Experience by NASA/ARC with drop tests of similar shapes in the desert (the planetary atmospheric entry test, PAET, vehicle) showed very stable and non-rebounding landings.

Based on the above results a matrix of configurations was identified at the midterm meeting as illustrated in Figure V-2 for final definition and costing in the last half of the study. The three probe classes for both the thin methane and thick nitrogen atmosphere models were included as well as comparison of the hard versus soft lander for the Class B probe case. In addition, trade studies were done for variations of the Class B probe to evaluate effects of descent to the extreme 10% probable surface location, effects of a liquid nitrogen surface, and effects of a 32-day extended surface mission. Definition of a baseline pre-entry science module concept as well as a few alternates were also included.

The following sections describe the technical considerations and results of the Titan probe configuration study matrix of Figure V-2 above.

Figure V-2 Titan Probe Conceptual Studies



CLASS A - ATMOSPHERIC PROBE
CLASS B - PRE-ENTRY, ATMOSPHERIC/LANDER - SHORT DURATION
CLASS C - PRE-ENTRY, ATMOSPHERIC/LANDER - INCREASED SURFACE SCIENCE

B. TITAN PROBE BASELINE DESIGNS

The six Titan probe baseline designs consist of the Class A, B, and C concepts for the thin methane atmosphere and also for the thick nitrogen atmosphere down to the 30% probable surface location as illustrated in Figure V-2 of the previous section.

The thin methane and thick nitrogen atmosphere cases are considered to be separate design requirements and there is no intent to design to both cases simultaneously. It is assumed that the atmosphere will be much better defined prior to the start of the hardware design phase sometime after 1983 since both Pioneer 11 and Voyager spacecraft may obtain new data on Titan's atmosphere.

The probes for the thin methane atmosphere have been designed for the worst case uncertainties within the thin atmosphere definition. In the case of the thick nitrogen atmosphere, the baseline probes have been designed to meet the 60% and 30% probable surface locations but not the 10% probable surface location extreme. It was felt at the midterm meeting that the 10% probable surface location requirement would unrealistically drive the baseline designs. However, the impact of this extreme was evaluated as a trade to the baseline design and the results are included in Section V E.

1. Class A Probe - The Class A probe carries atmospheric entry and descent science and is not required to survive landing impact. The science payload is defined in detail in Section III and consists of the following experiments:

- o Atmospheric structure instrument
- o Multispectral radiometer
- o Nephelometer with DTA
- o Neutral Mass Spectrometer
- o Gas Chromatograph
- o Doppler/wind experiment (stable oscillator)

The Class A probe configuration is shown in Figure V-3 and consists of a 60 degree half angle cone aeroshell with a Viking type ablative material (SLA 561) for entry heat protection. The same concept is applicable to both the thin (methane) atmosphere and the thick (nitrogen) atmosphere, however, the thin atmosphere configuration as shown requires the addition of a parachute to slow the descent rate.

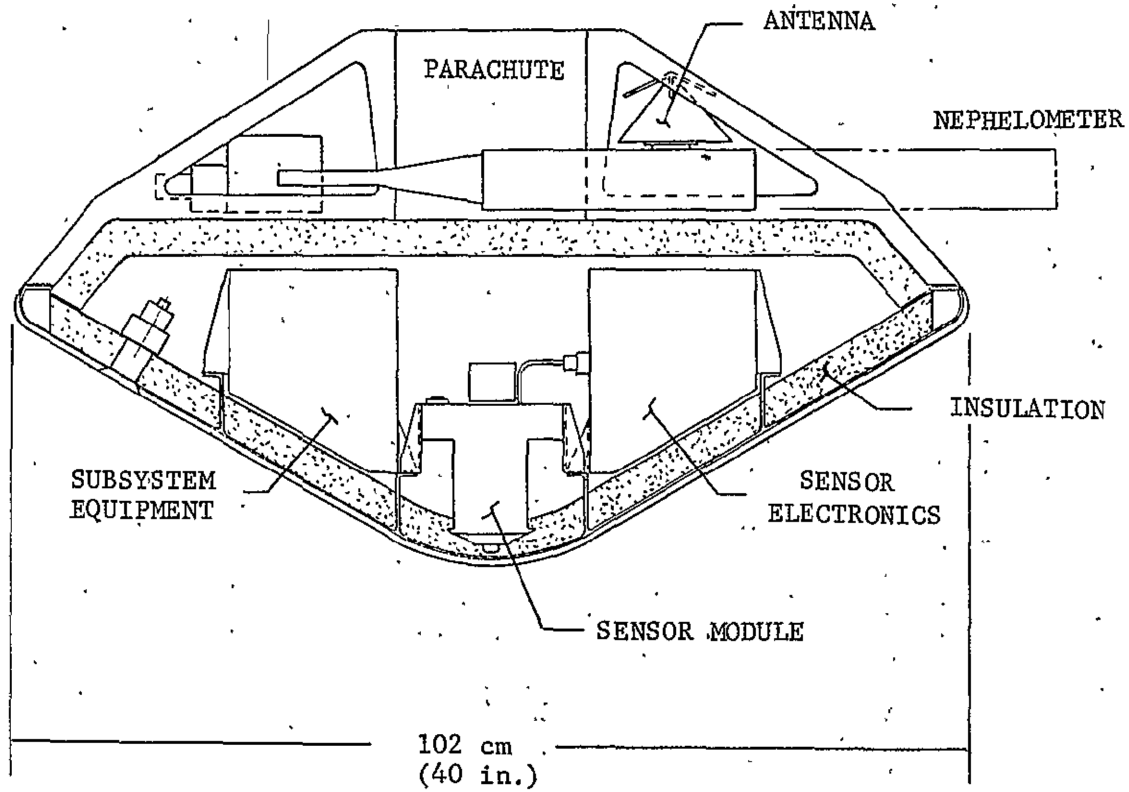
The forward aeroshell consists of a ring stiffened structure with the internal subsystem components mounted on the ring stiffeners and contoured to the aeroshell to improve packaging efficiency. Most of the components and electronics are protected from the cold environment by an insulation layer on the back face of the aeroshell and over the back side of the components. Isotope heaters are used for thermal control during the coast phase after probe separation from the orbiter. Thermal isolators are required between the components and the ring frames.

The nephelometer, temperature probe, and radiometer cover are deployed from the aft cover after entry at about 0.8 M to obtain descent science. The forward cover for the inlet to the neutral mass spectrometer and gas chromatograph is also jettisoned after entry.

For the probe designed for the thin atmosphere, an aft structural truss is required to support the parachute canister and carry the parachute loads to the aeroshell structure. This truss can be eliminated for the thick atmosphere and replaced by an aft cover.

The detailed breakdown of the science characteristics is given in Table III-3 and the subsystem and structural equipment lists are given in Table V-2, Section V B 4. The total probe weight is summarized in Table V-1 by subsystem grouping and the weight for the Class A probe designed for the thin (methane) atmosphere is 113.2 kg while the weight for the Class A probe designed for the thick (nitrogen) atmosphere is 114.3 kg. Although the total weights are nearly identical, the subsystem weights vary considerably. The basic difference is that the thin atmosphere probe requires a parachute while the thick atmosphere probe requires additional batteries to accommodate the longer descent time.

Figure V-3 Class A - Probe Configuration



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2. Class B Probe - The Class B Titan probe is a combination atmosphere and lander vehicle which also incorporates a pre-entry science module. This probe class has received the greatest emphasis in the study because it basically meets the general science objectives yet it is a reasonably simple and moderate weight concept.

The science complement is defined in detail in Chapter III and listed in Table III-1. In addition to the atmospheric science instruments, the probe carries the following surface science experiments:

- o Descent imagery
- o Surface imagery
- o Impact accelerometer
- o Composition (GC and MS)
- o Meteorology

Also, the pre-entry science module carries the following pre-entry science experiments:

- o Neutral Mass spectrometer
- o Ion mass spectrometer
- o Retarding potential analyzer
- o Elèctron temperature probe

The configuration and equipment layout are shown in Figures V-4 and V-5. The external configuration uses a 1.47 m diameter 70-degree half angle cone aeroshell and ablator with a segment of a sphere for the aft cover. The combination aeroshell and landing impact attenuator incorporate a honeycomb structure which limits the impact deceleration to less than 300 g's with a 15 cm stroke of the crushable honeycomb at an impact velocity of 20 m/s. This approach simplifies the landing system considerably compared to a Viking type soft lander since neither the aeroshell nor the aft cover have to be staged. A comparison of hard versus soft lander concepts is included in Section V D 1.

The configuration shown was designed for the thin (methane) atmosphere and, therefore, requires a parachute to slow descent rate. The

Figure V-4   Class B - Probe/Lander Configuration

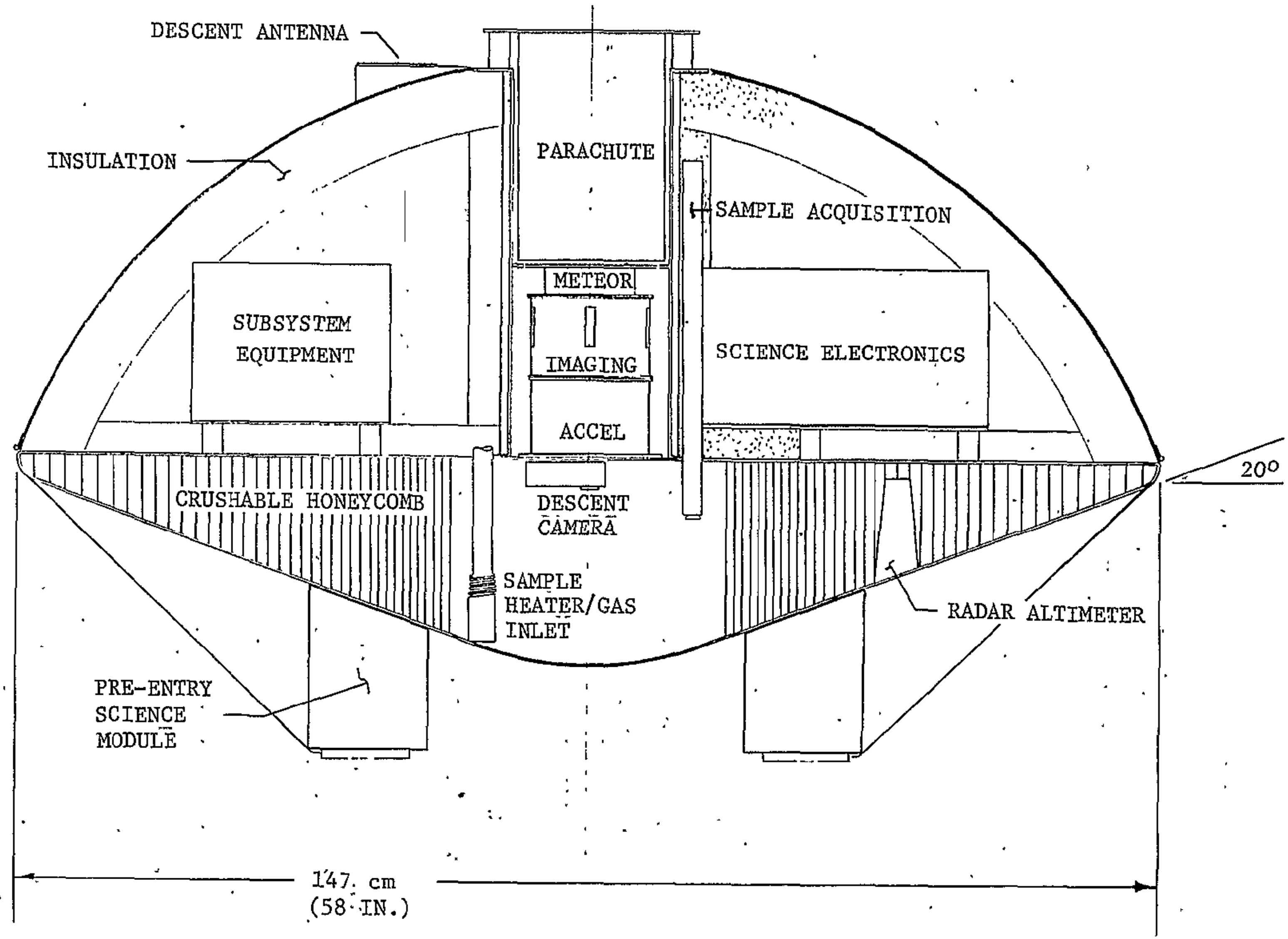
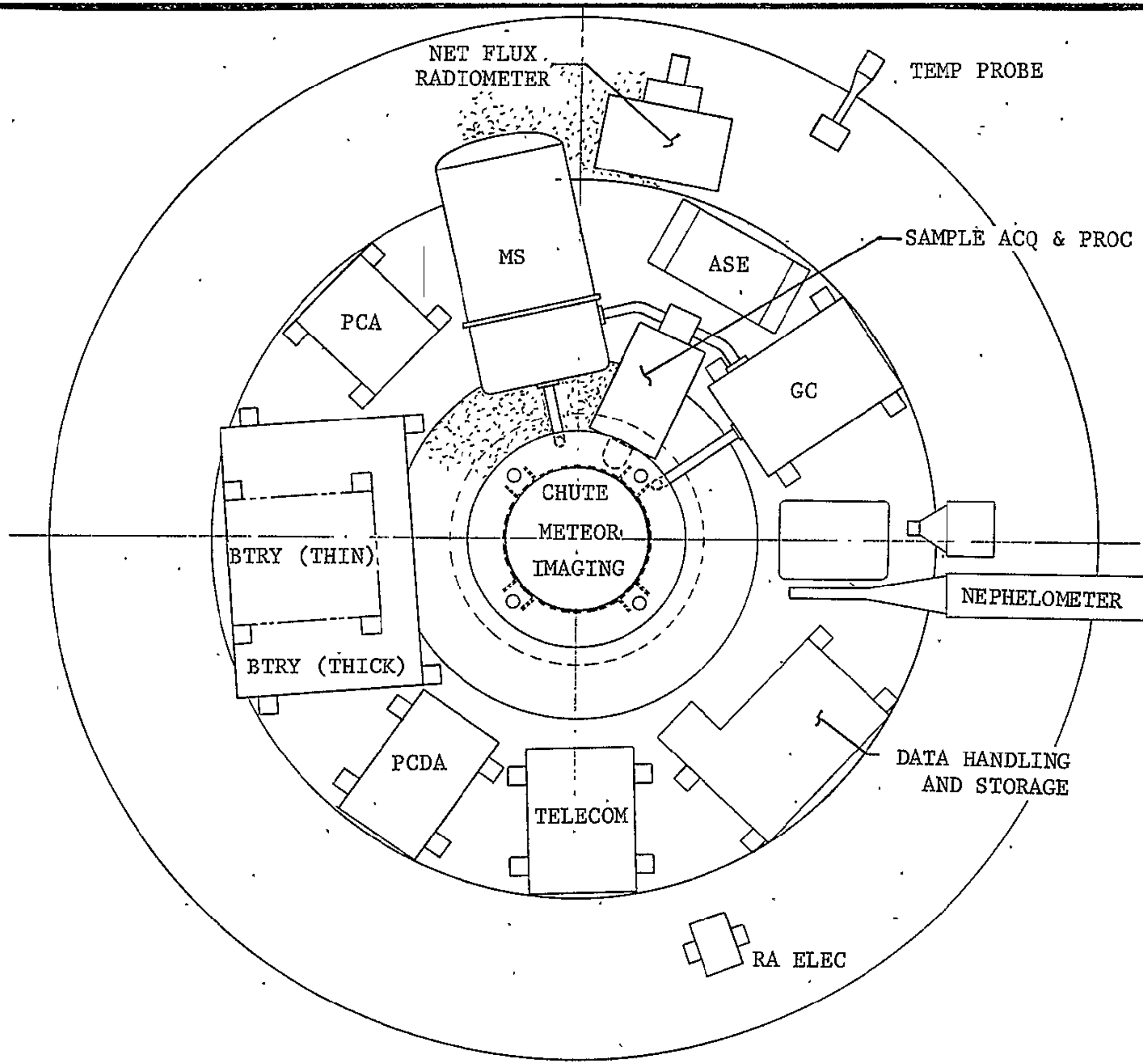


Figure V-5 Class B - Probe/Lander (Plan View)



parachute is mounted at the top of a central structural tube which encloses the extendible science mast. This mast is used to deploy the meteorology and imaging experiments after touchdown and carries a second microstrip type RF antenna on top since the descent antenna may be blocked from line-of-sight to the orbiter after touchdown.

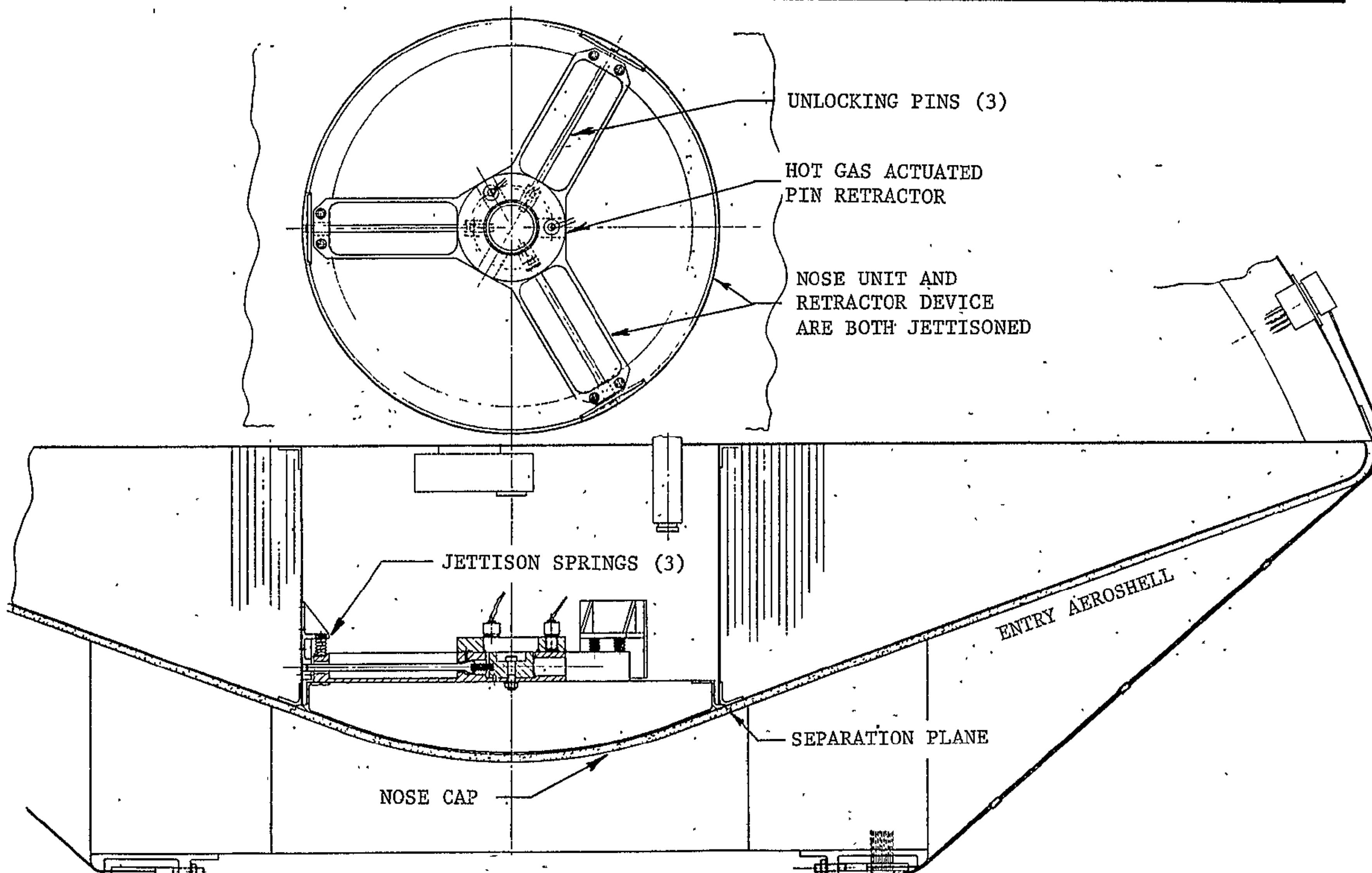
This probe lander design features a jettisonable nose cap with a cylindrical cutout in the center of the vehicle which provides access for obtaining science samples both during atmospheric descent and on the surface. A detail of the nose cap is shown in Figure V-6. A hot gas actuated pin retractor is used to unlock the nose cap and jettison springs provide a positive separation of the complete mechanism thus clearing the opening. This separation takes place just after entry when the vehicle reaches a subsonic velocity of about 0.8 M.

A collapsible atmospheric sampling inlet is shown in Figure V-4. This inlet provides sample gases to the mass spectrometer and gas chromatograph during descent and collapses at touchdown. A sample acquisition drill device is then deployed to the surface to obtain solid samples. Further discussion of the science implementation is given in Section V C.

A 7.0 cm thick layer of insulation at 64 kg/m^3 (4 lbs/ft^3) is attached to the back cover and encloses the components. The components are mounted on thermal isolation standoffs which are attached to the honeycomb back plate with insulation between the two. The honeycomb structure provides load paths from the components to the aeroshell without additional frames. The parachute loads are carried through the cylindrical mast enclosure tube down into the honeycomb backing plate.

In this hard lander concept the relatively flat aeroshell provides good impact and attitude stability on the surface and prevents surface penetration. The configuration will float if it lands on a liquid nitrogen surface (see Section V D 2) and the aft cover thermally

Figure V-6 Jettisonable Nose Cap Detail



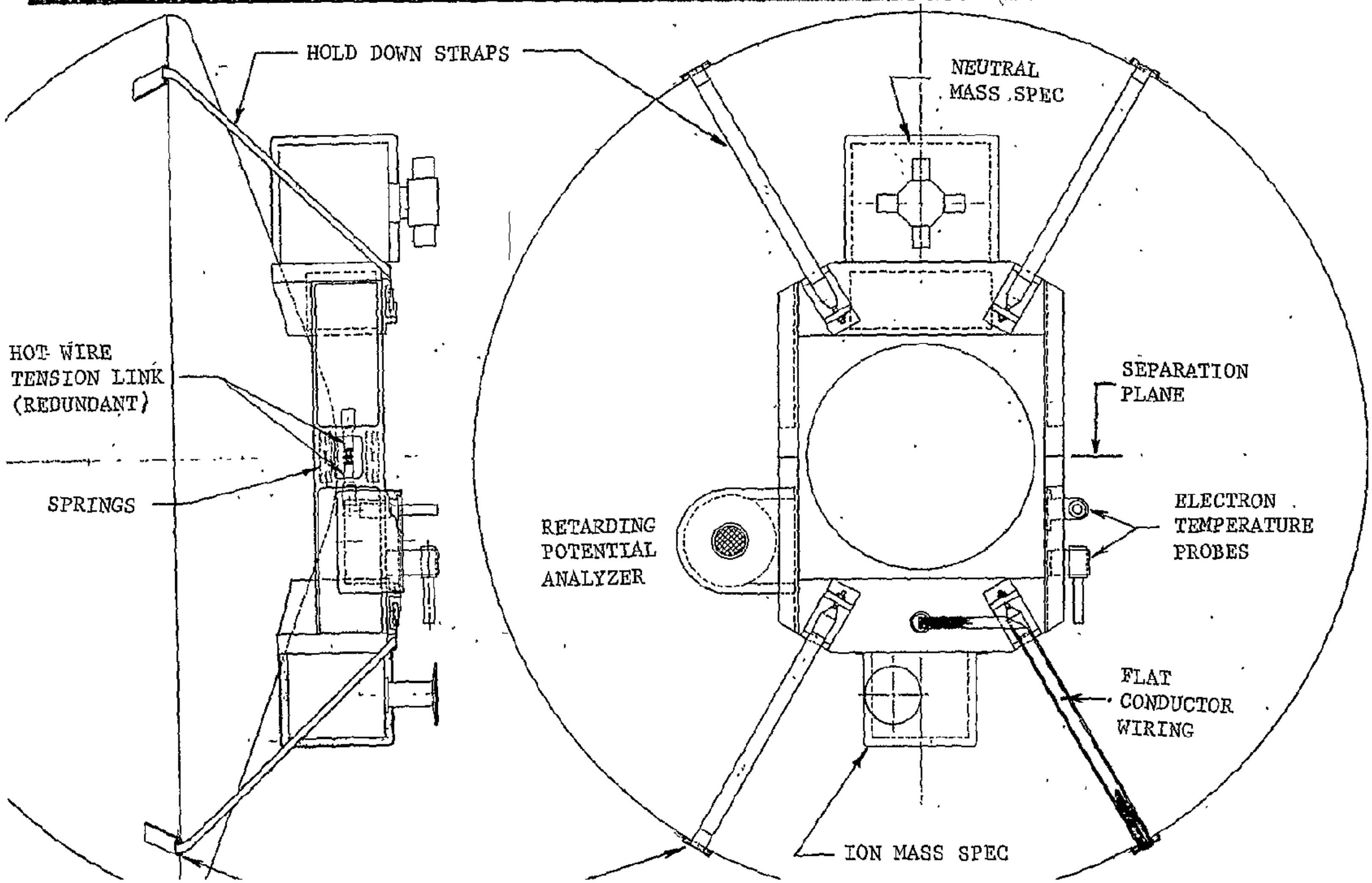
insulates the components and protects from possible splash or debris at touchdown.

For the Class B probe, an 8 m diameter parachute is required to control the touchdown descent velocity to within 20 m/s with a resulting maximum impact deceleration of 300 g's with the 15 cm attenuator stroke. In the proposed concept, the parachute is designed to provide a velocity at 100 m altitude which results in 20 m/s touchdown velocity after free fall from 100 m. This allows the parachute to drift free of the lander. The parachute can be rigged to drift to the side of the lander and, by retaining the canister on the risers, the parachute will remain inflated. A small radar altimeter is used to signal the 100 m release altitude and is located in the honeycomb area as illustrated in Figure V-4. An RF transparent cover provides line-of-sight through the aeroshell.

Pre-entry Science Module Configuration - The Class B and Class C probe configurations include a pre-entry science module as illustrated in Figure V-7. The unit is strapped onto the forward heat shield with straps that are attached by pins in notches at the maximum diameter of the vehicle. The module is separated into two parts when the redundant hot wire tension links are severed. At that point, three forces provide positive separation of the module from the entry vehicle. These forces are produced by the springs between the module halves, the centrifugal force due to the spinning vehicle, and any low level aerodynamic loads which may be building up at time of release. The science instruments are located as shown to assure clean, uncontaminated samples of the upper atmosphere. Further discussion of the pre-entry science implementation is covered in Section V C 1 a.

The detailed breakdown of science characteristics is given in Table III-3 and the subsystem equipment lists are included in Table V-2, Section V B 4. The total probe weights are summarized in Table V-1 by subsystem grouping and the weight for the Class B probe designed for the thin (methane) atmosphere is 227 kg while the weight for the Class B probe designed for the thick (nitrogen) atmosphere is

Figure V-7   Pre-Entry Science Module Detail



226 kg. Again, as for the Class A probes, the total weights are nearly identical, however, the subsystem weights vary considerably. As in the Class A probe, the Class B probe designed for the thick (nitrogen) atmosphere does not require a parachute and the science mast can be relocated higher up in this area. The thick atmosphere design does, however, require additional batteries to accommodate the extended descent time and increased transmitter power requirement.

3. Class C Probe - The Class C Titan probe, like the Class B probe, is a combination atmosphere and lander vehicle but it includes an expanded surface science payload and is required to survive an extended period up to several months. This probe also includes the pre-entry science module that was described in the previous section.

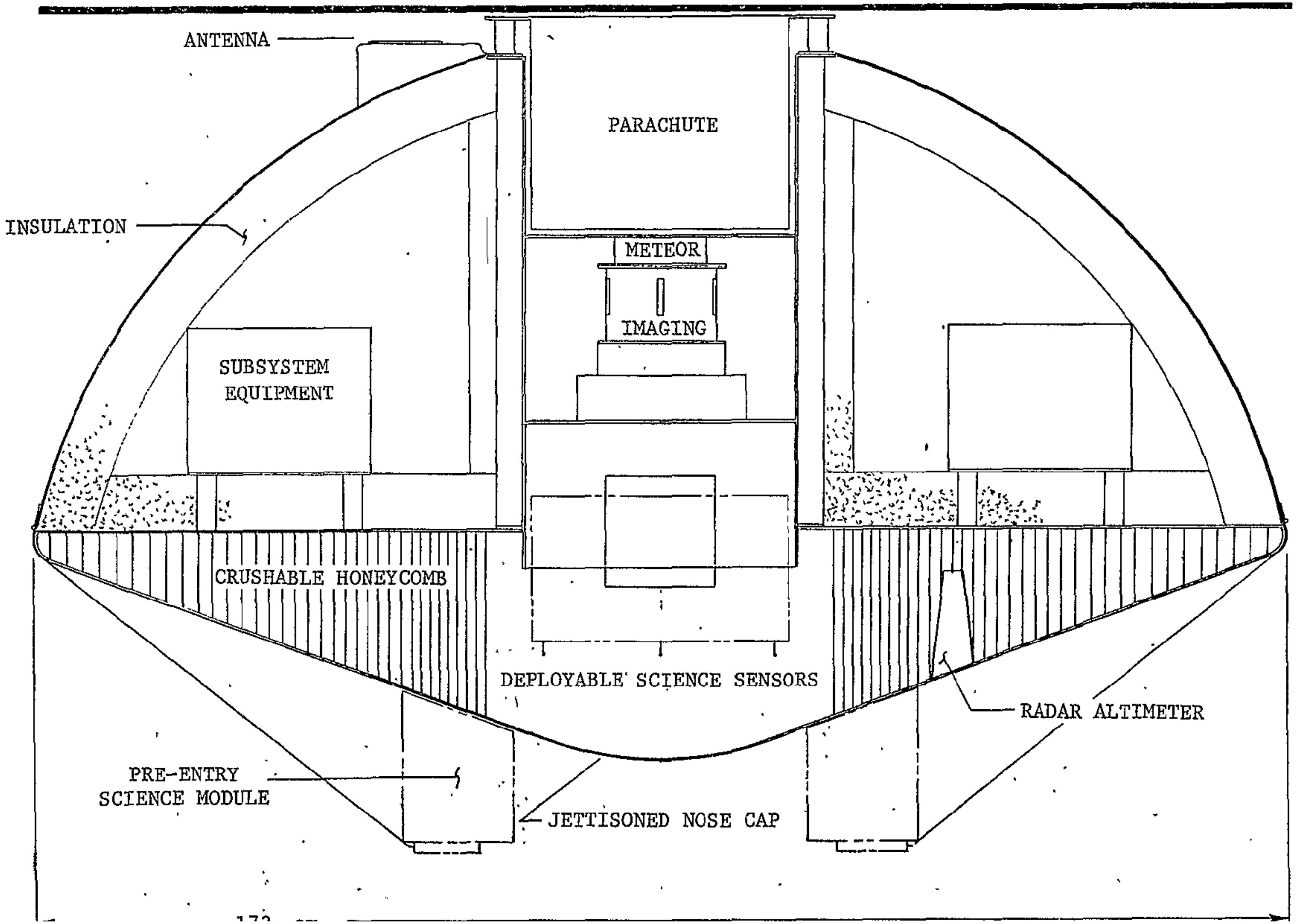
The science payload is described in detail in Chapter III and listed in Table III-1. In addition to the atmosphere and surface science instruments of the Class B probe, this probe also carries the following expanded surface science complement:

- Passive seismometer
- Microscope
- Precipitation experiment
- Active wet chemistry "ozone analysis"
- Alpha-backscatter experiment

The Class C probe configuration is shown in Figure V-8 and is essentially a larger version of the Class B probe with a diameter of 1.73 m (68 in.) compared to 1.47 m (58 in.) for the Class B probe. The structural design and layout is similar to that described for the Class B probe in Section V B 2.

The major changes from the Class B probe are the addition of a module for deploying some of the expanded science experiments as shown in Figure V-8 and a modified power subsystem. This science unit requires additional insulation, heaters, and a deployment mechanism. It contains the seismometer, the microscope sensor head with a fiber optics line to the main instrument, and the alpha-backscatter sensor. See

Figure V-8 Class C - Probe/Lander Configuration



Section V C 1 c for a discussion of science implementation. The power subsystem for the Class C probes consists of a combination of batteries and RTGs to handle the extended duration mission power requirements and the RTG waste heat is used for thermal control.

The detailed breakdown of the science characteristics is given in Table III-3 and the subsystem and structural equipment lists are given in Table V-2, Section V B 4. The total probe weights are summarized in Table V-1 by subsystem grouping and the weight for the Class C probe designed for the thin (methane) atmosphere is 355 kg while the weight for the Class C probe designed for the thick (nitrogen) atmosphere is 350 kg. The expanded surface science and increased mission time result in the large increase in weight of both engineering support equipment and structure over that of the Class B probe. Again, although the total weights are similar for the thin and thick atmosphere designs, the parachute (structures/mechanisms) and power subsystems are considerably different.

4. Summary of Baseline Probe Weights and Equipment Lists - A summary of the baseline Titan probe weights is presented in Table V-1 and support equipment lists are presented in Table V-2.

The weights for the three classes of probes (A, B, C) are shown for both the thin (methane) atmosphere and the thick (nitrogen) atmosphere. These probe designs are discussed in the previous sections (V B 1 through 3) and in Chapter VI under subsystem design. The detailed list of science payloads for each probe class is given in Chapter III, Table III-1 and their characteristics are presented in Table III-3.

Notice that the science instrument weights include a margin and then the total system weight has an additional 15% weight contingency. Each instrument, according to its uncertainty of definition for application to this mission, was assigned a margin varying from 10% to 30%. These weight margins are listed in Table III-3, and represent uncertainty in both the instrument definition and in implementing the integration and sample acquisition.

Table V-1 Titan Probe Weight Comparison

PROBE CLASS	MASS (KG) THIN ATMOSPHERE A	B	C	THICK ATMOSPHERE (30% PROB SURF. LOCATION) A	B	C	B(1) 10% SURF.	B(2) 32 DAY EXT.
SCIENCE PLUS MARGIN	28.0	51.0	107.0	28.0	51.0	107.0	51.0	51.0
TELECOMMUNICATIONS	0.95	2.6	4.5	0.95	3.4	5.7	4.85	3.4
POWER/PYRO/CABLING	16.7	29.4	41.0	24.7	43.6	56.7	66.6	45.6
THERMAL	4.9	21.0	30.9	4.9	16.4	26.0	24.2	18.4
STRUCTURES/MECHANISMS	41.64	81.5	112.8	34.64	69.5	96.8	96.8	82.0
DATA HANDLING & CONTROL	6.20	12.56	12.56	6.20	12.56	12.56	12.56	12.56
SUBTOTAL	98.39	197.3	308.76	99.39	196.47	304.76	256.01	212.96
15% CONTINGENCY	14.76	29.6	46.31	14.90	29.47	45.71	38.4	31.94
TOTAL	113.15	226.9	355.07	114.29	225.93	350.47	294.41	244.90
DESIGN GOAL	175.0	225.0	400.0	175.0	225.0	400.0	225.0	225.0

NOTES: (1) CLASS B PROBE DESCENDING TO 10% SURFACE LOCATION.

(2) CLASS B PROBE WITH EXTENDED SURFACE MISSION TO 32 DAYS.

Table V-2 Titan Probe Support Equipment List

		CLASS A PROBE			CLASS B PROBE			CLASS C PROBE		
HERITAGE		MASS (KG)	SIZE (cm^3)	POWER (W)	MASS (KG)	SIZE (cm^3)	POWER (W)	MASS (KG)	SIZE (cm^3)	POWER (W)
	POWER/PYRO/ CABLING S/S	16.7 THIN 24.7 THICK			29.4 THIN 43.6 THICK			41.0 THIN 56.7 THICK		
VL	RTG	N/A	N/A	N/A	N/A	N/A	N/A	3.24	4717	25 W (226 W THERMAL OUTPUT)
NEW	AgZn BATTERIES	2.5 10.5	2320 9880	6 AH THIN 25 AH THICK	6.8 21.1	6454 19900	16 AH THIN 50 AH THICK	8.4 24.4	7900 23000	20 AH THIN 57 AH THICK
-	PYROS	16(.25)=4.0	--	--	26(.25)=6.50	--	--	28(.25)=7.0	--	--
-	CABLING (6% OF GROSS S/C WEIGHT)	5.3 5.3	--	--	11.2 THIN 11.1 THICK	--	--	17.5 THIN 17.2 THICK	--	--
VL	PCDA	2.63	4917	--	2.63	4917	--	2.63	4917	--
SCATHA	PYRO CONTROL ASSY	2 27	2950	--	2.27	2950	--	2.27	2950	--
	DATA HANDLING AND COMMAND S/S	6.2			12.56			12.56		
GALILEO PROBE	DATA HANDLING & COMMAND UNIT	6.2	6555	6 W	6.2	6555	6 W	6.2	6555	6 W
NEW	DATA RECORDER	N/A	N/A	N/A	6.36	6077	10 W RECD 15 W PB	6.36	6077	10 W RECD 15 W PB
	TELECOMMUNICATIONS SUBSYSTEM	0.95 THIN 0.95 THICK			2.6 THIN 3.4 THICK			4.5 THIN 5.7 THICK		
CONIC CORP.	TRANSMITTER	0.35	400	14.3 W-IN 1.0 W-OUT	1.0 1.8	1133 2040	28 W-IN 2.5 W-OUT) THIN 50 W-IN 6 W-OUT) THICK	1.2 2.4	1360 2720	33 W-IN; 3 W-OUT THIN 50 W-IN; 10 W-OUT THICK
GALILEO PROBE	RECEIVER & CMD DETECTOR	N/A	N/A	N/A	N/A	N/A	N/A	1.7	1277	4 W(RCVR); 3 W (CD)
-	TIMER	0.1	--	0.001 W	0.1	--	0.001	0.1	--	0.001
VL SCATHA	ANTENNA (TURNSTILE)	0.5	1230	--	0.5	1230	--	0.5	1230	--
-	RADAR ALTIMETER	N/A	N/A	N/A	1	1133	1	1	1133	1
	THERMAL S/S	4.9 THIN 4.9 THICK			21.0 THIN 16.4 THICK			31.1 THIN 26.0 THICK		
VL	INSULATION	4.9 THIN 4.9 THICK	75900 75900	--	14.5 THIN 14.5 THICK	227000 227000	--	24.0 THIN 24.0 THICK	375000 375000	--
-	ISOTOPE HEATERS	1.7 THIN 1.7 THICK	--	--	3.7 THIN 1.9 THICK	-- --	-- --	2.9 THIN N/A THICK	-- --	-- --
	RESISTANCE HEATERS	N/A	N/A	N/A	1 THIN N/A THICK	--	--	2.0 THIN N/A THICK	--	--
-	BASE COVER	N/A	N/A	N/A	1.8 THIN N/A THICK	-- --	-- --	2.2 THIN 2.0 THICK	-- --	-- --

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Table V-2 (concluded)

		CLASS A PROBE			CLASS B PROBE			CLASS C PROBE		
HERITAGE		MASS (KG)	SIZE (cm^3)	POWER (W)	MASS (KG)	SIZE (cm^3)	POWER (W)	MASS (KG)	SIZE (cm^3)	POWER (W)
	STRUCTURES S/S	41.64 THIN 34.64 THICK			81.5 THIN 69.5 THICK			112.8 THIN 96.8 THICK		
VL	BIOSHIELD	16	--	--	20	--	--	26	--	--
VL	AEROSHELL/HEAT SHIELD	10.5	--	--	3 HEAT SHIELD ONLY	—	--	4.3 HEAT SHIELD ONLY	--	--
VL	BASE COVER	4	--	--	10	--	--	15	--	--
VL	CHUTE/MORTAR/ CANISTER	7.0 THIN N/A THICK	3.15 cmD x 3.15 cmL	--	12 THIN N/A THICK	3.9 cmD x 3.35 cmL	--	16 THIN N/A THICK	4.7 cmD x 4.7 cmL	--
-	ATTENUATOR/AERO-SHELL (HONEYCOMB)	N/A		N/A	22	141609	--	30	195421	--
-	EQUIPMENT SHELF	N/A		N/A	4	--	--	5.5	--	--
-	EQUIPMENT MAST/ MECH.	N/A		N/A	4.5	2.4 cmD x 4.3 cmL	--	5.5	2.4 cmD x 4.3 cmL	--
-	PRE-ENTRY STRUCTURE MODULE	3	--	--	3	--	--	3.5	--	--
-	SENSOR HOUSING (DEPLOY MECH.)	N/A		N/A			N/A	3.5	--	--
-	NOSE CAP	N/A		N/A	1	40.6 cm Diam.	--	1.5	40.6 cm Diam.	--
-	SENSOR MODULE & MECHANISM	1.14	--	--		N/A			N/A	
NEW	SAMPLE DRILL	N/A		N/A	2	1180	100	2	1180	100

The probes were designed to meet the thin (methane) atmosphere environment separately from the thick (nitrogen) environment. In comparing the thin versus thick atmosphere probe weights, it can be seen that the total weights are nearly the same for a given probe class. As discussed earlier there are significant differences in the subsystem weights. The thin atmosphere probe designs require a parachute (structures/mechanisms) while the thick atmosphere probe designs require additional batteries to accommodate the extended descent times and increased data transmission ranges. The major design driver is the probe class or science payload complement as reflected in the science weight. The engineering support system weights are roughly proportional to the science payload weights.

Early in the study, weight design goals were established by NASA/ARC in conjunction with JPL and they are shown at the bottom of Table V-1. The Class A and C probe design weights were well under these goals while the Class B probe designs only slightly exceeded the values. These weight classes were also used as design goals in the parallel JPL study of the Saturn orbiter mission design.

Also shown on this table are weights for two additional probe design variations and these are discussed in Sections V E and V F.

Detailed weight, power, and size characteristics are given in Table V-2 for the engineering support equipment for all baseline designs. Detailed discussions of the design of these various subsystems are presented in Chapter VI.

C. SCIENCE INTEGRATION AND IMPLEMENTATION

This section includes discussions on science integration and implementation for the pre-entry, atmospheric, and surface science. Although most of the science instruments are either the same as or based on current instrument designs, a few present unique integration or implementation problems due to the unusual environment of Titan. Such environmental conditions as extreme cold, low light levels, and the possibility of a snowy or liquid surface are some of the major considerations. This section focuses primarily on the unique problem areas and presents both a baseline approach and possible alternate approaches where appropriate.

1. Pre-Entry Science

a. Implementation Problem - Implementation of the pre-entry science on the Titan probe has the same basic problem as was experienced on other similar planetary pre-entry science experiments. To gather the maximum effective science data we must ensure that the instruments will measure samples from free space which have not been contaminated or altered by the probe. The instrument inlets must, therefore, sample ions, electrons and elements that have not previously contacted the probe, and have not been affected by the magnetic or electric field radiating from the probe.

A second concern in integrating the pre-entry science experiments into the probe mission is their possible impact on mission success. The three general approaches to pre-entry science integration include placing the instruments internally in the probe, having a completely independent pre-entry vehicle, or using a jettisonable module on either the front or sides. The first approach of integrating the instruments into the probe carries a low risk of affecting mission success; however, it appears difficult in this approach to provide instrument inlet locations that would be free of heat shield contamination. Also, inlets through the heat shield carry some risk and represent heat shorts to the interior but careful design can minimize these problems. Further study of this approach is warranted.

The second approach, a separate pre-entry science vehicle, can provide quality science measurements and would have no impact on the reliability of the basic probe mission. However, this approach is certainly the most costly in dollars, weight and complexity.

A jettisonable pre-entry science module is probably the easiest design concept to integrate onto the probe and, when mounted on the front, provides a simple approach for eliminating sample contamination. This is a relatively low cost concept, however, it does impose some risks to the mission if it is not properly jettisoned. This approach has been selected as the study baseline and techniques for minimizing associated risks are proposed.

b. Design Approach - The baseline design is a pre-entry science module which mounts on the front of the Titan probe. This configuration is shown in Figure V-7 of Section V B 2 and it requires that the pre-entry package be jettisoned prior to encountering the severe entry environment. The conceptual design conceived straps the pre-entry science package to the aeroshell without penetrating the ablative heat shield. The straps holding the package are pinned to the backside of the probe and the science module, which is made in two segments, is separated based on an accelerometer signal. At entry the segmented science package is separated by either a spring force, or a pyro-gas device. The impulse drives each segment radially from the nose of the probe, and frees the straps, which are pinned to the back edge of the probe. In addition to the separation force provided by the springs, the pre-entry module segments are also forced off the face of the aeroshell by the centrifugal force due to probe spin, and by the aerodynamic loads which are just beginning to build up at time of separation.

Electrical interfaces to the probe are carried on flat wire cables which are attached to the hold down straps and can be disconnected using a hot wire, spring-disconnect connector, such as used on the Viking spacecraft. An alternate design concept for the electrical interface, which does not require an electrical connector, is discussed in the *"Optional Design"* section.

The data interface to the probe's data system is minimized by providing a data buffer in the science subsystem which time-tags the data from each instrument and multiplexes the data, over one set of wires, to the Titan probe data system.

Each instrument will be designed to sequence itself after receiving a bi-level command at separation from the orbiter. The pre-entry sequences are preprogrammed into the instruments and will require no operational command. Calibration of the instrument will similarly be commanded by a single bi-level signal.

As illustrated in Figure V-7, the science instruments are located on the front of the pre-entry science module so that contaminant free samples can be obtained. It is important for the mass spectrometer and retarding potential analysis instruments that no sample particles contact the structure before entering the inlets. At high entry velocities some molecular sputtering is possible wherein the incoming molecule strikes the surface and knocks surface molecules into the inlets thus contaminating the measurement. This is eliminated by placing the inlets ahead of all structural elements as is done in the proposed concept.

The forward aeroshell/heat shield portion of the probe must be grounded to reduce electrical field effects on the science readings. This is done by wrapping the probe in an aluminized mylar cover as was done on the Viking lander vehicle.

c. *Optional Designs*

1) Autonomous Probe - An optional pre-entry science concept was evaluated which uses an autonomous probe for the pre-entry science. This space probe separates from the orbiter independent of the entry probe and provides its own sequencing, data handling and data transmission to the orbiter.

The configuration of the autonomous pre-entry science probe is a spacecraft structure that is spin-stabilized and provides the environmental protection required for the coast trip to Titan. The inlets for each of the pre-entry instruments are located forward of any structure thereby minimizing or eliminating sample contamination. The pre-entry probe is separated from the orbiter so that it has a trajectory that is significantly different than that of the Titan probe. This different trajectory is to insure that there is no possible interference from the Titan probe. After spin up and separation from the orbiter the pre-entry instruments will sequence and transmit the pre-entry data directly to the orbiter. The pre-entry science will be designed to operate and transmit data for at least 33 minutes.

Power requirements for the autonomous probe are estimated at 39.5 W and 39.5 W-hr of energy required. In the autonomous probe, power is required for the data handling and transmitting system as well as for the science instruments. The battery for the autonomous probe will be a silver-zinc, remotely activated type battery, which is activated prior to separation from the orbiter.

The obvious advantage of the autonomous pre-entry probe is that it has no direct impact on the Titan probe design. The orbiter design must provide spin-up for the two probes and have a separation mechanism that will not compromise the Titan probe reliability because of the autonomous pre-entry probe separation. The disadvantage of the autonomous concept is the added weight, complexity and cost that is added to the overall system. The cost can be minimized by using the data handling subsystem and transmitter that is in the Titan probe.

2) Optional Electrical Interface to Baseline Concept - In the baseline design the electrical interfaces between the pre-entry science and the Titan probe are made through a standard type connector. The seven-year transit time to Titan may degrade the mechanical, surface-to-surface electrical contact. A method of eliminating the connector is to use an "air gap" transformer to complete the electrical circuits between the Titan probe and the pre-entry science subsystem.

The concept considered is to develop an air gap pulse transformer that has one-half of its split core mounted on the inside surface of the probe and the other half clamped outside, and then connected to the windings from the pre-entry science subsystem. Figure V-9 shows this concept. The advantage of using a transformer rather than a pin type of connector to complete the circuit, is that physical surface-to-surface contact is not required. Once the air gap is established by mating the halves it can only change due to the expansion and contraction of the clamp. Careful design of the air gap transfer will allow variation in the air gap without affecting performance. Another advantage of this concept is that when the pre-entry packages are jettisoned it will not be required to depend on a mechanical disconnect. Instead the release of the clamp straps, in the baseline design will also release the clamped air gap transformer. A more reliable jettison action will result.

3) Alternate Pre-entry Science Power Device - An option to using an electrical power connector would be to pass the power from the probe through an air gap transformer, after inverting the battery dc voltage to some convenient ac power. Similar to the air gap pulse transformer presented in the previous section this would provide for a "contact-less" electrical connection as well as allowing the jettison disconnection to be made without depending on a mechanical connector.

2. <u>Atmospheric Science</u>

a. Implementation Problems - The atmospheric science experiments are described in some detail in Chapter III and include the following:

- o Atmosphere structure instrument
- o Multispectral radiometer
- o Nephelometer with differential thermal analyzer
- o Neutral mass spectrometer

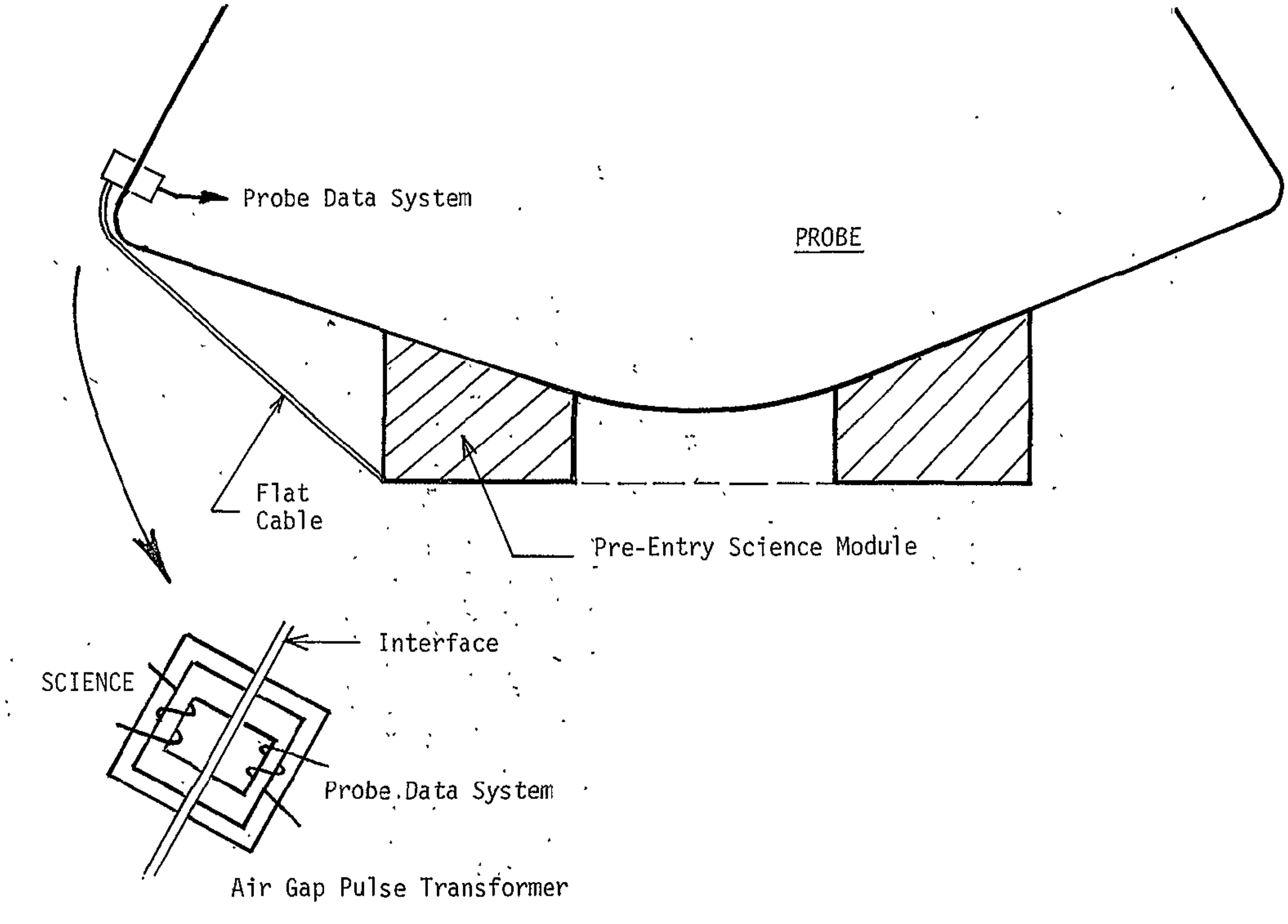


Figure V-9 Optional Pre-Entry Science Interface with Probe

- o Gas chromatograph
- o Descent imagery
- o Doppler/wind (stable oscillator)

All of these experiments except the descent imagery have been previously integrated into atmosphere probe vehicles such as the Pioneer Venus probe, the Viking lander, and the Galileo probe. No unusual problems are anticipated in integrating these science instruments into the Titan probe designs, however, techniques must be implemented for deployment of the nephelometer, the temperature sensor, and the atmospheric inlet for the mass spectrometer and gas chromatograph. The multispectral radiometer sensor must be uncovered after entry to provide its specified field of view.

b. Design Approach - In the Class A probe, the atmospheric inlet penetrates the heat shield at the center of the nose or the stagnation point. To eliminate possible contamination the inlet is spring-loaded to protrude beyond the heat shield boundary layer when deployed.

For the Class B and C probes, a nose cap of about 35 cm in diameter is ejected after entry as illustrated in Figures V-4, V-6, and V-8 of Section V B. This nose cap is released just after entry at the time the descent parachute is deployed for the probes designed for the thin atmosphere. This condition is at a descent condition of about 0.8 M for both the thin and thick atmosphere designs. With the nose cap removed, the atmospheric inlet is exposed as well as the descent imaging camera. The inlet tube is also deployed out slightly beyond the boundary layer region to eliminate possible contamination. This tube is designed to collapse on contact with the ground since its function is completed at that time.

The descent imagery camera is pointed directly down with a 90-degree field of view of the landing area. A CCD type camera was selected since it can stop the motion by providing a snapshot of the scene. The analog image is temporarily stored on the CCD matrix and then the analog signal is read into a special CCD buffer storage device called an analog delay line. From here the signal is digitized and interleaved into the data stream for direct transmission to the orbiter. Further discussion of this data handling device is given in Section VI D 3.

The imaging system must be designed for relatively low light levels according to estimates made at this time. The maximum estimated light levels at the subsolar region on Titan are about .009 W/m^2 which is about 3 times full moonlight on earth. The more likely light levels will be reduced somewhat (possibly a factor of 2) by the presently poorly defined cloud layers in the Titan atmosphere.

A more detailed discussion of this situation is given in Section V C 3, for the surface imaging camera. However, in summary, the preferred design approach is to use either available light or a light intensifier depending on the assessment of light requirements at the time of hardware design. If the current light level estimates are correct, a CCD type imager has sufficient sensitivity to obtain images without augmentation. The second choice would be to add a light intensifier. Intensifiers are being built and used today with gains from 10,000 to 40,000 and these devices are very small and lightweight. They do, however, require a high voltage power supply. Other more drastic approaches were considered such as dropping flares but the above discussed approaches appear satisfactory at this time.

3. Surface Science

a. Implementation Problems - The primary implementation problems arise from the uncertainty in the surface characteristics. At this time, the atmosphere and surface model uncertainties are so broad that it is possible to have a surface consisting of combinations of solid ices and clathrates, or relatively soft "snow", or even liquid nitrogen. This situation complicates surface sample acquisition and the design of a reliable seismic experiment with effective coupling with the surface.

The uncertainty in light levels at the surface due to unknown cloud densities will require an automatic light level camera adjustment, however, this is commonly done within the current state of the art. If new science analysis, based on data from the Pioneer 11 and Voyager missions, results in significantly lower light level than currently estimated, then artificial light sources may be required. However, current light level estimates indicate that present camera systems alone or in conjunction with light intensifiers can satisfactorily image the surface in the general vicinity of the subsolar region.

It is anticipated that the uncertainties in the Titan atmosphere light levels and surface characteristics will be considerably narrowed before the hardware design phase starts sometime after 1983. Within the current model definitions, it appears that no major new developments are required. If the uncertainties remain rather broad, it will result in more costly solutions to the surface science implementation, but reasonable concepts are available.

b. Design Approach - The surface science experiments have been described in Chapter III, Section III D and include the following:

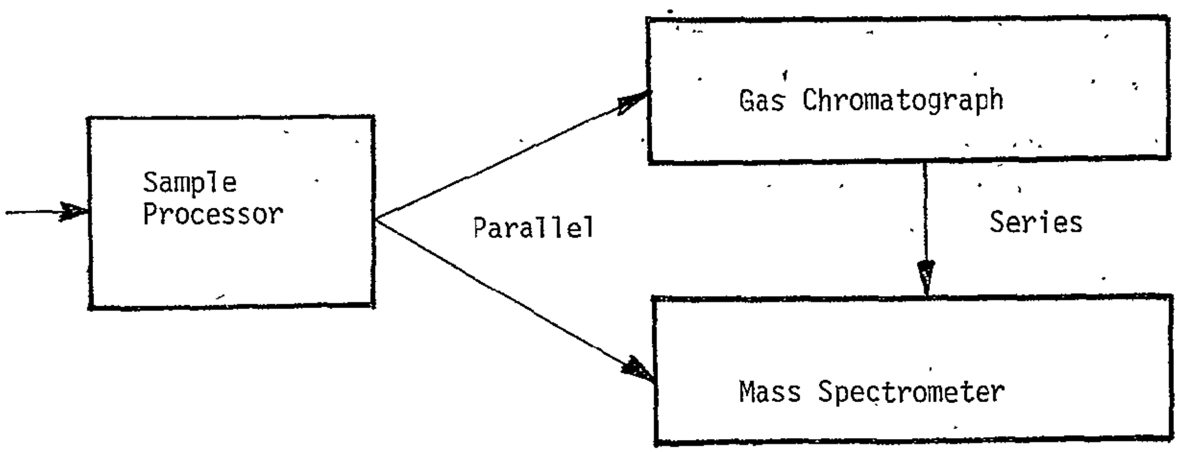
- Impact accelerometer
- Meteorology
- Composition (GCMS)
- Active wet chemistry "ozone analysis"
- Alpha-backscatter
- Surface imaging

- o Microscope
- o Passive seismometer
- o Precipitation experiment

The impact accelerometer may use either the entry accelerometer triad switched to a high range or, more likely, a separate accelerometer located near the center of gravity of the lander. The impact data will be buffered and later interleaved into the science data stream for direct transmission to the orbiter. About 60,000 data bits are required. The accelerometer is activated by the low altitude radar altimeter which also triggers release of the parachute for the thin atmosphere designs.

The meteorology experiment is mounted near the top of the science mast just under the flat microstrip RF antenna and above the imager camera. It consists of hot wire elements similar to the Viking lander meteorology. Figures V-4 and -8 show the experiment location in the stowed position on the Class B and C landers.

The Class B probe uses the GCMS for composition measurement and the expanded science payload of the Class C probe also includes the wet chemistry unit and the alpha-backscatter unit. The GCMS experiment uses an inlet and manifold system as illustrated below which allows both parallel and series measurements.



In series measurements, the sample goes through the GC first and then the MS as illustrated above. Figure V-5 shows the general layout of the GCMS and processor.

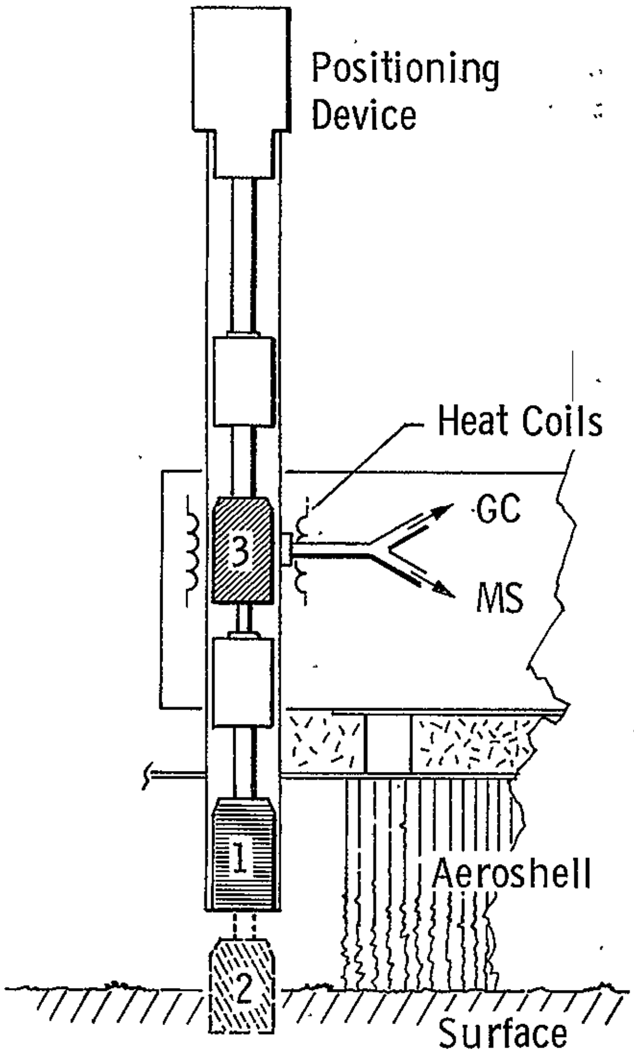
The wet chemistry ozone analysis experiment is a front end processor which feeds the output gases from its reactive chemistry into the GCMS for detection. This experiment needs more development for a detailed definition, however, the physical characteristics assumed for this evaluation are based on a fairly extensive study by Martin Marietta of a similar instrument for use on a Mars rover concept.

Both of the above composition devices have a common requirement for sample acquisition and delivery to the instrument processor. Figure V-10 summarizes the requirements, problems, and activities related to surface sample acquisition on Titan. Also, a proposed sample acquisition concept is shown. A Viking type soil scoop is not applicable for the Titan surface because the surface probably does not contain any granular soil or rock. The Titan low bulk density indicates that the body must consist mainly of ices with a low percentage of rock which is probably at the core rather than on the surface. It has been postulated that various organic compounds have formed in the atmosphere and aerosol layers and precipitated out to the surface over a long period of time. Based on these considerations, the surface may consist of ices or clathrates, "snow" from atmospheric gases or aerosols, and possibly liquid nitrogen. For composition measurements, it is a requirement to obtain and seal the sample so that no fractions are lost in handling. The sample must be heated throughout to a controlled temperature level and then the gases are carried to the GCMS for detection. This process is repeated in 8 to 10 steps in order to accurately define the composition.

The problems are listed in Figure V-10. The surface uncertainty makes it difficult to obtain and handle the sample. The concept shown assumes that the surface is primarily ice or dense snow. If a liquid surface is encountered, it would probably be most practical to have a secondary, parallel sample acquisition system capable of handling

Figure V-10 Surface Sample Acquisition

Core Sample Acquisition



Requirements or Goals:

Obtain Sample (Ice, Snow, Liquid)
Seal Sample
Heat & Stabilize in Increments
Deliver Gas Products to GCMS

Problems:

Surface Uncertainty (Ice, Snow, Liquid)
Maintaining Sample Integrity
Sealing
Multiple Samples
Precise Temperature Control

Related Activities

- "Mars Permafrost Sampling Requirements". JPL Lab Tests
- "Study of Sample Drilling Techniques for Mars Sample Return Mission." Martin Marietta Study, NASA Contract 9-15613.

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C-2

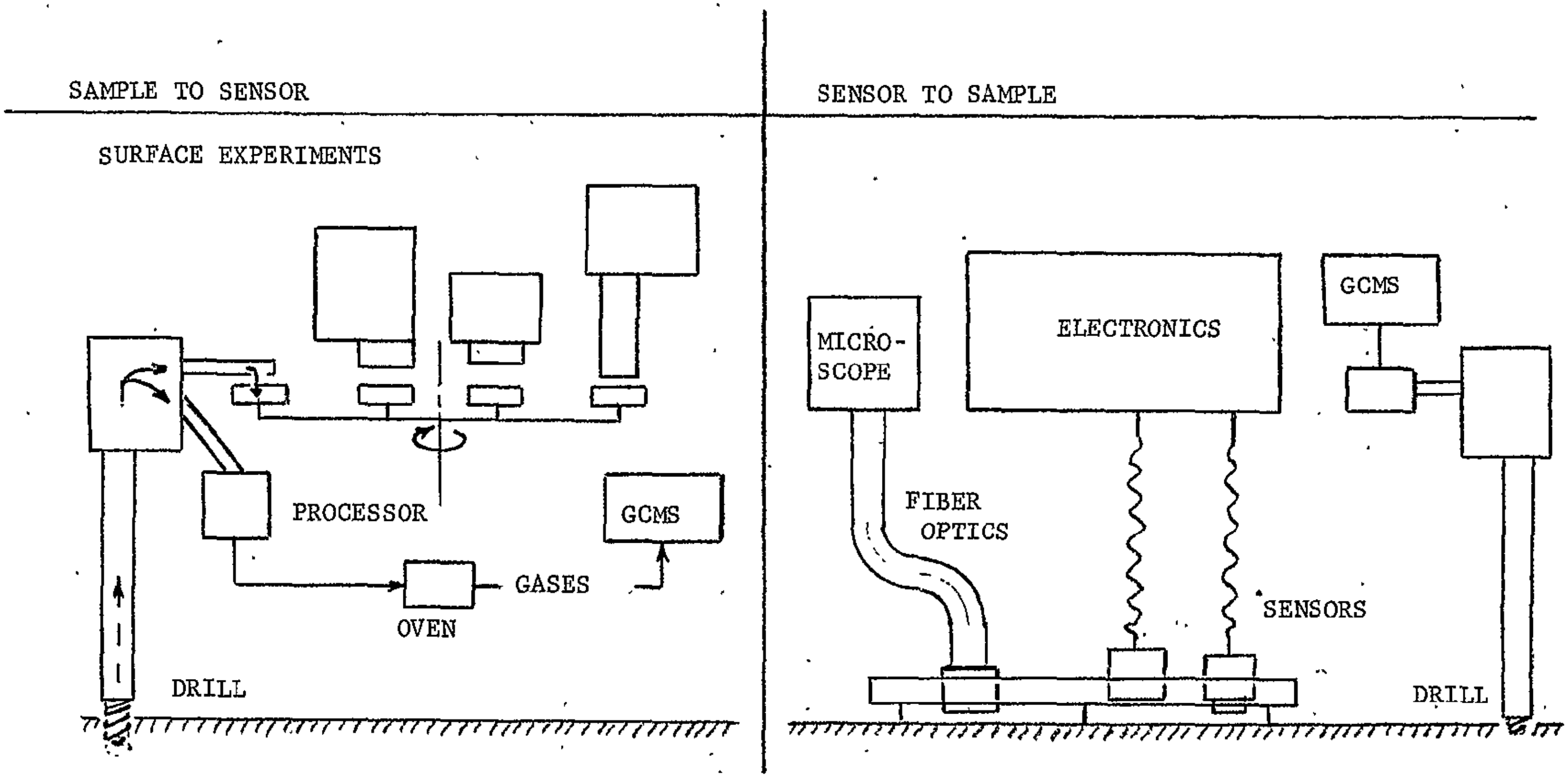
liquid. In the solid surface case as shown, a core type drill is proposed which extends into the surface, either cuts a sample with slow rotary motion or by means of impact, retracts the sample to the heater coil area, and finally applies heat to drive off the gases. The concept assumes the core sample extraction and movement into the heater area is done fairly rapidly so that only the sample surface may be lost to melting or crumbling. As long as the bulk of the sample is undisturbed, the scientific results will be valid. Laboratory tests of a core type drill were performed by JPL in a study titled *"Mars Permafrost Sampling Requirements"* and Martin Marietta, under NASA contract is currently working on the same basic problem in an effort titled *"Study of Sample Drilling Techniques for Mars Sample Return Missions"*. Additional development is required to perfect these techniques since problems have been encountered with the sample partially melting during the coring operation, then refreezing inside the core tube. However, methods of solving these problems have been proposed.

An optional sample acquisition technique involves placing a tube and heater on the surface and carrying only the gases up from the surface to the GCMS. This approach is less satisfactory from a science standpoint because there is little control of the bulk temperature and less information can be obtained in this manner.

The alpha-backscatter experiment requires that a sample be placed very close to the alpha-source and detector. This is especially important if the thick atmosphere is encountered since alpha particles are significantly absorbed by dense atmosphere. Two concepts were considered for this application and are illustrated in Figure V-11. The one concept consists of carrying the sample to the sensor as was proposed for the GCMS experiments. For the alpha-backscatter device, the microscope, and the seismometer it appears practical to deploy the sensor to the sample or surface as shown in the figure. This implementation is also shown for the Class C probe in Figure V-8.

The microscope also requires accurate positioning of the sample because of the very short focal length inherent in the optics. By

Figure V-11 Science Acquisition Concepts



using a fiber optics extender, the object lense can be brought close to the surface without destroying the sample by handling. Also, a small light source can be mounted to the head of the microscope to provide known intensity and direction of the light.

The seismometer has a unique problem in obtaining effective coupling with the surface. Ideally, the sensor should be placed in direct contact with the solid surface. For the icy surface, this can be accomplished by driving the sensor box down until spikes are securely forced into the surface. The box must be well thermally insulated and heated with small resistance heaters to survive many weeks. If the surface is soft and "snowy" then poor coupling will result.

For imaging, the requirements and lighting conditions are given in Figure V-12. The descent imaging experiment was discussed in Section V C 2 b, however, the lighting situation is similar. As shown in the figure, the requirement has been established to obtain a minimum of one complete 360^{o} panoramic color image of the surface area after touchdown. Since a color image requires three black and white images using different filters, the imaging effectively has triple redundancy for black and white imaging thus improving the probability of receiving some pictures. The maximum light level at the subsolar region is estimated to be .009 W/m^2. This is equivalent to about three times a bright moonlight night on earth. This light level is more than sufficient for excellent, high contrast imaging with current CCD or facsimile silicon photosensor array type cameras. The probable surface light level may be reduced by atmospheric aerosols by a factor of two or so; however, if this reduction is very large a light intensifier may be added to the camera optics. Light intensifiers use very little power, are compact, and those available today provide gains of from 10,000 to 40,000. They do require a high voltage power supply just as the mass spectrometer does. However, today's CCDs and photosensors are extremely sensitive and, with appropriate noise subtraction techniques used today, the addition of intensifiers or artificial light will probably not be required. If the light levels turn out to be unexpectedly low, which is not likely, artificial light sources could be included such as synchronized Zenon or laser spotlights, floodlights, or flares.

Figure V-12 Imaging Requirements

REQUIREMENTS

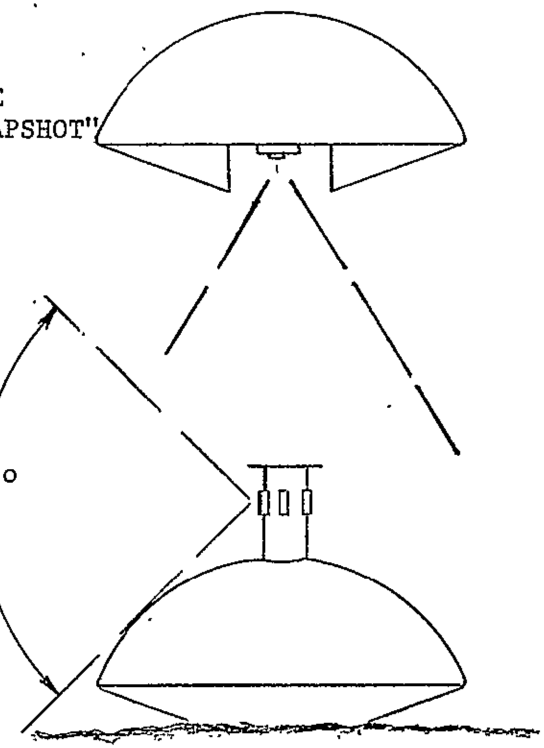
- o OBTAIN IMAGES OF LANDING AREA DURING DESCENT
- o OBTAIN PANORAMIC (COLOR) IMAGES ON SURFACE AFTER TOUCHDOWN

LIGHT ENVIRONMENT

- o MAXIMUM LIGHT LEVEL .009 W/m^2 (~ 3X MOONLIGHT ON EARTH)
- o PROBABLE SURFACE LIGHT LEVEL LESS THAN MAX. DUE TO ATMOSPHERIC HAZES

LIGHT LEVEL ENHANCEMENT

- o PREFERRED APPROACH:
  - ADD LIGHT INTENSIFIERS TO CAMERA
  - GAINS OF 10,000 TO 40,000 ARE AVAILABLE TODAY
  - .009 W/m^2 X 10,000 = 90 W/m^2 (BY COMPARISON, AN EARTH OVERCAST DAY IS ABOUT 40 W/m^2)
- o ALTERNATE APPROACHES:
  - DROP FLARES FOR DESCENT IMAGE
  - SYNCHRONIZED XENON OR ARGON LASER SPOTLIGHT
  - FLOODLIGHTS (IE: RUSSIAN VENERA)
  - LOFT FLARES FROM SURFACE



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4. <u>Alternate Science - Balloon Sonde</u>

a. Implementation Problems - The primary considerations in the design of a balloon sonde for use on Titan include the impact of the extremely low temperature, reliable inflation and deployment of the balloon, and selection of the inflation gas. The baseline design provides a temperature and pressure profile with altitude and transmits its data back to the lander for storage and later retransmission to the orbiter. A more ambitious option would be to also track the balloon from the lander to obtain wind data; however, this option would require the addition of a directional antenna on the lander.

Titan atmospheric temperatures may be as low as about 70 K at balloon operating altitudes in the thick atmosphere. The balloon mission does not appear feasible in the thin atmosphere model because of the low densities. The low temperatures require a well insulated balloon gondola to thermally protect the electronics during ascent. However, the most critical problem associated with the low temperature is the selection of a balloon skin material that will remain reasonably flexible when exposed to the environment. Many conventional balloon materials such as Mylar or Kapton become brittle at the anticipated temperatures. Further evaluation of available materials is required to fully assess this problem. Certain classes of plastics such as Teflon do retain some flexibility at low temperature and with sufficient pre-heating of the material prior to deployment and inflation, a practical design may be possible.

The balloon could be inflated with helium, hydrogen, or hot atmosphere. As discussed in Chapter III the hot atmosphere, solar heated Montgolfiere type balloon concept was dropped from further consideration at this time because the estimated solar energy available at reasonable float altitudes was insufficient. Cursory assessments of an actively heated hot atmosphere balloon by both Dr. Blamont of CNES and by Martin Marietta indicated that a reasonable design would be excessively heavy for this particular mission design.

Helium gas is proposed for the baseline design of a balloon sonde because it results in the lightest weight combination of inflation gas plus gas storage system. Helium can be stored in titanium tanks at very high pressures (4500 psi) for long periods. However, if the boron or glass wrap tank technology comes of age by the time the hardware phase of the Titan mission starts sometime after 1983, then hydrogen would be the best choice for the inflation gas. Not only does it have half the molecular mass of helium but it has a lower leak rate because of its diatomic structure. Unfortunately, hydrogen cannot be used in a titanium tank because of its hydrogen-embrittlement of titanium.

b. Design Approach - The helium inflated balloon sonde design is summarized in Figure V-13. The science payload includes pressure and temperature sensors and a radio altimeter design similar to those commonly used on earth weather sondes. A small battery and transmitter are enclosed with the electronics in a lightweight box structure and a layer of insulation maintains the temperature in the gondola utilizing the electronics waste heat. The total mass of the gondola is 2.8 kg.

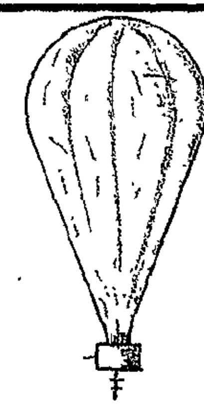
A 4 m diameter helium filled balloon is required to provide flotation for the system and it reaches full inflation at an altitude of 167 km (2867 km radius) which is about 4 density scale heights above the 60% probable surface in the thick (nitrogen) atmosphere. The schematic in Figure V-13 shows the proposed inflation and packaging concept. A 31.5 cm diameter titanium tank which weighs 10.8 kg contains 0.7 kg of helium at 4500 psi pressure. The total system weight including gondola, balloon tank, and support structure is 19.0 kg. The balloon is folded on top of the gondola and enclosed in an insulated canister.

A short period before deployment of the balloon sonde, the battery will be remotely activated and the canister pre-heater will be energized to heat soak the balloon material and assure that it becomes flexible before the deployment and inflation process begins. Then a

Figure V-13 Balloon Concept - Thick Atmosphere Only

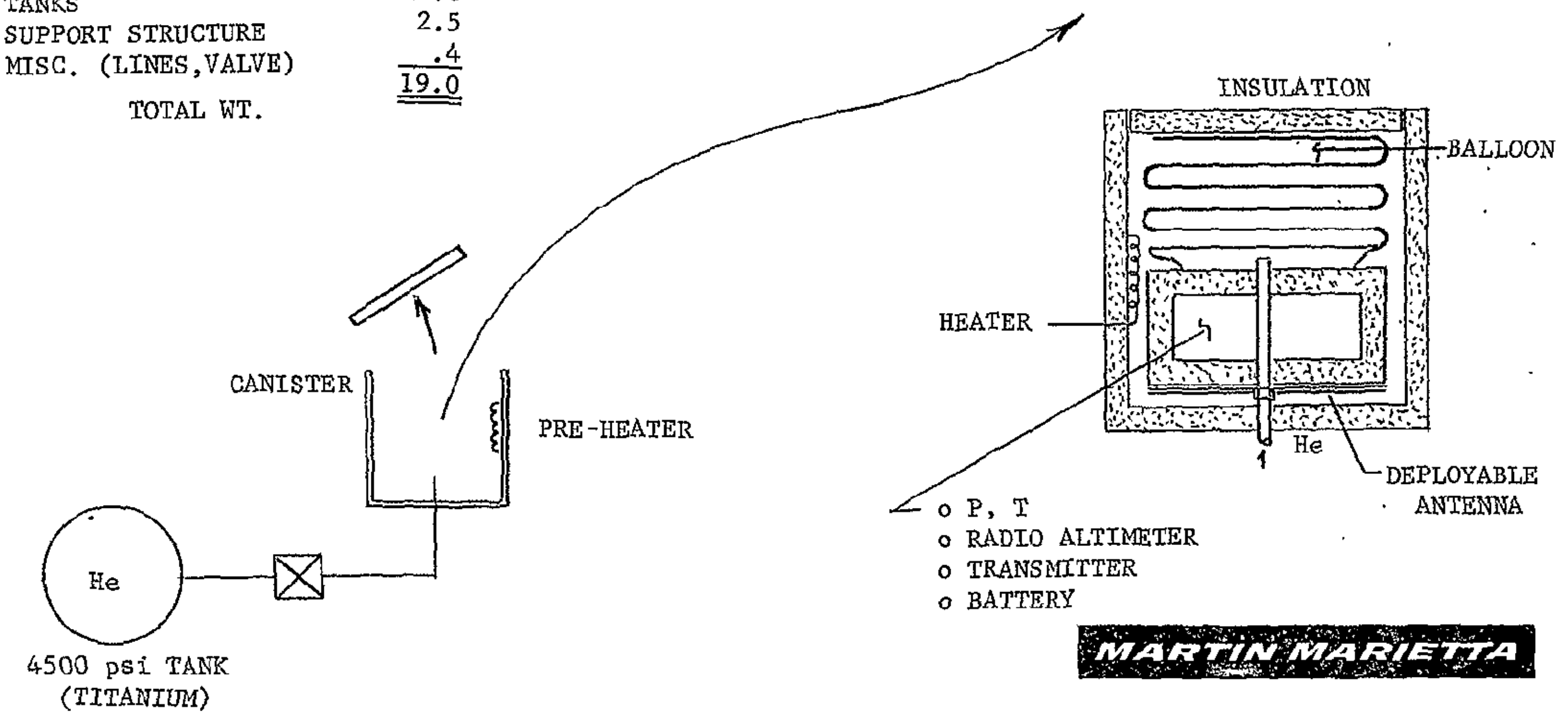
<u>WEIGHT STATEMENT</u>

		KG
P,T SENSORS / ALTIMETER / ANTENNA	SCIENCE	.3
TRANSMITTER		.5
BATTERY		1.0
STRUCTURE, INSULATION		1.0
GONDOLA		2.8
BALLOON (4.0 M DIA.)		1.8
He		.7
FLOATED WT.		5.3
TANKS		10.8
SUPPORT STRUCTURE		2.5
MISC. (LINES,VALVE)		.4
TOTAL WT.		19.0



MAJOR PROBLEM:

1. FLEXIBLE BALLOON MATERIAL AT CRYOGENIC TEMPERATURE



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pyro valve releases the helium gas through a constricting orifice into the balloon and as it starts to inflate it forces the insulated cover off. The helium bubble will buoy the top of the balloon up thus deploying its full length. After the helium tank is exhausted a second pyro device will sever the helium fill line thus releasing the balloon sonde. As the balloon ascends it will measure pressure, temperature, and altitude and transmit the data back to the lander for storage.

D. LANDING SYSTEM OPTIONS

The baseline landing concept is a hard lander configuration described in Section V B 2 for the Class B probe. This section compares a soft lander concept similar to the Viking lander with a hard lander. In addition, a discussion of landing and flotation considerations for a liquid or snowy surface are presented.

1. Hard Versus Soft Lander Comparison - Early in the study a trade off between hard versus soft landers was performed for the Class B probe designed for the thin atmosphere.

The results of this analysis showed that the soft lander reduced the landing shock by slightly more than an order of magnitude, i.e. 30 g's vs 300 g's. However, the soft lander cost and weight was higher than that of the hard lander; i.e. 80% and 10% respectively. The hard lander concept was selected over the soft lander on the basis of unfavorable weight, complexity, and cost penalties.

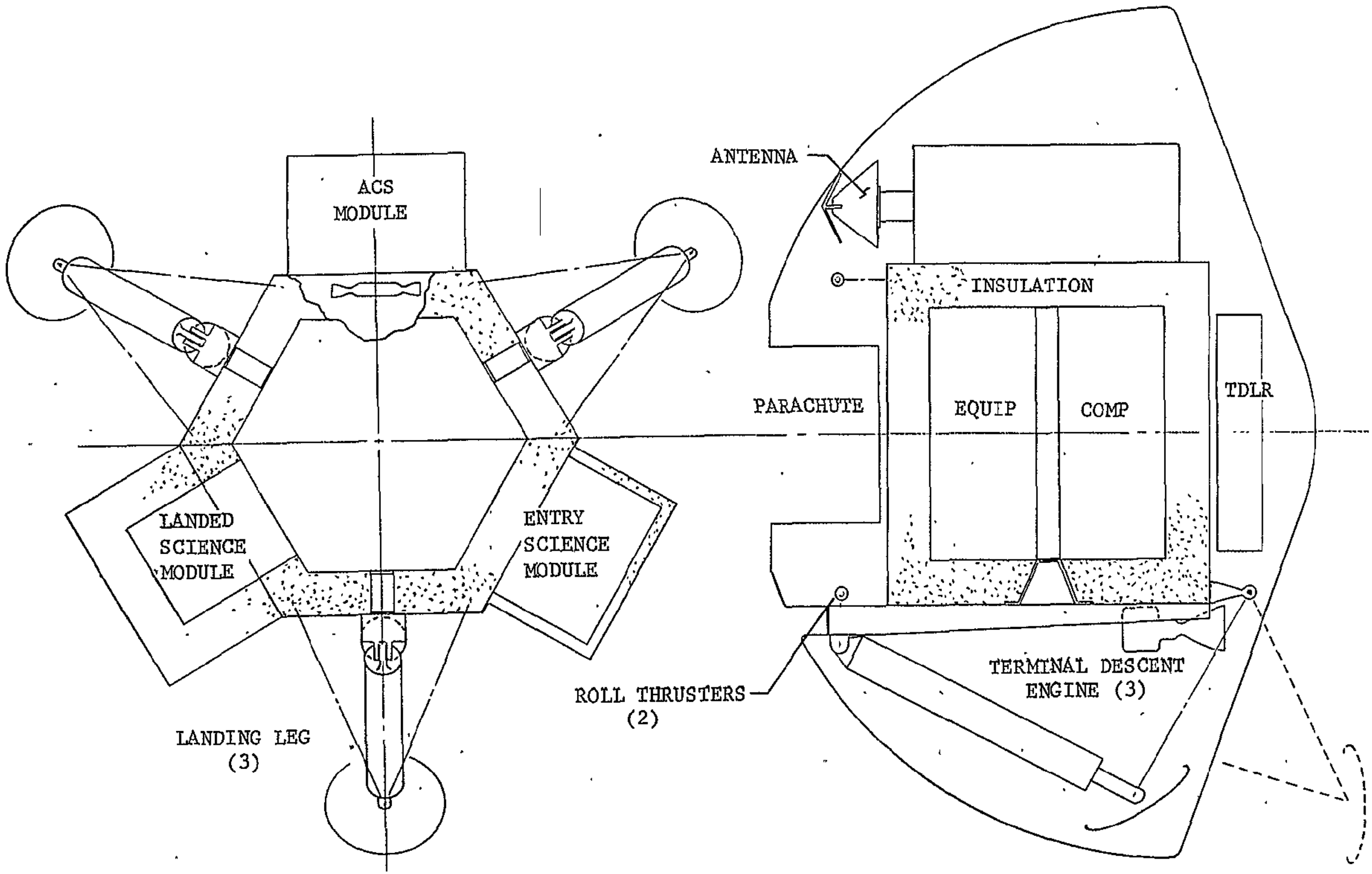
The hard lander configuration shown in Figure V-4, uses a combination aeroshell and crushable honeycomb shock attenuation system. The system is designed to limit the touchdown deceleration to less than 300 g's with a 20 m/s impact velocity and a 15 cm stroke. A short range radar altimeter provides the signal to release the parachute at about 100 m altitude and the lander then free falls to the surface. The weight characteristics of this design are shown in Table V-3. Note that the science payload is somewhat less than that of the Class B probe baseline design of Section V B 2. This trade off was done early in the study and the baseline science payloads were redefined at the midterm meeting. However, the relative comparison of the hard versus soft lander designs is valid.

The soft lander configuration is shown in Figure V-14 and it is conceptually similar to the Viking lander. The lander is packaged inside the entry aeroshell and, after entry, the parachute is deployed which extracts the lander from the aeroshell. The lander then descends through the atmosphere on the parachute until it reaches an altitude

Table V-3 Class B Probe Weight Comparison - Hard Versus Soft Lander

	MASS, KG	
	HARD LANDER	SOFT LANDER
SCIENCE	40.2	40.2
TELECOMMUNICATIONS	3.9	3.9
DATA HANDLING AND CONTROL	6.2	6.2
POWER/PYRO/CABLING	22.7	23.6
THERMAL	8.8	8.8
STRUCTURES/MECHANISMS	52.8	75.7
ATTENUATOR STRUCTURE	22.0	-
RADAR ALTIMETER	1.0	-
SOFT LANDER SYSTEM:		
TDLR/RATE GYRO	-	9.3
VALVE DRIVE AMPLIFIER	-	4.5
MICROPROCESSOR	-	2.3
PROPULSION/ACS	-	10.0
SUBTOTAL	157.6	184.5
15% CONTINGENCY	23.6	27.7
TOTAL	181.2	212.2

Figure V-14 Class B - Probe/Lander Configuration (Soft Lander)



of 100 m above the surface. At this point the terminal descent and landing radar (TDLR) signals release of the parachute and activation of the terminal descent propulsion. A guidance and attitude control subsystem are required to bring the lander to the surface. Three terminal descent engines with controllable thrust provide thrust level, pitch and yaw control and two small thrusters provide roll control. A touchdown velocity of 2 m/s or less can easily be obtained. The landing legs use crushable material for shock attenuation and this eliminates possible rebound at touchdown.

Table V-3 presents a weight comparison for the two concepts and a cost comparison is given in Chapter VIII, Table VIII-3. In summary, the soft lander concept increases the weight over that of the hard lander by 17%. The soft lander requires the addition of the following subsystems:

- o Terminal descent and landing radar (TDLR)
- o Rate gyro
- o Valve drive amplifier (ACS control)
- o Microprocessor
- o Propulsion/ACS
- o Landing leg structure and mechanism

By comparison, the hard lander required:

- o Honeycomb shock attenuator system
- o Radar altimeter

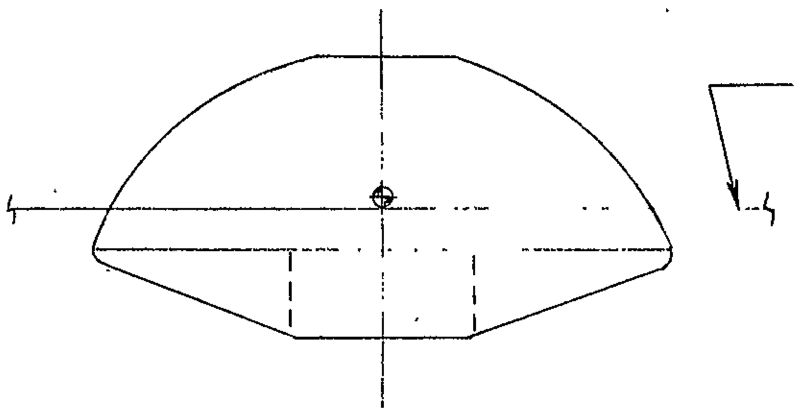
The increased complexity of the soft lander over the hard lander is reflected in the above comparison of additional subsystems and in the cost comparison. From Table VIII-3 of Chapter VIII, the soft lander cost is about 80% greater than that of the hard lander.

2. <u>Snow or Liquid Surface Considerations</u> - The baseline design concept, which retains the entry aeroshell configuration to the surface, provides a large surface area on contact with a soft, snowy or liquid surface. On a soft or snowy surface this configuration minimizes the penetration and provides a very stable platform for subsequent science measurements.

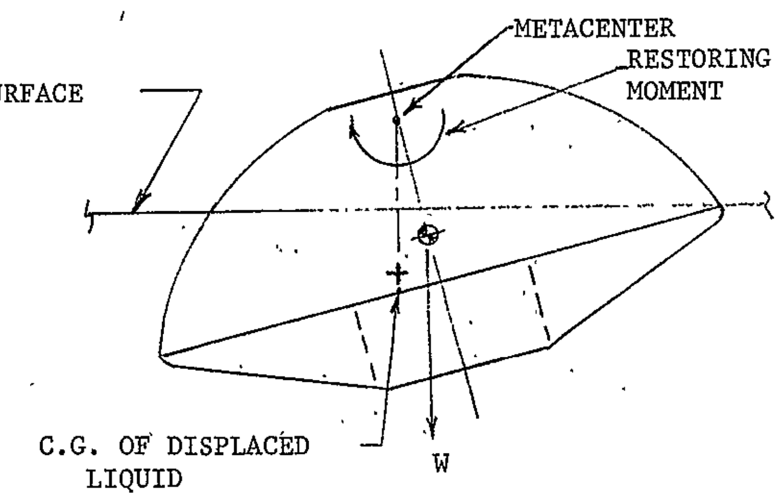
The lander capsule buoyancy characteristics in liquid nitrogen (density = 810.4 kg/m^3) were investigated. It was assumed that the capsule was sealed internally in the area of the deployed nose cap and deployable science sensors and at the aeroshell/base cover interface. The capsule will float in the upright condition with the liquid surface approximately 9 cm aft of the aeroshell/base cover interface, Figure V-15. If the capsule is displaced as shown at the right side of the figure, a restoring moment is produced which tends to return the capsule to its upright position, denoting a stable buoyancy condition. A deployable outrigger design could be added for greater stability as illustrated on Figure 15 if there turned out to be a high probability of a liquid surface. Additional data on the probable surface characteristics are expected to be available prior to hardware design.

Figure V-15 Lander Buoyancy Characteristics

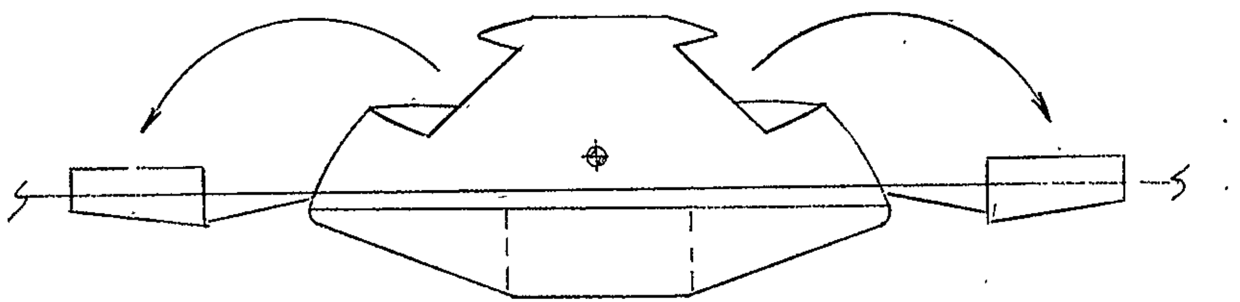
STABLE POSITION



DISPLACED POSITION



LIQUID NITROGEN,
DENSITY = 810.4 KG/m^2



POSSIBLE OUTRIGGER DESIGN FOR
ADDED FLOAT STABILITY

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E. CLASS B PROBE IN 10% PROBABLE THICK ATMOSPHERE

1. <u>Introduction</u> - This section presents a discussion of the impact of the extreme 10% probable surface in the thick atmosphere on the baseline Class B probe design. At the midterm meeting it was decided that the bulk of the configuration trades to be completed in the study should be limited to the 60% and 30% probable surface locations since the 10% probable surface would unrealistically drive the design conclusions. However, the impact of designing to the 10% surface was evaluated and the results are presented in the following paragraphs.

The primary effect of probe descent to the 10% probable surface is an increase in descent time of about 3.8 hours beyond the 30% probable surface and an altitude increment of 43 km. Although the pressure rises up to about 21 bars at the 10% surface, the environment has very little impact on the system design. The major impact results from the additional 3.8 hours of descent time wherein more total battery energy is required and the probe to orbiter communication link range is increased.

Two design approaches were evaluated for meeting the increased time requirement. The first was to maintain the baseline configuration and evaluate the impact of the increased time on battery size, communications range, increased transmitter power, and modified orbiter flyby altitude. The second approach was to consider staging from the entry configuration into a higher ballistic coefficient shape which would reduce the descent time back to something like the baseline descent time. Each of these concepts and the resulting system impacts are discussed in the following paragraphs.

2. <u>Class B Probe Baseline Configuration in 10% Probable Thick Atmosphere</u> - The Class B probe baseline configuration was designed to descend through the 60% probable surface location (2786 km radius) and on down to the 30% probable surface (2743 km radius). Figure IV-14 of Chapter IV presents the entry and descent time history for the thick

(nitrogen) atmosphere case. The descent time after entry to the 30% probable surface is 4.81 hours and to the 10% probable surface is 8.68 hours or an increase of 3.87 hours.

In order to accommodate the communications link and maintain the orbiter in view of the probe, the orbiter radius of closest approach for the baseline design was raised from 12.8 R_T (Titan radii) to 20.0 R_T for the 10% probable surface design. The resulting communications link geometry is shown in Figure V-16 and can be compared to the baseline design link of Figure VI-2. The touchdown times are shown on the figure for the 60%, 30% and 10% probable surface locations for the baseline subsonic descent ballistic coefficient of 94 kg/m^2.

The resulting system design changes are summarized in Table V-3. The increased descent time resulted in increased communications link range, increased RF transmitter power, increased battery supply time and, therefore, increased total battery size. The required battery energy nearly doubled over that for the baseline design. All of these increases resulted in an increase in probe thermal and structural support requirements with an overall weight increase of 30% over the baseline design as shown in the weight summary included in Table V-3.

3. <u>Vehicle Incorporating Staging to Increased Ballistic Coefficient</u> - The second approach to designing a probe to meet the requirements of descending to the 10% probable surface was to stage to a higher ballistic coefficient in order to reduce descent time. Figure V-17 illustrates a few of the configurations that were considered for this approach and compares their characteristics to the baseline entry shape.

The baseline shape is a 70° half angle cone entry configuration which is maintained to the surface. A segment of a sphere covers the back side and provides good packaging volume. Its subsonic ballistic coefficient of 95 kg/m^2 results in a descent time of 4.9 hours to the 30% probable surface (2743 km radius) and 8.7 hours to the 10% probable

Figure V-16 Configuration Geometry - Thick (Nitrogen) Atmosphere - Long Range

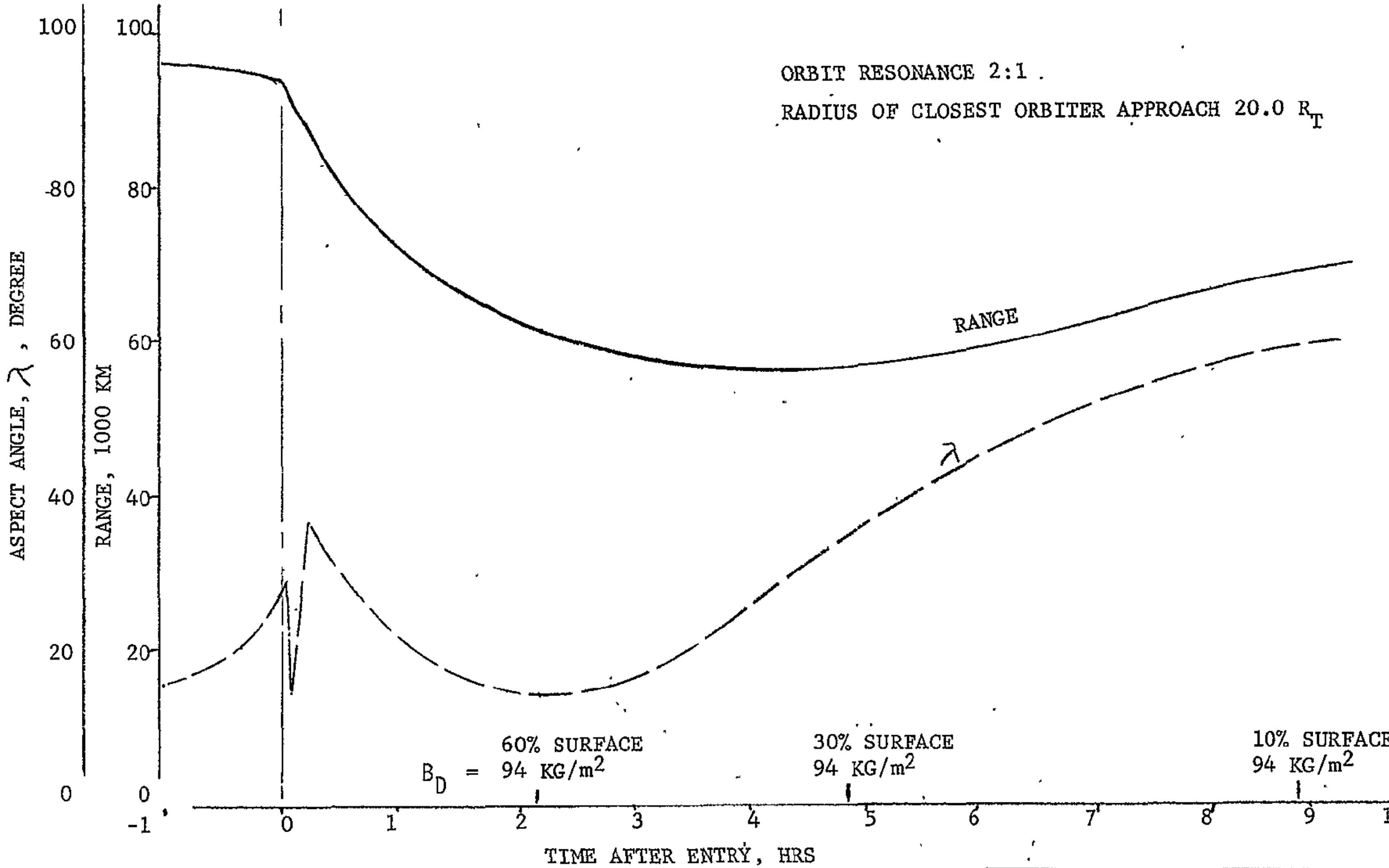

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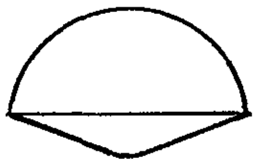
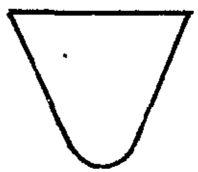
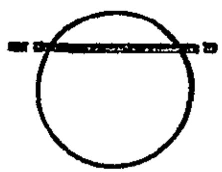
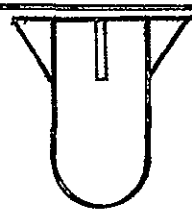
Table V-3 Comparison of Baseline Probe Design Parameters with 10% Probable Surface Probe Design

	Class B Probe	
	Baseline 30% Probable Surface	10% Probable Surface
Descent Time from Entry, hr.	4.81	8.68
Communication Design Range, km	50,000	76,000
Design Data Rate, bps	750	960
Transmitter RF Power, W	6	20
Battery Energy Required, W-Hr	1,392	2,495
Weight Comparison, kg		
Science plus Margin	51.0	51.0
Telecommunications	3.4	4.8
Power/Pyro/Cabling	43.6	66.6
Thermal	16.4	24.2
Structures/Mechanism	69.5	96.8
Data Handling & Control	12.6	12.6
Subtotal	196.5	256.0
15% Contingency	29.5	38.4
Total	226.0	294.4

Figure V-17 Thick Atmosphere - Configuration Considerations

SUBSONIC CONFIGURATION	SUBSONIC C_D	β Kg/m^2	TIME TO 10% SURFACE HRS	TIME TO 30% SURFACE HRS	PACKAGING	LANDING STABILITY	FLOTATION ON SURFACE
	1.05	95	8.7	4.9	GOOD	GOOD	GOOD
	0.45	190	6.1	3.4	FAIR	POOR	POOR
	0.50	235	5.6	3.1	FAIR	FAIR	POOR
	0.55	$\geq$ 315	$\geq$ 4.8	$\geq$ 2.7	POOR	POOR	POOR

surface (2786 km radius). This configuration has good landing stability and low surface penetration because of its large forward surface area. As described in Section V D 2, the configuration also floats on a liquid nitrogen surface if appropriately sealed.

The second configuration is a typical low angle blunted cone shape which reduces the drag considerably, however, it is more difficult to package densely with a sufficiently far forward center of gravity for stability. It does reduce the time of descent somewhat and this shape could be used as the entry configuration with no staging required. Its disadvantage is that it would require an attitude erection system after touchdown.

The third shape is a sphere with a "burble" fence attached for stability. This shape packages better than the blunted cone and significantly reduces the descent time. It also requires an attitude erection device, however, it would be relatively easy to roll upright. Its natural flotation stability in a liquid would be poor although outriggers could be added. It probably requires an aeroshell for entry.

The last shape is essentially a cylinder stabilized by fins and, by extending the length, the ballistic coefficient can be increased to nearly any desired value. This configuration has poor packaging, poor landing stability, and poor flotation. It also requires an attitude erection system after touchdown.

In summary, all of the higher ballistic coefficient configurations require considerably more complex systems for touchdown and attitude erection. Also, they appear less versatile than the baseline concept from a packaging and surface flotation standpoint. Since the baseline concept can be adapted to the greater descent depth (ie: 10% probable surface, Section V E 2) with a reasonable weight penalty of 30%, the investigation of the higher ballistic coefficient concepts was not carried any further.

F. CLASS B PROBE EXTENDED SURFACE MISSION

A trade study was conducted to evaluate the impact of extending the Class B probe baseline mission beyond the initial landing for another 32 Earth days or two Titan days. The extension would allow measurement of meteorology data over two diurnal cycles and additional composition and imaging at time of re-encounter.

Table V-4 compares the probe designs for the two mission options. The baseline probe performs its primary surface mission in 1.5 hours and continues secondary science measurements until the orbiter passes out of communications range a few hours later thus terminating the mission. The extended mission operates in the same sequence during the initial landing period. After the orbiter goes out of range, the extended mission probe is powered down so that only the meteorology and data handling subsystems are operating. An RTG provides power for both the active electronics and for recharging the primary batteries. Its waste heat is used in conjunction with isotope heaters for thermal control. The same primary batteries can be used for both probes without change since they have the same energy requirements during the orbiter initial encounter and second encounter periods and the RTG recharges these batteries before second encounter.

The weight comparison illustrates that the extended mission requires less than 10% more weight than the baseline mission. The addition of the RTG and associated power control equipment as well as additional thermal control resulted in the increased probe volume and structural weight.

The increase in program cost for the extended mission is \$6.9 M compared to the baseline cost of \$78.0 M or an increase of 9% as discussed in Chapter VIII and detailed in Figure VIII-5.

Table V-4 Comparison of Class B Probe Baseline and Extended Mission Concepts

	Class B Probe	
	Baseline (Initial Landing Only)	32-Day Extended Mission
Surface Mission Time	2.5 Hrs.	32.2 Days
Battery Energy Required, W-Hrs.	812	812
RTG Power Required (BOL), W	None	12
Additional Science Obtained	--	Meteorology Imaging Composition
Weight Comparison, kg		
Science plus Margin	51.0	51.0
Telecommunications	3.4	3.4
Power/Pyro/Cabling	43.6	45.6
Thermal	16.4	18.4
Structures/Mechanisms	69.5	82.0
Data Handling & Control	12.6	12.6
Subtotal	196.5	213.0
15% Contingency	29.5	31.9
Total	226.0	244.9

VI. SUBSYSTEM DESIGN

A. INTRODUCTION

This chapter describes the various subsystem designs and discusses critical design and integration considerations. Because of the large number of configurations covered in the study matrix, Figure V-2, the subsystems are discussed in general terms with specific examples defined where appropriate. In Section VI B, the science mission sequences are identified and the data rate requirements for each probe class are established. Using these data rates in conjunction with the communications geometry between probe and orbiter for each design, the RF transmission power and input power requirements were determined, Section VI C. From these results the data handling system was defined, Section VI D, and from the total power load history the probe power subsystem was established. Finally, using all heat loads from the electronic subsystems, requirements for thermal insulation and additional heat sources were determined, Section VI F.

B. SCIENCE SEQUENCES AND DATA RATES

The science sequences and resultant data rate requirements are based on required science instrument measurement periods and sampling intervals. The individual instrument data rates were specified in Chapter III, Table III-2, and the entry and descent time profiles for the thin and thick atmospheres are shown in Figures IV-13 and IV-14.

The science instrument mission operational phases were determined from the science measurement requirements and are summarized by probe class in Table VI-1. The operational phase times are shown at the bottom of the figure for both the thin and thick atmosphere models. The major difference between atmosphere models is reflected in the descent time to the surface. The bars indicate the period in which each instrument operates, and the probe

Table VI-1 Science Instrument Mission Operational Phases

SCIENCE	PROBE CLASS A	B	C	MISSION OPERATIONAL PHASE: WARM-UP CALIBRATE	PRE-ENTRY	ENTRY	DESCENT	TOUCHDOWN INITIAL SURFACE	EXTENDED SURFACE STORE/AUTO	RE-ENCOUNTER
PRE-ENTRY										
1. Neutral Mass Spec		X	X							
2. ION Mass Spec		X	X							
3. Retarding Potential Analyzer		X	X							
4. Electron Temperature Probe		X	X							
ATMOSPHERE										
1. Atmosphere Structure Instrument	X	X	X							
2. Multispectral Radiometer	X	X	X							
3. Nephelometer with DTA	X	X	X							
4. Neutral Mass Spec	X	X	X							
5. Gas Chromatograph	X	X	X							
6. Descent Imagery		X	X							
7. Doperler/Wind (Stable Osc.)	X	X	X	5 Hrs						
SURFACE								Class B & C →	Class C →	
1. Impact Accelerometer		X	X							
2. Composition (GCMS)		X	X							
3. Meteorology		X	X							
4. Surface Imaging		X	X							
5. Passive Seismometer			X							
6. Microscope			X							
77. Precipitation Experiment			X							
8. Active Wet Chemistry			X							
9. Alpha-Backscatter			X							
MISSION TIME (THIN ATMOSPHERE) MIN.				10	33	11	25	90	(32 Days)	90
MISSION TIME (THICK ATMOSPHERE) MIN.				10	33	8	283(1)	90	(32 Days)	90-

NOTE: (1) Descent to the 30% probable surface location.

class for instrument application is indicated by the check. The Class A probe does not obtain pre-entry science measurements or surface measurements while the Class B mission is complete after the initial surface period. The dashed lines indicate operation of the Class C science in the extended period required of this probe class.

Table VI-2 summarizes the probe data requirements by mission operational phase for each probe class in the thin and thick atmosphere models. It was assumed that all probe designs required a 10-minute warm-up and calibrate period with data storage. In addition, it requires a 5-hour period to warm up the stable oscillator, however, no data storage is required during that time. Only the Class B and C probes have pre-entry science and this data is stored for later transmission during descent. The worst case thin atmosphere pre-entry time of 33 minutes was assumed the same for both the thin and thick atmosphere. The differences in atmosphere model composition and altitude profile resulted in smaller density scale heights for the thick atmosphere. The science data is transferred from the pre-entry module to the entry probe through the connecting cable and stored for later transmission.

During the entry phase, the atmospheric structure instrument data is stored, and also transmitted throughout entry and possible blackout in order to provide a signal using the stable oscillator to gain additional information about the atmosphere. Both Doppler tracking data and signal degradation due to blackout can be obtained during this period. The entry science data is proportional to the entry time in each atmosphere model. This data as well as all previously stored calibration, pre-entry, and entry data are interleaved and transmitted to the orbiter during the descent period. The total bits shown in the descent phase include both stored and newly measured science data.

For the Class A probe designs, the communications link is designed by the descent data rate and range requirements. Since

Table VI-2 Baseline Probe Data Requirements by Mission Operational Phase

PROBE DESIGN		WARM-UP CALIBRATE	PRE-ENTRY	ENTRY	DESCENT	TOUCHDOWN INITIAL SURFACE		EXTENDED SURFACE	RE-ENCOUNTER
THIN ATMOSPHERE, TIME, MIN		10	33	11	25	90		(32 Days)	90
Class A									
o Total Bits	Bits	10,000	-	15,345	50,720	-		-	-
o Data Rate	bps	Store	-	Store	96(1)	-		-	-
						30 M	60 M		
Class B									
o Total Bits	bits	10,000	72,000	15,345	$2.3X10^6$(2)	$4.1X10^6$	$2.2X10^6$	-	-
o Data Rate	bps	Store	Store	Store	1,560	2,284	630	-	-
						60 M	30 M		
Class C									
o Total Bits	bits	10,000	72,000	15,345	$2.56X10^6$ (2)	$4.6X10^6$	$1.1X10^6$	$14.2X10^6$	$14.2X10^6$
o Data Rate	bps	Store	Store	Store	1,722	1,283	600	Store	2,625
THICK ATMOSPHERE, TIME, MIN		10	33	8	283	60	30	(32 Days)	90
Class A									
o Total Bits	bits	10,000	-	12,960	120,500(1)	-		-	-
o Data Rate	bps	Store	-	Store	21	-		-	-
Class B									
o Total Bits	bits	10,000	72,000	12,960	$12.7X10^6$(3)	$4.1X10^6$	$1.1X10^6$	-	-
o Data Rate	bps	Store	Store	Store	750	1,142	600	-	-
Class C									
o Total Bits	bits	10,000	72,000	12,960	$17.3X10^6$(4)	$4.6X10^6$	$1.1X10^6$	$14.2X10^6$	$14.2X10^6$
o Data Rate	bps	Store	Store	Store	1,018	1,283	600	Store	2,625
Class B to 10% Surface									
o Total Bits	bits	10,000	72,000	12,960	$12.7X10^6$	$5.2X10^6$		-	-
o Data Rate	bps	Store	Store	Store	750	960		-	-

NOTES

(1) Multiple playback of entry data

(2) Two descent images

(3) Eleven descent images

(4) Fifteen descent images

the rate requirement was modest, the stored data was assumed to be retransmitted about four times. For the Class B probe in the thin atmosphere, a minimum of two descent images was required while in the thick atmosphere, sufficient descent time was available to obtain eleven or more images. The data rate and communications range in the descent phase were balanced against those of the surface operation period in order to minimize the transmitter power requirements. In general, the surface operation requirements designed the system thus allowing additional imaging measurement during descent.

The orbiter and probe link geometry and timing, Figures VI-1 and VI-2, were adjusted for each probe design to minimize the range during the surface operation so that a high data rate could be used to transmit the bulk of the real time imaging and composition data. The major portion of the surface data, 4×10^6 bits, is made up from the three black and white filtered images which constitute one color 360-degree panorama.

The Class C probe designs also operate during an indefinite cycle of 32-day increments and all data must be stored during each period for transmission to the orbiter on its re-encounter. During the re-encounter, the orbiter is targeted to a relatively low flyby altitude so that a high data rate can be used to transmit the stored data.

These data rates were used in conjunction with the orbiter/probe range profiles to determine the communications transmitter power requirements of Section VI C.

C. PROBE TELEMETRY SYSTEM

The probe telemetry system is based on providing the RF power required to transmit at the required data rate over the worst-case range for each design condition. The seven designs are listed in Tables VI-3 and -4. The data rates for each design are based on both science instrument requirements and variations in descent times as discussed in Section VI B. The communications link geometry (range and aspect angles) used in the design are shown for the thin and thick atmospheres in Figures VI-1 and -2. The aspect angle is measured from the probe centerline to the orbiter. The radius of closest approach for the thick atmosphere was raised to 12.8 R_T (Titan radii) compared to 6.1 R_T for the thin atmosphere in order to maintain the orbiter in view during the long probe descent time in the thick atmosphere. The relative timing between the probe and orbiter has been adjusted for each design case to balance and minimize the descent and surface transmission requirements.

Other performance parameters of the RF link are based on the Jupiter Galileo probe design. The baseline design for the JOP transmitter operates at 1400 MHz using phase modulation (BPSK) with a convolutional code compatible with a 3-bit soft decision Viterbi decoder to provide code enhancement.

The transmitter power required for each baseline design was calculated based on the guidelines discussed previously. The thick atmosphere requires the largest probe-to-orbiter communication ranges and Class C thick with the highest data rate, requires the maximum transmitter power. An alternate trade was also done for a Class B thick case, which descends to the 10% probable surface with a much increased descent time and communication range of 76,000 km. This design is discussed in Section V E.

The communications link summary for the worst-case baseline design (C thick) is shown in Table VI-5. A 10-watt transmitter operating at 1400 MHz is required to operate with a 3 dB margin

Table VI-3 Communication Link Summary

Design Case	Data Rate (bps)	Max. Range (km)	RF Power (W)	Margin (dB)
Thin Atmosphere				
A	96	17,000	1.0	13.7
B	2,284	18,200	2.5	3.0
C	2,625	18,400	3.0	3.0
Thick Atmosphere (30% Probable Surface)				
A	21	55,000	1.0	20.1
B	750	50,000	6.0	3.3
B, Long Range	962	76,000	20.0	3.8
C	1,283	49,000	10.0	3.3

NOTES:
1. The worst-case probe design from a data transmission standpoint is C thick.
2. Design B thick, long range, is an alternate trade and was considered separately.
3. The margin is over the RSS of the adverse tolerances.

Table VI-4 Titan Probe Telecommunication Subsystem

	ATMOSPHERE						
	THIN			THICK (30% SURFACE)			THICK (10% SURF)
PROBE CLASS	A	B	C	A	B	C	B
REQUIREMENTS							
o DESIGN RANGE (KM)	17,000	18,200	18,400	55,000	50,000	49,000	76,000
o MAX. BIT RATE (BPS)	96	2,284	2,625	21	750	1,283	960
o OUTPUT POWER (W)	1.0	2.5	3.0	1.0	6	10	20

ASSUMED BEAMWIDTHS:

o PROBE ANTENNA $\lambda = 70^{\circ}$ (3 dB DOWN)

o ORBITER ANTENNA $\lambda = 12.8^{\circ}$ (3 dB DOWN) MUST BE POINTED IN SEVERAL INCREMENTS

SYSTEM DESCRIPTION

- o BIT RATE DETERMINED BY SCIENCE SEQUENCE AND TRANSMISSION TIME AVAILABLE
- o COMMUNICATION LINK WITH ORBITER ONLY
- o COMMAND LINK ONLY TO CLASS C PROBE (FROM ORBITER)
- o CLASS B PROBE TRANSMITS DATA TO ORBITER ON INITIAL ENCOUNTER
- o CLASS C PROBE TRANSMITS DATA TO ORBITER ONCE EVERY 32-DAY CYCLE
- o MICRO STRIP ANTENNA PROVIDES 70° BEAMWIDTH

Figure VI-1 Communications Geometry - Thin (Methane) Atmosphere

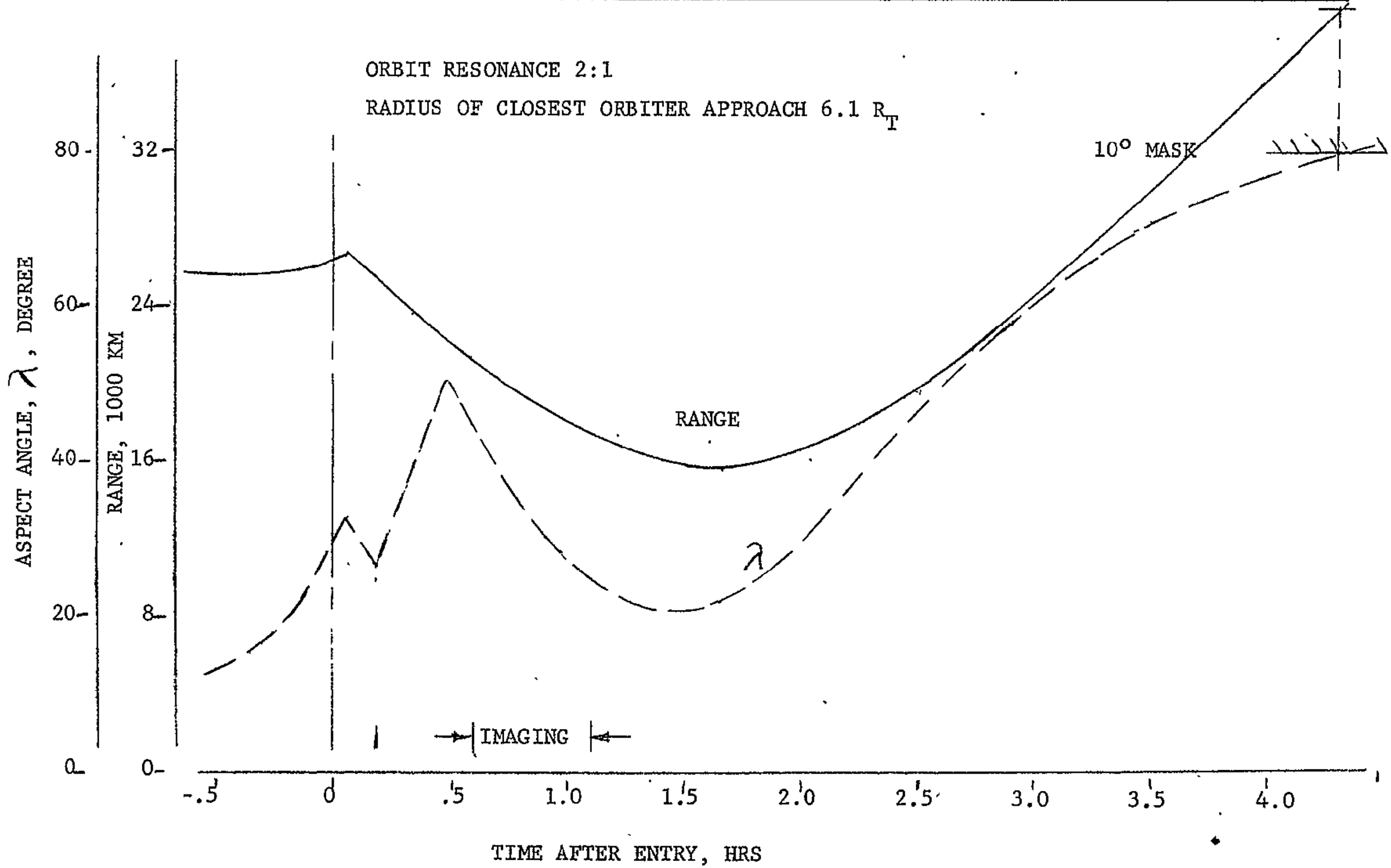


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Figure VI-2 Communications Geometry - Thick (Nitrogen) Atmosphere

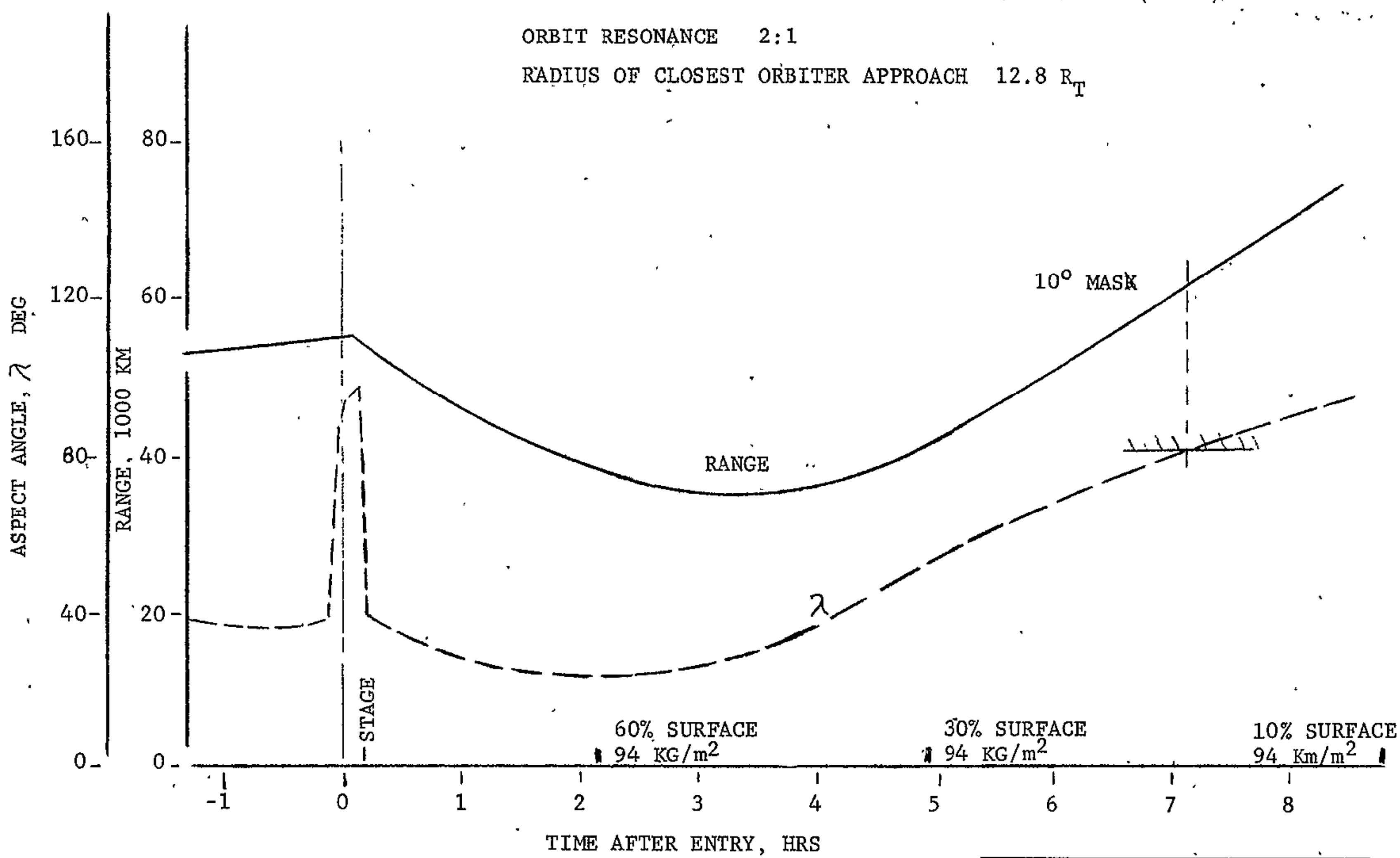

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Table VI-5 Class C Probe/Lander, Thick Atmosphere Communications Link Summary, Reference Design

	Parameter (dB Except as Indicated)	Nominal Value	Adverse Tolerance
1.	Transmitter Power Out, dBm, 10 W	40.0	-0.3
2.	Line Loss (3-ft coaxial cable)	-0.5	-0.1
3.	Antenna Beamwidth 140°, Peak Gain	4.4	-0.1
4.	Pointing Loss @ 70° Aspect Angle	-3.0	-0.2
5.	Space Loss, 49,000 km, 1400 MHz	-189.4	-0.2
6.	Atmospheric Absorption at Surface	-0.2	0.0
7.	Fading Loss	-0.1	0.0
8.	Polarization Loss	-0.3	-0.1
9.	Receiving Antenna Beamwidth 12.8°, Peak Gain	20.5	-1.5
10.	Line Loss to Receiver (6-ft Cable)	-0.9	0.0
11.	Pointing Loss	-3.0	-0.4
12.	Net Circuit Loss (Σ 2→11)	172.5	-1.6
13.	Received Power, dBm (1 + 12)	132.5	-1.7
14.	System Noise Power Density; dBm/Hz Referred to Antenna, T_s = 380 ± 100° K	-172.8	-1.0
15.	Received Signal-to-Noise Density, dB-Hz (13-14)	40.3	-2.0
16.	Data Rate,1283 bps	31.1	0.0
17.	Receiver System Losses, Noisy Phase Reference 0.2 dB, Other 0.7 dB	-0.9	-0.1
18.	Relay-to-DSN Loss	-0.3	0.0
19.	Net Received Energy per Data Bit, E_b/N_o (15-16+17+18)	8.0	-2.0
20.	Required E_b/N_o Modulation, Coding Assumed: BPSK, Convolutional/Viterbi, K = 7, R = 1/2	3.0	-0.2
21.	Margin Over Nominal (19-20)	5.3	2.0
22.	Margin Over Adverse Tolerances (21-21 Adv)	3.3	

Conditions:

1. Titan Probe worst-case conditions
2. Orbiter Flyby, RCA = 37,325 km (12.8 R_T), γ = -30°, T_L = 70 min.
3. BPSK, Convolutional Code, K = 7, R = 1/2
4. Viterbi Decoder, 3-Bit Soft Decision
5. RMS all Adverse Tolerances
6. Thick Atmosphere, 100% N_2, P = 7.5 bars, 30% surface probability.

over the sum of adverse tolerances. The data rate is 1283 bps and the maximum slant range of 49000 km occurs at an aspect angle near the 3 dB point of the probe antenna. The thick atmosphere model consisting of nitrogen gas at a pressure of 7.5 bars presents microwave absorption levels similar to the Earth's atmosphere. Absorption in the Earth's atmosphere is primarily due to the presence of water vapor which is not present on Titan so the attenuation of 0.2 dB is conservative in line 6 of Table VI-5. The thin atmosphere model which consists of 100% methane also presents negligible RF absorption of the operating frequency.

The probe antenna is a flat microstrip design 10 cm square and 0.6 cm thick. The antenna is circularly polarized and has a beamwidth of 140 degrees with a peak gain, on axis, of 4.4 dB which produces a conical pattern. The maximum axial ratio is 3 dB at the 3 dB beamwidth point. The thick atmosphere design does not have a parachute and the antenna is located on the centerline of the rear portion of the probe. For the thin atmosphere design, two antennas are employed since a parachute is used. During descent, an antenna located parallel to the probe centerline and on the aft edge is used for the relay link to the orbiter. After surface impact, the transmitter is switched by an impact switch to a second identical antenna located on the aft centerline of the probe on top of the imaging mast. This antenna is fed by a coiled, flexible coaxial cable located in the mast. The receiving antenna is based on the JOP and has a beamwidth of 12.8 degrees with a peak, on-axis gain of 20.5 dB as shown in line 9 of Table VI-5. Three dB pointing losses are assumed for both probe and orbiter antennas to account for the initial contact geometry and less than optimum alignment during descent.

The approach geometry is such that Saturn is not in the background of Titan during the mission and the only external sources of noise temperature are background cosmic noise and disk noise from Titan. A receiver noise figure of 3 dB is assumed for the orbiter receiver at 1400 MHz. The resulting system noise temperature is 380°K with the major contributor being the noise figure of the receiver. A disk brightness temperature of 100°K was used for Titan and the orbiter antenna temperature for the dipole pattern is 50°K. An uncertainty of 100°K was included for contingencies.

The receiver system losses due to a noisy phase reference, other system losses, and modulation losses to the DSN from the orbiter are listed on lines 17 and 18 of Table VI-5. The required energy per data bit (ε_b/N_o) with coding is based on JOP which proposes a rate of 1/2, constraint length, K = 7, convolutional code with a 3-bit soft decision Viterbi decoder. This provides a 3.8 dB enhancement when used with BPSK modulation in a non-fading environment by reducing the ε_b/N_o from 6.8 dB to 3.0 dB at the design point with a bit error rate of 10^{-3}. This performance is based on simulations conducted at JPL for the Viterbi decoder. A convolutional code was chosen due to its simple encoding structure and the Viterbi algorithm is the baseline for future probe missions.

The adverse tolerances account for uncertainties, variations in performance parameters, and other contingencies not specifically known at this time. These tolerances add to the RF power required since a 3 dB margin must be maintained over the adverse tolerances for a conservative data link. Since all the adverse tolerances are not present simultaneously, the root sum square of 2 dB represents the mean adverse condition and was used to determine the weighted adverse tolerance. This is also considered a conservative and realistic approach to handling these random adversities.

Solid state transmitters were selected for each design based upon standard available power levels with a minimum of 1 watt, as seen in Table VI-3. Power conversion efficiencies vary from 7% for the 1-watt unit to 20% for the 10- and 20-watt unit. The efficiency is mainly a function of packaging, thermal control, and heat sink size and is higher for the higher power levels where the enclosure size is larger. The baseline design (C thick) requires 10 watts of RF power at 1400 MHz with an efficiency of 20% and provides 3.3 dB of design margin. Margins for other designs are a minimum of 3 dB as shown in Table VI-3.

D. DATA HANDLING SYSTEM

1. Design Requirements - The data handling system for the Titan probe is active at some level from the time of separation from the orbiter through coast, pre-entry, entry, descent, and surface operation. Its general functions include the following:

   a. Pre-separation checkout through the orbiter interface.

   b. At separation, provide a timer for probe activation prior to entry.

   c. At probe activation, provide sequences for science instrument warm-up and calibrate. Store calibration data.

   d. Provide sequencing of pre-entry science through umbilical to module and store returning data. (Class B and C only)

   e. At deceleration signal, activate pre-entry module jettison sequence.

   f. Provide sequencing and data storage of entry science measurements.

   g. At deceleration and/or timer signal, sequence pyros for parachute release, nose cap release, and instrument deployment functions. (Parachute in thin atmosphere only.)

   h. Provide sequencing of descent science measurements and interleave stored data with real time data for transmission to orbiter.

   i. At altitude of 100 m, radar signals release of parachute.

   j. After surface touchdown, provide deployment and sequencing of surface science, and control of data in or out of buffers and large scale data storage as required by each probe class.

The data storage requirements vary with probe class and for the Class A probe, the small data memory in the data handling system unit is sufficient.

For the Class B probe, storage of a CCD camera image is required and this can be handled by a buffer device called an analog delay line.

For the Class C probe a more extensive data recording capability is required to handle the large amount of data taken during the 32-day surface operations.

These data buffer or storage requirements are as follows:

Probe Class	Maximum Storage (bits)	
	Entry	Surface
A	25,000	-
B	97,000	1.08×10^6
C	97,000	14.2×10^6

2. Data Handling System Design - The basic data system processor for all three probe classes is summarized in Figure VI-3. The processor characteristics were based on a preliminary design which was done by Hughes Aircraft Company for the Galileo Jupiter atmospheric entry probe. The memory capacity has been slightly increased from the original design to meet the Titan probe requirements. The programmable format would be valuable in modifying the descent sequence based on atmosphere definition update during the preliminary Titan flyby sequences. At least two flyby encounters by the orbiter are planned in the baseline mission prior to the Titan probe release.

3. Data Storage Concepts - There are three levels of data storage required in the Titan probe system designs depending on probe class. As shown above, the entry data storage requirements for all probe classes are minimal (ie: 25K-97K) and can easily

Figure VI-3 Titan Probe - Data Handling and Command Subsystem

o DATA PROCESSOR

- (Class A - 60K, Class B,C - 135K) Memory (Control, Data Storage, Format, Sequence, Scratch Pad)
- (Class A - 25K, Class B,C - 97K) Bits of Storage in Memory
- Fixed and Programmable Formats
- Fixed <u>or</u> Programmable Descent Sequence
- 254 Available Command Channels (from Orbiter)
- 96 Discrete Command Lines (from Sequencer)
- 79 Output Commands (from DHCS)
- 6.2 KG; 6556 CM^3; 6 Watts

be accommodated by the memory chips in the data processor. These chips are nominally CMOS technology. The Class B probe requires buffer storage of one CCD camera image, the last image in the descent sequence. All previous images are buffered temporarily and then transmitted during descent at a data rate compatible with the telemetry system. The last image is taken just before touchdown and is stored for later transmission from the surface. A CCD analog delay line device is used for this application.

For the Class C probe, there is a requirement for large scale data storage (ie: 14.2×10^6 bits) over a 32-day period. Nonvolatile memories are available in both bubble and magnetic tape while low power CMOS and CCD memories are also reasonable. The state of the art in bubble, CCD, and CMOS memories indicates that all three approaches are viable candidates for the 1987 mission. The standard NASA tape recorder at 10^8 bits is a very compact, low power unit. However, it has been dropped from consideration because of its relatively poor reliability for use in a long life (8 year) mission. For comparison, the NASA standard tape recorder has the following characteristics:

o Capacity	5×10^8 bits
o Mass	6.3 kg
o Volume	6077 cm^3
o Power	10 watts record
	15 watts playback

The four storage concepts are compared in Figure VI-4 and commercial, non aerospace qualified bubble and CCD memory units are shown in the inset. The CCD memory can be used in a unique way with the CCD imaging camera. They are both analog devices and the memory can store the image pixel as an analog voltage before conversion to a digital data stream. The result is that the analog storage requirement for a 10^6 bit image is only about 1/12 or 90,000 analog data bits.

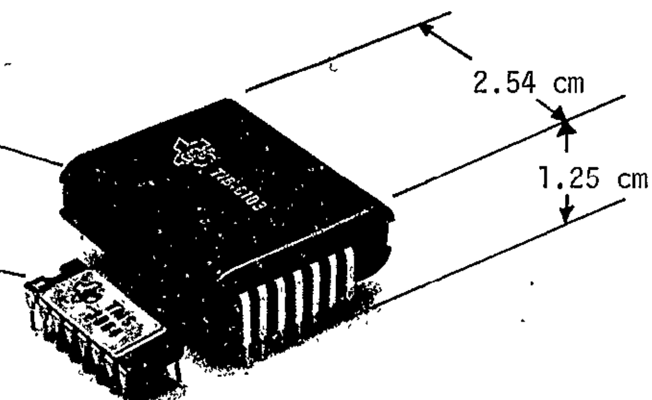
Figure VI-4 Data Storage Summary

REQUIREMENTS:

Class B Probe: 10^6 Bits for Descent Imagery
Class C Probe: 14.2×10^6 Bits over 32-day Period for Surface Science

CANDIDATE STORAGE DEVICE	ACTUAL OR ESTIMATED MASS (kg)	VOLUME (cm^3)	POWER (W)	TOTAL BITS
1. CCD	~ 0.1	~ 75	6.7	10^6
2. Bubble Memory	~ 10	~ 7,200	~ 20	14×10^7
3. CMOS	~ 10	~ 10,000	~ 5.5	14×10^6
4. Magnetic Tape (NASA STD.)	6.3	6,080	15	5×10^8

TEXAS INSTRUMENTS



MARTIN MARIETTA

Table IV-2 Direct Versus Out-of-Orbit Entry

	OUT-OF-SATURN ORBIT	DIRECT ORBIT	SYSTEM IMPACT
ENTRY VELOCITY, KM/SEC	4.55	10.4	—
HEAT RATES, $\dot{q}$--BTU/FT^2	17.5	215	5X HEATSHIELD
TOTAL HEAT, Q--BTU	2,513	17,028	
DYNAMIC PRESSURE MAX.--PSF	60	328	1.7X AEROSHELL
DYNAMIC PRESSURE, STAGE--PSF	3.6	4.1	1.14X PARACHUTE
COMMUNICATION RANGE-- $\frac{R_{DIRECT}}{R_{ORBIT}}$	1.0	GREATER	$\sim$ 1.5X R_{ORBIT}

MARTIN MARIETTA

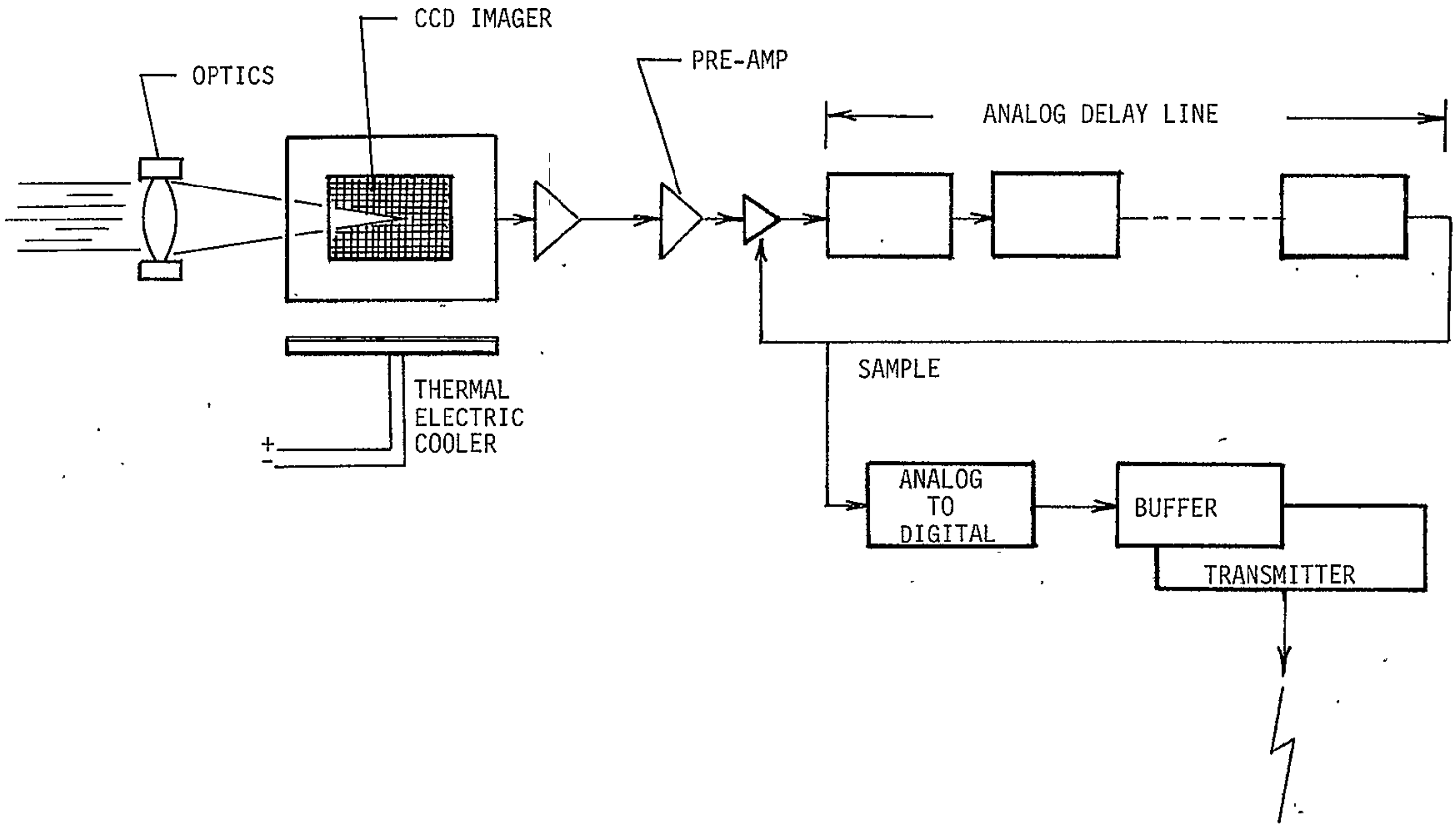


Figure VI-5 CCD Imaging and Data Buffer Schematic system was delivered to NASA Langley in the summer of 1978 by Rockwell International and its characteristics are summarized in Figure VI-6. The power requirement is high for a very high data input/output rate; however, at lower rates of about 2000 bps the power requirements are comparable to other memory systems at less than 20 W. Flight quality bubble memory systems are predicted by 1980.

A CMOS semiconductor mass storage system was also considered. The mass storage system contains 10^7 bits. Since semiconductors are a volatile storage medium (ie: the contents are lost when power is removed) and it is desired to have very low power consumption, only CMOS devices were examined. CMOS is noted for its very low power consumption while in standby mode and for its fast read/write cycle times. The last characteristic is not important in this application however since the data transfer rate is a very modest 5×10^3 bits per second.

Two contemporary CMOS devices were evaluated: the Harris HM-6508 and the American Microsystems, Inc. S5101L-1. The Harris device is a radiation hardened high reliability device of the type in most spacecraft systems. The S5101L-1 is representative of CMOS RAMS commercially available. The characteristics of the two devices just mentioned are shown in Table VI-6. The HM-6508 requires 100 μA at 5 volts for 10^3 bits. The power consumption for a 10^7 bit system would therefore be about 5 watts in standby mode. If it is assumed that a maximum of 32×10^3 bits are in operating mode at any one time then the previous number must be incremented by .624 W for a total power consumption of 5.624 watts.

Similar analysis of a system based on the S5101L-1 shows a total power consumption of 3.7 watts.

Both the HM-7508 and S5101L-1 are available as Dual In-line Packages. Space requirements for the HM-6508 are about 40,000 cm^3.

Figure VI-6 Magnetic Bubble Memory Technology

NASA-LANGLEY SPACECRAFT DATA RECORDER

STORAGE -- 10^8 BITS

WEIGHT -- 21 Kg

SIZE -- 32.4 x 32.3 x 13.5 cm

VOLUME -- 14,102 CC

MANUFACTURER -- ROCKWELL

FEATURES --

- NONVOLATILE
- SERIAL ACCESS (RELATIVELY LONG TIME)
- DEVELOPING PARALLEL ACCESS
- FLIGHT QUALITY BY 1980

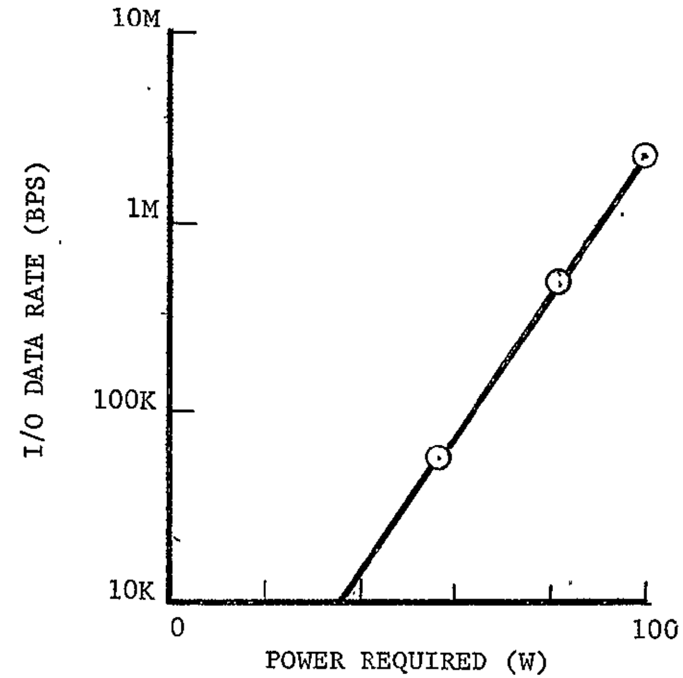


Table VI-6 CMOS RAM Characteristics

Device	HM-6508	S5101L-1
Technology Base	CMOS	CMOS
Type	Static	Static
Organization	1024 X 1	256 X 4
No. Chips Required	10^4	10^4
Size/DIP	3/4" X 1/3"	1" X 1/3"
Operating Power (μA)	4000	22000
Standby Power (μA)	100	10
Access Time (NS)	250	450
R/W Cycle Time (NS)	350	450
Chips/4K Bytes	32	32

Space requirements for the S5101L-1 are 82,000 cm^3. The above calculations do not include power or space requirements for the drive electronics, cooling or shielding. It should also be noted that other packaging techniques, though not as standard as DIPs, are available. These include hybrid fabrication in which there is more than one chip per DIP and Hermetic Chip Carriers. These techniques could reduce the total system size by a factor of 3 to 6.

E. POWER AND PYRO

1. Design Requirements and Alternatives. - The Titan probe power system design is greatly influenced by the selection of Titan atmospheric model and probe class, both resulting in different life, stored energy and power requirements. In general, remotely activated silver zinc batteries have been selected as the primary energy source for both Class A and B probes for the thick and thin atmosphere models. For Class C probes, remotely activated silver-zinc secondary batteries have been selected for both atmospheric models to provide energy for a minimum of three encounters with the orbiter. A small, high performance selenide radioisotope fueled thermoelectric generator (RTG) is provided to recharge the batteries slowly between re-encounters with the orbiter and the concomitant data dump. While the probe is attached to the orbiter, all housekeeping power is assumed to be supplied by the orbiter. For Class C probes, the RTG will be operated in a short circuit mode until immediately prior to probe separation, utilizing the waste heat generated for thermal control as required.

Mission and Environment - Key requirements identified during the study include:

- 7-year cruise life
- Sterilization, no contamination
- Landing shocks (nominally 300 g)
- Thermal integration for a low temperature environment (150°K at 30% surface for thick atmosphere model; 78°K for thin atmosphere model)
- High peak/average power ratios
- Re-encounter transmission power (Class B, C probes)
- Short active mission life (11 to 107+ days)
- Low Weight and volume

Of these, probably the most significant requirements are the combinations of 7-year cruise life, high peak/average power, no contamination, and short active life. These requirements limit potential power system component choices. Sterilization has been demonstrated only for a few battery systems (Zn-AgO, NiCd, and possibly a lithium battery). High landing shocks, thermal design and integration, and low weight and volume requirements are expected to represent moderate design constraints.

Pyro Functions - The following pyro functions have been identified for the three probe classes:

a. Probe Activation - The silver-zinc batteries require remote activation. Also, the pre-entry module must be jettisoned after observation of the upper atmosphere science. Total initiators = 5.

b. Probe Entry/Descent - During descent the parachute must be deployed, the nose cap jettisoned, the parachute and aft cover must be staged, and the nephelometer released. The Neutral Mass Spectrometer and Gas Chromatograph valves must be opened/closed. Total initiators = 18.

c. Probe Landed Operations - After landing, the equipment mast is released, the drill is released, the seismometer is uncaged. Total initiators = 6.

d. Each class of probe requires different quantities of pyro initiators based on the number of science activities for each probe type.

2. Design Approach - Design emphasis was placed upon identifying systems which met the probe power requirements, while also satisfying the contamination, 7-year cruise life, high peak-to-average power, short active life, minimum weight and small volume requirements. Power sources considered were primary batteries, secondary batteries, radioisotope fueled generators, fuel cells, ram air generators, and auxiliary power units. Of these, fuel cells and auxiliary power units evolve exhaust products which may interact with and/or contaminate the scientific experiments

or environment. For commonality of approach to all probe applications, ram air generators were disregarded since they could only supply power during entry and descent.

The 7-year cruise life requirement is severe for battery systems unless degradation can be limited by storage at low temperatures, by using remote activation, and/or by using battery systems with low inherent degradation. Of the high energy density batteries, lithium systems have the potential for sterilization while retaining their low degradation characteristics during wet stand. Hermetically sealed NiCd, NiH_2, AgH_2, and remotely activated Zn-AgO battery systems also appear capable of meeting these requirements with appropriate consideration for degradation.

For probe applications, battery systems are energy limited, while radioisotope fueled generators are power limited. RTGs and lithium batteries (which have a low discharge rate) when sized for minimum weight to meet the probe energy requirements, may not reliably meet the peak power required. For the longer duration Class C probes, RTGs may be combined with secondary batteries to provide both high power and high energy capability in a lightweight system. For the shorter duration Class A and B probes, both the power and energy requirements may be met with high energy density primary batteries for a lightweight, least cost configuration. Redundancy may be provided in the energy storage system by requiring that the mission capability remain after one battery failure. The RTG is assumed to be internally redundant.

The requirement to survive landing shocks of 300 g is much more severe than current specifications for spacecraft RTGs and remote activation systems for batteries. While achieving this shock capability is believed feasible, some additional development of these devices will be required. Lithium primary battery systems could avoid the necessity to develop either of these devices, however, their life and degradation characteristics for such long periods have not been firmly established. Some lithium battery designs develop degradation limiting passivating layers on the plates while others do not.

Martin Marietta has had extensive experience with silver zinc (Zn-AgO) batteries, both in design and application, for long life primary and secondary battery applications, with and without remote activation. Under NASA contract Martin Marietta has demonstrated over 100 cycles with sterilized Zn-AgO cells. Martin Marietta has also developed the coded switch batteries used on USAF Titan missiles. These are 4 A-Hr Zn-AgO secondary batteries which have demonstrated greater than four year wet stand life under float charge conditions.

Couples such as Nickel Hydrogen, Silver Hydrogen, Zinc Oxygen and other metal air systems have high energy density at the expense of high cost and lack of historical performance data. These systems are not readily available and certainly not standard. Lithium batteries, however, are currently being used on the Galileo spacecraft program and on Shuttle solid rocket boosters and will be qualified in time for use by the Titan probe.

Our investigation identifies only one power source that can definitely meet all the requirements of the probe missions, that has historical data to demonstrate reliability and accurately estimate cost, and although uniquely designed for this program, uses existing standard design approaches, processes and materials. This power source is the remotely activated Zinc Silver Oxide battery modified to survive a minimum of 107 days wet stand after the dry charge cruise period.

Consider for example a comparison of the NiCd and the remote Zn-AgO battery systems. Certainly substantial historical data exists for both sources, they are available at reasonable cost and are reliable. However, the following should be considered:

1. Typically NiCd batteries are less than 8 Whr/lb packaged as new. With degradation allowances for cruise and open circuit stand this energy density could reduce to 6 Whr/lb.

2. Recharge and conditioning of the NiCd battery requires additional electronics and more interface between spacecraft and probe, thus increasing weight, cost and complexity.

3. Typically "Off-the-shelf" remote activated zinc silver oxide batteries with 6-hour wet life are 5 to 15 Whr/lb. These batteries can be designed up to the 30 Whr/lb energy density desired but the effort and cost would be equivalent to a new design effort.

4. Remote activated Zn-AgO batteries with 30 Whr/lb energy density and greater than 107 day wet life are feasible for the 1985-1987 time frame. Preliminary design concepts of these batteries have been previously proposed to Ames Research Center by Martin Marietta Corporation. The increased energy density available is largely the result of an improved remote activation device design.

The activation mechanism is essentially an electrolyte storage device that transfers electrolyte to the cells upon receipt of a discrete signal. Two major components are required to fulfill this function, the electrolyte reservoir and the energy device necessary to achieve transfer.

Selection of the energy device and activation mechanism is somewhat dependent on the requirements of the vehicle system. Energy devices can range from high pressure storage containers, solenoid initiators, set back shock as in shell fuses, high deceleration of the battery, heat expansion devices and electrically ignited gas generators. In keeping with the philosophy of optimizing energy density the latter device was chosen for the Titan probe design.

As with the energy devices, the electrolyte reservoir designs that have been used are many and varied. The most commonly used designs are the low cost tubular reservoir and the piston/cylinder combination.

Both types are extremely reliable but at the expense of weight and volume. The Martin Marietta design utilizes reservoirs that are minimum weight and volume.

Lithium batteries appear as viable alternate candidates for the Class A and B probes. Their degradation characteristics appear to be predictable and test programs are in progress at NASA-ARC (Galileo program) to characterize their long term performance. Estimated degradation is 2½% per year. Because of their high internal impedance, discharge rates are limited to the range C/5 to C/3 with pulse capability to approximately 1.5 C. Voltage regulation for a 13-cell module is 39 to 25 volts requiring a regulator for equipment with more stringent input requirements. Lithium batteries are not viable for Class C probes where the long life and recharging requirements necessitate use of secondary batteries.

The RTGs proposed use selenide thermoelectrics currently in advanced development and are assumed to be 11% efficient with a specific power of 3.5 W/lb. The fuel is $PU^{238} O_2$. Over the 7-year cruise life, the fuel, insulation and thermoelectric power degradation combined are expected to be 13%. To minimize thermal cycling, the RTG is operated at the maximum power point continuously with a full shunt regulator. The RTG has a dc/dc converter to boost the output voltage to approximately 37 volts for input to the shunt regulator and battery chargers. The chargers are of the highly efficient linear charge current control design which operate by sensing loads, battery state of charge, and shunt regulator state to operate near saturation of the step-down regulator stages. Special consideration in the design of the RTG is required to meet the 300 g landing shocks. Contemporary RTG designs normally are specified to less than 50 g. (The Viking Lander Capsule landing shock was 17 g.)

3. Power Subsystem Designs - The baseline power system design for all probe classes uses the 30 Whr/lb remotely activated, 19 cell, Zn-AgO batteries for energy storage. Because of their long life, Class C probes and the 32-day extended mission Class B probes use a

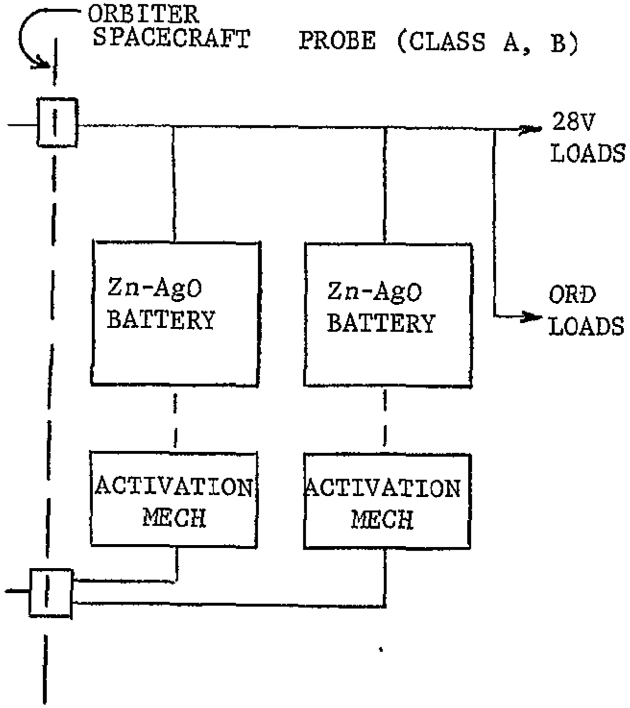
small RTG to recharge the batteries between encounters with the Saturn orbiter for data relay. Schematic block diagrams of the power system concepts are shown in Figure VI-7. Activation of the batteries (and verification of activation) requires a minimum of six hours and is performed while the probes are still attached to the orbiter. Similarly, all probe power is assumed to be supplied by the orbiter until after probe separation. The systems will be designed to provide full mission power and energy after one battery has failed.

The dry charged Zn-AgO batteries were assumed to be temperature controlled in the range -10°C to 0°C during the cruise portion of the mission to minimize degradation. Under these conditions, the actual cell capacity should degrade less than 7% in 7 years. The nameplate capacity (predicted capacity of the battery after sterilization) has been reduced by a factor of 0.88 to account for the capacity distribution effects of manufacturing tolerances and sterilization. The final factor necessary for sizing the batteries, given the load profile, is the allowable depth of discharge (DOD). For primary battery applications the maximum allowable DOD was assumed to be 85%, while for secondary battery applications, a maximum 50% DOD was assumed.

Table VI-7 summarizes the load requirements and mission life for the eight missions identified as options. The required minimum system battery capacity in watt-hours has been found by adding 4% distribution losses plus 15% design margin to the load energy, then compensating for the battery design, degradation, and utilization factors discussed above. In the secondary battery applications, the batteries were sized to meet the more stringent requirement imposed by the entry, landing, and initial surface operating conditions.

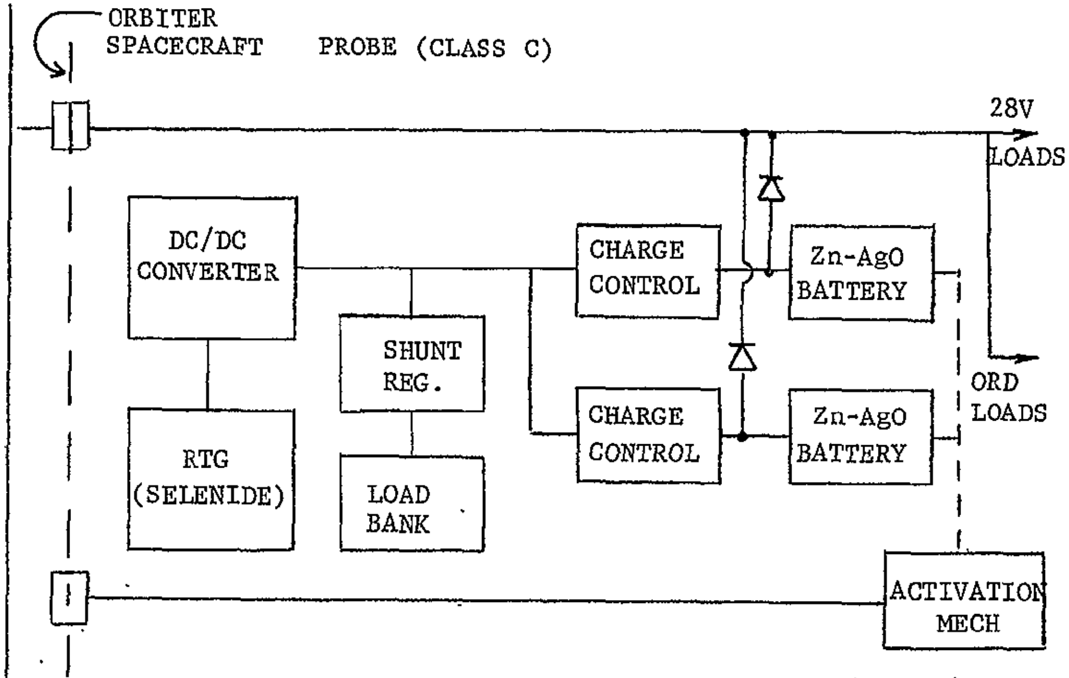
If lithium batteries are used for Class A and B probes, total capacity degradation of 17% would be expected during the 7-year cruise. To avoid end of discharge mismatch of cells, lithium batteries should not be discharged to greater than 80% DOD. In

Figure VI-7 Electrical Power Subsystem Design Factors



BATTERY DEGRADATION/SIZING FACTORS

o MANUFACTURING TOLERANCE	.88
o DRY STORAGE LOSS (7 YEARS AT 30°F)	.93
o MAX DEPTH OF DISCHARGE	.85
DISTRIBUTION LOSS	4%
DESIGN LOAD MARGIN	15%
BATTERY ENERGY DENSITY	30 W HRS/LB



RTG DEGRADATION (FUEL & THERMOELECTRICS)	.87
BATTERY DEGRADATION/SIZING FACTORS	
o MANUFACTURING TOLERANCE	.88
o DRY STORAGE LOSS (7 YEARS AT 30°F)	.93
o WET STAND LOSS	.92
o MAX DEPTH OF DISCHARGE	.50
DISTRIBUTION LOSS	4%
DESIGN LOAD MARGIN	15%
BATTERY ENERGY DENSITY	30 W HRS/LB

Table VI-7 Electrical Power Subsystem Summary

	ATMOSPHERE							
	THIN			THICK (30% SURFACE)				THICK (10% SURFACE)
PROBE CLASS	A	B	C	A	B	C	B 32-DAY EXTENDED	B
REQUIREMENTS								
ENERGY (W-HRS)	95	263	322	404	812	938	812	1456
PEAK POWER (W)	73	103	127	73	125	127	125	175
ACTIVE MISSION DURATION (DAYS)	11	11	107	11	11	107	43	12
IMPLEMENTATION								
BATTERY TYPE*	Zn-AgO	Zn-AgO	Zn-AgO	Zn-AgO	Zn-AgO	Zn-AgO	Zn-AgO	Zn-AgO
REQUIRED TOTAL CAPACITY (W-HRS)	162	451	552	693	1392	1608	1392	2495
RTG POWER (BOL)(W)	-	-	25	-	-	25	12	-
EPS WEIGHT (KG) (INCLUDES BATTERIES, PCDA, ORDNANCE CONTROL ASSEMBLY, RTG)	17	29	41	25	44	57	46	67

*BATTERIES REMOTELY ACTIVATED

addition, under some circumstances, battery capacity must be increased to maintain the peak discharge rate at less than C/3. Table VI-8 shows that a Class A probe in a thin atmosphere has this requirement. If an energy density of 200 Whrs/lb is assumed for the lithium batteries, and a discharge regulator is incorporated into the PCDA, the EPS weights given in Table VI-8 are slightly less than those for the Zn-AgO systems of Table VI-7.

Table VI-8 Lithium Battery System Characteristics

	ATMOSPHERE			
	THIN		THICK	
PROBE CLASS	A	B	A	B
REQUIREMENTS				
Energy (W-Hrs)	95	263	404	812
Peak Power (W)	73	103	73	125
Active Mission Duration (Days)	11	11	11	11
IMPLEMENTATION				
Battery Type (Primary)	Lithium	Lithium	Lithium	Lithium
Required Total Energy Capacity (W-Hrs)	170	471	724	1455
Capacity Required for C/3 Peak Discharge Rate (W-Hrs)	261	367	261	446
EPS Weight (kg) (Includes Batteries, PCDA, and Ordnance Control Assembly)	17	26	19	41

F. THERMAL CONTROL

1. Design Requirements - The thermal control design requirements are a function of probe class and atmospheric model with the Class C probe mission being the most severe conditions. The probe mission phases are briefly summarized as follows:

Probe Class	Mission Phase		
	Launch, Cruise Coast, Entry, Descent	Initial Surface	32-Day Surface
A	X		
B	X	X	
C	X	X	X

The Titan atmosphere thermal environment is shown in Figures III-1 and III-2 of Section III F in terms of temperature versus altitude for the thin methane and thick nitrogen atmospheres. The steady state thermal losses from a probe on the surface of Titan were calculated for various conditions and the results are presented in Figures VI-8, -9 and -10. These calculations were based on a compartment temperature of 278 ^{o}K (40^{o}F) using an FA fiberglass and show the effect of compartment surface area and insulation thickness on thermal heat loss.

2. Design Approach - The overall design approach for the thermal control system is summarized in Table VI-9 for each probe class. During the launch and cruise phases the probe thermal environment can be maintained through use of spacecraft support. During the post separated coast, entry and descent phases some additional internal heat source such as an isotope heater is required. For the extended surface operation, additional heat is also required in the form of isotope heaters and/or RTGs. For the Class B and C probes, a coolant loop to a base cover radiator is required in some cases during cruise and coast to dump excess isotope heater or RTG waste heat.

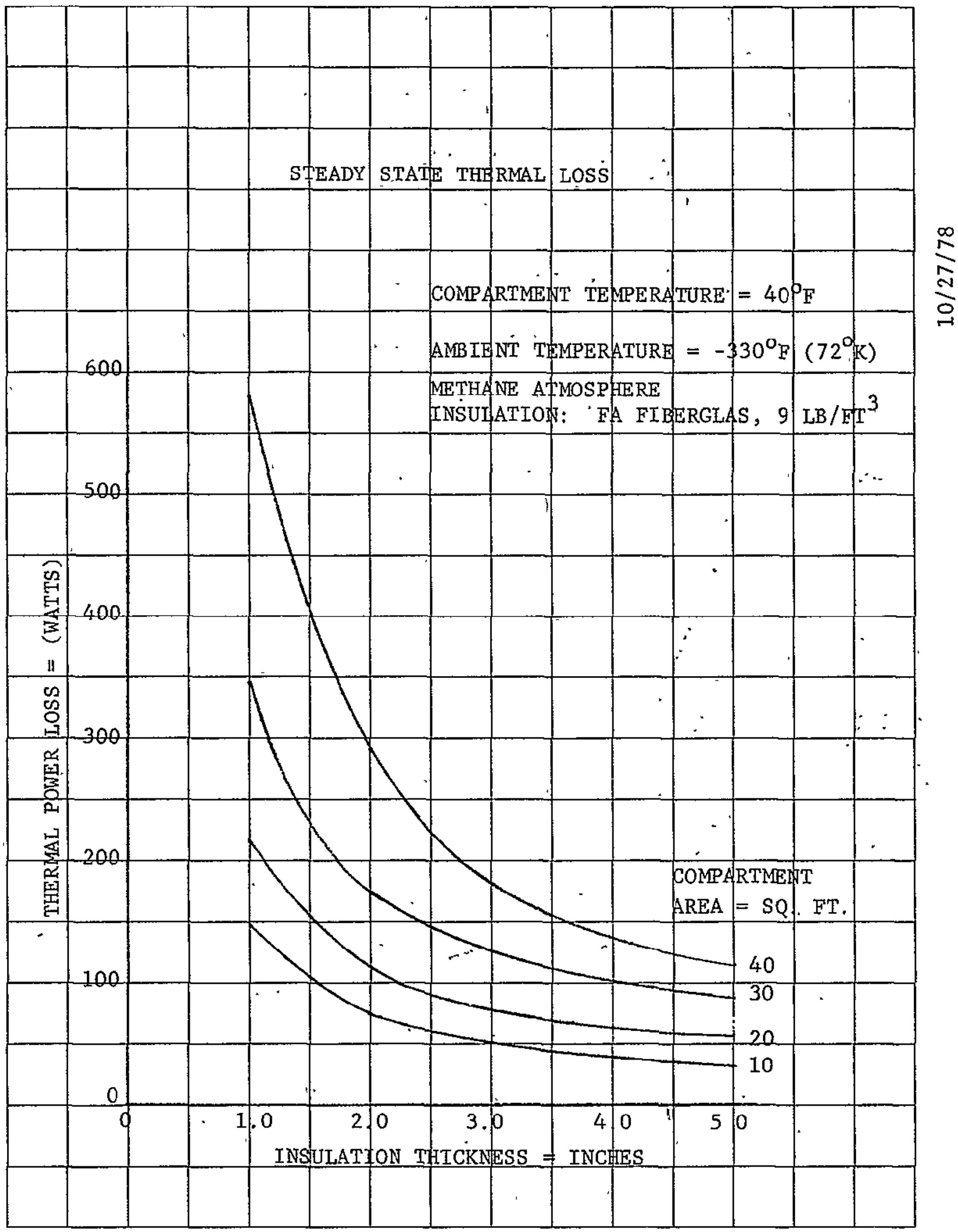


Figure VI-8 Steady State Thermal Loss at Surface - Thin Methane Atmosphere

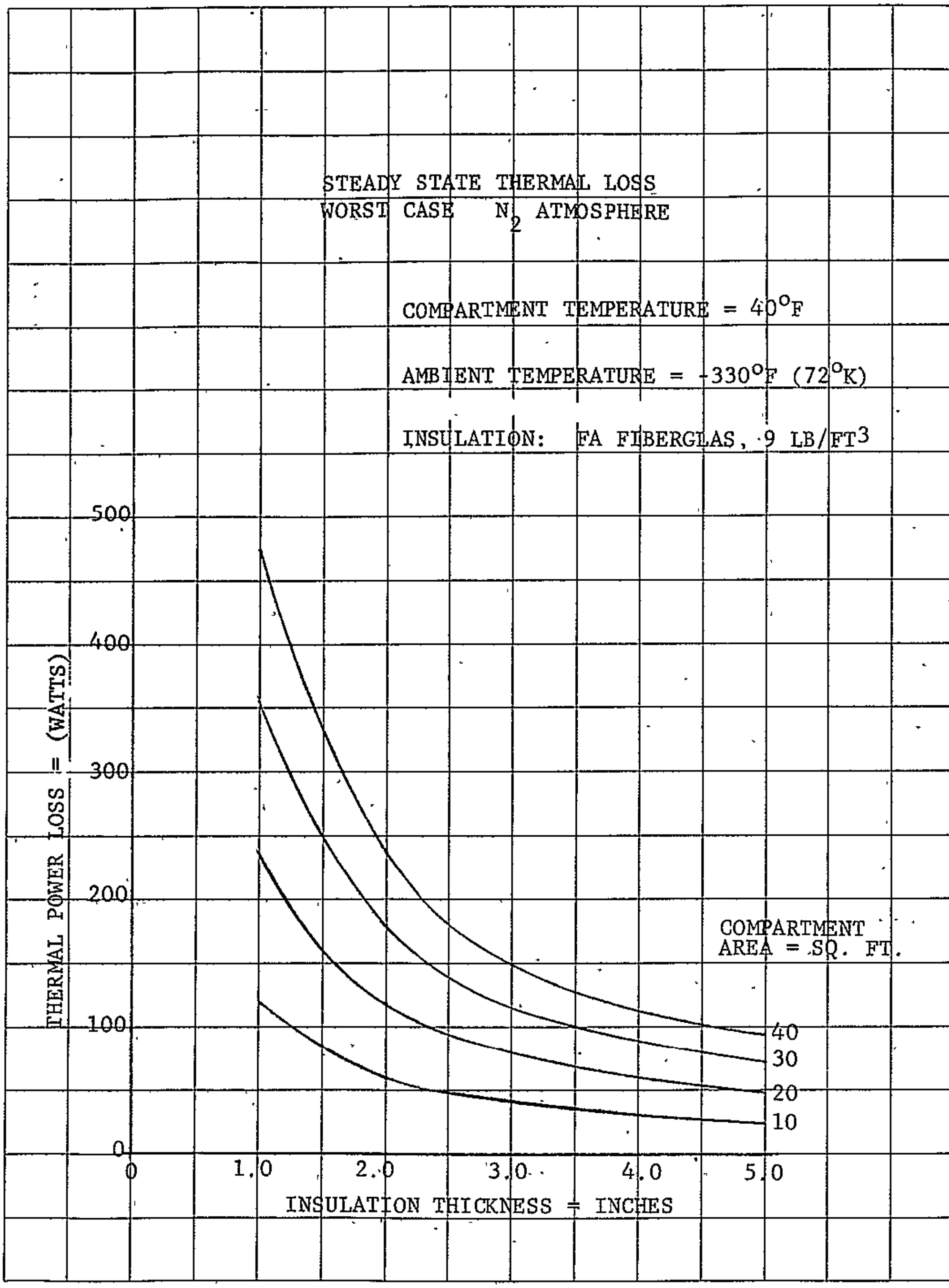


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Figure VI-9 Steady State Thermal Loss on Surface - Thick Nitrogen Atmosphere, 60% Probable Surface

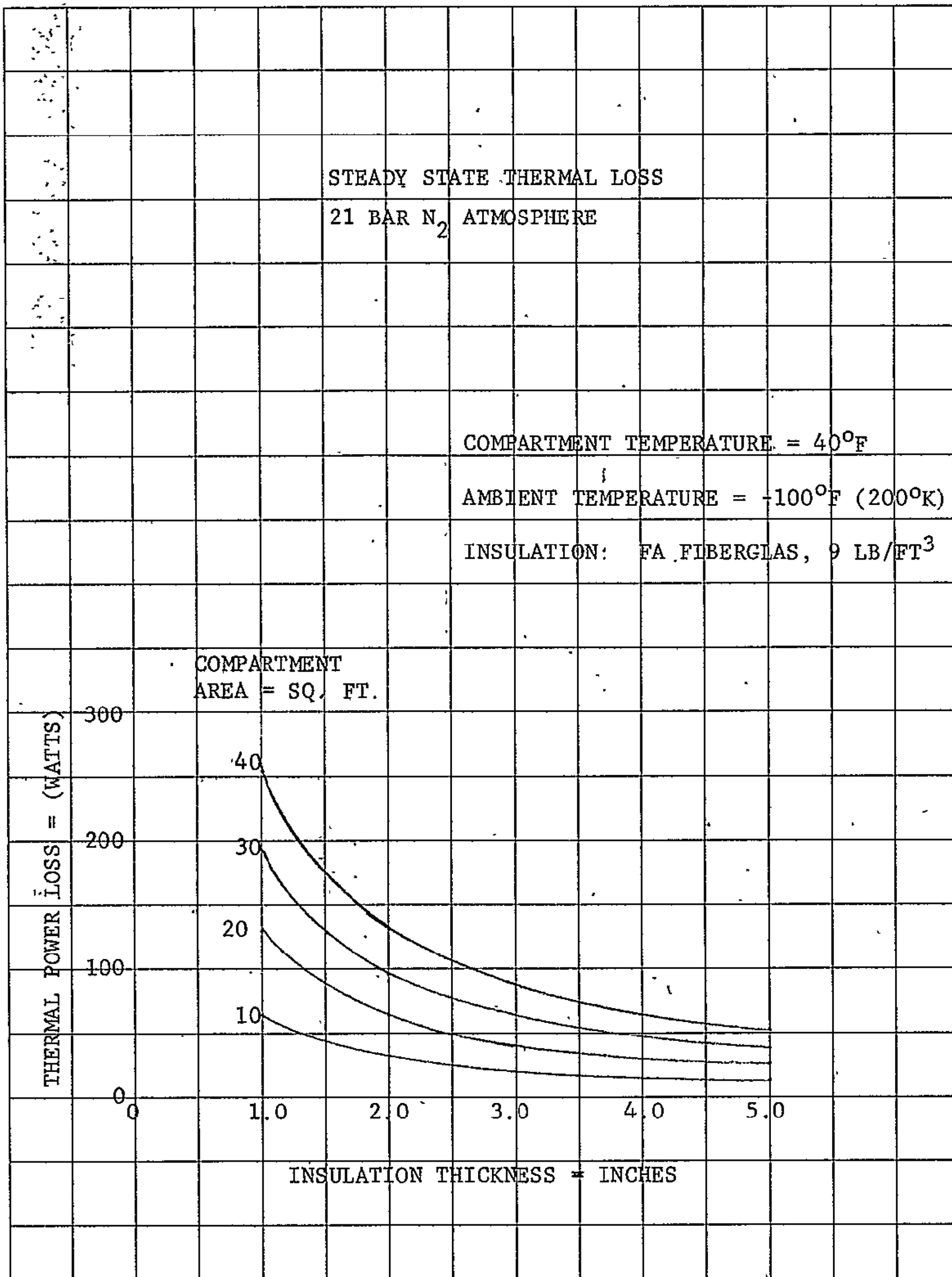

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Figure VI-10 Steady State Thermal Loss on Surface - Thick Nitrogen Atmosphere, 10% Probable Surface

Table VI-9 Thermal Control Design Approach

MISSION PHASE	PROBE CLASS A	PROBE CLASS B	PROBE CLASS C
Pre-Launch	o Cooling - Ground Coolant Loop	o Cooling - Ground Coolant Loop	o Cooling - Ground Coolant Loop
Cruise	o Warming - Isotope Heaters Plus Spacecraft Power	o Cooling - Heat Pipes Reject Isotope Heater Load to Probe or Spacecraft Radiator	o Cooling - Heat Pipes R Reject RTG Load to Probe or Spacecraft Radiator
Coast	o Warming - Isotope Heaters	o Cooling - Heat Pipes Reject Isotope Heater Load to Probe or Spacecraft Radiator	o Cooling - Heat Pipes Reject RTG Load to Probe Base Cover Radiator
Descent/ Surface	o Warming - Isotope Heaters Plus Electronic Waste	o Warming - Isotope Heaters, Electronic Waste Heat	o Warming - RTG Waste Heat, Electronic Waste Heat

Figure VI-11 presents a typical entry and descent time history of the probe compartment temperature for a 7.6 cm insulation thickness. This case assumed that the compartment was preheated to 306°K (90°F) and internal heat consisted of electrical dissipation and thermal capacity of the equipment only. This temperature at end-of-mission (EOM) is acceptable, however, the final designs for the Class B probe have the addition of a few isotope heaters to stabilize the temperature on the surface.

a. Titan Probe Thermal Control Concepts for Surface Operation - Maintaining the probe interior within operational limits on the Titan surface will require an energy source. Candidates are:

1. Radioisotope heaters,
2. Waste heat from a Radioisotope Thermal Electric Generator (RTG),
3. Battery powered electric heaters, and
4. Chemical heat source.

The mission duration (~32 days minimum, on Titan surface) coupled with the need for electric power for probe operation make 2. or a combination of 1. and 2. the most viable option. Parametric studies performed to date show that approximately 200 watts of thermal energy will maintain the probe at 40°F on the Titan surface (worst case methane atmosphere). This can be obtained from an RTG that provides approximately 20 watts electrical. The RTG weight will be on the order of 7 to 9 kg.

Once a radioisotope heat source has been selected, a preliminary set of basic requirements for the TCS can be written.

TCS Requirements

I. Pre-Launch

1. Maintain probe temperature within storage limits while rejecting approximately 250 watts thermal to ground cooling system.
2. Provide means for pre-launch checkout of TCS.

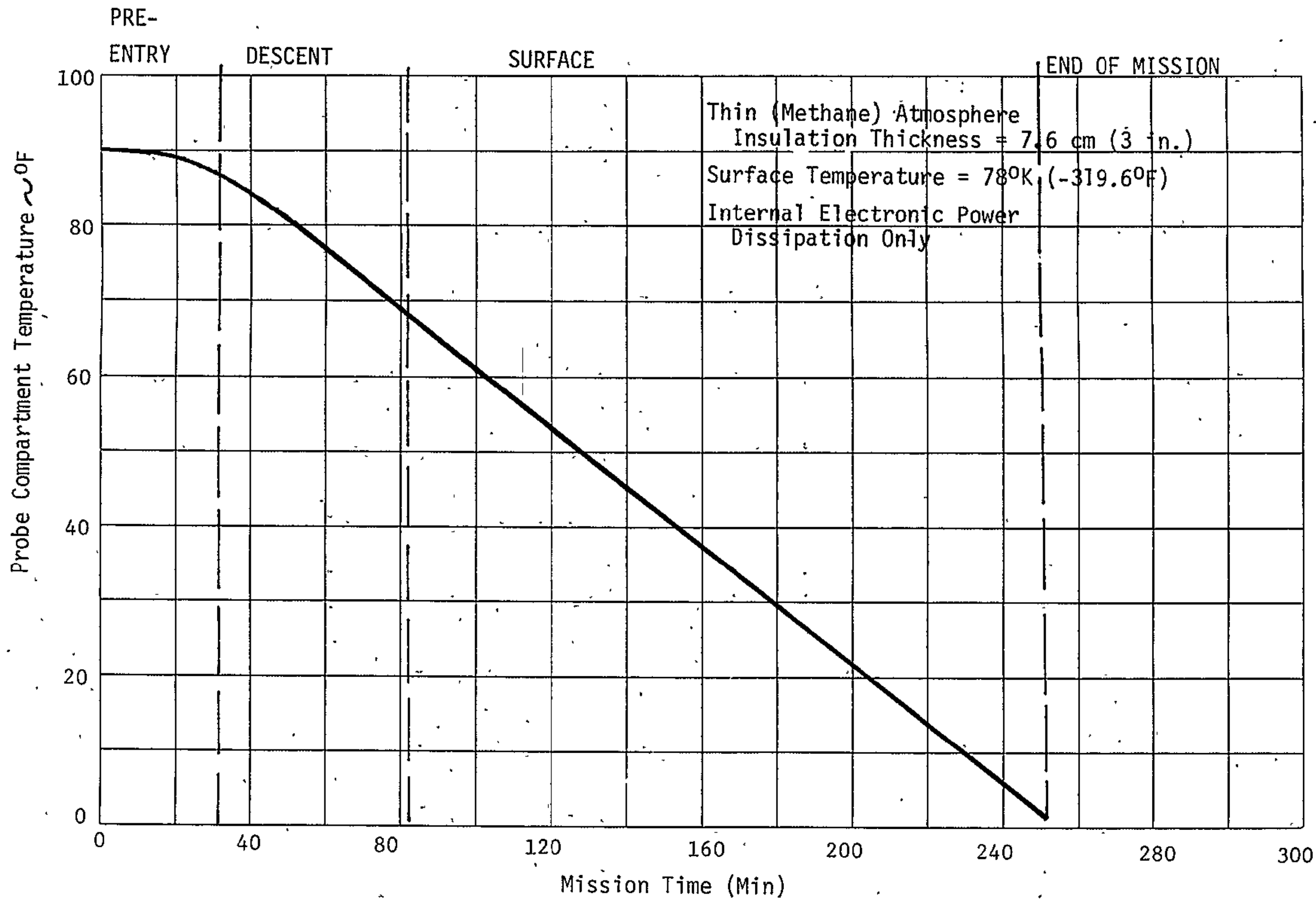


Figure VI-11 Probe Compartment Temperature Versus Time

II. Cruise Phase

1. Maintain probe interior within storage temperature limits while rejecting 200 to 250 watts thermal to space.

III. Maintain probe interior within operating temperature limits during terminal cruise phase while rejecting approximately 200 watts thermal to space. Probe is separated from spacecraft.

IV. Maintain probe interior within operating temperature limits during descent and landed phases while rejecting approximately 200 watts thermal to Titan environment.

Candidate designs are summarized in Table VI-10 and discussed below:

- *Movable RTG* - Under this concept, the RTG would be located external to the probe during pre-launch, cruise and pre-entry. Just prior to entry, the RTG would be transferred mechanically to the probe interior through a hole that would be mechanically closed with an insulated door or plug. RTG heat rejection would be passive, through radiation and conduction, prior to entry. Probe insulation would be sized for the Titan atmosphere determined from Pioneer and Voyager information. Given present knowledge, it would be necessary to insulate the probe for the thin methane atmosphere and mechanically swing away some insulation should the relatively warm heavy nitrogen atmosphere be encountered.

- *Heat Pipe System* - Under this concept, the RTG would be located inside the probe and would reject its heat through a series of parallel path heat pipes connected to spacecraft and probe-mounted radiators. Prior to probe separation, the heat pipes to the spacecraft radiator would be vented and cut with ordnance devices. Probe insulation configuration would be similar to

Table VI-10 Thermal Control

TRADE-OFF MATRIX

CONCEPT	ADVANTAGES	DISADVANTAGES
I. MOVABLE RTG	1. NO BASIC PROBLEM WITH 7-YEAR MISSION DURATION. 2. QUALIFICATION TESTING STRAIGHT-FORWARD.	1. RELATIVELY COMPLEX MECHANICAL DESIGN. 2. LIMITED TOLERANCE TO UNANTICIPATED TITAN ENVIRONMENT CONDITIONS. 3. NO ACTIVE HEAT REJECTION PATH FOR INDIVIDUAL PROBE COMPONENTS.
II. HEAT PIPE SYSTEM	1. NO MOVING PARTS OTHER THAN ORDNANCE. 2. PROBE INSULATION SHELL ARRIVES "AS BUILT" ON TITAN. 3. HISTORICAL BACKUP. HEAT PIPES NOW HAVE 3- TO 4-YEAR CONTINUOUS OPERATION HISTORY ON ATS. 4. REDUNDANCY EASILY PROVIDED. 5. MINIMAL QUALIFICATION TESTING.	1. LIMITED TOLERANCE TO UNANTICIPATED TITAN ENVIRONMENT EXTREMES. (MUST HAVE ATMOSPHERE DEFINITION OR VARIABLE INSULATION.) 2. ULTRA-CLEAN ASSEMBLY REQUIRED FOR LONG LIFE HEAT PIPES. 3. CONFIGURATION MUST BE CONSTRAINED TO PROVIDE OPERATION AT 1 g (PRELAUNCH). 4. PROBE COMPONENTS MUST OPERATE WITHOUT INDIVIDUAL HEAT REJECTION PATHS AFTER LANDING.
III. ACTIVE COOLING LOOP	1. PRECISE TEMPERATURE CONTROL FOR ALL PHASES. 2. INDIVIDUAL HEAT REJECTION PATH FOR ANY COMPONENT CAN BE EASILY PROVIDED.	1. QUESTIONABLE RELIABILITY OVER MISSION LIFE. 2. DIFFICULT TO ESTABLISH QUALIFICATION TEST CRITERIA. 3. REQUIRES POWER. 4. REDUNDANCY OBTAINABLE ONLY WITH A WEIGHT/VOLUME PENALTY (EXTRA PUMPS).

the Movable RTG concept. The heat pipes to the probe-mounted radiator would be required only during pre-entry. They would be designed for zero-g operation only and would automatically turn off upon encountering atmosphere.

- *Active Cooling Loop* - This concept is similar to the Heat Pipe System concept, except that pump driven cooling loops would replace the heat pipes for heat rejection during all mission phases, including post-landing. The loop connecting the probe interior with the probe-mounted radiator would be activated at probe separation. This loop would be available, however, if a partial failure of the spacecraft loop occurred during cruise. This design would succeed with either atmosphere now postulated, without movable insulation.

The most flexible, dependable, and certainly the most elaborate thermal control system would be a combination of the Heat Pipe System concept and the Active Cooling Loop concept where heat pipes would be used during cruise and a pump driven cooling loop would be activated at probe separation. This design is probably justified only if no more precise definition of the Titan thermal environment is established before the design must be finalized.

Given reliable data from Pioneer, Voyager and continuing astronomy, the Heat Pipe System concept is recommended.

Data from present and future spacecraft systems using heat pipes will be available to justify or reject this preliminary recommendation.

3. Summary of Thermal Control Designs - The thermal control designs are summarized in Figure VI-12 for the three probe classes and the thin and thick atmospheres. The subsystem element thermal characteristics are given in this figure and their corresponding weights are given in the detailed equipment list breakdown of

Figure VI-12 Thermal Control Design

THERMAL SUBSYSTEM ELEMENTS:

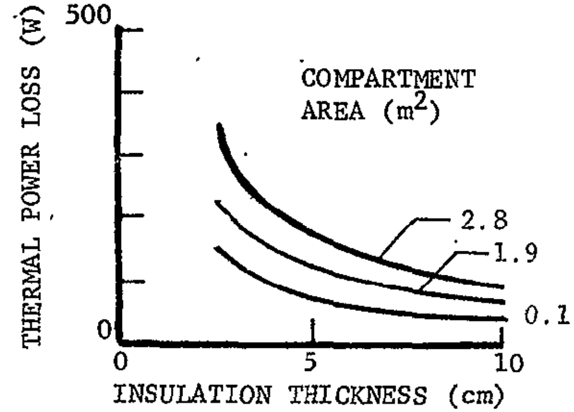
- o INSULATION
- o ELECTRONIC HEAT DISSIPATION
- o RTG HEAT WASTE
- o ISOTOPE HEATERS
- o HEAT PIPES/BASE COVER RADIATORS FOR DUMPING EXCESS HEAT

ATMOSPHERE	THIN			THICK		
PROBE CLASS	A	B	C	A	B	C
COMPARTMENT SURFACE AREA (m^2)	1.5	3.3	4.9	1.5	3.3	4.9
ELECTRICAL DISSIPATION (W)	73.0	95.0	22.0	73.0	106.0	**22.0
RTG DISSIPATION (W)	-	-	200.0	-	-	200.0
ISOTOPE HEATER DISSIPATION (W)	30.0	65.0	50.0	30.0	34.0	-
TOTAL INTERNAL DISSIPATION (W)	103.0	160.0	272.0	103.0	140.0	222.0
STEADY STATE HEAT LOSS (W)	60.0	160.0	270.0	80.0	140.0	180.0
INSULATION THICKNESS (cm)	5.0	7.0	7.6	5.0	7.0	7.6
RADIATOR REQ'D FOR COAST PHASE		X	X		X	X

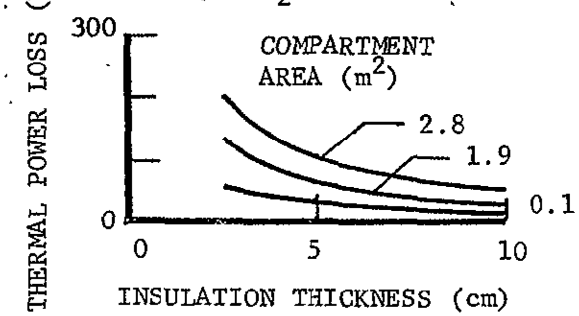
*10% PROBABLE SURFACE

**CLASS C PROBE DESIGNED BY LOW ACTIVITY 30 DAY PERIOD

THIN (CH_4) ATMOSPHERE



THICK (N_2) ATMOSPHERE*



MARTIN MARIETTA

Table V-2. The steady state heat loss is based on surface operation conditions which design the Class B and C probes. For the Class A probe, the isotope heaters are provided for the coast phase where the thermal heat loss is much lower than on the surface where atmospheric conduction dominates.

VII. ORBITER SUPPORT REQUIREMENTS

A. OPERATIONAL SUPPORT REQUIREMENTS

1. Ground Checkout - See Table VII-1. The Saturn orbiter must provide subsystem support (structure, thermal, power, telecommunications) during checkout. The spin mechanism for release of the probe into Titan must be checked out also with the probe attached to the orbiter.

2. Launch and Cruise - The following environmental and interface considerations must be developed.

   a. A structural field joint is required to mate with the probe between the adapter truss and the orbiter.

   b. The pyrotechnic shock levels, solar absorptivity between the bioshield base and orbiter, vibration levels, propulsion products contamination, ordnance combustion products contamination, orbiter RTG radiation protection, alignment, thermal control (to supply heater power and dissipate the probe RTG heat load) must be further investigated.

   c. The bioshield cap should be separated from the probe during cruise.

3. Special Operations - Cruise checkout, GCMS bakeout and vent, and preseparation checkout are the operations requiring orbiter power to the probe.

4. Separation Sequence - The orbiter will have to perform the following activities during separation:

   a. Spin up probe (with a spin table or by spinning the orbiter).

   b. Orient the probe to the inertial attitude for entry.

   c. Release probe.

Table VII-1 Launch Site Operations

- RECEIVE/INSPECT
- VERIFICATION TEST
- PREPARATION
- MOVE AND MATE ORBITER/PROBES
- ORBITER/PROBES INTERFACE AND SYSTEMS TEST
- PATHFINDER TESTS
- SPACECRAFT - SHUTTLE TESTS
- DEMATE AND MOVE
- INSTALL FLIGHT HARDWARE
- SCIENCE AND SUBSYSTEM TEST
- FLIGHT COMPATIBILITY TESTS (RELAY LINK)
- STERILIZATION
- PREPARE FOR MATE
- MATE AND LOAD COMPUTER
- MATE WITH SHUTTLE
- LAUNCH

d. Maneuver the orbiter for proper timing and flyby altitude for communications through the relay link.

e. Separate the bioshield base from the orbiter.

5. Orbiter Flyby - Initial Encounter -

a. The orbiter relay antenna (0.9 meters, diameter) must be pointed and slewed or step wise positioned ($\pm 12^{\circ}$) through a 140-degree total angle.

b. The orbiter recorder must have the capability of receiving and storing data for transmission to Earth ($\sim 15 \times 10^{6}$ bits).

6. Orbiter Flyby - Re-encounter

a. The orbiter must maneuver for the required flyby radius to support the relay link.

b. The orbiter sequence must include initiation of recording of the relay link data at specified times.

c. The orbiter relay antenna must be pointed and either slewed or step wise positioned through a 140-degree angle.

d. The orbiter must transmit to the probe to activate the probe. (Probe also has timer as backup.)

e. The orbiter will then receive probe data and store for transmission to Earth.

B. ELECTRICAL INTERFACES

The orbiter/probe interface must support the power, command, and data requirements anticipated in Table VII-2.

Table VII-2 Saturn Orbiter/Titan Probe Electrical Interfaces

POWER

- UNREGULATED 28 VDC, 300 WATTS MAXIMUM CONTINUOUS TO TWO 150-WATT REGULATORS
- FOR CRUISE (CAL, C/O, B/O, VENT)
- FOR SEPARATION

COMMAND

- ACTIVATE PROBE SEQUENCER
- PYRO ARM/FIRE/SAFE FUNCTIONS
- REMOTE ACTIVATION OF BATTERIES
- SEPARATION MODE
- 6 WATT, 100 OHM RESISTANCE HEATERS
- ORBITER GENERATED READOUT ENABLE AND CLOCK PULSES
- PRESEPARATION C/O
- COMPUTER TO PCDA
- SEQUENCER UPDATE

EMC

- COMPATIBILITY

DATA

- UMBILICAL FOR SIGNALS
- CRUISE DATA POWER SOURCE
- PRESEPARATION C/O DATA AT TWO DIFFERENT RATES (650 BPS, 2000 BPS)

VIII. TITAN PROBE PROGRAM PLAN AND COST

A. PROGRAM APPROACH

The program is based upon fabricating two flight-type probes. One is referred to as a Proof Test Model (PTM), the second a flight article. (The PTM is a flight backup unit.) Two sets of System Test Equipment (STE) assembled in two identical vans are used for all test operations of the two probes. The basic structural parts for both the PTM and flight article will be fabricated using one tooling setup. The PTM will be assembled first, and with simulators for components, subjected to a series of tests to obtain an early confirmation of the dynamic environment for all components. Also, early verification is obtained that critical mechanical alignments are within allocations following exposure to significant mission environments. The PTM is then reassembled with qualification hardware and subjected to the series of proof-level environmental tests including a thermal vacuum test.

The PTM testing proves the probe design will meet the mission requirements with adequate margin. Therefore, the flight article will be subjected to only vibration and thermal vacuum tests to prove workmanship.

The PTM is a complete, operational spacecraft, fabricated to flight article drawings, using flight-type hardware.

Following completion of environmental testing in Denver, the PTM and its STE Van are shipped to the JPL for compatibility testing with the Saturn orbiter. Following this test they are shipped back to Denver and the PTM is used for the final system level testing of the flight software, configured for shipment, and then sent to KSC. The STE Van is also shipped to KSC.

Meanwhile the flight article is assembled and checked out, subjected to the vibration and thermal vacuum tests and configured for shipment to KSC. These activities require use of the second STE Van set.

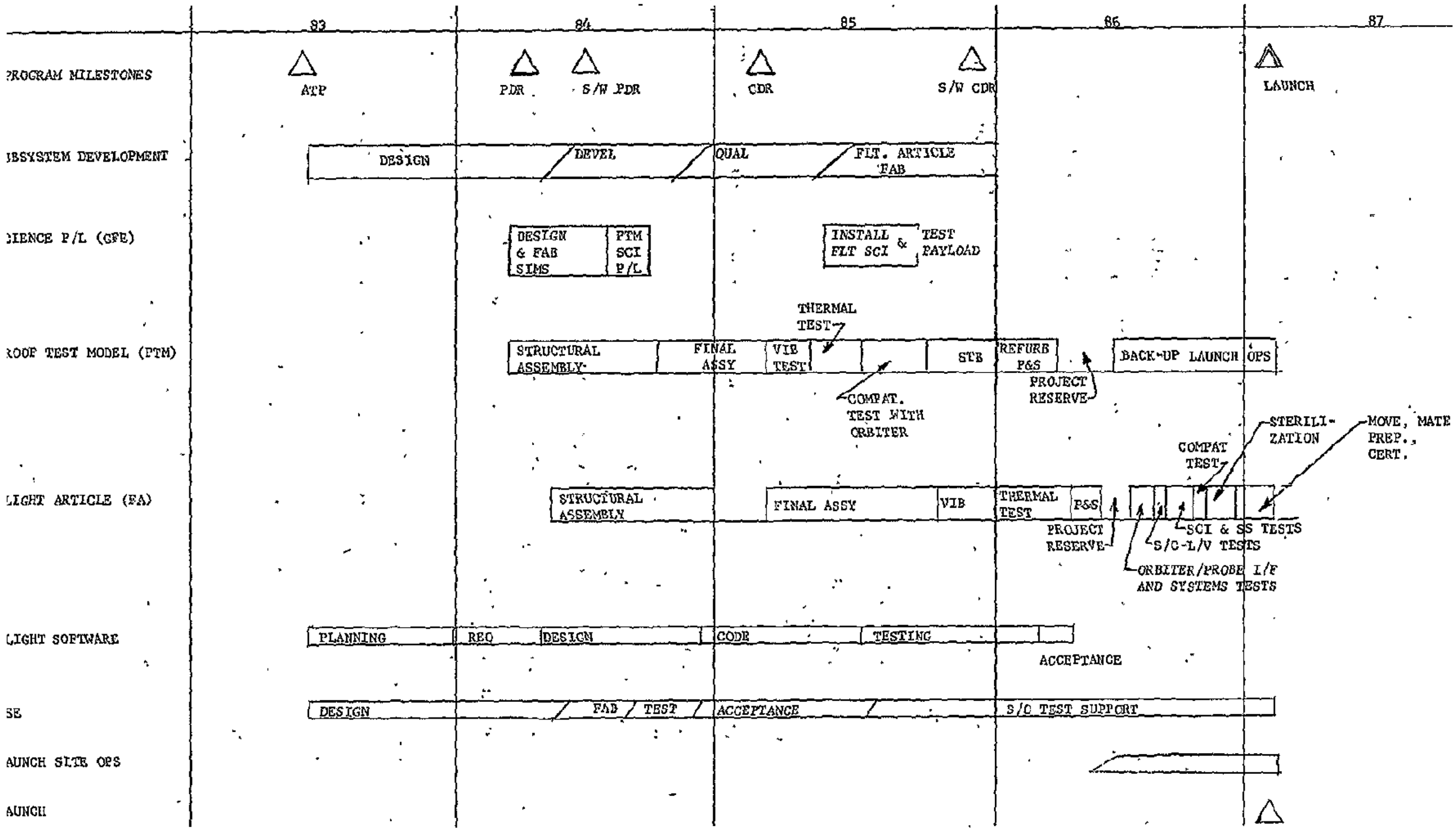
B. PROGRAM PLAN

The program plan is shown in Figure VIII-1. It is based upon an Authority to Proceed (ATP) of 1 June 1983 and a launch date of January 1987. A two-month project reserve is shown which can be utilized if unforeseen problems arise. The key milestones, in addition to those above, are the spacecraft Preliminary Design Review (PDR) and Critical Design Review (CDR); flight software PDR, CDR, Test Readiness Review (TRR), Acceptance Review (AR), and flight article and PTM on-dock data at ETR.

Program Assumptions - The following ground rules and assumptions were used in developing the Budgetary Cost Estimate and Schedule included in this volume.

1. Titan Probe program ATP on 1 June 1983.
2. Phase B Study and Critical long lead activities will precede the 1 June 1983 program start.
3. Single launch on Shuttle is assumed.
4. Ames is Probe Program Manager, Martin Marietta will perform all probe integration functions with the spacecraft.
5. The science payload is GFE. All science is delivered to Martin Marietta by 1 August 1984.
6. Science instruments do not have to be returned to suppliers for final calibration.
7. No receiving bench tests are required for the science instruments.
8. Martin Marietta will provide science interface documentation.
9. Science simulators are GFE. The simulators are representative for mass, electrical loads, and thermal properties.
10. The Saturn orbiter interface tool is GFE.

gure VIII-1 Titan Probe Program Plan



11. Martin Marietta will have access to the hardware specification from VO '75, Voyager, Galileo and other NASA programs which used the hardware selected for Titan Probe.

12. The Jupiter probe software and supporting documentation will be made available to Martin Marietta.

13. Martin Marietta will perform all spacecraft operations at the ETR through mating and checkout with the Saturn probe and publish prelaunch activity reports.

14. No mission operation activities are required for Martin Marietta.

15. Martin Marietta is responsible for the following MA&D effort:

    a) MA&D Plan
    b) Mission Profile Specification
    c) Mission Design Review
    d) Reference Mission Design
    e) Operational Mission Design

16. Martin Marietta will perform the following major functions:

    a) Probe Planning and Control
    b) Probe Integration
    c) Science Integration
    d) Probe Test Planning
    e) Probe Prelaunch Operations

17. A PTM will be built to flight drawings and will be used for environmental testing, orbiter compatibility testing, final flight software validation, and spare flight article.

18. Component/subsystem qualification will be performed only on that hardware which is new or has major modifications to it.

19. All offsite to Martin Marietta facilities will be provided GFE.

20. No Earth orbit spacecraft checkout will be performed which requires Martin Marietta support.

21. The Martin Marietta effort is complete at the time of launch except for issuing a final spacecraft report.

22. No mission support software is required from Martin Marietta.

C. PARAMETRIC COST ESTIMATE

1. Introduction - Program costs for the Titan Probe mission, as shown in this section, were developed by analogy. Our Cost Analysis Data Base (CADB), upon which these costs are based, contains actual cost data collected from previous programs such as the Titan series, Viking, Skylab, Pioneer Venus, SCATHA, and many others. Wherever possible, the estimated cost for a given component or subsystem was arrived at by multiple methods; i.e., a piece of structure was estimated by dollars per pound, dollars per unit surface area, and by analogy to previously built structures of similar complexity. This technique applies a "test of reasonableness" that any single method lacks, and helps preclude gross errors.

Similarly, costs for non-hardware portions of the probe mission were estimated using CERs (Cost Estimating Relationships) relating program complexity and duration to required manpower, as well as other constituent parts relating to program management and administration.

2. Costing Ground Rules and Assumptions - The following ground rules and assumptions were used for this cost estimate.

- Ground Rules
  - 2 Spacecraft - 1 Flight, 1 PTM
  - All $ are 1978 $
  - Manufacturer startup costs are reflected in selected procurement items
  - Costs to integrate procured and GFE components are reflected at the component level.

- Assumptions
  - Certain Viking hardware as well as selected hardware from other previous missions is available to us as GFE
  - Shuttle interfaces are limited to latching mechanisms similar to the IUS mechanisms
  - Saturn orbiter interfaces are described elsewhere
- Management Task Labor Estimates

  Program Management Task Labor estimates were estimated based upon historical factors from previous programs.
  - Engineering Administration was estimated at 3% of the total Engineering manmonths.
  - Contract Requirements and Documentation, Planning and Cost Management and Manufacturing Production Control were estimated at 15% of the total Engineering manmonths.
- Material and Subcontract Costing Approach

  The Material and Subcontract estimate for the Titan Probe is based upon new procurement, rebuy/refurbishment of Viking and other program hardware, and procurement of NASA standards.

  Wherever possible, advantage was taken of existing, flight proven hardware. Where applicable, appropriate startup costs were estimated, based on the complexity of the equipment, the quantity to be procured, and the status of the supplier.

3. Other Program Costs Comparison - Three different programs were reviewed for analogy to the Titan Probe. These were:

   a. The Pioneer Venus Large Probe (Martin Marietta Phase C/D proposal updated to 1978 dollars)

b. The Viking Lander (updated to 1978 dollars and normalized for non-recurring R&D costs)

c. The estimated Galileo cost (see Table VIII-1)

Comparison included changes due to probe usage and design (i.e.: no Attitude Control System).

The Viking Lander can be compared to the Titan Class C probe with the following reductions. (See Table VIII-2)

The cost of the Class B hard lander differs from the cost of the Class C probe in experiment integration (5 less experiments on B), power (no RTG on B), pyros, telecommunications (no receiver and command detector on B). In addition, a sequencer on B could replace the computer used on C. The test program differs by the surface life requirements for the two probes.

Rationale for differences in costs between the different classes of Titan Probes:

a. Structures and Mechanisms - The more science instruments, the more complex are the mechanisms and housings. In addition, the size of the probe increases as the science complement increases. The soft lander requires additional design and development.

b. Parachute - The differences are strictly caused by weight.

c. Thermal - Study of thermal problems on the Titan surface increases the design complexity.

d. Power - Addition of the RTG on the Class C probe increases cost.

e. Aerodynamics and Stability - Development testing costs increase with landing requirements.

f. Communications - Two-way communication requirements for the Class C probe add to its cost. The Class A probe uses a smaller transmitter because of lower link requirements.

Table VIII-1 Other Program Costs

	Pioneer Venus (PV) Large Probe	Viking Lander (VL)	Galileo Probe
Project Management	3.3 M	43.1 M	
Systems Engineering	5.5 M	78.7 M	
Probe Subsystems	23.6 M	135.3 M	
Experiment Integration	0.5 M	6.8 M	
Systems Integration, Test, Launch	3.5 M	88.3 M	
Product Assurance	2.3 M	33.4 M	
	38.7 M	385.6 M	35-40 M

Table VIII-2 Normalized Costs of VL Compared to Titan C Probe

	Normalized VL	Titan C Probe
Power	-	1/4
Electronics	-	1/5
Structures	-	1/3
Thermal	-	3/4
Test and Launch	-	1/10
Software	-	1/8
Experiment Integration	-	5/6

NOTE: Cost for Project Management (10.6%), Systems Engineering (25%), and Product Assurance (4.6%) are percentages of the cost of the rest of the probe.

g. Data Handling - The Class C probe has a large recording requirement.

h. GSE - The Class A probe interface requirements are much less than the other classes of probes.

i. Software - The soft lander has an attitude control computational requirement.

j. System Development Hardware - Same

k. Science Accommodation - Cost is based on the number of instruments.

l. Test and Launch Support - Test complexity varies as to time active on the Titan surface; hard or soft landing

m. Propulsion - Only the soft lander has a propulsion system

D. APPROACH AND MODEL COST SUMMARY

For the Titan Probe, costs were developed for each subsystem contained in the program Work Breakdown Structure. Input data required for each item or grouping of items within each subsystem were derived from the subsystem equipment lists. Emperical data sets derived from Viking, Space Shuttle, SCATHA, or Titan actual cost experience were used for each item as appropriate.

Table VIII-3 is a cost summary by WBS element for the Titan Probe. A few elements were not calculated because the input data required was beyond the scope of this study. Where a cost was not available from the model, the analogy cost has been used.

Table VIII-4 presents the cost summary for the baseline pre-entry science module depicted in Figure V-23.

Table VIII-5 is a summary of the additional cost incurred for the baseline Class B probe when the mission surface operational time is extended 32 days to allow for increased science measurements and a re-encounter of the orbiter for a final science data transmission.

Table VIII-3 Cost Summary

	WBS	A	Class B Hard Land	Class B Soft Land	C
Titan Probe	1.0				
- Probe Subsystems	1.3				
Structures & Mechanisms	1.3.1	5.1	11.0	24.0	14.4
Parachute	1.3.6	1.1	3.4	3.4	3.4
Thermal	1.3.2	1.0	2.0	3.0	3.0
Power	1.3.3	4.0	4.0	4.0	5.5
Aerodynamics & Stability (ACS)	1.3.7	0.6	2.7	8.0	2.7
Communications	1.3.4	2.5	5.5	5.5	8.0
Data Handling	1.3.5	6.5	6.5	6.5	9.0
Ground Support Equipment	1.3.9	6.0	9.0	9.0	11.0
Software (Flight)	1.3.8	1.0	1.5	6.0	2.5
Systems Development Hardware	1.3.10	0.8	0.8	0.8	0.8
Propulsion	Separate	-	-	10.6	-
- Science Accommodation	1.4.3	1.0	2.6	2.6	3.4
- Test & Launch Support	1.4	3.4	6.7	18.8	8.8
- Product Assurance (4.6%)	1.5	1.5	2.5	4.7	3.3
- Systems Engineering (25%)	1.2	8.2	13.9	25.5	18.1
- Project Management (10.6%)	1.1	3.5	5.9	10.7	7.7
Titan Probe Total		46.2	78.0	143.7	101.6
Cost Ranges		40-50	70-80	140-150	95-105

Table VIII-4 Cost Estimate for Titan Probe Pre-Entry Module

Probe Elements Affected:

- Subsystem: Structure, Mechanisms, Pyro, Thermal, Aerodynamics, GSE
- Science Accommodation for Four Experiments
- Test

	Million
Project Management	$0.3
Systems Engineering	0.6
Probe Subsystems	1.1
Experiment Integration	0.9
Systems Integration, Test, Launch	0.5
Product Assurance	0.1
Total	$3.5

Note: Science Instruments Cost Not Included (GFE).

Table VIII-5 Titan Class B Probe Cost Estimate for Surface Operation Change

32-Day Extension of Surface Operation Will Result in Additional Costs Caused by the Following Changes:

- Adding RTG (GFE) and Base Cover Radiator
- Additional Analysis of Experiments in Operation on Surface
- Additional Testing and Development
- Additional Thermal Analysis

Estimated Cost Increase for 32-Day Surface Mission:

	Million
Project Management	$0.5
Systems Engineering	1.2
Probe Subsystems	2.8
Experiment Integration	0.2
Systems Integration, Test, and Launch	2.0
Product Assurance	0.2
Total Cost Increase	$6.9

Note: RTG Cost Not Included (GFE).

WORK BREAKDOWN STRUCTURE

1.0 Titan Probe

1.1 Probe Project Management

1.2 Probe Systems Engr

- 1.2.1 Systems Analysis & Requirements
- 1.2.2 Interfaces and Configuration
- 1.2.3 Verification Requirements
- 1.2.4 Launch & Crew (Shuttle) Ops
- 1.2.5 Design Integration
- 1.2.6 Reliability Engr
- 1.2.7 Mass Properties
- 1.2.8 Environmental Definition
- 1.2.9 Probe Mission Analysis

1.3 Probe Subsystem Design, Fabrication, Development and Qualification

- 1.3.1 Structural/Mechanical
- 1.3.1.1 Aeroshell
- 1.3.1.2 Mechanisms
- 1.3.1.3 Pyro Devices
- 1.3.1.4 Science Instrument Support Hardware
- 1.3.1.5 Probe Shell

- 1.3.2 Thermal Control
- 1.3.2.1 Aeroheating Analysis
- 1.3.2.2 Heat Shield
- 1.3.2.3 Thermo-Physics Analysis
- 1.3.2.4 Insulation Coatings Phase Change

- 1.3.3 Power & Cabling
- 1.3.4 Telecommunications (Transmitter, Oscillator, Antenna, Receiver/ CMD Detector, RAD)—
- 1.3.5 Data Handling, Control and Computation (Transducers, Signal Conditioning, Processor)
- 1.3.6 Parachute
- 1.3.7 Aerodynamics & Stability
- 1.3.8 Flight Software
- 1.3.9 Ground Support Equipment
- 1.3.10 Systems Development Hardware (Simulation)

1.4 Probe Assembly and Verification

- 1.4.1 Probe Assembly
- 1.4.2 Probe Bus Verification
- 1.4.3 Science Payload Integration
- 1.4.4 Probe Verification
- 1.4.5 Verification Software
- 1.4.6 Launch Site Operations

1.5 Product Assurance

IX. CONCLUSIONS

This study has defined the technical requirements, conceptual designs, science return and schedule/cost implications of three probe classes for use in Titan exploration. Based on these study results, the following conclusions have been made:

- All probe classes are feasible in both the thick and thin atmosphere. The thin atmosphere designs require a parachute to provide sufficient descent time for science, while the thick atmosphere designs require additional battery power to accommodate lengthy descent times.

- The hard lander concept is a practical design approach for the Class B and C probe/landers. The hard lander configuration provides:
  - Good impact stability
  - Low penetration on ice or snow
  - Flotation on liquid surface

- The Class B probe meets the overall science requirements without major developments. The Class B probe is 1.5 m in diameter with a mass of 227 kg.

- The Titan probe masses required to meet the study mission requirements are:

	Thick Atmosphere (30% Probable Surface)	Thin Atmosphere (Worst Case)
Class A - Atmosphere Probe	114 kg	113 kg
Class B - Atmosphere/Lander	226	227
Class C - Expanded Atmosphere/Lander	351	355

- The Titan probe program costs required to meet the study mission requirements are;

Class A - Atmosphere Probe	$40 - 50 M
Class B - Atmosphere/Lander	$70 - 80 M
Class C - Expanded Atmosphere/Lander	$95 -105 M

- Impact of thin versus thick (30% Probable Surface) atmosphere on design is minimal.
- Thick (10% Probable Surface) atmosphere increased Class B probe design weight by 30% over that of the 30% probable surface.
- 32-day extended mission time increased Class B probe weight by 10% and program cost by 9%.
- Soft lander concept increased Class B probe weight by 17% and program cost by 84% due to the increased complexity of the guidance, attitude control, and terminal propulsion.
- The pre-entry science module program cost is $3.5 M not including the science instruments which are assumed GFE.
- The primary mission design drivers are:
  - Atmospheric uncertainty
  - Surface physical characteristics uncertainty
  - Eight-year flight time prior to probe operation
  - Data volume required to support imaging
- The major hardware uncertainties are:
  - Surface sample acquisition at low ambient temperature (70 to 100°K)
  - Properties of mechanical devices and materials at low ambient temperatures
- No major new technologies are required for the Titan probe mission. However, some critical hardware development is required as defined above.

X. RECOMMENDATIONS

Recommended areas for future study include:

- Titan physical properties model including atmosphere, surface, and light level definition,
- Pre-entry science implementation,
- Impact on probe system design of direct entry rather than out-of-orbit entry as baselined in the current study,
- Science sample acquisition and handling at very low ambient temperatures (70-100°K),
- Properties of mechanical devices and materials at very low ambient temperatures (70-100°K).

XI. REFERENCES

1. J. Caldwell and D. Hunten, *"Summary of Current Titan Atmosphere Models for Entry Probe Studies"*, Attachment 1 to NASA/ARC Request for Proposal 2-27205, dated April 28, 1978, for the Study of Entry and Landing Probes for the Exploration of Titan.

2. *"Saturn System Workshop"*, Conference Report Draft, February 9th and 10th, 1978, Reston, Virginia.

3. J. L. Wright, *"Saturn Orbiter Dual Probe Mission Concept"*, Jet Propulsion Laboratory Report 710-20, September 1978.

XII. APPENDIXES

A. JPL TRAJECTORY DATA

This appendix presents the trajectory position data for the orbiter and probe as received from the JPL. Data shown include orbiter stand-off distances (radius at probe entry) of 10 R_T, 20 R_T and 22 R_T. Definitions of parameters and conditions included are described in the attached sheets.

Notes to Titan Probe Entry Data

1. Probe entry is assumed to occur at r = 3200 km with an entry angle of -30°. The first table for each case uses probe entry time as the zero point of time, which is expressed in seconds.

2. RC is the radius of Titan.

3. Latitude and longitude are fixed to surface of Titan.

4. Probe phase is the angle between the Titan-probe line and the Titan-sun line. A phase angle of less than ~90° implies that a body on the surface of Titan is in sunlight.

5. All cases have been targeted such that both probe and orbiter are at the same (Titan) latitude at entry time while their longitudes are such that the orbiter is lagging the probe by 30° of longitude at that time.

6. The probe travels ballistically down from r = 3200 km to the surface of Titan at r = 2916 km.

7. In the second table for each case the zero point for time is redefined as the time of periapse of the orbiter.

8. The aspect angle is defined as being the angle between the negative of the velocity vector (relative to the Titan atmosphere) and the vector from the probe to the orbiter.

9. All azimuths are with respect to the N. pole of Titan.

10. Relative longitudes are based on a zero point of the longitude of the orbiter at periapse.

Cases presented:

2 Titan encounters are considered:

a) Coming in on a 1:1 resonance with Titan with probe entry at: 94/08/05, 11:51:56.
V_∞ = (3.8851, -16.3113, 34.4068)
$|V_\infty|$ (ks^{-1}) decl. (deg) R.A. (deg) Titan Equator System.

b) Coming in on a 2:1 resonance with Titan with probe entry at : 94/07/20, 13:12:27.
V_∞ = (3.8825, -19.3648, 17.7766)

For each case the orbiter is delayed 30° in longitude with respect to the probe at entry. The standoff radius is taken to be 10 Titan radii and 20 Titan radii for each case.

For each of the 4 combinations time resolutions of 10^{mins} and 1^{min} have their results presented.

Key

Case #	Orbit Resonance	Standoff Radius/R_T	Δt (min)
1	1:1	10.	10.
~~2~~	~~1:1~~	~~10.~~	~~1.~~
3	1:1	20.	10.
~~4~~	~~1:1~~	~~20.~~	~~1.~~
5	2:1	10.	10.
~~6~~	~~2:1~~	~~10.~~	~~1.~~
7	2:1	20.	10.
~~8~~	~~2:1~~	~~20.~~	~~1.~~

TITAN ENTRY PROFILES
EXAMPLE TRAJECTORIES

$r_{orb} = 10 R_T$

SJK
Jet Propulsion Laboratory

DATE 082378 PAGE 1-1

I	TIME	PROBE R/RC	PROBE LATITUDE	PROBE LONGITUDE	ORBITER R/RC	ORBITER LATITUDE	ORBITER LONGITUDE	PROBE PHASE	CANOPUS FROM ORBITER ELEV.ANG.	CANOPUS FROM ORBITER AZIMUTH	CAN SEE CANOPUS?
1	-7200.0	10.589	15.414	198.678	18.485	8.485	187.242	42.147	-14.451	221.734	YES
2	-6600.0	9.779	15.333	197.967	17.740	8.104	186.313	41.654	-13.555	221.707	YES
3	-6000.0	8.967	15.235	197.215	16.999	7.687	185.312	41.072	-12.790	221.667	YES
4	-5400.0	8.155	15.115	196.345	16.263	7.230	184.240	40.375	-11.846	221.630	YES
5	-4800.0	7.343	14.967	195.319	15.531	6.729	183.084	39.522	-10.812	221.591	YES
6	-4200.0	6.530	14.776	194.079	14.806	6.175	181.831	38.459	-9.675	221.548	YES
7	-3600.0	5.717	14.524	192.532	14.087	5.562	180.469	37.094	-8.421	221.503	YES
8	-3000.0	4.904	14.176	190.530	13.377	4.881	178.981	35.274	-7.033	221.456	YES
9	-2400.0	4.092	13.667	187.805	12.675	4.121	177.348	32.733	-5.489	221.406	YES
10	-1800.0	3.285	12.857	183.834	11.985	3.269	175.546	28.941	-3.765	221.354	YES
11	-1200.0	2.498	11.407	177.455	11.308	2.312	173.549	22.793	-1.832	221.301	YES
12	600.0	1.726	8.294	165.593	10.646	1.231	171.323	14.037	.345	221.248	YES
13	.0	1.097	.000	136.917	10.003	.007	168.829	17.184	2.805	221.196	YES
14	600.0	1.000	-3.462	128.062	9.383	-1.382	166.020	28.292	5.597	221.149	YES
15	1200.0	1.000	-3.462	128.062	8.791	-2.959	162.841	28.146	8.771	221.107	YES
16	1800.0	1.000	-3.462	128.062	8.232	-4.746	159.228	28.001	12.384	221.073	YES
17	2400.0	1.000	-3.462	128.062	7.715	-6.762	155.110	27.856	16.492	221.046	YES
18	3000.0	1.000	-3.462	128.062	7.248	-9.012	150.412	27.711	21.143	221.016	YES
19	3600.0	1.000	-3.462	128.062	6.841	-11.482	145.065	27.566	26.357	220.955	YES
20	4200.0	1.000	-3.462	128.062	6.507	-14.124	139.017	27.421	32.114	220.796	YES
21	4800.0	1.000	-3.462	128.062	6.257	-16.844	132.263	27.276	38.317	220.397	YES
22	5400.0	1.000	-3.462	128.062	6.101	-19.507	124.863	27.131	44.779	219.492	YES
23	6000.0	1.000	-3.462	128.062	6.047	-21.949	116.970	26.987	51.204	217.632	YES
24	6600.0	1.000	-3.462	128.062	6.097	-24.019	108.824	26.842	57.203	214.161	YES
25	7200.0	1.000	-3.462	128.062	6.256	-25.615	100.737	26.696	62.328	208.314	YES
26	7800.0	1.000	-3.462	128.062	6.498	-26.714	92.933	26.554	66.138	197.010	YES
27	8400.0	1.000	-3.462	128.062	6.829	-27.356	85.692	26.410	68.311	188.581	YES
28	9000.0	1.000	-3.462	128.062	7.234	-27.526	79.113	26.266	68.865	177.039	YES
29	9600.0	1.000	-3.462	128.062	7.699	-27.618	73.247	26.123	68.149	166.954	YES
30	10200.0	1.000	-3.462	128.062	8.215	-27.419	68.103	25.979	66.659	159.184	YES
31	10800.0	1.000	-3.462	128.062	8.773	-27.096	63.574	25.836	64.502	153.506	YES
32	11400.0	1.000	-3.462	128.062	9.359	-26.705	59.605	25.693	62.836	149.568	YES
33	12000.0	1.000	-3.462	128.062	9.903	-26.276	56.125	25.549	60.902	146.764	YES
34	12600.0	1.000	-3.462	128.062	10.625	-25.835	53.061	25.407	59.057	144.733	YES
35	13200.0	1.000	-3.462	128.062	11.287	-25.398	50.352	25.264	57.254	143.247	YES
36	13800.0	1.000	-3.462	128.062	11.963	-24.972	47.945	25.121	55.737	142.141	YES
37	14400.0	1.000	-3.462	128.062	12.653	-24.565	45.795	24.979	54.345	141.303	YES
38	15000.0	1.000	-3.462	128.062	13.359	-24.177	43.863	24.836	53.026	140.658	YES
39	15600.0	1.000	-3.462	128.062	14.065	-23.811	42.120	24.694	51.820	140.155	YES
40	16200.0	1.000	-3.462	128.062	14.783	-23.467	40.517	24.552	50.716	139.756	YES
41	16800.0	1.000	-3.462	128.062	15.508	-23.143	39.094	24.411	49.703	139.436	YES
42	17400.0	1.000	-3.462	128.062	16.240	-22.839	37.771	24.269	48.773	139.177	YES
43	18000.0	1.000	-3.462	128.062	16.976	-22.555	36.554	24.128	47.917	138.965	YES
44	18600.0	1.000	-3.462	128.062	17.717	-22.288	35.429	23.987	47.129	138.790	YES
45	19200.0	1.000	-3.462	128.062	18.461	-22.037	34.386	23.846	46.397	138.644	YES
46	19800.0	1.000	-3.462	128.062	19.209	-21.801	33.414	23.705	45.721	138.522	YES
47	20400.0	1.000	-3.462	128.062	19.960	-21.580	32.506	23.564	45.092	138.418	YES
48	21000.0	1.000	-3.462	128.062	20.714	-21.372	31.654	23.424	44.507	138.330	YES
49	21600.0	1.000	-3.462	128.062	21.470	-21.176	30.853	23.284	43.961	138.254	YES
50	22200.0	1.000	-3.462	128.062	22.229	-20.991	30.097	23.144	43.451	138.189	YES
51	22800.0	1.000	-3.462	128.062	22.989	-20.816	29.383	23.004	42.973	138.133	YES
52	23400.0	1.000	-3.462	128.062	23.751	-20.651	28.705	22.864	42.525	138.084	YES
53	24000.0	1.000	-3.462	128.062	24.513	-20.495	28.061	22.725	42.108	138.041	YES

ENTRY

ORIGINAL PAGE IS OF POOR QUALITY

SJK**

DATE 082378

55	25200.0	1.000	-3.462	128.062	26.046	-20.207	26.861	22.447	41.333	137.971	YES
56	25800.0	1.000	-3.462	128.062	26.813	-20.074	26.300	22.308	40.980	137.942	YES
57	26400.0	1.000	-3.462	128.062	27.581	-19.947	25.762	22.170	40.646	137.916	YES
58	27000.0	1.000	-3.462	128.062	28.351	-19.826	25.246	22.031	40.330	137.893	YES
59	27600.0	1.000	-3.462	128.062	29.121	-19.711	24.749	21.893	40.030	137.872	YES
60	28200.0	1.000	-3.462	128.062	29.892	-19.602	24.270	21.756	39.745	137.854	YES
61	28800.0	1.000	-3.462	128.062	30.664	-19.497	23.807	21.618	39.474	137.838	YES

I	RELATIVE TIME	PROBE-ORBITER GEOMETRY RANGE	ELEV.ANG.	AZIMUTH	ASPECT ANGLE	REL.VEL.	PROBE F.P.A.	F.P.AZ.	PROBE LAT.	REL.LONG.	ORBITER LAT.	REL.LONG.
1	-13209.5	8.517	60.607	239.404	35.081	3.977	-82.147	262.997	15.414	70.566	8.485	70.399
2	-12609.5	8.542	60.995	238.949	35.043	3.983	-81.816	262.523	15.333	69.905	8.104	69.467
3	-12009.5	8.569	61.569	238.398	34.999	3.989	-81.398	262.125	15.235	69.153	7.687	68.470
4	-11409.5	8.596	62.253	237.716	34.946	3.998	-80.869	261.699	15.115	68.264	7.230	67.398
5	-10809.5	8.624	63.082	236.851	34.884	4.008	-80.191	261.238	14.967	67.257	6.729	66.241
6	-10209.5	8.654	64.107	235.715	34.807	4.021	-79.309	260.732	14.774	66.017	6.175	64.969
7	-9609.5	8.687	65.408	234.154	34.709	4.038	-78.138	260.163	14.524	64.470	5.562	63.626
8	-9009.5	8.722	67.112	231.870	34.580	4.060	-76.537	259.502	14.176	62.468	4.881	62.138
9	-8409.5	8.762	69.430	228.190	34.398	4.091	-74.255	258.698	13.667	59.743	4.121	60.505
10	-7809.5	8.809	72.716	221.227	34.118	4.137	-70.805	257.657	12.857	55.772	3.269	58.704
11	-7209.5	8.867	77.352	203.357	33.623	4.210	-65.107	256.207	11.407	49.393	2.312	56.706
12	-6609.5	8.945	79.174	140.772	32.528	4.340	-54.331	254.085	8.294	37.532	1.231	54.480
13	-6009.5	9.070	56.518	89.987	29.298	4.573	-30.000	252.043	.000	10.755	.007	51.956
14	-5409.5	8.617	47.927	87.809	42.073	.000	.000	.000	-3.462	.000	-1.382	49.178
15	-4809.5	7.989	51.185	90.200	38.815	.000	.000	.000	-3.462	.000	-2.959	45.999
16	-4209.5	7.394	54.863	93.450	35.117	.000	.000	.000	-3.462	.000	-4.746	42.386
17	-3609.5	6.840	59.040	98.081	30.960	.000	.000	.000	-3.462	.000	-6.762	38.268
18	-3009.5	6.338	63.491	105.079	26.409	.000	.000	.000	-3.462	.000	-9.612	33.576
19	-2409.5	5.902	68.239	116.376	21.761	.000	.000	.000	-3.462	.000	-11.982	29.222
20	-1809.5	5.540	72.112	135.274	17.888	.000	.000	.000	-3.462	.000	-14.124	22.175
21	-1209.5	5.292	73.376	163.158	16.624	.000	.000	.000	-3.462	.000	-16.844	15.420
22	-609.5	5.149	70.521	190.772	19.479	.000	.000	.000	-3.462	.000	-19.507	8.020
23	-9.5	5.129	64.529	209.288	25.471	.000	.000	.000	-3.462	.000	-21.949	.127
24	590.5	5.233	57.206	220.354	32.794	.000	.000	.000	-3.462	.000	-24.019	-8.019
25	1190.5	5.454	49.711	227.229	40.289	.000	.000	.000	-3.462	.000	-25.615	-16.126
26	1790.5	5.778	42.646	231.792	47.354	.000	.000	.000	-3.462	.000	-26.714	-23.910
27	2390.5	6.190	36.279	235.083	53.721	.000	.000	.000	-3.462	.000	-27.356	-31.151
28	2990.5	6.672	30.683	237.371	59.317	.000	.000	.000	-3.462	.000	-27.626	-37.720
29	3590.5	7.211	25.825	239.162	64.175	.000	.000	.000	-3.462	.000	-27.618	-43.876
30	4190.5	7.794	21.626	240.609	68.374	.000	.000	.000	-3.462	.000	-27.419	-48.740
31	4790.5	8.412	17.995	241.760	72.005	.000	.000	.000	-3.462	.000	-27.096	-53.269
32	5390.5	9.058	14.843	242.706	75.157	.000	.000	.000	-3.462	.000	-26.705	-57.237
33	5990.5	9.726	12.093	243.496	77.907	.000	.000	.000	-3.462	.000	-26.276	-60.717
34	6590.5	10.411	9.678	244.165	80.322	.000	.000	.000	-3.462	.000	-25.835	-63.781
35	7190.5	11.112	7.544	244.738	82.456	.000	.000	.000	-3.462	.000	-25.398	-66.490
36	7790.5	11.824	5.645	245.234	84.355	.000	.000	.000	-3.462	.000	-24.972	-68.897
37	8390.5	12.545	3.946	245.666	86.054	.000	.000	.000	-3.462	.000	-24.565	-71.048
38	8990.5	13.275	2.416	246.045	87.584	.000	.000	.000	-3.462	.000	-24.177	-72.979
39	9590.5	14.011	1.030	246.380	88.970	.000	.000	.000	-3.462	.000	-23.811	-74.723
40	10190.5	14.753	-.233	246.678	90.233	.000	.000	.000	-3.462	.000	-23.467	-76.306
41	10790.5	15.500	-1.388	246.944	91.388	.000	.000	.000	-3.462	.000	-23.143	-77.749
42	11390.5	16.252	-2.451	247.183	92.451	.005	.000	.000	-3.462	.000	-22.839	-79.071
43	11990.5	17.006	-3.434	247.398	93.434	.000	.000	.000	-3.462	.000	-22.555	-80.269
44	12590.5	17.764	-4.345	247.592	94.345	.050	.000	.000	-3.462	.000	-22.288	-81.413
45	13190.5	18.525	-5.194	247.768	95.194	.000	.000	.000	-3.462	.000	-22.037	-82.457
46	13790.5	19.288	-5.987	247.927	95.987	.000	.000	.000	-3.462	.000	-21.801	-83.429
47	14390.5	20.053	-6.732	248.073	96.732	.000	.000	.000	-3.462	.000	-21.580	-84.337
48	14990.5	20.820	-7.432	248.206	97.432	.000	.000	.000	-3.462	.000	-21.372	-85.189
49	15590.5	21.588	-8.093	248.327	98.093	.000	.000	.000	-3.462	.000	-21.176	-85.990
50	16190.5	22.358	-8.719	248.438	98.719	.000	.000	.000	-3.462	.000	-20.991	-86.745
51	16790.5	23.129	-9.314	248.540	99.314	.000	.000	.000	-3.462	.000	-20.816	-87.460
52	17390.5	23.902	-9.879	248.633	99.879	.000	.000	.000	-3.462	.000	-20.651	-88.137
53	17990.5	24.675	-10.418	248.718	100.418	.000	.000	.000	-3.462	.000	-20.495	-88.782
54	18590.5	25.450	-10.934	248.797	100.934	.000	.000	.000	-3.462	.000	-20.347	-89.396

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55	19190.5	26.225	-11.428	248.869	101.428	.000	.000	.000	-3.462	.000	-20.207	-89.982
56	19790.5	27.001	-11.902	248.936	101.902	.000	.000	.000	-3.462	.000	-20.074	-90.543
57	20390.5	27.778	-12.357	248.996	102.357	.000	.000	.000	-3.462	.000	-19.947	-91.080
58	20990.5	28.556	-12.796	249.052	102.796	.000	.000	.000	-3.462	.000	-19.826	-91.597
59	21590.5	29.334	-13.220	249.104	103.220	.000	.000	.000	-3.462	.000	-19.711	-92.094
60	22190.5	30.112	-13.629	249.151	103.629	.000	.000	.000	-3.462	.000	-19.602	-92.573
61	22790.5	30.891	-14.025	249.194	104.025	.000	.000	.000	-3.462	.000	-19.497	-93.035

GPR

1:1 res. $r_{orbt} = 20 R_T$

I	TIME	PROBE R/RC	PROBE LATITUDE	PROBE LONGITUDE	ORBITER R/RC	ORBITER LATITUDE	ORBITER LONGITUDE	PROBE PHASE	CANOPUS FROM ORBITER ELEV.ANG.	CANOPUS FROM ORBITER AZIMUTH	CAN SEE CANOPUS?
1	-7200.0	10.589	15.414	198.628	27.816	5.602	181.487	42.147	-8.502	221.506	YES
2	-6600.0	9.779	15.333	197.967	27.131	5.264	180.668	41.654	-7.812	221.482	YES
3	-6000.0	8.967	15.235	197.215	26.450	4.908	179.816	41.072	-7.087	221.458	YES
4	-5400.0	8.155	15.115	196.345	25.775	4.532	178.929	40.375	-6.323	221.432	YES
5	-4800.0	7.343	14.967	195.319	25.105	4.135	178.002	39.523	-5.518	221.407	YES
6	-4200.0	6.530	14.776	194.079	24.440	3.716	177.035	38.459	-4.669	221.381	YES
7	-3600.0	5.717	14.524	192.532	23.782	3.273	176.024	37.093	-3.773	221.354	YES
8	-3000.0	4.904	14.176	190.530	23.131	2.804	174.965	35.274	-2.826	221.327	YES
9	-2400.0	4.092	13.667	187.805	22.487	2.307	173.854	32.733	-1.824	221.301	YES
10	-1800.0	3.285	12.857	183.834	21.851	1.781	172.689	28.941	-.763	221.274	YES
11	-1200.0	2.488	11.407	177.455	21.224	1.222	171.464	22.703	.361	221.247	YES
12	-600.0	1.726	8.294	165.593	20.607	.630	170.176	10.837	1.553	221.221	YES
13	.0	1.097	.000	138.617	20.001	.001	168.818	17.184	2.817	221.196	YES
14	600.0	1.000	-3.462	128.062	19.406	-.668	167.386	28.292	4.160	221.172	YES
15	1200.0	1.000	-3.462	128.062	18.823	-1.377	165.873	28.146	5.586	221.149	YES
16	1800.0	1.000	-3.462	128.062	18.255	-2.131	164.275	28.001	7.102	221.127	YES
17	2400.0	1.000	-3.462	128.062	17.701	-2.930	162.583	27.856	8.713	221.108	YES
18	3000.0	1.000	-3.462	128.062	17.165	-3.778	160.791	27.711	10.425	221.090	YES
19	3600.0	1.000	-3.462	128.062	16.647	-4.677	158.893	27.566	12.244	221.074	YES
20	4200.0	1.000	-3.462	128.062	16.149	-5.627	156.879	27.421	14.175	221.060	YES
21	4800.0	1.000	-3.462	128.062	15.673	-6.630	154.744	27.276	16.223	221.048	YES
22	5400.0	1.000	-3.462	128.062	15.221	-7.686	152.479	27.131	18.393	221.035	YES
23	6000.0	1.000	-3.462	128.062	14.796	-8.793	150.078	26.987	20.686	221.019	YES
24	6600.0	1.000	-3.462	128.062	14.399	-9.948	147.534	26.842	23.104	220.998	YES
25	7200.0	1.000	-3.462	128.062	14.034	-11.149	144.842	26.698	25.644	220.966	YES
26	7800.0	1.000	-3.462	128.062	13.702	-12.386	141.998	26.554	28.302	220.916	YES
27	8400.0	1.000	-3.462	128.062	13.407	-13.653	139.002	26.410	31.071	220.836	YES
28	9000.0	1.000	-3.462	128.062	13.150	-14.938	135.853	26.266	33.938	220.710	YES
29	9600.0	1.000	-3.462	128.062	12.935	-16.229	132.559	26.123	36.885	220.519	YES
30	10200.0	1.000	-3.462	128.062	12.762	-17.511	129.126	25.979	39.893	220.235	YES
31	10800.0	1.000	-3.462	128.062	12.635	-18.766	125.568	25.836	42.933	219.822	YES
32	11400.0	1.000	-3.462	128.062	12.553	-19.978	121.902	25.693	45.975	219.238	YES
33	12000.0	1.000	-3.462	128.062	12.519	-21.131	118.150	25.549	48.984	218.428	YES
34	12600.0	1.000	-3.462	128.062	12.533	-22.208	114.338	25.407	51.921	217.331	YES
35	13200.0	1.000	-3.462	128.062	12.594	-23.196	110.494	25.264	54.744	215.877	YES
36	13800.0	1.000	-3.462	128.062	12.701	-24.086	106.647	25.121	57.410	213.993	YES
37	14400.0	1.000	-3.462	128.062	12.854	-24.871	102.828	24.979	59.877	211.608	YES
38	15000.0	1.000	-3.462	128.062	13.052	-25.549	99.065	24.836	62.103	208.667	YES
39	15600.0	1.000	-3.462	128.062	13.291	-26.119	95.384	24.694	64.049	205.138	YES
40	16200.0	1.000	-3.462	128.062	13.569	-26.585	91.807	24.552	65.682	201.034	YES
41	16800.0	1.000	-3.462	128.062	13.886	-26.955	88.353	24.411	66.979	196.426	YES
42	17400.0	1.000	-3.462	128.062	14.237	-27.236	85.036	24.269	67.930	191.446	YES
43	18000.0	1.000	-3.462	128.062	14.620	-27.436	81.864	24.128	68.542	186.276	YES
44	18600.0	1.000	-3.462	128.062	15.033	-27.566	78.844	23.987	68.836	181.118	YES
45	19200.0	1.000	-3.462	128.062	15.474	-27.635	75.977	23.846	68.848	176.162	YES
46	19800.0	1.000	-3.462	128.062	15.939	-27.651	73.263	23.705	68.621	171.553	YES
47	20400.0	1.000	-3.462	128.062	16.428	-27.624	70.697	23.564	68.204	167.378	YES
48	21000.0	1.000	-3.462	128.062	16.938	-27.560	68.275	23.424	67.640	163.672	YES
49	21600.0	1.000	-3.462	128.062	17.467	-27.466	65.991	23.284	66.969	160.431	YES
50	22200.0	1.000	-3.462	128.062	18.013	-27.349	63.838	23.144	66.224	157.622	YES
51	22800.0	1.000	-3.462	128.062	18.575	-27.213	61.808	23.004	65.433	155.203	YES
52	23400.0	1.000	-3.462	128.062	19.151	-27.062	59.894	22.864	64.616	153.123	YES
53	24000.0	1.000	-3.462	128.062	19.741	-26.901	58.089	22.725	63.788	151.337	YES
54	24600.0	1.000	-3.462	128.062	20.343	-26.731	56.384	22.586	62.961	149.802	YES

ORIGINAL PAGE IS OF POOR QUALITY

55	25200.0	1.000	-3.462	128.062	20.956	-26.556	54.774	22.447	62.145	148.480	YES
56	25800.0	1.000	-3.462	128.062	21.578	-26.377	53.252	22.308	61.343	147.337	YES
57	26400.0	1.000	-3.462	128.062	22.210	-26.197	51.810	22.170	60.562	146.347	YES
58	27000.0	1.000	-3.462	128.062	22.851	-26.016	50.444	22.031	59.804	145.487	YES
59	27600.0	1.000	-3.462	128.062	23.499	-25.836	49.147	21.893	59.070	144.736	YES
60	28200.0	1.000	-3.462	128.062	24.154	-25.658	47.916	21.756	58.361	144.078	YES
61	28800.0	1.000	-3.462	128.062	24.816	-25.481	46.749	21.618	57.678	143.500	YES

I	RELATIVE TIME	PROBE-ORBITER GEOMETRY RANGE	ELEV.ANG.	AZIMUTH	ASPECT ANGLE	REL.VEL.	PROBE F.P.A.	F.P.AZ.	PROBE LAT.	REL.LONG.	ORBITER LAT.	REL.LONG.
1	-19330.1	18.179	59.316	241.588	36.334	3.977	-82.147	262.897	15.414	70.566	5.602	64.159
2	-18730.1	18.230	59.802	241.179	36.306	3.983	-81.816	262.523	15.333	69.905	5.264	63.340
3	-18130.1	18.281	60.372	240.685	36.274	3.989	-81.398	262.125	15.235	69.153	4.908	62.468
4	-17530.1	18.334	61.053	240.075	36.235	3.998	-80.869	261.699	15.115	68.284	4.532	61.601
5	-16930.1	18.389	61.878	239.304	36.188	4.008	-80.191	261.238	14.967	67.257	4.135	60.675
6	-16330.1	18.445	62.903	238.297	36.130	4.021	-79.309	260.732	14.776	66.017	3.716	59.707
7	-15730.1	18.504	64.206	236.921	36.055	4.038	-78.138	260.163	14.524	64.470	3.273	58.696
8	-15130.1	18.567	65.921	234.922	35.953	4.060	-76.537	259.502	14.176	62.468	2.804	57.637
9	-14530.1	18.634	68.270	231.736	35.804	4.091	-74.255	258.698	13.667	59.743	2.307	56.527
10	-13930.1	18.709	71.652	225.794	35.564	4.137	-70.805	257.657	12.857	55.772	1.781	55.361
11	-13330.1	18.795	76.656	210.700	35.116	4.210	-65.107	256.207	11.407	49.393	1.222	54.136
12	-12730.1	18.904	80.268	148.794	34.072	4.340	-54.331	254.085	8.294	37.532	.630	52.848
13	-12130.1	19.058	58.349	89.999	30.850	4.573	-30.000	252.043	.000	10.755	.001	51.490
14	-11530.1	18.643	48.657	86.831	41.343	.000	.000	.000	-3.462	.000	-.668	50.058
15	-10930.1	18.044	50.220	87.785	39.760	.000	.000	.000	-3.462	.000	-1.377	48.545
16	-10330.1	17.456	51.870	88.876	38.130	.000	.000	.000	-3.462	.000	-2.131	46.947
17	-9730.1	16.886	53.610	90.135	36.390	.000	.000	.000	-3.462	.000	-2.930	45.255
18	-9130.1	16.332	55.442	91.602	34.558	.000	.000	.000	-3.462	.000	-3.778	43.463
19	-8530.1	15.796	57.369	93.328	32.631	.000	.000	.000	-3.462	.000	-4.677	41.565
20	-7930.1	15.280	59.388	95.386	30.612	.000	.000	.000	-3.462	.000	-5.627	39.551
21	-7330.1	14.787	61.493	97.870	28.507	.000	.000	.000	-3.462	.000	-6.630	37.416
22	-6730.1	14.318	63.671	100.915	26.329	.000	.000	.000	-3.462	.000	-7.686	35.151
23	-6130.1	13.877	65.898	104.709	24.102	.000	.000	.000	-3.462	.000	-8.793	32.750
24	-5530.1	13.466	68.132	109.515	21.868	.000	.000	.000	-3.462	.000	-9.948	30.206
25	-4930.1	13.088	70.304	115.691	19.696	.000	.000	.000	-3.462	.000	-11.148	27.514
26	-4330.1	12.746	72.305	123.695	17.695	.000	.000	.000	-3.462	.000	-12.386	24.670
27	-3730.1	12.443	73.969	133.985	16.031	.000	.000	.000	-3.462	.000	-13.653	21.674
28	-3130.1	12.181	75.070	146.711	14.930	.000	.000	.000	-3.462	.000	-14.938	18.526
29	-2530.1	11.965	75.370	161.203	14.630	.000	.000	.000	-3.462	.000	-16.229	15.231
30	-1930.1	11.795	74.731	176.629	15.269	.000	.000	.000	-3.462	.000	-17.511	11.798
31	-1330.1	11.679	73.192	183.872	16.808	.000	.000	.000	-3.462	.000	-18.766	8.240
32	-730.1	11.604	70.934	199.511	19.066	.000	.000	.000	-3.462	.000	-19.978	4.574
33	-130.1	11.585	68.171	207.814	21.829	.000	.000	.000	-3.462	.000	-21.131	.822
34	469.9	11.619	65.084	214.219	24.916	.000	.000	.000	-3.462	.000	-22.208	-2.990
35	1069.9	11.703	61.809	219.194	28.191	.000	.000	.000	-3.462	.000	-23.196	-6.834
36	1669.9	11.838	58.448	223.113	31.552	.000	.000	.000	-3.462	.000	-24.086	-10.661
37	2269.9	12.022	55.074	226.250	34.926	.000	.000	.000	-3.462	.000	-24.871	-14.500
38	2869.9	12.252	51.742	228.804	38.258	.000	.000	.000	-3.462	.000	-25.549	-18.263
39	3469.9	12.525	48.491	230.914	41.509	.000	.000	.000	-3.462	.000	-26.119	-21.944
40	4069.9	12.840	45.349	232.680	44.651	.000	.000	.000	-3.462	.000	-26.585	-25.521
41	4669.9	13.193	42.334	234.178	47.666	.000	.000	.000	-3.462	.000	-26.955	-28.975
42	5269.9	13.580	39.458	235.462	50.542	.000	.000	.000	-3.462	.000	-27.236	-32.292
43	5869.9	14.000	36.726	236.572	53.274	.000	.000	.000	-3.462	.000	-27.436	-35.464
44	6469.9	14.449	34.140	237.541	55.860	.000	.000	.000	-3.462	.000	-27.566	-38.484
45	7069.9	14.925	31.697	238.392	58.303	.000	.000	.000	-3.462	.000	-27.635	-41.351
46	7669.9	15.425	29.394	239.146	60.606	.000	.000	.000	-3.462	.000	-27.651	-44.065
47	8269.9	15.947	27.225	239.817	62.775	.000	.000	.000	-3.462	.000	-27.624	-46.631
48	8869.9	16.488	25.182	240.418	64.818	.000	.000	.000	-3.462	.000	-27.560	-49.053
49	9469.9	17.047	23.260	240.958	66.740	.000	.000	.000	-3.462	.000	-27.466	-51.337
50	10069.9	17.623	21.450	241.447	68.550	.000	.000	.000	-3.462	.000	-27.349	-53.490
51	10669.9	18.213	19.744	241.890	70.256	.000	.000	.000	-3.462	.000	-27.213	-55.520
52	11269.9	18.816	18.136	242.293	71.864	.000	.000	.000	-3.462	.000	-27.062	-57.434
53	11869.9	19.432	16.618	242.661	73.382	.000	.000	.000	-3.462	.000	-26.901	-59.239
54	12469.9	20.056	15.185	242.999	74.815	.000	.000	.000	-3.462	.000	-26.731	-60.943

SUK..

55	13069.9	20.694	13.829	243.309	76.171	.000	.000	.000	-3.462	.000	-26.556	-62.554
56	13669.9	21.339	12.545	243.594	77.455	.000	.000	.000	-3.462	.000	-26.377	-64.076
57	14269.9	21.992	11.328	243.858	78.672	.000	.000	.000	-3.462	.000	-26.197	-65.518
58	14869.9	22.653	10.172	244.102	79.828	.000	.000	.000	-3.462	.000	-26.016	-66.864
59	15469.9	23.320	9.073	244.328	80.927	.000	.000	.000	-3.462	.000	-25.836	-68.181
60	16069.9	23.994	8.028	244.538	81.972	.000	.000	.000	-3.462	.000	-25.658	-69.412
61	16669.9	24.673	7.031	244.733	82.969	.000	.000	.000	-3.462	.000	-25.491	-70.584

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I	TIME	PROBE R/RC	PROBE LATITUDE	PROBE LONGITUDE	ORBITER R/RC	ORBITER LATITUDE	ORBITER LONGITUDE	PROBE PHASE	CANOPUS FROM ORBITER ELEV.ANG.	CANOPUS FROM ORBITER AZIMUTH	CAN SEE CANOPUS?
1	-7200.0	10.583	18.288	181.894	18.438	10.058	170.675	27.584	-4.758	221.309	YES
2	-6600.0	9.773	18.190	181.228	17.696	9.605	169.757	27.097	-3.921	221.199	YES
3	-6000.0	8.762	18.073	180.470	16.957	9.110	168.774	26.522	-3.012	221.082	YES
4	-5400.0	8.151	17.930	179.594	16.224	8.568	167.718	25.833	-2.020	220.958	YES
5	-4800.0	7.339	17.751	178.561	15.496	7.972	166.581	24.993	-.935	220.826	YES
6	-4200.0	6.527	17.523	177.312	14.774	7.315	165.351	23.944	.257	220.685	YES
7	-3600.0	5.714	17.222	175.757	14.059	6.588	164.014	22.600	1.571	220.536	YES
8	-3000.0	4.902	16.805	173.745	13.352	5.781	162.557	20.614	3.025	220.377	YES
9	-2400.0	4.091	16.196	171.010	12.656	4.881	160.959	18.332	4.639	220.209	YES
10	-1800.0	3.263	15.229	167.034	11.970	3.873	159.199	14.663	6.440	220.031	YES
11	-1200.0	2.487	13.601	160.671	11.299	2.740	157.251	8.866	8.456	219.844	YES
12	-600.0	1.726	9.603	148.914	10.643	1.463	155.084	6.928	10.723	219.647	YES
13	.0	1.097	-.000	122.630	10.008	.019	152.660	32.185	13.280	219.441	YES
14	600.0	1.000	-4.089	112.094	9.396	-1.617	149.934	43.245	16.173	219.227	YES
15	1200.0	1.000	-4.089	112.094	8.812	-3.470	146.855	43.094	19.453	219.005	YES
16	1800.0	1.000	-4.089	112.094	8.264	-5.567	143.360	42.943	23.174	218.770	YES
17	2400.0	1.000	-4.089	112.094	7.758	-7.926	139.381	42.792	27.386	218.515	YES
18	3000.0	1.000	-4.089	112.094	7.303	-10.553	134.845	42.641	32.129	218.211	YES
19	3600.0	1.000	-4.089	112.094	6.910	-13.429	129.680	42.490	37.412	217.800	YES
20	4200.0	1.000	-4.089	112.094	6.590	-16.499	123.830	42.339	43.194	217.150	YES
21	4800.0	1.000	-4.089	112.094	6.354	-19.657	117.276	42.188	49.355	215.992	YES
22	5400.0	1.000	-4.089	112.094	6.211	-22.751	110.059	42.038	55.663	213.807	YES
23	6000.0	1.000	-4.089	112.094	6.169	-25.598	102.306	41.887	61.741	209.674	YES
24	6600.0	1.000	-4.089	112.094	6.229	-28.029	94.234	41.736	67.040	202.177	YES
25	7200.0	1.000	-4.089	112.094	6.389	-29.928	86.124	41.586	70.829	189.969	YES
26	7800.0	1.000	-4.089	112.094	6.641	-31.261	78.265	41.435	72.412	173.969	YES
27	8400.0	1.000	-4.089	112.094	6.975	-32.070	70.895	41.285	71.732	158.628	YES
28	9000.0	1.000	-4.089	112.094	7.379	-32.443	64.166	41.134	69.529	147.514	YES
29	9600.0	1.000	-4.089	112.094	7.844	-32.488	58.141	40.984	66.648	140.617	YES
30	10200.0	1.000	-4.089	112.094	8.358	-32.301	52.814	40.833	63.614	136.583	YES
31	10800.0	1.000	-4.089	112.094	8.913	-31.963	48.134	40.683	60.683	134.272	YES
32	11400.0	1.000	-4.089	112.094	9.502	-31.534	44.034	40.533	57.958	132.969	YES
33	12000.0	1.000	-4.089	112.094	10.119	-31.057	40.437	40.382	55.471	132.259	YES
34	12600.0	1.000	-4.089	112.094	10.758	-30.561	37.273	40.232	53.221	131.899	YES
35	13200.0	1.000	-4.089	112.094	11.417	-30.064	34.478	40.082	51.193	131.750	YES
36	13800.0	1.000	-4.089	112.094	12.091	-29.578	31.997	39.932	49.366	131.727	YES
37	14400.0	1.000	-4.089	112.094	12.778	-29.109	29.784	39.782	47.715	131.779	YES
38	15000.0	1.000	-4.089	112.094	13.477	-28.663	27.799	39.632	46.224	131.875	YES
39	15600.0	1.000	-4.089	112.094	14.185	-28.240	26.008	39.482	44.873	131.995	YES
40	16200.0	1.000	-4.089	112.094	14.901	-27.840	24.385	39.332	43.645	132.129	YES
41	16800.0	1.000	-4.089	112.094	15.624	-27.465	22.907	39.182	42.525	132.267	YES
42	17400.0	1.000	-4.089	112.094	16.353	-27.111	21.554	39.032	41.502	132.406	YES
43	18000.0	1.000	-4.089	112.094	17.088	-26.780	20.310	38.863	40.563	132.542	YES
44	18600.0	1.000	-4.089	112.094	17.827	-26.468	19.162	38.733	39.699	132.674	YES
45	19200.0	1.000	-4.089	112.094	18.570	-26.175	18.098	38.583	38.903	132.800	YES
46	19800.0	1.000	-4.089	112.094	19.316	-25.900	17.107	38.434	38.167	132.921	YES
47	20400.0	1.000	-4.089	112.094	20.066	-25.641	16.183	38.284	37.485	133.036	YES
48	21000.0	1.000	-4.089	112.094	20.818	-25.397	15.316	38.134	36.850	133.145	YES
49	21600.0	1.000	-4.089	112.094	21.573	-25.167	14.502	37.985	36.260	133.248	YES
50	22200.0	1.000	-4.089	112.094	22.330	-24.950	13.735	37.836	35.708	133.346	YES
51	22800.0	1.000	-4.089	112.094	23.089	-24.746	13.010	37.686	35.193	133.439	YES
52	23400.0	1.000	-4.089	112.094	23.850	-24.552	12.322	37.537	34.710	133.526	YES
53	24000.0	1.000	-4.089	112.094	24.612	-24.368	11.669	37.388	34.256	133.609	YES
54	24600.0	1.000	-4.089	112.094	25.376	-24.194	11.047	37.239	33.829	133.688	YES

55	25200.0	1.000	-4.089	112.094	26.141	-24.029	10.454	37.090	33.427	133.762	YES
56	25600.0	1.000	-4.089	112.094	26.907	-23.873	9.886	36.941	33.047	133.833	YES
57	26400.0	1.000	-4.089	112.094	27.675	-23.724	9.342	36.792	32.689	133.900	YES
58	27000.0	1.000	-4.089	112.094	28.443	-23.582	8.820	36.643	32.349	133.964	YES
59	27600.0	1.000	-4.089	112.094	29.212	-23.447	8.318	36.494	32.027	134.024	YES
60	28200.0	1.000	-4.089	112.094	29.983	-23.316	7.834	36.345	31.722	134.082	YES
61	28600.0	1.000	-4.089	112.094	30.754	-23.194	7.367	36.196	31.431	134.137	YES

I	RELATIVE TIME	PROBE-ORBITER GEOMETRY RANGE	ELEV.ANG.	AZIMUTH	ASPECT ANGLE	REL.VEL.	PROBE F.P.A.	F.P.AZ.	PROBE LAT.	REL.LONG.	ORBITER LAT.	REL.LONG.
1	-13146.9	8.525	59.362	234.382	34.121	3.974	-82.180	261.434	18.288	69.800	10.658	67.667
2	-12546.9	8.551	59.841	233.873	36.082	3.980	-81.846	260.968	18.190	69.134	9.605	66.748
3	-11946.9	8.577	60.403	233.258	36.037	3.987	-81.425	260.514	18.073	68.376	9.110	65.765
4	-11346.9	8.604	61.073	232.500	35.983	3.995	-80.892	260.007	17.930	67.501	8.568	64.710
5	-10746.9	8.632	61.863	231.541	35.920	4.005	-80.211	259.460	17.751	66.467	7.972	63.573
6	-10146.9	8.662	62.885	230.288	35.842	4.018	-79.326	258.859	17.523	65.218	7.315	62.342
7	-9546.9	8.694	64.153	228.578	35.743	4.035	-78.152	258.184	17.222	63.661	6.588	61.006
8	-8946.9	8.729	65.809	226.102	35.612	4.058	-76.547	257.400	16.805	61.651	5.781	59.546
9	-8346.9	8.769	68.050	222.176	35.429	4.089	-74.261	256.447	16.196	58.914	4.881	57.950
10	-7746.9	8.815	71.202	214.971	35.148	4.134	-70.806	255.217	15.229	54.941	3.873	56.191
11	-7146.9	8.873	75.578	197.737	34.653	4.207	-65.104	253.509	13.501	48.577	2.790	54.293
12	-6546.9	8.951	77.661	143.286	33.565	4.337	-54.324	251.025	9.803	36.621	1.463	52.076
13	-5946.9	9.074	56.500	89.962	30.377	4.571	-30.000	248.654	-.000	10.536	.019	49.652
14	-5346.9	8.628	48.050	87.371	41.950	.000	.000	.000	-4.089	.000	-1.617	46.926
15	-4746.9	8.010	51.238	90.191	38.762	.000	.000	.000	-4.089	.000	-3.470	43.846
16	-4146.9	7.427	54.815	93.997	35.185	.000	.000	.000	-4.089	.000	-5.567	40.352
17	-3546.9	6.885	58.768	99.351	31.232	.000	.000	.000	-4.089	.000	-7.926	36.373
18	-2946.9	6.398	62.974	107.247	27.026	.000	.000	.000	-4.089	.000	-10.553	31.837
19	-2346.9	5.978	67.054	119.392	22.946	.000	.000	.000	-4.089	.000	-13.429	26.671
20	-1746.9	5.641	70.106	137.964	19.894	.000	.000	.000	-4.089	.000	-16.499	20.822
21	-1146.9	5.401	70.642	162.432	19.358	.000	.000	.000	-4.089	.000	-19.657	14.267
22	-546.9	5.274	67.738	185.843	22.262	.000	.000	.000	-4.089	.000	-22.751	7.050
23	53.1	5.267	62.193	202.641	27.807	.000	.000	.000	-4.089	.000	-25.698	-.703
24	653.1	5.380	55.409	213.513	34.591	.000	.000	.000	-4.089	.000	-28.029	-8.775
25	1253.1	5.606	48.399	220.645	41.601	.000	.000	.000	-4.089	.000	-29.928	-16.885
26	1853.1	5.933	41.732	225.542	48.268	.000	.000	.000	-4.089	.000	-31.261	-24.744
27	2453.1	6.344	35.676	229.063	54.324	.000	.000	.000	-4.089	.000	-32.070	-32.114
28	3053.1	6.824	30.317	231.698	59.683	.000	.000	.000	-4.089	.000	-32.443	-38.842
29	3653.1	7.359	25.636	233.734	64.364	.000	.000	.000	-4.089	.000	-32.488	-44.867
30	4253.1	7.939	21.568	235.350	68.432	.000	.000	.000	-4.089	.000	-32.301	-50.194
31	4853.1	8.553	18.034	236.661	71.966	.000	.000	.000	-4.089	.000	-31.963	-54.874
32	5453.1	9.195	14.954	237.743	75.046	.000	.000	.000	-4.089	.000	-31.534	-58.975
33	6053.1	9.859	12.258	238.650	77.742	.000	.000	.000	-4.089	.000	-31.057	-62.572
34	6653.1	10.541	9.884	239.420	80.116	.000	.000	.000	-4.089	.000	-30.561	-65.736
35	7253.1	11.238	7.781	240.081	82.219	.000	.000	.000	-4.089	.000	-30.064	-68.531
36	7853.1	11.947	5.907	240.654	84.093	.000	.000	.000	-4.089	.000	-29.578	-71.011
37	8453.1	12.665	4.226	241.154	85.774	.000	.000	.000	-4.089	.000	-29.109	-73.224
38	9053.1	13.392	2.711	241.594	87.289	.000	.000	.000	-4.089	.000	-28.663	-75.210
39	9653.1	14.126	1.337	241.983	88.663	.000	.000	.000	-4.089	.000	-28.240	-77.000
40	10253.1	14.866	.084	242.329	89.916	.000	.000	.000	-4.089	.000	-27.840	-78.623
41	10853.1	15.611	-1.064	242.639	91.064	.000	.000	.000	-4.089	.000	-27.465	-80.101
42	11453.1	16.360	-2.120	242.914	92.120	.000	.000	.000	-4.089	.000	-27.111	-81.454
43	12053.1	17.113	-3.097	243.167	93.097	.000	.000	.000	-4.089	.000	-26.780	-82.698
44	12653.1	17.869	-4.004	243.393	94.004	.000	.000	.000	-4.089	.000	-26.468	-83.846
45	13253.1	18.627	-4.848	243.598	94.848	.000	.000	.000	-4.089	.000	-26.175	-84.911
46	13853.1	19.389	-5.636	243.784	95.636	.000	.000	.000	-4.089	.000	-25.900	-85.901
47	14453.1	20.152	-6.379	243.954	96.379	.000	.000	.000	-4.089	.000	-25.641	-86.826
48	15053.1	20.918	-7.077	244.109	97.077	.000	.000	.000	-4.089	.000	-25.397	-87.692
49	15653.1	21.686	-7.735	244.251	97.735	.000	.000	.000	-4.089	.000	-25.167	-88.506
50	16253.1	22.453	-8.359	244.381	98.359	.000	.000	.000	-4.089	.000	-24.950	-89.273
51	16853.1	23.223	-8.950	244.500	98.950	.000	.000	.000	-4.089	.000	-24.746	-89.999
52	17453.1	23.994	-9.513	244.609	99.513	.000	.000	.000	-4.089	.000	-24.552	-90.686
53	18053.1	24.767	-10.050	244.709	100.050	.000	.000	.000	-4.089	.000	-24.368	-91.334
54	18653.1	25.540	-10.564	244.801	100.564	.000	.000	.000	-4.089	.000	-24.194	-91.961

55	19253.1	26.314	-11.055	244.886	101.055	.000	.000	.000	-4.089	.000	-24.029	-92.555
56	19653.1	27.089	-11.527	244.963	101.527	.000	.000	.000	-4.089	.000	-23.873	-93.122
57	20453.1	27.865	-11.980	245.035	101.980	.000	.000	.000	-4.089	.000	-23.724	-93.666
58	21353.1	28.641	-12.417	245.101	102.417	.000	.000	.000	-4.089	.000	-23.582	-94.188
59	21553.1	29.418	-12.836	245.161	102.838	.000	.000	.000	-4.049	.000	-23.447	-94.691
60	22253.1	30.196	-13.246	245.216	103.246	.000	.000	.000	-4.087	.000	-23.318	-95.175
61	22853.1	30.974	-13.639	245.267	103.639	.000	.000	.000	-4.089	.000	-23.194	-95.641

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I.	TIME	PROBE R/RC	PROBE LATITUDE	PROBE LONGITUDE	ORBITER R/RC	ORBITER LATITUDE	ORBITER LONGITUDE	PROBE PHASE	CANOPUS FROM ORBITER ELEV.ANG.	CANOPUS FROM ORBITER AZIMUTH	CAN SEE CANOPUS?
1	-7200.0	10.583	18.288	181.694	27.751	6.631	165.023	27.584	1.495	220.546	YES
2	-6600.0	9.773	19.190	181.228	27.070	6.230	164.219	27.097	2.217	220.465	YES
3	-6000.0	8.962	18.073	180.470	26.394	5.808	163.383	26.522	2.977	220.382	YES
4	-5400.0	8.151	17.930	179.594	25.723	5.362	162.512	25.833	3.777	220.298	YES
5	-4800.0	7.339	17.751	178.561	25.057	4.892	161.604	24.993	4.619	220.211	YES
6	-4200.0	6.527	17.523	177.312	24.398	4.396	160.657	23.944	5.506	220.122	YES
7	-3600.0	5.714	17.222	175.757	23.745	3.871	159.667	22.600	6.443	220.031	YES
8	-3000.0	4.902	16.805	173.745	23.100	3.216	158.631	20.814	7.432	219.938	YES
9	-2400.0	4.091	16.196	171.010	22.462	2.728	157.546	18.332	8.477	219.842	YES
10	-1800.0	3.283	15.229	167.034	21.832	2.106	156.408	14.663	9.583	219.744	YES
11	-1200.0	2.487	13.501	160.671	21.212	1.446	155.219	8.866	10.753	219.644	YES
12	-600.0	1.726	9.803	148.914	20.602	.746	153.958	5.928	11.993	219.543	YES
13	.0	1.097	-.000	122.630	20.003	.004	152.635	32.185	13.307	219.439	YES
14	600.0	1.000	-4.089	112.094	19.416	-.784	151.242	43.245	14.701	219.334	YES
15	1200.0	1.000	-4.089	112.094	18.842	-1.620	149.772	43.094	16.179	219.227	YES
16	1800.0	1.000	-4.089	112.094	18.282	-2.507	148.219	42.943	17.748	219.118	YES
17	2400.0	1.000	-4.089	112.094	17.738	-3.447	146.577	42.792	19.413	219.007	YES
18	3000.0	1.000	-4.089	112.094	17.212	-4.444	144.840	42.641	21.179	218.894	YES
19	3600.0	1.000	-4.089	112.094	16.704	-5.498	143.000	42.490	23.052	218.778	YES
20	4200.0	1.000	-4.089	112.094	16.217	-6.612	141.050	42.339	25.036	218.657	YES
21	4800.0	1.000	-4.089	112.094	15.753	-7.786	138.983	42.188	27.136	218.530	YES
22	5400.0	1.000	-4.089	112.094	15.314	-9.020	136.792	42.038	29.354	218.393	YES
23	6000.0	1.000	-4.089	112.094	14.901	-10.312	134.469	41.887	31.692	218.241	YES
24	6600.0	1.000	-4.089	112.094	14.518	-11.660	132.008	41.736	34.148	218.067	YES
25	7200.0	1.000	-4.089	112.094	14.166	-13.057	129.403	41.586	36.721	217.861	YES
26	7800.0	1.000	-4.089	112.094	13.849	-14.497	126.651	41.435	39.403	217.608	YES
27	8400.0	1.000	-4.089	112.094	13.568	-15.969	123.747	41.285	42.183	217.286	YES
28	9000.0	1.000	-4.089	112.094	13.326	-17.462	120.693	41.134	45.047	216.867	YES
29	9600.0	1.000	-4.089	112.094	13.124	-18.961	117.491	40.984	47.975	216.312	YES
30	10200.0	1.000	-4.089	112.094	12.966	-20.448	114.149	40.833	50.940	215.567	YES
31	10800.0	1.000	-4.089	112.094	12.852	-21.906	110.675	40.683	53.910	214.563	YES
32	11400.0	1.000	-4.089	112.094	12.784	-23.315	107.086	40.533	56.847	213.210	YES
33	12000.0	1.000	-4.089	112.094	12.762	-24.658	103.401	40.382	59.706	211.345	YES
34	12600.0	1.000	-4.089	112.094	12.787	-25.915	99.642	40.232	62.433	208.983	YES
35	13200.0	1.000	-4.089	112.094	12.858	-27.074	95.836	40.082	64.966	205.820	YES
36	13800.0	1.000	-4.089	112.094	12.975	-28.122	92.011	39.932	67.239	201.757	YES
37	14400.0 4	1.000	-4.089	112.094	13.136	-29.051	88.198	39.782	69.177	196.682	YES
38	15000.0	1.000	-4.089	112.094	13.340	-29.858	84.424	39.632	70.708	190.592	YES
39	15600.0	1.000	-4.089	112.094	13.585	-30.544	80.718	39.482	71.771	183.655	YES
40	16200.0	1.000	-4.089	112.094	13.858	-31.111	77.102	39.332	72.338	176.249	YES
41	16800.0	1.000	-4.089	112.094	14.188	-31.566	73.598	39.182	72.419	168.864	YES
42	17400.0	1.000	-4.089	112.094	14.542	-31.919	70.222	39.032	72.070	161.995	YES
43	18000.0 5	1.000	-4.089	112.094	14.927	-32.178	66.984	38.883	71.374	155.963	YES
44	18600.0	1.000	-4.089	112.094	15.342	-32.355	63.693	38.733	70.420	150.890	YES
45	19200.0	1.000	-4.089	112.094	15.783	-22.459	60.953	38.583	69.291	146.751	YES
46	19800.0	1.000	-4.089	112.094	16.248	-32.501	58.164	38.434	68.054	143.437	YES
47	20400.0	1.000	-4.089	112.094	16.737	-32.491	55.524	38.284	66.759	140.813	YES
48	21000.0	1.000	-4.089	112.094	17.246	-32.436	53.030	38.134	65.443	138.748	YES
49	21600.0 6	1.000	-4.089	112.094	17.773	-32.345	50.676	37.985	64.132	137.128	YES
50	22200.0	1.000	-4.089	112.094	18.318	-32.225	48.455	37.836	62.844	135.858	YES
51	22800.0	1.000	-4.089	112.094	18.879	-32.082	46.360	37.686	61.589	134.866	YES
52	23400.0	1.000	-4.089	112.094	19.453	-31.919	44.385	37.537	60.375	134.090	YES
53	24000.0	1.000	-4.089	112.094	20.041	-31.743	42.522	37.388	59.206	133.485	YES
54	24600.0	1.000	-4.039	112.094	20.641	-31.556	40.763	37.239	58.084	133.016	YES

55	25200.0	1.000	-4.089	112.094	21.252	-31.362	39.102	37.090	57.011	132.653	YES
56	25800.0	1.000	-4.089	112.094	21.873	-31.162	37.531	36.941	55.985	132.375	YES
57	26400.0	1.000	-4.089	112.094	22.503	-30.959	36.045	36.792	55.006	132.165	YES
58	27000.0	1.000	-4.089	112.094	23.141	-30.755	34.637	36.643	54.072	132.008	YES
59	27600.0	1.000	-4.089	112.094	23.787	-30.551	33.301	36.494	53.181	131.895	YES
60	28200.0	1.000	-4.089	112.094	24.441	-30.349	32.033	36.345	52.332	131.816	YES
61	28800.0	1.000	-4.089	112.094	25.100	-30.148	30.827	36.196	51.523	131.765	YES

I	RELATIVE TIME	PROBE-ORBITER GEOMETRY RANGE	ELEV.ANG.	AZIMUTH	ASPECT ANGLE	REL.VEL.	PROBE F.P.A.	F.P.AZ.	PROBE LAT.	REL.LONG.	ORBITER LAT.	REL.LONG.
1	-19180.5	18.185	58.283	236.799	37.282	3.974	-82.180	261.434	18.288	69.800	6.631	61.502
2	-18580.5	18.235	58.760	236.337	37.253	3.980	-81.896	260.988	18.190	69.134	6.230	60.698
3	-17980.5	18.287	59.320	285.780	37.220	3.987	-81.425	260.514	18.073	68.376	5.808	59.861
4	-17380.5	18.340	59.988	235.094	37.181	3.995	-80.892	260.007	17.930	67.501	5.362	58.990
5	-16780.5	18.394	60.798	234.230	37.134	4.005	-80.211	259.460	17.751	66.467	4.892	58.063
6	-16180.5	18.450	61.802	233.105	37.075	4.018	-79.326	258.859	17.523	65.218	4.396	57.135
7	-15580.5	18.509	63.078	231.577	36.999	4.035	-78.152	258.184	17.222	63.663	3.871	56.145
8	-14980.5	18.571	64.751	229.377	36.897	4.058	-76.547	257.400	16.805	61.651	3.316	55.109
9	-14380.5	18.639	67.035	225.917	36.747	4.089	-74.261	256.447	16.196	58.916	2.728	54.025
10	-13780.5	18.713	70.300	219.626	36.508	4.134	-70.806	255.217	15.229	54.941	2.106	52.887
11	-13180.5	18.799	75.058	204.587	36.062	4.207	-65.104	253.509	13.501	48.577	1.446	51.692
12	-12580.5	18.907	78.706	150.720	35.028	4.337	-54.324	251.025	9.803	36.821	.746	50.436
13	-11980.5	19.060	58.344	89.993	31.047	4.571	-30.000	246.654	-.000	10.536	.004	49.114
14	-11380.5	18.652	48.811	86.226	41.189	.000	.000	.000	-4.089	.000	-.784	47.720
15	-10780.5	18.061	50.352	87.356	39.646	.000	.000	.000	-4.089	.000	-1.620	46.250
16	-10180.5	17.464	51.972	88.647	38.028	.000	.000	.000	-4.089	.000	-2.507	44.697
17	-9580.5	16.923	53.674	90.133	36.326	.000	.000	.000	-4.089	.000	-3.447	43.056
18	-8980.5	16.379	55.457	91.857	34.543	.000	.000	.000	-4.089	.000	-4.444	41.318
19	-8380.5	15.854	57.321	93.879	32.679	.000	.000	.000	-4.089	.000	-5.498	39.478
20	-7780.5	15.350	59.258	96.274	30.742	.000	.000	.000	-4.089	.000	-6.612	37.529
21	-7180.5	14.869	61.259	99.143	28.741	.000	.000	.000	-4.089	.000	-7.786	35.462
22	-6580.5	14.414	63.302	102.620	26.698	.000	.000	.000	-4.089	.000	-9.020	33.270
23	-5980.5	13.987	65.355	106.885	24.645	.000	.000	.000	-4.089	.000	-10.312	30.947
24	-5380.5	13.590	67.368	112.169	22.632	.000	.000	.000	-4.089	.000	-11.660	28.486
25	-4780.5	13.227	69.262	118.752	20.738	.000	.000	.000	-4.089	.000	-13.057	25.882
26	-4180.5	12.900	70.927	126.924	19.073	.000	.000	.000	-4.089	.000	-14.497	23.129
27	-3580.5	12.612	72.208	136.866	17.792	.000	.000	.000	-4.089	.000	-15.969	20.225
28	-2980.5	12.366	72.932	148.423	17.068	.000	.000	.000	-4.089	.000	-17.462	17.171
29	-2380.5	12.165	72.941	160.902	17.059	.000	.000	.000	-4.089	.000	-18.961	13.970
30	-1780.5	12.010	72.166	173.198	17.834	.000	.000	.000	-4.089	.000	-20.446	10.627
31	-1180.5	11.904	70.653	184.292	19.347	.000	.000	.000	-4.089	.000	-21.906	7.154
32	-580.5	11.848	68.534	193.671	21.466	.000	.000	.000	-4.089	.000	-23.315	3.565
33	19.5	11.842	65.967	201.313	24.033	.000	.000	.000	-4.089	.000	-24.658	-.141
34	619.5	11.887	63.075	207.453	26.705	.000	.000	.000	-4.089	.000	-25.915	-3.880
35	1219.5	11.982	60.037	212.386	29.963	.000	.000	.000	-4.089	.000	-27.074	-7.686
36	1819.5	12.126	56.884	216.379	33.116	.000	.000	.000	-4.089	.000	-28.122	-11.511
37	2419.5	12.317	53.706	219.646	36.294	.000	.000	.000	-4.089	.000	-29.051	-15.324
38	3019.5	12.553	50.556	222.350	39.444	.000	.000	.000	-4.089	.000	-29.858	-19.098
39	3619.5	12.831	47.472	224.616	42.528	.000	.000	.000	-4.089	.000	-30.544	-22.804
40	4219.5	13.149	44.482	226.534	45.518	.000	.000	.000	-4.089	.000	-31.111	-26.420
41	4819.5	13.505	41.605	228.175	48.395	.000	.000	.000	-4.089	.000	-31.566	-29.924
42	5419.5	13.894	38.854	229.592	51.146	.000	.000	.000	-4.089	.000	-31.919	-33.300
43	6019.5	14.314	36.234	230.826	53.766	.000	.000	.000	-4.089	.000	-32.178	-36.538
44	6619.5	14.763	33.747	231.908	56.253	.000	.000	.000	-4.089	.000	-32.355	-39.628
45	7219.5	15.239	31.394	232.863	58.606	.000	.000	.000	-4.089	.000	-32.459	-42.568
46	7819.5	15.738	29.170	233.712	60.830	.000	.000	.000	-4.089	.000	-32.501	-45.357
47	8419.5	16.256	27.071	234.470	62.929	.000	.000	.000	-4.089	.000	-32.491	-47.997
48	9019.5	16.796	25.091	235.151	64.909	.000	.000	.000	-4.089	.000	-32.436	-50.492
49	9619.5	17.355	23.223	235.765	66.777	.000	.000	.000	-4.089	.000	-32.345	-52.846
50	10219.5	17.929	21.462	236.321	68.538	.000	.000	.000	-4.089	.000	-32.225	-55.067
51	10819.5	18.515	19.800	236.827	70.200	.000	.000	.000	-4.089	.000	-32.082	-57.161
52	11419.5	19.117	18.231	237.288	71.769	.000	.000	.000	-4.089	.000	-31.919	-59.136
53	12019.5	19.736	16.740	237.710	73.252	.000	.000	.000	-4.089	.000	-31.743	-61.000
54	12619.5	20.354	15.345	238.097	74.655	.000	.000	.000	-4.089	.000	-31.556	-62.759

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55	13219.5	20.988	14.017	238.453	75.983	.000	.000	.000	-4.089	.000	-31.362	-64.420
56	13819.5	21.630	12.758	238.782	77.242	.000	.000	.000	-4.089	.000	-31.162	-65.991
57	14419.5	22.261	11.562	239.085	78.438	.000	.000	.000	-4.089	.000	-30.959	-67.477
58	15019.5	22.939	10.427	239.366	79.573	.000	.000	.000	-4.089	.000	-30.755	-68.885
59	15619.5	23.604	9.347	239.627	80.653	.000	.000	.000	-4.089	.000	-30.551	-70.221
60	16219.5	24.276	8.317	239.869	81.683	.000	.000	.000	-4.089	.000	-30.349	-71.489
61	16819.5	24.953	7.336	240.094	82.664	.000	.000	.000	-4.089	.000	-30.148	-72.695

GPR.S

I	TIME (SECS.)	PROBE R/RP	PROBE LATITUDE	PROBE LONGITUDE	ORBITER R/RP	ORBITER LATITUDE	ORBITER LONGITUDE	PROBE PHASE	CANOPUS FROM ORBITER ELEV.ANG.	CANOPUS FROM ORBITER AZIMUTH	CAN SEE CANOPUS?	ORBITER ASPECT
1	-7200.0	10.623	19.142	182.148	27.396	7.041	142.364	29.789	14.002	215.782	YES	34.168
2	-6600.0	9.809	19.040	181.483	26.657	6.582	141.029	29.303	15.057	215.465	YES	34.141
3	-6000.0	8.995	18.917	180.726	26.331	6.102	139.649	28.729	16.152	215.130	YES	34.112
4	-5400.0	8.180	18.767	179.852	25.819	5.599	138.222	28.040	17.286	214.776	YES	34.076
5	-4800.0	7.365	18.581	178.820	25.322	5.073	136.747	27.200	18.466	214.401	YES	34.041
6	-4200.0	6.549	18.342	177.572	24.641	4.523	135.222	26.152	19.687	214.003	YES	33.998
7	-3600.0	5.733	18.027	176.019	24.377	3.950	133.646	24.806	20.950	213.581	YES	33.946
8	-3000.0	4.917	17.591	174.010	23.930	3.352	132.018	23.017	22.257	213.132	YES	33.889
9	-2400.0	4.103	16.954	171.281	23.502	2.730	130.338	20.524	23.606	212.654	YES	33.819
10	-1800.0	3.293	15.943	167.314	23.095	2.083	128.604	16.825	24.996	212.143	YES	33.732
11	-1200.0	2.493	14.136	160.969	22.707	1.412	126.816	10.868	26.427	211.597	YES	33.621
12	-600.0	1.729	10.268	149.254	22.342	.717	124.974	4.403	27.897	211.012	YES	33.473
13	.0	1.097	-.000	123.081	22.000	-.001	123.078	29.909	29.402	210.385	YES	33.275
14	600.0	1.000	-4.275	112.615	21.683	-.741	121.130	40.972	30.939	209.710	YES	34.735
15	1200.0	1.000	-4.275	112.615	21.390	-1.501	119.129	40.822	32.505	208.983	YES	36.781
16	1800.0	1.000	-4.275	112.615	21.124	-2.280	117.079	40.672	34.095	208.199	YES	38.889
17	2400.0	1.000	-4.275	112.615	20.885	-3.075	114.980	40.522	35.702	207.351	YES	41.055
18	3000.0	1.000	-4.275	112.615	20.674	-3.883	112.837	40.372	37.320	206.432	YES	43.275
19	3600.0	1.000	-4.275	112.615	20.493	-4.703	110.651	40.222	38.942	205.437	YES	45.542
20	4200.0	1.000	-4.275	112.615	20.341	-5.529	108.428	40.072	40.559	204.358	YES	47.851
21	4800.0	1.000	-4.275	112.615	20.220	-6.360	106.170	39.922	42.161	203.186	YES	50.194
22	5400.0	1.000	-4.275	112.615	20.130	-7.190	103.884	39.772	43.739	201.916	YES	52.564
23	6000.0	1.000	-4.275	112.615	20.072	-8.017	101.574	39.622	45.283	200.539	YES	54.952
24	6600.0	1.000	-4.275	112.615	20.046	-8.836	99.246	39.473	46.781	199.049	YES	57.350
25	7200.0	1.000	-4.275	112.615	20.051	-9.643	96.906	39.323	48.222	197.442	YES	59.749
26	7800.0	1.000	-4.275	112.615	20.089	-10.435	94.561	39.173	49.596	195.714	YES	62.141
27	8400.0	1.000	-4.275	112.615	20.158	-11.208	92.217	39.024	50.892	193.863	YES	64.517
28	9000.0	1.000	-4.275	112.615	20.259	-11.958	89.879	38.874	52.100	191.893	YES	66.865
29	9600.0	1.000	-4.275	112.615	20.391	-12.683	87.554	38.725	53.211	189.808	YES	69.189
30	10200.0	1.000	-4.275	112.615	20.553	-13.381	85.249	38.575	54.218	187.617	YES	71.471
31	10800.0	1.000	-4.275	112.615	20.744	-14.049	82.968	38.426	55.115	185.334	YES	73.708
32	11400.0	1.000	-4.275	112.615	20.965	-14.685	80.717	38.277	55.897	182.976	YES	75.895
33	12000.0	1.000	-4.275	112.615	21.214	-15.289	78.500	38.127	56.562	180.562	YES	78.027
34	12600.0	1.000	-4.275	112.615	21.489	-15.861	76.323	37.978	57.111	178.115	YES	80.100
35	13200.0	1.000	-4.275	112.615	21.791	-16.399	74.188	37.829	57.546	175.660	YES	82.113
36	13800.0	1.000	-4.275	112.615	22.117	-16.904	72.100	37.680	57.869	173.221	YES	84.061
37	14400.0	1.000	-4.275	112.615	22.467	-17.376	70.059	37.531	58.087	170.820	YES	85.945
38	15000.0	1.000	-4.275	112.615	22.840	-17.817	68.070	37.382	58.206	168.480	YES	87.764
39	15600.0	1.000	-4.275	112.615	23.235	-18.226	66.132	37.233	58.235	166.219	YES	89.516
40	16200.0	1.000	-4.275	112.615	23.650	-18.606	64.247	37.084	58.182	164.051	YES	91.203
41	16800.0	1.000	-4.275	112.615	24.084	-18.958	62.417	36.935	58.055	161.987	YES	92.823
42	17400.0	1.000	-4.275	112.615	24.537	-19.282	60.640	36.787	57.864	160.036	YES	94.385
43	18000.0	1.000	-4.275	112.615	25.007	-19.581	58.917	36.638	57.617	158.202	YES	95.862
44	18600.0	1.000	-4.275	112.615	25.494	-19.856	57.248	36.489	57.322	156.486	YES	97.319
45	19200.0	1.000	-4.275	112.615	25.996	-20.109	55.631	36.341	56.987	154.857	YES	98.697
46	19800.0	1.000	-4.275	112.615	26.513	-20.340	54.066	36.192	56.619	153.402	YES	100.019
47	20400.0	1.000	-4.275	112.615	27.044	-20.552	52.552	36.044	56.224	152.027	YES	101.287
48	21000.0	1.000	-4.275	112.615	27.587	-20.745	51.087	35.896	55.807	150.756	YES	102.502
49	21600.0	1.000	-4.275	112.615	28.143	-20.922	49.670	35.747	55.375	149.585	YES	103.667
50	22200.0	1.000	-4.275	112.615	28.711	-21.083	48.300	35.599	54.930	148.505	YES	104.784

I	TIME (SECS.)	PROBE R/RP	PROBE LATITUDE	PROBE LONGITUDE	ORBITER R/RP	ORBITER LATITUDE	ORBITER LONGITUDE	PROBE PHASE	CANOPUS FROM ORBITER ELEV.ANG.	CANOPUS FROM ORBITER AZIMUTH	CAN SEE CANOPUS?	ORBITER ASPECT.
51	22800.0	1.000	-4.275	112.615	29.289	-21.229	46.974	35.451	54.477	147.512	YES	105.855
52	23400.0	1.000	-4.275	112.615	29.877	-21.363	45.693	35.303	54.019	146.598	YES	106.882
53	24000.0	1.000	-4.275	112.615	30.475	-21.484	44.453	35.155	53.558	145.757	YES	107.868
54	24600.0	1.000	-4.275	112.615	31.082	-21.593	43.254	35.007	53.097	144.965	YES	108.813
55	25200.0	1.000	-4.275	112.615	31.698	-21.693	42.093	34.859	52.638	144.274	YES	109.721
56	25800.0	1.000	-4.275	112.615	32.322	-21.782	40.969	34.711	52.182	143.620	YES	110.592
57	26400.0	1.000	-4.275	112.615	32.953	-21.863	39.882	34.564	51.731	143.019	YES	111.429
58	27000.0	1.000	-4.275	112.615	33.591	-21.936	38.828	34.416	51.285	142.465	YES	112.233
59	27600.0	1.000	-4.275	112.615	34.236	-22.002	37.807	34.269	50.846	141.955	YES	113.005
60	28200.0	1.000	-4.275	112.615	34.888	-22.061	36.818	34.121	50.414	141.484	YES	113.748
61	28800.0	1.000	-4.275	112.615	35.546	-22.114	35.859	33.974	49.990	141.050	YES	114.463

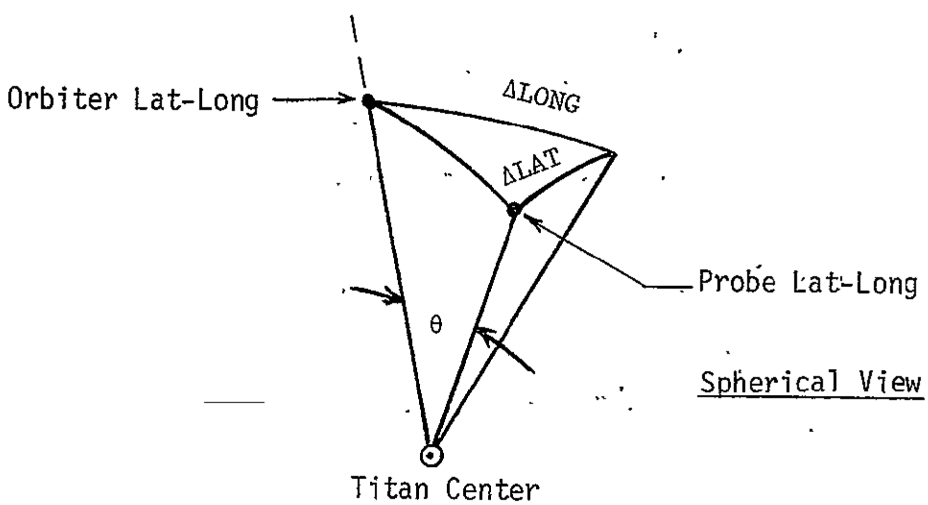
I	TIME (SECS.)	PROBE-ORBITER GEOMETRY R/RP	ELEV.ANG.	AZIMUTH	PROBE ASPECT	REL.VEL.	PROBE F.P.A.	F.P.AZ.	PROBE LAT.	REL.LONG.	ORBITER LAT.	REL.LONG.
1	-7200.0	20.509	29.879	258.062	67.891	3.990	-82.221	260.991	19.142	83.662	7.641	43.678
2	-6600.0	20.526	30.397	257.895	67.707	3.996	-81.888	260.523	19.040	82.997	6.582	42.543
3	-6000.0	20.543	31.007	257.700	67.518	4.003	-81.468	260.026	18.917	82.241	6.102	41.163
4	-5400.0	20.561	31.737	257.468	67.321	4.011	-80.937	259.495	18.767	81.366	5.599	39.736
5	-4800.0	20.580	32.625	257.188	67.113	4.022	-80.258	258.921	18.581	80.334	5.073	38.261
6	-4200.0	20.600	33.730	256.843	66.891	4.035	-79.375	258.292	18.342	79.087	4.523	36.736
7	-3600.0	20.622	35.145	256.407	66.649	4.051	-78.204	257.585	18.027	77.533	3.950	35.160
8	-3000.0	20.645	37.021	255.840	66.374	4.073	-76.603	256.766	17.591	75.526	3.352	33.532
9	-2400.0	20.672	39.631	255.076	66.046	4.104	-74.323	255.771	16.954	72.795	2.730	31.852
10	-1800.0	20.704	43.511	253.997	65.614	4.150	-70.874	254.486	15.943	68.828	2.083	30.118
11	-1200.0	20.744	49.868	252.390	64.954	4.222	-65.178	252.704	14.136	62.483	1.412	28.330
12	-600.0	20.802	61.956	249.937	63.649	4.352	-54.394	250.113	10.268	50.768	.717	26.468
13	.0	20.903	90.000	247.557	60.003	4.565	-30.000	247.640	-.000	24.595	-.001	24.592
14	600.0	20.696	80.347	67.666	9.653	.000	.000	.000	-4.275	14.129	-.741	22.644
15	1200.0	20.398	82.582	67.096	7.418	.000	.000	.000	-4.275	14.129	-1.501	20.643
16	1800.0	20.128	84.875	66.020	5.125	.000	.000	.000	-4.275	14.129	-2.280	18.593
17	2400.0	19.836	87.219	63.126	2.781	.000	.000	.000	-4.275	14.129	-3.075	16.495
18	3000.0	19.674	89.527	29.448	.473	.000	.000	.000	-4.275	14.129	-3.883	14.351
19	3600.0	19.493	87.893	257.605	2.107	.000	.000	.000	-4.275	14.129	-4.703	12.165
20	4200.0	19.344	85.418	253.097	4.582	.000	.000	.000	-4.275	14.129	-5.529	9.942
21	4800.0	19.227	82.903	251.723	7.097	.000	.000	.000	-4.275	14.129	-6.360	7.684
22	5400.0	19.144	80.361	251.048	9.639	.000	.000	.000	-4.275	14.129	-7.190	5.398
23	6000.0	19.093	77.801	250.642	12.199	.000	.000	.000	-4.275	14.129	-8.017	3.088
24	6600.0	19.077	75.232	250.365	14.768	.000	.000	.000	-4.275	14.129	-8.836	.760
25	7200.0	19.094	72.664	250.162	17.336	.000	.000	.000	-4.275	14.129	-9.643	-1.579
26	7800.0	19.145	70.104	250.004	19.896	.000	.000	.000	-4.275	14.129	-10.435	-3.925
27	8400.0	19.230	67.561	249.875	22.439	.000	.000	.000	-4.275	14.129	-11.208	-6.269
28	9000.0	19.348	65.043	249.760	24.957	.000	.000	.000	-4.275	14.129	-11.958	-8.607
29	9600.0	19.498	62.557	249.675	27.443	.000	.000	.000	-4.275	14.129	-12.683	-10.932
30	10200.0	19.680	60.111	249.594	29.889	.000	.000	.000	-4.275	14.129	-13.381	-13.237
31	10800.0	19.892	57.711	249.521	32.289	.000	.000	.000	-4.275	14.129	-14.049	-15.518
32	11400.0	20.135	55.362	249.454	34.638	.000	.000	.000	-4.275	14.129	-14.685	-17.769
33	12000.0	20.406	53.068	249.393	36.932	.000	.000	.000	-4.275	14.129	-15.269	-19.985
34	12600.0	20.705	50.833	249.336	39.167	.000	.000	.000	-4.275	14.129	-15.861	-22.163
35	13200.0	21.030	48.661	249.282	41.339	.000	.000	.000	-4.275	14.129	-16.399	-24.297
36	13800.0	21.380	46.552	249.231	43.448	.000	.000	.000	-4.275	14.129	-16.904	-26.386
37	14400.0	21.755	44.510	249.183	45.490	.000	.000	.000	-4.275	14.129	-17.376	-28.427
38	15000.0	22.152	42.533	249.136	47.467	.000	.000	.000	-4.275	14.129	-17.817	-30.416
39	15600.0	22.571	40.622	249.091	49.378	.000	.000	.000	-4.275	14.129	-18.226	-32.354
40	16200.0	23.011	38.778	249.048	51.222	.000	.000	.000	-4.275	14.129	-18.606	-34.238
41	16800.0	23.469	36.998	249.006	53.002	.000	.000	.000	-4.275	14.129	-18.958	-36.069
42	17400.0	23.946	35.282	248.964	54.718	.000	.000	.000	-4.275	14.129	-19.282	-37.846
43	18000.0	24.440	33.629	248.924	56.371	.000	.000	.000	-4.275	14.129	-19.581	-39.569
44	18600.0	24.949	32.037	248.884	57.963	.000	.000	.000	-4.275	14.129	-19.856	-41.238
45	19200.0	25.474	30.503	248.845	59.497	.000	.000	.000	-4.275	14.129	-20.109	-42.855
46	19800.0	26.013	29.026	248.807	60.974	.000	.000	.000	-4.275	14.129	-20.340	-44.420
47	20400.0	26.566	27.604	248.769	62.396	.000	.000	.000	-4.275	14.129	-20.552	-45.934
48	21000.0	27.131	26.235	248.731	63.765	.000	.000	.000	-4.275	14.129	-20.745	-47.399
49	21600.0	27.707	24.916	248.694	65.084	.000	.000	.000	-4.275	14.129	-20.922	-48.816
50	22200.0	28.295	23.645	248.657	66.355	.000	.000	.000	-4.275	14.129	-21.083	-50.186

I	TIME (SECS.)	PROBE-ORBITER GEOMETRY R/RP	ELEV.ANG.	AZIMUTH	PROBE ASPECT	RFL.VEL.	PROBE F.P.A.	F.P.AZ.	PROBE LAT.	REL.LONG.	ORBITER LAT.	REL.LONG.
51	22800.0	28.893	22.421	248.620	67.579	.000	.000	.000	-4.275	14.129	-21.229	-51.511
52	23400.0	29.500	21.241	248.584	68.759	.000	.000	.000	-4.275	14.129	-21.363	-52.793
53	24000.0	30.117	20.102	248.548	69.898	.000	.000	.000	-4.275	14.129	-21.484	-54.033
54	24600.0	30.742	19.005	248.511	70.995	.000	.000	.000	-4.275	14.129	-21.593	-55.232
55	25200.0	31.376	17.945	248.475	72.055	.000	.000	.000	-4.275	14.129	-21.693	-56.393
56	25800.0	32.016	16.922	248.440	73.078	.000	.000	.000	-4.275	14.129	-21.782	-57.516
57	26400.0	32.664	15.933	248.404	74.067	.000	.000	.000	-4.275	14.129	-21.863	-58.604
58	27000.0	33.319	14.978	248.368	75.022	.000	.000	.000	-4.275	14.129	-21.936	-59.658
59	27600.0	33.980	14.054	248.332	75.946	.000	.000	.000	-4.275	14.129	-22.002	-60.676
60	28200.0	34.647	13.160	248.297	76.840	.000	.000	.000	-4.275	14.129	-22.061	-61.668
61	28800.0	35.319	12.294	248.261	77.706	.000	.000	.000	-4.275	14.129	-22.114	-62.627

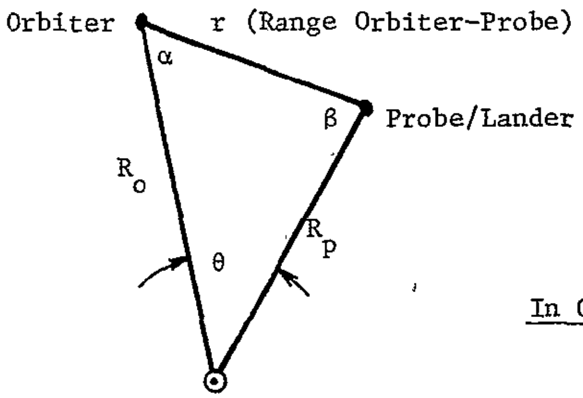
B. COMMUNICATIONS LINK ANALYSIS

Probe-orbiter communications link geometry (range and aspect angle) were calculated using JPL data from Appendix A and entry trajectories data calculated by Martin Marietta. For trajectory times prior to the entry interface (3200 km radius), both orbiter and probe radial distance and sub-latitide and longitude data are from Appendix A. For times after the entry interface has passed, orbiter data are from Appendix A and probe radius, flight path angle, heading angle and latitude-longitude position are from entry trajectories run by Martin Marietta.

Communication link geometry equations were derived as follows:



$$\cos\theta = \cos(\Delta LAT) \times \cos(\Delta LONG) \quad (1)$$

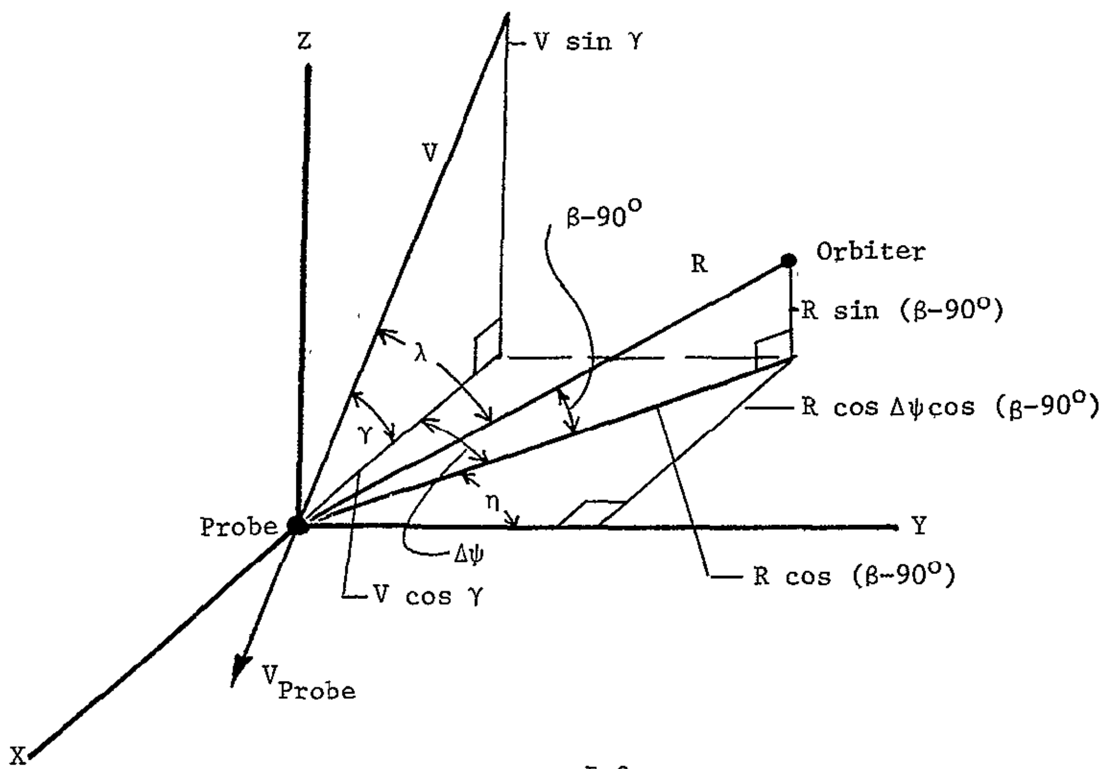


In Orbiter-Probe Plane

$$r^2 = R_o^{\ 2} + R_p^{\ 2} - \text{Cos}\ \theta\ (2\ R_o\ R_p) \tag{2}$$

$$\beta = 180 - \sin^{-1}\left(\frac{R_o \sin\theta}{r}\right) \tag{3}$$

The angle between the probe velocity vector and the probe-orbiter line, aspect angle λ, is developed as follows in the probe velocity vector axis system:



$$\vec{R} = -\vec{i}\ R \cos \Delta\psi \cos (\beta-90^{o}) + \vec{j}\ R \sin \Delta\psi \cos (\beta-90^{o})$$
$$+ \vec{k}\ R \sin (\beta-90^{o})$$

$$\vec{V} = -\vec{i}\ V \cos \gamma + \vec{k}\ V \sin \gamma$$

$$\frac{\vec{R}}{|R|} = -\vec{i} \cos \Delta\psi \cos (\beta-90^{o}) + \vec{j} \sin \Delta\psi \cos (\beta-90^{o})$$
$$+ \vec{k} \sin (\beta-90^{o})$$

$$\frac{\vec{V}}{|V|} = -\vec{i} \cos \gamma + \vec{k} \sin \gamma$$

$$\vec{R} \cdot \vec{V} = |R|\ |V| \cos \lambda$$

$$\cos \lambda = (-\vec{i} \cos \Delta\psi \cos (\beta-90^{o}) + \vec{j} \sin \Delta\psi \cos (\beta-90^{o})$$
$$+ \vec{k} \sin (\beta-90^{o})/R$$
$$\bullet (-\vec{i} \cos \gamma + \vec{k} \sin \gamma)$$

$$\cos \lambda = \cos \Delta\psi \cos \gamma \cos (\beta-90^{o}) + \sin \gamma \sin (\beta-90^{o})$$

$$\lambda = \cos^{-1} \left[\sin \gamma \sin (\beta-90^{o}) + \cos \gamma \cos \Delta\psi \cos (\beta-90^{o})\right] \qquad (4)$$

where:

$$\Delta\psi = 270^{o} - |\psi_p| - |\eta|$$

ψ_p = heading of probe (trajectory data)

$$\eta = \cos^{-1} (\tan \Delta \text{ lon } * \frac{1}{\tan \theta})$$