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Study of Alternative Probe Technologies

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MARTIN MARIETTA

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FINAL REPORT

STUDY OF ALTERNATIVE PROBE TECHNOLOGIES

DECEMBER 1977

Prepared Under Contract No. NASA 2-9635 By
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For
AMES RESEARCH CENTER
National Aeronautics & Space Administration

Approved

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SUMMARY

This study effort has examined a number of implied technologies for a deep probe mission: i.e., one that would provide the capability to scientifically examine planetary atmospheres at the 1000 bar level. Conditions imposed by current Jupiter, Saturn, and Uranus atmospheric models were considered throughout the study.

Science objectives were established through discussions with selected members of the science community, and an integrated complement of measurements and instruments was developed. The major thrust of the measurements was to determine lower atmosphere composition, even to trace constituents of one part per billion. Instruments having this accuracy do not have the ability to operate within the extreme environments of the outer planets, and therefore represent a basic enabling technology development. Two types of instruments having the necessary accuracy to meet the science objectives were considered and integrated into a deep probe configuration; however, further studies must be performed to determine whether these instrument concepts can be developed to meet mission requirements.

Various technology options were considered for elements of a deep probe mission. These options identified potential mechanizations which, in turn, were catagorized as being 1) state-of-the-art technology, 2) technology available but complex, or 3) technology advancement required. The technology requirements were identified as being either "enabling", i.e., required before the mission could be flown, or "enhancing", i.e., adding to mission science return.

One deep probe option that resulted from this study was identified as a "Minimum Technology Development" approach. The significant feature of this option is that only three technology developments are required to enable the mission, i.e., 1) science instrument development, 2) advanced data processing, and 3) external high pressure/thermal insulation.

A probe designed for a Jupiter mission could, with minor changes, be used for a Saturn or Uranus mission.

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Dr. Donald Hunten - University of Arizona
Dr. John Lewis - MIT
Mr. Larry Manning - Ames Research Center
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ABBREVIATIONS AND SYMBOLS

Atm	Atmosphere
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
b/s	Bits Per Second
BTU	British Thermal Units
C	Compression Ratio
CCD	Charge Coupled Device
CMOS	Complementary Metal-Oxide-Semiconductors
C_p	Specific Heat
db	Decibel
^{o}F	Degrees Farenheit
GC	Gas Chromatograph
GHZ	GigaHertz
h	Plank's Constant
H_p	Density Scale Height
IC	Integrated Circuit
I^2L	Integrate-Injection Logic
k	Boltzmann's Constant, or Thermal Conductivity
K	Degrees Kelvin, or Permeability
kg	Kilogram
km	Kilometer
kw	Kilowatt
LSI	Large Scale Integrated Circuits
m	Electron Mass
mb	Millibar
MHZ	MegaHertz

MNOS	Metal-Nitride Oxide-Silicon
MOD	Modulation
MOS	Metal-Oxide-Semiconductors
MS	Mass Spectrometer
m/s	Meters Per Second
Ne	Electron Density
P	Power (watts)
PER	Angle From Periapsis
psig	Pounds Per Square Inch, Gage
PSK	Phase Shift Keying
R_A	Radius of Apoapsis
RAM	Random Access Memory
RF	Radio Frequency
ROM	Read Only Memory
R_P	Radius of Periapsis
R_J	Radius of Jupiter
Sl	Slug
SOA	State-of-the-Art
TTL	Transistor-Transistor Logic
VLSI	Very Large Scale Integrated Circuits
V_T	Terminal Velocity
XMT	Transmitter
X_r	Ionization Potential
β	Ballistic Coefficient, or Coefficient of Volumetric Expansion
ΔV	Change in Velocity
λ	Lead Angle
μ	Viscosity
ρ	Atmosphere Density at Altitude, or Material Density
θ	Angle From Zenith

1. INTRODUCTION

The general study objective of this contract was to identify the technology developments that would allow deep atmospheric investigations of the various planets to advance beyond currently planned investigations of the upper atmosphere. Studies were conducted for a deep probe mission that would provide the capability to scientifically examine planetary atmospheres at the 1000 bar level. These studies were conducted within the conditions imposed by current Jupiter, Saturn, and Uranus atmospheric models. Jupiter presents the most severe set of conditions, i.e., at the 1000 bar level temperatures of 1400°K can be expected.

The study plan is presented in Figure I-1 and the schedule was as shown on Figure I-2.

In order to completely investigate technology requirements, it was first necessary to define science requirements. This was accomplished through a series of discussions with selected members of the science community: Drs. John Lewis, Don Hunten, Tom Donahue, Jim Pollack, William Hubbard, and Jim Anderson. These discussions established the science objectives, what should be measured and how frequently, and the need for experiment and instrument technology developments. The derived scientific objectives for a deep probe mission as recommended by this group are shown in Figure I-3. Based upon these recommended objectives, an integrated complement of measurements and instruments was summarized, as well as the desired frequency of measurement. The major thrust of the measurements is to determine the lower atmosphere composition with the desire to measure trace constituents down to one part per billion. It was determined that instruments having this accuracy do not exist for operation in the extreme environments presented by the outer planets. Since the mass spectrometer and gas chromatograph would be extremely difficult to develop for this environment, two other types of instruments were considered: the absorption spectrophotometer and the resonance fluorescence spectrometer. These types of instruments were then integrated into a deep probe configuration, without any attempt at optimization, and are reported upon in the following chapters.

Various technology options were considered for a range of deep probe elements. These options were formed into a matrix with the probe elements listed in columns and the various potential mechanizations considered for each element form rows. These potential mechanizations are grouped into three categories;

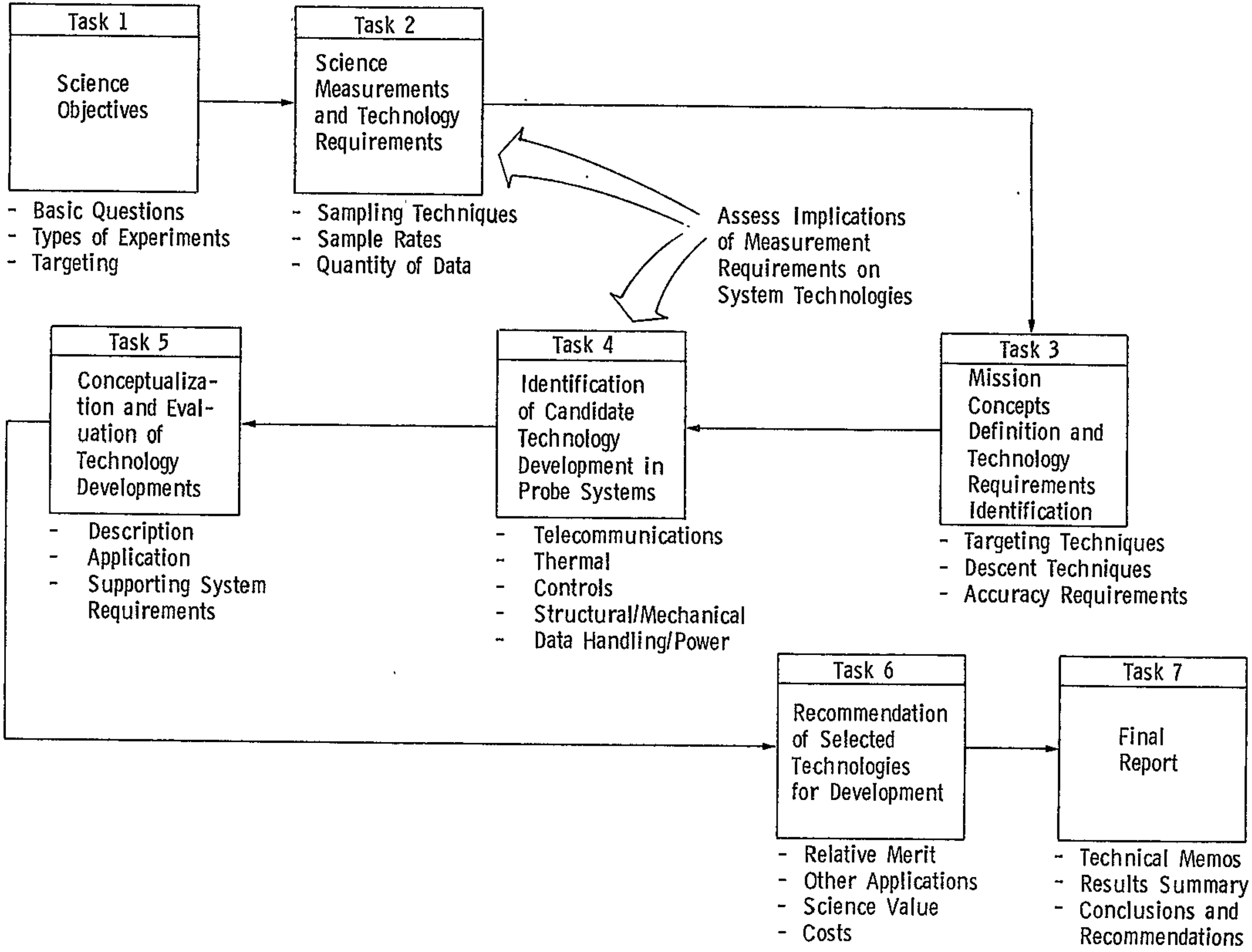


Figure II-1 Study Plan

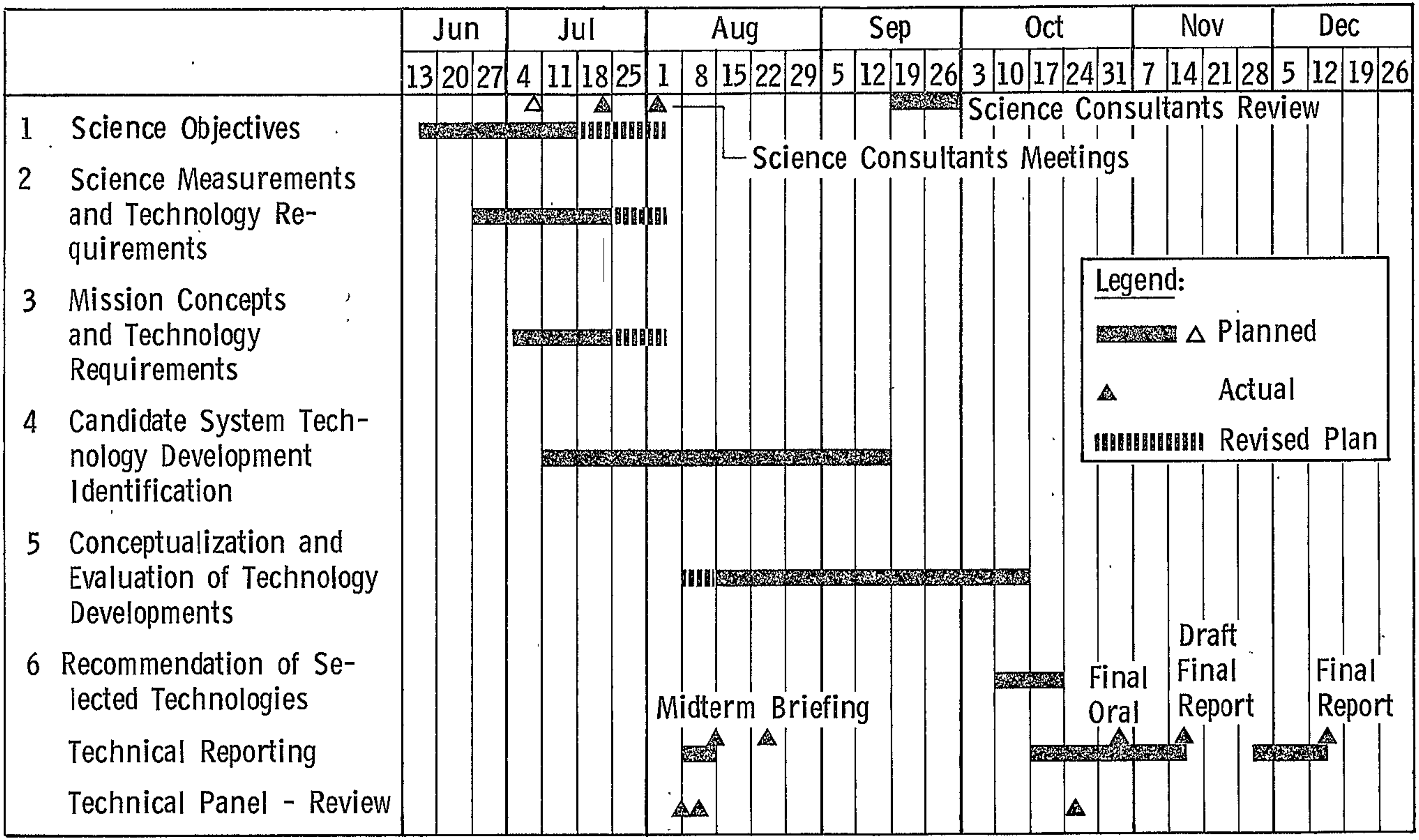


FIGURE I-2 - STUDY SCHEDULE

I. Test Theories of Solar System/Planetary Formation
  - Enhanced (Greater-Than-Solar) Abundances of "Ice-Bearing" Molecules (CH_4, NH_3, H_2O)
  - Enhanced "Rock-Bearing" Abundances (mg, Si, Fe)
  - "Baseline" Solar Abundances, Particularly Light Elements (Li, Be, B)

II. Determine Internal Structure and Comparative Evolutionary State of Jupiter, Saturn and Uranus
  - Internal Mass Distribution
  - Location of Transition Region for Radiative/Convective Transfer
  - Location of Possible Deep "Secondary" Radiative Zones
  - Deep Magnetic Field Strengths, Higher Order Moments
  - Electrical Conductivity
  - Accurate Temperature Gradient, Location of Adiabatic Region, Nature of Internal Heat Source

III. Determine the Physical and Dynamic Structure of the Outer Regions and Their Chemical Evolution Process
  - Location of Deep Cloud Structure Relative to Condensibles
  - Temperature/Pressure Profiles
  - Composition Profiles (Trace and Bulk Constituents)
  - Horizontal/Vertical Wind Fields

FIGURE I-3 - RECOMMENDED SCIENTIFIC OBJECTIVES FOR A DEEP-PROBE MISSION

1) State-of-the-Art Technology, 2) Technology available but complex or new application, and 3) Technology advancement required. Thus, depending upon which ground rules one applies to the mission, such as desiring minimum new technology development, a path can be traced through the matrix which best satisfies this ground rule. The matrix and some options are discussed in this report.

The overall technology assessment for the deep probe mission is shown in Figure I-4. The technology requirements are divided into two categories, enabling technologies and enhancing technologies. The enabling technologies must be developed before a mission of this type could be flown. The enhancing technologies, if developed, would add to the science return of this mission.

A concern developed during the study when calculations showed that a possibility of atmospheric ionization exists before the 1000 bar level is reached. On Jupiter this would prevent or degrade RF communication between the probe and orbiter during the final descent phase. If later studies show that this is a strong possibility, then other techniques must be employed for data transmission during the final descent phase.

The key technology and mission configuration driving functions were found to be:

1) Science Instrument Measurement Requirements,
2) Pressure and Temperature Environmental Conditions, and
3) Potential Atmospheric Ionization

This study assumed a technology base derived from the Pioneer Venus, JOP and Viking Missions. The limited number of technology developments identified in this study are dependent upon successful development of all planned technologies for these programs.

The conclusions which have been formulated throughout this study are listed in Figure I-5. The conclusion that a probe designed for Jupiter can be used, with minor changes, for Saturn and Uranus missions is noteworthy, since it could significantly reduce the overall mission costs to these outer planets. The recommendations from this study are listed in Figure I-6. Note that the recommendations are based upon the assumption that thermal ionization does not occur above the pressure altitude of interest.

Enabling Technologies

The Major Potential Obstacles to Deep-Probe Missions, and the Related Technology Developments, Appear to Be:

- Science Instrument Technology Does Not Exist for Making the Sensitive Composition Measurements Needed - Instrument Conceptual Studies Should be Conducted to Define Development Approach
- Efficient Temperature Control Will Necessitate Either Development of Flow-Resistant External Insulations or Much Improved High-Temperature Structures - Alternatives Involve Solving a Number of Other Problems Induced by Very Heavy Probes
- Thermal Ionization May Produce a Conducting Atmosphere That Would Preclude Normal Telecommunications - Early Tests Are Required To Determine Ionization Levels

Enhancing Technologies

Below are Examples of Technologies That Would Enhance the Mission (Some would Become Enabling Technologies If Advances Above Are Not Realized)

- Improvements in Source Data Encoding and Error-Correction Technology
- Adaptive Science Techniques
- High-Power Transmitters
- Improvements in Energy Storage Technology
- High-Temperature Parachutes
- Advanced Heat Shield Materials

FIGURE I-4 - TECHNOLOGY ASSESSMENT - DEEP-PROBE REQUIREMENTS

Mission has scientific merit if atmospheric composition can be determined, including trace elements.

Technology advance required to develop composition instruments, such as resonance fluorescence spectrometer to operate in lower atmosphere.

Probe system can be developed (brute force) with present technology concepts, but resulting probe is large, heavy, and complicated.

Advanced on-board data analysis can enhance deep probe mission.

Externally insulated pressure vessel design is lightest approach with moderate technology advancement.

Probe designed for Jupiter with minor changes can satisfy Saturn and Uranus missions with dual orbiters.

Probe RF communications at depths below 0.6 kilobars may be lost due to thermal ionization. Further analysis and testing should be undertaken.

FIGURE I-5 - STUDY CONCLUSIONS

Recommendations Are Based on the Assumption That NO Ionization Constraints Exist Down to the Pressure Level of Interest

Plan Any Future Deep Probe Missions on "Minimum-Technology" Basis

Further Investigation and Development of Selected Candidate Technology Items:

- Absorption Spectrophotometer Instrument Concept
- Resonance-Fluroscence Spectrometer Instrument Concept
- Advanced Data-Processing Technology
- High-Pressure (External) Thermal Insulation Materials

FIGURE I-6 - STUDY RECOMMENDATIONS

II. SCIENCE OBJECTIVES, MEASUREMENTS, AND INSTRUMENTS

INTRODUCTION

A long range strategy in the investigation of the physical properties of the outer planets has been developed for NASA by several scientific working groups commissioned by the National Academy of Sciences. Long-range guidelines are provided, which are consistent with investigations of fundamental questions on the origin and formation of the planets and solar system. A first generation of planetary entry probes, such as JOP, applied to each of the Jovian planets and some of their satellites, would provide an extensive homogeneous basis of scientific data that could considerably advance the understanding of the solar system in the next decade. Clearly any second generation entry probes would employ investigations which provide continuity to the studies performed by earlier planetary missions. Hence, any definition of scientific requirements for a deep atmospheric probe for the outer planets should be consistent with the long range strategy that has been developed in order to ensure maximum scientific return.

Some fundamental questions which a second generation probe may address are listed in Table II-1. These questions provide a framework within which more detailed investigations can be formulated. In the following discussions more specific investigations have been outlined for a deep probe mission to Jupiter, Saturn, and Uranus within the context of the questions given in Table II-1. These questions/investigations were formulated with the assistance and recommendations of the MMC Science Consultant Panel consisting of Drs. J. Lewis, T. Donahue, and D. Hunten.

A. COMPOSITION/CLOUD STRUCTURE

Recent models of the interior of Jupiter, which are consistent with all of the observations and based on solar helium/hydrogen values, appear to require the existence of a small rocky core surrounded by a nearly solar composition fluid mixture. The rocky core is required to initiate the collapse of the

TABLE II-1 - LONG RANGE SCIENTIFIC QUESTIONS REGARDING THE OUTER PLANETS/SATELLITES

1. WHAT PHYSICAL PROCESSES WERE RESPONSIBLE FOR THE FORMATION OF THE SOLAR SYSTEM AND ITS PLANETS AND SATELLITES?
2. WHAT IS THE INTERNAL STRUCTURE OF THE OUTER PLANETS AND WHAT PROCESSES HAVE BEEN RESPONSIBLE FOR THEIR PRESENT EVOLUTIONARY STATE?
3. WHAT ARE THE PHYSICAL, STRUCTURAL, AND COMPOSITIONAL CHARACTERISTICS OF THE OUTER ENVELOPES OF THE OUTER PLANETS, AND HOW HAVE THE ENVELOPES EVOLVED?

hydrogen-helium envelope of the Proto-Jupiter. Hence, an enhancement of the "rock-bearing" constituents, and possibly the "ice-bearing" constituents, is expected on the basis of cosmogenic considerations (Stevenson, D. J., and Salpeter, E. E., 1976). The degree of enhancement ranges from 5-10% of the planetary mass, providing approximately a few tens of times the solar abundance of refractory materials. On the basis of these considerations, an actual measurement of the abundances of rock-bearing elements would constitute a severe observational constraint on theoretical models of Jupiter and the outer planets. Hence, a major scientific objective for a deep probe mission for the Jovian planets would be a measurement of the composition of their deep atmospheres.

As a guide for future exploration studies; the anticipated composition of Jupiter's deep atmosphere has been studied by Barshay and Lewis (1977). Solar abundances compiled by Cameron were employed in chemical equilibrium calculations. The temperature/pressure distribution corresponding to a Jupiter adiabat was used (the adiabats for Jupiter, Saturn, and Uranus are compared in Figure II-1). The calculations have been performed for the Jupiter adiabat, but may be used to approximate the data for Saturn and Uranus by selecting the composition data at temperatures adjusted for the different pressures. The calculations yielded equilibrium abundances of over 500 compounds of 27 selected elements. The results have been used to predict some possibly observable constituents which have not yet been observed in Jupiter's atmosphere. Anticipated constituents with concentrations in excess of 1 part per billion are collected from these calculations and summarized in Table II-2. Figure II-2 illustrates, schematically, the results of the calculations by Barshay and Lewis (1977). A deep probe ($T \sim 1200^{o}K$) should be capable of making observations directly of the rock-bearing constituents. It may be possible to observe such constituents, either by remote spectroscopy or by a JOP-type probe, provided adequate sensitivity was available. However, it is not clear if the convective mixing extends sufficiently deep, or whether the mixing is sufficiently rapid to transport the constituents upward before chemically interacting with the surrounding environment, or whether the constituents condense out before reaching observable layers within the atmosphere. The most promising candidates for possible spectroscopic detection are underlined in Figure II-2. In fact, both CO and PH_3 have been observed, and Barshay and Lewis (1977) have argued

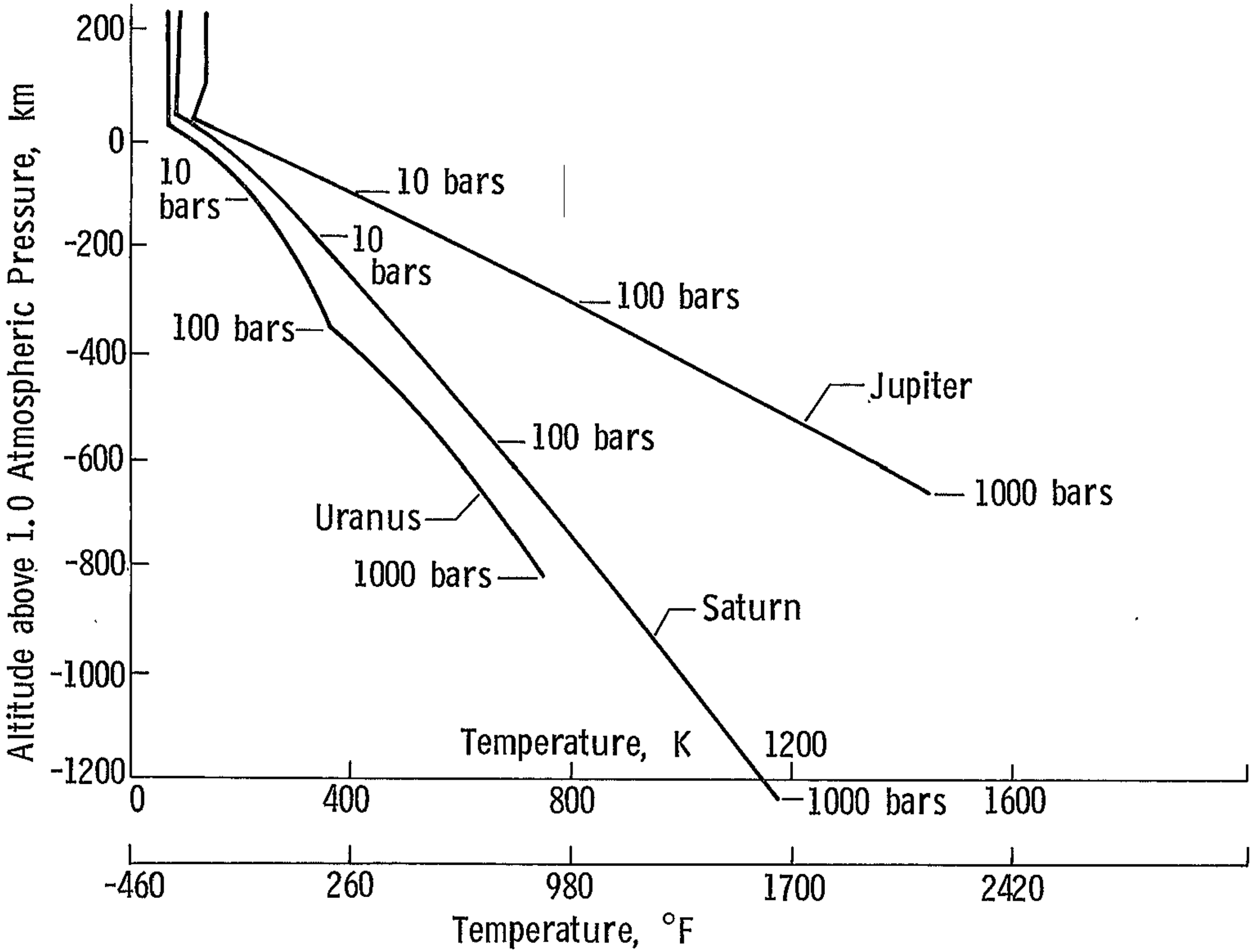
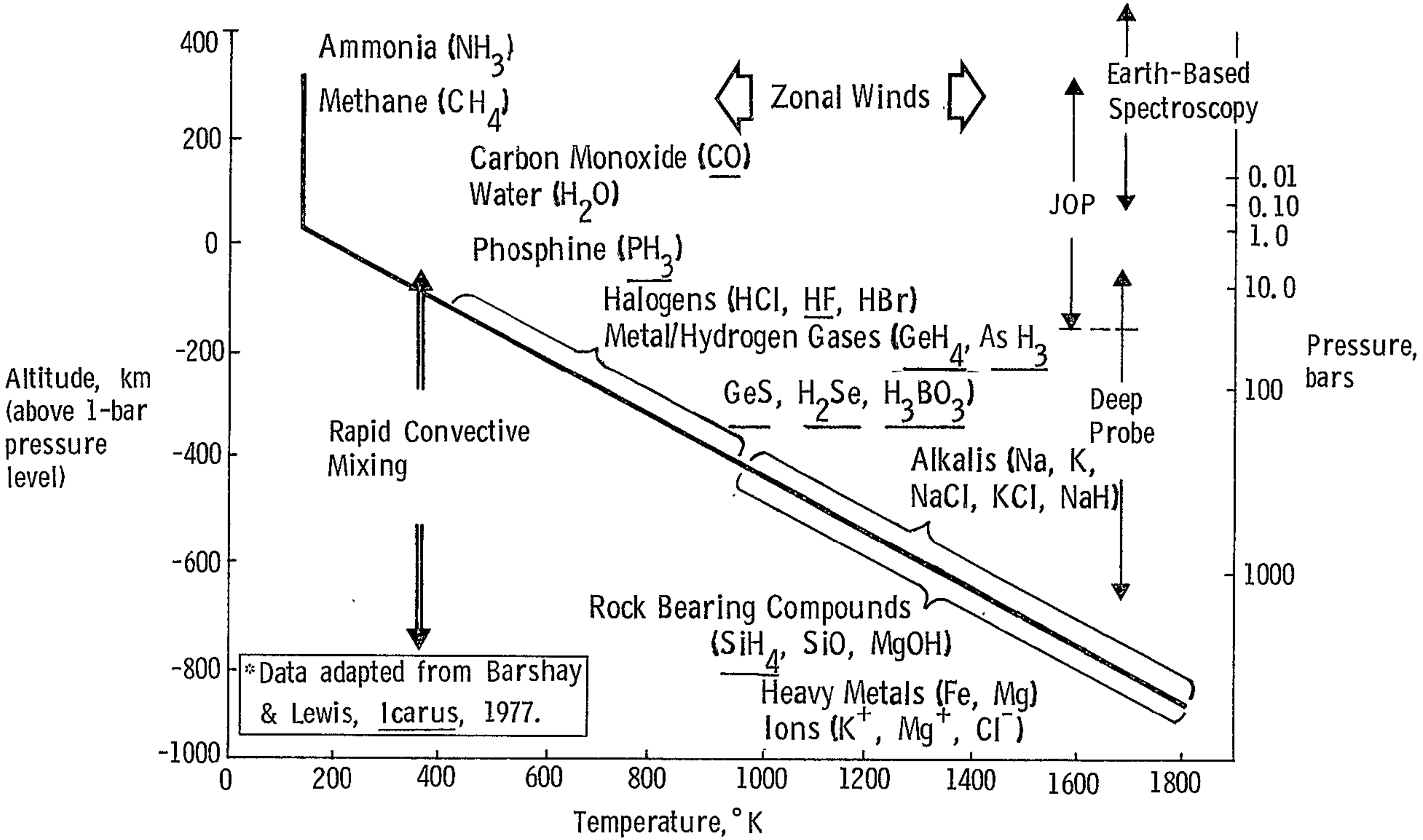


FIGURE II-1 - COMPARISON OF OUTER PLANET ATMOSPHERE TEMPERATURE PROFILES



*Data adapted from Barshay & Lewis, *Icarus*, 1977.

FIGURE II-2 - SCHEMATIC ANTICIPATED ATMOSPHERIC COMPOSITION - JUPITER (TRACE COMPONENTS)

TABLE II-2

SUMMARY OF EXPECTED CONSTITUENTS NEAR 1 KILOBAR WITH CONCENTRATIONS IN EXCESS OF 1 PART PER BILLION

CH_3
CH_3OH
C_2H_4

N_2
HCN
NH_2
CH_3NH_2
OH

HS
SiS
H_2S

PH_3
PH_2
P_4O_6

HCl
KCl
NaCl

HF
HBr
NaF
NaBr
Na
NaH
K
HK
KOH

Mg
MgOH
MgH

SiH_4
SiO
SiO_2

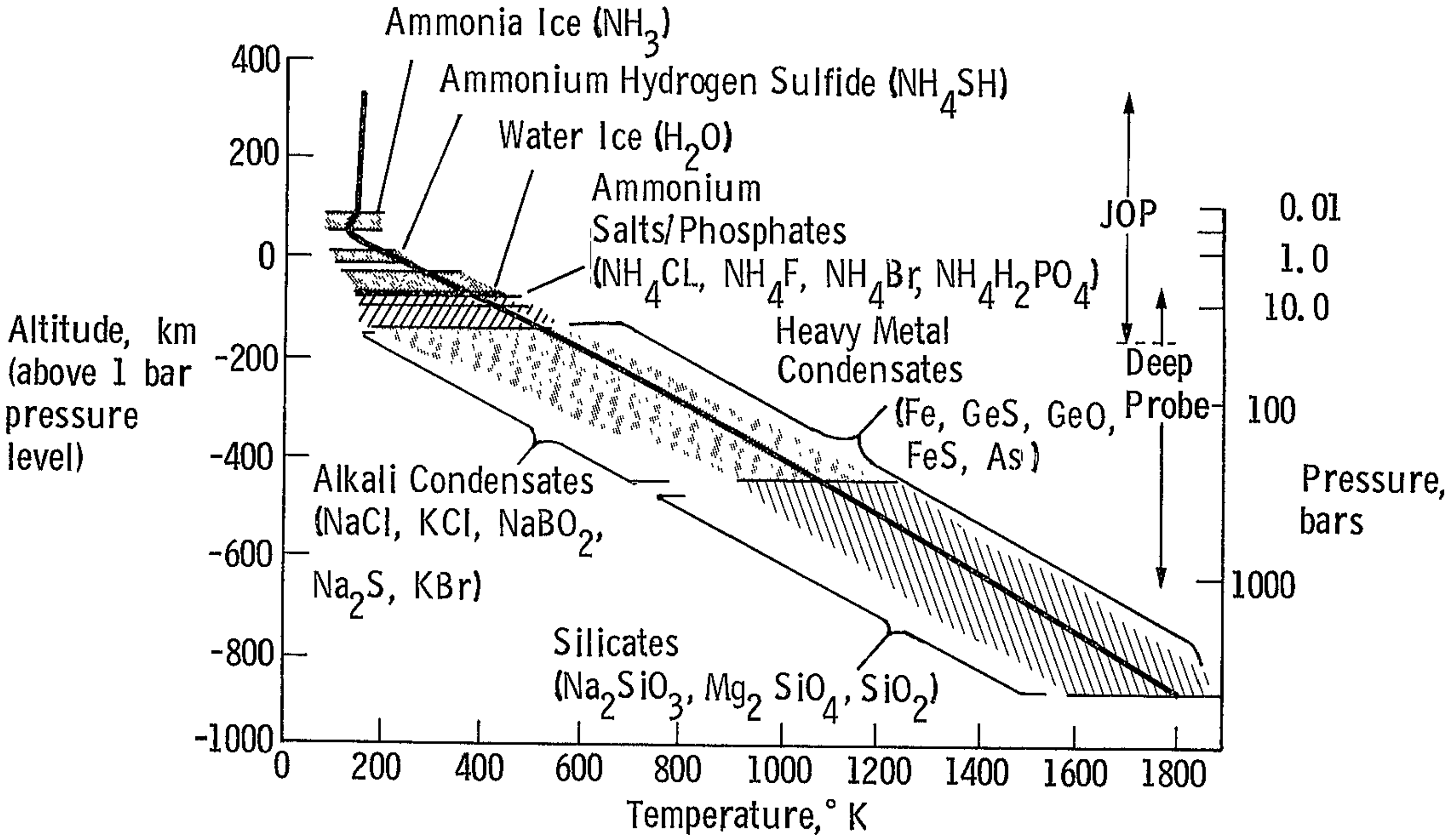
H_3BO_3

H_2Se

GeS
GeO
AsH_3

that, since these species are only stable at high temperatures, their existence in spectroscopically observable regions is evidence for rapid convective mixing from layers extending down to temperatures at about 1000°K. The observability of the remaining species is dependent on many uncertainties, and a reliable confirmation of the predicted constituents can probably be best observed by a deep probe, particularly for the rock-bearing compounds, some of which are chemically stable at temperatures near 2000°K and pressures of several kilobars.

The calculations performed by Barshay and Lewis also yield predictions of anticipated condensates at various pressure and temperature levels (Figure II-3). The actual concentrations of the condensates are not available, but the results may be used as a guide to the possible existence of cloud layers. The situation is extremely complex in the deeper layers, and considerable overlap of condensates is expected. The combined results shown in Figures II-2 and II-3 may be used as a guide to understanding Jupiter's deep atmosphere, and have been extremely useful for the development of scientific objectives for a deep probe mission. The identification and localization of deep cloud layers, the measurement of their vertical structures, and determination of particle sizes would be quite useful. The determination of the abundances of trace rock-bearing constituents in conjunction with the atmospheric composition is important for understanding not only the structure, composition, and dynamics of Jupiter's outer region, but also for inferring the prevailing conditions in the deep interior of Jupiter, and obtaining clues to its initial formation from the primeval solar nebula.



*Data adapted from Barshay & Lewis Icarus, 1977.

FIGURE II-3 - SCHEMATIC ANTICIPATED DEEP ATMOSPHERIC CLOUD STRUCTURE - JUPITER

B. OBJECTIVES FOR DEEP PROBE

On the basis of the previous discussions, a set of investigations have been compiled and are listed in Table II-3. The investigations are intended to be carried out by an orbiter-probe mission, with the probe conducting the major portion of the required measurements by in-situ techniques. These investigations comprise a comprehensive integrated study of the deeper layers of the Jovian planets. With the exception of the required composition measurements, extensions of existing techniques appear to be adequate for conducting the required measurements. The emphasis, however, is placed on the determination of the march of the chemical composition of both bulk and trace species for these planets, for which a clearly defined technique is not evident.

C. RECOMMENDED MEASUREMENTS

The required measurements to meet the scientific objectives previously outlined are tabulated in Table II-4. The desired frequency of measurement is also indicated in terms of the desired spatial scale. Possible instruments are identified, and a significant conclusion from this brief study is that major technology development appears to be able to effect the composition measurements, particularly of the trace species which are expected to be present at concentrations on the order of 1 part per billion or less.

TABLE II-3 - SUGGESTED SCIENTIFIC OBJECTIVES - DEEP PROBE MISSION - OUTER PLANETS

I. TEST THEORIES OF SOLAR SYSTEM/PLANETARY FORMATION AND CHEMICAL EQUILIBRIUM PREDICTIONS

- ENHANCED "ICE BEARING" MOLECULAR ABUNDANCES, (CH_4, NH_3, H_2O)
- ENHANCED "ROCK BEARING" ABUNDANCES, (Mg, Si, Fe)
- "BASELINE" SOLAR ABUNDANCES, PARTICULARLY LIGHT ELEMENTS (Li, Be, B)

II. DETERMINE INTERNAL STRUCTURE/COMPARATIVE EVOLUTIONARY STATE

- INTERNAL MASS DISTRIBUTION
- LOCATE TRANSITION REGION FOR RADIATIVE/CONVECTIVE TRANSFER
- LOCATE POSSIBLE DEEP "SECONDARY" RADIATIVE ZONES
- DEEP MAGNETIC FIELD STRENGTHS, HIGHER ORDER MOMENTS
- ELECTRICAL CONDUCTIVITY/RELATION TO THERMAL IONIZATION
- ACCURATE TEMPERATURE GRADIENT/LOCATION OF ADIABAT/CHARACTERIZE INTERNAL HEAT SOURCE

III. DETERMINE PHYSICAL AND DYNAMIC STRUCTURE AND CHEMICAL EVOLUTION OF OUTER ATMOSPHERES: TEST PHOTOCHEMICAL PREDICTIONS: TEST ROLE OF SATELLITE IN POSSIBLE ION EXCHANGE WITH JOVIAN ATMOSPHERE

- LOCATE DEEP CLOUD STRUCTURE/RELATION TO CONDENSIBLES
- TEMPERATURE/PRESSURE PROFILES
- COMPOSITION PROFILES (TRACE AND BULK CONSTITUENTS, e.g.:NH_3, N_2, N_2H_y, CH_3NH_2, TRACE ORGANICS)
- HORIZONTAL/VERTICAL WIND FIELDS

TABLE II-4 - RECOMMENDED DEEP-PROBE MEASUREMENTS

Measurement	Instrument Alternatives	Remarks
Composition Profiles 2-3 per Scale Height, ppm to ppb Sensitivity	GC, MS, GC/MS Absorption Spectrophotometer Resonance-Fluorescence Spectrometer	Instrument Technology Does Not Exist
Cloud Structure and Composition 2-3 per Scale Height	Nephelometer/Particle Spectrometer	May Be Adaptable from Existing Instruments
Magnetic Field and Electrical Conductivity 5 per Descent	Magnetometer/Electrometer	
Pressure/Temperature/Density 10 per Scale Height	Pressure/Temperature Gage/Accelerometer	

D. POTENTIAL INSTRUMENT CONCEPTS FOR COMPOSITION MEASUREMENTS

Assuming that a probe could be designed to survive under the severe environmental constraints of one kilobar pressure and 1200 to 1400°K temperature, a measurement technique is required to determine abundances of constituents at concentration levels of one part per billion or less. Conventional in-situ techniques do not appear to be adequate for conducting such measurements under these severe conditions. At present, it is not clear whether <u>any</u> technique is possible, but several methods have been suggested, and their feasibility needs to be considered in greater detail. Present in-situ techniques by mass spectrometer or gas chromatograph are limited to more benign environments. Several discussions with investigators who have developed state-of-the-art instruments for operation in more severe environments have been held. These investigators feel that, with sufficient development time and resources, both the gas chromatograph and mass spectrometer could be built to meet the deep probe requirements. The major difficulty with these conventional techniques is concerned with the acquisition of the sample and preparing it for analysis by the instruments without destroying the chemical integrity of the sample, (many species are radicals or volatiles and may interact or condense within the instrument). One possible concept for acquiring and handling a sample of hot gas at high pressures would be to inlet the sample into a chamber under rapid expansion to cool the sample to avoid condensation. The inlet leaks to the GC and MS could be run off of this chamber and the pressure reduced in several stages to a level which is consistent with the nominal operation of these instruments. A two-stage or multiple stage pressure reduction system with the capability for dissipation of large heat loads would be required. The primary development concerns would address the front-end sample acquisition and valving system.

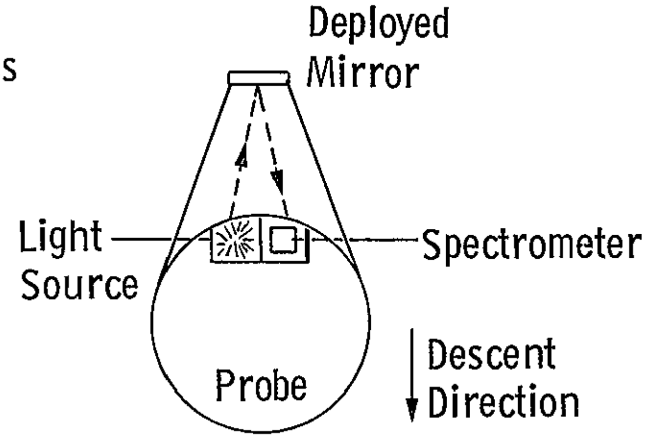
In addition, several other techniques were suggested which employ remote optical methods. With emission spectroscopy, an arc discharge within the atmosphere at the measurement location could excite most of the chemical constituents present. A wide spectral coverage spectrometer could then analyze the emission spectrum obtained for abundance determinations. A disadvantage of this possible technique is that the chemical integrity of the species present could be substantially modified by the excitation source, thus leaving the determination of the true chemical state somewhat obscure. Another possible technique could employ an incandescent source deployed about a meter from the probe. In this case, a spectrometer could measure the absorption spectrum of the intervening atmospheric gases to provide an abundance determination. A disadvantage of this method, however, is the short absorption path length ($\leq$ 1 meter) which would yield adequate sensitivity for species present to one part per million. Much longer path lengths ($\geq$ 1 km) would be required for measuring constituents at the 1 part per billion level. A third potential technique is the resonance fluorescent scattering method developed by Dr. J. G. Anderson. Several lamps may be excited by microwave discharges to produce resonance radiation, which could then be absorbed/scattered by constituents in the illuminated sample volume, and subsequently detected. The method has very high sensitivity (ability to detect species to 1 part per trillion), but suffers from the disadvantage that the identity of the gases present must be known. However, further development of the present instrument could provide a search mode with a front-end spectrometer, which could be used in a quasi-exploratory mode.

At the present, it is not clear whether any of these techniques will prove to be possible for the application considered here. To be completely fair and unbiased, all of these possible techniques (there may be others not listed here) should be carefully evaluated for feasibility and further development pursued on the more promising techniques. Figure II-4 illustrates several of these possible concepts.

Composition Instruments

① GCMS - Would Require New Techniques to Analyze Gases at 1000-bar Pressure/ 1400 K Temperature

② Absorption Spectrophotometer



③ Resonance-Scattering Photometer

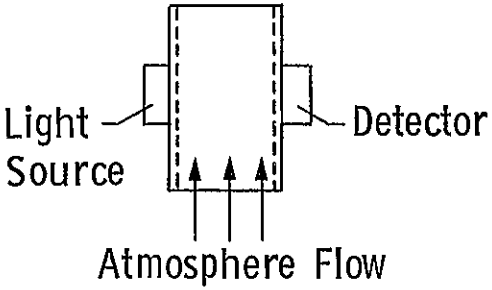


FIGURE II-4 - SCIENCE INSTRUMENT - TECHNOLOGY DEVELOPMENT

A technique which can satisfy the design to measure atmospheric trace elements in the lower atmosphere down to one part per trillion is atomic and molecular resonance fluorescence, the basis of which is depicted in Figure II-5 . A beam of photons, resonant in energy with a preselected electronic transition of the atom or molecule under study is passed through the sample gas. This method has been proven in stratospheric flights by Dr. J. G. Anderson of the University of Michigan.

The absorption and subsequent re-emission of the resonant photon results in the isotropic re-distribution of energy from the incident beam. The number of photons scattered at right angles to the incident beam per unit time, in the absence of re-absorption of the scattered photon, is proportional to the number of atoms or molecules per unit volume which have transitions out of the ground state to an upper bound electronic state with an energy difference equal to the energy of the incident resonant photons. In practice, there is little difficulty in achieving uniqueness in the determination of which species are responsible for the fluorescence because the energy separation of individual transition for different atoms or diatomics is much greater than the band pass of either the source or the detector.

In addition to detecting the atom or radical, it is essential that the measured sample remain unaltered by the presence of the detection equipment because most of the species of interest re-combine with unit efficiency at any wall with which they collide. This problem is circumvented by flowing the sample gas at high velocity in a direction perpendicular to both the incident beam and the direction of observation of the detector, as shown in Figure II-5 . In order to facilitate the absolute calibration of the detector-source combination and to provide optical protection for the detector, the system is enclosed in a cylindrical pipe also shown schematically.

For the application of resonance fluorescence to <u>in-situ</u> measurements it is necessary to arrange the pressure, velocity, and detection chamber dimensions such that the diffusion time from the scattering volume to the chamber wall is at least two orders of magnitude more than the residence time of the sample within the instrument (i.e., the time between entry and detection). In addition, because the species are extremely sensitive to changes in temperature, it is

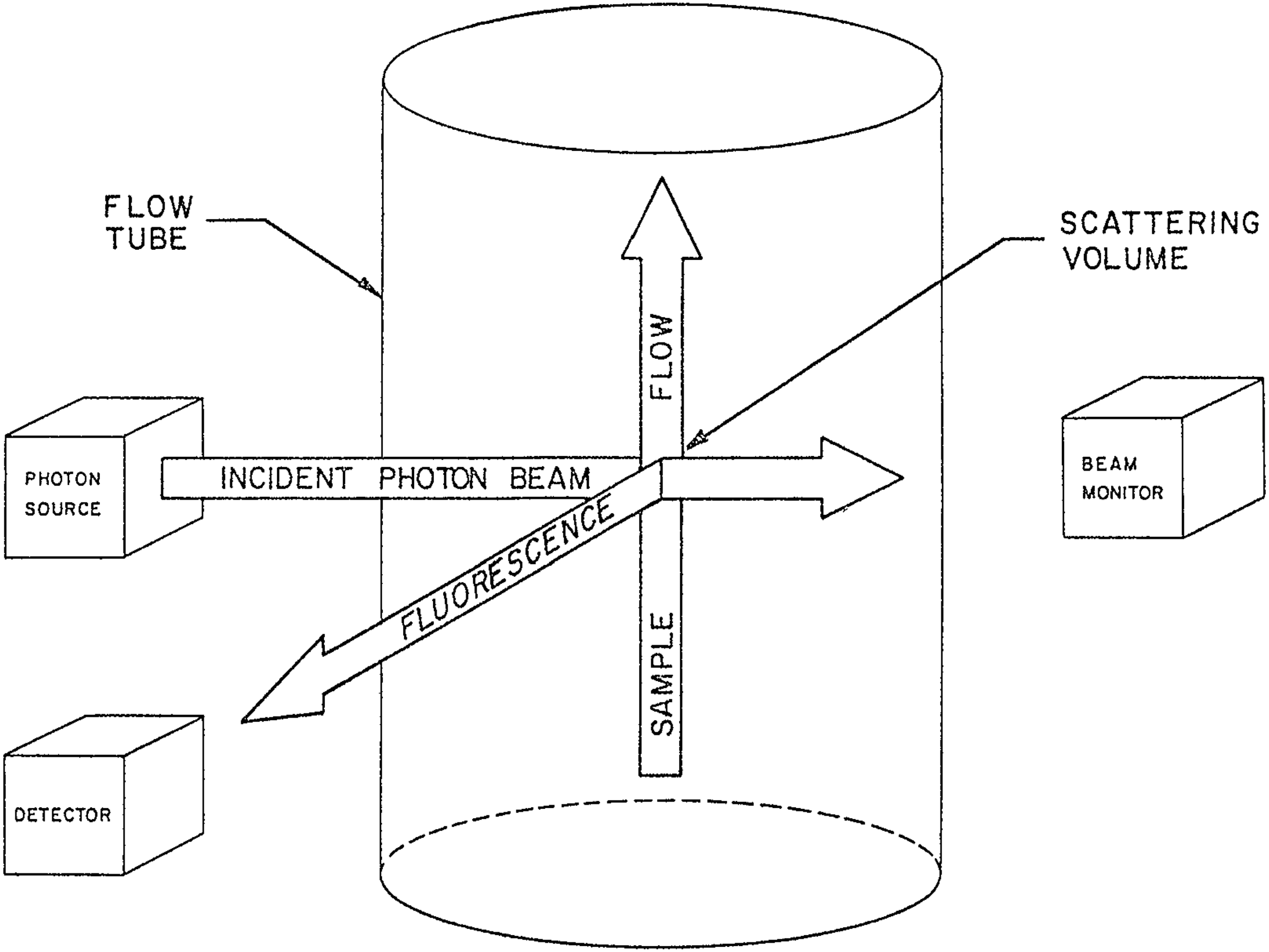


FIGURE II-5 - FLOW THROUGH RESONANCE FLUORESCENCE important that heating processes, such as those encountered during traversal of a shock front, be eliminated.

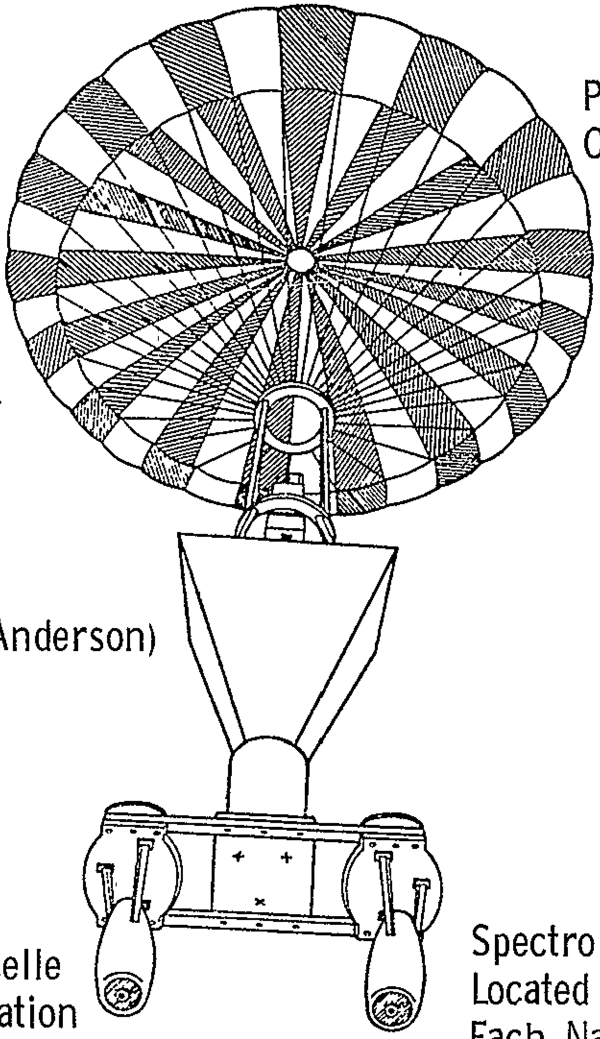
In order to minimize the diffusion rate to the wall, the detection chamber and flow pipe are housed in an aerodynamically shaped pod or "nacelle" which establishes laminar flow around and through the instrument. This shape also desensitizes the flow characteristics to changes in the angle of attack of the instrument, which is important for measurements which may be made in a turbulent atmosphere. The stratospheric measurements have been made with the instrument descending under a parachute as shown in Figure II-6 .

There are several candidate sources which can be used to induce fluorescence in atomic and molecular species, and they generally fall within three categories: (a) a high temperature blackbody such as a Xenon arc, (b) a plasma discharge resonance lamp, or (c) a tunable dye laser with frequency doubling.

Several objectives must be considered in the design of the instrument: First, optical rejection of the photon beam used to induce fluorescence by the detector must be achieved and the instrument must discriminate against atmospheric back scatter; Secondly, provision must be made for eliminating the fluorescing species from the measured sample in order to determine the background count rate; and thirdly, the instrument must be sufficiently small such that a simultaneous measurement of a number of interrelated species can be made from a single experimental platform.

Figure II-7 shows a perspective of the detection chamber through which the sample flows during descent. A cross section through the optical axis is shown in Figure II-8 , which shows the collimator and baffle system used to achieve rejection of the photon beam after one traversal of the sample, and Figure II-9 shows a cross sectional view through the axis of the flow pipe showing the light trapping system used to eliminate contributions to the background count from atmospheric scatter. Elimination of the fluorescing species from the sample is achieved by adding a reactant gas through the loop injector at the entry throat, thus eliminating the atom or radical from the flow. The gas addition method can also be used to convert a molecule not amenable to resonance fluorescence technique to one which is easily detectable.

Balloon-Launched for
Earth Stratospheric
Analysis



Parachute for
Controlled Descent

(From Report by Dr. J. G. Anderson)

Dual-Nacelle
Configuration

Spectrometer
Located in
Each Nacelle

FIGURE II-6 - RESONANCE FLUORESCENCE SPECTROMETER DESCENT IN EARTH'S STRATOSPHERE

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OF POOR QUALITY

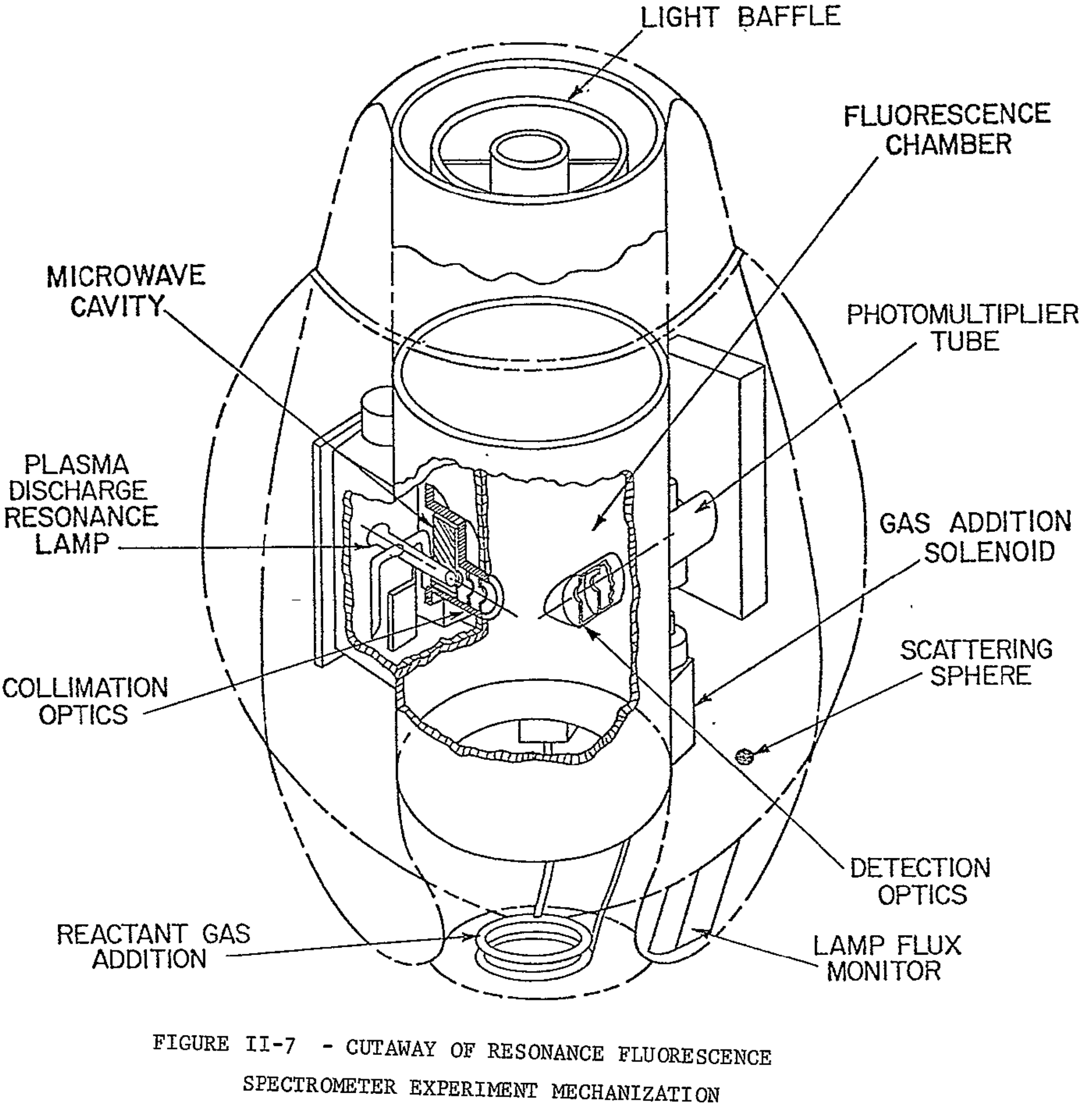


FIGURE II-7 - CUTAWAY OF RESONANCE FLUORESCENCE SPECTROMETER EXPERIMENT MECHANIZATION

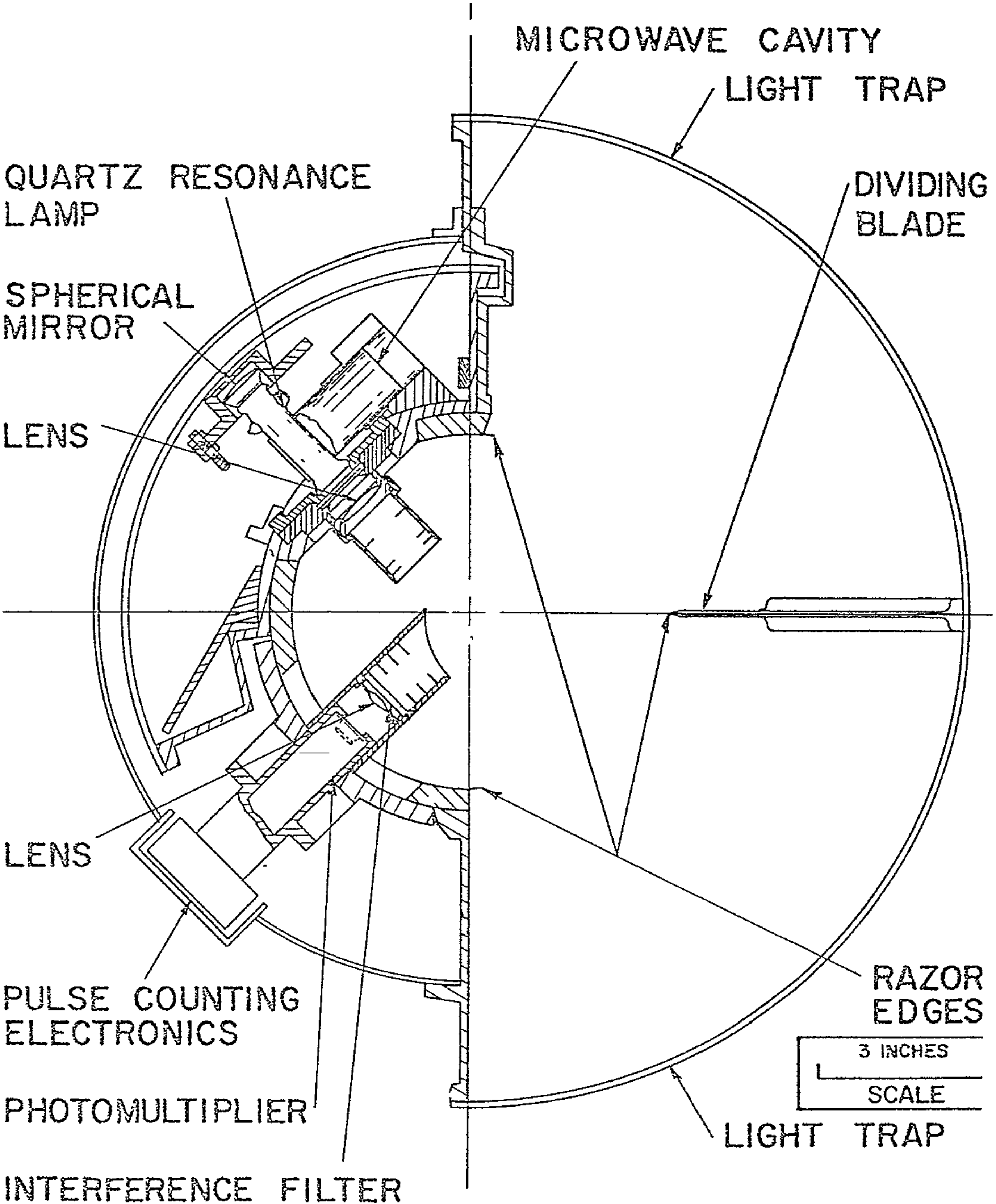


FIGURE II-8 - LAYOUT OF RESONANCE FLUORESCENCE SPECTROMETER EQUIPMENT

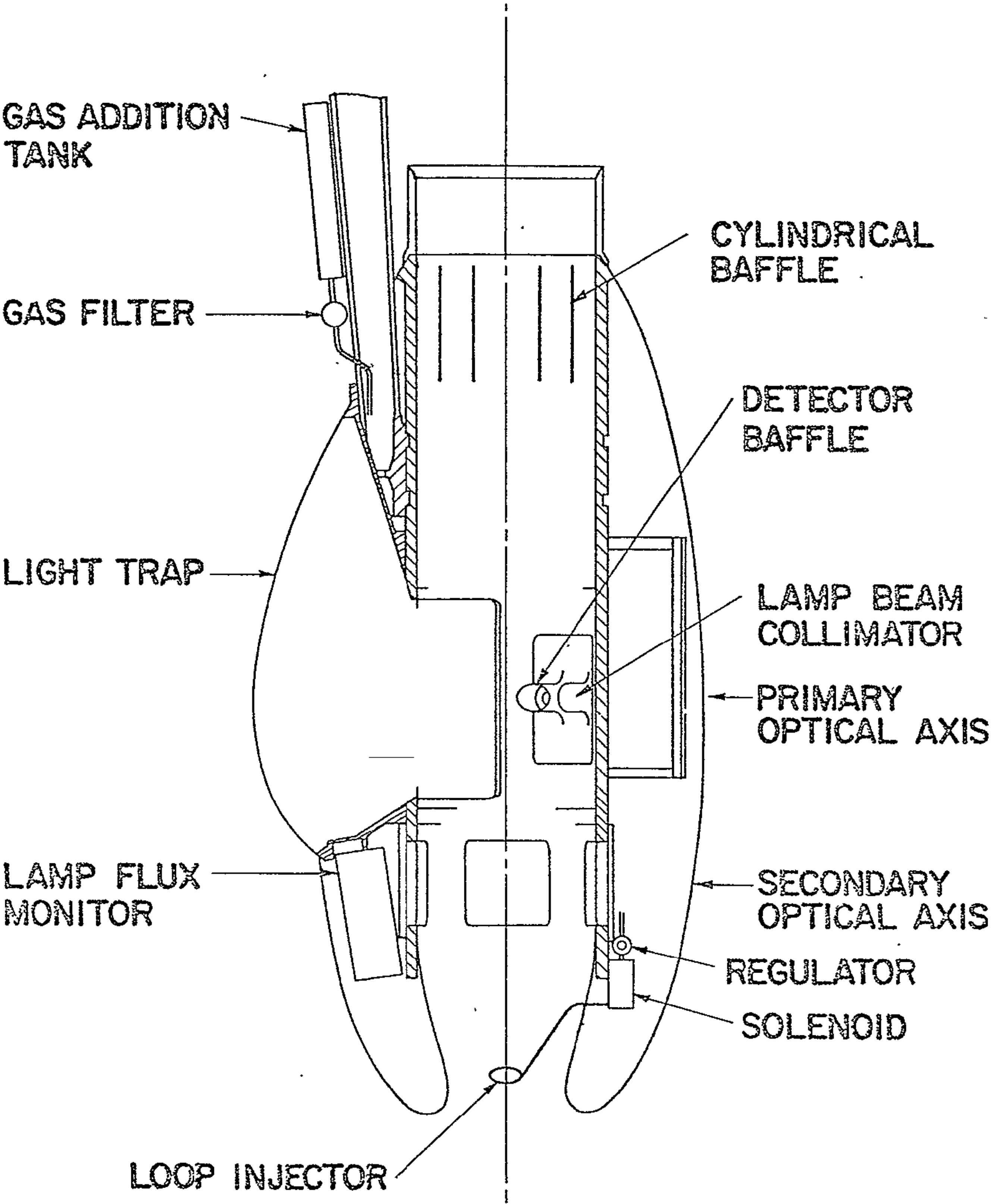


FIGURE II-9 - CUTAWAY OF NACELLE SHOWING EXPERIMENT LAYOUT

E. SCIENCE DATA REQUIREMENTS

In order to scope the impact of science data requirements on the probe data handling and communication system, the data requirements have been estimated for the most demanding science instrument identified as a candidate for a deep probe mission, which is the absorption spectrophotometer. The following estimate of data requirements is based on a 1,000 bar depth and a scanning range from 2,000 angstroms to 12,000 angstroms.

The instrument will generate 10,000 spectral elements per scan, and 10 bits per spectral element, for a total of 100,000 bits per scan. Assuming 1 scan per 1/3 scale height ($\sim$ 75km), this results in a data rate of approximately 150 b/s for a 100 minute descent probe.

At shallower depths, the atmosphere scale heights are smaller and descent velocities higher, resulting in a higher bit rate requirement. However, this is mitigated by reduced atmospheric attenuation; therefore the requirements generated for the 1000-bar situation provides a good basis for evaluating probe mission concepts and communication system technology requirements.

III MISSION CONCEPTS

Within the guidelines of an orbiter-supported probe mission that is not constrained from either a mass or technology standpoint, a wide variety of mission concepts can be considered. These concepts range from staged fixed-ballistic-coefficient probes to probes with continuously variable descent rate control to designs incorporating lateral range or hovering and climbing capability. In terms of data return concepts, it is possible to transmit the data from the deep probe directly to the delivery orbiter, or via a second, shallower, communications relay probe. A second orbiter phased to come into range towards the end of the probe descent is another alternative.

All of these techniques have been examined, but based on the science objectives identified in the previous chapter, it appears that the simpler mission concepts are adequate. For example, the degree of lateral range which could be achieved after entry, by aerodynamic lift or propulsive techniques, does not appear to afford a sufficiently different sampling region to justify the added complexity, in view of the huge scale of Jovian atmospheric features. Likewise, hovering at a given altitude or ascending to a previous altitude turn out to be not of particular interest from a science sampling viewpoint. However, for the case in which an ionized atmosphere is encountered, preventing RF communications, it would be desirable to physically transport the probe, or a data capsule from it, out of the ionized region.

Continuously variable ballistic coefficient control is a feature that would certainly enhance the science sampling aspects of the mission, as well as simplify the thermal control and data transmission designs. For these reasons, concepts for achieving this feature have been evaluated. Continuously variable control does not appear to be, however, a fundamental requirement for a successful deep probe mission.

In view of the above, it was decided that staged, fixed-ballistic-coefficient descents would be appropriate for the purpose of establishing descent profiles for use in defining probe subsystem requirements. These profiles are described in the following paragraphs in conjunction with the resulting probe-orbiter communications geometry.

A. DESCENT PROFILES - JUPITER

1. Rapid Descent

The two-stage descent profile of Figure III-1 represents about the most rapid descent that is consistent with achieving the science objectives. The probe is staged from the entry aeroshell at a pressure altitude of about 0.1 bars. Obtaining composition measurements from that altitude to 10 bars takes about 25 minutes, which corresponds to a probe ballistic coefficient of ~ 50 kg/m^2 (compared to an entry ballistic coefficient of ~ 150 kg/m^2). Staging at 10 bars to a ballistic coefficient of ~ 1900 kg/m^2 produces a descent rate of ~ 400 m/s, which is near the maximum that is compatible with composition measurements. With this ballistic coefficient, the 1000 bar level is reached in 100 minutes, at which time the descent velocity has slowed to ~ 80 m/s.

During the 100-minute time period, the orbiter has passed overhead and reached a range of approximately 100,000 km, depending on its location at the time the probe enters the atmosphere, see Figure III-2. These calculations are based on an orbiter periapasis radius of 1.8 Jupiter radii, which is near optimum from a communications standpoint. Although this trajectory places the orbit within the region of relatively high radiation levels, it is assumed that adequate shielding mass can be provided. The other parameter of interest is the probe/orbiter aspect angle. A small value for this angle is desirable, particularly when the probe is deep in the atmosphere, to minimize antenna beam width requirements and to minimize attenuation losses due to atmospheric scattering.

Because of the high velocity at 1000 bars, the bit rate at which the science data must be transmitted is also high, ~ 150 b/s for the absorption spectrometer. This bit rate, combined with the 100,000 km range and the losses in signal due to the atmospheric attenuation, dictate beyond the state-of-the-art technology transmitters or advanced data compression techniques. Developments in these areas are considered (Chapter IV), but as an alternative, the use of a relay probe (as originally suggested in MCR-11-1, Jupiter Atmospheric Entry Mission Study, April 1971, is also considered. The trajectory of the relay probe is shown in Figure III-3. In addition to relaying data from the deep probe, the relay probe would also obtain science data to about 30 bars. This approach permits the use of state-of-the-art communications and data systems.

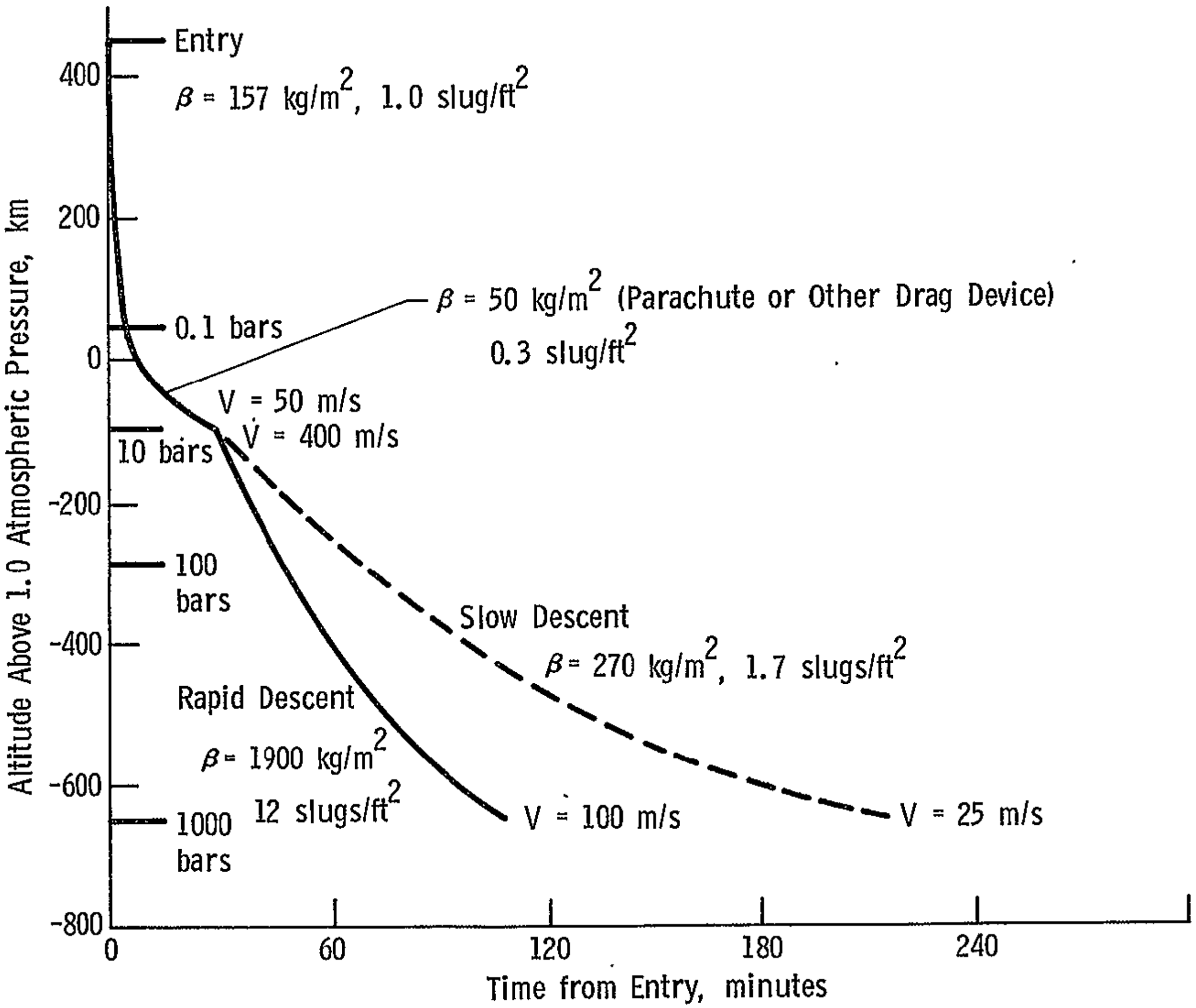


FIGURE III-1 - EXAMPLE DESCENT TIME HISTORIES

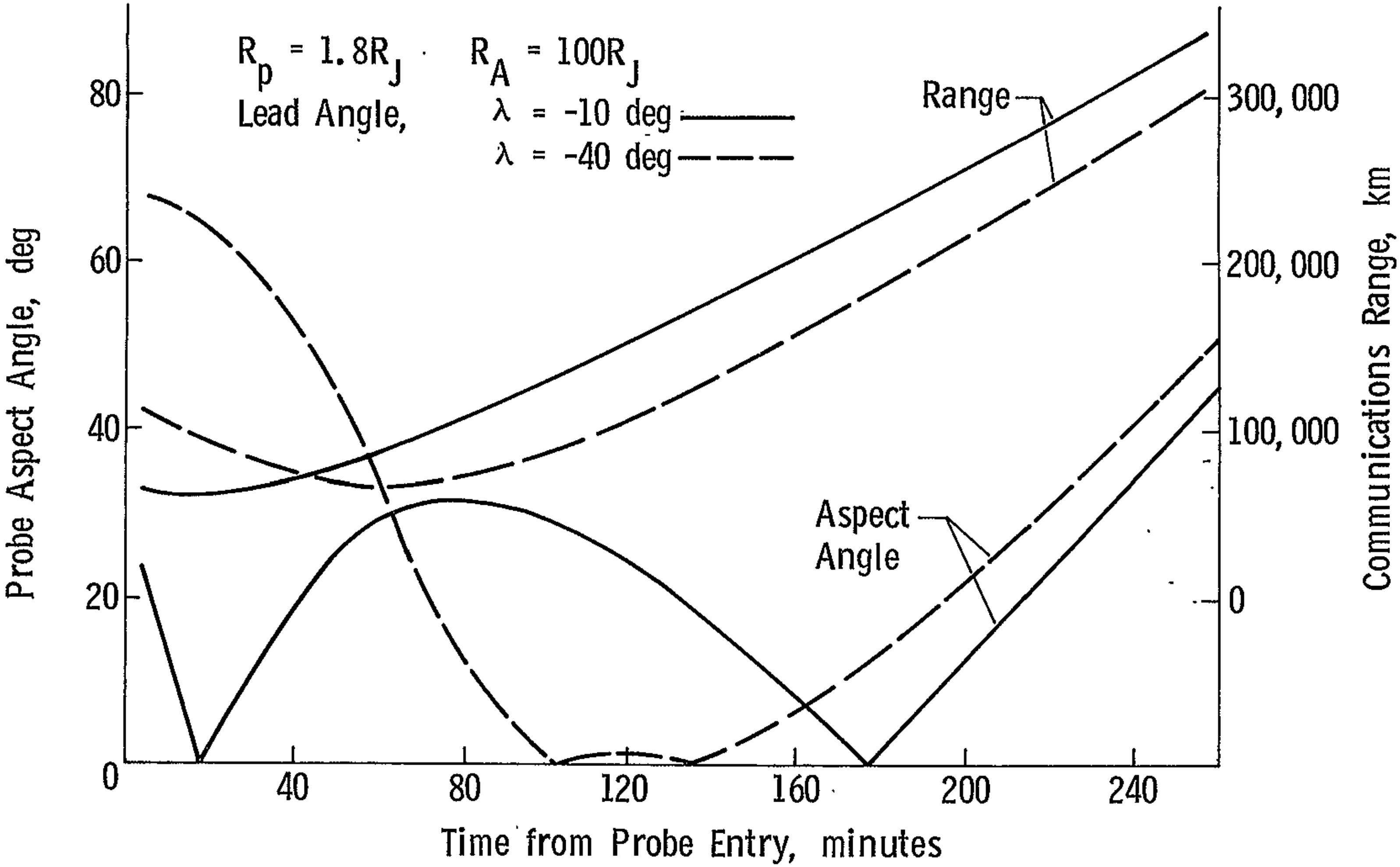


FIGURE III-2 - JUPITER PROBE TO ORBITER RANGE AND ASPECT ANGLE

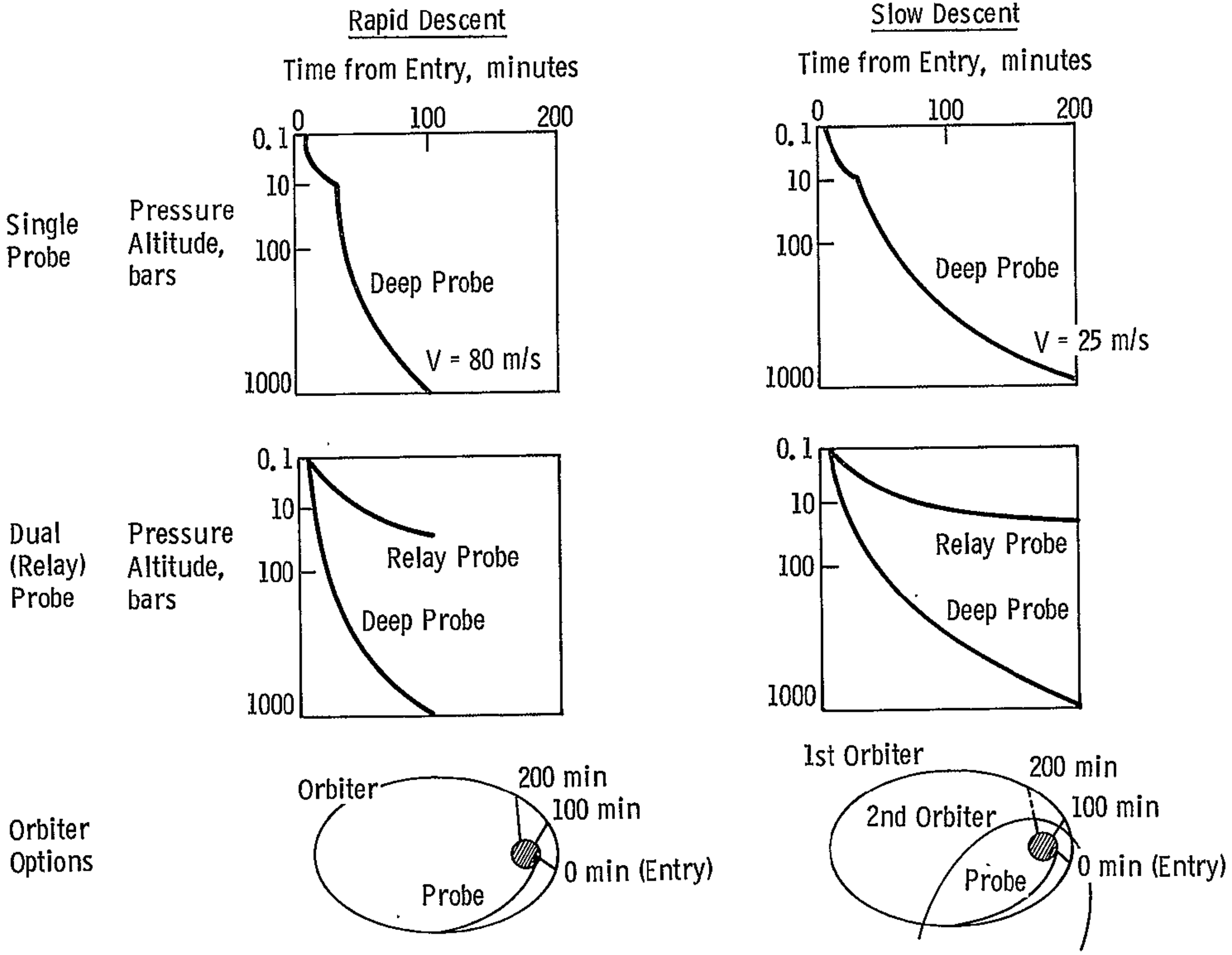


FIGURE III-3 - EXAMPLE DESCENT PROFILES

2. Slow Descent

The data rate problem can be relieved for the single probe case by a slower descent, which would also facilitate data sampling and processing. A 200 minute descent profile is shown in Figure III-1. The velocity at 1000 bars is reduced by about one-fourth to 25 m/s, and the data rate is reduced a corresponding amount. The data rate reduction is offset, however, by a doubling of the range to the orbiter, Figure III-2, unless a second orbiter is introduced to pick up the probe transmission during the latter part of the descent. The dual orbiter approach appears feasible, since by use of "pumping and cranking" techniques (using the gravity assist potential of the Jovian satellites), it should be possible to achieve an orbit whose periapasis is shifted 60 degrees around from that of the 1st orbiter, see Figure III-4. This would keep the maximum range below 100,000 km. A relay probe is also a possibility with the slow descent and would further enhance the acquisition and transmission of scientific data.

A disadvantage of the slow descent is the increased thermal load, and for this reason the possibility of an active thermal control system was examined.

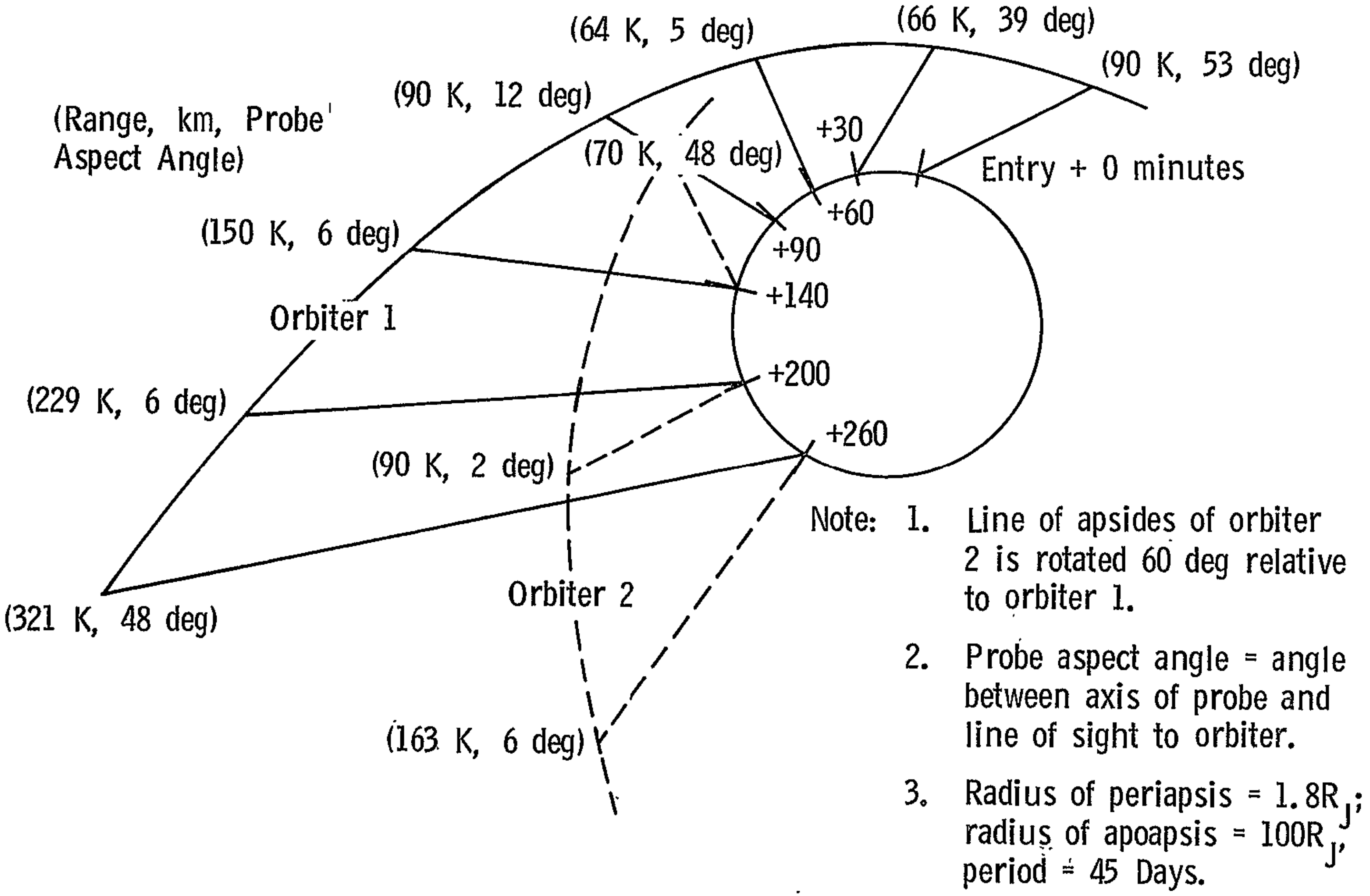
Figure III-3 summarizes the descent profiles and the orbiter/probe relative geometry for the cases considered. Appendixes C and D contain more details of the trajectory calculations.

B. DESCENT PROFILES FOR SATURN AND URANUS

Due to the different masses and atmospheric densities, the descent profiles and relative probe/orbiter geometries for Saturn and Uranus differ from those for Jupiter. Figure C-8 of Appendix C shows the descent profiles for the three planets for the same ballistic-coefficient probe. The Saturn and Uranus probes are seen to take about three times as long as the Jupiter probe to descend to the 1000 bar level. Figures D-11 and D-12 of Appendix D show the relative communications geometry for Saturn and Uranus.

The significant things these plots reveal are the following:

In the case of Uranus, the longer descent time if offset by the closer-in orbiter trajectory, i.e., due to the smaller planet radius, the 1.8 R_p orbiter trajectory results in a range from the probe to the orbiter at 1000 bars



Note: 1. Line of apsides of orbiter 2 is rotated 60 deg relative to orbiter 1.

2. Probe aspect angle = angle between axis of probe and line of sight to orbiter.

3. Radius of periapsis = $1.8R_J$; radius of apoapsis = $100R_J$, period ≐ 45 Days.

FIGURE III-4 - JUPITER PROBE - DUAL ORBITER RELAY LINK GEOMETRY that is no greater than the 100,000 km range that exists at Jupiter. (This might suggest going in closer than a 1.8 planet radius at Jupiter, but this does not improve the communication geometry in that planet because of the higher orbiter velocity that results.)

The longer descent time in Saturn and Uranus is no more severe from a thermal control standpoint than the Jupiter descents due to the lower atmospheric temperatures at 1000 bars in Saturn and Uranus.

In the case of Saturn the probe-to-orbiter range associated with the 1000 bar level is about twice the range for the Jupiter case. This is a consideration in the determination of the probe technology advances required and is discussed in Chapter IV.

IV. PROBE TECHNOLOGIES

A number of alternative mission, system, and subsystem concepts have been considered for accomplishing the science objectives discussed in Chapter II. This chapter presents a matrix of these concepts, identifying those that require the development of new or advanced technologies. These concepts can be combined in various ways in synthesizing deep probe missions. The combination of concepts judged to require a minimum of new technology development is discussed first, followed by a combination that would produce a minimum-mass probe. Other combinations are then considered that involve advanced technologies, which development would further enhance the science accomplishments, or which would provide alternatives to the concepts identified in the first group. Finally, the potential for thermal ionization in the deeper layers of Jupiter's atmosphere is analyzed, and several advanced technology concepts are identified for coping with the breakdown in RF communications which would take place in an ionized atmosphere.

A. PROBE TECHNOLOGY MATRIX

The matrix of Figure IV-1 identifies the mission and system concepts that have been considered in each area to implement a deep probe mission. The main part of this chart lists options appropriate to a planetary atmosphere in which ionization levels have not reached concentrations that would create a conducting atmosphere and thus prevent RF communications. The depth at which ionization is likely to become a problem is difficult to predict with any certainty. A preliminary analysis (see Section D) indicates that although ionization is not likely to be encountered until a depth of nearly 1000 bars is reached, it could be encountered at a depth of 600 bars if significant vertical mixing is taking place. For this reason, options for dealing with an ionized atmosphere are shown on the right hand side of the matrix.

In the matrix of Figure IV-1, those concepts that appear to require only state-of-the-art technology, or relatively straightforward applications of existing technology, are indicated by an open box. Those involving new or beyond the state-of-the-art technologies are indicated by shaded boxes. Certain options fall somewhere in between these extremes, e.g., the use of a shallow probe for relaying data from the deep probe appears to be a straightforward application of JOP technology, but adds complexity and has not been done before. Options that fall in between the extremes are indicated by a cross hatched box.

Looking at the first column of Figure IV-1, it would appear that with the exception of science instrument development and pressure vessel penetration development (high pressure/temperature feedthroughs, inlets, etc.), it would be possible to synthesize a deep probe with state-of-the-art probe subsystems. This is not quite true, since the SOA options in the various areas are not all mutually compatible. For example; direct transmission from the probe to the orbiter, a state-of-the-art technique, results in too high a data rate for a state-of-the-art transmitter to handle if conventional data handling techniques are used. Thus, either advanced data compression techniques, advanced transmitter technology, or the introduction of a relay probe would be required. A similar situation exists with regard to trying to combine all state-of-the-art subsystems in the thermal/structural area. Combinations of subsystem options which are compatible and which satisfy specific objectives are identified and discussed in the following sections.

B. "MINIMUM" PROBE TECHNOLOGIES

1. "Minimum" Probe Matrix

Figures IV-2A and IV-2B illustrate two different ways which the mission and system concepts from IV-1 can be combined to provide a probe capable of achieving the recommended science objectives. The first Figure (IV-2A) presents a combination requiring minimum new technology development. The second Figure (IV-2B) identifies objects which should provide a minimum-mass probe. The latter combination involves several options in certain subsystem areas as indicated. The concepts requiring advanced technology development are again identified by the shaded boxes.

a. Minimum Technology-Development Probe - Although comprised of relatively few concepts that require technology breakthroughs (the science instruments as discussed previously in Chapter II being the major exception), this combination does contain a number of elements that are either very heavy, require sizable volume, or add complexity to the system. For this reason, this approach may not be the least costly, even in a period of increased payload mass capability.

The new or advanced technology items in this group include (in addition to the science instruments): a separate relay probe; a refractory metal pressure vessel; a high temperature antenna; and feedthroughs, windows, inlets, etc., capable of withstanding the high pressure differential and high temperature. The use of a relay probe to alleviate the high data rate is believed to require less technology advancement than the development of data processing techniques which would provide the large degree of data compression required. A comparison of these two approaches is provided in subsequent paragraphs. The refractory metal pressure shell is identified as the minimum-technology (albeit heavy) solution in the thermal/structural area since off-the-shelf refractory metal alloys are available that can withstand crushing in the 1400K (2100°F) environment. Use of a metalic pressure shell means the antenna will have to be externally located and will thus have to be capable of operating in the 1400K temperature. Suitable materials appear to be available, but designs have not been developed. (Thermally insulating the antenna is also an option, but the development of a high pressure/temperature insulation for the antenna is not consistent with the selection of an uninsulated refractory metal pressure shell --the insulation development option is treated in connection with the minimum mass probe.)

JOP entry technology can be applied, but the dual probe approach (one for relay communications), and the selection of a heavy refractory metal pressure vessel, combine to produce a very heavy probe system. This dictates that a much larger diameter aeroshell must be provided than is required for JOP to keep the entry heating within heatshield capability limits.

Finally, pressure shell penetrations must be developed, i.e., feedthroughs for electrical wires and coax cables, and inlets and windows for instruments. Previous experience (pioneer Venus probes) extends to only 1/10 the pressure levels and 1/2 the temperature levels.

Science Objectives / Probe Elements	Obtain Recommended Measurements to 1000 Bars or to Ionized Region (Whichever Encountered is First)					Obtain Measurements to 1000 bars - Even if Ionized Region is Encountered
Science Instruments	▨ Atmos Comp □ PT Accel Mag, etc	□ Press./Temp Transponder				
Descent Profile	□ Rapid Descent	□ Slow Descent				
Orbiter Support	□ Single Orbiter	▨ Dual Orbiter				
Data Return Mode	□ Direct to Orbiter	⬚ Relay via Probe				▨ Ascending Balloon Capsule
Data Handling	□ Conventional Data Processing	▨ Advanced Processing	▨ Autonomous Data Analysis			
Telecommunications	□ Moderate Power Transmitter	▨ High-Power Transmitter				▨ Laser Communications
Power	□ Remote Activated Battery	▨ Lithium Battery	▨ High-Temperature Battery			
Thermal/Structural	⬚ Refractory Metal Pressure Vessel	▨ Externally Insulated Pressure Vessel	▨ Ceramic or Metal Matrix Press. Vessel	▨ Vented or Press. Equalized	▨ Active Cooling	
Antenna	□ Insulated Antenna	□ Inside Pressure Vessel or Insulated	⬚ High-Temperature Antenna			
Guidance & Control	□ Aerostabilized	▨ Variable-Pitch Rotating Blades	▨ Constant Altitude Balloon	□ Nonstabilized		▨ Nonmechanical Gyroscopes
Entry Systems	□ JOP H/S & A/S Technology	▨ Reflective H/S	▨ Combined Heat Shield/Pressure Vessel			
Mechanical/Electrical	▨ High-Press./Temp. Feedthroughs	▨ High-Press/Temp Electronics	□ No Penetrations			▨ High-Exhaust Pressure Propulsion

Legend:
- ▨ Technology Advance Required
- □ State-of-the-Art Technology
- ⬚ Technology Available but Complex or Untried Application

FIGURE IV-1 - PROBE TECHNOLOGY MATRIX

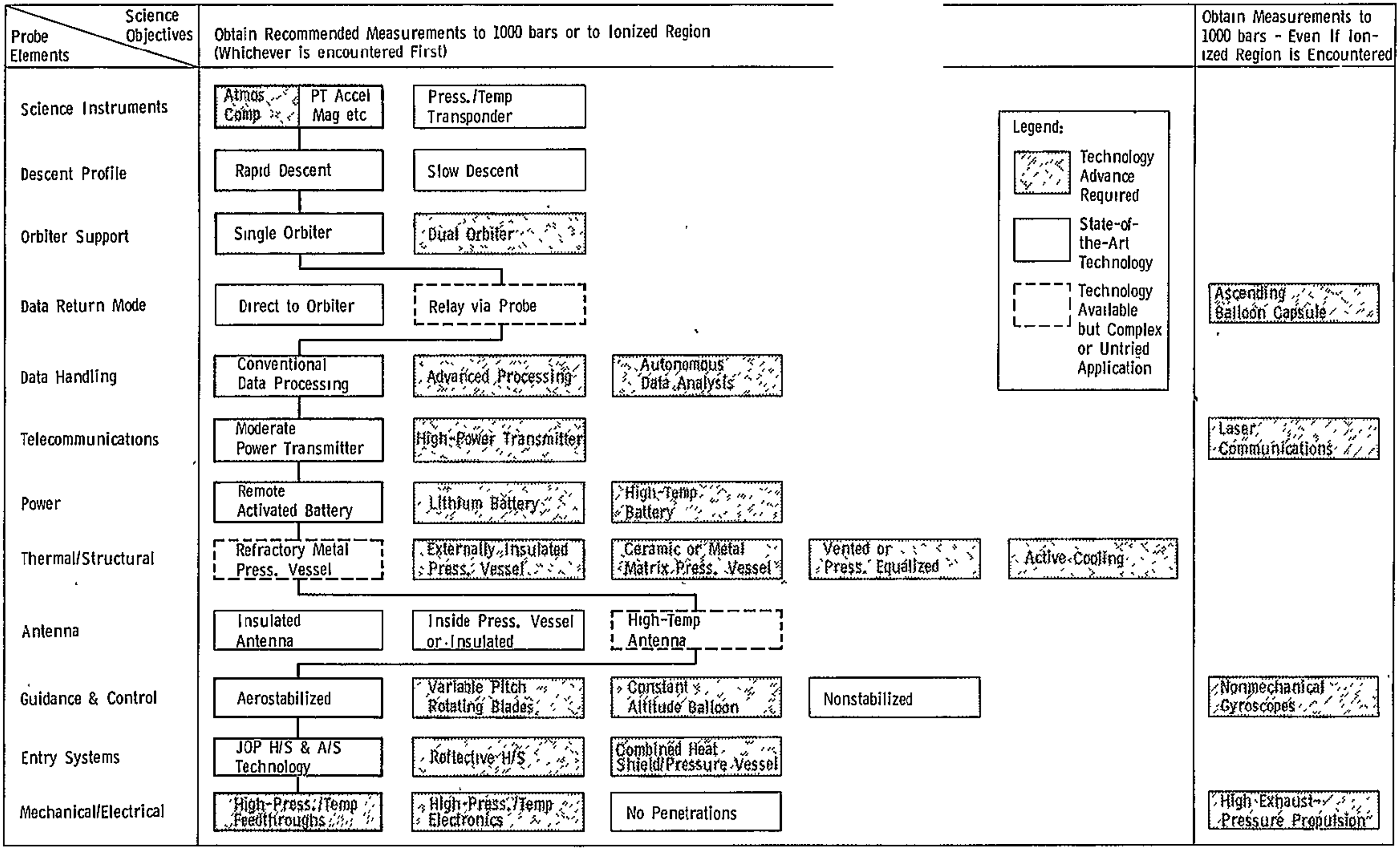
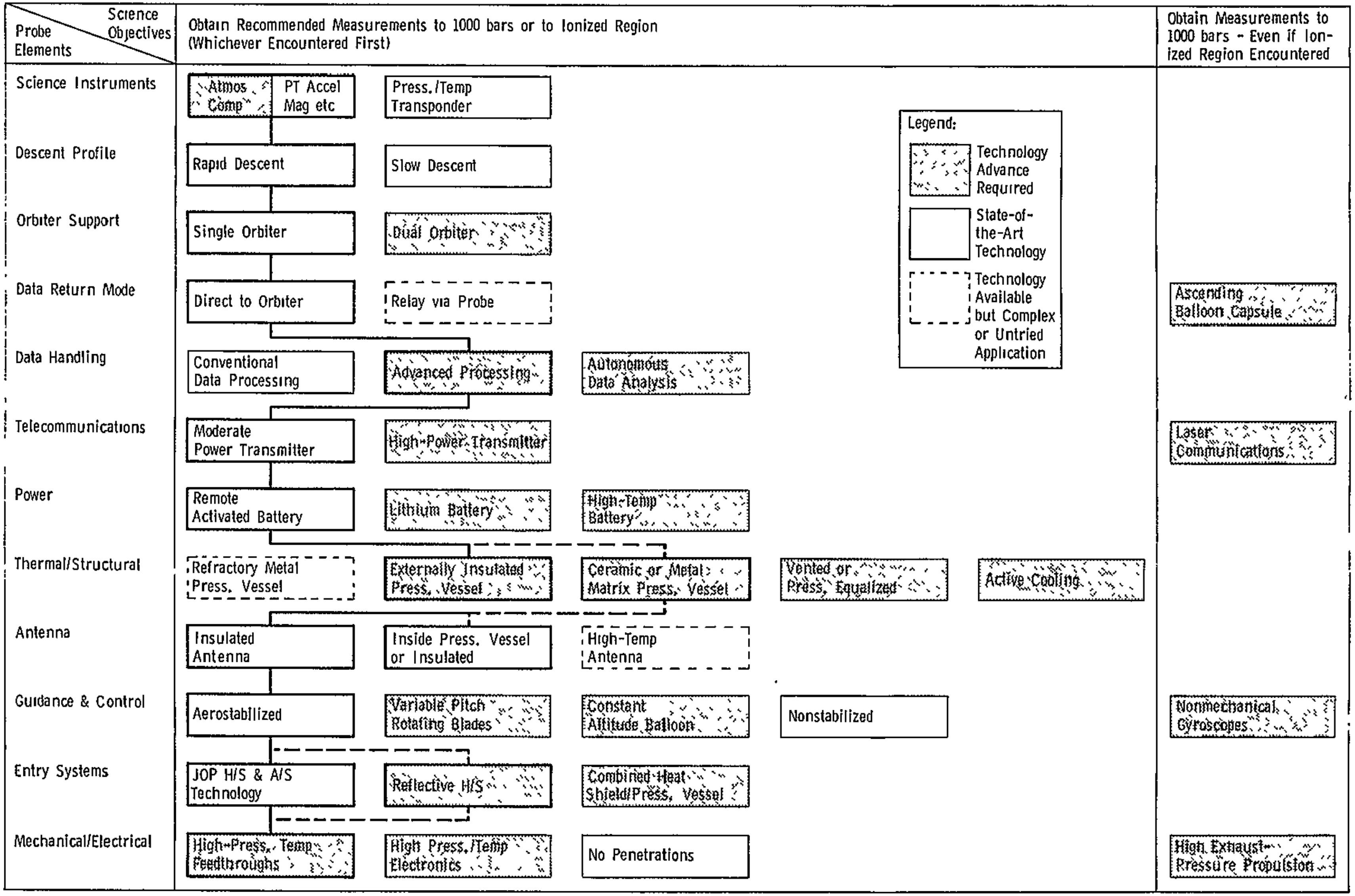


FIGURE IV-2A - MINIMUM TECHNOLOGY DEVELOPMENT PROBE



Science Objectives / Probe Elements	Obtain Recommended Measurements to 1000 bars or to Ionized Region (Whichever Encountered First)					Obtain Measurements to 1000 bars - Even if Ionized Region Encountered
Science Instruments	▨ Atmos Comp ☐ PT Accel Mag etc	☐ Press./Temp Transponder				
Descent Profile	☐ Rapid Descent	☐ Slow Descent				
Orbiter Support	☐ Single Orbiter	▨ Dual Orbiter				
Data Return Mode	☐ Direct to Orbiter	⬚ Relay via Probe				▨ Ascending Balloon Capsule
Data Handling	☐ Conventional Data Processing	▨ Advanced Processing	▨ Autonomous Data Analysis			
Telecommunications	☐ Moderate Power Transmitter	▨ High-Power Transmitter				▨ Laser Communications
Power	☐ Remote Activated Battery	▨ Lithium Battery	▨ High-Temp Battery			
Thermal/Structural	⬚ Refractory Metal Press. Vessel	▨ Externally Insulated Press. Vessel	▨ Ceramic or Metal Matrix Press. Vessel	▨ Vented or Press. Equalized	▨ Active Cooling	
Antenna	☐ Insulated Antenna	☐ Inside Press. Vessel or Insulated	⬚ High-Temp Antenna			
Guidance & Control	☐ Aerostabilized	▨ Variable Pitch Rotating Blades	▨ Constant Altitude Balloon	☐ Nonstabilized		▨ Nonmechanical Gyroscopes
Entry Systems	☐ JOP H/S & A/S Technology	▨ Reflective H/S	▨ Combined Heat Shield/Press. Vessel			
Mechanical/Electrical	▨ High-Press., Temp Feedthroughs	▨ High Press./Temp Electronics	☐ No Penetrations			▨ High Exhaust-Pressure Propulsion

Legend:
- ▨ Technology Advance Required
- ☐ State-of-the-Art Technology
- ⬚ Technology Available but Complex or Untried Application

FIGURE IV-2B - MINIMUM MASS/VOLUME PROBE

The above technologies are further described and discussed in sections of this chapter.

b. Minimum-Mass Probe - A second combination of options that should yield a more compact and lighter-weight probe than the minimum-technology probe group just identified is shown on Figure IV-2A. This group involves more new technology development, but would not necessarily more expensive to implement, depending on the payload dollars per pound relation at the time the mission is flown. Due to its lesser mass and volume, a probe comprised of these options would also be more amenable to being flown as an adjunct to a mission whose primary objective was not the exploration of the deep atmosphere regions.

The new technologies involved in this group, again in addition to the science instrument and pressure shell penetrations technologies, are: an advanced data encoding and error correction encoding system; the development of an external insulation material to limit the temperature of the pressure vessel so that a light weight alloy can be used for the pressure vessel, or the development of a more efficient high temperature pressure vessel design for external use than the refractory metal design, e.g., a design employing a ceramic or metal-matrix-composite material. An additional option for a minimum-mass probe would be the advanced reflective heat shield currently under development at Ames Research Center.

The above concepts are further described and compared with the previously defined minimum-technology probe concepts in the following paragraphs.

2. Data Return and Telecommunications Options

The two leading candidates for dealing with the large amount of data generated by the suggested composition instruments are the inclusion of a relay probe, and the development of advanced data processing techniques.

a. Relay Probe - The relay probe approach is illustrated in Figure IV-3. Since the range from the deep probe to the relay probe doesn't exceed 600 km (1000 km in the case of Saturn), it is possible to transmit the desired 150 b/s with a low power transmitter and a low gain antenna, i.e., less than a 1 watt transmitter is required at a frequency of .4 GHZ. The relay probe can then transmit the deep probe data to the orbiter, along with an additional 150 b/s of data from the relay probe's own instruments, with a state-of-the-art, 50 watt transmitter (at 2.3 GHZ), see Appendix E.

The disadvantages of this approach are the added mass and system complexity introduced by the additional vehicle. From a volume standpoint, however, it appears that the relay probe can be accommodated within the same diameter entry aeroshell as is required by a single deep probe, see Figures IV-4 and IV-5. (The JOP probe volume was used to lay out the relay probe in the integration sketches of Figures IV-4 and IV-5.) The staging operations and parachute subsystems do not appear to require any new technology, and hence, the relay probe approach, although untried, would appear to be a straightforward application of JOP technology.

The total mass of the deep probe and the relay probe is estimated to be about 1.5 times the single deep probe mass. This would require either an increase of 20% in aeroshell diameter over the single probe case, or a moderately more severe entry heating and deceleration environment than that experienced by the single probe.

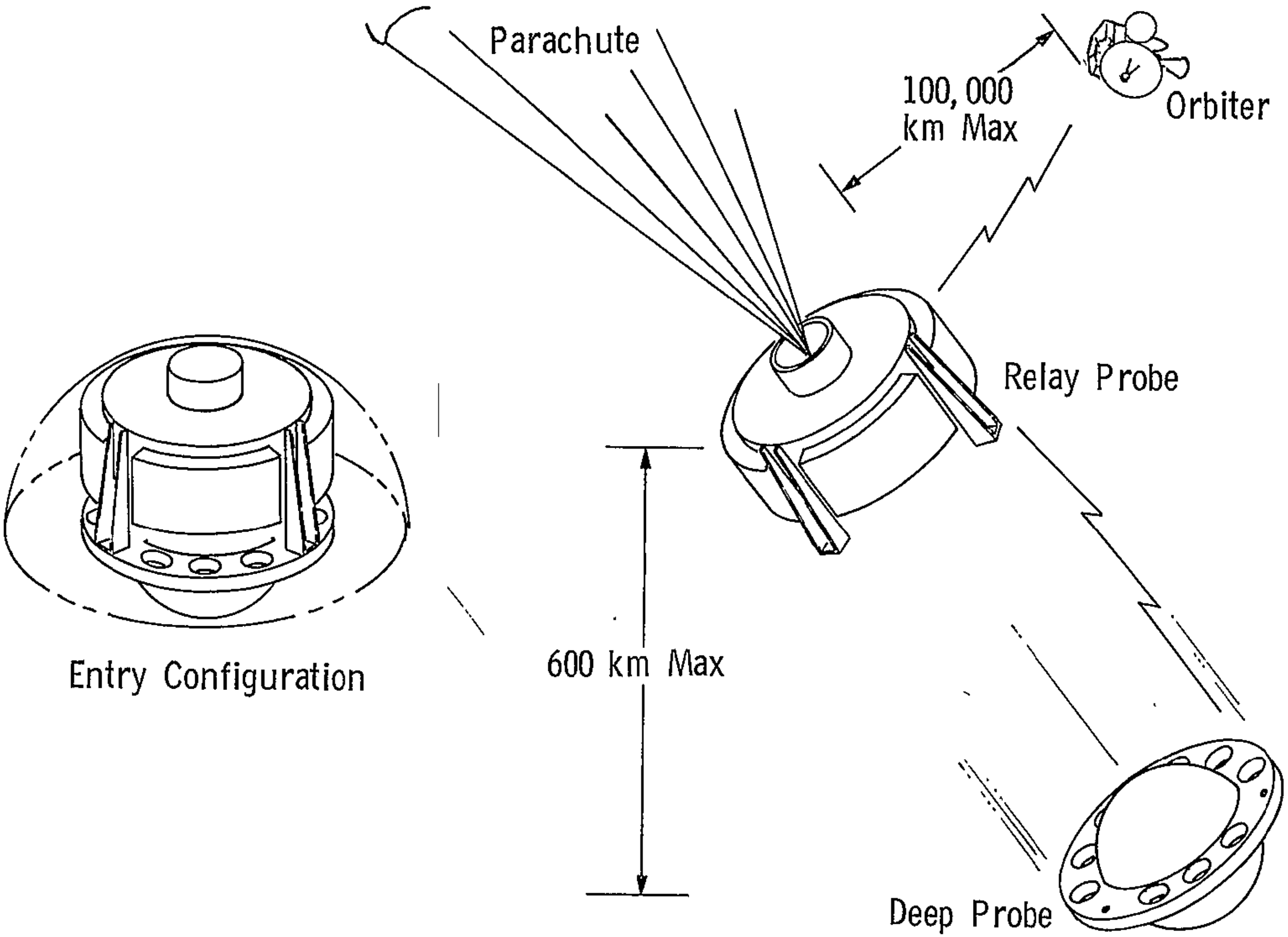


FIGURE IV-3 - RELAY PROBE

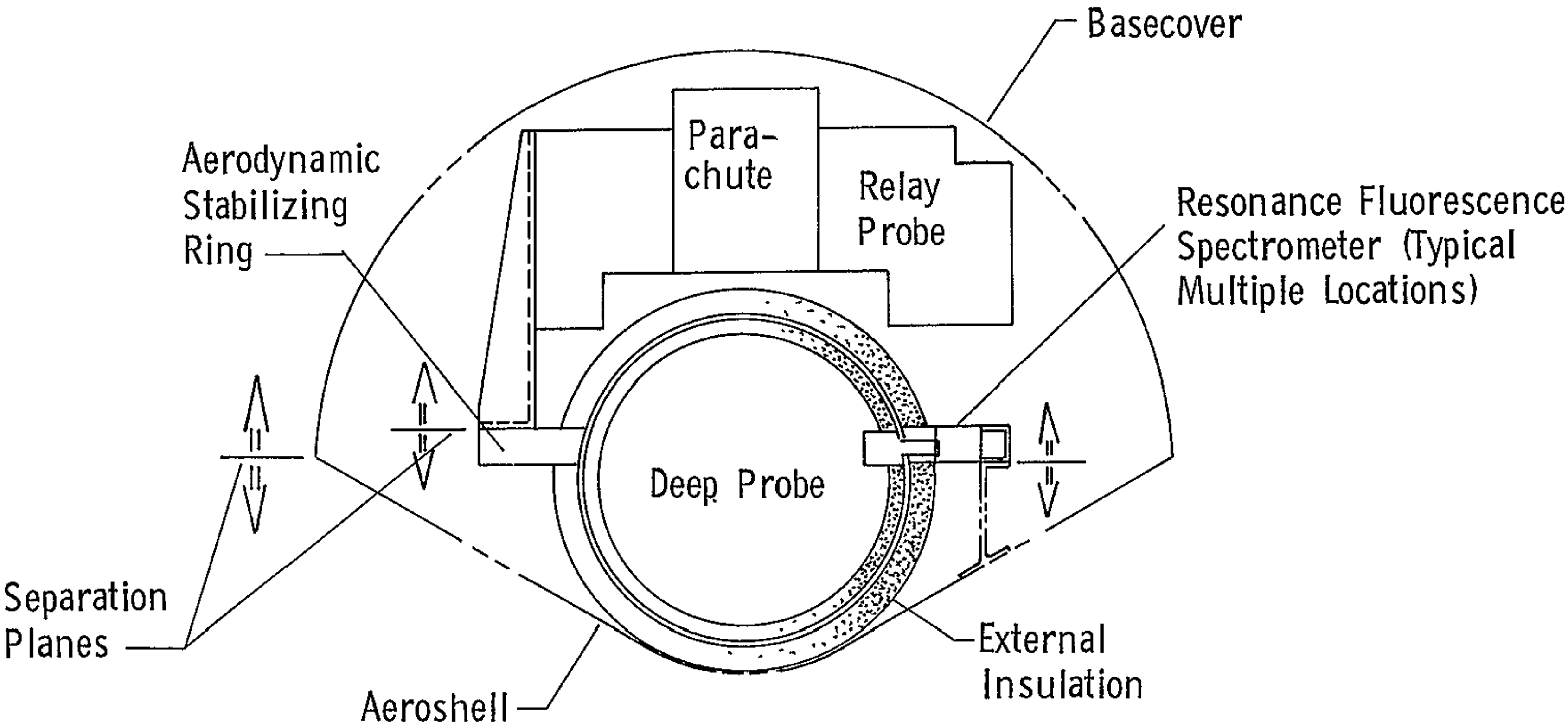


FIGURE IV-4 - PROBE CONCEPT WITH RESONANCE SCATTERING PHOTOMETER IN STABILIZING RING

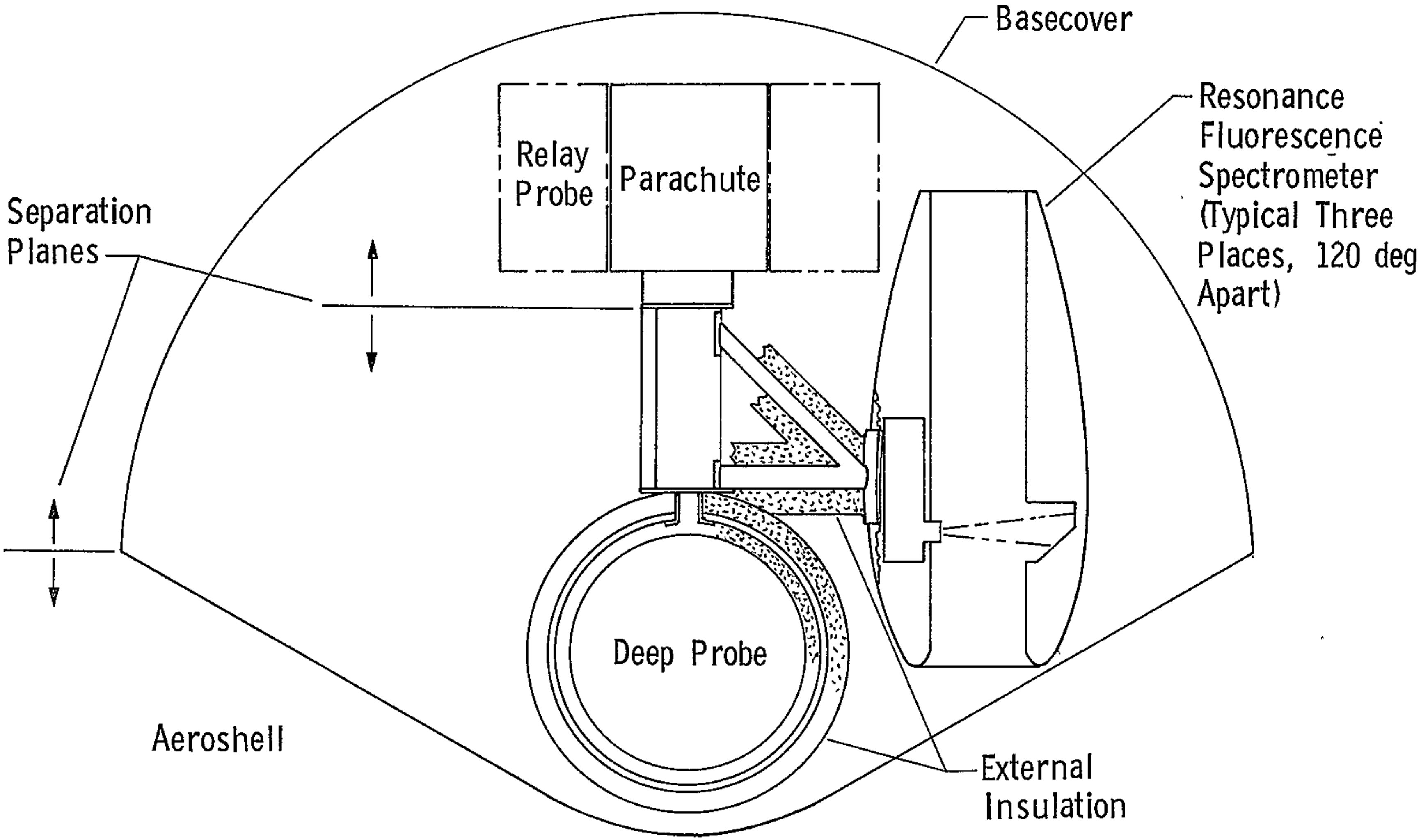


FIGURE IV-5 - PROBE CONCEPT WITH RESONANCE SCATTERING PHOTOMETER IN NACELLE

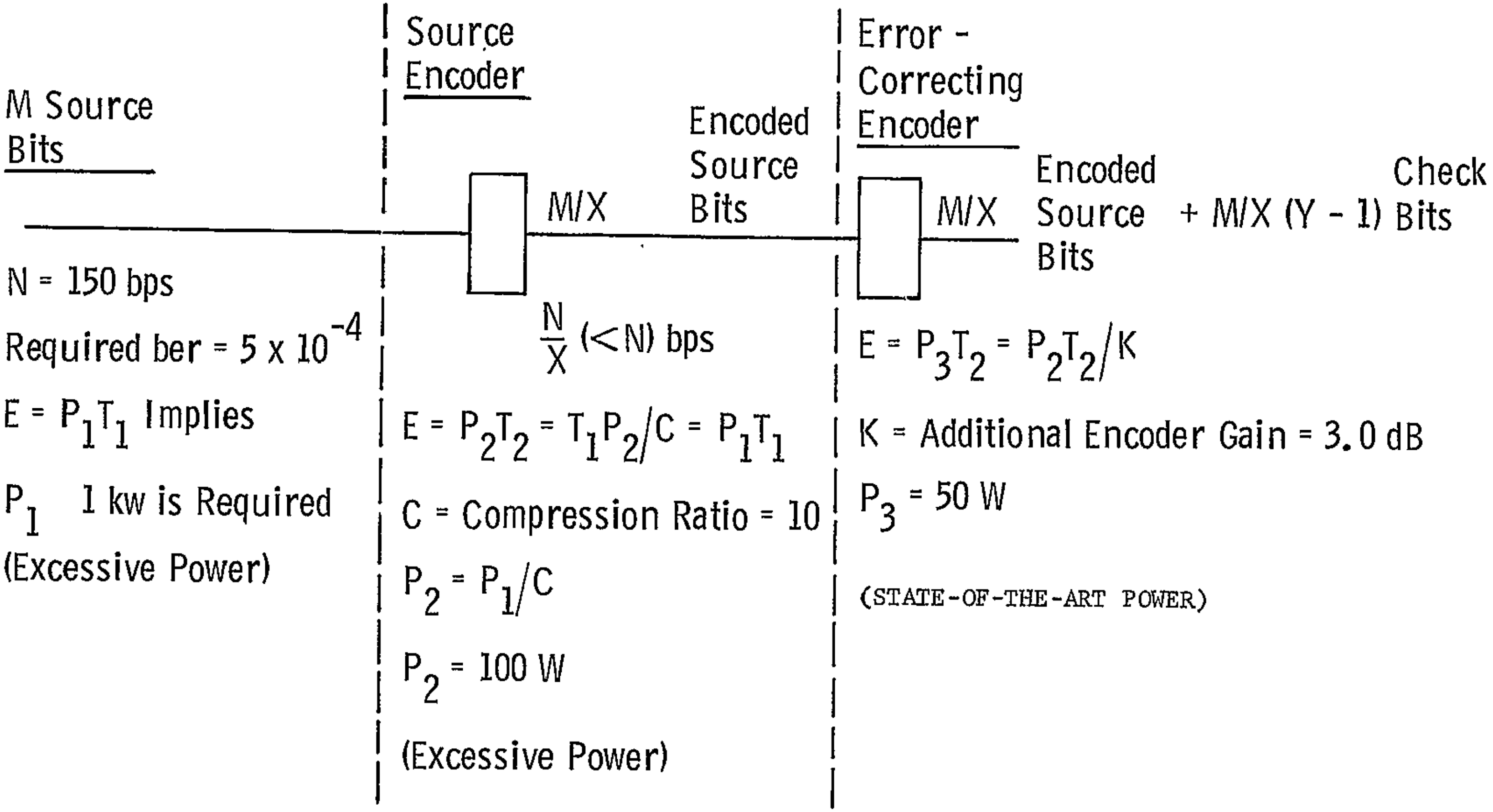


FIGURE IV-6 - DATA COMPRESSION AND CODING

b. Advanced Data Processing Technology:

1) Introduction - The objective of probe data handling design is to aid in maximizing the scientific information return to earth. The data handling system includes all processing of signals that are in binary form. The design includes performance evaluation of the functions performed, plus hardware design. Defining the scope of the data handling system this way implies that the characteristics of the scientific experiments and communication link be carefully considered in the data handling system design.

It is clear, conceptually, that to maximize the scientific information yield, the data required to represent the source information should be minimized while maintaining acceptable fidelity and reliability in order to minimize the transmission power and energy requirements. In fact, it is shown in a later section, that without maximum possible coding gain a single probe mission may not be feasible. It also appears advantageous to perform adaptive sequencing of the experiments, depending upon the experimental data values actually measured during descent. At the same time, the probe design must be simple in order to maximize reliability and minimize size, power consumption, and weight. Recent and anticipated microcomputer technology provides a natural choice for the majority of the processing functions specified for the probe. The alternative of specially designed hardware using medium-scale or large-scale integrated circuits suffers from a lack of adaptability to evolutionary requirements, difficulty in testing to the confidence levels required, and cost per function for the low quantity of units required. Even today, microcomputers are a natural choice whenever the logic functions require more than about 100 medium scale integrated circuits or a much lower number of large scale integrated circuits. Based on a "surprise free" technology forecast, a microcomputer is the logical choice for the major control and data processing element in a probe intended to fly in the mid 1980's. In the section on hardware, reasons will be given why even unforeseen technology breakthroughs are unlikely to impact this choice. Once this choice has been made, a general level of processing capability to enhance probe data handling is inherent in the system, and this capability is basic to the data handling system concepts.

2) Data Handling Functions - Data handling functions include data gathering, source encoding, multiplexing, error correction coding, and command sequencing. Data gathering involves clocking the analog to digital converters (ADC) in the scientific instruments at the appropriate time. This sequence is a combined effect of pre-programmed logic or stored program sequencing and clocking from a master oscillator.

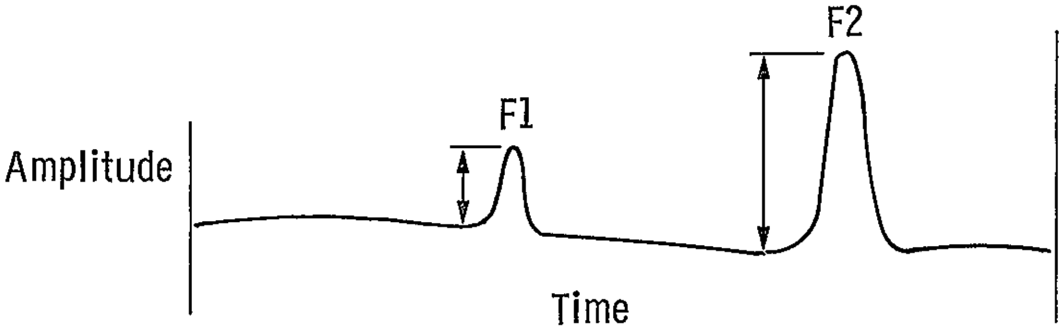
Source encoding is a function applied to the experiment ADC output to reduce the number of bits required to adequately represent the source information. This results in transmitter power reduction. From sampling theory it is known that a band-limited source must be sampled at a rate equal to twice the highest frequency component of the source. Source encoding essentially takes advantage of the fact that the source need be sampled at maximum frequency only during those time intervals when the source is changing at its maximum frequency. The frequency of the encoder output is between the lowest and highest frequency component of the source and is kept constant. An example of a source signal is given in Figure IV-7 . The changes at F1 and F2 contain information with maximum frequency content, plus amplitude content. The changes contain bits of information, while zero bits of information are contained elsewhere. The source ADC's put out samples of 10 bits throughout the interval. A source encoder uses only the number of bits required to represent the information in the changes at F1 and F2 and constant level or near zero information elsewhere.

Multiplexing provides the data handling capability of sampling more than one source during the same time interval. A format delineates the transmission sub-interval time slots assigned to the various sensors and is controlled by the micro-computer. With the small number of probe sensors, multiplexing should be quite easy.

Error correcting encoding involves adding redundant bits to a bit stream to be used to detect and correct transmission errors. The channel error correcting encoder follows the source encoder with possibly a multiplexer in between.

The command sequence controls the science payload order, power control, engineering measurements, and adaptive alterations in measurement sources.

Source Data



Changes at F1 and F2 Contain Bits of Information with Zero Bits Elsewhere

Encoding Techniques Capitalizing on This:

- Delta Modulation (Voice)
- Hadamard Transform (Video)
- Delta/Hadamard Hybrid (Video)
- Run Length Codes (Data)
- Karhunen Loeve Expansion

Source Encoding Minimizes Number of Bits to Represent Source Data

FIGURE IV-7 - DATA HANDLING - SOURCE ENCODING

3) Hardware - A typical probe data handling system is depicted in Figure IV-8 . The probe microcomputer hardware components consist basically of the microprocessor, memory, master oscillator, and countdown chain. In addition, data compression and error correction coding may utilize specially built hardware, or these functions may be incorporated into the basic microcomputer. The latter is perhaps more desirable and is feasible; however, this should be decided in a more detailed design study.

There are quite a number of microprocessors available to date using bipolar or MOS technology. In either bipolar or MOS technology, space qualified and radiation hardened devices will be available within five years with high probability. Intersil presently has available space qualified memory. By early 1978, three microprocessors are expected to have mil specs; two are 8-bit n-channel metal-oxide-semiconductor (MOS) devices, the Intel 8080A and the Motorola 6800, and the other is the American Micro Devices 4-bit bipolar slice ("Electronics", Sept. 1, 1977, p. 76). The RCA COSMAC microcomputer is presently undergoing military and space qualification and radiation hardening.

Of the two technologies, the MOS devices use less power, while the bipolar devices would increase the power consumption enough to affect the total probe power budget. Thus, the MOS technology is the preferrable device type at this time. The RCA COSMAC is an 8-bit machine with 3 msec instruction fetch-execute time, 65K bytes of memory, power dissipation less than 30mw, and uses 3 to 12 volts supply. The instruction set is sufficient for all anticipated operations required for probe data handling. This appears to be an excellent candidate, not only for the above reasons, but also because of its "orthogonal" architecture that allows extreme flexibility in choosing or altering memory size, input/output functions, and other parameters without affecting the rest of the system. This is in contrast to microcomputers with "bundled" architecture that are relatively inflexible to requirement changes (see "Computer Design", Sept. 1977, pp. 83-91 for an in-depth discussion).

Implementation in custom LSI or VLSI chips is not an attractive option for several reasons: 1) The cost of low LSI parts in low quantity is prohibitive, even with the projected computerized mask making techniques, and 2) The testability of LSI suffers from the "tyranny of numbers"; all or even a substantial portion of the possible logic combinations are simply not testable within any reasonable time frame, even years.

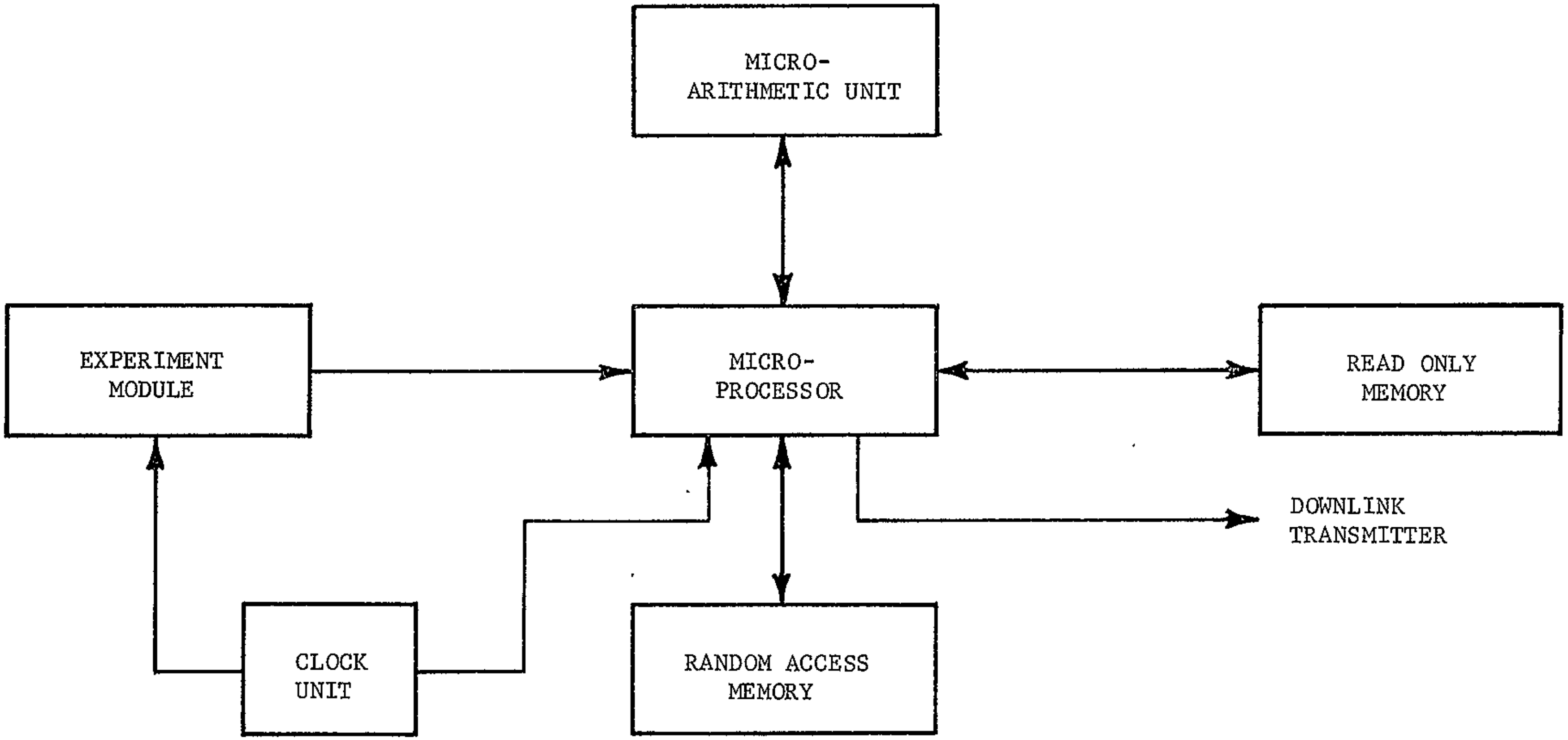


FIGURE IV-8 - ON-BOARD DATA PROCESSING MICROCOMPUTER CONFIGURATION

The memory required by the probe system includes random access memory (RAM) and read only memory (ROM). Semiconductor memories, such as bipolar, MOS, charge coupled device (CCD), or probably some hierarchical combination of these technologies, are likely choices for these functions. Some magnetic memory devices are viable candidates, however, and should be considered, although they are more difficult to interface.

It is important to the probe mission that large amounts of data do not reside in the volatile RAM memory because of the threat of data loss in case of power outage. Thus, programs and fixed data are stored in ROM. The RCA COSMAC micro-computer has RAM and ROM associated. There is additional work being done with MNOS (metal-nitride-oxide-silicon) devices to produce highly reliable non-volatile memory. In MNOS memory charge is captured in a layer depletion region. The voltage across this space charge region offsets the MOS channel threshold voltage. Thus, when the voltage supply is removed, the voltage across the nitride region remains. These can be used in special RAM operations, but are slow because of the parasitic capacitance across the nitride. Erasible ROM is also becoming available, which adds flexibility during the programming stage.

Magnetic devices are attractive because of their survivability in adverse temperature and radiation environments. Bubble memories will be available from Texas Instruments within the year. Bubble memories for space use are being developed by the USAF and NASA, both separately and jointly, and are very attractive from the standpoints of power consumption, bit density, and non volatility. Rein Turn of the Rand Corporation ("Computers In The 1980's", Columbia University Press, 1974) predicted that plated wire memories would find applications in space probes of the 1980's, but in spite of successful usage in the Viking Lander computer, plated wire does not appear to be a viable competitor for bubble, CCD, or other semiconductor memories.

Bubble and CCD memories are most cost effective in the mid-range of the memory hierarchy, essentially being considered as replacements for tape-recorders. (For an excellent discussion of memory technology, hierarchies and a forecast, see D. A. Hodges, "Scientific American", Sept. 1977, pp. 130-144.) These technologies are important to adaptive processing, discussed below. The

CCD memory has an advantage in that the massive inertia of silicon technology is behind it, whereas bubble memories are effectively being developed in isolation from any massive technological base.

4) Adaptive Processing - Adaptive processing consists of using the probe on-board processor to obtain the best information gathering and transmission parameter values based upon the environmental conditions as they are actually found to be. The subject areas are on-board data analysis, data gathering sequence, and perhaps thermal control. The specific design and benefits of the adaptive aspects can be detailed more after further developments result in the science area. If the spectrophotometer is used as an example, spectral peaks and their amplitudes could be identified by on-board analysis in a microcomputer and transmitted in real time while the raw digitized data was stored for later transmission as long as it could be received error-free. The on-board microprocessor can calculate orders of magnitude faster than the data link can transmit.

5) Hardware Development Emphasis - The following developmental emphasis is recommended:

a) The on-board data processing technology should be identified on the order of 5 years before the expected launch data and confidence of reliability gained through intensive usage and test. This approach strongly argues for a microcomputer with an orthogonal architecture as opposed to dedicated special purpose logic devices.

b) No matter what electronic technology is chosen for control, command, and data analysis and processing, its embodiment will undoubtedly be partly or entirely in large scale integrated circuits (LSI). Microcomputers presently contain about five LSI chips. Regularity of structure should be emphasized so that cell patterns are repeated within the LSI chip. This confers a number of advantages; more complete testing possible, highly increased yield and reliability, higher confidence in reliability predictions. Memory embodied in LSI is an example. That cell functional capability is utilized only fractionally is inconsequential; the area occupied by transistors in LSI is driving toward a 1000-fold reduction and already the parts cost little compared to the packaging and test.

c) Low power will undoubtedly be a stronger drive than size (see b above). For this reason, two families of microcircuits should be considered, CMOS and Integrate-Injection Logic (I^2L). In both the power used is dependent upon the speed of operation, usually expressed in millions of instructions per second (MIPS). While I^2L is relatively new technology, it is nonetheless an excellent candidate for LSI implementation, and is considered to be relatively radiation resistant compared to the other available implementations. The question is whether manufacturers other than Texas Instruments push the development of I^2L.

d) Memories, except for magnetic bubble, will probably evolve sufficiently through the efforts of private industry to meet the needs of space probes in the 1980's. However, space qualification will be a burden to be borne by a small group of users, including NASA. Bubble memories for space use will probably be developed only through direct funding by the benefiting agencies. Even an offer of such funding may not suffice (see e below).

e) A distinct problem arises when private industry is requested by special users, such as NASA, to upgrade reliability, radiation hardness, and temperature range of otherwise standard products. These activities do not enhance the commercial product lines, but instead dilute efforts aimed at the latter. The burden of extensive analysis, testing, burn-in, characterization of failure modes, and documentation may well shift to the systems integration contractors.

6) <u>Technology Development Requirements</u> - The primary technology requirements are in the area of source and channel coding techniques and their microcomputer implementation. The coding objective is to significantly reduce the power requirement for a single probe rapid descent mission. Using the rate of descent and frequency of measurements, the data rate required is:

$$\frac{10^4 \text{ elements}}{\text{scan}} \times \frac{10 \text{ bits}}{\text{element}} \times \frac{1 \text{ scan}}{700 \text{ sec.}} = 150 \text{ bits/sec.}$$

Over the distance from probe to orbiter through the Jupiter atmosphere, the required power could be as high as

$$P = 3KW$$

at 5×10^{-4} bit error rate for a non-optimized link budget. In order for a single rapid descent probe mission to be feasible, this power requirement must be lowered from 3 KW to about 40W to 60W. The 40W to 60W limit is established by power amplifier capabilities.

The coding gain can be calculated as follows: The bit error rate for low rate frequency or phase shift keying (PSK) digital carrier modulation is determined entirely by the energy per bit, E, to single sided noise spectral density ratio. For the uncoded channel,

$$E = PT = 5 \times 10^3 T$$

where P is the power and T is the bit interval. For the channel using source encoding, the data interval is expanded by compressing the data by a factor C called the compression ratio. The power can be reduced by C while E remains constant.

$$E_C = P_C T_C = P_c TC = PT$$

or

$$P_C = P/C$$

Error correcting encoding provides the same bit interval and bit error rate for reduced energy and power due to the error correcting capability of the code. Thus,

$$E_R = P_R T_C = P_C T_C/K = PT_C/CK.$$

The final reduced power after source and channel encoding has been reduced by a factor CK,

$$P_R = P/CK$$

and the bit interval has been expanded from T (equal to 1/150) seconds to CT seconds. The source information, however, maintains its original fidelity and reliability.

If the power amplifier capability is taken to be between 40W and 60W, the total coding gain required is

$$CK = 3KW/50W = 60 = 17.8db.$$

In terms of energy per bit to noise spectral density, this is,

$$\frac{E}{N} = \frac{P_R T}{N} = \frac{PT}{CKN}$$

To assess the feasibility of achieving this amount of gain, we first consider the error correcting coding gain K. Uncoded PSK on an additive white Gaussian noise (AWGN) channel requires E/N equal to 9db for BER equal to 4×10^{-4}.

The Shannon limit states that it is theoretically possible to achieve this BER (actually zero BER) for E/N equal to -1.6db. Therefore,

$$K = 9 + 1.6 = 10.6 \text{ db} = 10 \text{ maximum}.$$

This implies that the compression gain, C, must be equal to or greater than 6. There is a Shannon Rate-Distortion function that relates to maximum possible values for C. Unfortunately, this theory has serious drawbacks in applications and will not be used here. However, values of C greater than 6 have been achieved for voice and video signals. Video signals have been reduced from 8 to 10 bits/picture element (pixel) to 1 to 2 bits/pixel. The compression ratio, C, is between 4 and 10. Theoretically, then it does appear possible to achieve a coding gain of

$$CK = 10 \times 10 = 100 \text{ theoretical maximum}$$

and,

$$P_R = 3 \times 10^3/100 = 30W .$$

Now let us consider the coding gain achievable using existing coding techniques. The coding value of -3db for E/N implies infinite coding capability, or infinite number of check bits, i.e., infinite bandwidth expansion. For a code that adds two check bits for every data bit (a rate 1/3) code the Shannon limit an E/N is -.3db. In practice 1.7db has been achieved with hybrid bootstrap soft decision sequential decoding and 1.93db with concatenated Viterbi Reed/Solomon coding. These techniques have been implemented in hardware. Other techniques using iterative probabalistic decoding have approached these values in computer simulation. Thus, a coding gain of

$$K = 9 - 1.7 = 7.3\text{db} = 5.4$$

has been achieved on the AWGN channel.

There are numerous source encoding techniques that have been simulated and developed into hardware. These techniques include delta modulation, Hadamard transformation, hybrid delta/Hadamard, run length codes, and Kahunen Loeve expansion. Values of C (compression ratio) of up to about 10 have been achieved for audio and video signals. Using a value of 10 for C gives,

$$CK = 54 \text{ and}$$

$$P_R = \frac{3 \times 10^3}{} = 54W .$$

This is within the anticipated power capabilities of power amplifiers so that a single probe mission appears feasible.

Some very significant words of caution must be added to the above discussion. It is because of the considerations to be delineated now that the codings gain area must be considered a technology item. First, all the values used above are for the AWGN channel. Theoretically, the AWGN Shannon limit is worst case, and limits for well-defined fading channels should fall within the AWGN limits. In practice, this does not turn out to be the case. The particular error correcting techniques mentioned are sensitive to fading and would require modifications such as interleaving to combat fading. Also, for a coherent demodulator, the carrier tracking loss affects the coding performance. Finally, implementing with microcomputer technology onboard the probe and orbiter vehicles may cause degradations. A very approximate degradation for these factors should be between 1.0 and 2.5db. Thus,

$$K = 6.3\text{db} = 4.4$$

when estimated degradations are included.

Similarly, for the source encoding gain, certain degradations from ideal environment performance are involved. First, in the above, the effects of bit errors in the source decoding were ignored. For some source encoding techniques, error rates below 10^{-6} have little effect. Still, it must be assumed that greater values of E are required for the compressed (source encoded) data than for the source data. Also, bit synchronization errors and fading propagation effects affect the source decoding process. An estimate of this degradation in E/N is reasonably taken to be about 1db. Thus,

$$C = 9$$

when estimated degradations are included. Thus,

$$\text{Coding Gain} = CK = 9 \times 4.4 = 39.6 \approx 40,$$

$$P_R = \frac{3\text{kw}}{40} \approx 75\text{W} .$$

This power requirement represents the transmission power level required using existing state-of-the-art coding techniques with estimated Jupiter channel effects. This resultant power requirement indicates that coding development technology is required for a single rapid descent Jupiter probe mission. The link budget resulting in the 3kw uncoded power requirement is not optimized, and a 2 or 3db reduction in this level is likely. This would reduce the power requirement to

$$P_R = 45W$$

for optimized link budget.

With respect to source encoding, it is very important to consider source statistics and scientist user requirements. The effects of source statistics and initial source data rate requirements could easily change the value of C by a factor of 2 or 3, and therefore reduce the power required by that same factor. The design lies in the power level region in which this could make the difference between whether the mission is feasible or not. Also, whatever coding techniques are used, they must be carefully worked out with the scientific community reactions. This is because source encoding effects must ultimately be assessed by the user, and anticipated source data waveforms could be very useful in designing a source encoding technique.

7) Hardware Component Requirements for Coding Implementations - In order for the coding requirements discussed above to be practical for a space mission, the hardware component count and power requirements must be reasonable. Also, the decoding hardware requirements should be assessed in order to allow trade-offs to be made concerning orbiter data processing impact. It is important to be able to determine whether the data should be fully reconstructed and decoded in the orbiter. It appears that the decoding should be performed at the earth terminals, since the coding bandwidth expansion is small and there is no reason for the orbiter to have access to the uncoded data. Nonetheless, it is interesting to know what the hardware impact on the orbiter for full decoding would be.

As mentioned in the preceding paragraph, the most important part of the encoding/decoding process for probe applications is in the encoder. The total number of components required can be established by considering individually the source encoder, channel encoder, source/channel encoder total, channel decoder, source decoder, channel/source decoder total, and the grand total. This can be approximated for a number of combinations of techniques as summarized in Table IV-1.

A channel encoder for Viterbi/BCH concatenated encoding can be achieved with less than 37 TTL chips. A Hadamard source encoder requires about 281 TTL IC's. The encoder total is 318 chips, with the greatest portion being in the source encoder. An encoder to be used with sequential decoder plus an interleaver for fading would require a very small number of chips, less than 20. The concatenated Viterbi decoder requires about 200 chips, and

TABLE IV-1 - COMPONENT REQUIREMENT (IC PACKS)

	Encoder	Decoder
Viterbi/BCH	37	200
Hybrid Sequential	20	250
Viterbi	5	120
Sequential	5	150
Hadamard	281	160
Adaptive 2D DPCM	220	
ZD DPCM	115	
1D DPCM	10	
Viterbi/BCH and ADPCM	135 (future)	
Sequential and ADPCM	175 (future)	
Sequential and DPCM	30	

the sequential decoder requires about 250 chips. The source decoder requires 160 IC's. These numbers are for presently available components. A two dimensional adaptive differential pulse code modulation (DPCM) encoder requires about 220 IC's. Non-adaptive two-dimensional DPCM requires about 115 IC's. For the two dimensional DPCM/sequential encoder combination, the component requirement is about 135 IC's. A one-dimensional DPCM/sequential encoder probably could be constructed using 30 IC's. This could also be accomplished with a long constraint length Viterbi encoder, but the decoder is more complex than the sequential decoder. Projecting into the future, these numbers can be reduced and the total for the adaptive DPCM/sequential encoder combination can be estimated to take about 175 IC's. The power consumption is approximately 12W using MOS technology. This is the most attractive combination with respect to performance and encoder hardware requirements. However, a large number of components and high power consumption are required.

Two steps are required next. The first is a closer component requirement count, and secondly, simpler coding techniques specifically designed for the data sources must be assessed. A desirable number of IC's for the encoding is more like 25 to 50, with less than several watts of power consumption.

8) Conclusions - The primary conclusion drawn from this first cut approximate analysis of probe requirements is the amount of coding gain obtainable with microcomputer technology pushes the state-of-the-art. The theoretically available coding gain using source coding and error correction coding is estimated to be 100 (20dB). With existing technology on ideal channels, the gain is estimated as 54, and with realistic channel effects, about 40 (15dB).

3. Thermal/Structural System Options

The choice between an external hot structure pressure vessel using "off the shelf" refractory metal materials versus the development of an external insulion system that could protect the pressure vessel to temperatures consistent with existing structural alloys is discussed here. A third option, the development of a ceramic pressure vessel or a metal matrix composite pressure vessel in the "hot structure" approach is also considered.

a. Refractory Metal Pressure Vessel - MMC Report MCR71-1 "Jupiter Atmospheric Entry Mission Study", April, 1971, reported the evaluation of existing structural alloys for operation at 1400K (2100°F) and concluded that a refractory metal could be used, for example) B066 Columbian. A significant amount of even a very efficient insulation material, such as multilayer, would be required inside the pressure vessel to keep the equipment compartment at normal equipment operating temperatures (along with some phase change material). This dictated a large pressure vessel diameter relative to the external insulation approach, 20 inches vs. 15 inches, to contain a one-cubic foot volume payload. The weight of such a system was thus found to be quite large compared to the externally insulated approach, approximately 450 kg. vs. 100 kg. to 150 kg.

This approach, however, would permit a more direct extrapolation of Pioneer Venus Probe technology since the PV design utilizes a hot (750 K, 900°F) external pressure vessel (Titanium), and multilayer internal insulation. The Venus probe is exposed to a 100 bar pressure environment. Solving the differential expansion problems at penetrations in the higher temperature environment of Jupiter, as well as the spherical shell fabrication problems with the less ductile material, are modest technology advances that would have to be addressed even in this "minimum technology" approach.

b. External Insulation Development - An externally insulated pressure vessel concept allows the use of efficient, conventional metal alloys for the pressure shell, but exposes the insulation to the extreme atmospheric environment. The risks associated with this concept involve the extrapolation of the behavior of the known insulation materials at these extremes of pressure and temperature; the test data to date only covers up to 120 bars at 600°F. Data would have to be obtained up to 1000 bars and 2100°F. This is further discussed in Appendix F , Thermal Control Systems Study.

Free convection within the insulation at high pressure levels is a distinct possibility. If present, the free convection has a serious degrading effect on the insulation performance. The material selected should have as small a permeability as is possible.

Two external insulation candidates which show promise for this mission are MIN-K and LI-900. The MIN-K has excellent properties over the total range of temperatures and pressures tested todate and appears to exhibit acceptable permeability. The LI-900, to be used on the Space Shuttle, has excellent properties and is used on external surfaces of the SS which experience high shear forces associated with turbulent flow fields.

Since the external insulated pressure sphere is the preferred concept, the external insulation technology should be expanded to the extreme environments expected at the 1 kilobar level.

c. Ceramic or Metal Matrix - Two other material classes which were considered for the pressure vessel structure are ceramics and metal matrix composites. Some forms of both exhibit strength/weight ratios at 2100°F, which would result in a reasonable structural weight. Admittedly, the lower the weight, the greater the cost and risk.

The ceramics, such as alumina oxide, would require extensive development testing to demonstrate ability to design around its inherent sensitivity to holes and attachment loads induced by vibration, pyrotechnic and thermal environments. Methods would have to be derived to ensure that the design reliability not be excessively degraded by the low tensile allowable of the ceramics. This basic class of materials has had little or no application for spacecraft primary structural applications in the past, and would definitely appear to present a high risk design without some development test breakthroughs.

Several high temperature metal matrix composites are currently being investigated in the industry. Among others, we contacted Mssrs. Bob Signorelli and Ed Winsa of NASA/LeRC on this subject. They very obligingly put together the data shown in Table IV-2 . It is very preliminary and involved a very limited amount of research; however, it does begin to give an appreciation of the potential of this material class. The M200 super alloy is shown to be reinforced with two different performance levels of tungsten fibers (TFRS) and one design of silicon carbide fibers (SICFRS). This material class has a high reliability potential with further development strength testing at temperature to determine optimum fiber density. This testing, together with experience in fabricating wound spherical shapes, should be given further consideration.

TABLE IV-2 - METAL MATRIX PRESSURE VESSEL DATA

Material	Efficiency Density, lb/ft^3	Development Cost, M$ ++	Production Cost, K$/ft^3	Estimated Probability of Success %
MAR M200	5000	Unknown	100 to 200	98
Low Cost TFRS	1500	2*	145	95
High Performance TFRS	600	2.5*	170	85
SICFRS	400	2.5*	125	40

++ Based upon 2 development spheres, plus 1 flight sphere.

* Based upon 3 spheres with all 3 castings concurrent.

4. Mechanical/Electrical Penetrations

Pressure vessel penetrations must be addressed for any concept considered for the deep probe. These can be classified under two categories: 1) electrical, and 2) mechanical. Within these categories there are two general types, bulkhead and feed-through. Optical windows would fall under the bulkhead type. The extreme pressure differential of 1000 bars at the extreme temperature makes each penetration through the pressure vessel a major consideration. Pioneer Venus probe penetrations have been designed and tested for each of the above types; however, the environment they will experience is almost an order of magnitude less than this probe would experience. The petrochemical industry has had to develop high pressure, high temperature pressure vessel penetrations and form the basis of this technology.

It is suggested that any further technology development of penetrations await the specific requirements of the science instruments. It is believed that the lead time for this technology would not pace a deep probe development.

C. ALTERNATIVE PROBE TECHNOLOGIES

The previous section discussed the technologies involved in the synthesis of a minimum-technology probe and a minimum-mass probe. Other technology advances have been identified (see Figure IV-1) that could further enhance the scientific accomplishment of a deep probe mission, or that would serve as alternatives to those discussed previously.

The new technologies involved in this group, that have not been discussed previously, are listed below and discussed in the following paragraphs:

- Dual Orbiter for Supporting Probe Communications
- Autonomous Data Analysis
- High Power Transmitter
- Higher Energy/Density Batteries
- Vented or Pressure-Equalized Equipment Compartment
- Active Cooling
- Variable-Pitch Rotating Blades for Descent Control
- Constant Altitude Balloon
- Combined Reflective Heat Shield and Pressure Vessel
- High Pressure/Temperature Electronics

1. Dual Orbiter

A slower probe descent would reduce the data rate problem, and would also provide more time for analyzing samples on board (which might be required if a gas chromatograph type instrument, for example, was in the science complement). The range to the orbiter becomes a limiting factor, however, in descents exceeding 100 minutes or so. This problem can be alleviated by the introduction of a second or "daughter" orbiter, which would be phased to pick the transmission from the second half of descent periods lasting up to 200 minutes or more.

2. High Power Transmitters

Although it has been shown that a deep probe mission to Jupiter is possible with present state-of-the-art transmitter technology, it is obvious that the availability of higher power transmitters would create a wider range of options from which to select a spacecraft configuration. Specifically, it would alleviate the need for a "mother" ship to serve as a relay station, thereby reducing payload weight and complexity.

Link calculations show that transmitters in the 1000 watt class will be required to support a Jupiter deep probe mission. Such transmitters should be modular solid-state devices that operate in the UHF band. For example, the use of 50 watt output transistors in parallel combination is envisioned to achieve a 200 watt module. An assembly of 8 such modules can then provide an output of 1000 watts. Development effort should include work on combining networks and on effective cooling methods.

It is recognized that the use of high-power transmitters creates the attendant problem of providing sufficient energy storage to power such devices. Trade studies should be performed which evaluate the impact of this problem relative to the benefits derived from a simplified vehicle design.

3. Autonomous Data Processing

Autonomous data processing covers a broad area that includes on-board data processing, signature correlation, adaptive sequencing, and experiment control and adaptive source encoding. On-board processing is comprised of digital computations that are normally included as part of ground data processing. The output is the final data result that is transmitted from the probe in place of transmitting the raw data. The motivations for this are that the power required to do the computations on-board results in a reduction in the amount of data to be transmitted. This consumed power is less than the power required to transmit the raw data, and the result is an improvement in data reliability. Furthermore, the impact of the computation hardware in size and weight is tolerable. An example is to perform the spectral analysis for the spectrophotometer on-board and transmit only the atmospheric content data. It is anticipated that this could reduce the amount of transmitted data by a factor of eight to ten. This would help considerably towards obtaining the data reduction factor requirement of 10 that was discussed earlier. Another method of accomplishing on-board data processing results is to perform comparisons of the data with stored on-board anticipated signatures of the experimental data. In the spectrophotometer example signatures are spectrum shapes. By correlating the raw experimental data with expected data shapes in this manner a signature of the data can be found. The signature code is then transmitted in place of the raw data. This provides the potential for greatest data reduction. However, there is higher risk with this approach because there is always some probability that a close signature will not be found among those anticipated and stored on-board. If the data link is designed based upon finding a close correlation, and thus a low data rate, there may not be enough link data rate capacity to detect a no correlation condition and initiate raw data transmission. An alternative is to transmit the closest signature and a number representing the closeness of the match. Still, if there is a large mismatch, there may be no way of determining what the raw data really looked like.

Adaptive sequencing was discussed earlier. This provides the capability to re-orientate the sequence or rate of measurements. Experiment parameters can also be altered, as for example in tuning the spectrophotometer. In a general sense source encoding also falls in the area of autonomous data processing. For example, run length codes as discussed earlier are similar to signature transmission.

In summary, autonomous data processing capability to increase the probe information return and the reliability of experiment results has increased profoundly over recent years. This has been due to digital system hardware innovations in microprocessers, memories, and integrated logic circuitry. Significant increase is anticipated over the coming years. Factors that must be considered in employing autonomous data processing, in addition to the hardware design, include the system ramifications. By this we mean the effects and risks involved in failure of the data processing scheme in case the data is considerably different from what is expected. This must be traded against the probability of data link failure because of unknowns in the transmission path if the raw data were transmitted.

4. High Density Energy Storage

The electrical energy demands of a Jupiter deep probe may well require an advance in energy storage technology beyond that now available. Certainly any improvement in energy density would enhance such a mission by allowing more weight allocation for payload items. Currently, the best space qualified energy storage system for this type of application is the silver-zinc battery, which yields an energy density in the range of 50 to 60 watt hours per pound for a high discharge rate design. Because of the extremely long cruise times required for outer planet missions, and the stand time limitations of the silver-zinc battery, remote activation of the battery would be a necessity, thus adding to the weight, complexity, and unreliability of such a system.

An alternative to this system is the dry cell lithium chemistry battery, which is currently being developed and tested by several agencies. The lithium battery offers several advantages over the silver-zinc battery which could significantly enhance an outer planet mission. These are: 1) an increase of 30 to 40 percent in energy density, 2) a decrease in volume requirements, and 3) a stand time compatible with the outer planet cruise times (2 to 8 years).

It would be advantageous to future outer planet mission designs to insure that the lithium chemistry battery is brought to a level of maturity that qualifies it for space applications.

5. Vented Probe

Venting the equipment container avoids the massive shell weight. This approach requires that components be able to operate at high pressure. The vented gas can be cooled with a phase-change material heat exchanger, but heat exchanger weight tends to negate the advantage of avoiding a heavy pressure shell. Complete potting of the probe interior affords another way of pressure equalization, as is gas stored in a high-pressure bottle used to equalize the internal pressure. These concepts are further discussed in Appendix F, Thermal Control Systems Studies.

6. Balloon Technology

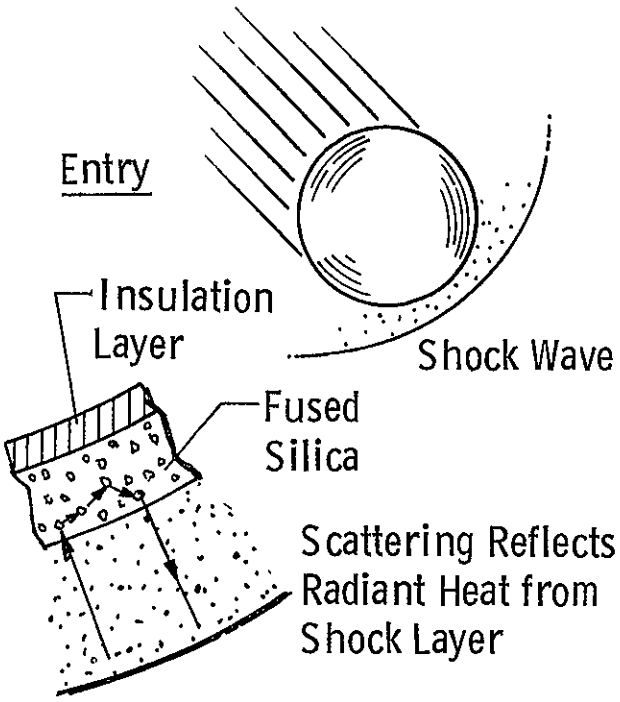
Balloon flotation systems have been studied and proposed as an acceptable method of reducing descent rates for various Venus missions. This concept was briefly examined as a means of reducing the descent rate for a portion of the Deep Jupiter Probe Mission. Appendix H contains a summary discussion of the theoretical aspects of a Jupiter balloon system. The data contained in this appendix shows that the use of a balloon for descent rate control for Jupiter is <u>not</u> practical from a system design standpoint. The data in Figures 1-3 in Appendix H shows that the use of a hydrogen filled balloon could <u>not</u> support any useful payload weight below 100 bars. These results are not surprising when one considers the problems associated with gas containment, high temperature balloon materials, and structural elements that would be subjected to high tension load conditions at high temperatures.

A unique high temperature elastomer materials technology development requirement would exist for which <u>no</u> candidate materials are currently known.

Engineering subsystems weights would undoubtedly increase when hardware solutions for these types of problems were considered, which would tend to further reduce available payload weight.

7. Combined Reflective Heat Shield/Pressure Vessel - For the mission design involving several simple descent probes widely dispersed over the planet, a combined reflective heat shield/pressure vessel design could be considered. The science would be severely limited since penetrations would have to be limited and the sphere would not be stabilized. Simple measurements, such as pressure, temperature, and acceleration could be considered. Each of the multiple probes could be tracked through the RF link.

The fused-silica reflective heat shield material under consideration for such an entry probe also possesses surprising compressive strength at elevated temperatures. In fact, its strength increases with temperature and peaks at about the 2100°F temperature of the atmosphere at the 1000-bar level. If this strength is utilized in construction of a spherical pressure vessel, the resulting shell thickness is no greater than that required for the entry heat rejection function. Thus, it is conceivable that a single sphere of this material with some internal insulation would provide both entry and descent protection at a very modest total mass. Figure IV-9 shows this concept and the pertinent facts and requirements.



Reflective Heat Shield Can Double as External Pressure Vessel Shell in 1000-bar Descent

Material: Fused Silica

Applications: - Multiple, Small, Transponder Probes - Nonstabilized
- Composition Measurement Probe - Stabilized

Major Development Requirements:
Attachments, Fabrication, Penetrations

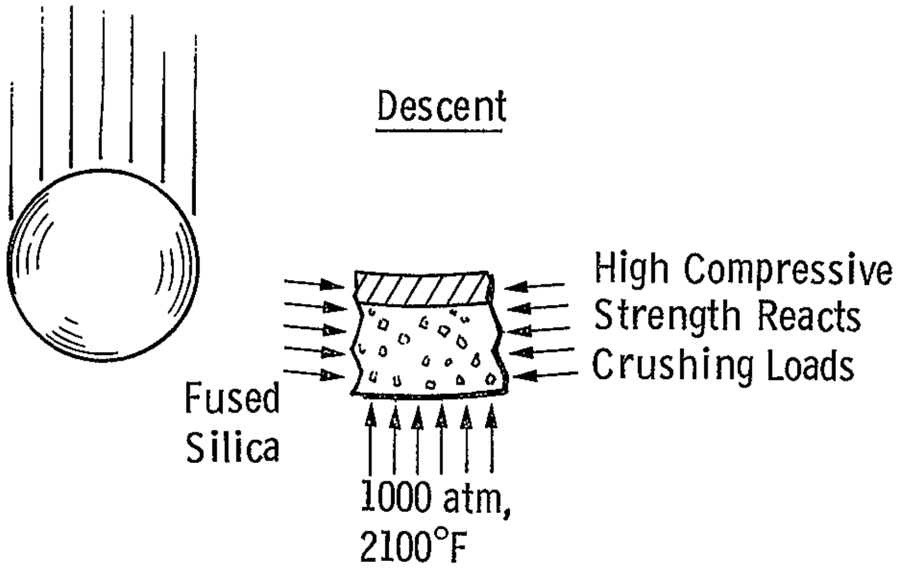


FIGURE IV- 9 - COMBINED ENTRY/DESCENT VEHICLE

8. High Pressure/High Temperature Electronics

The elevated pressure and temperature of the Jovian atmosphere imposes severe requirements on the probe design, primarily in the pressure vessel and thermal control system areas. In large part, these constraints are a result of limitations of the electronics vis-a-vis pressure and temperature. Thus, an extension of these limits would simplify the overall probe design problem in these areas.

Martin Marietta and others have performed testing and evaluation of electronic components and circuits at elevated temperatures. Good results have been obtained at temperatures approaching 200°C, albeit with some degradation in performance. Further design and testing are required to establish design techniques, operating temperature limits, component types, and circuit types.

In the area of high pressure electronics, some data are available up to 3000 psig. These data indicate that some components, such as ceramic DIP parts, will survive at the 3000 psig pressure. However, no testing at pressures approaching 1000 bars has been accomplished. Further investigation into new packaging techniques and testing at both the piece-part and box level are required to establish operating pressure limits and design guidelines for the application of electronics to this high-pressure regime.

D. IMPLICATIONS OF ATMOSPHERIC IONIZATION ON PROBE TECHNOLOGY REQUIREMENTS

1. Effects of Ionization on Communications

As one penetrates the deeper layers of Jupiter's atmosphere, very high pressures and temperatures are encountered. Of particular concern to the communications subsystem is the rapid increase of temperature with depth and the possibility of increased ionization and the presence of free electrons (ions may be neglected). The calculations of Barshay and Lewis (1977) indicate that the ionization of metals with low ionization potentials does, in fact, become significant at levels corresponding to a kilobar. The dominant electron contributors are potassium and magnesium, with some contribution due to sodium and iron at somewhat deeper levels. As the deep probe descends into the higher pressure and temperature levels, the number density of free electrons increases rapidly due to thermal ionization, and as the electron density increases, the frequency range of the communication system becomes more severely restricted due to interaction of the electromagnetic waves with the electrons.

A set of simplified calculations have been performed to determine the maximum depth of penetration of a deep probe due to communication limitations resulting from ionization. The communications frequency has been selected as 0.6 gigaHertz on the basis of an optimization study considering the many sources of attenuation present in the Jovian atmosphere (such as ammonia absorption, cloud particle scattering and absorption). The brief analysis presented below addressed two questions: (1) what electron densities are required such that plasma frequency becomes equal to the communication's frequency (hence producing a limitation on the communication link); (2) at what level in the Jovian atmosphere does this limit occur?

The analysis of the transmission of microwave radiation through an ionized medium has been studied in detail by many investigators in the past. For conditions where the magnetic field effects are unimportant (collision frequency $\gg$ gyro frequency), the relation between electron density and critical transmission frequency is:

$$fc = 9.0 \times 10^3 (N_e)^{\frac{1}{2}} . \quad (N_e \text{ in cm}^{-3}, f_c \text{ in Hz})$$

For Jupiter's atmosphere in the environment of the deep probe, the collision frequency $\nu \approx 5 \times 10^{12}$ cycles/sec, so that the above condition $\nu \gg \Omega$ is satisfied. Values of the electron density were taken from the calculations of Barshay and Lewis (1977), and the dependence on temperature was calculated using the ionization equation:

$$\left(\frac{N_{r+1}}{N_r}\right) N_e = \frac{2.U(r+1)}{U(r)} \left(\frac{2\pi m^3}{h^3}\right) T^{\frac{3}{2}} e^{-Xr/kt}$$

where Ne = electron density (cm^{-3})

U (r+1) and U (r) = partition functions

Xr = ionization potential (ev)

m = electron mass

h = Planck's Constant

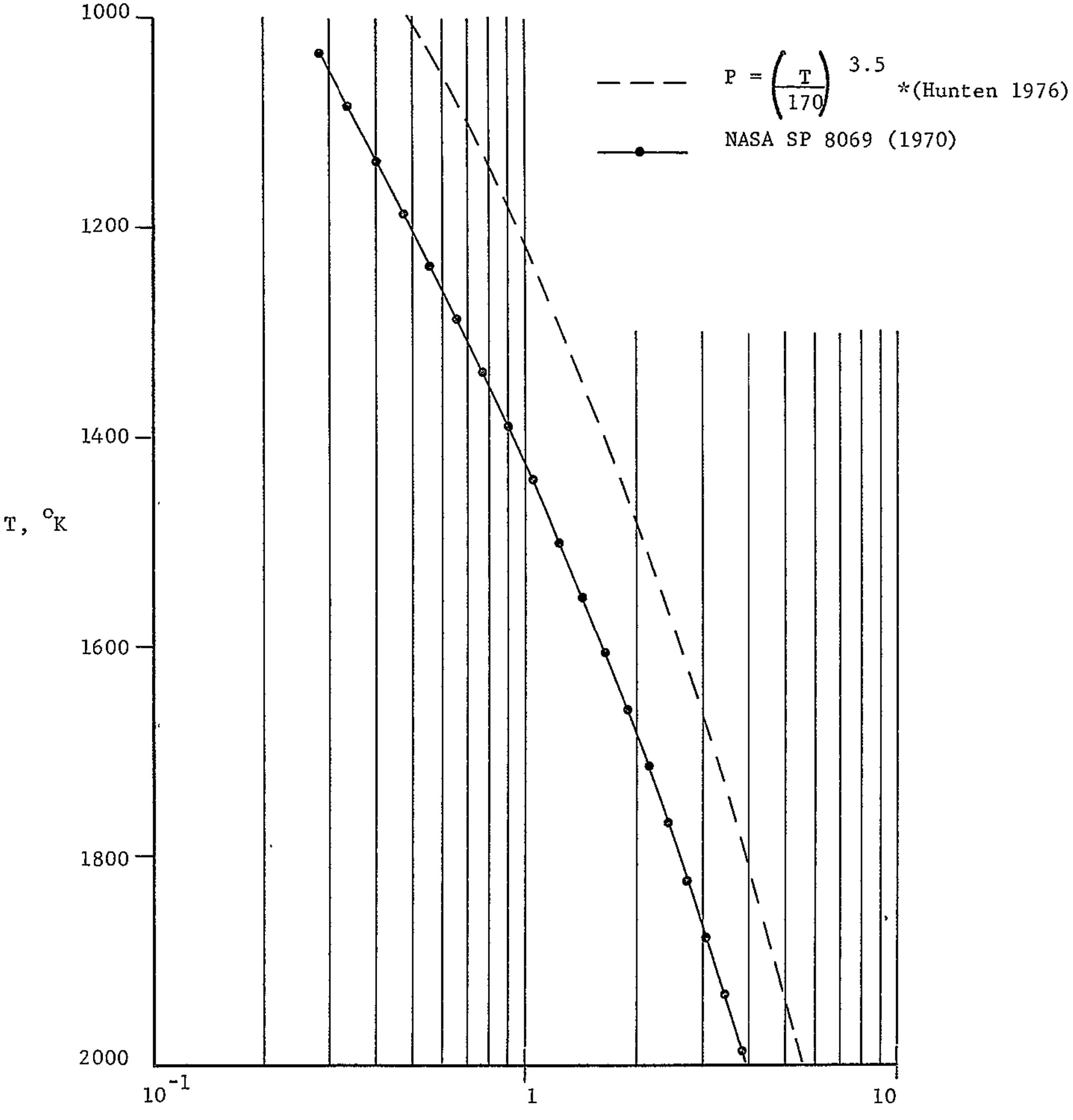
k = Boltzmann's Constant

and $N_{(r+1)}$ and $N_{(r)}$ represent the numbers of atoms in the (r+1) and r states of ionization. The run of pressures and temperatures (Figure IV-10) follows the Jupiter adiabat given by:

$$P = \left(\frac{T}{170}\right)^{3.50} .$$

The electron densities resulting from the ionization equations are shown in Figure IV-11, and the resulting plot of critical frequency as a function of depth (temperature) is shown in Figure IV-12. The results show that the electron density providing a critical frequency at 0.6 ghz. is achieved at 1350°K. Increasing the selected communications frequency to increase the temperature at which the critical frequency is encountered results in such an increase in signal attenuation from atmospheric absorption effects as to render such an approach impractical.

Since there are several uncertainties in the pressure/temperature profile, and in the calculated electron densities (due to possible rapid mixing from deeper levels), limiting bands are placed on the electron densities and the corresponding values of the critical frequency to account for these uncertainties. The curves in Figure IV-11 show values of the calculated nominal values, and in additions, values for factors of 10 greater than and smaller than the nominal values of electron density. The limits shown in Figure IV-12 correspond to these



*D. M. Hunten, "Atmospheres & Ionospheres", p. 22 in _Jupiter_, (ed. T. Gehrels), 1976.

FIGURE IV-10 - PRESSURE VS TEMPERATURE FOR JUPITER ATMOSPHERE

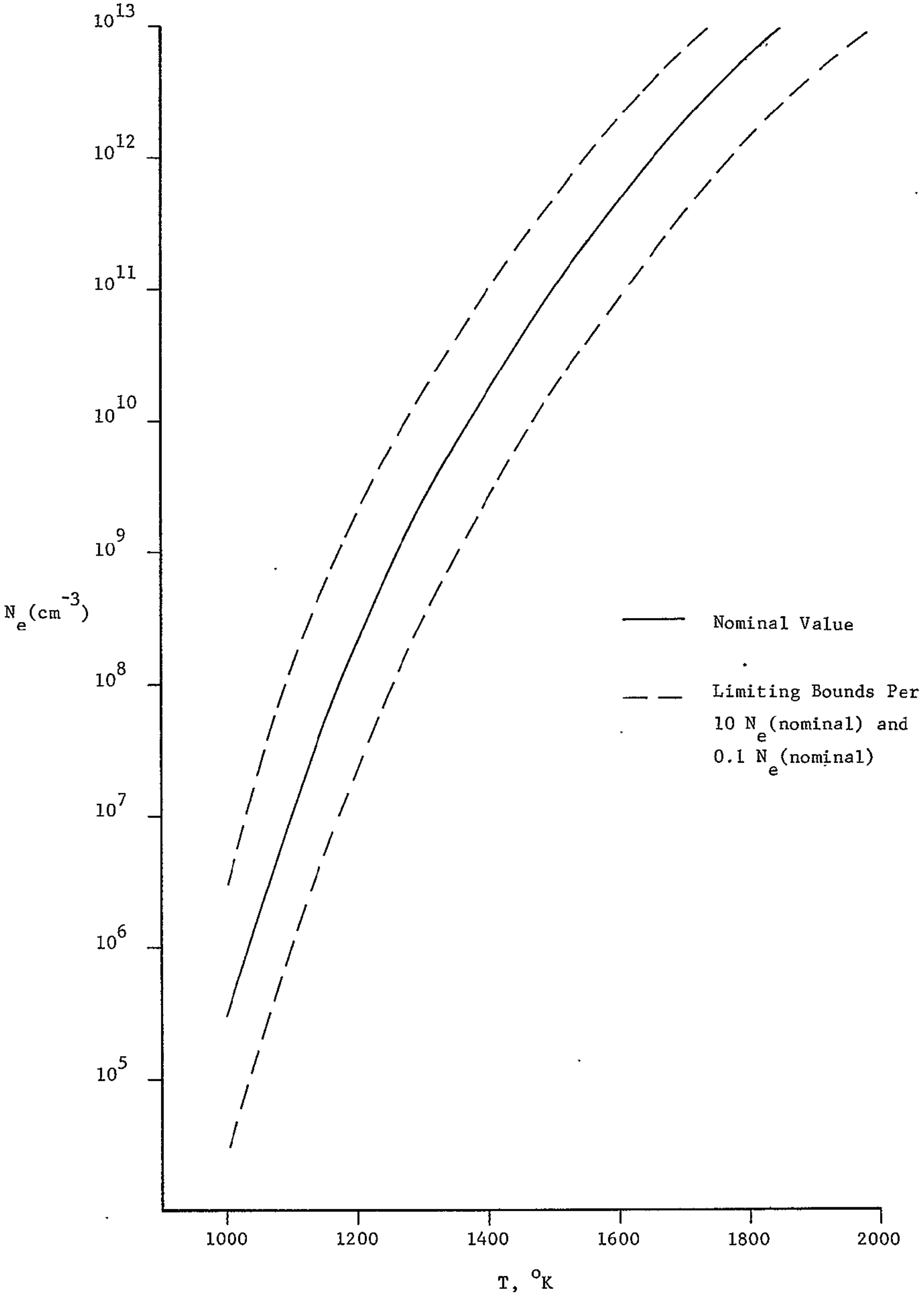


FIGURE IV-11 - ELECTRON DENSITY FOR JUPITER ATMOSPHERE

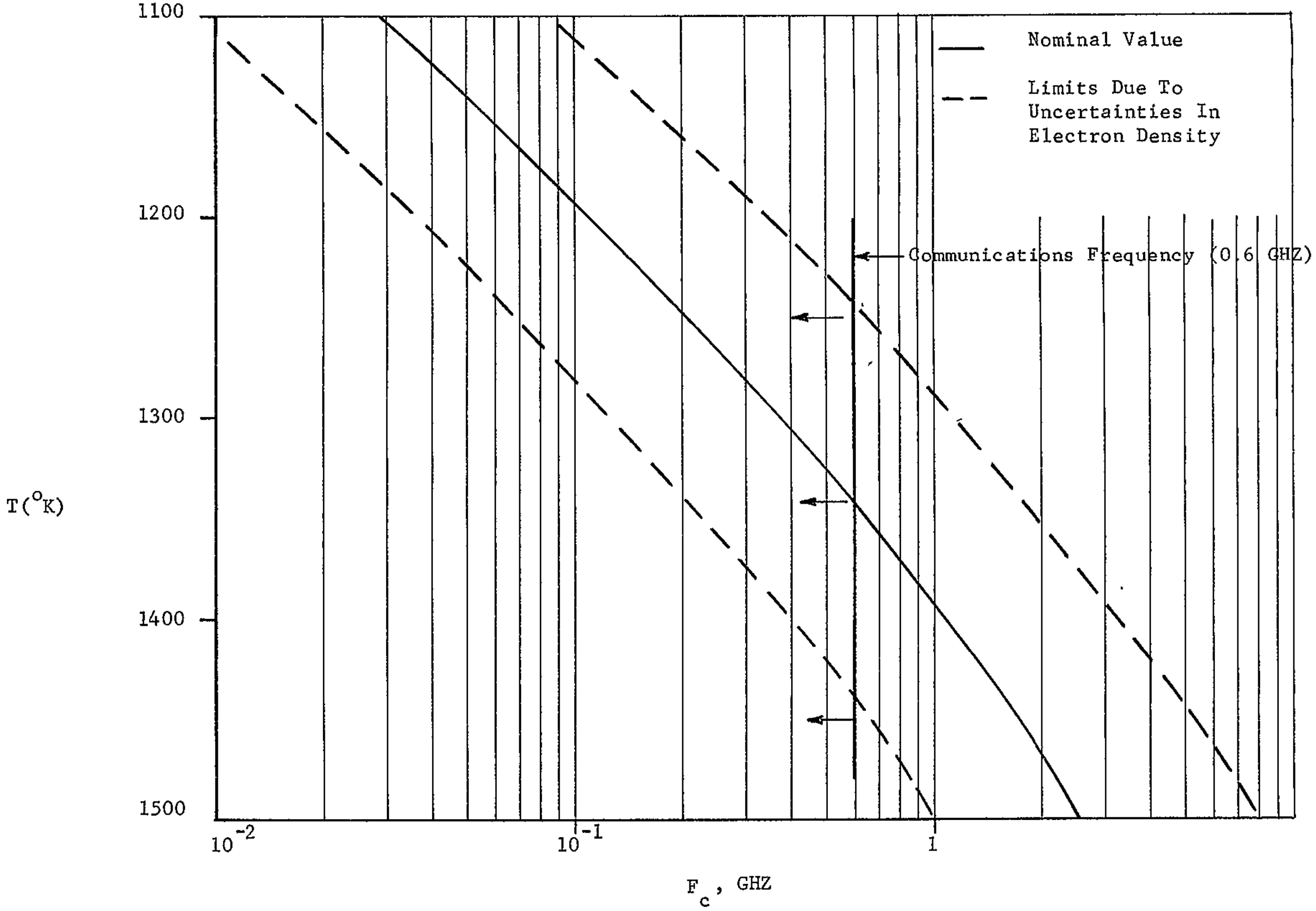


FIGURE IV-12 - CRITICAL FREQUENCY PROFILE FOR JUPITER data. It may be concluded, within these uncertainties, that the effects of ionization would black out the RF transmission at altitudes below those corresponding to pressures of about 1.1 to 1.8 kilobars (Hunten adiabat) or 0.6 to 1.0 kilobars (NASA SP 8069 adiabat).

2. Probe Technology Options for Coping with Atmospheric Ionization

a. Telecommunications - One method of communicating through an ionized atmosphere is the use of laser energy. This scheme could be considered if radio transmission is attenuated as discussed above.

The existence of clouds at high altitudes will preclude direct laser transmission from the deep probe to an orbiting spacecraft. Therefore, it is more reasonable to consider the laser transmission to a higher altitude relay probe which could then use radio transmission to the orbiting spacecraft. This concept is shown in Figure IV-13. Laser transmission distances of 500 km must be considered through the heavy atmosphere. Coupled with this uncertain atmospheric scattering are navigation, altitude determination and control, laser pointing and laser power.

Each of these considerations are potential subjects for further study as part of the laser communications technology items.

b. Probe Guidance and Control - The potentially severe RF attenuation of the lower atmosphere suggests that radio communications may not be practical, and that laser communication may have to be considered. In either case, it appears that antenna pointing or laser beam pointing may be required. This implies that attitude orientation of the probe may be required, which leads one to consider gyroscope technology.

Gyroscopes for such an application will have to have to exhibit long shelf life, low drift, high input range, and high acceleration tolerance. Low drift characteristics are needed because of the expected coast time between separation from the orbiter and the entry and descent events. The combination of performance characteristics implies non-mechanical devices such as a laser or quantum electron gyroscope.

Desired gyroscope characteristics for a deep probe requiring a laser relay communications link with an upper probe are shown in Figure IV-14. One possible concept is shown for illustration, namely, a fiber optic laser gyroscope.

c. Balloon Data Capsule - An imaginative concept which would eliminate the need to transmit data through the lower hostile atmosphere has been suggested. It involves lifting a payload consisting of a small transmitter, data storage device, associated control electronics, a battery, and thermal protection by means of a balloon from the descending probe and floating upward to the more

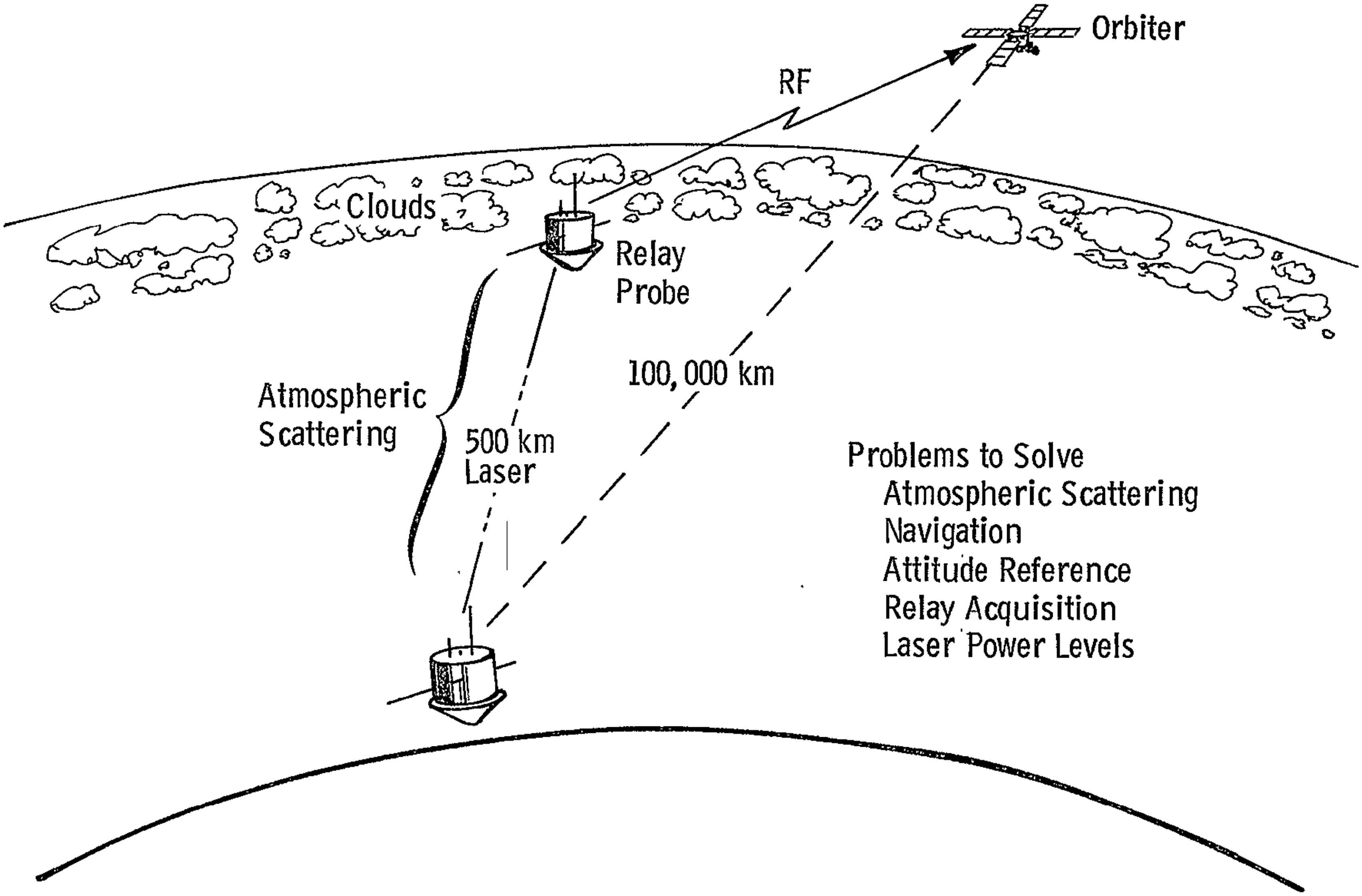


FIGURE IV-13 - LASER COMMUNICATION TECHNOLOGY

Desired Gyroscope Characteristics:

Input Range	0 to 1.0 rad/s
Low Drift	0.001 deg/hr
High Acceleration	300-g peak
Long Life	10 years

Possible Implementation: Fiber Optic Laser Gyro

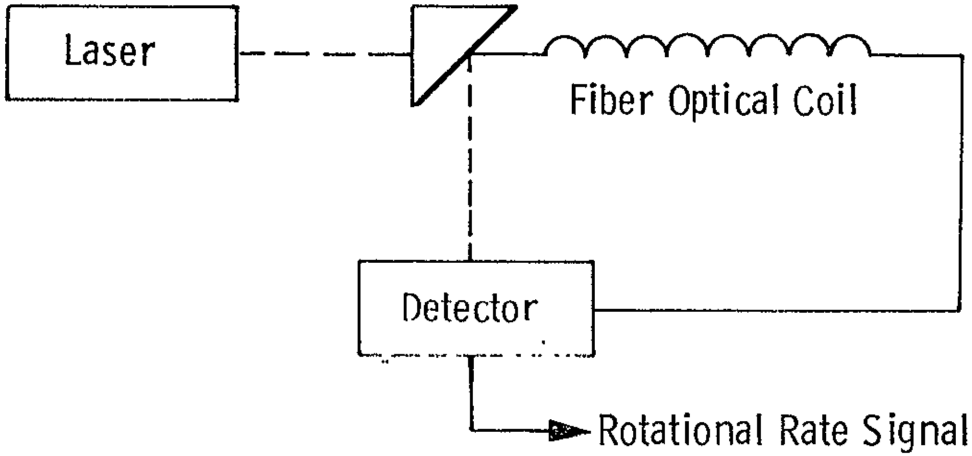


FIGURE IV-14 - GYROSCOPE TECHNOLOGY

C-2

hospitable atmosphere.

A study was performed assuming a payload of 20 pounds to be lifted to a pressure altitude of 500 bars. A balloon fabricated of high temperature material of 240 ft.^{3} is required to lift the package in slightly less than 24 hours. The inflation gas was assumed to be stored in a high pressure gas tank, the size is plotted as a function of storage pressure in Figure IV-15.

The data to be transmitted directly from the balloon data capsule to the orbiting spacecraft was assumed to be of the order of $3x10^5$ bits. These data were primarily accumulated from the atmospheric composition measurements in the lower atmosphere. Therefore, to transmit these data within a reasonable time (distance) associated with an orbiter pass, the required data rate is of the order of 300 bps. However, this requires a transmitter in the 50 watt range.

When all of the above factors are considered, the concept does not hold together for this particular mission.

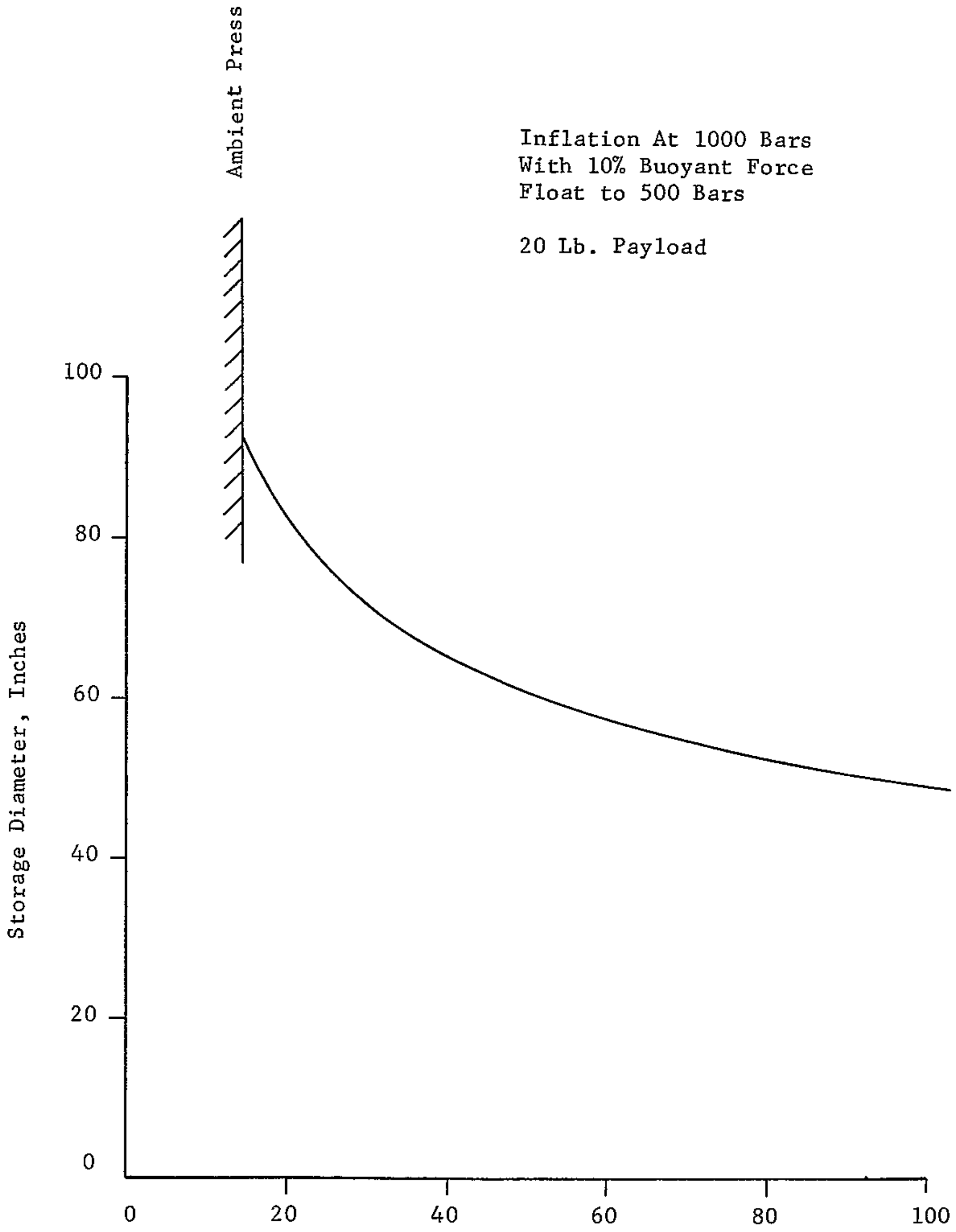


FIGURE IV-15 - BALLOON INFLATION GAS STORAGE VESSEL SIZE

V. PROBE TECHNOLOGY RECOMMENDATION

A. TECHNOLOGY DEVELOPMENT SCENARIOS

The various technology options that were considered for each probe subsystem discipline are shown in Figure IV-1 in matrix form. A major division is shown if thermal ionization is experienced at pressure altitude levels above the 1000 bar desired maximum depth. If this were to occur and it was required that data be returned, normal RF communications could not satisfy this requirement. Thus, the new technology items listed in that column would have to be realized.

The ascending balloon capsule, in which a data package containing the recorded science data, and associated equipment to transmit this data to the orbiter, would be lofted by balloon to an altitude above the ionization region, is not feasible. Laser communications is probably feasible, but places extreme guidance and control requirements upon that discipline to insure that the beam can be directed accurately at the receiver. This guidance and control of the deep probe would necessitate such new technology developments as non-mechanical gyroscopes, and possibly a reaction control subsystem requiring the development of a high exhaust pressure, greater than 1000 bars, propulsion system. From this discussion it appears that the onset of thermal ionization would be the limiting factor for data transmission.

The development of atmospheric composition measurement instruments is one technology which is common to any of the probe configurations recommended. All of the science consultants were very adament that this was the primary science return from a deep probe mission.

Each of the possible methods of implementing the probe elements is shown with respect to its present technology development. The following discussions will indicate how one can trace a path through the element mechanization to produce a minimum mass and volume probe, or derive a mission with minimum technology development required.

The selected mechanization for each of the probe elements which produces a probe of minimum mass and volume is highlighted on Figure IV-2B. This probe is assumed to have an atmospheric composition instrument in addition to the simpler instruments, such as pressure, temperature, and accelerometers.

It would have a high ballistic coefficient creating a rapid descent through the lower atmosphere. This descent time is compatible with relaying all of its data directly to a single orbiter. Advanced data processing would be required to transmit all of the desired science data with the use of a moderate power transmitter. The power could be supplied by a remotely activated battery, which is within present technology capability. The recommended thermal structural concept is the externally insulated, high temperature alloy pressure vessel. An alternate approach could be the ceramic or metal matrix, internally insulated concept. A detailed analysis and moderate test program would provide the answer to the best approach.

If the externally insulated pressure vessel were selected, the antenna would have to be external to the pressure vessel and would require RF transparent insulation protection. If the ceramic pressure vessel approach were used, the antenna could be located within the vessel.

The probe can be satisfactorily stabilized utilizing the aerostabilized concept, such as employed by Pioneer Venus. The entry system can directly utilize the JOP heat shield and aeroshell technology, as well as the staging parachute. A possible alternate to this approach could be the reflective heatshield, but this would require some development. High pressure and temperature compatible feedthroughs are required, which will require a moderate development effort.

The minimum technology development probe is highlighted in Figure IV-2A It would also contain the atmospheric composition instruments and the other complementary science instruments. A rapid descent mode would be utilized to be compatible with a single orbiter. In this mission design a relay probe would be used to maximize the allowable data rate from the deep probe with the use of conventional data processing and moderate power transmitter. The relay probe would be descending slowly on a parachute and reach the JOP pressure level at the time the deep probe has completed its descent to one kilobar. It would relay the data from the deep probe to the orbiter in near-real time.

The other probe elements would be based upon state-of-the-art technologies, except for two areas, the refractory metal pressure vessel design and the use of a high temperature antenna. These two elements would be based upon existing technology, but are complex and new applications of these technologies.

B. RECOMMENDATIONS

The following recommendations are based upon the assumption that thermal ionization does not exist down to the pressure level of interest in the mission.

The first recommendation is to plan future deep probe missions around the minimum technology basis. This should allow for a minimum cost and risk mission with sufficient scientific merit.

Secondly, continue to investigate and develop select candidate technology items which produce the largest potential payoff. These are: Absorption Spectrophotometer and the Resonance-Fluorescence Spectrometer instruments, advanced data processing, and the external thermal insulation materials. The instruments are required to produce sufficient science data return to warrant a deep probe mission and form the basis for such a mission. The advanced data processing can enhance the mission by allowing more science data to be returned than with conventional data processing. The use of external thermal insulation could produce a minimum cost deep probe.

APPENDIX

A

ASSESSMENT OF PROBABLE ACCOMPLISHMENTS OF FIRST GENERATION OUTER PLANETS PROBES

The following memorandum contains the summary results of the detailed study performed for this contract.

APPENDIX A - ASSESSMENT OF PROBABLE ACCOMPLISHMENTS OF FIRST GENERATION OUTER PLANETS PROBES

As a starting point for the definition of a second generation deep probe mission, the objectives and probable accomplishments of the JOP mission were analyzed. The JOP mission emphasizes a study of the atmospheric structure and composition, and a detailed study of Jupiter's magnetosphere. The mission employs an orbiter for global remote sensing and in-situ measurements, and an atmospheric probe for local in-situ atmospheric measurements. Table A-1 summarizes the instruments and observables presently planned for the JOP missions, and Table A-2 presents an assessment of the potential results of that mission.

TABLE A-1 - JOP INSTRUMENTS AND OBSERVABLES

1. ORBITER	INSTRUMENT	OBSERVABLES
ATMOSPHERIC/CLOUD STRUCTURE	NEUTRAL AND ION MASS SPECTROMETER	NEUTRAL GAS AND ION DENSITY/ TEMPERATURE
	LANGMUIR PROBE	ELECTRON DENSITY/TEMPERATURE
	UV SPECTROMETER	THERMOSPHERIC COMPOSITION: AURORAL MAPPING
	NEAR IR SPECTROMETER	HIGH SPATIAL RESOLUTION TEMPERATURE DISTRIBUTIONS
	PHOTOPOLARIMETER/RADIOMETER CCD CAMERA	CLOUD STRUCTURE
MAGNETOSPHERIC STRUCTURE	ENERGETIC PARTICLE DETECTORS ELECTRON EMITTER PLASMA EXPERIMENT	PARTICLE ENERGY AND PITCH ANGLE DISTRIBUTIONS
	PLASMA WAVE RECEIVER	ELECTROMAGNETIC/ELECTROSTATIC WAVES
	MAGNETOMETER	MAGNETIC FIELD DISTRIBUTIONS
	DUST DETECTOR	DUST/SOLID PARTICLE DISTRIBUTION
RADIO SCIENCE	S-BAND TRANSMITTER	ATMOSPHERIC SCALE HEIGHTS/TEMPERATURE GRAVITATIONAL DISTRIBUTION

TABLE A-1 - JOP INSTRUMENTS AND OBSERVABLES (CONT'D)

2. <u>PROBE</u>

ATMOSPHERIC STRUCTURE	PRESSURE GAUGE, THERMOMETER ACCELEROMETERS	PRESSURE, TEMPERATURE, DENSITY (AND PERTURBATIONS)
	SPHERICS RECEIVER	ELECTRICAL DISCHARGES
COMPOSITION	HELIUM INTERFEROMETER	He/H_2 RATIO
	MASS SPECTROMETER	CH_4, NH_3, H_2O; PHOTO-CHEMICAL SPECIES; ISOTOPES
CLOUDINESS	NEPHELOMETER	CLOUD LOCALIZATION/ MORPHOLOGY
ENERGY BALANCE	NET-FLUX RADIOMETER	SOLAR ENERGY DISPOSITION PROFILE

TABLE A-2 - JOP PROBE MISSION - ANTICIPATED RESULTS

ORBITER-GLOBAL CHARACTERISTICS

ATMOSPHERE

- MULTI COLOR HIGH RESOLUTION HORIZONTAL CLOUD MAPPING
- HIGH RESOLUTION HORIZONTAL/VERTICAL TEMPERATURE DISTRIBUTIONS
- THERMOSPHERIC STRUCTURE/COMPOSITION

INTERIOR

- INTERNAL MASS DISTRIBUTION
- MASS ANOMALIES

MAGNETOSPHERE

- TIME DEPENDENT STRUCTURE OF TRAPPED ENERGETIC PARTICLE BELTS
- MAGNETIC/ELECTRIC FIELD DISTRIBUTIONS/PARTICLE ACCELERATION REGIONS/MECHANISMS
- PLASMA WAVE PROPERTIES/WAVE-PARTICLE INTERACTIONS
- AURORAL MORPHOLOGY/FREQUENCY - PARTICLE PRECIPITATION - ENERGY DEPOSITION/IONOSPHERIC COUPLING

PROBE-LOCALIZED IN-SITU PROPERTIES

IONOSPHERE

- PRESSURE, NEUTRAL TEMPERATURE, ELECTRON DENSITY, ELECTRON TEMPERATURE, NEUTRAL COMPOSITION PROFILES, ION COMPOSITION, TEMPERATURE PROFILES.

ATMOSPHERE

- PRESSURE, DENSITY, TEMPERATURE PROFILES
- He/H_2; CH_4, NH_3, H_2O PROFILES
- ENERGY DEPOSITION PROFILES
- VERTICAL CLOUD MORPHOLOGY - RELATION TO COMPOSITION/CONDENSIBLES

APPENDIX

B

SCIENCE CONSULTANTS/SCIENTISTS MEETINGS/TELECONS/BRIEF NOTES

The following memorandum contains the summary results of the detailed study performed for this contract.

APPENDIX B: SCIENCE CONSULTANTS/SCIENTISTS MEETINGS/TELECONS/BRIEF NOTES

During the course of the present study, a definition of scientific requirements for a deep probe mission to the outer planets (Jupiter, Saturn, and Uranus) was required. This definition was accomplished by a brief review of the recent literature, by discussions with the Martin Marietta group of planetary sciences consultants, and by discussions with several other scientists actively engaged in planetary studies. This definition assumes a successful JOP mission and builds on the data shown in Appendix A. The purpose of the present appendix is to provide a very condensed summary of the main points that resulted from these discussions. Table B-1 lists the contacts which were made, and the following pages include concise summaries of the suggestions and comments that resulted. A list of references which were consulted from the open literature is also provided.

TABLE B-1: LIST OF CONTACTS

1.	7/22/77	Meeting with J. Lewis and D. Hunten
2.	7/28/77	Meeting with J. Pollack
3.	7/29/77	Telecon with W. Hubbard
4.	8/02/77	Meeting with T. Donahue and S. Atreya
5.	8/12/77	Telecon with R. Hodges
6.	8/15/77	Telecon with V. Oyama
7.	9/07/77	Telecon with J. Anderson
8.	9/08/77	Telecon with D. Hunten
9.	9/13/77	Telecon with J. Lewis
10.	9/22/77	Telecon with T. Donahue

1. Lewis and Hunten Meeting (7/22/77) - Science Definition

Suggested Measurements:

- Deep Atmospheric Composition/Profiles (ppm to ppb)
- Pressure/Temperature Profiles
- Cloud Localization/Particle Size Distributions
- Magnetic Fields/Electric Fields (relation to thermal ionization)

Suggested Mission Priorities:

- JOP-Type Probe (Saturn/Uranus)
- Viking Type Titan Lander
- Long-Lived Venus Lander
- Multiple Location JOP-Type Probe (Jupiter, Saturn, and Uranus)
- Deep Probe (Jupiter, Saturn, and Uranus)

Remarks: MS or GC or GCMS techniques probably not usable for composition measurements. Consider looking at emission/absorption spectroscopy techniques. Possibly find ideas in flame chemistry field.

2. Pollack (7/28/77) - Science Definition

Suggested Measurements:

- Deep Atmosphere Composition/Profiles
- Pressure/Temperature Profiles
- Cloud Properties
- Magnetic Fields - Higher Order Moments
- Zonal/Meridional/Vertical Wind Fields

Suggested Mission Priorities:

- Multiple Location (esp. latitudes) JOP-Type Probe
- Deep Probe

3. Hubbard (7/29/77) - Science Definition

Suggested Measurements:

- Composition Profiles
- Pressure/Temperature Profiles (look for secondary radiative zones)
- Deep Cloud Layers
- Magnetic Field - Higher Order Moments

Suggested Mission Priorities:

- Multiple Location JOP-Type Probes
- Deep Probe

4. Donahue and Atreya (8/2/77) - Science Definition

Suggested Measurements:

- Composition Profiles. 1st order importance. (emphasize ammonia/hydrocarbon problems)
- Pressure/Temperature Profiles
- Cloud Properties
- Magnetic Fields
- Possible ion exchange of Io with footprints in Jovian atmosphere as alternative source for observed CO.

Suggested Mission Priorities:

- Multiple Location Probes (emphasize study of atmospheric dynamics)
- Deep Probe

Remarks: Suggest that Jim Anderson' experimental technique (resonance fluorescence/scattering) be considered for composition measurements.

5. Hodges (8/12/77) - Composition Measurement by Mass Spectrometer

Remarks:

- Mass spectrometer could probably be designed to operate under high pressure/temperature conditions.
- Avoid condensation by carefully inletting hot gas sample into a rapid expansion chamber; leak system run off of chamber into first stage pressure vessel (2-stage dewar-type); final stage of mass spectrometer reduced to operation of pressure of about 10^{-10} torr.

6. Oyama (8/15/77) - Composition Measurement by Gas Chromotograph

Remarks:

- GC could probably be designed to operate under high pressure/temperature.
- Main development would be concerned with sample acquisition/valving mechanism.
- Gas column may be run hot, but electronics/data handling package would have to be insulated/isolated.

7. Anderson (9/7/77) - Composition Measurement by Resonance Fluorescence Scattering

   Remarks:

   - This technique would be possible for such measurements; presently developing technique for Mars/Venus explorations.
   - Requirement for laminar flow for sample not critical for atomic species; presently still need for molecular species; materials selection may alleviate requirement totally.
   - Shelf-life of lamps presently 6-8 months, some are 1½ years; would need to have a minimum of 2 years for this application.
   - Would recommend use of microwave excitation source; can operate several lamps simultaneously with modest power consumption.

8. Hunten (9/9/77) - Update of Suggested Science Definition

   Remarks:

   - Suggests that discussion be prefaced with comment on extreme difficulty of such measurements.
   - Consider careful examination of all suggested composition measurement techniques.

9. Lewis (9/13/77) - Update of Suggested Science Definition

   Remarks:

   - Has unpublished calculations for non-solar compositions.
   - Data for Jupiter may be applied to Saturn/Uranus adiabats by judicious selection of temperature to compensate for pressure differences.
   - At 1 kilobar pressure many more species than those suggested for remote measurement in paper for possible observation are present, and could be considered for deep-probe in-situ measurements.
   - For more complete discussion of ionization levels (and expected electron densities) refer to calculations done for cool stellar atmospheres.

10. Donahue (9/ 22 /77) - Update of Science Definitions

    Remarks: No further recommendations.

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APPENDIX

C

DESCENT TRAJECTORIES INTO THE JUPITER, SATURN, AND URANUS NOMINAL ATMOSPHERES

The following memorandum contains the summary results of the detailed study performed for this contract.

MEMORANDUM

To: J. Mellin

From: C. E. French

Subject: Descent Trajectories into the Jupiter, Saturn, and Uranus Nominal Atmospheres

---

It is desired to evaluate the problems and possible new technologies associated with a Jupiter probe designed to return scientific data from the atmosphere of Jupiter from the end of the entry phase to a depth of 1000 earth atmospheres pressure. Also evaluated were the entry trajectories associated with the entry into the nominal atmospheres of the planets Saturn and Uranus.

In order to provide a framework for evaluation of the problems related to system design, thermal control, data acquisition, communications, etc., three descent trajectory cases for Jupiter are formulated, designed to stress the various technologies and subsystem requirements. The three cases are:

Case 1. This descent concept emphasizes system simplicity and is a single stage with a ballistic coefficient near that of the entry vehicle, 1.0 sl/ft^2. The probe descends through the upper atmosphere range (down to the order of 10 atmospheres) at a high rate, making science data acquisition and on board processing relatively difficult. The descent time from 300 to 1000 atmospheres is the longest, presenting maximum thermal control, power and communications problems.

Case 2. Down to a pressure altitude of 10 atmosphere, this case is identical to Case 1. At 10 atmosphere the probe is staged to a high ballistic coefficient (12 sl/ft^2). This staging results in a minimum time to 1000 atmosphere, relieving the thermal control and communications geometry problems, but further stressing the science acquisition and data handling problems.

Case 3. This descent concept requires the most complex mechanical system and is designed to facilitate the science data sampling and on board processing. A parachute system deployed after entry and two additional stagings to ballistic coefficients of 2.0 and 15 sl/ft^3 are required.

Table C-1 summarizes the relative characteristics of the three cases as they affect the relative difficulties presented to the various probe systems. M signifies a moderate degree of difficulty with + signifying maximum and - minimum relative difficulty.

TABLE C-1 - SUMMARY OF DESCENT TRAJECTORY CASES

CASE	SYSTEM COMPLEXITY	SCIENCE SAMPLING	THERMAL CONTROL	COMMUNICATIONS/ DATA PROCESS/POWER
1	-	M	+	+
2	M	+	-	-
3	+	-	M	M

Data which define the descent trajectories and atmospheric environment are presented on Figure C-1 through C-7.

Time from entry (450 km above the altitude at which the pressure equals 1 earth atmsophere) as a function of altitude is plotted on Figure C-1 for Cases 1 and 2 and on Figure C-4 for Case 3. Noted on the plots are the ballistic coefficients at the various segments of the trajectory. Also noted are the altitudes for various pressure levels. Ambient temperature as a function of time from entry for Cases 1 and 2 are presented on Figure C-2 and for Case 3 on Figure C-5. Time from entry and density scale height as functions of pressure altitude for Cases 1 and 2 are plotted on Figure C-3 and for Case 3 on Figure C-6. For easy reference, the Jupiter nominal atmosphere altitude-pressure model is plotted on Figure C-7. The Jupiter nominal is the model used in the present descent analysis.

Probe descent times into the atmospheres of Jupiter, Saturn, and Uranus are presented on Figure C-8. In each case, entry begins at 450 km above the altitude at which the ambient pressure is 1.0 bar. The entry phase, taken from Ref. A, continues down to a pressure altitude of 0.1 bar. This phase lasts approximately 3 min. and is assumed to be the same duration for all three planetary atmospheres.

At a pressure altitude of 0.1 bar, the probe ballistic coefficient is staged from the entry value of 157 x kg/m^2 (1.0 sl/ft^2) to a value of 47 kg/m^2 (0.3 sl/ft^2) in order to facilitate the sampling of scientific data. This ballistic coefficient is maintained down to a pressure altitude of 10.0 bar, at which time the probe is staged to a ballistic coefficient of 1885 kg/m^2 (12.0 sl/ft^2). Descent continues down to the 1000 m bar pressure level at this ballistic coefficient. Time from entry (450 km) to the 1000 bar level shows considerable difference in the three planetary atmospheres. The time to reach 1000 bar at Jupiter is 95 min. and occurs at an altitude 640 km below the 1.0 bar pressure level. At Saturn the values are 308 min. at -1230 km, and at Uranus, 283 min. at -830 km. Time to reach intermediate pressure levels are indicated on Figure C-8. All descent time profiles are based on nominal atmosphere models presented in Reference B, C, and D.

Descent from 0.1 bar pressure altitude (end of entry phase) to 1000 bar is considered to be at terminal velocity and at a 90° flight path angle. Terminal velocity is:

$$V_T = \frac{2 \beta G_P}{\rho}$$

where -

β = ballistic coefficient

G_P = acceleration of gravity for subject planet

ρ = atmosphere density at altitude.

Terminal velocity in m/sec are shown parametically as a function of ballistic coefficient on Figure C-9, C-11, and C-13. Derived descent times are shown parametically on Figures C-10, C-12, and C-14.

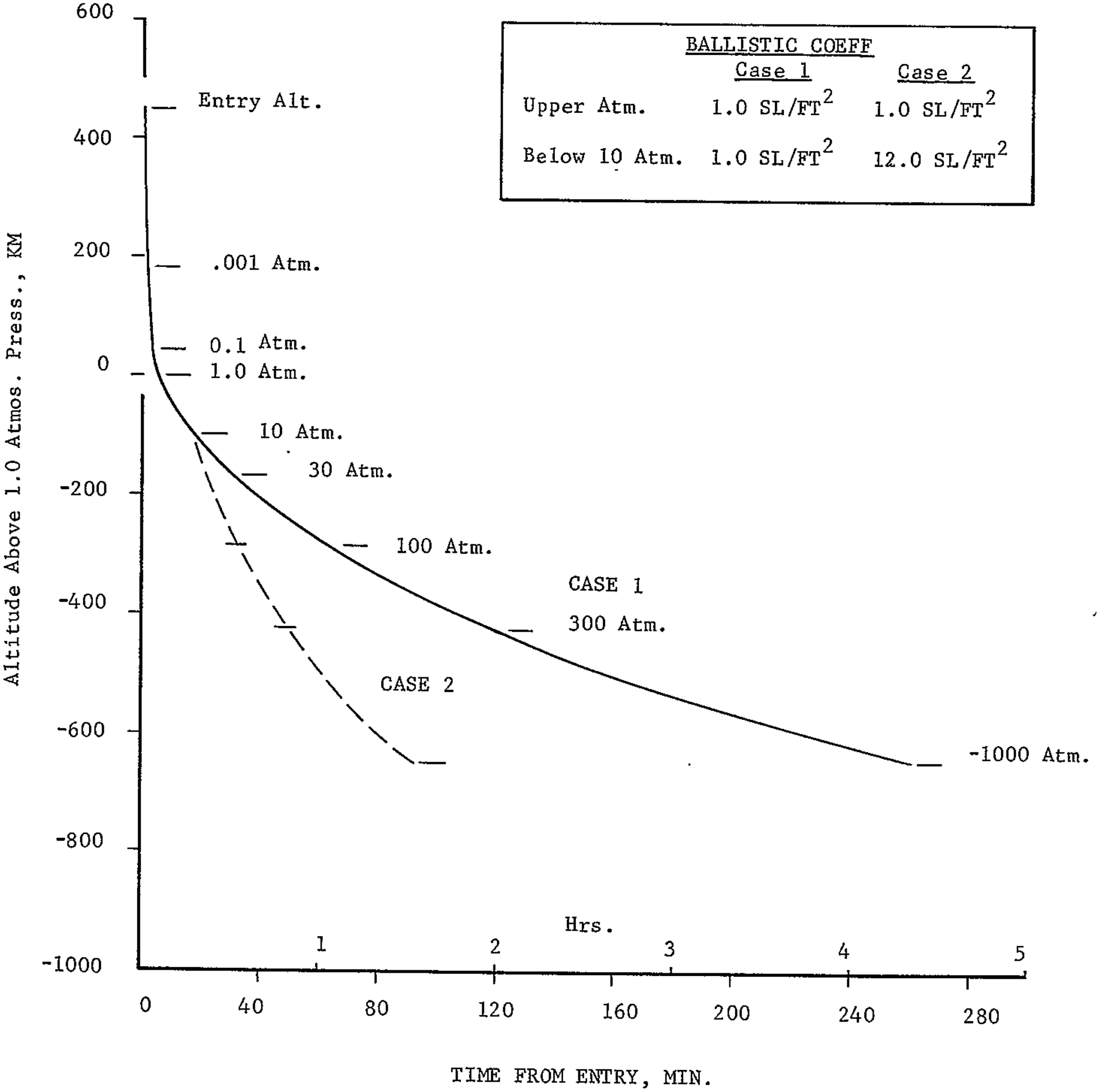


FIGURE C-1 - TIME FROM ENTRY VS ALTITUDE, CASES 1 and 2

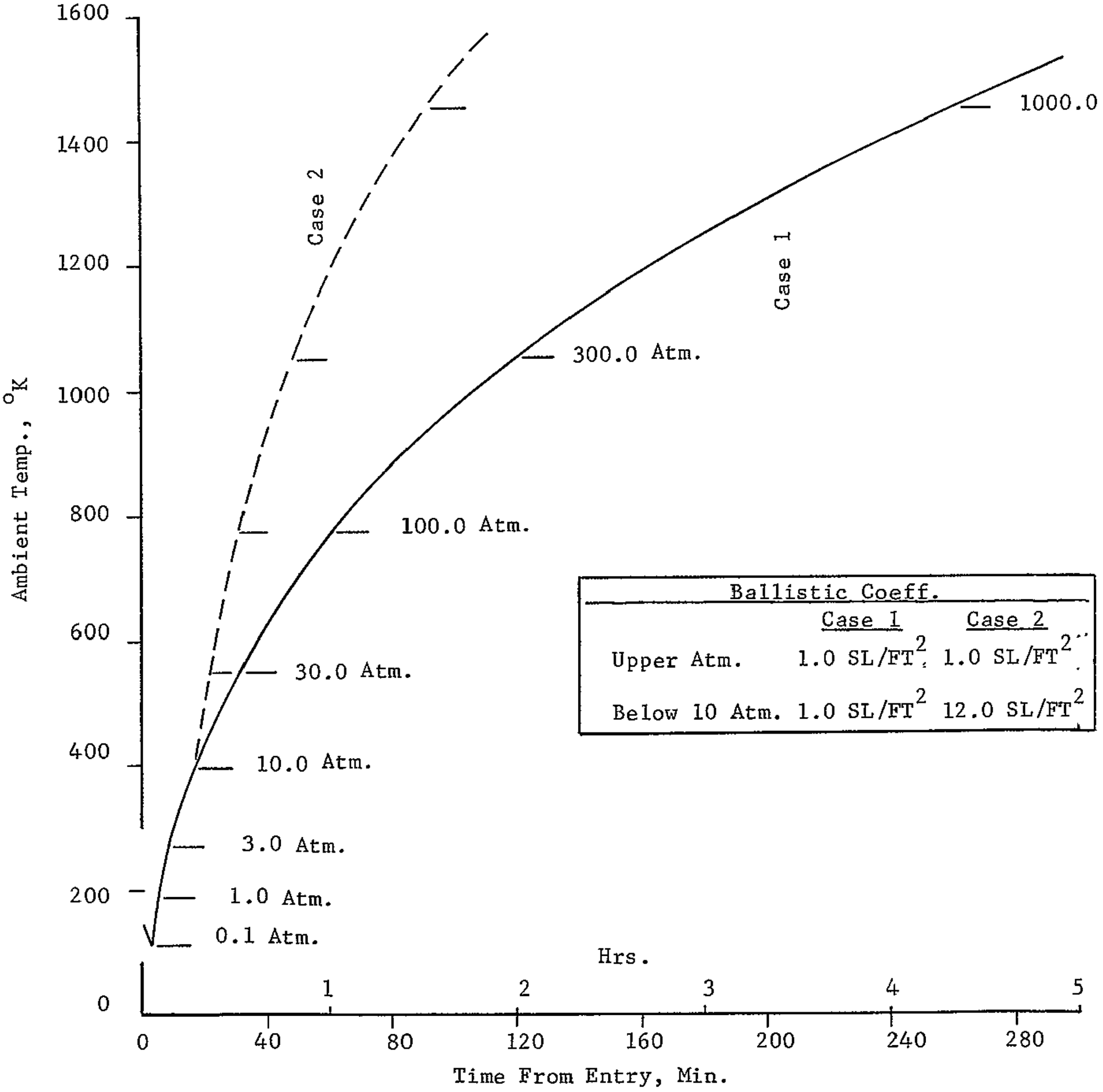


FIGURE C-2 - TIME FROM ENTRY VS TEMPERATURE, CASES 1 and 2

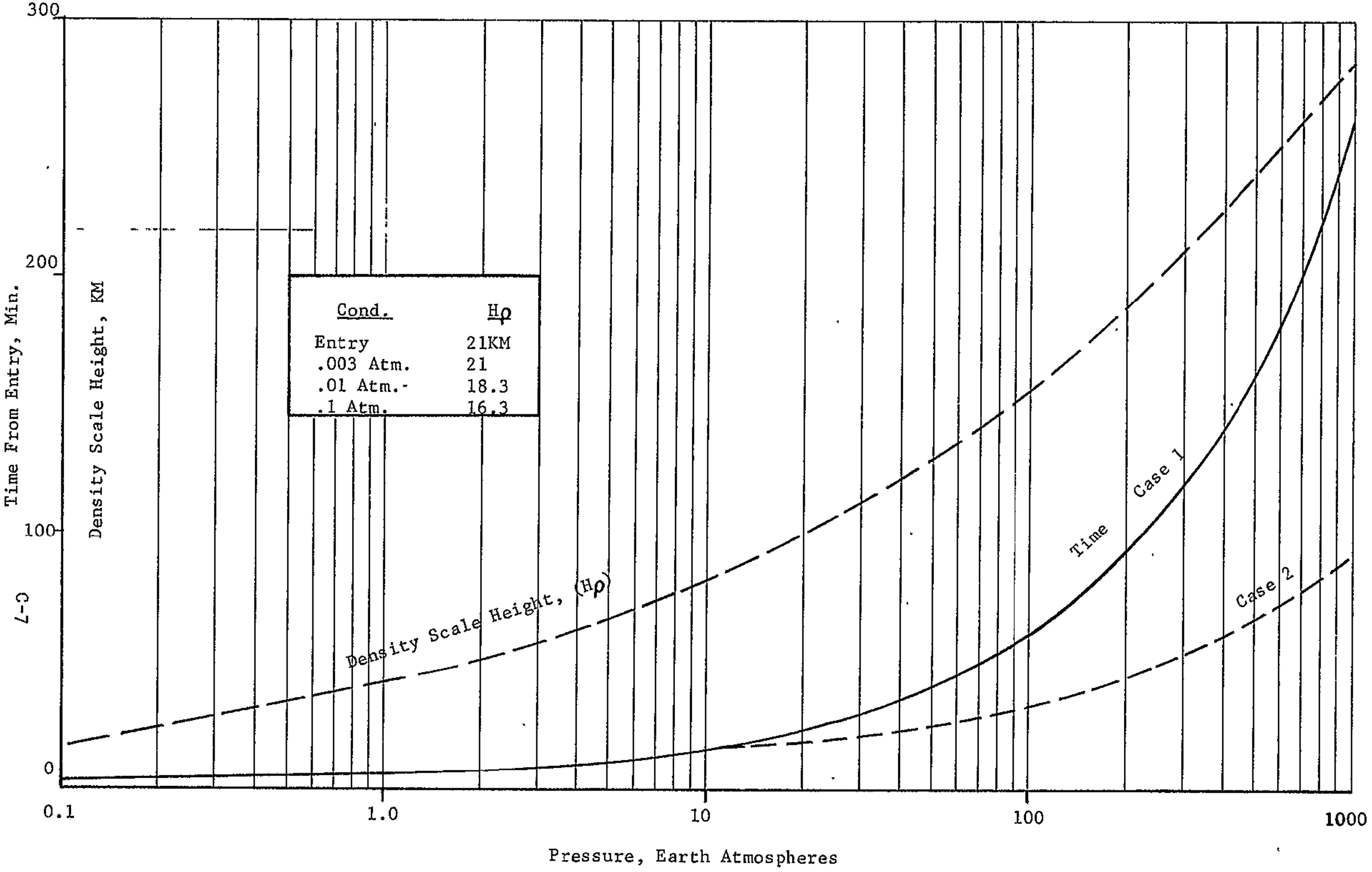


FIGURE C-3 - PRESSURE VS DENSITY SCALE HEIGHT TIME, CASES 1 and 2

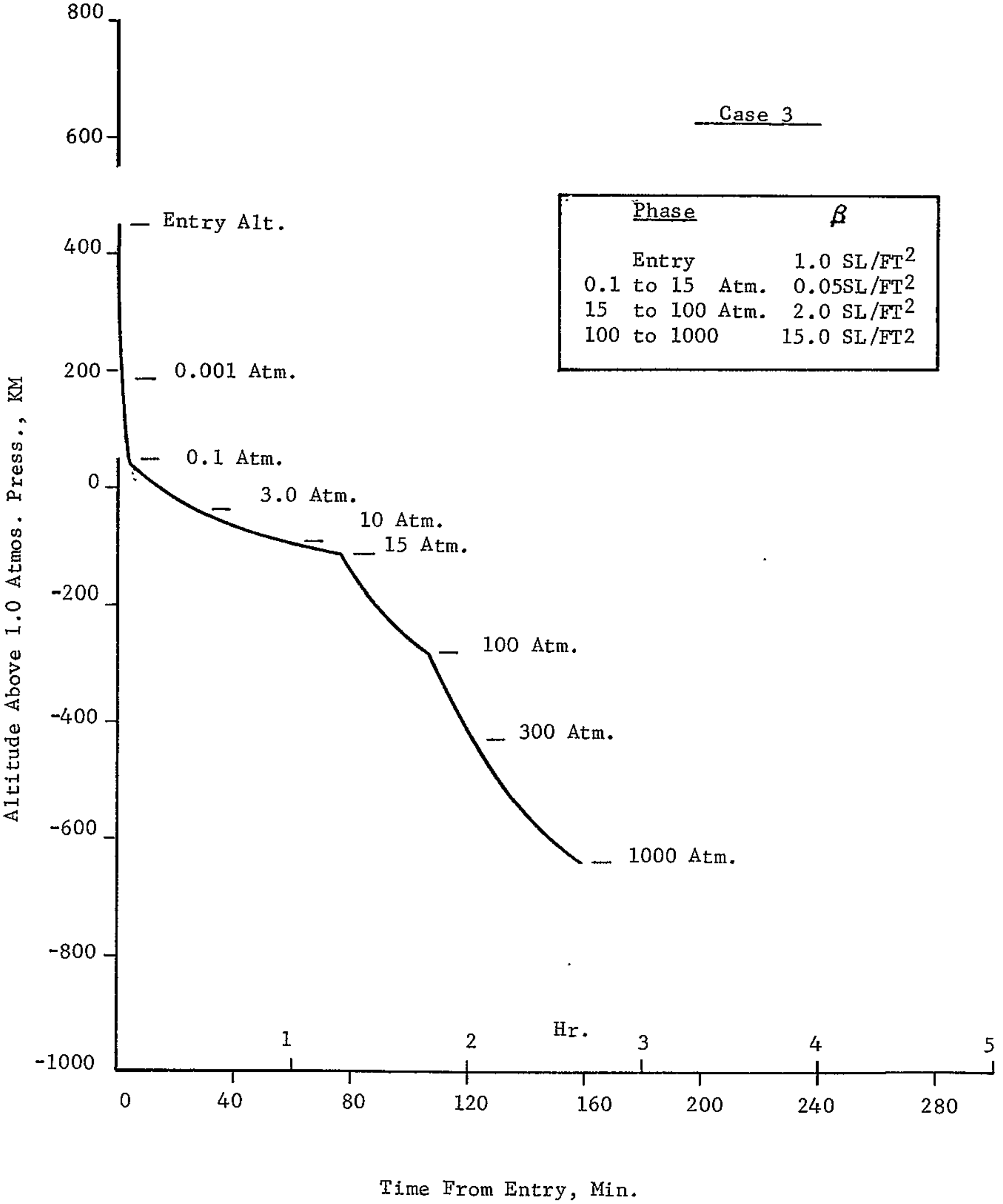
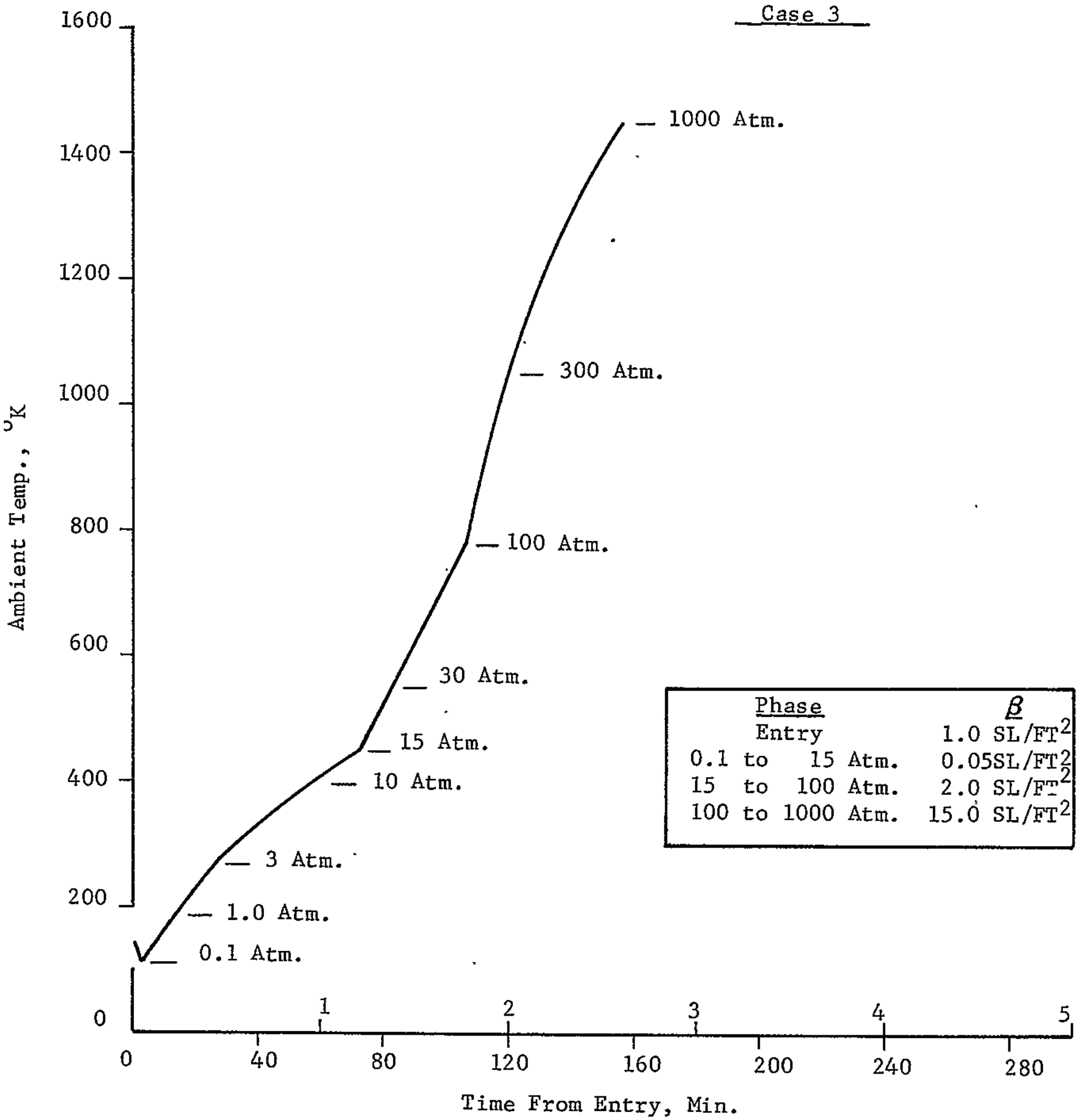


FIGURE C-4 - TIME FROM ENTRY VS ALTITUDE, CASE 3



Phase	β
Entry	1.0 SL/FT^2
0.1 to 15 Atm.	0.05SL/FT^2
15 to 100 Atm.	2.0 SL/FT^2
100 to 1000 Atm.	15.0 SL/FT^2

FIGURE C-5 - TIME FROM ENTRY VS TEMPERATURE, CASE 3

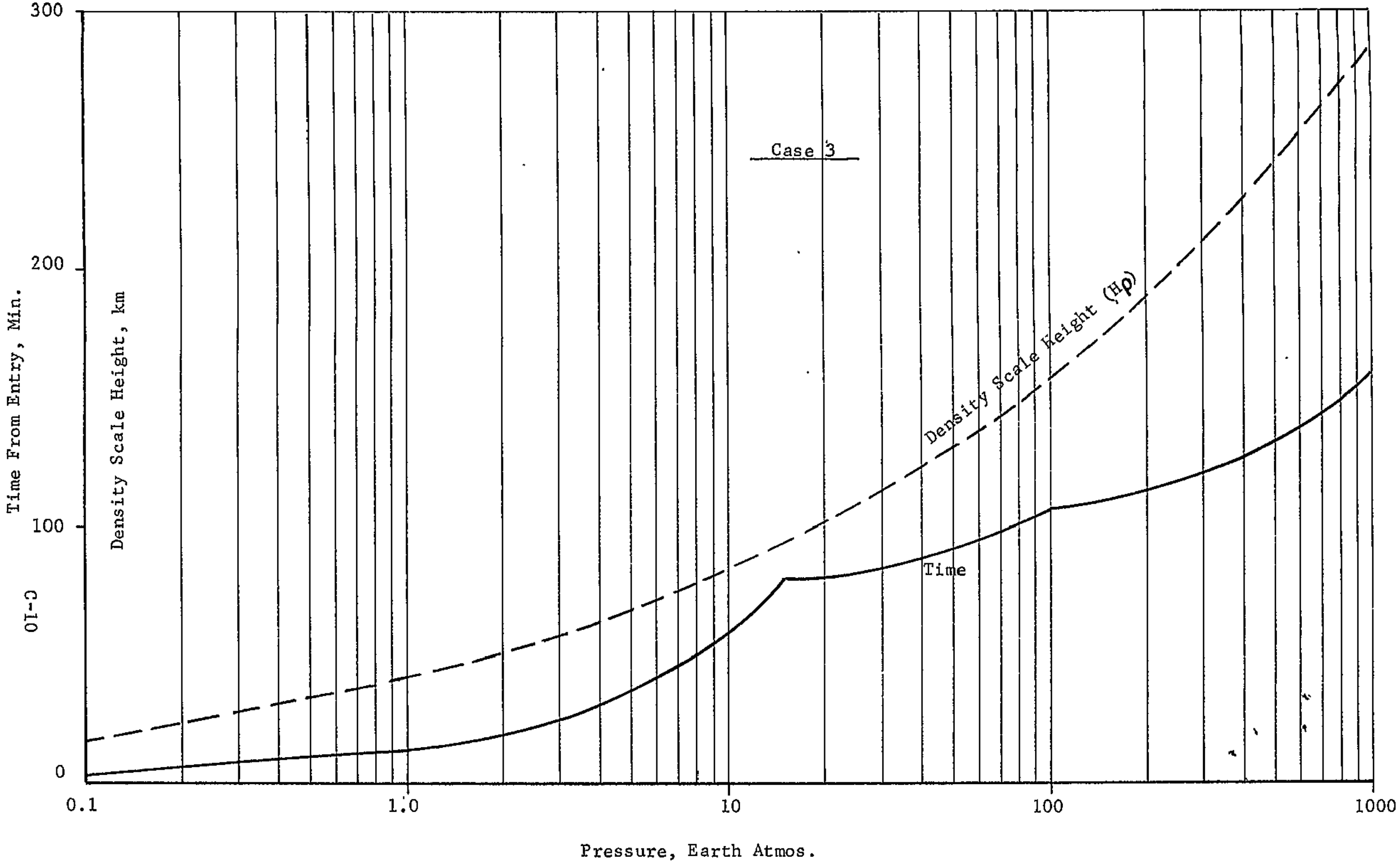


FIGURE C-6 - PRESSURE VS DENSITY SCALE HEIGHT AND TIME, CASE 3

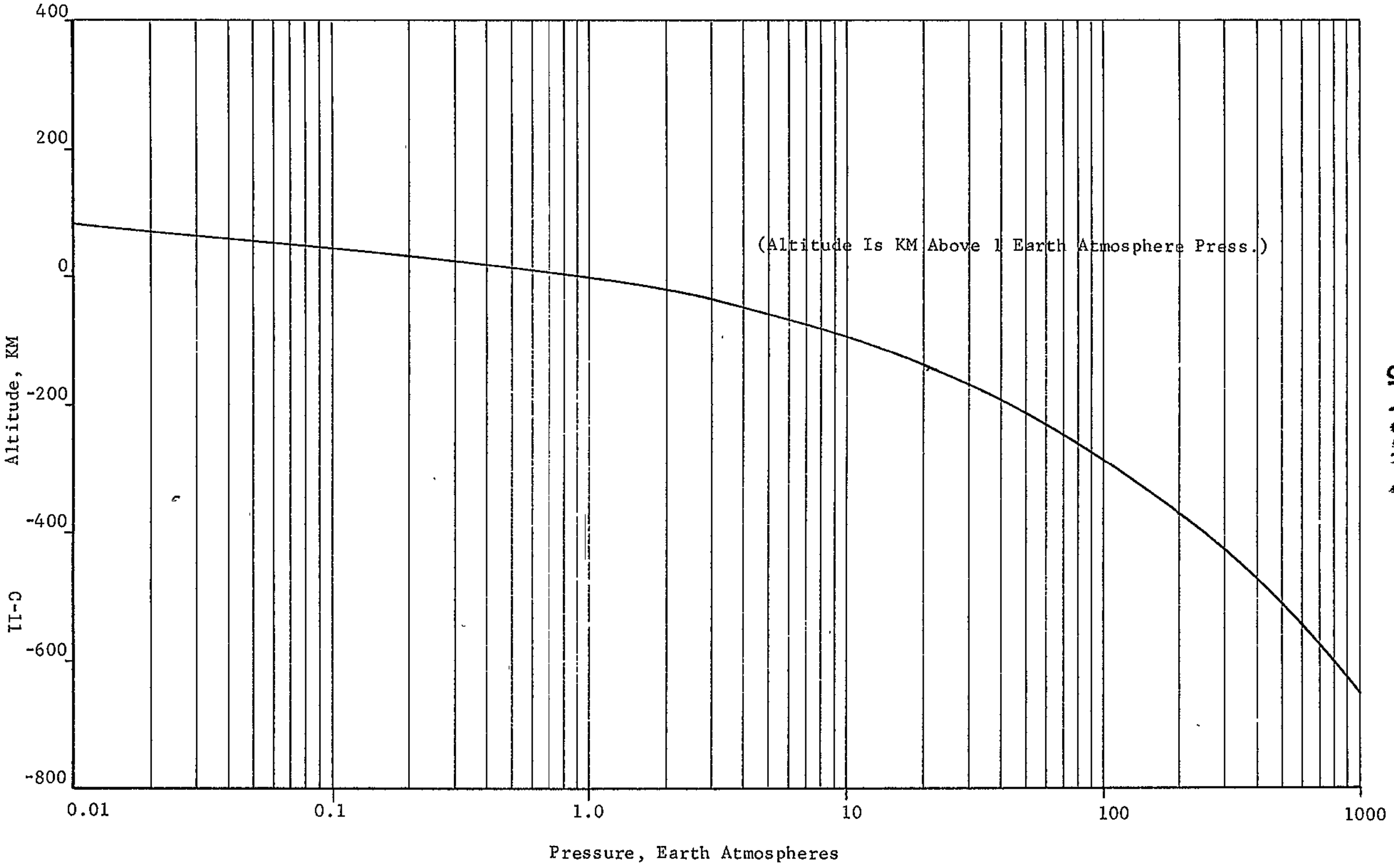


FIGURE C-7 - PRESSURE VS ALTITUDE, JUPITER

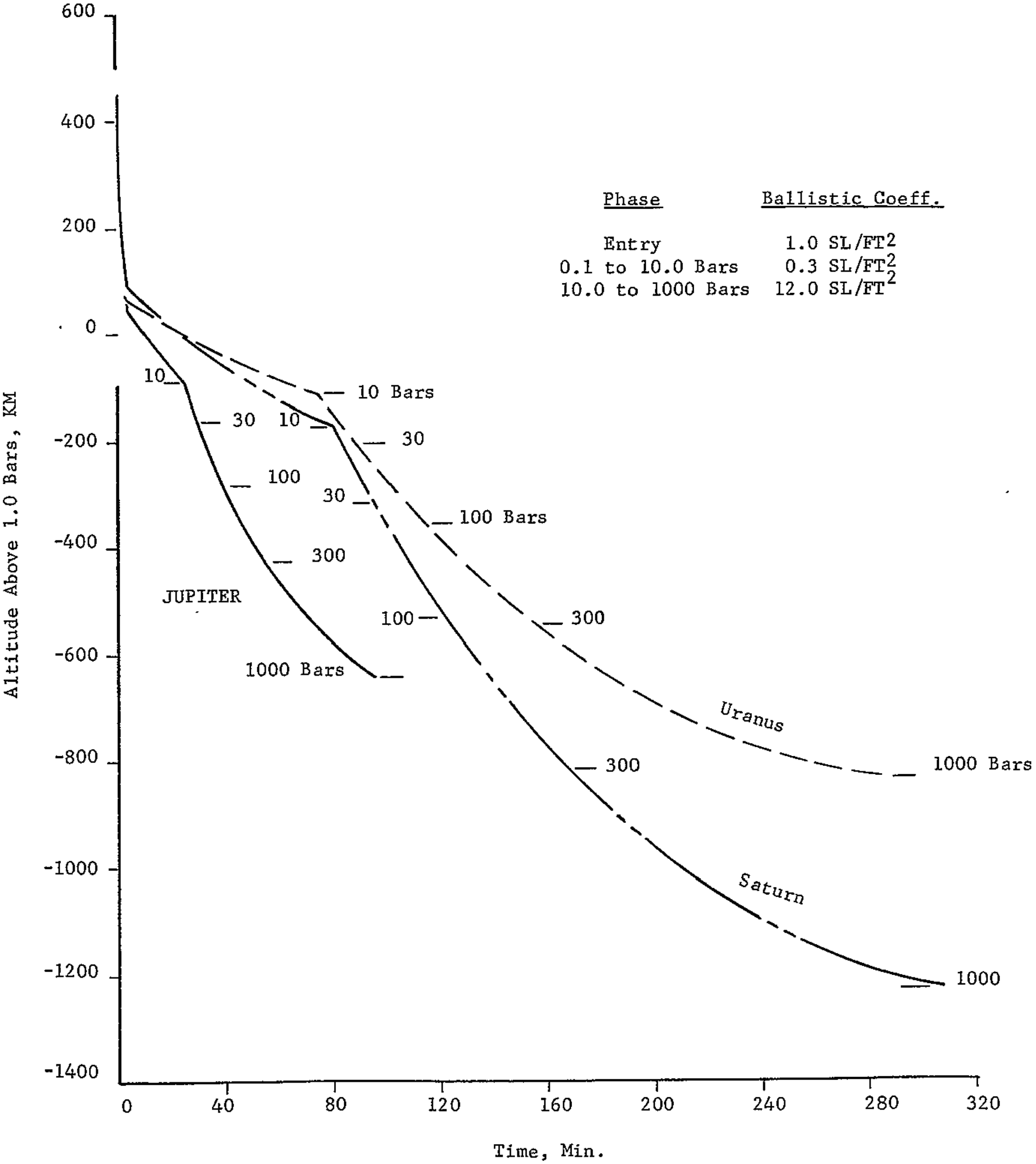


FIGURE C-8 - DESCENT TIMES FOR JUPITER, SATURN, AND URANUS ATMOSPHERES

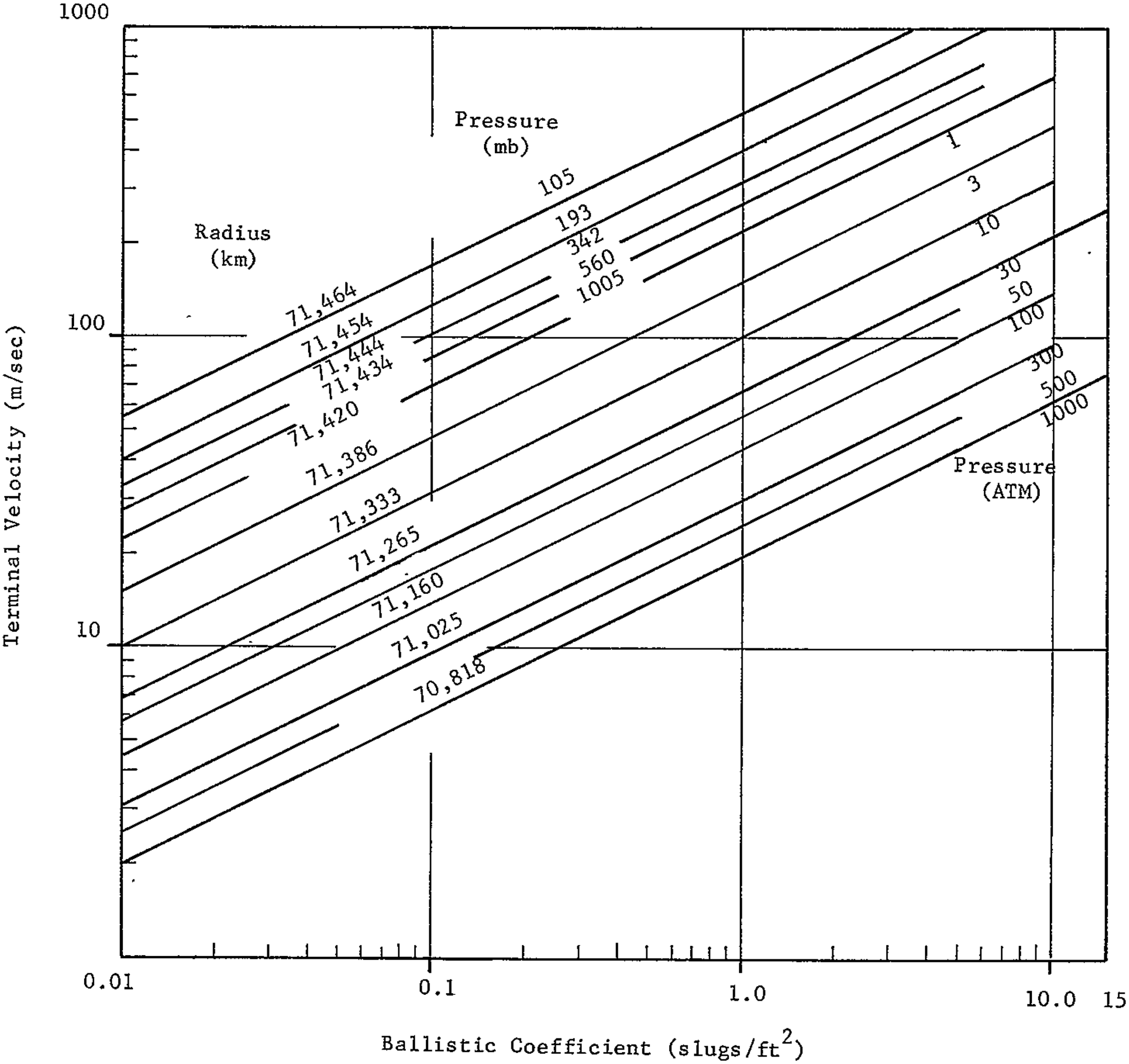


FIGURE C-9 - TERMINAL VELOCITIES FOR NOMINAL ATMOSPHERE (JUPITER)

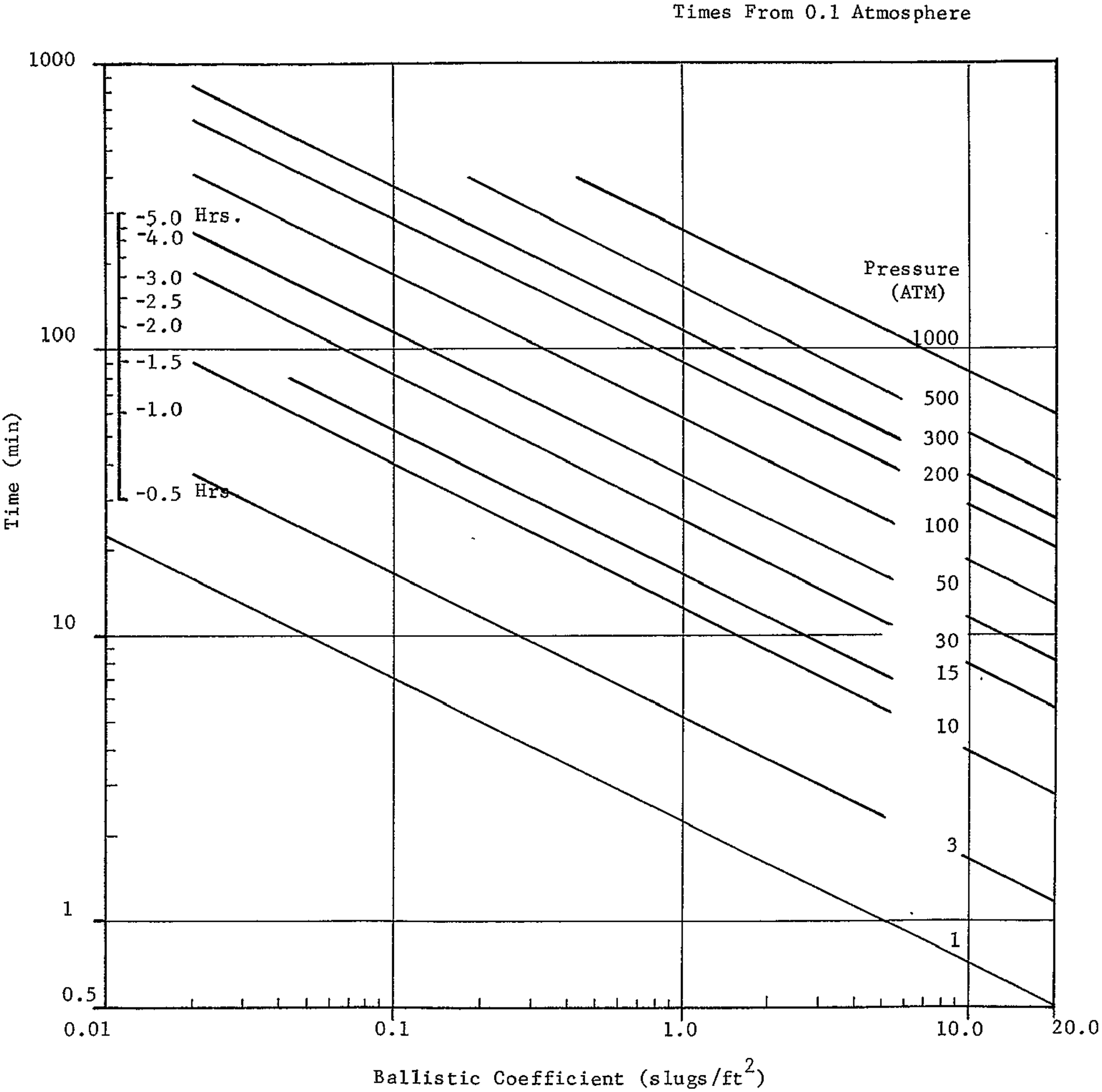


FIGURE C-10 - DESCENT TIMES FROM 100 MB FOR NOMINAL ATMOSPHERE (JUPITER)

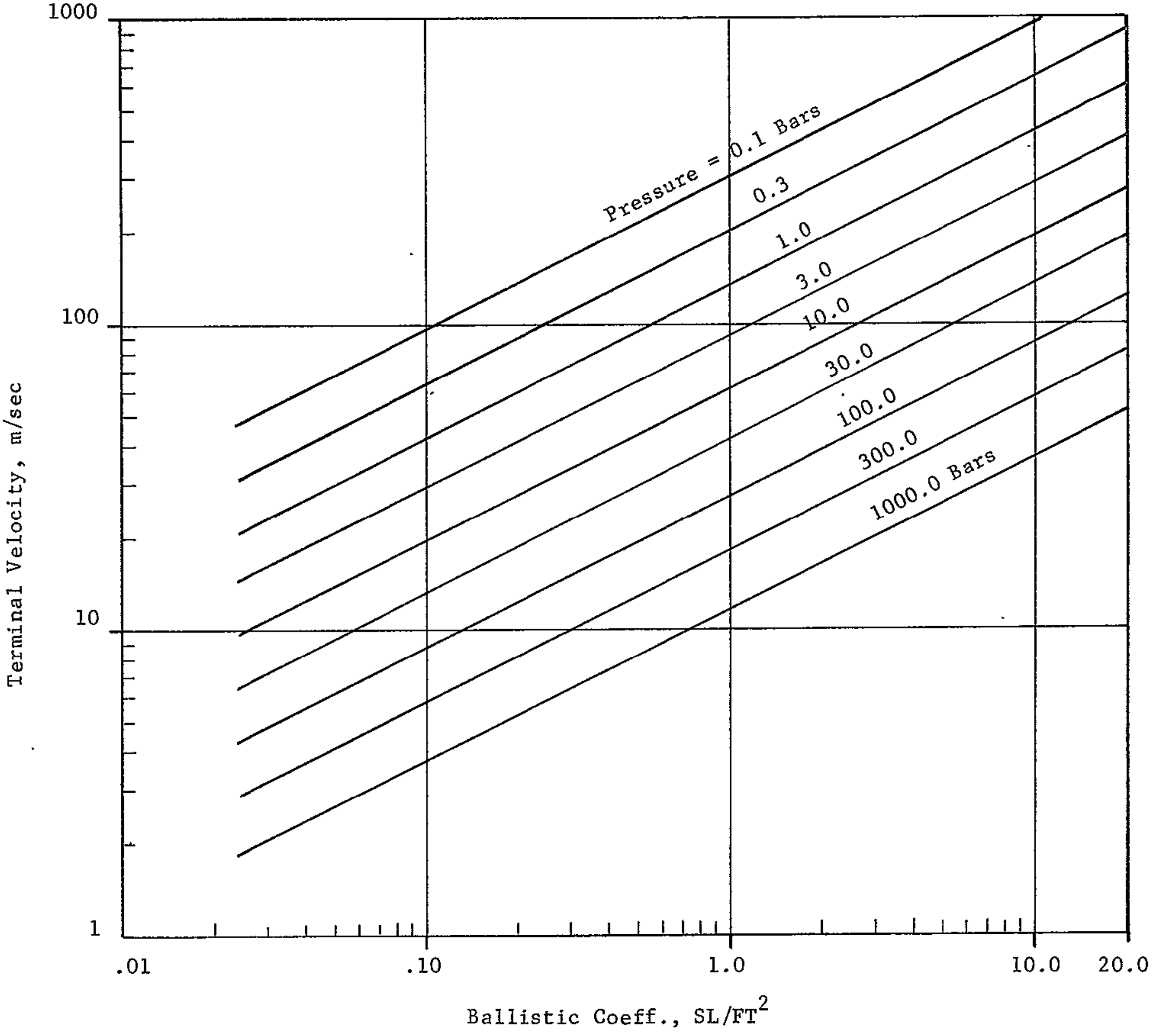


FIGURE C-11 - TERMINAL VELOCITIES FOR NOMINAL ATMOSPHERE (SATURN)

Time From 0.1 Bar

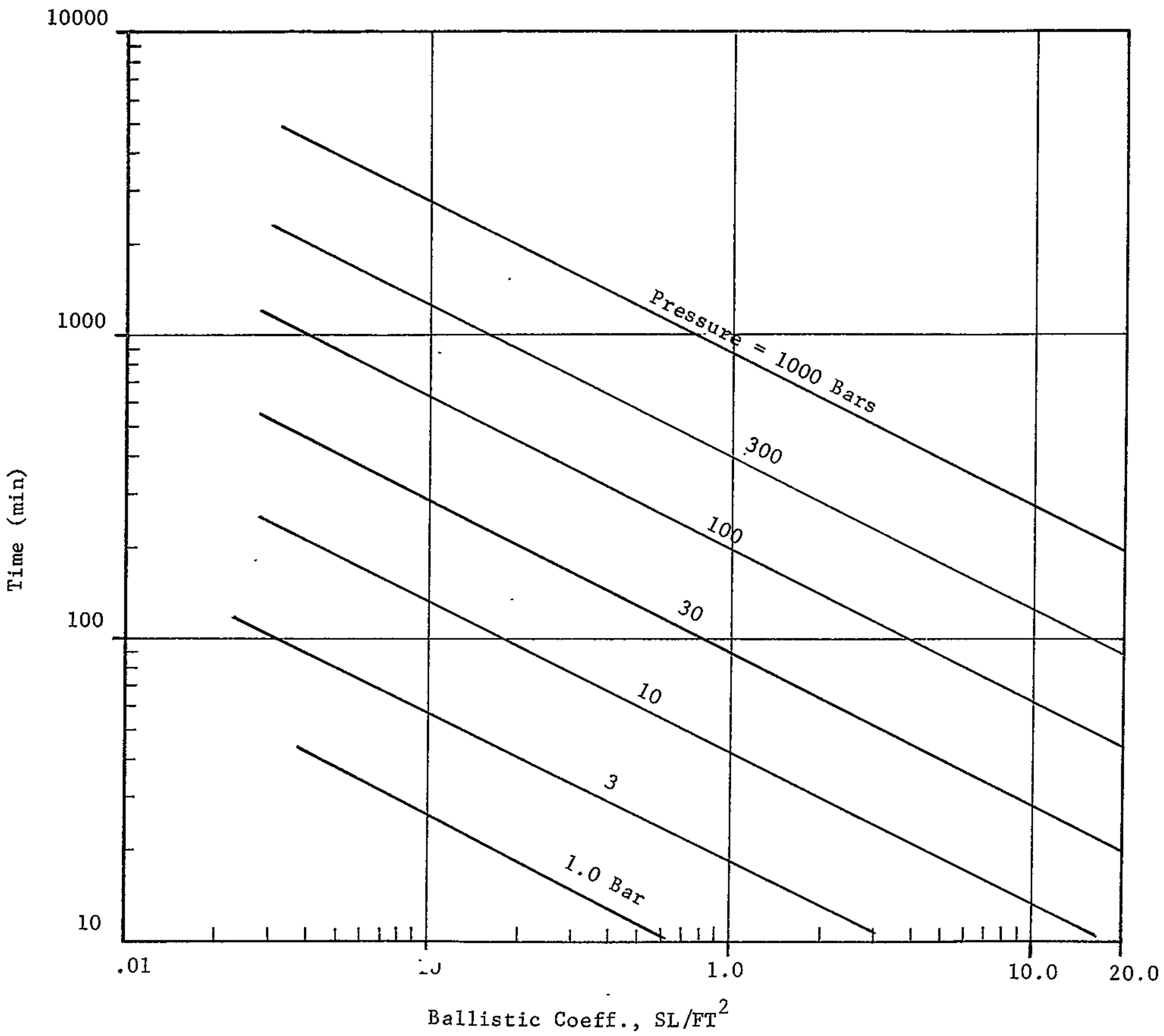


FIGURE C-12 - DESCENT TIMES FROM 100mb FOR NOMINAL ATMOSPHERE (SATURN)

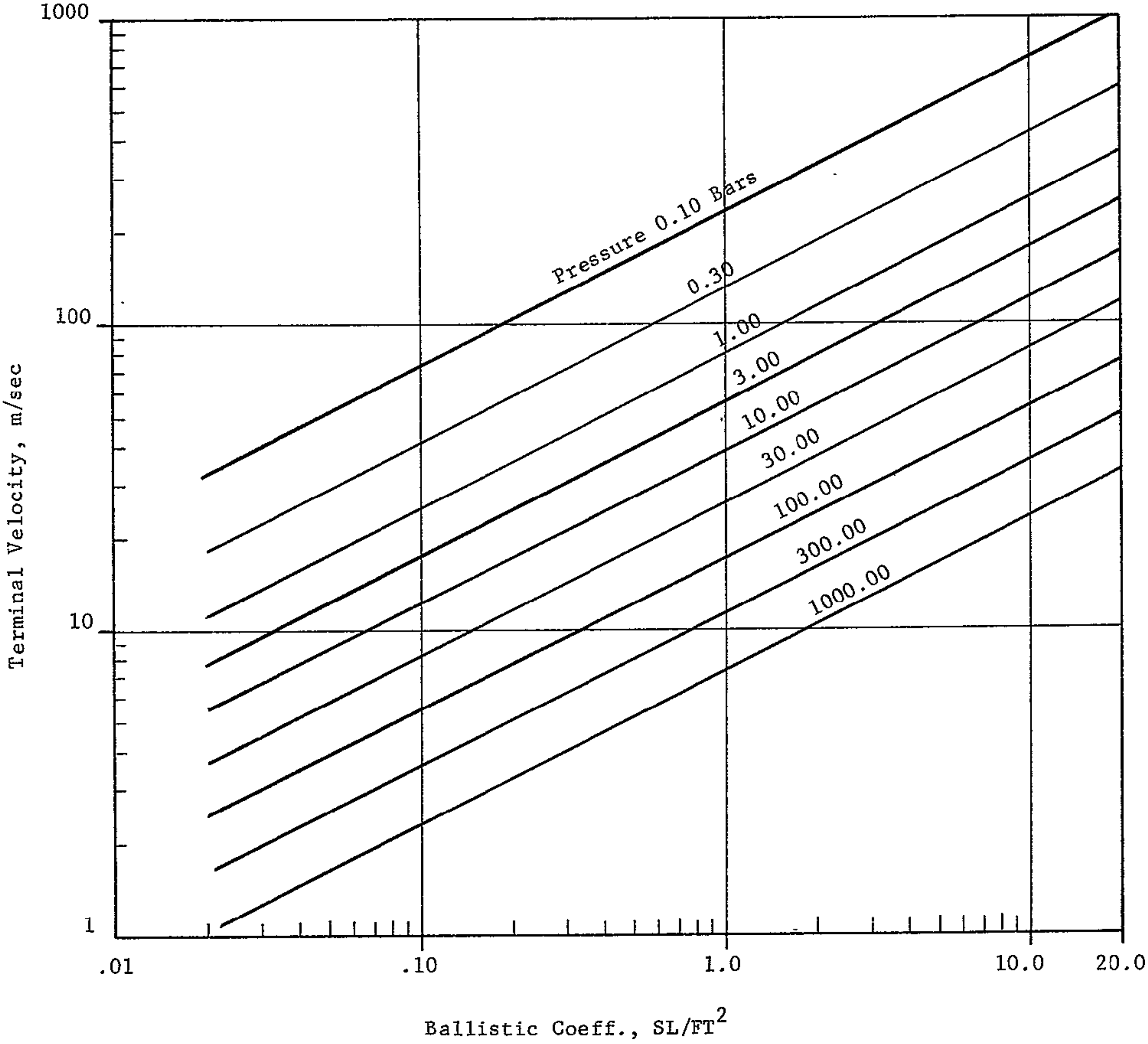


FIGURE C-13 - TERMINAL VELOCITIES FOR NOMINAL ATMOSPHERE (URANUS)

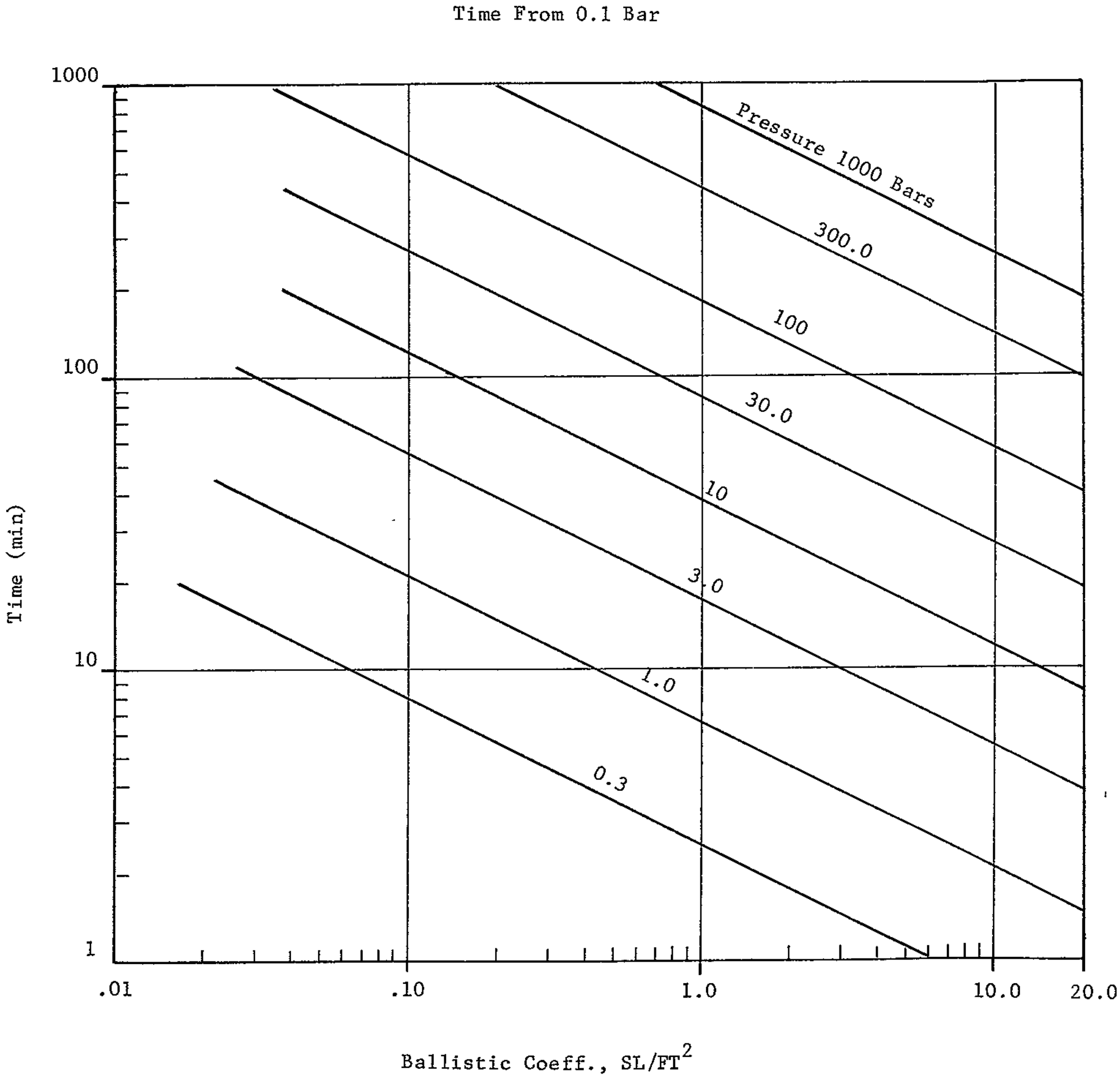


FIGURE C-14 - DESCENT TIMES FROM 100mb FOR NOMINAL ATMOSPHERE (URANUS)

References:

A) Outer Planet Atmospheric Entry Probe, Systems Descriptions, NASA/ Ames Research Center, July 1975

B) The Planet Jupiter (1970) NASA SP-8069, Dec. 1971

C) The Planet Saturn (1970) NASA SP-8091, June 1972

D) The Planets Uranus, Neptune, and Pluto (1971), November 1972

APPENDIX

D

PROBE TO ORBITER RELAY
LINK GEOMETRY

The following memorandum contains the summary results of the detailed study performed for this contract.

August 12, 1977

To: John Mellin   Memo No: RTG-77-406

From: R. T. Gamber

Subject: Jupiter Probe Relay Link Summary

Ref:
1) Descent Trajectories into the Jupiter Nominal Atmosphere, C. E. French, 12 July 1977
2) Jupiter Probe to Orbiter Relay Link Geometry, R. T. Gamber, 28 July 1977

Summary:

Studies have been conducted over the past month to characterize relay link geometry between a Jupiter Probe and a Jupiter Orbiter. This memo presents a set of conclusions of these studies, adds some summary figures, and adds to plots of Reference 2. This main thrust of the studies were to determine ways of reducing communication ranges and aspect angles to reduce communication power requirements. The dual orbiter concept has proven to be the most effective. A second orbiter whose line of apsides is rotated 60° relative to the first orbiter will provide a range that is 40% of the range of the first orbiter at the end of the longest (260 min.) descent.

Assumptions:

1. The orbiter will have a tracking relay link antenna so that the orbiter aspect angle is always near zero.

2. The orbiter can be protected from radiation sufficiently to allow an orbit periapsis of $1.8R_J$ for the orbit on which entry occurs (data is included for a $6R_J$ periapsis orbiter if radiation is a problem.)

3. The variations in Range and Aspect Angle between the Probe and Orbiter are minor for different probe descent rates (i.e. $\sim$ 500 km variation in probe altitude versus 100,000 km range). Thus the information shown in this memo is applicable to all descent rates referred to as fast (90 minutes), medium (160 minutes) and slow (260 minutes)

Conclusions:

1. Conclusions for 1.8 R_P Orbit

   a) Lead angle has a strong effect on the range and aspect angle for short descent times (90 and 160 minutes) as shown in Table 1. The range at entry plus 90 minutes can be reduced to 78,000 km with a -40 lead angle. This also provides a 160,000 km range at entry plus 160 min.

b) Lead angle does not have a large effect at entry plus 240 minutes. The range can be reduced to 310,000 km, with a -40° lead angle (vs 343,000 km for a minus 10° lead angle).

2. The radius of apoapsis does not have an effect on the communication geometry except for the long entry where the range can be reduced from 310,000 km to 279,000 km, as shown in Table 1. This requires a 15R_J apoapsis which could be obtained by flybys of the Galilean moons (for pumping) assisted by propulsion.

3. A 6R_J orbit results in ranges over 360,000 km for the whole descent and large aspect angles past entry plus 160 minutes.

4. A circular orbit of 2.24 R_J radius would be synchronous with the Jovian rotation. Very high ΔV requirements are necessary to achieve this orbit but pumping may help to achieve a low apoapsis radius. The resultant communication range of 87,000 km. would be constant for the entire descent. Weight and fuel requirements could be reduced by placing only a relay link module in the circular orbit.

5. A second orbiter with the line of apsides rotated 60° from the first would provide a reduction in range to 164,000 km for the 260 min descent case. The 164,000 km range occurs for the case with an orbiter lead angle of minus 25 degrees. The probe enters at a central angle of minus 70 degrees relative to the second orbiter periapsis. At the time of entry the second orbiter is at a true anomoly of minus 95 degrees. At approximately 120 minutes from entry, the second orbiter relay geometry would be more favorable than the first orbiter.

Discussion:

The remainder of this memo is a compilation of data for the Jupiter Probe to Orbiter relay link.

A. Jupiter Probe - Dual Orbiter Relay Link Geometry

The communication link geometry for a Jupiter entry probe is illustrated in Figure D-1. Specific time points from entry are shown to illustrate the communications link range and probe aspect angle. The case shown here has probe at 10° prior to periapsis with an orbiter lead angle of -30° (the orbiter is 30° behind in central angle at the time of probe entry). By entry plus 60 minutes the orbiter is nearly overhead of the probe (5° aspect angle) and the range is near minimum at 64,000 km. However, the probe soon is far ahead of the orbiter. At entry plus 260 minutes, the aspect angle is 48° with the range at 321,000 kilometers. A second orbiter is shown in the figure to illustrate a method to reduce the range and aspect angle to 163,000 km and 6° respectively at entry plus 260 minutes. The line of apsides of the second orbiter has been rotated 60° relative to the first orbiter. (This rotation could be accomplished by close flyby's of the Galilean satellites of Jupiter.) A second orbiter of Jupiter would be scientifically valuable by providing spatially varied Jovian science measurements at the same time as the first orbiter.

B. Jupiter Probe to Orbiter Range and Aspect Angle

The effect of orbiter lead angle on range and aspect angle variation is shown in Figure D-2 for lead angles of -10° and -40°. The data shown is for an orbiter with a periapsis radius of 1.8 R_J. The communications range reaches a minimum slightly prior to overfly of the probe for cases where overfly occurs after periapsis. Overfly (aspect angle of zero) usually occurs twice with the orbiter initially traveling faster than planet rotation near periapsis and cathes the probe. The orbiter is moving slower than the planet by one hour after periapsis and the probe catches the orbiter in central angle. The range increases rapidly after the second overfly. The information in the figure can be used for cases where the descent to 1000 bars takes less time than the 260 minutes shown since the depth in the atmosphere is small compared to the total range (640 km vs 100,000 km). This for a 90 minute entry the -40° lead angle would have a range of 78,000 km and a 5° aspect angle. The specific choice of lead angle is a trade-off based on science data requirements and communication system performance. High data rates early in descent (at 30 bars) would dictate a smaller negative lead angle. If higher data rates are desired at 1000 bars then a more negative lead angle would be desired to minimize range and aspect angle at this point.

C. Communication Link Parameters

A tabulated set of range and aspect angle values are given in Table D-2 as a factor of time and lead angle. It can be seen that only small variation in range and aspect angle is possible at 260 minutes after entry by varying the lead angle with the first orbiter. The second orbiter as illustrated in Figure D-1 can provide a significant improvement in the range and aspect angle. The lead angle of -30° for the second orbiter provides short ranges for the last two hours of entry but the aspect angles are high initially.

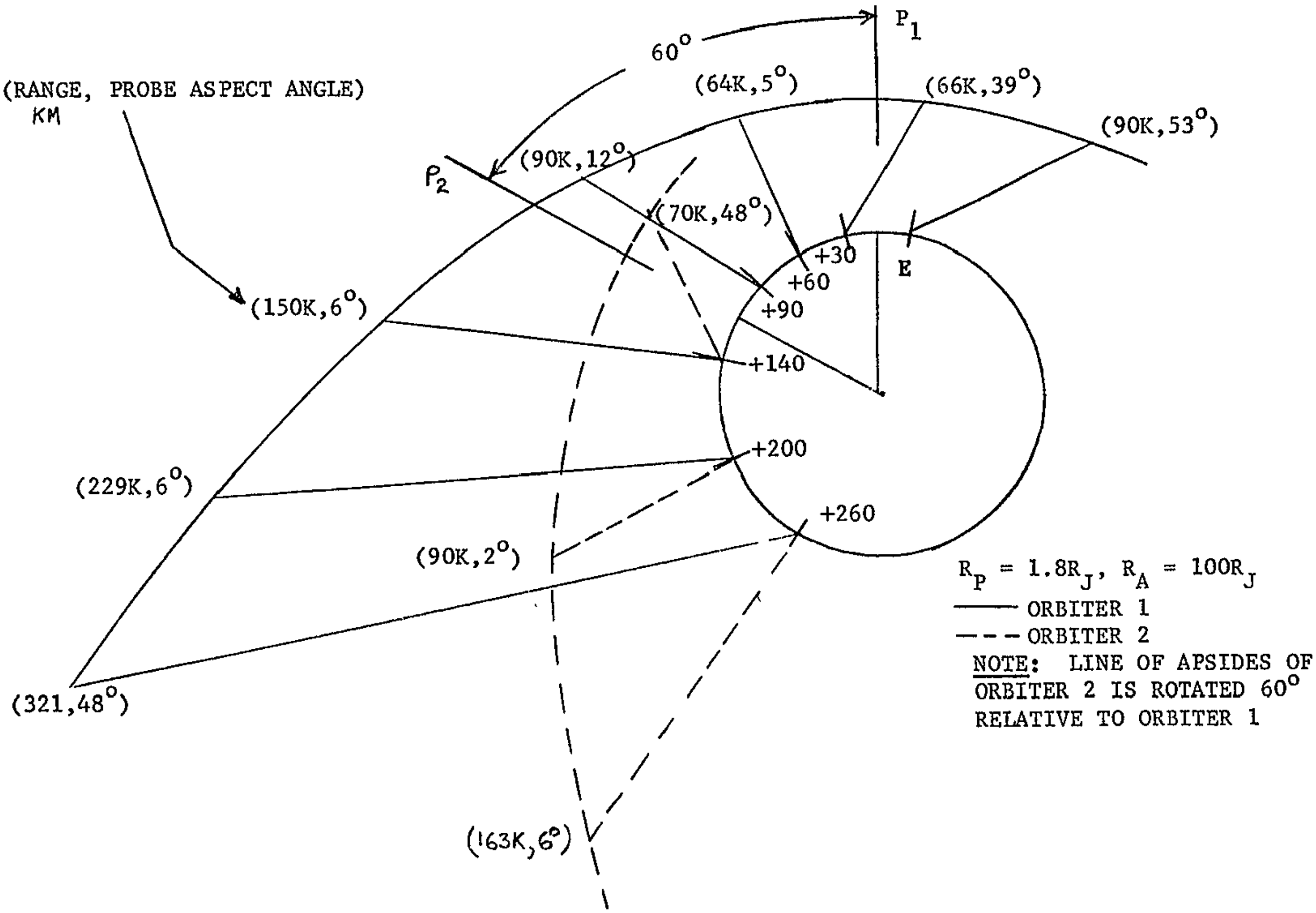
D. Compilation of Relay Link Geometry Plots

The range and aspect angle time histories for different orbit cases are summarized in Figures 3 through 10 which are:

Figure D-3: Communications Range: Probe to 1.8R_J Orbiter
Figure D-4: Probe Aspect Angle: Probe to 1.8R_J Orbiter
Figure D-5: Communications Range: Fast Descent Probe to 1.8R_J Orbiter
Figure D-6: Probe Aspect Angle: Fast Descent Probe to 1.8R_J Orbitter
Figure D-7: Communications Range: Probe to 6R_J Orbiter
Figure D-8: Probe Aspect Angle: Probe to 6R_J Orbiter
Figure D-9: Range and Aspect Angle: Probe to Second Orbiter $\lambda = -20$ & -35°
Figure D10: Range and Aspect Angle: Probe to Second Orbiter $\lambda = -25$ & -30°

TABLE D-1 - COMPARISON OF COMMUNICATION RANGE AND ASPECT ANGLE

Time From Entry	Orbiter Periapsis/Apoapsis, Lead Angle				
	$1.8\text{x}100, \lambda = -10^\circ$	$1.8\text{x}100, \lambda = -40^\circ$	$1.8\text{x}20, \lambda = -30^\circ$	$1.8\text{x}15, \lambda = -30^\circ$	$6\text{x}100, \lambda = +10$
E + 3	62K, 23°	110K, 67°	89K, 56°	88K, 56°	361K, 7.7°
E + 90	118K, 32°	78K, 5°	85K, 9°	83K, 8°	390K, 36°
E + 160	201K, 7°	160K, 6°	161K, 0°	155K, 0°	445K, 69°
E + 240	343K, 45°	310K, 50°	291K, 46°	279K, 45°	----



<u>NOTE</u>: LINE OF APSIDES OF ORBITER 2 IS ROTATED 60° RELATIVE TO ORBITER 1

FIGURE D-1 - JUPITER PROBE - DUAL ORBITER RELAY LINK GEOMETRY

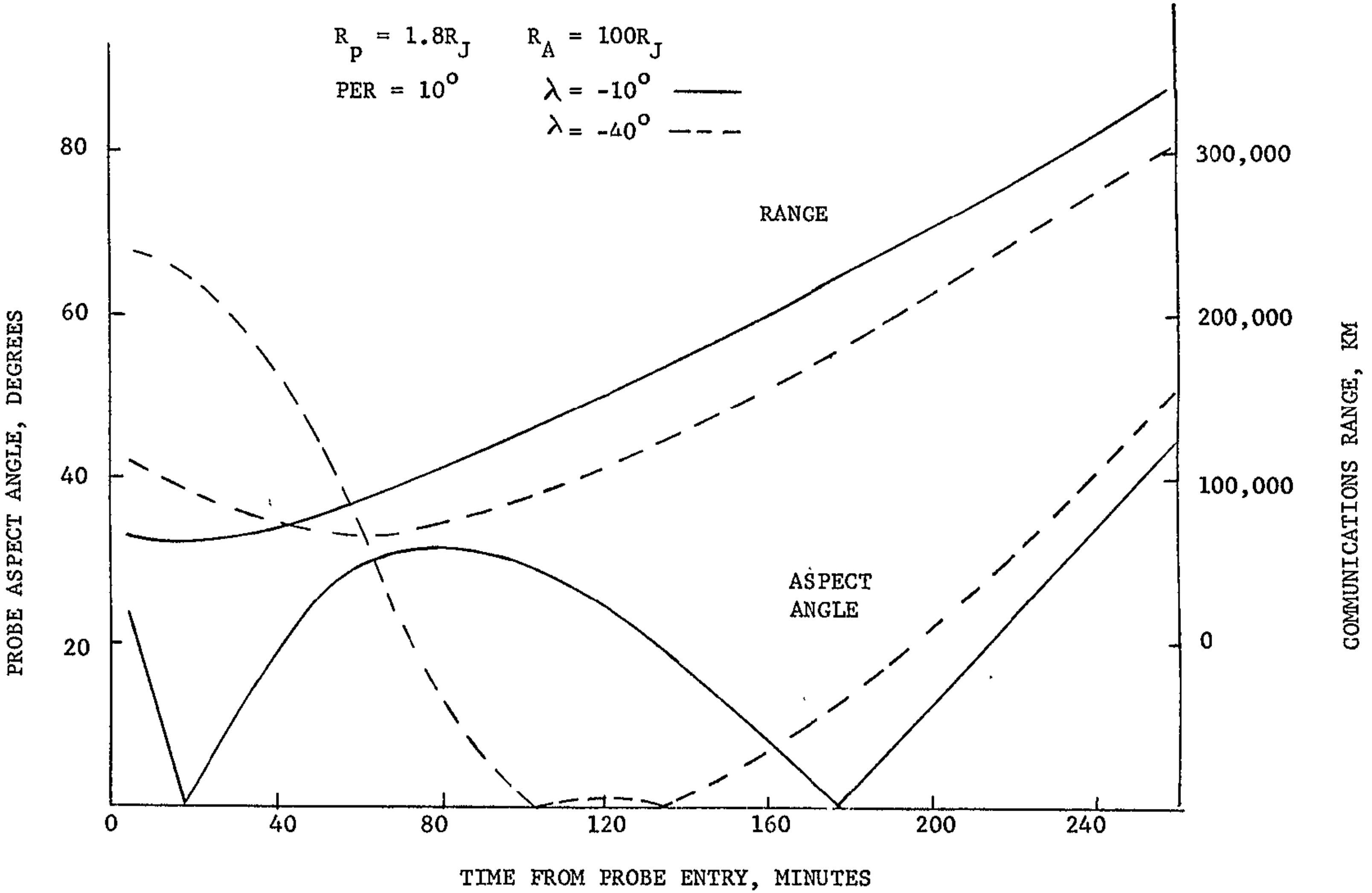


FIGURE D-2 - JUPITER PROBE TO ORBITER RANGE AND ASPECT ANGLE

TABLE D-2 - JUPITER PROBE TO ORBITER COMMUNICATION LINK PARAMETERS

ORBITER: $R_P = 1.8\ R_J$ $R_A = 100\ R_J$.

PROBE : PER = 10°, LEAD ANGLE IN TABLE(2)

TIME FROM ENTRY	RANGE(1)/ASPECT ANGLE			SECOND ORBITER	
	$\lambda = -10^\circ$	$\lambda = -30^\circ$	$\lambda = -40^\circ$	$\lambda = -25^\circ$	$\lambda = -30^\circ$
0	63K, 21°	90K, 53°	110K, 65°		
30	60K, 9°	66K, 39°	81K, 59°		
60	84K, 30°	64K, 5°	64K, 32°		
90	118K, 32°	90K, 12°	78K, 5°	120K, 65°	
110	141K, 27°	113K, 13°	98K, 1°	98K, 64°	138K, 81°
140	176K, 16°	149K, 6°	134K, 1°	70K, 48°	104K, 78°
200	253K, 13°	229K, 18°	215K, 22°	90K, 2°	77K, 33°
260	343K, 45°	322K, 48°	309K, 50°	164K, 6°	138K, 19°

NOTES:
1. RANGE IN THOUSANDS OF KILOMETERS
2. LEAD ANGLE SELECTION DEPENDENT ON SCIENCE DATA REQUIREMENTS.

$R_P = 1.8\ R_J \quad R_A = 100\ R_J$
PER = +10°

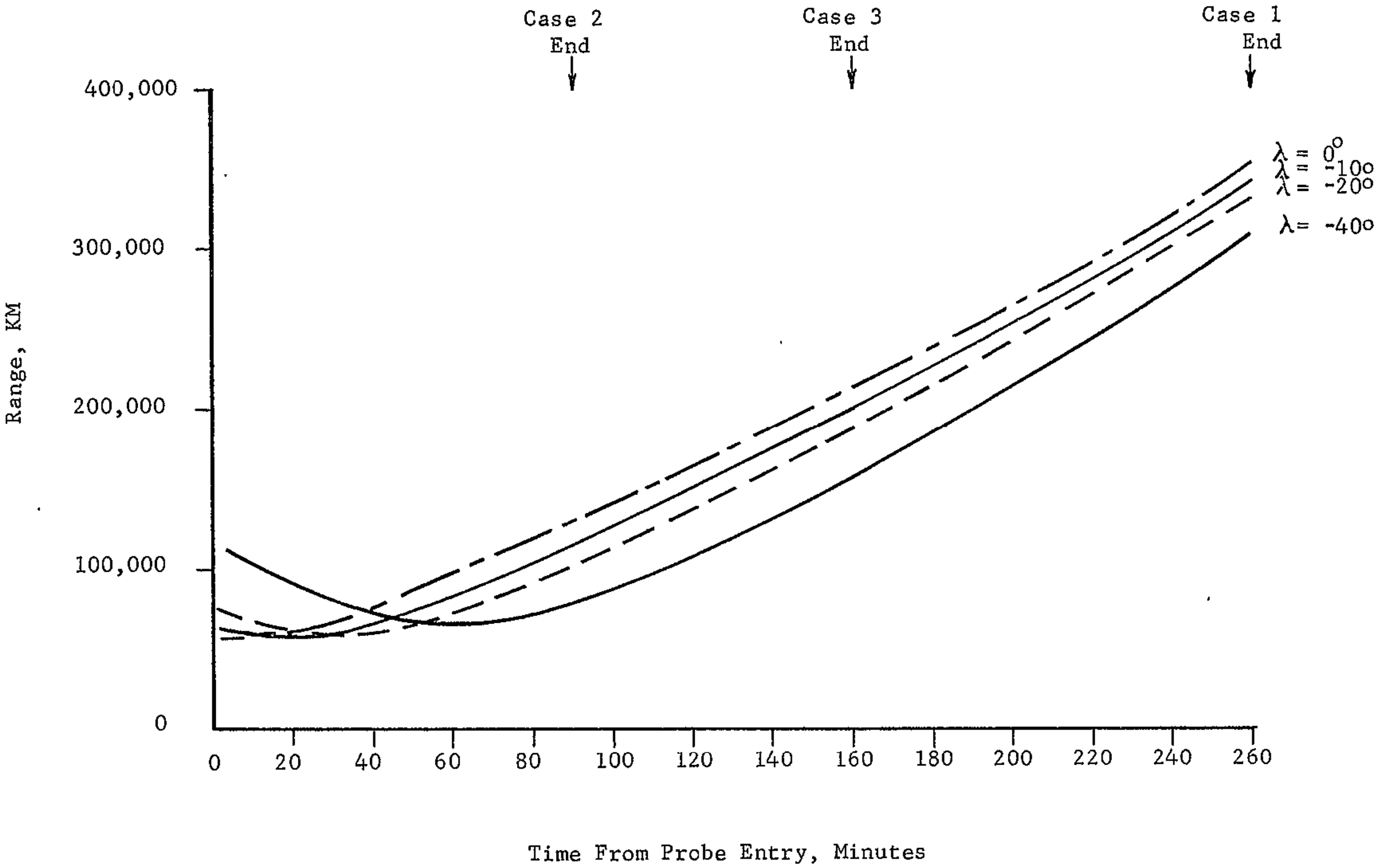


FIGURE D-3 - COMMUNICATIONS RANGE: PROBE TO 1.8 R_J ORBITER

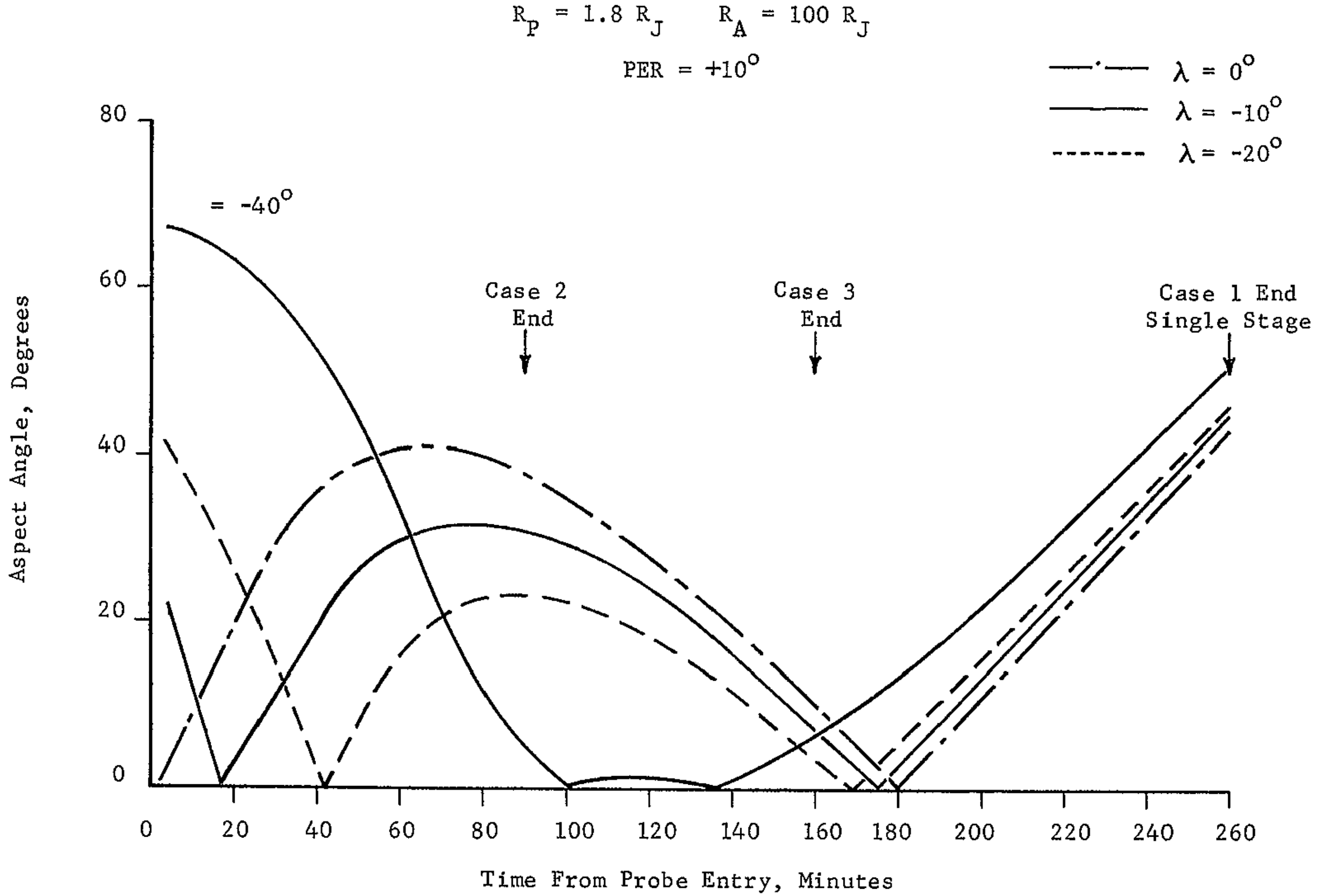


FIGURE D-4 - PROBE ASPECT ANGLE: PROBE TO 1.8 R_J ORBITER

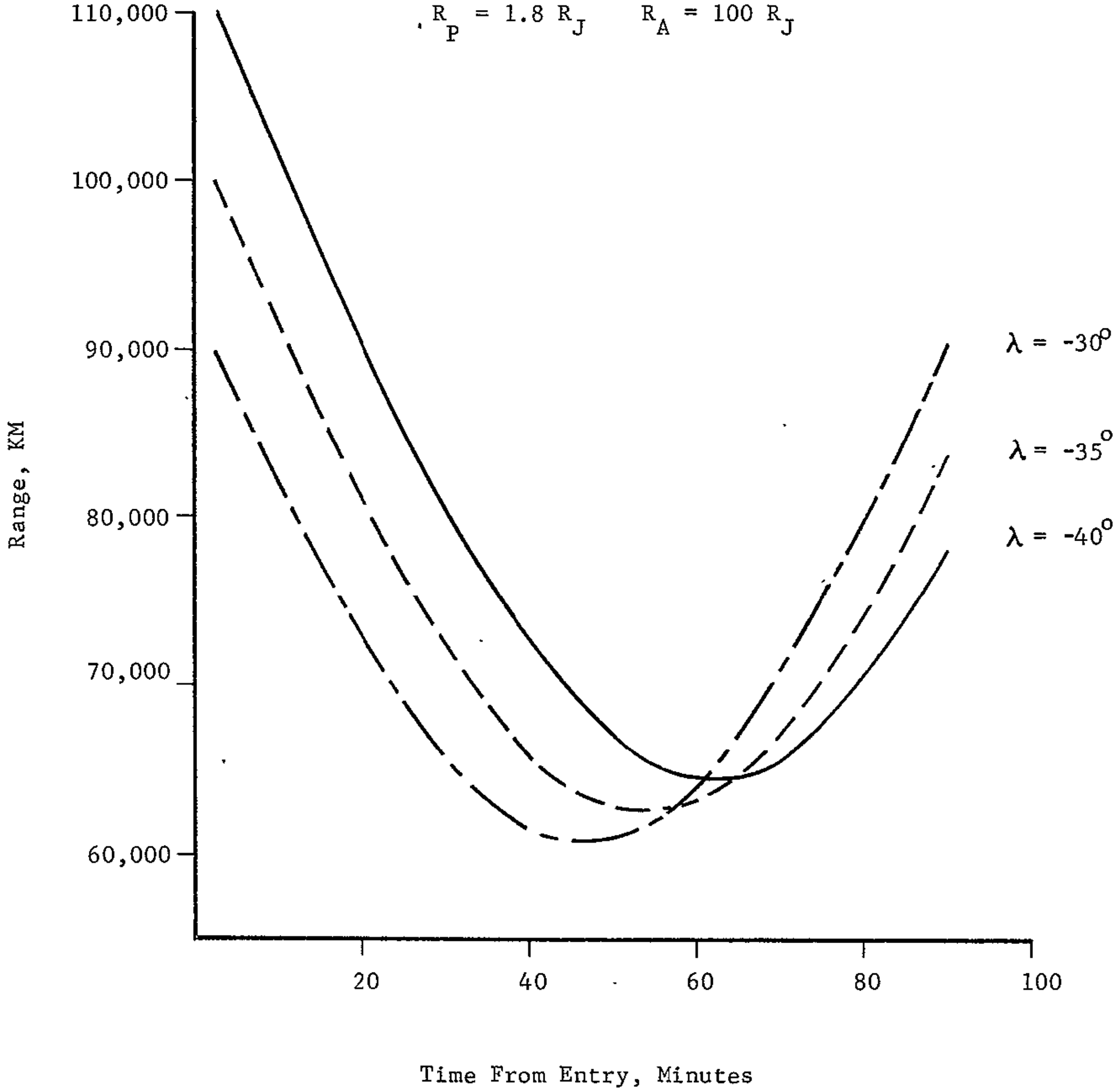


FIGURE D-5 - COMMUNICATIONS RANGE: FAST DESCENT PROBE TO 1.8 R_J ORBITER

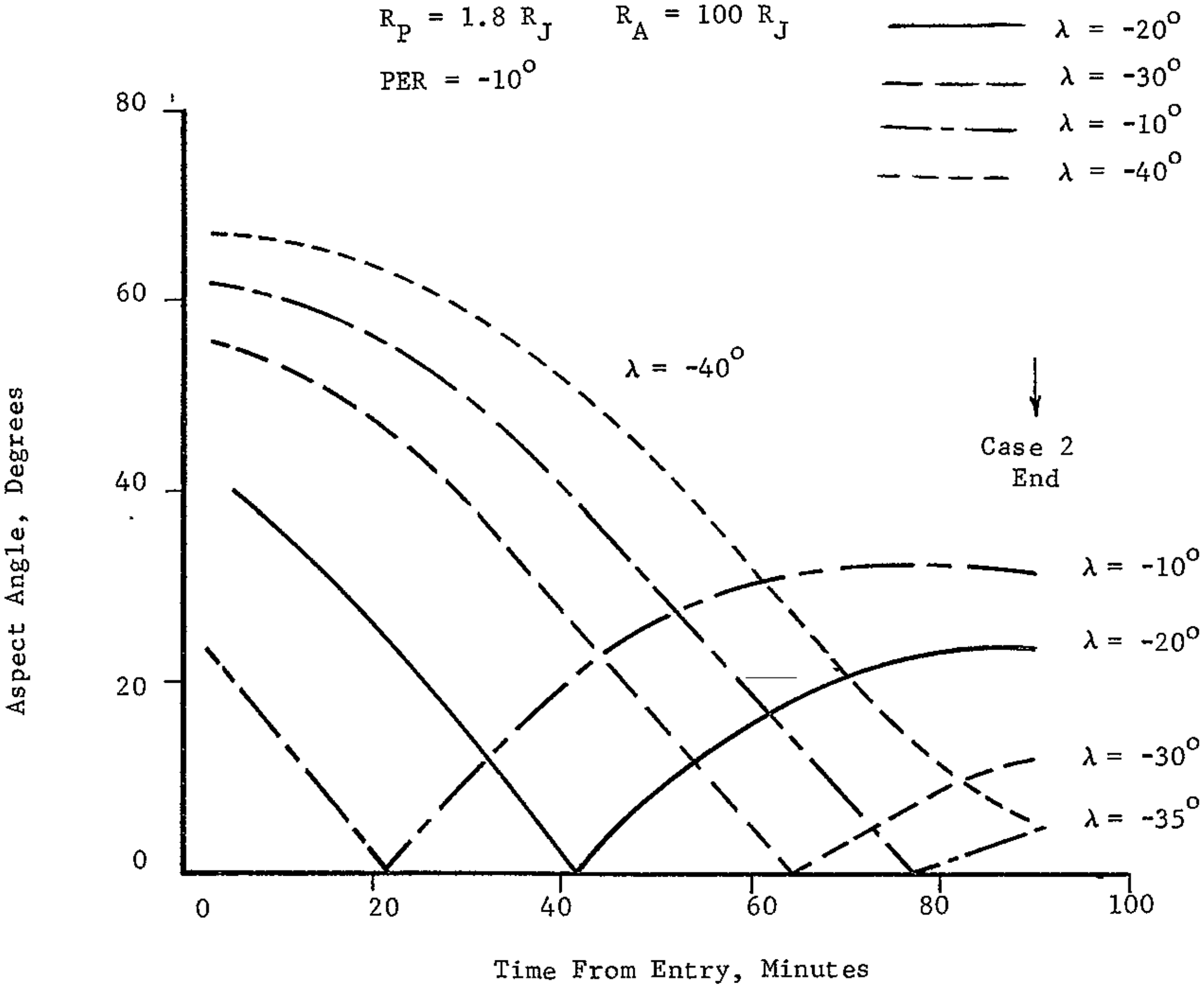


FIGURE D-6 - PROBE ASPECT ANGLE: FAST DESCENT PROBE TO 1.8 R_J ORBITER

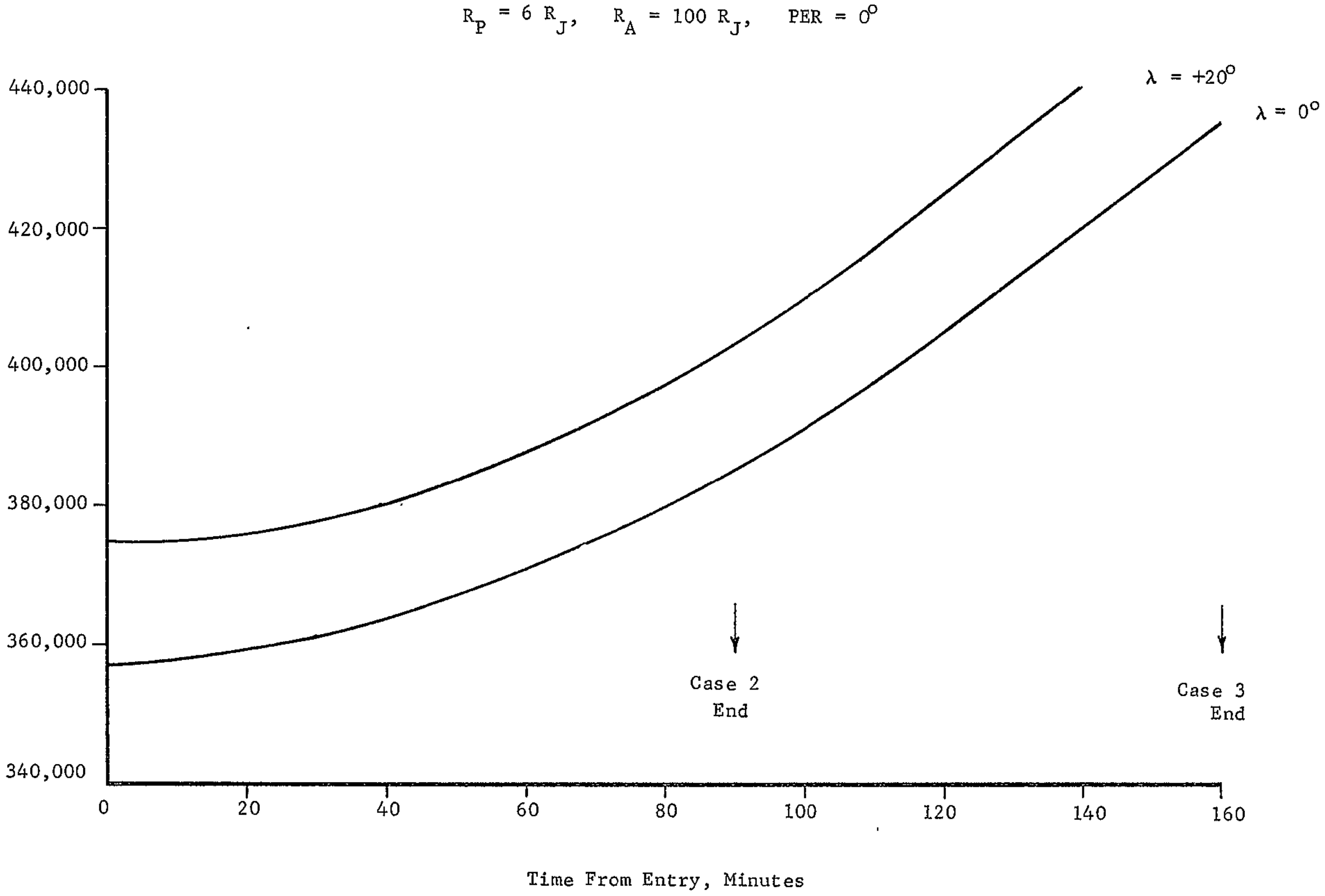


FIGURE D-7 - COMMUNICATIONS RANGE: PROBE TO 6 R_J ORBITER

$R_P = 6\ R_J \quad R_A = 100\ R_J$

PER = 0

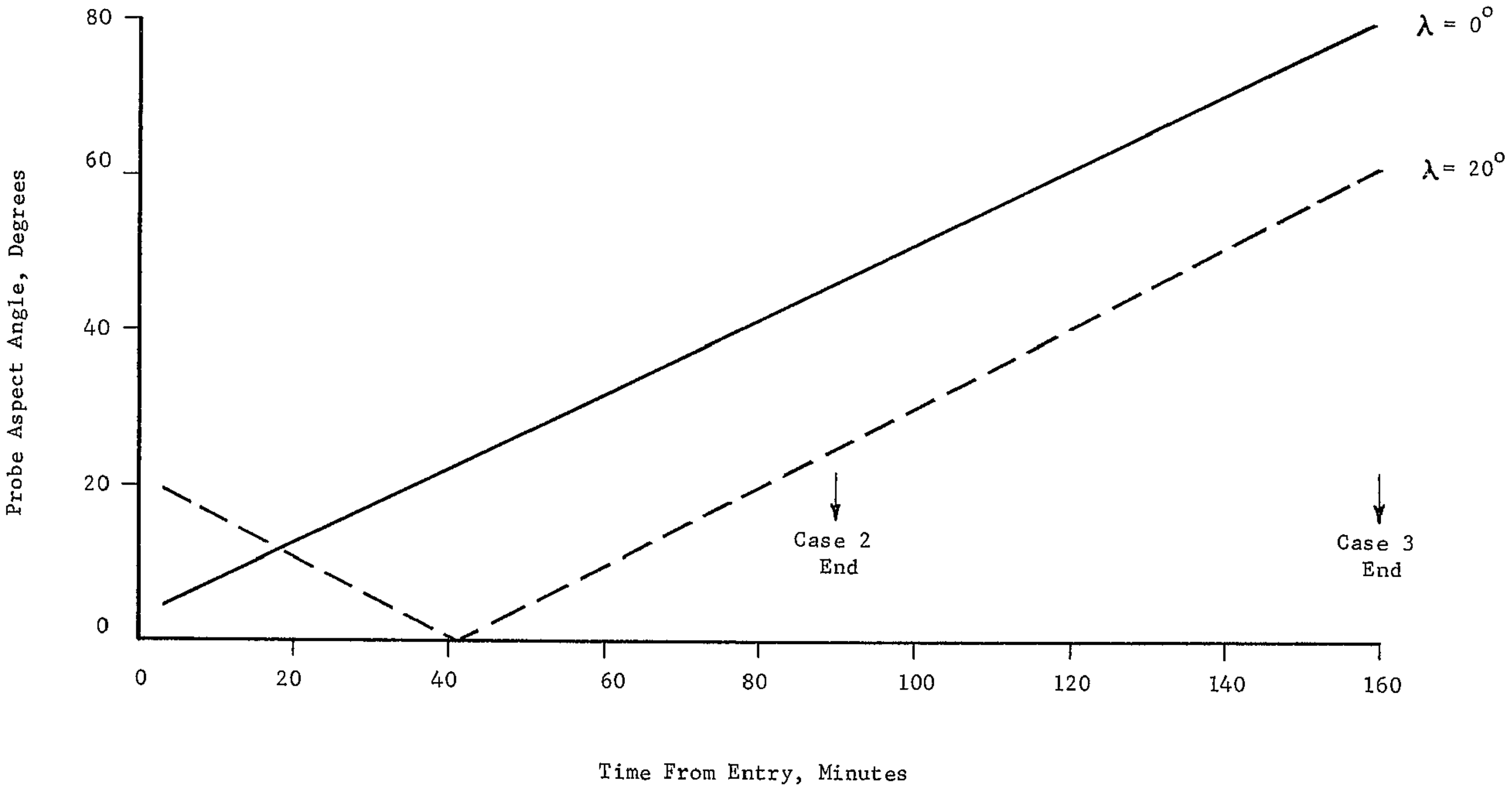


FIGURE D-8 - PROBE ASPECT ANGLE: PROBE TO 6 R_J ORBITER

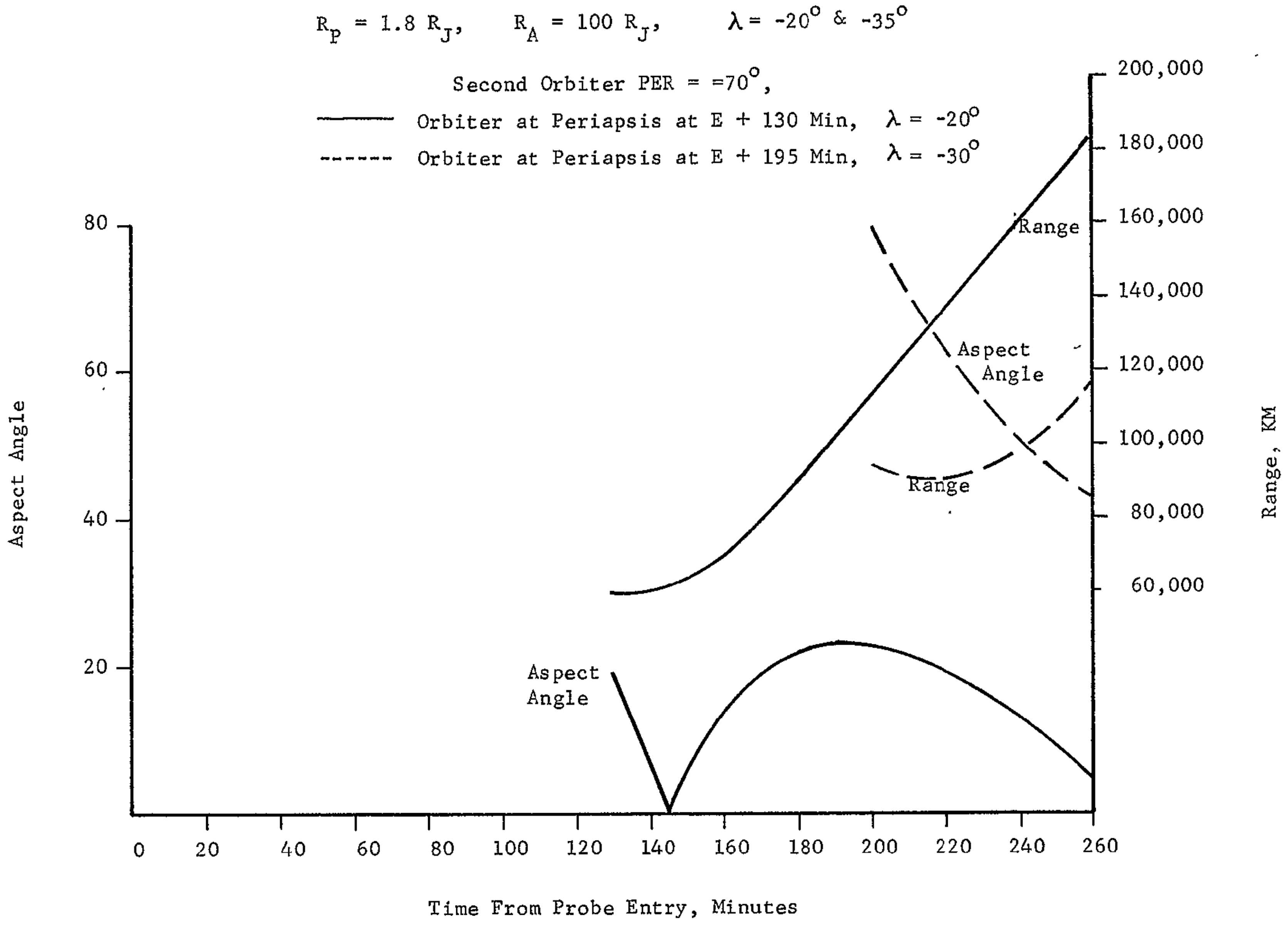


FIGURE D-9 - RANGE AND ASPECT ANGLE: PROBE TO SECOND ORBITER

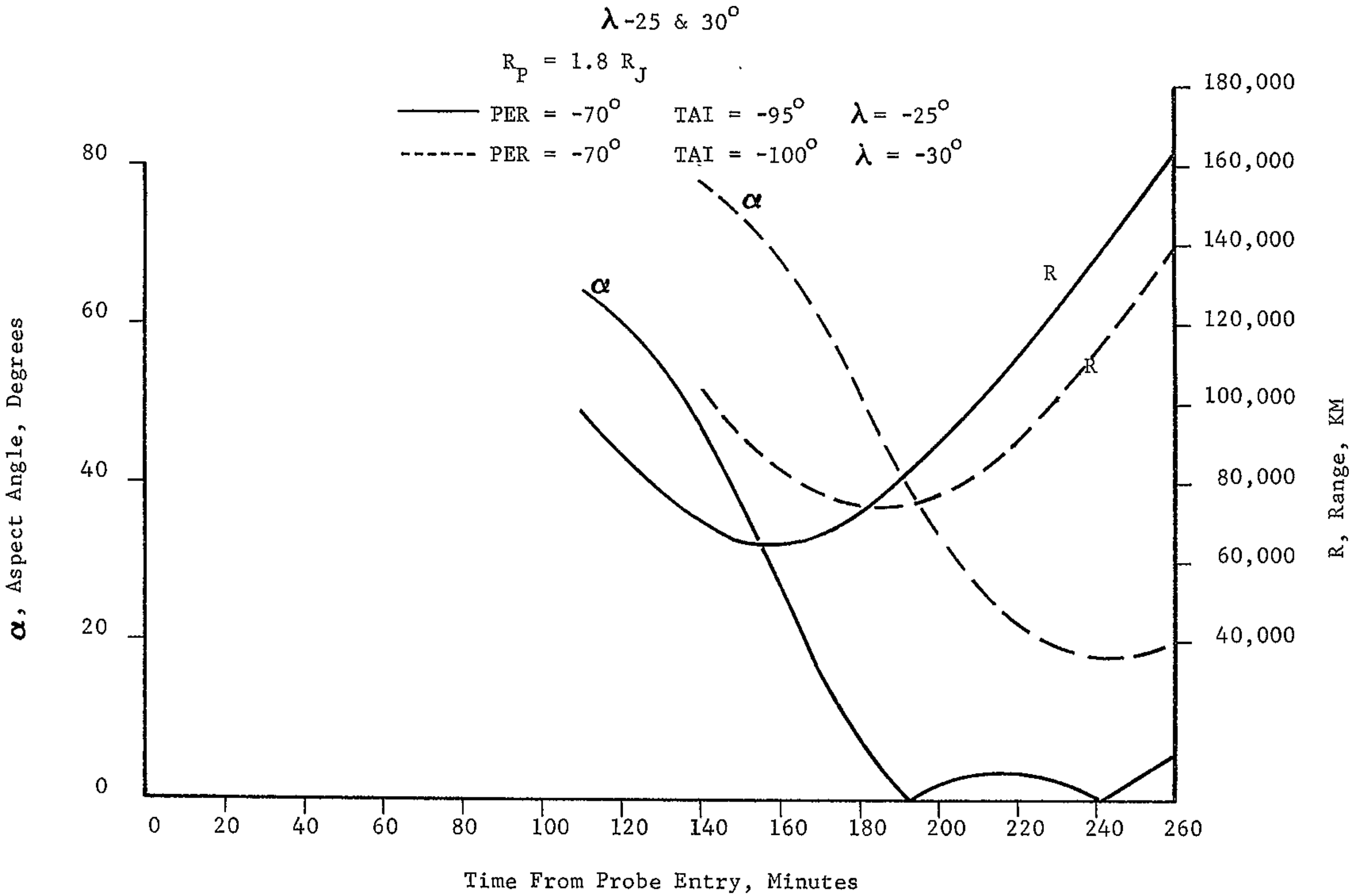


FIGURE D-10 - RANGE AND ASPECT ANGLE: PROBE TO SECOND ORBITER

To: John Mellin Date: September 15, 1977

From: R. T. Gamber

Subject: Saturn and Uranus Probe Relay Link Geometry

Ref: Jupiter Probe Relay Link Summary

Discussion:

The relay link geometry between entry probes and an orbiter for Saturn and Uranus has been studied to compare to the geometry for a Jupiter probe. The orbit selected for the Saturn and Uranus orbiter is the same as for the Jupiter orbiter in terms of planet radii; 1.8 planet radii for periapsis and 100 planet radii for apoapsis. This preliminary study has not considered required adjustments to the orbit to avoid the planetary rings. It should also be pointed out that the geometry shown in Figures D-11 and D-12 for Saturn and Uranus would be nearly identical for a fly-by spacecraft supporting the relay link.

The Saturn geometry in Figure D-11 shows that the probe range at the end of a 300 min. entry is 250,000 km., with about a 70° probe aspect angle. The Jupiter probe requires a 330,000 km. range at the end of entry compared to the 250,000 km. range for Saturn. A dual orbiter for the Saturn probe support could reduce this range by at least a factor of two. (See the reference for a discussion of the dual orbiter concept.)

The Uranus Probe range (120,000 km.) and aspect angle (45°) are much better than for Jupiter. There is a large uncertainty in the Uranus rotation rate, but a change in the daily rotation rate from 10.8 hr. to 15 hr. does not make a significant change in relay link power requirements.

Conclusions:

1. Probe power requirements for Saturn and Uranus entries are lower than for Jupiter probes due to the shorter range requirements.

2. The orbiter radii for a Saturn probe should be slightly less than 1.8 radii to allow the orbiter to catch up with the probe during the middle of the descent.

$R_P = 1.8\ R_S \qquad R_A = 100\ R_S \qquad PER = 10^{\circ} \qquad \lambda = -20^{\circ}$

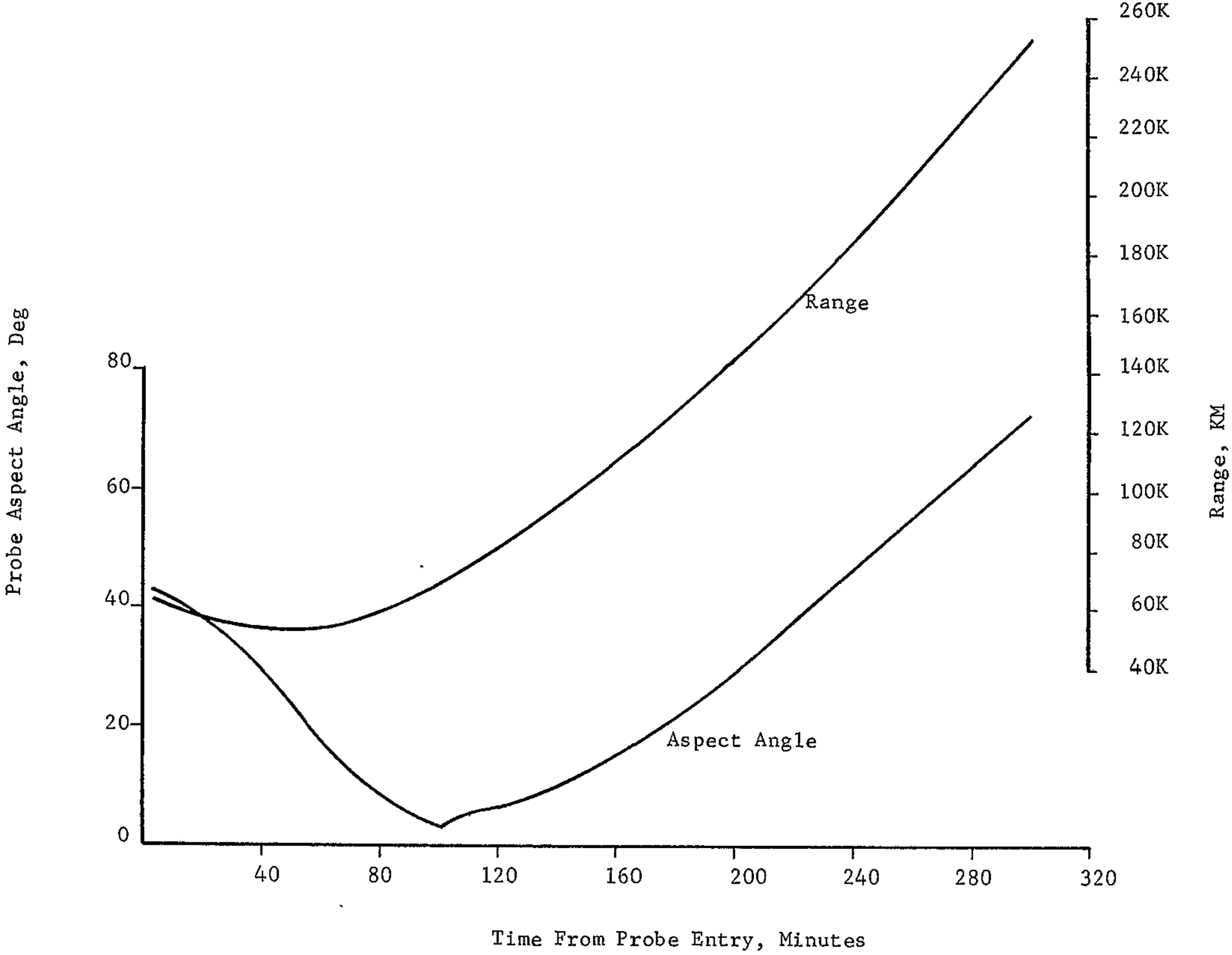


FIGURE D-11 - SATURN PROBE TO ORBITER RANGE & ASPECT ANGLE

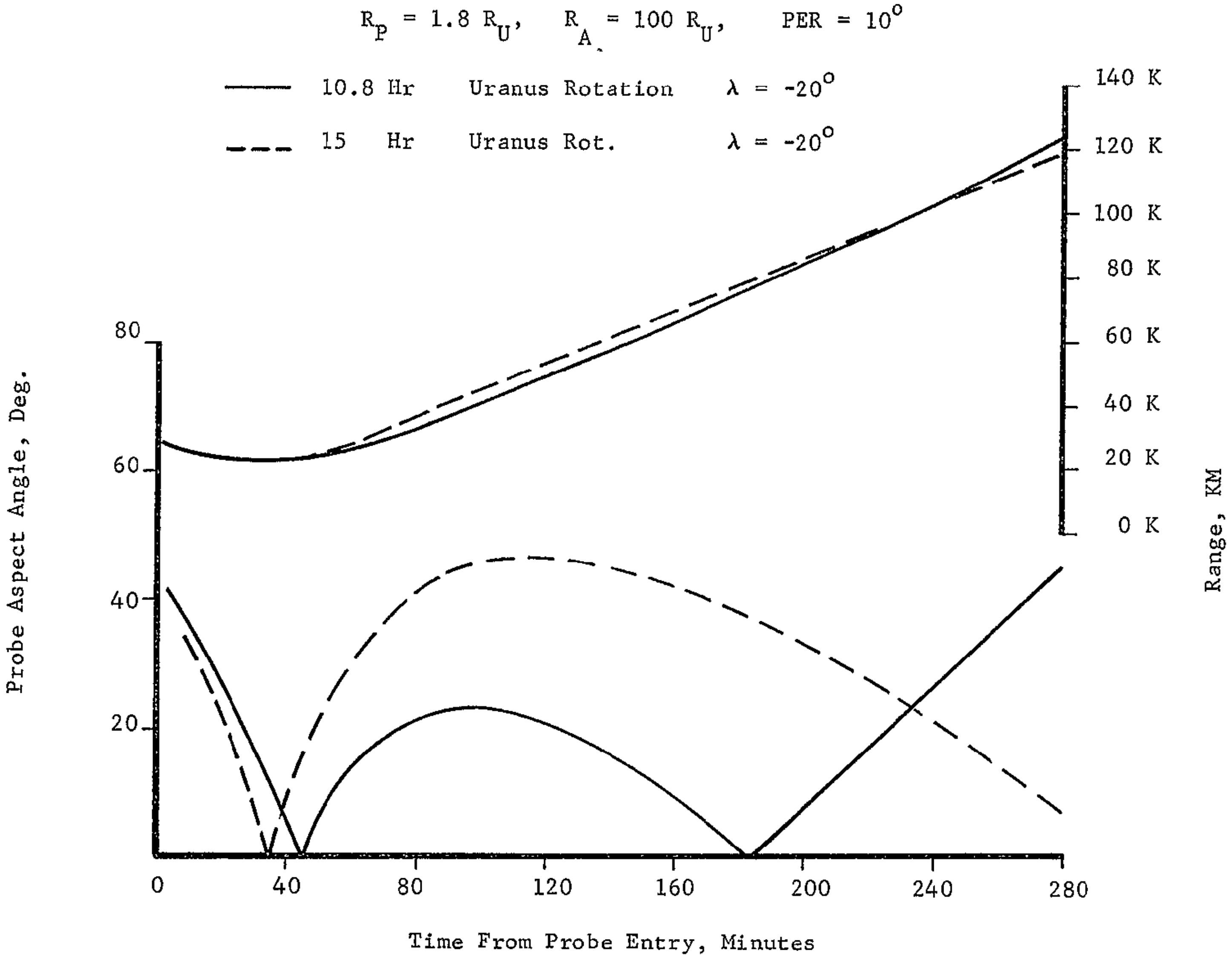


FIGURE D-12 - URANUS PROBE TO ORBITER RANGE & ASPECT ANGLE

APPENDIX

E

COMMUNICATION FROM 1000 BARS

The following memorandum contains the summary results of the detailed study performed for this contract.

Interoffice Memo MARTIN MARIETTA

August 11, 1977

To: J. Mellin

From: J. Damski

Subject: Summary of Communications Task for Jupiter Deep Probe Study

Propagation - The "Latest available" information was utilized to determine the effect the Jovian atmosphere would have on the communications link. The following propagation areas were reviewed:

1) Jupiter Ionospheric Amplitide Scintilation. Source - "Scintilation estimates for a Jupiter entry probe" Technical Memorandum 33-475, R. Woo, F. C. Yang; Nov. 1, 1975.

   The 1% Margins for Ionospheric Scintilation are provided for the frequency range of interest. Phase scintilation was not investigated and it is felt that through proper receiver design the slow varying phase changes can be adequately tracked. (Although the total plase excursion is large the spectral bandwidth is quite narrow).

2) Ionospheric Absorption.
   Absorption due to the ionosphere appears to be well below 0.1dB across the band of interest and has been neglected at this time.

3) Atmospheric Absorption. Source - "Jupiter Atmospheric Entry Mission Study" Martin Marietta Corp., April 1971.

   The baseline atmospheric model for the Deep Probe Study is essentially the same as the nominal model used in determining atmospheric absorption in the 1971 study. It was assumed that the minor differences would not effect the resulting values sufficiently to warrant validation at this time. Attenuation values are provided for the frequency range of interest (study results at 2.3 GHZ were related to other frequencies by the F^2 relationship.)

4) Synchrotron Noise Temperature. Source - "Jupiter Synchrotron Emission Model for outer planet Atmospheric Entry Probe" T. L. Grant; NASA, Ames Research Center; Aug - 1976.

   Grant et-al have developed a computer porgram which provides synchrotron Noise Temperature contribution as a function of specific Ante and Geometrical parameters. A case was selected from available data that would represent a conservative estimate of these parameters (see attachment) and Noise Temperature Values relating to the selected case were used in the link calculations. The Noise Temperature Values determined by Grant are considerably below those utilized in the earlier JAEMS. To obtain temperature values during any link optimization cycle, the specific cases should be developed.

5) Planet and Receiver Noise Temperature Contribution

Planet Temperatures across the frequency band of interest where interpolated from a "curve" in NASA-SP-8069, Dec-71. Those values ranged from 350K to 450K (2.36HZ - .4GHZ) but are of course reduced by the disk size relative to the Antenna Beamwidth and range. The resulting Temperature Contribution was somewhat greater (Approx - 140K) than the 70K planet contribution cited in "Preentry Communication Design Elements for Outer Planets Atmospheric Entry Probe" Hughes A/C Company; July 1976, but would have little effect at this stage.

It was assumed that the Galetic contribution was negligible and that a Receiver NF of 2dB across the band was achievable. System Temperature (minus synchrotron contribution) ranges from 293 to 328K (2.3 to 0.4 GHZ).

Frequency Selection

Summing up the potential loss values (see Carrier Frequency Loss Comparison) including noise temperature, a minimum is observed at about 600 MHZ. This is the selected value for a single probe carrier frequency. The carrier frequency is based on a loss comparison only and not on size or capability constraints that might occur as a function of frequency. It should be pointed out that the optimum frequency (at least from a loss comparison standpoint) may not be exactly 600MHZ and if an exact frequency is desired the area about 600 MHZ would require further evaluation.

For a split probe concept it is advantageous to use low frequencies in the region below the Ionosphere and high frequencies about that point. Carrier frequencies for the Split Probe Concept have been selected as 400MHZ for the Deep Probe to Relay Link and 2.3 GHZ for the Relay to Orbiter Link.

Link Analysis

The Link Analyses are summarized in the com links Jupiter Probe - 1000 Bars Table. None of the links have been optimized. The modulation scheme used is essentially that described in the JAEMS (including loss values). If a split probe concept is selected it may be advantageous to go noncoherent for the deep probe to relay link and coherent for the second link (dependent upon the final selected bit rate). The link calculations include demodulation to Baseband at each receiving point. The following draft link tables are provided:

#1 Single Probe @ 10 BPS, 128,000 KM
#2 Single Probe @ 150 BPS, 100,000 KM
#3 Single Probe @ 40 BPS, 100,000 KM
#4 Split Probe 150 BPS, Deep to Relay
300 BPS, Relay to Orb.

No effort was expended to Trade off ante gains at the Relay Probe and Orbiter with higher Powers etc. Although the Single Probe Concept has the advantage of simplicity if high data rates are required the split probe approach also has some rather obvious advantages, e.g. low Deep Probe Transmit power requirements; high data rates, OdB antenna deep probe, data gathering capability on the relay probe (added 3dB of Data Rate). It should be pointed out that Deep Probe data rates can be increased considerably if so desired, with recording capability being provided on the relay probe if the S-Band Link (which is the sensitive link) rates are exceeded. Along with the split probe advantages are some disadvantages the most apparent being the Tracking (Relay Probe and Orbiter) problem although I believe a program track approach on the relay could lead to a simplification of the problem. In any event it is not felt that major problems would be encountered with the split probe concept.

We should be cautioned not to bias our presentations towards the split probe approach until the factors of necessity are in (Data Rate requirement, compression evaluation, more advanced encoding (FEC) techniques and transmitter availability) which would then lead to a more objective selection.

Concerns

I submit my 25 July items of concern "Memo" as still being areas in which I feel further effort is required.

J. Damski

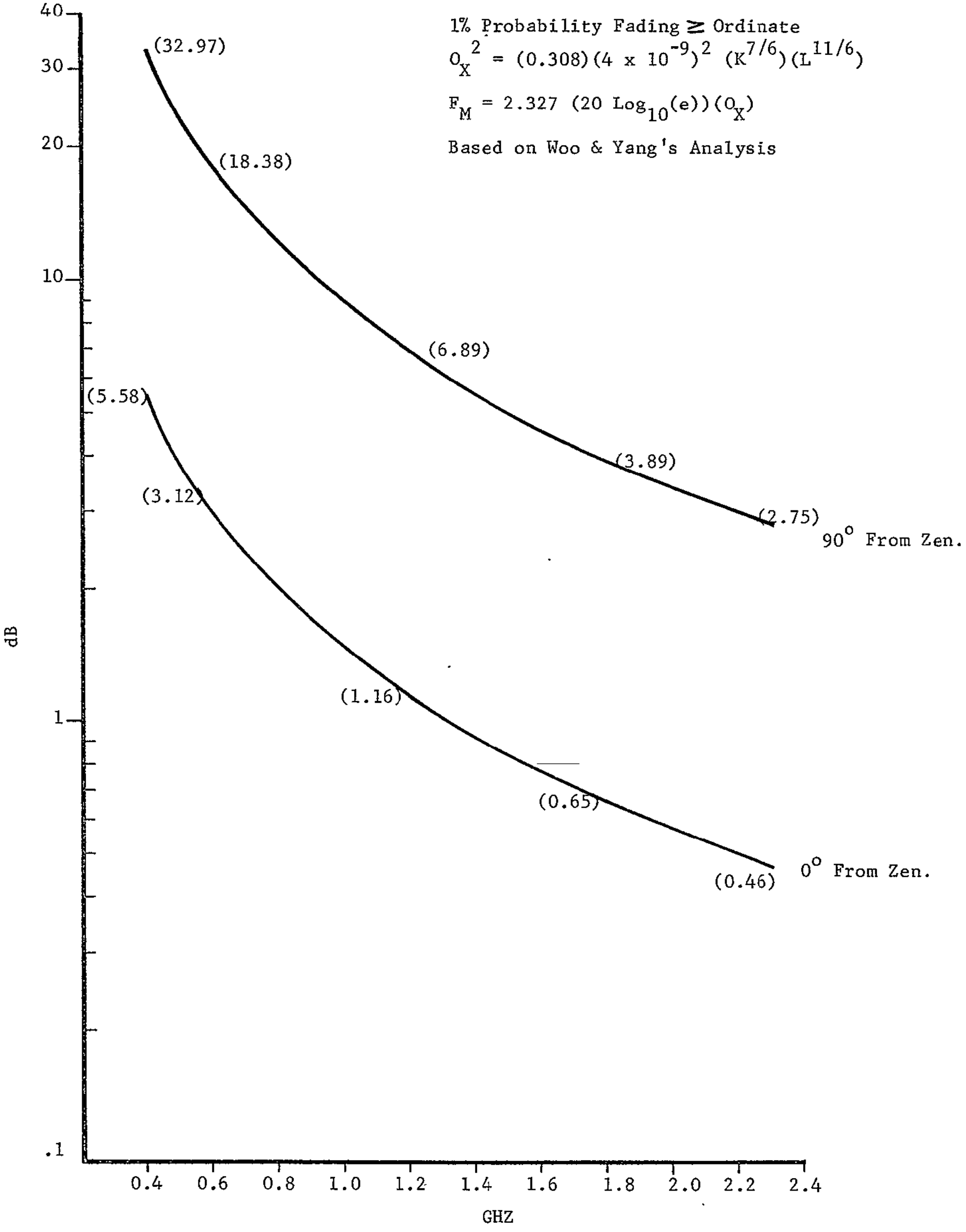
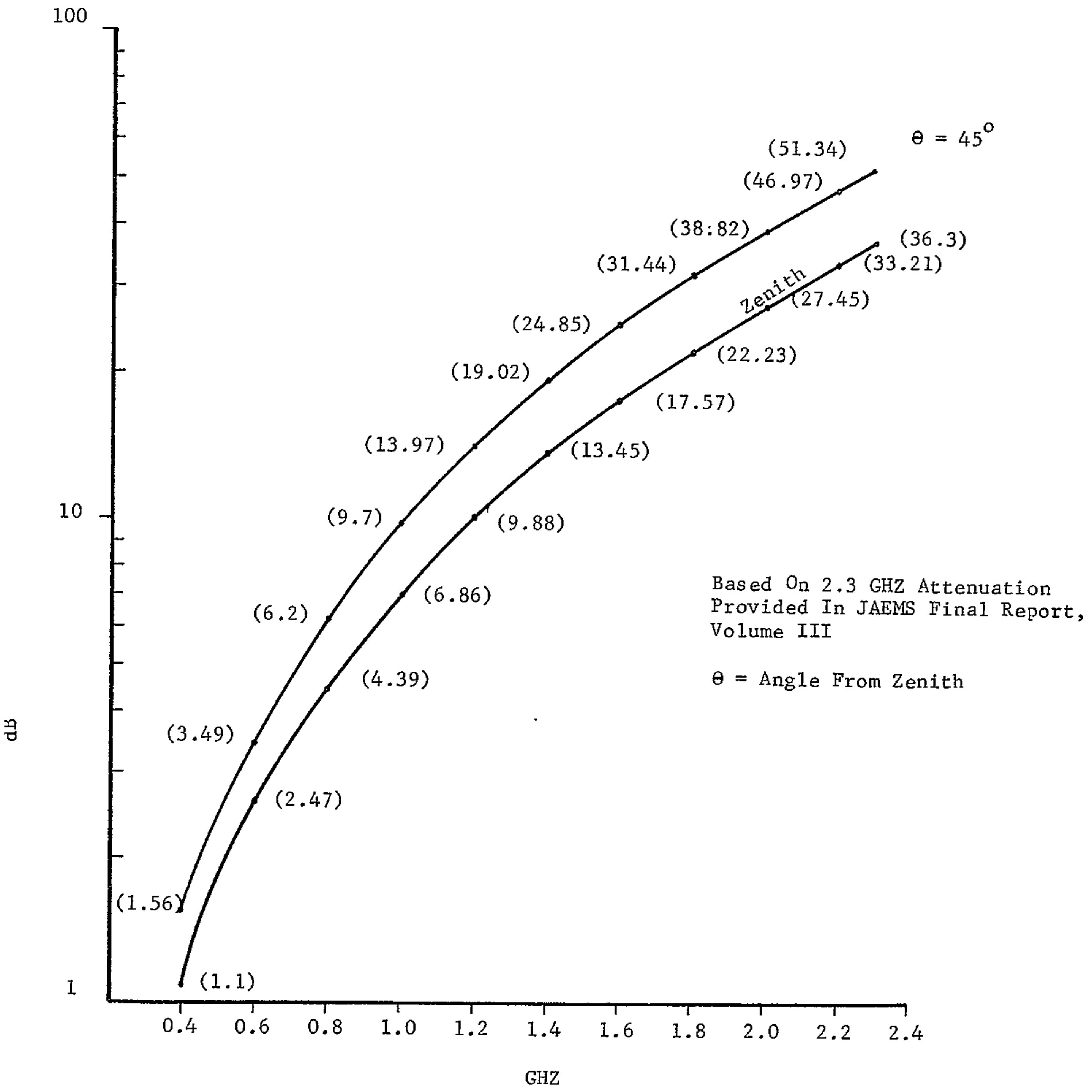


FIGURE E-1 - AMPLITUDE FADE MARGIN



Based On 2.3 GHZ Attenuation
Provided In JAEMS Final Report,
Volume III

θ = Angle From Zenith

FIGURE E-2 - ATMOSPHERIC ABSORPTION FROM 1000 BARS

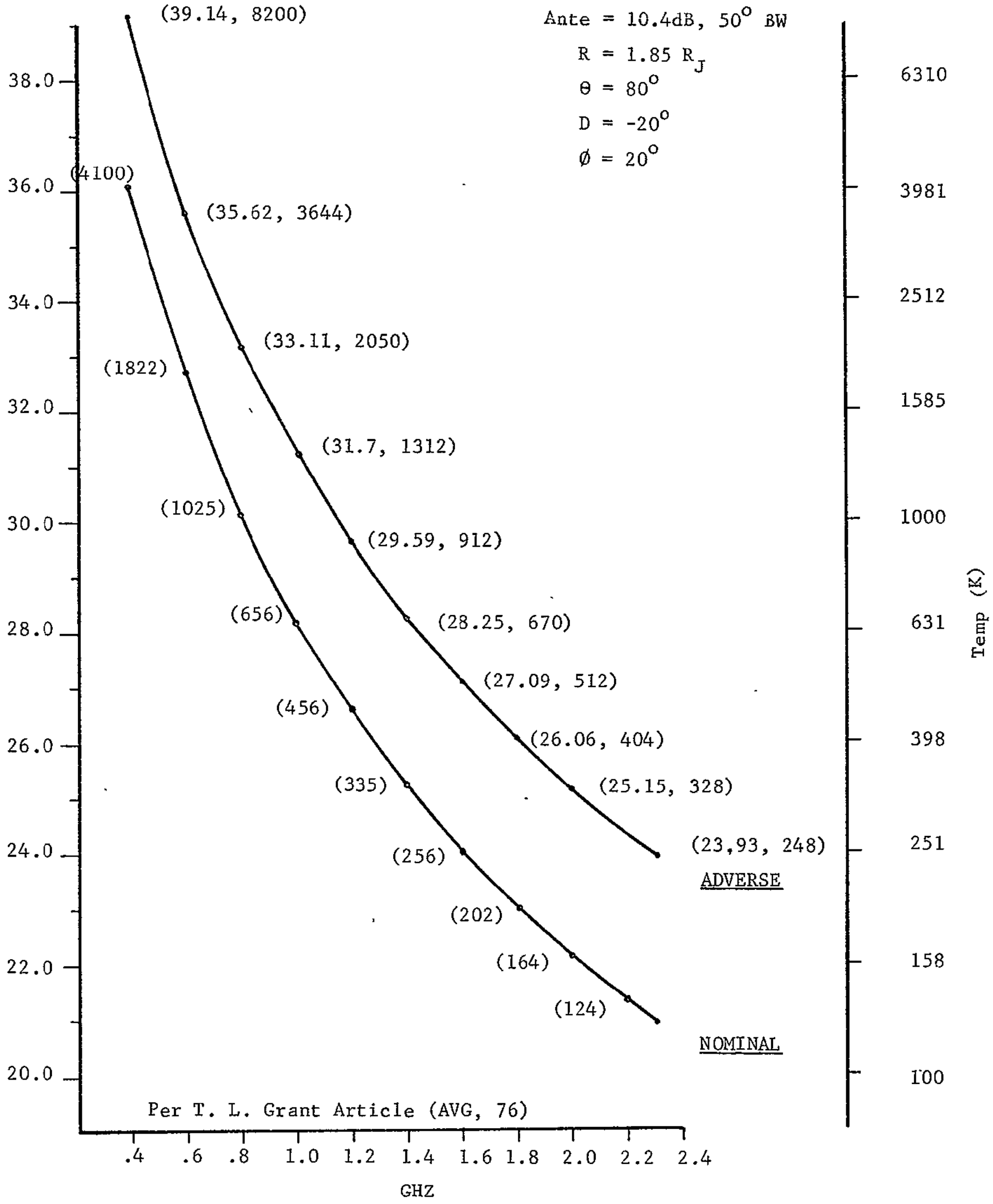


FIGURE E-3 - SYNCHROTRON NOISE TEMP. CONTRIBUTION

TABLE E-1 - CARRIER FREQUENCY LOSS COMPARISON

Frequency (GHZ)	0.4	0.6	1.2	1.8	2.3	Remarks
Ionospheric Scintillation	5.58	3.12	1.16	0.65	0.46	1% Fade Margin @ Zenith (dB)
Atmos. Absorp.	1.10	2.47	9.88	22.23	36.3	From 1000 Bars @ Zenith (dB)
Iono. Absorp.	Neg.					
Free Space Loss	186.67	190.19	196.21	199.74	201.86	$\sigma \simeq 128^{106}\text{m}$
Synch. Temp.	8200	3644	912	404	24B	Adverse Temp. in ^{o}K; see specific curve for parameters.
Planet & Receiver Temp.	328	310	303	297	293	NF = 2dB (Rec.); degrees K G = 10.9, R = 1.8
	232.65	231.75	238.1	251.08	265.95	Total @ Zenith
45^{o} Absorp. Δ	0.46	1.02	4.09	9.21	15.04	
45^{o} Scintillation Fade Margin	7.5	4.2	1.58	0.89	0.63	
	240.61	236.97	243.77	261.18	280.62	Total @ 45^{o} Comm. Angle

TABLE E-2 - COMMUNICATION LINKS JUPITER PROBE 1000 BARS

Approach	Freq. GHZ	Comm. Range KM	Data Rate BPS	XMT Pwr-Watts	Margin #1 dB	Margin #2 dB	Remarks
1) Single Probe	0.6	128K	10	100	8.3	1.4	Zenith Calculation
2) Single Probe	0.6	100K	150	1256	3.64	-1.3	
3) Single Probe	0.6	100K	40	335	3.64	-2.26	
4) Split Probe							
Probe to Relay	0.4	750K	150	1	24.4	23	45° ASP Angle; Relay @ 15 Bars-Demod to Baseband
Relay to Orbiter	2.3	139K	300	50	6.0	1.7	Demod to Baseband
Relay to Orbiter	2.3	100K	300	50	9.0	4.7	

#1 Prior to Adv. Tol.
#2 After Adv. Tol.

Absorption Loss Gain

1) 100 Bar $\simeq$ 280 KM (from 1 Bar)

2) 1000 Bar $\simeq$ 600 KM (from 1 Bar)

@ 2.3 GHZ Loss @ 280 KM $\simeq$ 14dB

@ 2.3 GHZ Loss @ 600 KM $\simeq$ 36dB

$\underline{F^2}$

@ 0.6 GHZ Loss @ 280 KM $\simeq$ 0.95 dB

@ 0.6 GHZ Loss @ 600 KM $\simeq$ 2.45 dB

Atten. Gain (ABS) = 2.45 - 0.95 = 1.5dB

Free Space Loss Gain

20 Log(100,000 KM/99680) $\simeq$ 0.03dB

Data Rate Loss

10 Log 150/400 $\simeq$ 4.26dB

Net Effect = Gain - Losses

Abs. Gain = 1.5 dB

Free Space Gain = 0.03dB

Bit Rate Loss $\simeq$ $\underline{4.26\text{dB}}$

NET -2.73dB (Single Probe Margin Prior to Adv. Tol. = 3.64)

JUPITER DEEP PROBE

10 BPS - 128,000 KM

Parameter	Value	Comments
Probe Transmit		
XMT Power	20.0 dBw	100 Watts
XMT Ante Gain	5.0 dBi	
Pointing Loss	0.3 dB	
Pol. Loss	0.5 dB	
Circuit Loss	0.7 dB	
EIRP	23.5 dBw	
Propagation		
Iono Scintilation	3.12 dB	1% Fade Margin
Atmos Absorp.	2.47 dB	Zenith (1000 Bars)
Iono Absorp.	--	
Defocusing	--	
Space Loss	190.19	128,000 KM
Propagation Loss	195.78 dB	
Receive Pwr.	-172.28 dBw	
Orbiter Receive		
Rec. Ante Gain	10.4 dBi	
Pointing Loss	0.3 dB	
Pol. Loss	--	
Circuit Loss	0.2 dB	
System Temp. Synch. 1822K Planet & Rec. 310 K	33.3 dB	
Received Power	-162.38 dBw	
C/KT	32.93 dB-HZ	

Data Channel

Bit Rate	10.0	dB	
EB/NO	4.0	dB	(Per Study)
Sub Carrier Loss	0.9	dB	(Per Study)
Noise Degradation	2.1	dB	(Per Study)
Mod. Loss	7.6	dB	(Per Study)
Available C/KT	32.93	dB-HZ	
Req'd. C/KT	24.6	dB-HZ	
Margin	+ 8.3	dB	

Adverse Tolerance

Circuit Loss	0.4	dB	(Per Study)
XMT Pointing Loss	1.5	dB	
Rec. Pointing Loss	0.1	dB	(Per Study)
System Temp.	3.0	dB	(Per Study)
MOD Index	0.4	dB	(Per Study)
Range	0.5	dB	(Per Study)
Attenuation	1.0	dB	(Per Study)
TOTAL ADV. TOLERANCE	6.9	dB	

JUPITER DEEP PROBE

150 BPS @ 100^{106}M

Parameter	Value	Comments
Probe Transmit		
XMT Power	30.99 Bw	1,256 Watts
XMT Ante Gain	5.0	
Pointing Loss	1.5	45°ASP Angle
Pol. Loss	0.5	
Circuit Loss	0.7	
EIRP	33.29 dBw	
Propagation		
Iono Scintilation	7.32	$\theta = 45^\circ$
Atmos Absorp.	3.49	$\theta = 45^\circ$
Iono Absorp.	--	
Defocusing	--	
Space Loss	188.13	100,000 KM
Propagation Loss	199 dB	
Receive Pwr.	-165.71 dBw	
Orbiter Receive		
Rec. Ante Gain	10.4 dBi	
Pointing Loss	0.3	
Pol. Loss	--	
Circuit Loss	0.2	
System Temp. Synch. 1822K Planet & Rec. 310 K	33.29	
Received Power	-155.81 dBw	
C/KT	40 dB-HZ	

Data Channel

Bit Rate	21.8	dB
EB/NO	4.0	dB
Sub Carrier Loss	0.9	
Noise Degradation	2.1	
Mod. Loss	7.6	
Available C/KT	40.0	dB-HZ
Req'd. C/KT	36.36	dB-HZ
Margin	3.64	dB

Adverse Tolerance

Circuit Loss	0.4	
XMT Pointing Loss	0.5	
Rec. Pointing Loss	0.1	
System Temp.	3.0	
MOD Index	0.4	
Range	--	
Attenuation	0.5	
TOTAL ADV. TOLERANCE	4.9	dB

JUPITER DEEP PROBE

40 BPS @ 100^{106}M

Parameter	Value	Comments
Probe Transmit		
XMT Power	25.25	335 Watts
XMT Ante Gain		
Pointing Loss		
Pol. Loss		
Circuit Loss		
EJRP		
Propagation		
Iono Scintilation		
Atmos Absorp.		
Iono Absorp.		
Defocusing		
Space Loss		
Propagation Loss		
Receive Pwr.		
Orbiter Receive		
Rec. Ante Gain		
Pointing Loss		
Pol. Loss		
Circuit Loss		
System Temp.		
Synch. 1822K		
Planet & Rec. 310 K		
Received Power		
C/KT		

JUPITER

Probe

0.4 GHZ @ 1000 Bars

Parameter	Value		Comments
Probe Transmit			
XMT Power	0	dBw	1 Watt
XMT Ante Gain	5	dBi	
Pointing Loss	1.5		(45° ASP)
Pol. Loss	0.5		
Circuit Loss	0.7		
EIRP	2.3	dBw	
Propagation			
Iono Scintilation	--		
Atmos Absorp.	1.1	dB	@ 45° (total-0.5dB)
Iono Absorp.	--		
Defocusing	0.5	dB	(est.)
Space Loss	142.0	dB	530 KM (to 15 Bar) 750 KM @ 45° Aspect
Propagation Loss	143.6	dB	
Receive Pwr.	-141.3	dBw	
Relay Receive			
Rec. Ante Gain	5	dBi	
Pointing Loss	1.5	dB	(45° ASP)
Pol. Loss	--		
Circuit Loss	0.2	dB	
System Temp.	30	dB	
Planet & Rec. (1000K)			Planet ≈ 400K Rec. ≈ 5dB NF
Received Power	-138.0	dBw	
C/KT	60.8	B-HZ	

Data Channel

Bit Rate (150 BPS)	21.8		Assumes Demod to Baseband
EB/NO	4.0		
Sub Carrier Loss	0.9		
Noise Degradation	2.1		
Mod. Loss	7.6		
Available C/KT	60.8	dB-HZ	
Req'd. C/KT	36.36	dB-HZ	
Margin	24.4	dB	

Adverse Tolerance

Circuit Loss	0.4	
XMT Pointing Loss	--	
Rec. Pointing Loss	--	
System Temp.	--	
MOD Index	.4	
Range	--	
Attenuation	.5	
TOTAL ADV. TOLERANCE	--	
SUM	1.3	dB

JUPITER DEEP PROBE

Relay Probe @ 15 Bars to Orbiter @ 2.3 GHZ

Parameter	Value		Comments
Probe Transmit			
XMT Power	17	dBw	50 Watts
XMT Ante Gain	20	dBi	2.0 Ft. @ n = 50%
Pointing Loss	3	dB	BW = 15°
Pol. Loss	0.5	dB	
Circuit Loss	1.0	dB	
EIRP	32.5	dBw	
Propagation			
Iono Scintilation	1.1	dB	@ 45°
Atmos Absorp.	2.8	dB	@ 45°
Iono Absorp.	--		
Defocusing	--		
Space Loss	202.6	dB	1.8rj (140,000-500KM) ≃ 139,500 KM
Propagation Loss	206.5	dB	
Receive Pwr.	-174	dBw	
Orbiter Receive			
Rec. Ante Gain	20	dBi	2 Ft. @ n ≃ 50%
Pointing Loss	3.0	dB	BW = 15°
Pol. Loss	--		
Circuit Loss	1.0	dB	
System Temp. Synch. - 124 Planet & Rec. - 293	26.2	dB	
Received Power	-158	dBw	
C/KT	45.4	dB-HZ	

Data Channel

Bit Rate (300BPS)	24.8	dB
EB/NO	4.0	
Sub Carrier Loss	0.9	
Noise Degradation	2.1	
Mod. Loss	7.6	
Available C/KT	45.4	dB-HZ
Req'd. C/KT	39.4	dB-HZ
Margin	6.0	dB

Adverse Tolerance

Circuit Loss	0.4	
XMT Pointing Loss	--	
Rec. Pointing Loss	--	
System Temp.	3.0	
MOD Index	0.4	
Range	--	
Attenuation	0.5	
TOTAL ADV. TOLERANCE	4.3	dB

JUPITER DEEP PROBE

Items for Investigation:

1. Solid State Transmitter

Investigate whether current concepts can provide the efficiency, weight, and output power requirements necessary for the deep probe mission. New concepts should be investigated with a first cut being acquired through vendor discussions on anticipated, most likely successful approaches.

2. Antenna

Investigate existing materials and most likely survivable materials for extreme deep probe environments.

Investigate light weight EDA for orbiter application. One concept that has been around for awhile, but not developed for this application (to the best of my knowledge), is the Harris Spiraphase approach. The Spiraphase would, no doubt, result in a significant weight savings, but requires investigation for this application.

Investigate high gain probe antenna approaches with simplified tracking schemes, e.g., Program Track.

3. Modulation

Investigate results of RPI Scintilation vs. Modulation Study and evaluate modulated approaches for most efficient concept.

4. Communication Blackout

Investigate the offset of blackout phenomena on Jupiter and approaches for eliminating or minimizing blackout effects. In addition, investigate the degree of ionization and its effect on communications around the 1000 bar level.

5. Carrier Frequency

Effects of absorption, ionospheric scintilation, and synchrotron temperature are generally provided for frequency ranges of approximately 0.4 to 2.3 Ghz. It would seem prudent to investigate whether or not F^2 law really applies at ULF and SHF frequencies with the highly unlikely hope that some sort of notching effect would be uncovered.

APPENDIX

F

THERMAL CONTROL SYSTEMS STUDY

THERMAL CONTROL SYSTEM STUDIES

The overwhelming challenge to the probe thermal control specialist is the combination of extreme pressure, 1000 bars, and the very high temperature, $2100^{\circ}F$, associated with this type mission. The probe descent times, while short, between 30 minutes and 210 minutes, allow the vehicle shell to reach near equilibrium temperatures. Three basic approaches to the thermal and structural requirements were investigated: 1) Pressure protected equipment; 2) pressure equalized equipment, and 3) active cooling thermal control.

Pressure-protected and pressure-equalized equipment compartment concepts have been reviewed to ascertain their applicability and to establish areas where advances in technology are needed. These systems are passive, involving insulation and phase-change materials. Active cooling was also considered as an alternative for the longer descents. These concepts are further subdivided as shown in Figure F-1.

An externally insulated pressure vessel concept, upper left, allows use of efficient conventional metal alloys for the pressure shell, but exposes the insulation to a difficult environment. With the pressure vessel external, upper right, low-density insulation can be used, but shell materials must resist crushing at very high stress levels. These concepts are treated further in subsequent paragraphs.

Venting the container avoids a heavy shell. This approach requires that components be able to operate at high pressure. The vented gas can be cooled with a phase-change material heat exchanger, but heat exchanger

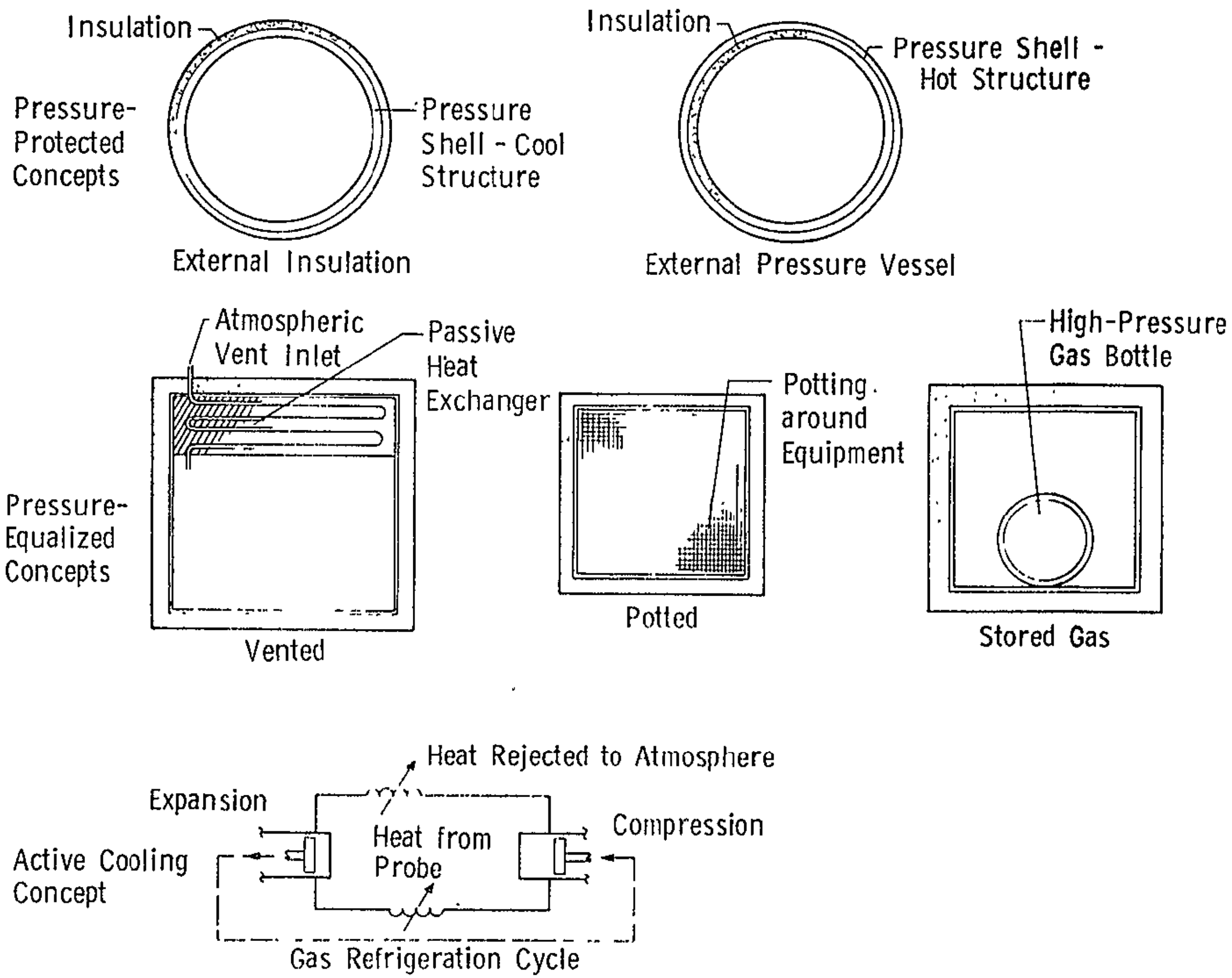


FIGURE F-1 - THERMAL/STRUCTURAL CONCEPTS weight tends to negate the advantage of avoiding a heavy pressure shell. Complete potting of the probe interior, center illustration, affords another way of pressure equalization. Finally, gas stored in a high-pressure bottle can be used to equalize the internal pressure.

A closed-loop ideal gas refrigeration cycle is illustrated schematically. Calculations have been made for the cooling power requirements based on this concept.

The assessment of these alternatives is shown in Table F-1. All of these concepts involve some technical risks.

PRESSURE-PROTECTED CONCEPTS

At the 1000-bar level the mass of a metal pressure vessel exposed to the atmosphere, 2100^{o}F, is very great. A 50-centimeter (20-in.) diameter sphere would weight about 450 kilograms (in earth's gravity field). This mass would be difficult to slow to the descent rates desired and would dictate either a very large entry aeroshell or significant advances in entry heat shield performance. Figure F-2 illustrates two alternative approaches to solving this problem.

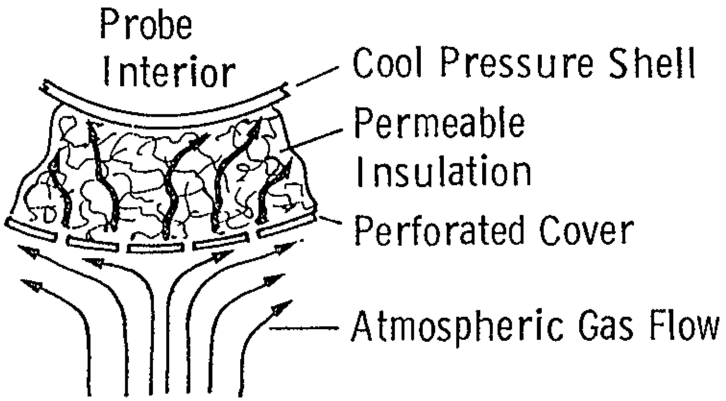
The most promising approach appears to be the pressure protected scheme with external insulation material. The risks associated with this concept involve the extrapolation of the behavior of the known insulation materials at these extreme of pressure and temperature. Figure F-3 indicates this extrapolation for a good candidate insulation, MIN-K, but since the test data to date only covers up to 120 bars at 600^{o}F, data would have to be obtained up to 1000 bars and 2100^{o}F.

Another insulation material investigated was LI-900, to be used on the Space Shuttle. This all-silica material can be formulated in densities ranging from 9 lbs./ft.^{3} to 30 lbs./ft.^{3}. It also has a low thermal expansion coefficient, high temperature stability, and low thermal conductivity.

TABLE F-1 - PRESSURE PROTECTED EQUIPMENT CONCEPTS

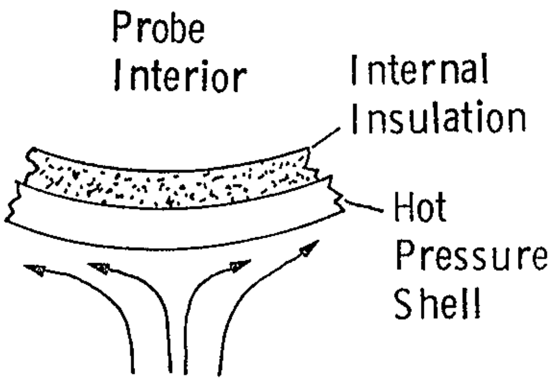
Technology	Possible Implementation	Comments
High-Pressure External Insulation	Permeable, Low-Density Silica Fiber Material	- Performance is Good for Descent Times Required - Based on Extrapolated Data - High-Pressure Turbulent Flow Environment Makes Extrapolation Uncertain - Development Required
	Rigid, Impervious Insulation Material	- 8X Heavier Than Permeable Insulation But Not Degraded by Atmosphere
Nonmetallic External Pressure Vessel	Dense Ceramic Material, e.g., Alumina	- Potentially as Light as the Externally Insulated Concept - Less Sensitive to Degradation - Flaw Sensitivity Requires Development
Active Cooling	Gas Refrigeration Cycle	Kilowatts of Power Needed for Descent Times Indicated by Science Measurements
Pressure-Equalized Container	Vented Design, Potted Design, Stored Pressurant	Vented Design Requires Major Breakthrough in High-Temperature Electronics - Other Versions Do Not Save Mass Relative to Conventional Pressure Vessel Design

External Insulation



- Permeable Insulation Theoretically Yields Moderate-Weight Design. Impervious Materials 8X Heavier.
- Performance Calculations Are Based on Data Extrapolated from 120 bars, 600 K (600 °F)
- Potential Degradation Due to Flow Effects Requires Evaluation

External Pressure Shell



- Nonmetallic Shell Material, e.g., Alumina, Offers, Factor of 4 Weight Improvement Relative to Refractory Metal

Flaw Sensitivity in Biaxial Compression Requires Investigation

Joints and Attachment Techniques Require Development

FIGURE F-2 - PRESSURE PROTECTED EQUIPMENT CONCEPTS

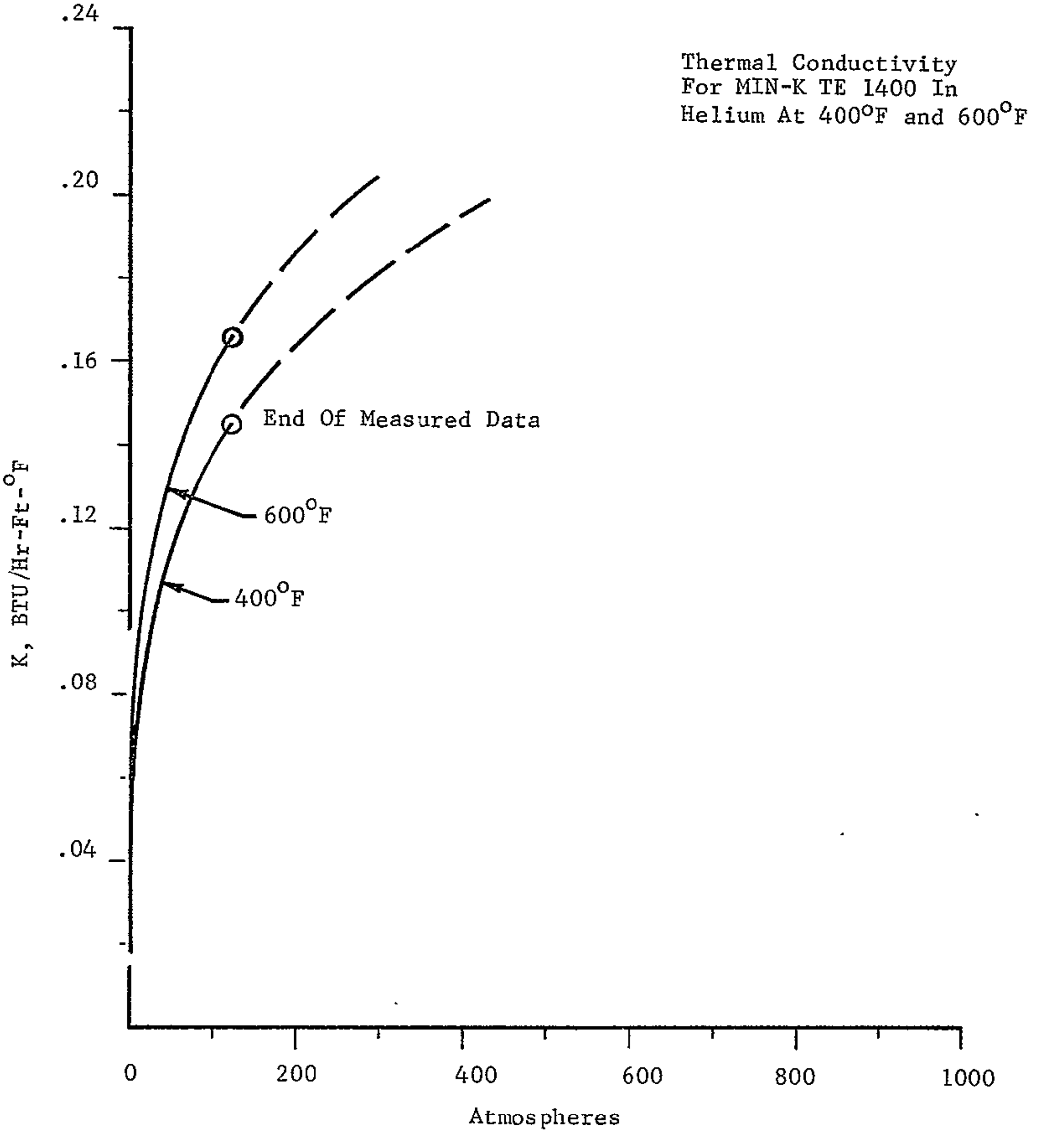


FIGURE F-3 - MIN-K AT HIGH PRESSURE AND TEMPERATURES

At 1 atmosphere, the conductivity is 0.15 btu/hr.ft.$^{\circ}$F (at 2100°F). However, there is no data on the degradation of the thermal conductivity at the 1000 bar pressure level.

Another material considered was LO-ERODE, a very good refractory insulation, but it is approximately 8 times heavier than MIN-K for the same protection.

Free convection within the insulation at high pressure levels is a distinct possibility. If present, the free convection has a serious degrading effect on the insulation performance. This problem is unusual relative to insulation systems and, indeed, is not mentioned in several heat transfer texts reviewed. Work in the area of free convection in porous media, however, has been performed in the oil and gas industry relative to reservoir engineering problems. The parameter which defines the onset of convection in a porous media is the Rayleigh number times the Darcy number and is given by:

$$R_a D_a = \frac{\rho^2 \beta g \quad TLCpK}{\mu k}$$

where: ρ = density

β = coefficient of volumetric expansion

g = gravitational acceleration

T = characteristic temperature difference

L = characteristic length

Cp = specific heat

K = permeability

μ = viscosity

k = thermal conductivity

Once the critical value of the Rayleigh-Darcy number has been reached, the free convection becomes stronger with increasing values of this number. It is interesting to note that the gas properties ($\rho^2\beta$ Cp/μ k) are a strong function of temperature with this grouping <u>decreasing</u> with increasing temperature. This tells one that in order to help to avoid free convection, the pressure shell (insulation interior) should be designed to run hot. The other large contributor to the Rayleigh-Darcy number is the permeability. It is obvious that one should use an insulation with as small a permeability as is possible.

PRESSURE EQUALIZED PROBE

Pressure equalization can be accomplished by means of a stored gas supply or by potting the contents with a compressible medium. The pressure equalized probe concept does not appear promising for this application because the mass of the stored gas container and the mass of potting material tend to exceed the mass of a pressure shell.

It had been hoped that by using phase change material as the potting compound, the insulation requirement could be drastically reduced, particularly if a more efficient phase change material could be found. It was anticipated that a higher melting point material might have greater heat capacity. Unfortunately, as illustrated in the table below, the higher melting temperature materials were not found to exhibit improved heat capacities.

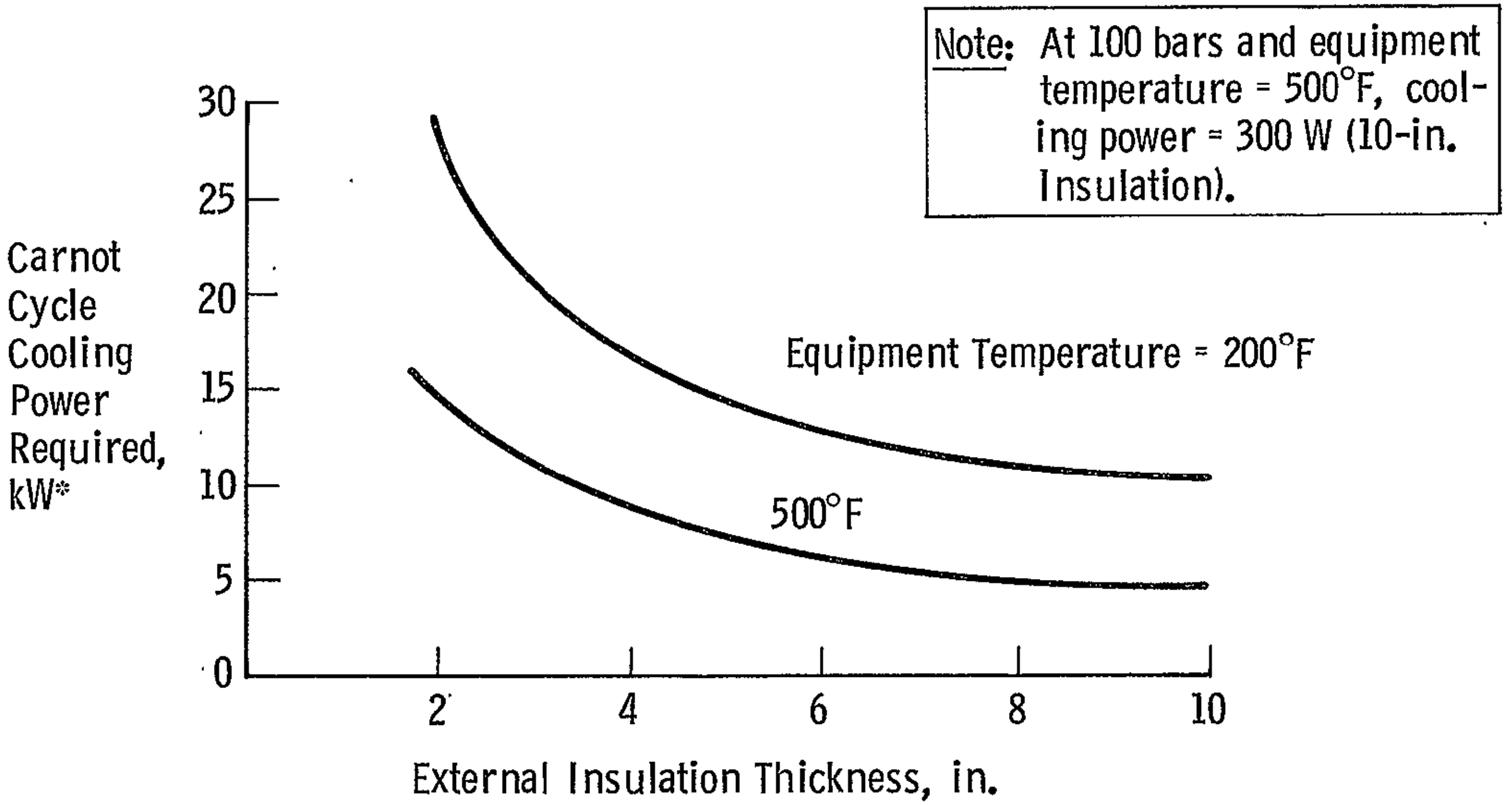
Material	Formula	Phase Change Temperature, °F	Heat Capacity Btu/lbm
Lithium Nitrate Tri-Hydrate	$LiNO_3.3H_2O$	85.8	128
O-Mannitol	$C_6H_{14}O_6$	331	126
Barium Hydroxide Octahydrate	$Ba(OH)_2.8H_2O$	172	129

This makes the use of phase change materials impractical for this concept.

ACTIVE COOLING THERMAL CONTROL

Refrigeration concepts were considered for this mission. A Carnot cycle using an ideal gas, which could be closely represented by air, was analyzed with a compression phase up to 146 atmospheres and an expansion down to 1 atmosphere. The resulting power required to accomplish this active, refrigeration was parametrically studied. The results are shown in Figure F-4, and indicate the excessive power requirements for this type of thermal control, even if high temperature electronics are available. The insert in Figure F-4 points out that for less severe conditions than those at 1000 bars, but with optimistically high equipment temperatures, the power requirements become a little more reasonable. This level of environment, incidently, corresponds closely to that existing on the surface of Venus.

Probe Inside Diameter = 20 in.



Note: At 100 bars and equipment temperature = 500°F, cooling power = 300 W (10-in. Insulation).

*Ideal gas cycle requires slightly greater power. Actual system would require at least 2X more power.

FIGURE F-4 - REFRIGERATION POWER REQUIREMENTS

APPENDIX

ROTATING AERODYNAMIC BLADES
FOR DESCENT VELOCITY CONTROL

The following memorandum contains the summary results of the detailed study performed for this contract.

MEMORANDUM

August 12, 1977

To: John Mellin

From: C. E. French

Subject: Use of Rotating Aerodynamics Blades for Descent Velocity Control On Jupiter Probe

Ref: (1) Aerodynamics of the Helicopter, Alfred Gesson and Gary Myers Jr., The MacMillian Co

A preliminary evaluation is made of the feasibility of using a helicopter type rotor as a means of descent velocity control. An estimate of the power required to hover and for a rate of climb (vertical) of 1000 fpm is also presented.

To a first approximation, an auto-rotating rotor will give a descent velocity equal to that of a parachute of equal diameter. This analysis is based on momentum theory and is confirmed by flight results, Ref. 1. For purposes of illustrating relative sizes and performance characteristics, a descent vehicle of total descent mass = 20 slugs and with a ballistic coefficient (parachute) of .05 sl/ft^2 is selected. A rotor diameter of 30 ft results in equivalent descent performance. This performance as a function of pressure altitude is shown on Figure 1.

The rotor will have a flexibility in selecting descent velocity by a change in blade pitch angle which will allow descent velocities from the minimum to the "feathered" conditions as shown on Figure G-1. Part of the total range would probably not be available due to blade stall.

Hovering power requirements are estimated for the 20 slug vehicle with 30 ft and 20 ft diameter rotors. These data are presented on Figure G-2 as a function of pressure altitude. The power requirements ranging from 150 KW at 1.0 atmosphere to 13 KW at 1000 atmosphere are seen to be unrealistic for a vehicle of this type. Also shown by the dashed line (Figure G-2) is the power required for a positive rate of climb of 1000 ft/min.

The possibility of generating power from auto-rotating blades during descent has been advanced. An auto-rotating system is dynamically stable. That is, the rotor rotation rate and rate of descent reach a point of stability for a given blade pitch angle in which the resultant of the lift and drag vectors achieve a direction which produces zero torque at the rotor. If a torque load were applied to the rotor the rotation would slow causing the drag coefficient to increase, further slowing the rotor as it sought its stability condition. This process would lead to an increased rate of descent until the blade eventually stalled. It thus appears power could only be generated in "bursts" at the expense of increased descent rate.

C. E. French

C. E. French

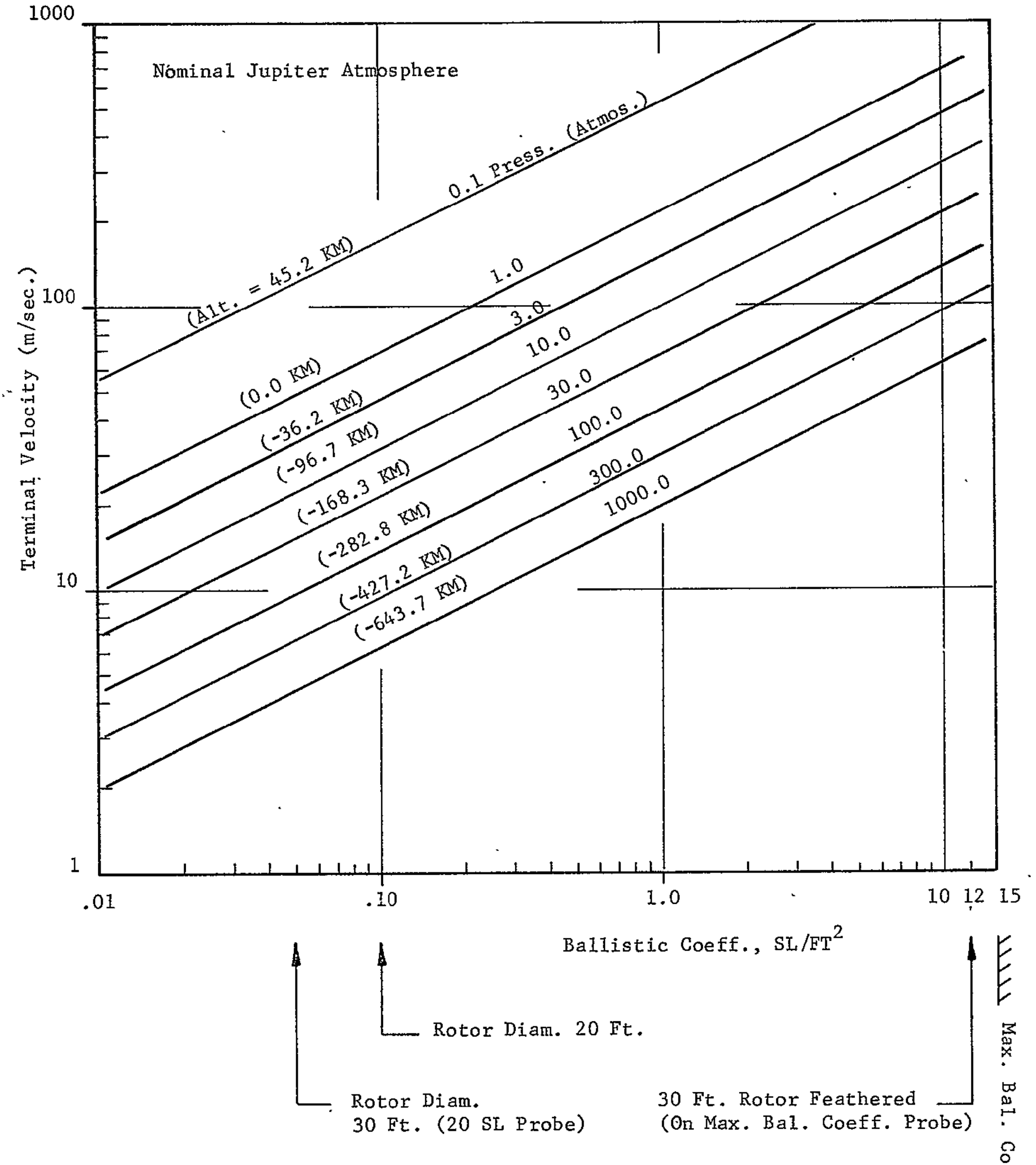


FIGURE G-1 - DESCENT VELOCITIES FOR DIFFERENT ROTOR CONFIGURATIONS

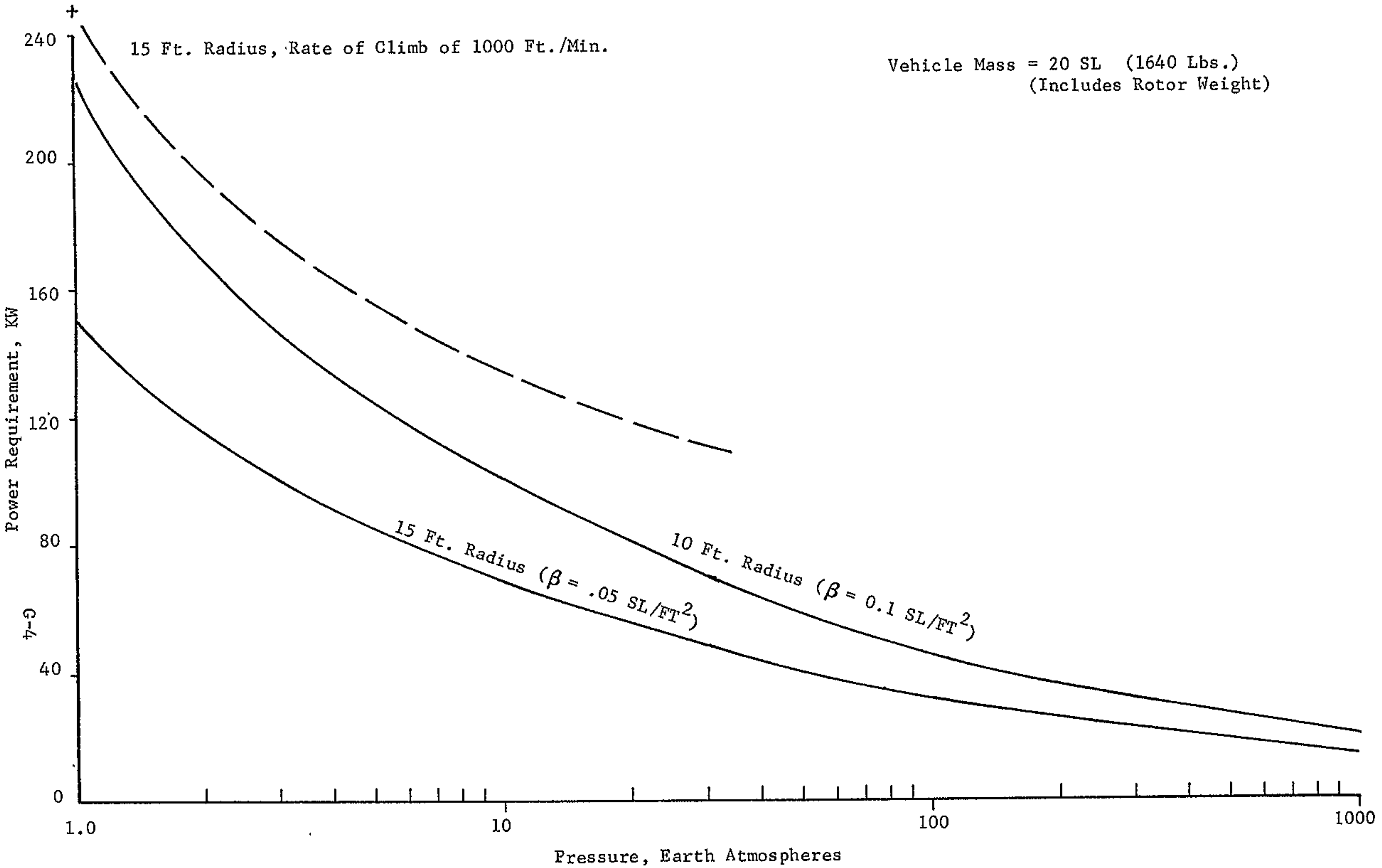


FIGURE G-2 - POWER REQUIRED TO HOVER

APPENDIX

H

BALLOON FLOTATION SYSTEM FOR A JUPITER PROBE

The following memorandum contains the summary results of the detailed study performed for this contract.

M E M O R A N D U M

To: John Mellin
Date: August 12, 1977

From: C. E. French

Subject: Balloon Flotation System for a Jupiter Probe

Ref. 1: Final Report Buoyant Venus Station Feasibility Study, Vol. II, R. E. Frank and J. F. Baxter, July 1967

2: Venus Balloon Mission Preliminary Study Report, June 15, 1973, Prepared for Center National D'Etudes Spatiales, Center Spatial De Toulouse

The feasibility of a balloon flotation system to achieve very low ($<$ 1. meter/sec) descent rates to float at constant altitude, or to possibly ascend thru an altitude range, has been investigated. The data show that a balloon flotation system is presently not feasible or practical at the lower depths associated with a deep probe. This is the result of both the low molecular weight of the Jupiter atmosphere and the extreme environment experienced by the balloon material.

Balloon structure and gas containment material with acceptable weight/strength characteristics, having the required properties for storage for long periods of time and the flexibility required for deployment and filling, present a significant technology problem. Ambient temperatures in the range of 700°K to 1500°K are encountered.

Using hydrogen as the flotation gas, the diameter of a sphere required for a range of total floated weights (balloon structure and payload) are shown as a function of pressure altitudes on Figure 1. The range of weights shown would pertain to floating only a portion of the total probe, possibly a data storage and transmitter module and special instrumentation, such as a resonance scattering photometer which requires very slow descent velocities. An estimate of balloon structure weight based on a Venus buoyant design (Ref. 2) results in the payload weights shown on Figure H-2. The structural weight for the Venus design are not compatible with the temperature environment of Jupiter. As no candidate materials are currently known (probably required to be non-organic), data showing the effect on the payload of applying factors of 2x and 3x to the structural weight of the 40 lb. total floated weight data of Figure H-2 are shown on Figure H-3. The rapid disappearance of the payload at 100 bar is evident.

Storage of the inflation gas (hydrogen) presents another technology problem. At 100 bars pressure altitude, the volume of a high pressure gas storage tank of 4500 psi (the maximum considered in the Venus mission), would be 1/3 the volume of the inflated balloon. At 1000 bar altitude, the ambient pressure is over 3 x the 4500 psi storage pressure. A technique involving balloon deployment and inflation at an altitude higher than the desired float altitude (100 to 1000 bar) is indicated. Cryogenic storage of the hydrogen would offer advantages from a volumetric standpoint, but would present long term storage and venting problems.

An unlimited supply of hydrogen is available at ambient conditions if a process for separating the helium at a rate commensurate with filling requirements could be developed. The potential of this concept has not been investigated at this time.

C. E. French
C. E. French

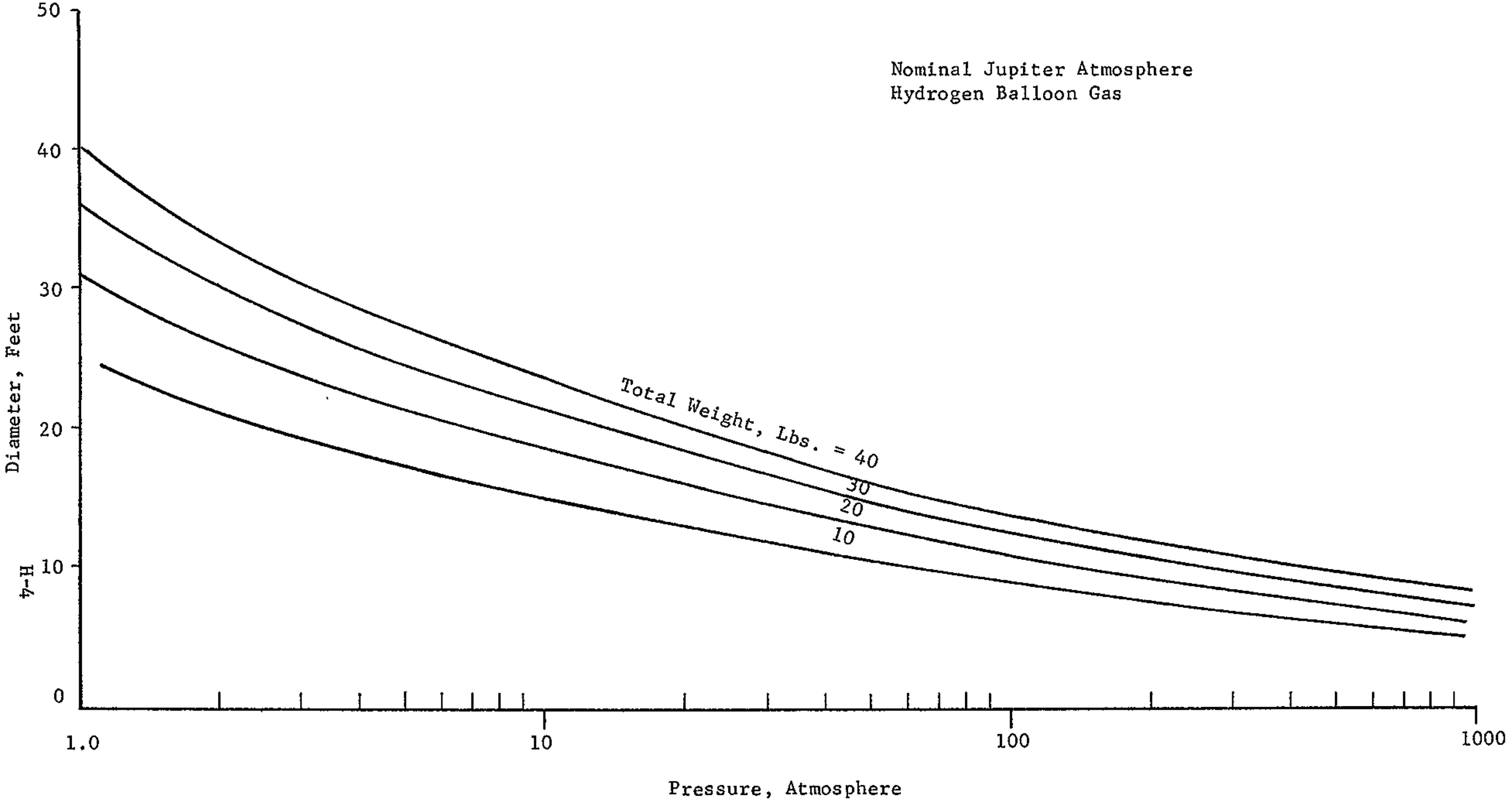


FIGURE H-1 - BALLOON DIAMETER VS TOTAL FLOATED WEIGHT

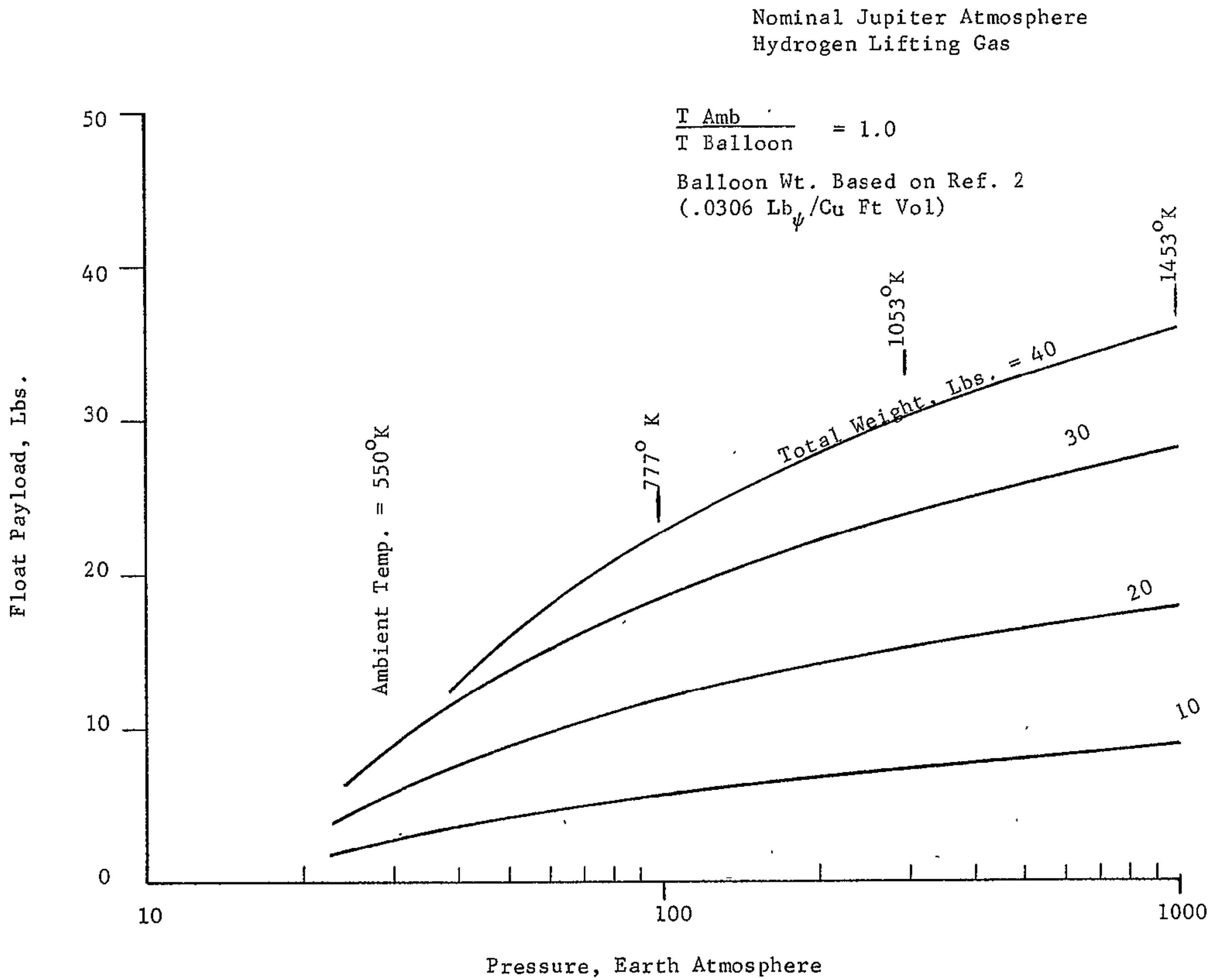


FIGURE H-2 - PAYLOAD WEIGHT VS TOTAL WEIGHT

C3

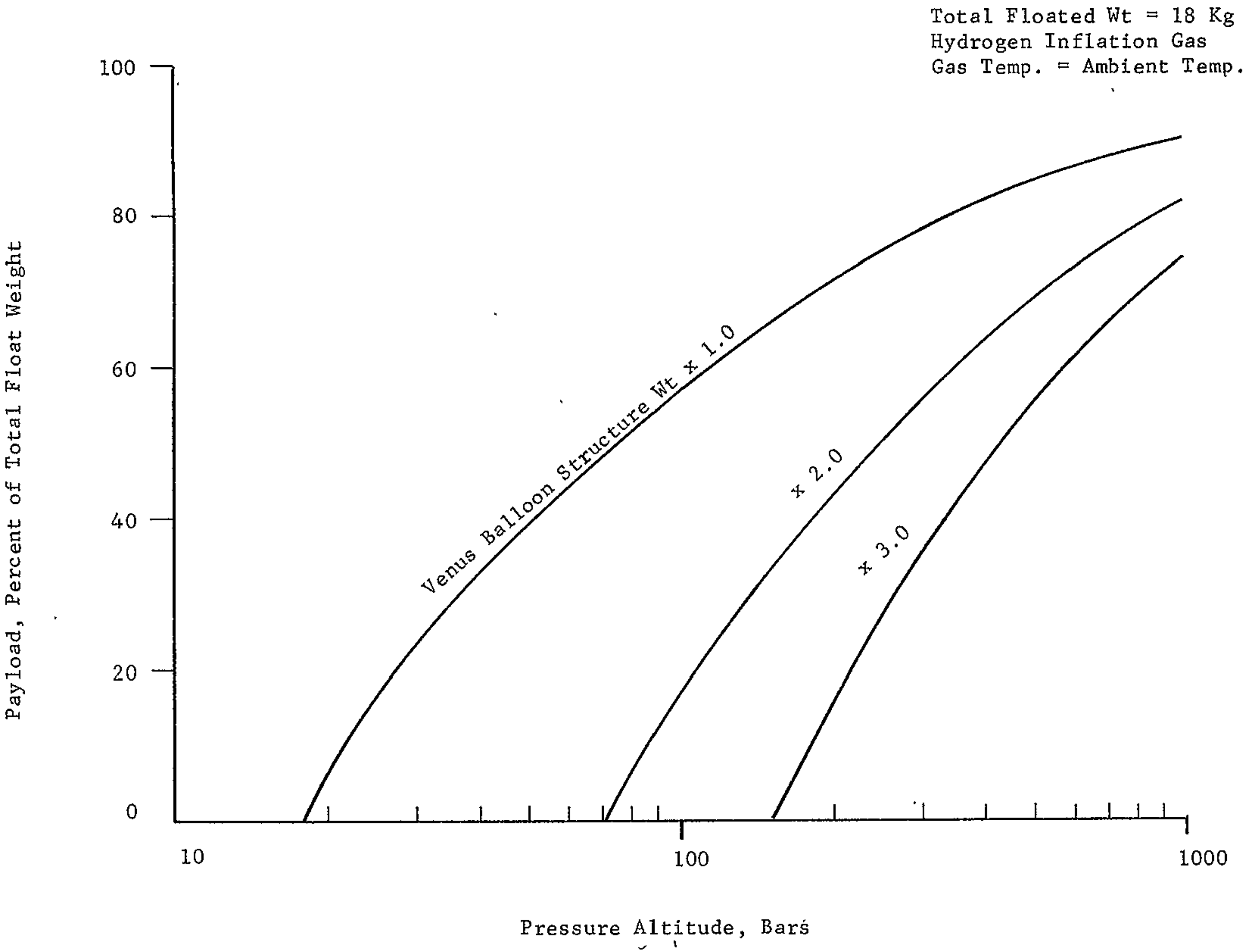


FIGURE H-3 - PAYLOAD AS PERCENT OF FATAL WEIGHT FOR DIFFERENT BALLOON STRUCTURES