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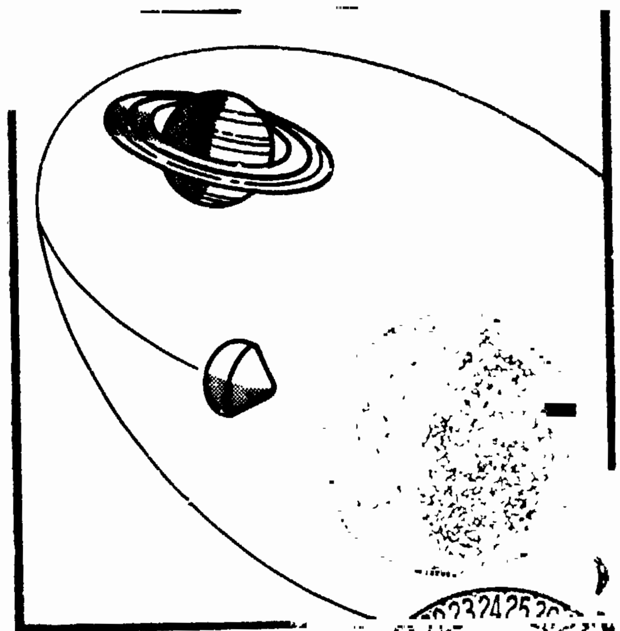
Contract NAS2-10380

Final
Report

July 1980

Titan Probe Technology Assessment and Technology Development Plan Study



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Moffett Field, California 94035

MARTIN MARIETTA

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TITAN PROBE TECHNOLOGY ASSESSMENT AND TECHNOLOGY DEVELOPMENT PLAN STUDY

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FOREWORD

This report is submitted in compliance with Article II, Item 1-b, of Contract Number NAS2-10380. This study was conducted in accordance with Martin Marietta, Denver Division, Operation Directive 203785 Supplement Number 100 and involved 2200 engineering-hours of work during the 9-month contract period. The mid-term review was held on 6 March 1980, at NASA-ARC, the final review was held on 23 May 1980, at NASA Headquarters.

J. P. Murphy (244-7) of Ames Research Center was the Technical Monitor for the study and A. J. Butts was the Program Manager for Martin Marietta.

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Darlene Desch	Final Report
Audree Scoggins	Final Report
Virgie Woods	Final Report

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ACRONYM LIST

AFML	Air Force Material Laboratory
AMU	Atomic Mass Unit
ARC	Ames Research Center
C	Capacity
°C	Degrees Celsius
C/O	Check Out
CCD	Charge Coupled Device
CMOS	Complimentary Metal Oxide Semiconductor
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
CW	Continuous Wave
DH&E	Data Handling and Command
DOD	Department of Defense
DTA	Differential Thermal Analyser
DTIC	Defense Technical Information Service
EMC	Electro magnetic Compatability
ERADCOM	Electronics Research and Development Command
ev	Electron-Volt
FM	Frequency Modulation
FMEA	Failure Modes and Effects Analysis
g	Earth Gravity Acceleration
GC	Gas Chromatograph
GCMS	Gas Chromatograph Mass Spectrometer
GHZ	Gigahertz
GSFC	Goddard Space Flight Center
HPBW	Half Power Beamwidth
IAPG	Interagency Advanced Power Group
IRAD	Internal Research and Development
JCS	Johnson Space Center
JPL	Jet Propulsion Laboratory
k	Thousand
°K	Degrees Kelvin
kg	kilograms
ksi	kips per square inch
LEM	Lunar Excursion Module
LRC	Langley Research Center
LV	Launch Vehicle
LVS	Launch Vehicle System

ACRONYM LIST

M	Mach
MBM	Magnetic Bubble Memory
MHZ	Megahertz
MMC	Metal Matrix Composite
MS	Mass Spectrometer
MSFC	Marshall Space Flight Center
MX	Missile-X
OSO	Orbital Solar Observatory
PCM	Pulse Code Modulation
PDR	Preliminary Design Review
PFPE	Perfluroalkyl Polyether
psi	pounds per square inch
RF	Radio Frequency
RFP	Request for Proposal
RGA	Residual Gas Analyzer
RHCP	Right Hand Circular Polarized
RTG	Radioisotope Thermal Generator
RTOP	Research and Technology Objectives and Plans
RTU	Radioisotope Thermal Unit
SEEGA	Solar Electric Propulsion and Earth Gravity Assist
SO	Saturn Orbiter
SO2P	Saturn Orbiter Dual Probe
SOS	Saturn Orbiter System
SOW	Statement of Work
S/S	Subsystem
TBD	To be Determined
TCS	Thermal Control System
TGA	Thermogravimetric Analysis
TP	Titan Probe
TPC	Titan Probe Capsule
TPS	Titan Probe System
VCM	Volatile Condensible Material
VL	Viking Lander
UTS	Ultimate Tensile Strength
WPAPL	Wright Patterson Aeropropulsion Laboratory

1.0 INTRODUCTION

1.1 Study Objectives

The objective of this study was to define the advances in technology required to permit a Titan Probe mission to be launched during the last few years of the 1980 decade. The study tasks are:

- o Define the technologies required to be developed.
- o Assess the status of those defined technologies.
- o Recommend a technology development plan for the required technologies.

1.2 Study Ground Rules, Guidelines, and Constraints

- o The determination of technologies was made for the baseline Class B Titan Probe described in the Pre-Phase A feasibility study completed in 1979 by Martin Marietta (Study of Entry and Landing Probes for Exploration of Titan-MCR-79-512, Contract NAS2-9985 June 1979). The Class A and Class C probes were considered as additional elements to the Class B baseline.

- o The technology requirements for science instruments were not studied but the accommodations for the instruments designated in the baseline configuration of the previous report, were reviewed for technologies required.

- o The Titan Probe project was assumed to start in 1985 with a launch in 1989 and arrival at Saturn in 1997. This time-frame is different than the time period given in the Contract Statement of Work. This time period was changed at the kickoff meeting of 5 November, 1979; it was agreed that 10 years in space would be used as the dormant time period to evaluate the hardware's life capability.

- No new information was received related to the Saturn Orbiter trajectories, nor was updated Titan atmosphere data available (refer to SOW constraint item D-5 and D-6). Therefore, the baseline data was used and at the kickoff meeting it was agreed to limit the atmospheric pressure, at the surface, to a range of .2 to 2 bars.

- A requirement for the contamination of the Titan surface was also added at the kickoff meeting. The probe was required to have a microbial reduction to 10^4 viable microorganisms. This was assumed to impose a Viking-type requirement of heat sterilization on the hardware and the entire probe.

- Surface sample acquisition requirements were added at the kickoff meeting and documented by the memo of Related Document 4 (Appendix C).

1.3 Final Report Organization

This report is organized to present the results of this study in Sections 2.0 and 3.0. Section 2.0 presents an overview of the results, while Section 3.0 contains the results for each technology as follows:

- The technology requirement,
- The development status of the technology,
- A technology development plan.

The Appendices present the details of how the study was conducted.

Appendix A describes the requirements for the study and the tasks followed in executing the study. The system analysis products, used to provide the requirement for the analysis of the hardware system, are also recorded in Appendix A. Appendix B presents documentation of the subsystem specialist's analysis of the subsystem hardware. The technologies required to be developed are also reported in Appendix B. Appendix C lists the related documents used in this study.

2.0 SUMMARY OF RESULTS

This report describes the results of a new technology study conducted for the Titan Probe. The objective of the study was to determine if technology advances are needed in order to accomplish the Titan Probe mission. The study involved defining the mission conditions and requirements and evaluating the technology impact on the baseline Titan Probe configuration. We then studied the development status of the required new technology by surveying the existing program activities which would advance the technologies required. In a few cases, where it was determined that the existing technology development program is inadequate, we have recommended a development plan and included an estimated cost for each.

As a result of this study we recommend continued activities in two areas: Technology Development and System Studies. For critical areas, such as surface sample acquisition and processing, studies should being as soon as possible in order to maximize the time for the identification, and resolution of any enabling technologies. The mission characteristics that were found to drive technology, and the corresponding recommended technology developments, are summarized in the following paragraphs.

- Ten Years Dormant Life in Space Vacuum - The requirement to be in space vacuum (inactive for 10 years) was found to be compatible with the design capability of state-of-the-art electronic components. Data exists from which reasonable accelerated life extrapolations have been made. These reports (Bibliographies are in Section 3.4) verify that the type of electronic parts assessed for use in the Titan Probe subsystems can function reliably after 10 years storage. The ten-year life capability of non-metallic materials, such as lubricants, gaskets, seals, adhesives, and structural plastics could not be verified from existing test data. Similarly, the life capability of Magnetic

Bubble Memory (MBM) devices is not verified. The status results and technology development plan for materials and MBM devices is discussed in Sections 3.3 and 3.4, respectively.

- Unknown Surface Conditions, Various Sample Material and Surface Temperatures - At this time the Titan surface is not well defined. There is no surface model that defines either slopes or rock distributions, nor is the physical condition of the surface material known. For this study the acquired surface material was assumed to be either solid, loose and granular, or in a liquid state. The science experiments further impose a requirement that the acquired sample should not be contaminated with either foreign organic material or Earth-based microbial organisms.

  These requirements and the vague surface definition, drove a need for technology development in a surface sampler system and a system design development for the landing system.

- Weight -The baseline configuration, and reasonable estimates of the Saturn Orbiter Dual Probe mission constraints, allocated the maximum weight of the Titan Probe to 225 kg. This study concluded that the weight allocation of the baseline configuration was reasonable, based on the heritage hardware defined for each subsystem. However, the immaturity of the structural design, the potential of needed redundancy in some subsystems, and the possibility of a more complex landing system, along with the potential results of a detailed dynamic analysis led to the conclusion that a weight reduction/minimization goal is necessary. It follows that weight reduction can come effectively from the "heaviest" subsystem and, therefore, this weight driver seeks technologies to reduce weight in the structure material, electrical power subsystem (primarily in battery weight and RTG weight in the Class C Probe), and in the subsystem electronics and data storage device.

Other mission drivers were considered; i.e., the 300g impact and sterilization temperature, were found to be environments that can be tolerated by proper design and/or verified by validating tests.

2.1 Recommended Technology

Section 3.0 discusses the studies conducted for each technology recommended, details the technology development status and then presents a development plan for the technology developments that were recommended. These recommendations developments are presented in the following paragraphs.

2.1.1 Surface Sample Acquisition System - The science experiments will require a unique, miniature-sized sampler design capable of acquiring samples of various type surface materials at cryogenic temperatures. No design and development of such a sampler is presently taking place. The work done for the Apollo-Lunar Drill, the Mars-Viking Mission and the study of Mars Return Sample Mission are related to the Titan Probe Mission, but are not directly applicable. As a result it is recommended that a surface sampler should be developed to meet the Titan Probe, multi-type surface material and minimum weight, requirement. Section 3.4 presents a surface sampler concept, which may prove to satisfy all performance requirements, as the recommended development.

2.1.2 Battery Powered System - The baseline design from the Pre-Phase A Feasibility Study used a remotely activated silver-zinc battery power system. Evaluation of the requirements for weight, considering the technology status of silver-zinc and lithium batteries, led to the conclusion that a lithium-thionyl chloride cell reserve battery should be developed for the Titan Probe. The main driver that requires a lithium system is the necessity to achieve minimum design weight. The lithium-thionyl chloride system is predicted to be capable of achieving an energy density of over 300 watt hours per kilogram. At the anticipated required discharge rate, and including the weight of the reserve system, we envision an energy density capability of at least 250 watt hours per kilogram for a reserve lithium-thionyl chloride system. The lithium battery has the potential of weighing only 1/5 that of a silver-zinc battery system.

The use of a remotely activated reserve system for the Titan Probe mission follows the experience of the remotely activated silver-zinc in silo-stored missiles. The experience of a wet lithium system use on the Galileo Project revealed problems with passivation, corrosion, and weld joints. A reserve system can minimize time-temperature chemical reactions by segregating the chemically active elements from each other during the 10-year dormant period.

Development of a lithium-thionyl chloride cell with the goal of an energy density and discharge rate capacity required for the Titan Probe is presently being accomplished. The Jet Propulsion Laboratory (JPL), under Research and Technology Objectives and Plans (RTOP) number 506-23-25, is working to a plan which anticipates testing a prototype cell in fiscal year 1983. The JPL study will follow the work being performed by DOD Agencies (these activities are listed in Section 3.2) and incorporate those results into the development of the prototype cell. This JPL study goal is to develop a cell with a density of 300 watt hours per kilogram with a 1-hour discharge rate. This capability range is directly applicable to the Titan Probe technology development required. However, the JPL study does not consider a reserve system. A remotely activated lithium battery system is presently being developed for the MX boost battery by Eagle Picher under contract to Wright Patterson Aero Propulsion Laboratory. The objective of the MX development is to use features of the proven silver-zinc remote activation system for the development of a reliable system for lithium.

We conclude that a battery technology development program is required in order to accomplish the Titan Probe mission. The development plan will be made up of three phases. The first phase is accomplished by augmenting the JPL study (RTOP 506-23-25) to include a goal to develop a cell usable for the Titan Probe. The second phase is to follow the work presently funded to develop a reserve system which meets the Titan Probe minimum weight and volume constraints. Finally, the cell and the remote activation system are combined to design and develop a Titan Probe remotely activated battery system. It is envisioned that the Titan Probe battery will be unique because of the 10 year life, weight and volume constraints.

Section 3.2 presents the requirements, technology status evaluation and a recommended technology development plan for a probe reserve lithium battery.

2.1.3 Materials - The technology development required for nonmetallic materials is to verify, by test, that applicable materials are compatible with 10 years in space vacuum.

It is common knowledge that spacecrafts have functioned in space for more than 5 years. We can surmise that the nonmetallic materials in those spacecraft are still functioning. Research performed during this study did not locate any analysis of operating spacecraft that would validate the life of these materials. Therefore, we cannot certify that nonmetallic materials can function after 10 years in vacuum. Viking nonmetallics are being evaluated by Martin Marietta, under Contract to NASA-MSFC, to assess the physical and mechanical properties of a limited number of samples after exposure to thermal vacuum environment. Investigations have determined that nonmetallic materials outgas and lose their plasticizers, binders, polymerizing agents, and catalyst. The outgassing rate and the subsequent effect on the physical and mechanical properties of the material is a function of time and local environment. Nonmetallics are available that do not have high outgassing characteristics. For the Titan Probe technology development, the task will be to analyze the results of the ongoing Viking material study and then chose candidate mateiials to be tested to the Titan requirements.

Lubricants theoretically will have the same outgassing problem as other nonmetallic materials. Past evaluations of lubricants have been limited to testing for 1 to 2 years in space vacuum. At present, NASA-MSFC is studying lubricants in space environments and plans to test for up to 5 years exposure to vacuum. Early determinations in that study have concluded that the perfluoroalkyl polyether (PFPE) chemical class of lubricants offers the best potential for long duration space application.

Weight reduction can effectively be accomplished in the structural design by using metal matrix composites (MMC) in place of aluminum. Studies of existing spacecraft show that a 40-50% weight reduction can be achieved practically. Section 3.2 documents the status of MMC and recommends the tests and analyses required to verify compatibility with the 10 year space vacuum requirement.

2.1.4 Magnetic Bubble Memory Device (MBM) - The MBM storage device was recommended in the baseline configuration. In this study we have reviewed the status of the technology and have found that significant development is taking place to assure that a 10^6 to 10^7 storage bit capability will be available for the Titan Probe program time-frame. NASA-LRC is developing the microprocessor-controller technology. By the beginning of the Titan Probe program we anticipate that the weight and power will be reduced significantly for these devices. The MBM data storage system will be qualified for all space environments but it will be necessary to verify, by analysis and test, that the MBM can meet a 10-year vacuum storage requirement.

2.2 System Studies

Our review and analysis of the baseline configuration from the Pre-Phase A Feasibility Study indicated that there were areas of system design that will require further tradeoff analysis, although it is not obvious that these tradeoff studies will uncover any new technology requirements. However, these system studies will be necessary before a meaningful Phase B type design can be completed.

The following system studies are recommended:

2.2.1 Landing System Study

- Landing Stability - The baseline configuration was developed in the previous study (Study of Entry and Landing Probes for Exploration of Titan - Related document 1 in Appendix C) by assuming the surface was flat, smooth and had no near-surface winds. Unless the surface is liquid there is a strong probability that the surface will be sloped and have some rock distribution. In that case the landing system must be designed for the most likely surface model defined by the science community. The design will be driven by the characteristic of the surface. Amplification factors in the probe structure, and in the science packages will depend on the damping characteristic of the system. A dynamic analysis of the selected configuration must be performed. The landing shock absorption system should be capable of absorbing nonhomogeneous impact forces due to rocks or slopes, and have the capability to land the probe in an upright position.

- Minimum Effect on Surface Condition - The landing system design should consider the effect it has on the surface. In the baseline conceptual design, the ablative material may adversely impact the surface by contaminating any samples obtained from the surface. Similarly, there is some possibility that the honeycomb material will contaminate the sample area accessable to the surface sampler. A design must be considered that assures that the surface area is not contaminated by the probe.

2.2.2 Pre-Entry Science - The Pre-Entry Science was configured in the baseline configuration based on a strawman group of science instruments. The Pre-entry and Entry science instruments will be defined prior to the Phase B design for the Titan Probe.

A system trade study must be conducted to assess the most effective and efficient science instrument locatio~. The analysis should be made by considering where the science instruments can be best located. Candidate locations include:

- o Integrated in the probe and possibly common with the entry science instruments.
- o In a module, as in the baseline configuration, which is jettisoned before entry.
- o In the rear of the base cover.
- o On booms that deploy away from the probe.
- o Independent of the probe and leads or follows, the probe into the atmosphere.

Evaluation of these science instrument locations should be examined against the effect on: Science return, mission risk, minimum weight, cost and schedule risk.

2.2.3 Reliability Study - The ground rule of this study was to perform a technology assessment based on the single-string system baseline configuration. It is felt that the technologies uncovered were generic in nature and would not be changed by a redundant system design. Development of the recommended technologies will provide the capability for the hardware to operate within its design specification after exposure to the mission driver conditions. However, an operations reliability analysis will be required to assess the probable risk to mission success; and then to establish a design criteria for the probe. The criteria can follow the traditional rule for programs: that no single failure shall cause the loss of data from more than one science experiment. After establishing a criteria, a study is conducted using a Phase A functional design concept as baseline; the critical functions are identified and a system level Failure Mode Effects Analysis (FMEA) is made. From the FMEA, a design specification is established that corrects single point failures on a system block level, or within a subsystem.

From past experience it is expected that such a reliability study would lead to some type of redundancy in the Data Handling System, the Telecommunications System and the Power System. Weight increases in these systems can be expected and redundancy should be developed considering the weight reduction plan.

The steps in performing this reliability study are:

- o Establish operating reliability goals;
- o Design to eliminate by design, single point failures;
- o Add redundancy as required;
- o Test reliability implementation.

2.2.4 Weight Reduction Study - The allocated weight for the baseline configuration from the previous study was 225 kg. Our review of the subsystems during this study concluded that the weight allocation was reasonable based on the hardware heritage defined for each subsystem. However, the immaturity of the structural design, the potential need for redundancy and the possibility of a more complex landing system may require a concerted weight reduction program to stay within the maximum allocated weight of 225 kg.

A typical weight reduction program should start during the Phase A concept study. The heaviest subsystems must be carefully scrutinized to find ways to drastically remove weight.

Table 2-1 shows the potential impact of a weight reduction study on the baseline configuration. The proposed allocation changes in Structures, Data Handling and Electrical Power subsystems are drastic enough to warrant technology developments to accomplish the reduction. The science payload is also a candidate "heavy" element that might be reduced through the technology developments. Candidate new technology developments that have the potential for large weight reductions in each of these are:

- o Structure - Use metal matrix composites for its structural members and skin sections.
- o Electrical Power Subsystem - Achieve weight reduction by using Lithium batteries and eliminating the Radio Isotope Thermal Generator (RTG.)
- o Data Handling and Science Subsystem - Achieve low weight by employing a minature design which uses hybrid packaging, integrated circuit components and bubble memories.

The addition of redundancy increases the weight but this increase can be minimized by designing for weight reduction and redundancy at the same time. The design and development for weight and redundancy should be completed by the System Concept Phase (Phase B) of the Titan Probe Program. The steps to be performed in a weight reduction study are:

- o Use of the Phase A Design Configuration;
- o Determine each subsystem's weight;
- o Tradeoff the weight of "heavy" subsystems (Structures, Power);
- o Redesign each subsystem for the new weight allocation.

Table 2-1 Titan Probe- Potential Weight Reduction and Redundancy Impact

Subsystem	Proposed Allocation Change	Δ To 225 kg
o Structures (82.5 kg)	-50%	-40
o Data Handling and Command (12.6 kg)	-50%	- 6
	Add redundancy	+ 3
o Electrical Power (29.4 kg)	-50%	-14
	Add redundancy	+ 4
o Telecommunication (2.6 kg)	Add redundancy	+ 5
o Landing System and Mechanisms	Add	+20
o Miscellaneous Redundancy	Add	+ 8
o Science (51 kg)	-50%	-25
	Total	-45 kg

3.0 STUDY RESULTS

3.1 Surface Sample Acquisition

3.1.1 Design Requirements

3.1.1.1 General Considerations - A significant portion of the surface science to be performed by the Titan lander probe depends on the successful operation of the surface sampler. Therefore, it is imperative that the selected technique be characterized as follows:

- Design based on techniques that have at least a limited heritage from previous programs;
- Design is relatively simple, and, therefore reliable;
- Operating technique must be accommodating for any type of surface material within the wide range of potential Characteristics;
- New technology development requirements should be minimized to the greatest extent possible.

The major design drivers for the surface sampler are expected to include the wide range of potential surface characteristics and the extremely low ambient operating temperatures external to the environmentally controlled capsule.

3.1.1.2 Surface Characteristics - Properties of the Titan Probe surface are currently poorly characterized because of limited observational data. The problem of surface characterization is much greater than the previously explored Lunar and Martian surfaces because of the abundance of observational data available months (and years) prior to the respective lander design, test, and operational phases.

The currently available Titan surface data indicates properties that range from solids, semi-loose materials to a liquid surface. Previous planetary probe samplers have been designed for solid rock materials such as basalt, and loose material composed of rock particulates with particle sizes ranging from microns to centimeters.

However, the potential Titan surface characteristics must be extended to include engineering properties with Earth analogs similar to consolidated ice, fractured snow, sticky slush, cryogenic liquids, or combinations of these materials.

The ideal surface sampler for the Titan Probe would be to accommodate a variety of sampler types, each of which could be designed specifically for a particular surface characteristic. However, payload weight and power limitations preclude such a luxury; and therefore, a "universal" sampling capability from a single device is required.

3.1.1.3 Operating Environment - The sampler will initially be exposed to the Titan capsule environment for 10 years during the Earth-to-Titan cruise. Temperatures within the capsule will be moderate and are not expected to impact the selected design approach. However, the effects of long-term vacuum exposure are not very well characterized at this time. Some limited data is being generated by the Viking laboratories (VL-1 and VL-2) currently operating on the Martian surface for more than 5 years. Additionally, engineering property degradation data is being gathered from representative Viking materials that have been stored under a vacuum-environment since fabrication of the spacecraft. Data generated from the Viking progrm will be useful in guiding the materials selection for the Titan probe sampler, but additional materials technology development is indicated.

The Titan atmosphere environments, 100% methane or 100% nitrogen at pressures ranging from 0.2 to 2.0 bars, is not expected to present a significant problem for the sampler. However, the extreme temperature of $70^{o}K$ represents a challenge for design of the sampler mechanism.

The recommended approach to accommodate the extremely harsh temperature range is to select a sampler design that requires all mechanisms and electro-mechanical devices to be housed within the environmentally controlled Titan capsule, and that only the "sample collector" (with no moving parts) extend through the environmental barrier.

3.1.1.4 Science Requirements - The science experiments require a positive sample that has not been physically or chemically changed. The ideal experiment sampling method is to measure the sample without removing it from the surface. Transporting the sample inside the probe has the uncertainty of exposing the sample to high temperatures. These temperatures can cause any volatiles condensed in the sample material to evaporate. To prevent the volatiles from changing phases and escaping detection, it would be ideal to perform the analysis with the material in situ. For the Titan Probe, deploying the instrument may be impractical. However, it is possible to transport the sample to the inside of the Probe while minimizing temperature effects by:

- o Allowing the sampler collection to come to equilibrium with the surface environment; this will retard heating the sample by providing some thermal inertia,
- o Rapidly transporting the sample to a selectable chamber,
- o Measuring the volatiles in situ, while they are in equilibrium with the enrivonment.

3.1.2 Past History of Planetary Samplers

3.1.2.1 Literature Search - A literature search was conducted to investigate the possibility that planetary sampling research/development activities may be underway at other research institutes. The literature search surfaced approximately 66 papers (see Bibliography, Section 3.1.6) generally related to planetary sampling. These papers were reviewed and found to be interesting, but not directly related to the technology requirements for the Titan sampler.

Most of the existing, practical, planetary sampling technology has been developed by Martin Marietta. The only past sample missions were; the 3-meter lunar drills used by the astronauts on Apollo missions (see Bibliography Items 50-53, 56, 57, and 61-64), the surface samplers used on the Mars Viking Landers (Bibliography Items 45, 46, and 66). The only other planetary samplers were the shallow drills used by the Russians on their Luna series missions. Some of the technology used for these drilling systems are applicable to the Titan Probe sampler, but a significant extension of the state-of-the-art is required. Martin Marietta also completed, in April 1980, "A Study of Sample Drilling Technology for Mars Sample Return Mission" (Bibliography Item 45) which is somewhat applicable to the Titan Probe.

3.1.3 Titan Probe Sampler

3.1.3.1 General Design Approach - The design approach recommended for the Titan sampler incorporates the principles used in the Apollo sampler, namely, a rotary percussion drill.

This system is capable of acquiring samples from solid rock or particulate surfaces, and more recent tests (Bibliography Item 45 -Mars Sample Return Mission, April 1980 Report) have indicated the feasibility of using this approach for acquiring shallow samples (up to approximately 5 cm) from water, ice, or simulated permafrost. A rather extensive development background for the rotary percussion drill system, studied in that Mars Study, is extremely valuable as a basis for the Titan sampler. An extension of the technology is required to provide the sampling capability from a cryogenic liquid surface.

Brief consideration was given to using the design approach employed for the Mars Viking lander samplers. However, this design is restricted to surfaces with a relatively narrow range of engineering properties, such as loose or semi-hard particulate materials.

3.1.4 Design Approach

The following derived design requirements were developed for the universal surface sampler:

- Operate after 10 years in space vacuum;
- Operate after 300g impact;
- Acquire solid material, semi-loose material, and liquid state material;
- Operate at the Titan surface environment of $70^{o}K$ at 0.2 to 2 bars atmosphere;
- Minimize sample contamination;
- Minimize effect on physical condition of the sample;
- Sample from three locations and analyses at three stations.

Figure 3- shows a concept for a universal sampler design. The design consists of a rotary percussion drill system located on the centerline of the probe. The drill is designed to acquire samples from all potential types of surface material. The motors and mechanisms are located within the thermally controlled compartment of the probe; therefore, the surface temperature will only affect the drill bit and not the components inside the compartment. Only the drill bit is extended through the thermal insulation and crushable honeycomb area. The honeycomb material is prevented from being forced into the center cavity area (thus contaminating the sample) by a restraining-telescoping tube.

The operation of the sampler system can be followed by studying Figure 3-2. During flight to Titan and until after landing, the sampler drill head is latched firmly by a support device. The initial transition and rotation motion of the drive motors are used to unlatch the drill. The motor operation then indexes the drill to a sampling port. At that position, the transition drive motor extends the drill bit through the port to the surface. After surface contact is sensed, the rotary percussion power head is operated and the drill is driven into the surface approximately 3 centimeters. During this downward action, the sample is acquired and the power head is powered-down. A diagram of the sample bit is shown in the inset of Figure 3-2. The surface material is forced into the center of the drill bit and is retained in the drill.

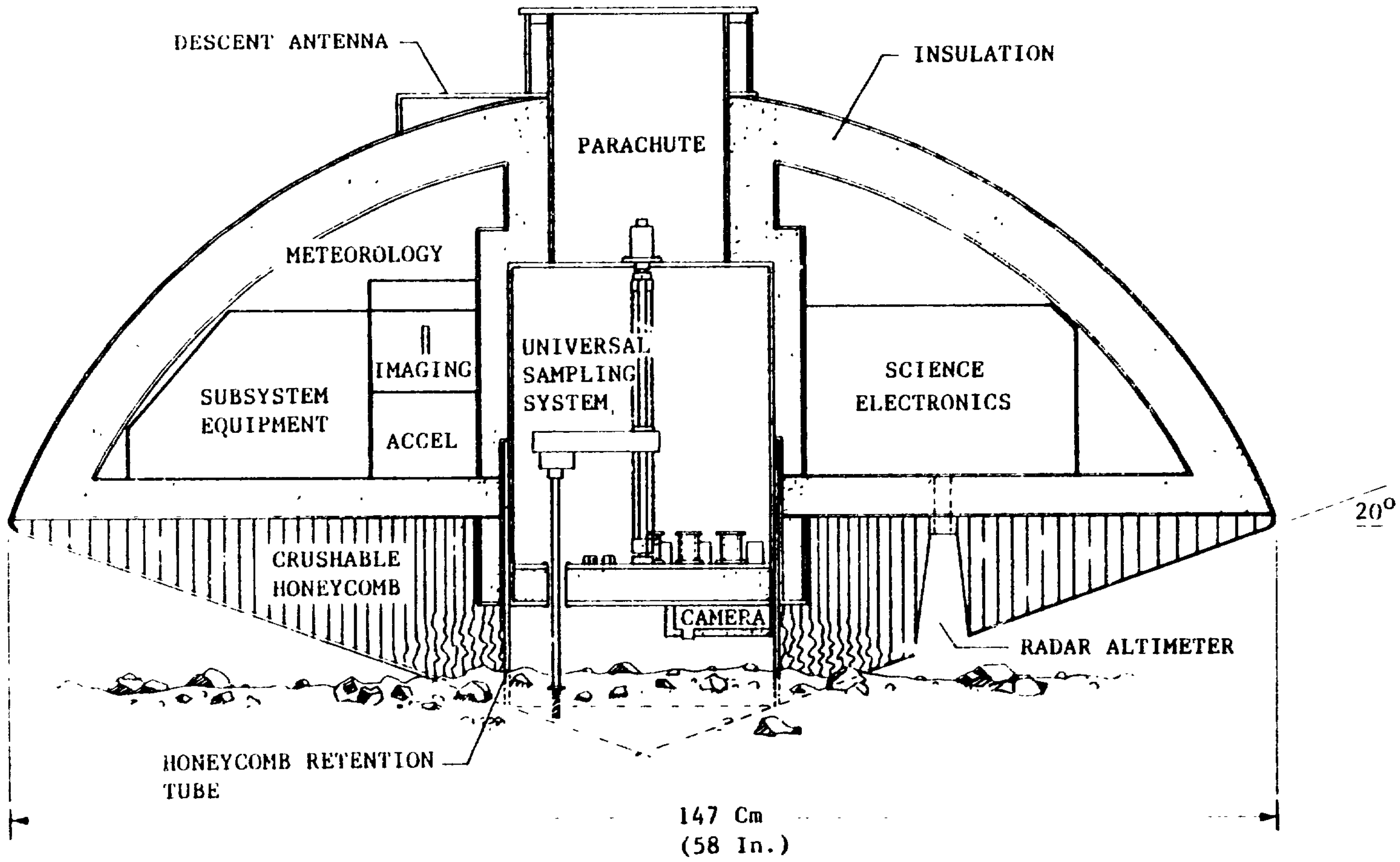

Figure 3-1 Universal Sampler Design Concept

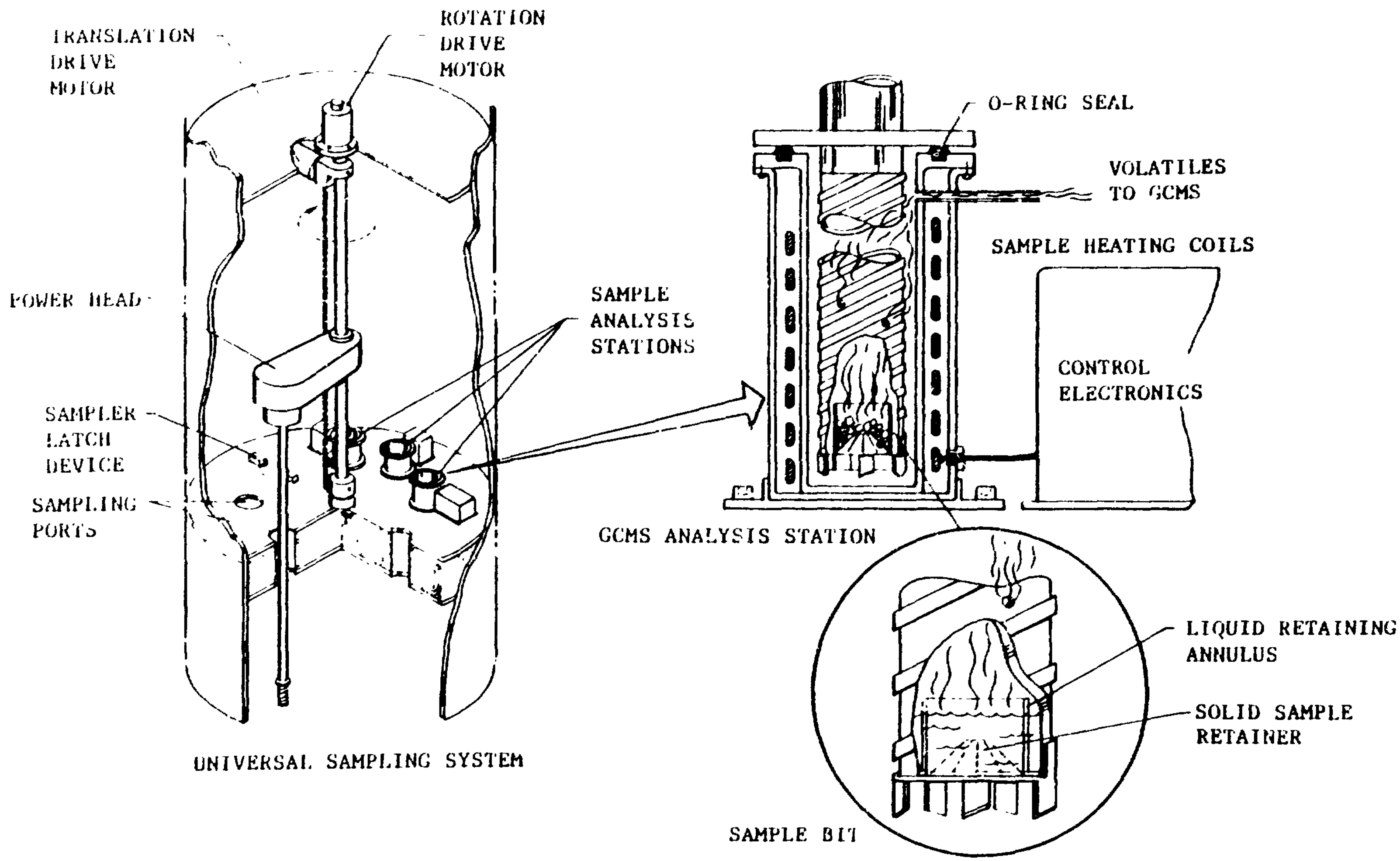

Figure 3-2 Universal Sampler Design Concept Detail

If the sample is solid or granular a spring-retainer holds it in the bit, an annulus-retainer holds any liquids present. The annulus is concentric to the inside wall of the drill bit.

After acquiring the sample the transition drive motor retracts the drill bit through the sampling port. The drill is then rotated to a position over an analysis station and moved down to seal the drill bit (with its sample) in the chamber. The analysis station chamber is also shown in Figure 3-2. It shows an analysis station for a Gas Chromatograph Mass Spectrometer (GCMS) science experiment. With the sample sealed in the chamber, the analysis sequence is then initiated and heating coils ramp the temperatures of the chamber through a prescheduled sequence. The volatile gasses from the sample can then be transported to the GCMS instrument.

Following analysis residual sample material left in the drill bit is not purged, but is pushed further into the bit during the next sample acquisition.

3.1.4.1 Alternate In Situ Sample Analysis - Acquiring a sample using the universal drill method has the potential of changing the physical state of the surface material. A more pristine sample can be acquired by heating the sample while it is still in the surface. Figure 3-3 is a sketch of this in situ sample concept.

The sampler arm is initially stowed with the sample heating tube attached to the bottom of the drill bit. Rotation and translation of the bit unlatches the heating tube where it is indexed to a port and extended to the surface. After surface contact is made, the sample heating tube is forced 1 to 2 centimeters into the surface. The heating coils are then energized, in accordance with the preprogrammed sequence, to volatilize the surface material. The volatilized gases are carried by an insulated, heated pipe to the GCMS instrument.

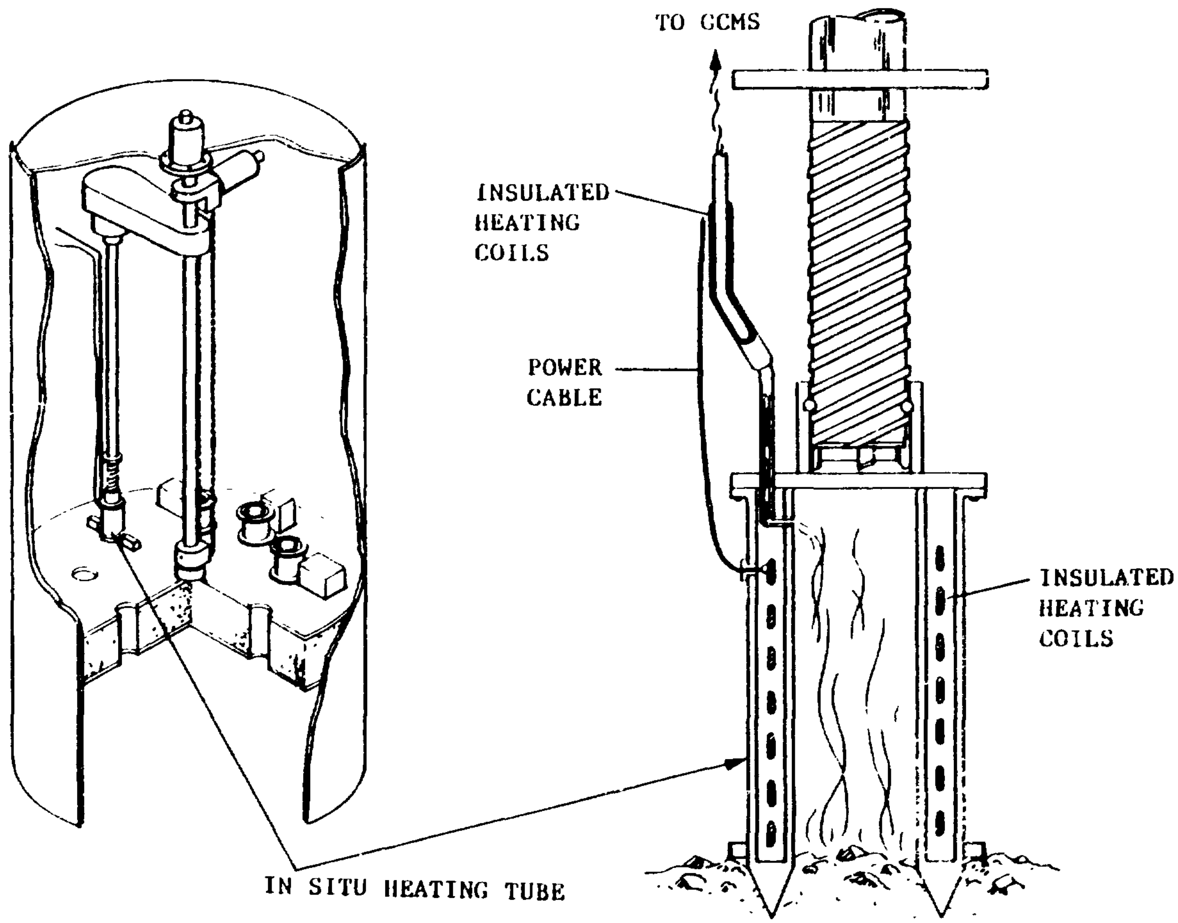

Figure 3-3 In Situ Heating Tube Option

The in situ heating tube could be designed to operate with the universal sampler, or it could be designed as an autonomous subsystem, thus providing limited redundancy.

3.1.5 Surface Sampler - Technology Development Plan - The steps required to develop a Titan Probe surface sampler include:

- o Drill Bit design and fabrication,
- o Universal surface sampler design, development, fabrication and test,
- o Surface sampler working model production.

The sampler bit design starts with drill bit material selected during material evaluation (Section 3.4). The candidate drill bit materials are used to design and then to fabricate candidate drill bits. These candidates are tested for performance and endurance at the surface temperature of 70°K. Performance is evaluated by testing in a wide range of potential surface materials. This drill bit design, along with the nonmetallic material and lubricants selected from the material study, are then used in the design of the miniature surface sampler. The design synthesis will involve fabrication of the surface sample model and then testing the design performance in simulated surfaces. Design changes as a result of these tests will in turn be similarily tested. The final product of this design study will be a working model of the surface sampler that can be used to test the design performance in new models of the Titan surface.

The design study time span is estimated to be at least 2 years, and the Rough Order of Magnitude (ROM) cost will be in the order of $600 thousand. The development should be completed prior to the start of the concept-validation phase (Phase B of the A-109 Acquisition cycle) of the Titan Probe program.

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3.2 Battery Technology

3.2.1 Titan Probe Technology Development Requirement - The power system design in the baseline configuration used a remotely activated silver-zinc battery. In this study, we evaluated the development of lithium cell technology and considered the requirement to minimize the weight of the Titan Probe; and therefore, recommend the lithium-thionyl chloride reserve battery. The lithium couple is in development (see Section 3.2.2) and a lithium-thionyl chloride cell system is predicted in the literature to have a theoretical energy density of 600 Watt-hours per kilogram at very low discharge rates. For the Titan Probe application a total energy of 1400 Watt-hours is required with a 446 Watt-hour capacity required for a peak C/3 discharge rate. For this worst case condition a 16 Amp-hour capacity is required. Evaluation of the predicted capability of lithium anticipates that a 300 Watt-hour per kilogram at a C/1 discharge rate will be developed within the next few years.

Table 3-1 lists the characteristics of potential lithium systems compared to the silver-zinc couple. The lithium-thionyl chloride system is capable of weighing 1/5 that of a silver-zinc battery system. Lithium also has the added advantages of a very high working voltage and occupying 1/5 of the volume.

3.2.2 Battery Technology Development Status

3.2.2.1 Silver-Zinc Status (Ag-Zn) - The silver-zinc battery was used extensively in the early space program and is in use today in the Titan and Patriot missile programs. Extensive data is available from these programs. Bibliography Items 35, 43, and 44 present storage reliability data for primary silver-zinc batteries. An analysis of a study conducted from 1974 through 1978 established the service life of remotely activated

Table 3-1 Comparison of Lithium and Silver-Zinc Batteries

System	Working Voltage	Energy W-hr/cm^3	Density W-hr/kg	Operating Temp. (°C)
LITHIUM:				
Sulfur dioxide ($Li-SO_2$)	2.9	115	265	-65 to 65
Thionyl chloride ($Li-SOCl_2$)	3.6	295	330	-65 to 71
Vanadium pentoxide ($Li-V_2O_5$)	3.4	180	265	-65 to 71
Polycarbon monfluoride ($Li-CF_N$)	2.5	410	463	-90 tp 120
SILVER-ZINC (Ag-Zn)	1.55	57	66	-40 to 54

silver-zinc batteries at 14.0 years with failure rates of 102 failures per 10^9 storage hours (Bibliography Item No. 43). From the reliability and space aging reports, Bibliography Items 2 and 11, the reliability of the remote activation system is substantiated with failures occurring after approximately 30 months of storage.

The silver-zinc data, however, is applicable to a relatively short operational life primary battery. The Titan Probe Class B mission falls beyond the 24-hour active life demonstrated for a remotely activated battery and the 90-day active life demonstrated for a manually activated primary system.

Secondary silver-zinc batteries have been used extensively in the past, however, extensive storage data is not available. Advanced development studies by Dr. D. Soles at NASA-LRC has demonstrated the wet life cyclic operation is at least 30 months. This new system uses an inorganic separator which evidently is an improvement over the asbestos separator system used in previous systems. Sealed silver-zinc batteries, developed for the Viking Program (1969), were tested (Bibliographyy Item No. 7). This test showed an average 12% capacity degradation for cells with a 20 ampere-hour capacity after 10 years storage. These sealed silver-zinc cells were submitted to sterilization temperatures and showed an average 25% degradation in capacity.

Status of the technology of the silver-zinc battery indicates that development would be required to substantiate a remotely activated battery with activated operational life of 11 days and a space storage life of 10 years.

3.2.2.2 Lithium Battery Technology Status - Lithium cell development has been in progress since the early 1970s. Significant development of very low discharge rate systems, such as lithium-vanadium pentroxide ($Li-V_2O_5$) and lithium-polycarbon monofluoride ($Li-Cf_N$) have been made by G.E., Honeywell, GTE, Eagle Picher, PCI, and Mallory. The more viable couples for the Titan Probe are lithium-sulfurdioxide ($Li-SO_2$) and lithium-thionyl chloride ($Li-SOCl_2$). These systems are predicted to be capable of energy densities in the order of 300 Watt-hours per kilogram with the $Li-SOCl_2$ having a higher capability in density and working voltage. The bibliography list for Batteries (Paragraph 3.2.4) lists the more pertinent reports.

3.2.2.3 Lithium Sulfur Dioxide Status - The $Li-SO_2$ system has had a significant amount of data collected. $Li-SO_2$ has been under development by the Navy as well as the Army Communication Center at Fort Monmonth. NASA-ARC has been developing an $Li-SO_2$ system for the Galileo mission. This mission uses a wet cell for a 3 year lifetime. Testing of the lithium-sulfur dioxide system has revealed a shelf life problem in glass-to-metal seals and corrosion on welds. The program has made manufacturing changes to correct these problems and are testing to verify the effectiveness of corrective actions.

Evaluation of the cells by Sandia Laboratory (S. Levy) on long term storage (2 years) and application show that the passivation film on the anode can be removed by periodical discharges, but that the film will regenerate as a function of time and storage temperature.

Evaluation of Li-SO_2 cells by C. Bennett (General Electric, Valley Forge), on the passivation effects, corrosion, and capacity degradation as a result of orientation, again has shown that the degree of passivation is a function of time and temperature. Corrosion, on the other hand, does not appear to be inhibited by temperature and will degrade most materials including plastics, stainless steel, and glass. Evaluation of capacity degradation as a function of orientation, as supported by H. Taylor of P. R. Mallory, shows that testing of the cells in an upside down state results in a capacity loss of 65 to 76% of fresh cells while testing of the cells lying on their sides results in a capacity loss of only 33%.

Safety aspects of the cells (evaluated by A. N. Dey of P. R. Mallory), has shown that the Li-SO_2 cells are susceptible to violent explosion as a result of forced overdischarge from either a short circuit, or a resistive load. High pressure build up problems, as a result of thermal run away, have been solved with a low pressure vent (100 to 300 psi) and appropriate fuses incorporated in the cells. Explosions as a result of anode limiting have also been eliminated. Explosions as a result of storage and resistive discharge are still under investigation.

3.2.2.4 Lithium Thionyl Chloride Status - Of the studies being performed at the present time, RTOP 506-23-25 is the most directly applicable to the Titan Technology required. This study is funded by NASA-OAST and is bei[illegible] performed by JPL. The goal of this study is "to develop improved lithium battery systems with substantially improved lifetime, reliability, safety, cycle and rate capab ty, and energy density operable at spacecraft ambient temperatures." JPL envisions a 300 Watt-hour per kilogram energy density at discharge rate of 1 hour. This is directly applicable to the Titan Probe. The RTOP plan is to test a prototype cell in fiscal year 1983.

The bibliography for batteries in Section 3.2.4 lists some of the pertinent studies on lithium cells. The JPL program plan for the RTOP (Bibliography Item No. 52) lists the related lithium battery activities being performed under DOD sponsorship. Since they are directly applicable to the study, the following primary lithium battery report is quoted from Bibliography Item 52.

> Air Force Aeropropulsion Laboratory (AFAPL), Dayton, Ohio, is sponsoring three programs. The first of these is concerned with studying and characterizing the passive film formed on the lithium anodes of primary $LiSOCl_2$ cells. Funding level is $36 thousand. This work is being carried out on contract with the University of Dayton. The second is concerned with the safety of primary $LiSOCl_2$ and $LiSO_2Cl_2$ cells. They are trying to define the conditions and causes of explosions in these cells. They hope to either eliminate the causes or specify a range of parameters under which safe operation can be achieved. This work is being carried out on contract with General Telephone and Electronics. Funding level is about $100 thousand. The third is aimed at developing manufacturing methods for making $LiSOCl_2$ primary batteries. This work is being carried out on contract with Honeywell.
>
> The United States Air Force, Space and Missile System Organization (SAMSO), Norton AFB, California, has a sizeable contract (about $2 million) with Honeywell to develop the $LiSOCl_2$ primary battery as a ground support power supply for the MX missile system. Honeywell is in the process of scaling up in steps from the existing 17 AH size cell to the required 17,000 AH cell size.

The Naval Surface Weapons Center (NSWC), Silver Spring, Maryland, has four exploratory development type programs in the area of lithium batteries. Funding levels are about $100 thousand for each. The first of these is to evaluate the primary $LiSOCl_2$, battery technology under development at Altus Company, Palo Alto, California. The second is to evaluate a primary 100 AH, 12-volt $LiSO_2$ reserve type battery. The third is to evaluate the explosive equivalent of primary $LiSO_2$, $LiSOCl_2$, and LiC_F cells. The fourth is to identify intermediates formed during discharge of primary $LiSO_2$ cells. All of this work is being carried out in-house at NSWC. NSWC also has a number of programs in progress wherein they are purchasing primary $LiSO_2$ and $LiSOCl_2$ cells to special order and evaluating them as power sources for hardware items such as underwater mines.

The Naval Oceans Systems Center (NOSC), San Diego, California, is engaged in a program identified as the High Energy Density Battery (HEDB) program. Funding to date has been $2 million. Objective of the program is to develop high energy, lightweight batteries as power sources to propel and operate electronics on classified underwater vehicles. After examining several candidated batteries NOSC has decided that the Altus primary $LiSOCl_2$ battery offers the most promise. For this reason NOSC has awarded a contract to Altus to scale their cells up to the 1000 AH cell size required for the vehicles.

JPL had been carrying out an in-house effort ($100 thousand) on characterization of commerical $LiSOCl_2$ cells from Altus Company. This involved electrical, thermal, and safety characterization of nominal 5 AH cells.

The Naval Sea System Command (NAVSEA), Washington, D.C. has a major program ($20 million) to develop Lightweight Torpedos. A promising contender for this application is the $LiSOCl_2$ system provided it can be shown to operate at high rates, i.e., 100 percent discharge in ten minutes. NAVSEA will be selecting a contractor in the near future.

The Army Electronic Research and Development Command (ERADCOM), Fort Monmouth, New Jersey, has a number of programs of about $100 thousand underway on primary lithium batteries. They are working both in-house and on contract on $LiSO_2$, $LiSOCl_2$, and $LiSO_2Cl_2$ batteries. Some of the programs are aimed at developing the batteries for specific types of communication equipment. Other programs are technology-oriented and deal with safety and passivation aspects of these cells. Their principal contractors for the $LiSO_2$ cells are Mallory and Honeywell. Their principal contractors for the $LiSOCl_2$ cells are GTE, Mallory, EIC, and Altus.

The Army Research Office, Washington, D.C., has a small program ($60 thousand) with EIC Company to study films on lithium electrodes exposed to thionyl chloride.

The following presently active programs are applicable to the Titan Probe requirements:

o Lithium reserve batteries for normal mines application for the NSWC by Honeywell with a funding of $50 thousand in 1978 under Don Warburton.

o Rechargeable lithium systems funded and internally worked by ERADCOM of Fort Monmouth, New Jersey, with a $100 thousand funding.

o Harrison Labs has been investigating the packaging of the lithium reserve power system with a funding of $13 thousand in 1979.

o P R Mallory has been unded by ERADCOM to evaluate hermetically sealed lithium system.

o McDonnell of ERADCOM is evaluating the lithium organic batteries.

o Dr. A. N. Dey of P R Mallory has been funded $12C thousand by ERADCOM for the evaluation of the lithium thionyl chloride system.

o Dr. Sol Gilman of ERADCOM has been funded for the improvement of lithim inorganic electrolyte cells.

o R. L. Higgins of Eagle Picher has been funded by Wright Patterson for the investigation and evaluation of the calcium inorganic electrolyte battery.

o Wright Patterson has also funded GTE (M. A. Salvin) for the development of the lithium organic battery.

o Dr. G. Holleck of EIC, evaluation of the electrically rechargeable lithium battery $58 thousand funding by ERADCOM.

o Eagle Picher (L. R. Erisman) has been funded by Wright Patterson $67 thousand in 1980 for the evaluation of the lithium inorganic electrolyte reserve battery.

o Altus Corporation has been funded with $89 thousand from Wright Patterson for the cell evaluation of the primary lithim thionyl chloride system.

Bibliography Item 53 is the latest issue of the "Interagency Advanced Power Group Briefs by Field of Interest." This periodic publication lists the advance power research projects being funded by government agencies. A significant number of lithium projects are ongoing; these are listed under Bibliography Item 53.

The following activity was reported at the 29th Power Sources Conference, Atlantic City, June, 1980.

o The Naval Surface Weapons Center is presently investigating the thermal analysis of the interactions of various components of the $LiSO_2$ and $LiSOCl_2$ cells.

o Modified $LiSO_2$ cells and componeut for long life applications, such as Galileo and future deep space probes, are being evaluated by Sam Levy of Sandia Labs. This study has approximately 2 years of testing completed.

o Evaluation testing of manufactured high reliability $LiSO_2$ batteries is presently ongoing by Power Conversion Inc.

o A 100 Ahr multicell $LiSO_2$, for Naval usage, is presently undergoing performance testing by Honeywell Power Source Center. This sytem could be a viable candidate that can be modified for Titan Probe application.

o P. R. Mallory is presently evaluating material for the $LiSO_2$ system to be used in the Galileo Program.

o Safety procedures in the handling, storage, and use of $LiSO_2$ cells are being prepared by the U S Army Electronics Technology and Devices Laboratory.

o High rate discharge characterization of the $LiSOCl_2$ are presently being evaluated by GTE.

o Characterization of $LiALCl_4$-$SOCl_2$ solutions for $LiSOCl_2$ application is presently being evaluated by Honeywell.

o Lithium Corrosion and voltage delay in $LiSOCl_2$ cells, with $Li_2B_{10}Cl_{10}/SOCl_2$ and $LiAlCl_4/SOCl_2$ additives, is being evaluated at GTE labatories.

In the past few years a major effort has been placed on the design, development and testing of the $LiSO_2$ and $LiSOCl_2$ systems. The quantity of work underway is made evident by the large number of technical papers presented at the society conferences, and the large number of development contracts from the various government agencies.

Safety has been upmost in the minds of the application engineer for both unmanned probes and spacecrafts as well as usage on the shuttle. Many agencies are at present preparing procedures in the proper handling, storage and usage of the lithium systems.

Although a large volume of work is being done on the primary systems very little work is being done in the reserve or remotely activated systems. It is recommended that a development and test program be instituted on the reserve system. This development and evaluation program would address the activation system, long term storage effects on cells, temperature effects on stored cells, and materials.

The JPL-RTOP effort is not looking at reserve systems. However, Eagle Picher is presently under contract, to Wright Patterson Aeropropulsion Laboratory (WPAPL) to develop a reserve system for the MX boost battery. WPAPL direction is for Eagle Picher to derive the remote activation component from the remote activation system used for the silver-zinc batteries.

In summary, the technology development for lithium thionyl chloride cells is presently being conducted. The status of development of a cell for the Titan Probe can come from this present activity. However, the development of a reserve $LiSOCL_2$ system cannot be realized directly from the present activity. An activity that directly develops a Titan Probe lithium battery should be funded.

3.2.3 Battery Technology Development Plan - To ensure a fully qualified operational system for the Titan Probe Launch battery development and evaluation should be undertaken immediately. Although the lithium system has matured in the past few years, the data base is still small. Development, test, and evaluations are required in the following areas:

- Remotely activated system,
- Corrosion,
- Effects of long term storage,
- Sterilization.

The program to develop a remotely activated lithium battery system should pursue the following plan:

- Develop $LiSOCL_2$ Cell -This activity can be inserted into the JPL-RTOP effort. An additional objective, to develop a Titan Probe prototype cell, can be included into that study. The time period for this additional task can be imposed into the present plan in order to have a Titan Probe prototype cell tested by the end of fiscal year 1983.

- Develop a Remote Activation System. - This will have to be a unique activity that draws the MX development that Eagle Picher is presently conducting. A separate activity will be required to design the system for the Titan Probe weight and volume. It is envisioned that this would take a year of development after the MX activity has reached some maturity. A component should be ready to prototype test with the cell in fiscal year 1983.

- Perform Long Term Storage Test - Prototype reserve battery systems will be tested for long life and system components, such as cells, manifolds, electrolyte tanks, and diaphrams can be life tested as early as they are designed. At least 3 years of testing, with samples being tested at useful intervals, will be necessary.

- Develop 10 Year Life Prediction Method - From the life tests, an attempt should be made to evolve a method for long life prediction from 3 years or less data. Analysis of the test data from less than 3 years of storage may be capable of being extrapolated to predict a failure rate after 10 years storage. The test should be designed, however, to store some samples for 8 to 10 years.

The battery storage test should be scheduled to have completed at least 3 years of storage time prior to the PDR in the System Concept Phase (Phase B in the A-109 Acquisition Cycle) of the Titan Probe mission. The rough order of magnitude estimate of cost for development and verification of the activated battery is $2.5 million.

3.2.4 Battery Bibliography

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b. Lithium Inorganic Electrolyte Reserve Battery,	WPAPL,	Eagle-Picher,
c. The Studies of the Lithium Electrode in Oxychloride Solvents	WPAPL,	Eagle-Picher,

d. Electrically Rechargeable Lithium Battery,	ERADCOM,	EIC,
e. Lithium Inorganic Electrolyte Battery,	WPWAL,	GTE,
f. Investigation of the Safety of Lithium-Thionyl,	ERADCOM,	EIC,
g. Lithium Anode in Oxyhalide Electrolytes,	ERADCOM,	GTE,
h. Improvement of Lithium-Inorganic Electrolyte Cells,	ERADCOM,	Internal,
i. Lithium-Thionyl Chloride Battery,	ERADCOM,	Internal,
j. Analysis of Pressure-Producing Reactions, in Li/SO_2 Cells,	ERADCOM,	Mallory,
k. Lithium-Water-Air Battery for Automotive Propulsion,	DOE,	Lockheed,
l. Lithium-Air Battery Research,	DOE,	LLL,
m. Lithium/Metal Sulfide Battery Development,	DOE,	ANL,
n. Lithium Organic Batteries,	ERADCOM,	Mallory,
o. Hermetically Sealed Lithium Batteries,	ERADCOM,	Mallory,
p. Packaging of Lithium Reserve Power Supplies,	HDL,	Internal,
q. Rechargeable Lithium Systems,	ERADCOM,	Internal,
r. Lithium Reserve Battery for Mines,	NWSC,	Honeywell,

3.3 Material Technology

3.3.1 Materials Technology Development Requirements - Proper material selection for the Titan Probe depends on a combination of design requirements and environment. The mission drivers for the Titan Probe are identified as:

- o 10 years in space vacuum;
- o Contamination level limits;
- o 70°K Titan surface temperature;
- o Weight constraints.

3.3.1.1 Space Vacuum Effects - Nonmetallic materials are generally recognized as being susceptible to changes in their functional properties due to the long term vacuum exposure. Nonmetallic materials include sealants, potting compounds, lubricants, paints and finishes, inks, films, fabrics, encapsulants, elastomers, structural plastics, composites, ablatives, adhesives, seals, gasket materials, and electrical and thermal insulations. Changes in functional properties of these nonmetallics are due to the loss of plasticizers, binders, polymerizing agents, and catalysts when exposed to vacuum. This phenomenon is defined as outgassing. Weight loss due to outgassing is a function of temperature and exposure time.

Degradation in critical design properties or weight loss in any material, even if slow at normal operating conditions, can eventually lead to failure. Therefore, the 10-year mission life presents a major concern for proper material selection. Real-time tests of materials that may be used in a system can be impractical and expensive. If short-time tests can be used to predict future chemical and mechanical behavior, these tests could become a significant tool, thus, considerably enhancing mission success. Analytical techniques and accelerated test methods, predicting long-term space vacuum effects (Bibliography Item 3), have not been used with confidence because their validity has not been verified by comparison with long-term, real-time test data.

A definite relationship exists between chemical changes and physical properties (Bibliography Item 4,5,6). If systematically investigated, the relationship could be formulated and a rational accelerated test developed. From this, the eventual changes in mechanical properties could be predicted at any temperature by simply carrying out a Thermogravimetric Analysis (TGA) test. TGA is the continuous weighing of a sample while it is being heated at a fixed heating rate 10°K/min. During this process the sample continuously loses weight. The TGA data are typically presented in graphical form as shown in Figure 3-4, giving weight loss versus temperature. A second curve having ten times the sensitivity of the standard TGA curve is used to give an accurate display of the first 10% loss of weight. This will give details of the early portion of the decomposition, which may be of importance in determining low temperature degassing, water absorption, etc. The time for a certain percent weight loss at a given temperature can be calculated from TGA data.

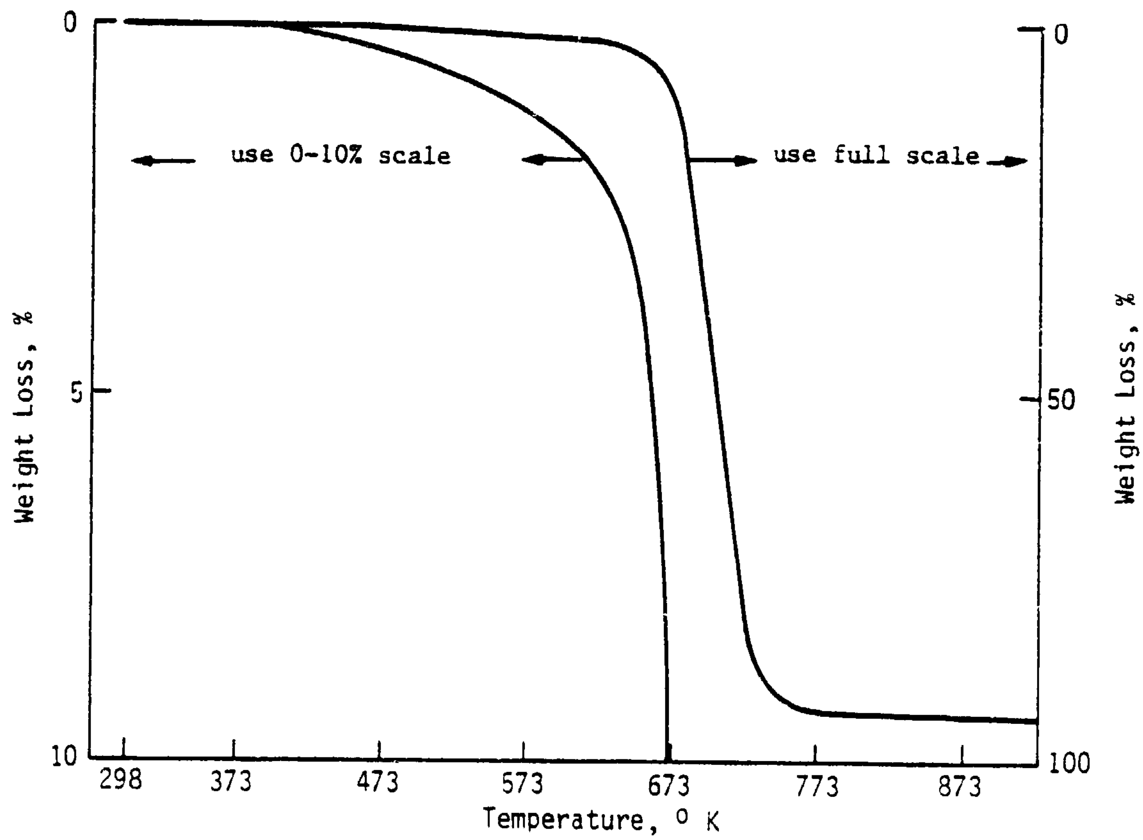

Figure 3-4 Thermogravimetric Analysis, in Vacuum, for Dacron Tape

Residual Gas Analysis (RGA) is a technique, using mass spectrometry, which qualitatively characterizes the volatile products as they are generated during the TGA test. When a volatilized molecule enters the ionization chamber of a mass spectrometer it is impacted by energetic (70-ev) electrons. The molecule is thereby fragmented into its characteristic mass spectrum, which is characterized by the mass-charge ratios and intensities.

Experiments were performed during the Viking Lander material evaluation (Bibiography item 1) data program, and the Table 3-2 is shown weight loss data for dacron fiber tape, at various temperatures in vacuum. The time for 1% weight loss were calculated from the TGA curves presented in Figure 3.4.

Table 3-2 Dacron Fabric Tape 1% Weight Loss Time

Temperature	Time in Hours
323°K(50°C)	2388.8
373°K(100°C)	116.6
423°K(150°C)	11.4

The 1 % weight loss time was adopted as Viking materials accept/reject criteria. Degradation in lap shear strength for film adhesive HT435 after thermal vacuum exposure is shown in Table 3-3. This table is a typical example of the effects of outgassing on the functional properties (Bibliography Item 2), where approximately 30 percent reduction in lap shear strength is experienced after 7 months of thermal vacuum exposure.

TABLE 3-3 Lap Shear Strength (ASTM D1002) For Film Adhesive HT 435

	Ultimate Strength Pa x 10^{-7}		
Exposure	High	Low	Average
Baseline	1.66	1.54	1.63
Heat Compatibility (1)	1.63	1.50	1.61
Heat Compatibility, 1 Month Thermal Vacuum (1) (2)	1.52	1.31	1.45
Heat Compatibility, 3 Months Thermal Vacuum (1) (3)	1.57	1.32	1.50
Heat Compatibility, 7 Months Thermal Vacuum (1) (4)	1.04	.90	1.13

Notes:

(1) Heat compatibility - 379 hours at 408°K (135°CO in N^2 atmosphere.

(2) Thermal vacuum - tested at 1 x 10^{-5} torr after 30 days at 338°K (65°C) and 1 x 10^{-6} torr.

(3) Same as Note (2), except exposure is 90 days.

(4) Same as Note (2), except exposure is 210 days.

3.3.1.2 Contamination level - Some of the decomposition (outgassing) products may lead to the contamination of optical surfaces or the gases may condense and contaminate samples of other scientific instruments. Such a decomposition product is defined as a Volatile Condensible Material (VCM) and identified in NASA document JSC-08962, List of VCM Materials based on short-term tests. To determine if the outgassing products from a material are condensible a small sample is placed in a vacuum furnace and the temperature is raised. The furnance is sealed except for a small orifice above which cooled Quartz Crystal Microbalance (QCMB) is located. The QCMB contains a goldplated quartz substrate cooled to 148°K. When the outgassing products condense, the condensation rate is monitored continuously until a constant deposition rate is established.

For the Viking Lander, an outgassing rate of $1x10\%^{-4}$ per day was regarded as the maximum allowed. Materials showing an outgassing rate greater than $1x10^{-4}$ % per day were not used. Acceptance criteria for the Titan Probe will have to be developed for each material as well as the total allowable contamination level for the probe.

3.3.1.3 Low Temperature - The surface temperature of Titan is estimated to be as low as 70°K. Most materials become brittle when exposed to such low temperatures. The major concern will be the drill bit material used in the surface sampling system. Figure 3-5 shows the degradation in impact strength as a function of decreasing temperature for a commonly used tool steel, H-11 (Bibliography Item 7).

It is anticipated that surface sample acquisition may require drilling hard rocks. The hardness of the rocks has not been established. The drill bit material has to be hard enough to drill these rocks and be sufficiently tough to withstand the drilling impact.

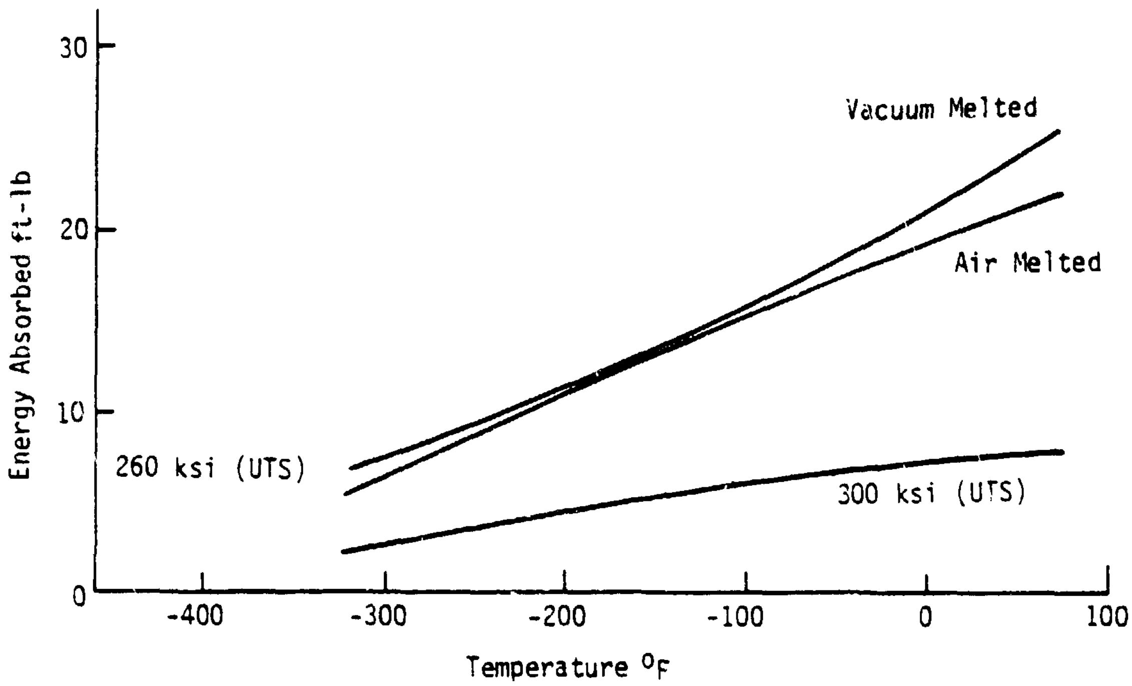

Figure 3-5 Impact Strength of H-11 (5% Cr) Steel Bars

Commonly used tool steels or carbides are not recommended for cryogenic applications due to their brittleness. Diamond impregnated tools have been investigated for lunar and Mars drilling operations; however, their applicability at 70°K for hard rock drilling was not evaluated. Some of the high strength steels such as 21-6-9, A286, or 18% Ni Maraging may have the required hardness and toughness for drilling on Titan but will have to be verified by simulated hard rock drilling tests.

Recent developments in ion implantation processes (Bibliography Item 8.9) can be used to improve the surface characteristics of commonly available tough materials. Ion implantation is a process whereby ions of a particular metal, such as chromium, can be implanted into the surface of a low alloy steel. The implanted surfaces have improved hardness and wear properties while the softer core of parent material provides greater toughness. Ion implanted low alloy steels capable of withstanding cryogenic environments could be ideal for the drill bit material.

3.3.1.4 Weight Constraints - It is desirable to make the Titan Probe as lightweight as possible within the design requirements. One way is to use lightweight materials such as metal matrix composites (MMCs). MMCs are fiber or particulate reinforced metallic structures, such as, graphite/aluminum (Gr/Al), graphite/magnesium (Gr/Mg) and Silicon carbide/aluminum (SiC/Al). Recent Air Force (Bibliography Item 10-13) studies have determined MMCs to be ideal material for space applications. They are stable in vacuum and possess high stiffness-to-weight ratios. Advantages of MMCs over organic matrix composites are listed in Table 3-4. A summary of a study (Bibliography Item 10), performed by Rockwell/Air Force on the P80-1 spacecraft, is presented in Table 3-5. The various components fabricated as conventional metallic structures, organic matrix composites and metal matrix composites were evaluated. The table shows that the MMCs offered the maximum weight savings and can be used to reduce the structural weight by as much as 44%.

3.3.2 Materials Technology Status - Literature searches were conducted through the Defense Technical Information Center and NASA literature search systems. In addition, various government agencies and private industries involved in similar studies were also contacted. A qualatative summary of results of this search are listed in Table 3-6. Each item was given a rating of 1, 2 or 3 depending on the data availability.

TABLE 3-4 Advantages of Metal Matrix Composites Over Organic Matrix Composites

1. High specific strength, stiffness and shear strength; improved transverse properties, higher strength-to-weight ratio.
2. Higher impact resistance, resistance to FOD.
3. Resistance to compressive buckling and Off-Axis Loading.
4. Resistance to Fatigue Spectrum Loading.
5. Higher interlaminar strength.
6. Higher thermal and electrical conductivity.
7. Low thermal expansion coefficient in fiber direction (near zero for Gr/Mg); dimensional stability over wide range of temperature.
8. High and low temperature capability (600°F to -300°F).
9. No moisture absorption.
10. No outgassing (freedom from contamination in vacuum).
11. Resistance to thermal cycling.
12. Resistance to laser, radiation and lightning damage.
13. Environmental resistance, impermeable to gases.
14. Erosion resistance.
15. Can be used in oxygen atmosphere.
16. Packing efficiency for Space Transport System.
17. Sheet metal fabrication technology applicable - joining, forming, machining, etc.

TABLE 3-5 *Shell Weight Comparison P80-1 Spacecraft

REGION	Baseline AL7075-T6	Metal Matrix			Graphite Epoxy GR/EP
		Graphite Aluminum GR/AL	Graphite Magnesium GR/MG	Silicon Carbide Aluminum SIC/AL	
Motor Support Cone	22.23	12.61	11.52	14.70	13.88
OIS Support Cone	31.30	18.05	16.06	19.69	18.60
Cylinder	6.44	4.04	3.86	4.72	4.40
Motor Support Cone	3.00	1.81	1.72	2.27	2.13
Spacecraft Thrust Cylinder	16.05	9.98	8.98	11.70	10.02
% Reduction	0	38	44	27	38

* Weight in kilograms

Data Extracted from Table 9, AFML-TR-78-38, Rockwell International.

Table 3-6 Results of Data Base Literature Search

Parameter	Rating*
1. Space Vacuum Effects on Non-Metallics	
a. Short Term (Less than 2 Years)	2
b. Long Term (Greater than 2 Years)	3
2. Contamination - Outgassing Rate	3
3. Cyrogenic Application	
a. Drill Bit Material	3
b. Sealants, Gaskets	1
4. Metal Matrix Composites (Gr/Al, Gr/Mg, SiC/Al)	
a. Mechanical Properties	1
b. Vacuum Effects	2
c. Forming, Joining	2
d. Non Destructive Investigation Techniques	2
e. Space Application Studies	1

* 1 = Significant data available; only verification of the existing data required.

* 2 = Limited data available; some development work is required.

* 3 = Technology gap; extensive development work is needed.

These ratings are strictly judgemental, based on the number of pertinent documents received and their direct application with the Titan Probe materials technology requirements. The current activities in each area were given major consideration. Details of the status assessment for each materials area are discussed separately in following sections.

3.3.2.1 Space Vacuum Effects - Forty-three document descriptors and abstracts were received and reviewed; only ten of these documents (Bibliography Items 1, 2, 14-21) discussed materials applications in vacuum to any extent. Only one document, "Non-Metallic Handbook" (Bibliography Item 1) has systematically evaluated material properties for space applications.

3.3.2.1.1 Nonmetallic Properties Data - The "Nonmetallic Handbook" was prepared by Martin Marietta Corporation for NASA-LRC on the Viking Project. Baseline values of the critical design properties for over 300 nonmetallic materials were evaluated and additional samples were then subjected to thermal-vacuum exposures ranging from 1 to 14 months. Property determinations were made, in situ, for some materials at intervals of 1, 3, 6 or 14 months to determine the influence of thermal vacuum on the performance of each material. During the course of the program, changes in technical direction eliminated or modified some qualification tests, therefore, not all materials reported had the same property tested or same thermal-vacuum exposure time. All information presented contained thermochemical data showing degradation as a function of temperature from room temperature through 500°C. These data include activation energies for thermal degradation, rate constants, and exo- and/or endo-therms. Also included were results of thermal degradation spectral data taken simultaneously during decomposition. Many materials also have data on condensation rates of decomposition products and isothermal weight losses.

3.3.2.1.2 Current Activity - At the conclusion of the Viking material qualification program, many samples of nonmetallic materials were left in the thermal-vacuum exposure containers. Presently Martin Marietta Corporation is under contract to NASA-MSFC (Contract No. NAS8-33578) to test some of these materials in vacuum as shown in Table 3-7. The type of tests being performed are shown in Table 3-8

Current activities regarding space vacuum effects on the lubricants are discussed in the following section.

3.3.2.1.3 Analytical Techniques - An effort was made (Bibliography Item 5) to predict the degradation kinetics of polymer systems at moderate temperatures from high-temperature TGA measurements. At moderate or low temperatures, thermal degradation of a polymer might be very slow; even so, it could still lead to failure. At high temperatures the degradation kinetics are rapid and can be studied in as short a time as 1 hour by TGA techniques. The TGA results are then extrapolated to much lower temperatures. To obtain thermal degradation (as measured by weight loss) at normal use temperatures the following first order kinetic equation is used

Table 3-7 Testing Required for Long Term Thermal/Vacuum Exposure Specimens

Material	Generic Type	No. of Specimens	Type Specimen	Exposure Time (Months)*	Conditioning Temperature °F	Test Method
F411 Lacing Cord	Polytetrafluoroethylene	3	Knot Strength	107	Ambient	CCC-T-191
F411 Lacing Cord	Ethylene/Glass Tape	3	Tensile Strength	107	Ambient	CCC-T-191
Kapton H	Polymide	5	Tear (Machined Direction)	106	150	D-1938
Adlock 851	Phenolic Glass Prepreg.	5	Tensile Strength	106	120	D-638
Adlock 851	Phenolic Glass Prepreg.	5	Flexural Strength	106	120	D-790
Adlock 851	Phenolic Glass Prepreg.	5	Compressive Strength	106	120	D-695
Adlock 851	Phenolic Glass Prepreg.	5	Bearing Strength	106	120	FTMS 406
Adlock 851	Phenolic Glass Prepreg.	3	Interlaminar Shear	104	120	M1051
EA 934	Epoxy Adhesive	5	Tensile Shear	104	150	D-1002
EA 934	Epoxy Adhesive	5	180° Peel	104	150	D-903
EC 2216		5	180° Peel	104	150	D-903
Scotchweld 2216		5	Tensile Shear	104	150	D-1002
Bioshield	Polyimide Film - Glass Cloth Laminate	5	Tension, Membrane	120	120	D-882
Bioshield	Polyimide Film - Glass Cloth Laminate	5	Tension, Splice	120	120	D-882
FM-96U	Adhesive, Film	10	Lap Shear	102	150	ASTM D-1002
HT424	Adhesive, Film	10	Lap Shear	102	150	ASTM D-1002
HT435	Adhesive, Film	10	Lap Shear	102	150	ASTM D-1002
Vespel SP-1	Polyimide Sheet	5	Tensile Strength Elongation	105	150	ASTM D-638
Vespel SP-1	Polyimide Sheet	5	Flexural Strength	105	150	D-790
Vespel SP-1	Polyimide Sheet	5	Hardness	105	150	D-785
Vespel SP-1	Polyimide Sheet	5	Dielective Strength	105	150	D-149
Flat Gray Silicone Coating	Silicone Thermal Control Coating	5	Emittance	103	150	Tion Emis.

* As of May 1980.

Table 3-7 Testing Required for Long Term Thermal/Vacuum Exposure Specimens (cont)

Material	Generic Type	No. of Specimens	Type Specimen	Exposure Time (Months)	Conditioning Temperature °F	Test Method
Hysol C7-4248	Epoxy Impregnant	4	Compresion Strength	103	150	D-695
Hysol C7-4248	Epoxy Impregnant	3	Dielectric Strength	103	150	D-149
Hysol C7-4248	Epoxy Impregnant	4	Dielectric Constant	103	150	D-150
Choseal 1224	RFI Gasket	3	Resistivity	102	150	V71/120P
Choseal 1224	RFI Gasket	3	Compression Set	102	150	ASTM D-395
Choseal 1236	RFI Gasket	3	Resistivity	102	150	V71/120P
Choseal 1236	RFI Gasket	3	Compression Set	102	150	ASTM D-395
DC-93-500	Silicone Encapsulant	3	Dielectric Constant	102	150	ASTM D-150-68
DC-93-500	Silicone Encapsulant	4	Dielectric Strength	102	150	D-149
Solithane 113	Polyurethane Conformal Coating	5	Insulation Resistance	105	Ambient	D-257
DC-92-007		1	Absorptance	104	Ambient	
RTV-511		1	Absorptance	104	Ambient	
Kapton F 919	Polymide Film	5	Tensile	104	150	D-882
Kapton F 919	Polymide Film	5	Abrasion	104	150	D-1175
Kapton F 919	Polymide Film	5	Surface & Volume Resistivity	104	150	D-149
Kapton F 011	Polymide Film	5	Tensile	104	150	D-882
Kapton F 011	Polymide Film	5	Abrasion	104	150	D-1175
Kapton F 011	Polymide Film	5	Dielectric Strength	104	150	D-149
Kapton F 011	Polymide Film	5	Surface & Volume Resistivity	104	150	D-257
Vespel SP-1	Polymide Sheet	3	Surface & Volume Resistivity	105	150	D-257
Vespel SP-1	Polymide Sheet	3	Dielectric Constant & Loss Tangent	105	150	D-150

Table 3-7 Testing Required for Long Term Thermal/Vacuum Exposure Specimens (concl)

Material	Generic Type	No. of Specimens	Type Specimen	Exposure Time (Months)	Conditioning Temperature °F	Test Method
Solithane 113 with Cat C113-300	Polurethane Conformal Coating	5	Adhesion to Substrate	106	Ambient	FTMS 6304.1
Solithane 113 with Cat C113-300	Polurethane Conformal Coating	5	Flexibility	106	Ambient	FTMS 141,622
Solithane 113 with Cat C113-300	Polurethane Conformal Coating	5	Bond Strentth	106	Ambient	ASTM D-1002
Kapton H	Polyimide Film	5	Tensile (Transverse)	106	150	ASTM D-882
Kapton H	Polyimide Film	5	Tensile (Machined Direction)	106	150	ASTM D-882
Kapton H	Polyimide Film	3	Dimensional	106	150	ASTM D-1204
Kapton H	Polyimide Film	10	Tear (Transverse Direction)	106	150	ASTM D-1938
Ecco Foam FPH	Polyurethane Foam Encapsulant	3	Compression Strength	103	150	D-1621
Ecco Foam FPH	Polyurethane Foam Encapsulant	3	Dielectric Constant	103	150	D-1673
Ecco Foam FPH	Polyurethane Foam Encapsulant	3	Dielectric Constant Strength	103	150	D-149
Stycast 2850 ft With Cat. 11	Epoxy Encapsulant	3	Dielectric Constant	103	150	D-150
Gloss Grey Silicone Coating	Silicone Thermal Control Coating	5	Emittance	103	150	Lion Emis.

Table 3-8 Test Categories

Mechanical	Electrical	Optical
Compression Strength	Dielectric Strength	Absorptance
Compression Set	Dielectric Constant	Emittance
Tension	Resistivity	
Flexure	Insulation Resistance	
Bend Strength	Surface and Volume	
Tear Strength	Resistivity	
180° Peel Strength		
Adhesion		
Abrasion		
Dimensional Stability		

$$K_T = \frac{dx/dt}{(a_o - x)} \qquad (1)$$

where: K_T is the rate constant at temperature T

dx/dt is the rate of weight loss,

x is the weight loss,

a_o is the initial amount of the "active component".

The active component is the portion of the original weight that participates in decomposition.

TGA data is used to experimentally determine dx/dt, x and a_o. The rate constant is given by the Arrhenius relationship

$$K = A \exp\left(\frac{-\Delta E}{RT}\right) \text{ time}^{-1} \qquad (2)$$

where: A is a constant,

R is the universal gas constant,

T is the absolute temperature,

E is the activation energy of the decomposition process.

Rate constants can be determined experimentally at several temperatures. The slope of the Arrhenius plot of K vs. 1/T will yield the activation energy.

To calculate the time to obtain x, the weight loss, at a given temperature, equation (1) is integrated to yield

$$a_o - x = a_o e^{-Kt} \qquad (3)$$

where: t is time.

Rewriting equation (3) gives the fraction of a_o remaining after time, t.

$$\frac{a_o - x}{a_o} = e^{-Kt}$$

Therefore:

$$\%\ \text{weight loss} = 1 - e^{-Kt} \times 100\% \qquad (4)$$

TGA data results in remarkably accurate predictions using the above technique. However, not enough data points for low temperature isothermal decomposition were taken. To have confidence in the above analytical technique more experimental data points are required. Once the technique is properly developed, accelerated test methods as a function of temperature and sample weight could also be devised.

At present Martin Marietta is applying the above technique in the work being performed under NASA Contract NAS8-33578. However, this data will not be completely effective for Titan Probe use since periodic time intervals of data are not being made; instead only the beginning and end points will be tested.

3.3.2.1.4 Mechanical Properties - Thermal Degradation Relationship - It has been established from uniaxial tension and creep-to-failure studies that time and temperature dependence of the strength of polymer in air can be expressed by

$$t = t_o \exp\left(\frac{U_o - \gamma\delta}{KT}\right)$$

where:

- t is time to failure,
- T is the absolute temperature,
- U_o is the activation energy in the absence of stress,
- γ, δ, t_o, and K are constants.

Whether the same time and temperature dependence is valid in a thermal-vacuum environment is open to debate (Bibliography Items 4,5). Bartenev and Zuyer state that the time dependence of the strength of these materials under vacuum and air is the same. Papazian, however, does not think so. In a thermal-vacuum environment the activation becomes independent of the work done on the system. This nonstress-dependent activation energy was found to be very near the activation energy of thermal decomposition in vacuum.

These results suggest there may be a correlation between thermal degradation and mechanical properties. A systematic experimental and analytical investigation is required to formulate the proper relationship.

At present, no work is being performed to correlate the thermal degradation and mechanical properties in thermal-vacuum.

3.3.2.2 Lubricants - Lubricants for space applications have been the subject of research and development for many years. Approximately 45 documents related to this subject were received from the literature search and screened on the basis of abstracts. Thirteen documents (Bibliography Items 22-34) were relevant to the application requirements of Titan Probe. Even though extensive research has been conducted there is no data available regarding long term in affects space vacuum.

Currently, NASA-MSFC is conducting a study entitled "An Evaluation of Grease Type Ball Bearing Lubricants Operating in Various Environments", wherein 33 lubricants were evaluated in five different environments for a 1 year period. The evaluation tests included hours-to-failure, or 1 year maximum, and percent weight loss in vacuum. Results of the vacuum tests are presented in Table 3-9. Based on these results four lubricants; PFPE-1, PFPE-2, M-3 and Si-2; were selected for further evaluation in vacuum for a period of five years. The conclusion of the study was, ". . . as a whole, the chemical class PFPE (Perfluoroalkyl polyether) has given the best performance in all the vacuum tests completed to date."

Table 3-9 Results of Lubricants in Vacuum Tests at 38°C

	Hours to Failure*					Weight Loss (%)**				
Lubricant	1	2	3	4	Average	1	2	3	4	Average
PFPE-2	8760	8760	8760	8760	8760	5	7	8.5	5	6.5
Si-2	8760	8760	8760	8760	8760	3.5	12	6	4.5	6.5
M-5	8760	8760	8760	8760	8760	7.5	5	8	6.5	6.8
PFPE-6	8760	8760	8760	8760	8760	6	13.5	12.5	7	9.8
M-3	8760	8760	t	8760	8760	6	13	12	8.5	10
PFPE-3	8760	8760	8760	8760	8760	10	15.5	8.5	8	10.5
FS-2	8760	8760	8760	8760	8760	7	21	17.5	11.5	14
PFPE-1	8760	8760	8760	8760	8760	10.5	33	15	17	19
M-10	8760	8760	8760	8760	8760	26	20.5	19	23	22.1
M-2	8760	8760	8760	8760	8760	66	49	39	50	51
M-1	8760	8760	8760	8760	8760	21.5	27.5	23	25	24
Si-1	8760	8760	1709	8760	6997	35	25	41	22.5	31
PFPE-4	684	8760	8760	8760	6741	26	11.5	13	9	15
ES-1	3524	8760	8437	4397	6280	24.5	39.5	23.5	18.5	26.5
M-7	2530	8760	8760	3367	5854	53.5	47	54.5	42	49.5
PFPE-5	2096	3517	8760	8760	5783	33.5	40.5	3.5	3.5	20.3
Si-X	1041	6015	8760	5710	5382	27.5	28	40	47.5	36
M-8	392	8760	8524	1976	4913	3.3	0.8	0.8	11.3	4.0
M-9	2543	1487	1199	8760	3497	34.5	27.5	49.5	24.5	34
Si-3	5613	2164	1659	456	2473	52.5	27	43.5	24.5	36.9
M-4	2671	859	311	160	1000	74.5	73.5	82	78	77
ES-2	427	696	743	911	694	61.5	56	72.5	62	63.5
ES-4	559	593	559	823	634	30.5	37.5	39	41	35.5
FS-1	174	245	831	511	440	7.5	14.5	22.5	15.5	15
M-6	473	219	336	286	329	67	76	68.5	70.5	70.5

* Or to end of test (1 year = 8760 hr).

** Percent of Weight loss of total weight of grease added to the two bearings of each motor (motor Nos. 1 through 4).

t Drive motor failed.

Based on the NASA-MSFC studies, it is recommended that PFPE-2, which is manufactured by Bray Oil Company under the designation of 3L-38RP, be evaluated for Titan Probe applications.

Martin Marietta Corportion evaluated Apiezon H, Dow Corning C-6-1103 and graphite lubricants for the Viking lander program. Apiezon H is a hydrocarbon type lubricant and Dow Corning C-6-1103 is a silicon-based compound treated to reduce volatile content.

Apiezon C has been extensively evaluated by Aerospace Corporation (Bibliography Items 26,27) for space application stored in Nylasint or micro-well reservoirs. It is not certain at this stage that a lubricant reservoir system, which can continuously supply the required lubricant over a long period; is necessary for Titan Probe applications. However, if no satisfactory lubricant is found, the reservoir technique could provide a suitable system.

Ball Brothers Research Corporation (Bibliography Item 23) has developed both liquid and dry lubricants for space applications including all the NASA Orbiting Solar Observatories (OSO). OSO-5 performed for 6 years, liquid VAC-KOTE 36194 and 37981 were used on British project SKYNET 'A' which lasted for 9.4 years. Although VAC-KOTE lubricants have been used successfully for space programs their percent weight loss in vacuum as a function of time and volatile materials content have not been defined. Ball Brothers has a continuing in-house program to evaluate VAC-KOTE lubricants for long-term space applications.

Martin Marietta Corporation used graphite lubricants N-366 and N-367 on the Viking project (Bibliography Item 37) for the Gas Chromatograph Mass Spectrometer (GCMS) science instruments. The system had stringent contamination requirements, and could not tolerate either organic materials or molybdenum disulfide (MoS_2) dry film lubricants. Graphite is an inert, non-outgassing material that performed satisfactorily for the Viking GCMS system.

In summary, there are continuing research and development activities in the field of lubrication technology as applied to spacecraft. There is a need; however, for a systematic investigation to accurately characterize the 10-year space vacuum effects on the lubricants and component performances and to define and analyze the percent weight loss as a function of time, decomposition products, volatile condensible materials and contamination hazards.

The following lubricants are recommended for evaluation:

- Liquid Lubricants
  1. PFPE-3 (3L-38-RP)
  2. Apiezon C and H
  3. VAC-KOTE
  4. C-6-1103

- Dry Lubricants
  1. VAC-KOTE
  2. Graphites (N-366, N-367)

3.3.2.3 Drill Bit Material - The literature search produced 173 documents related to the subjet of rock drilling. Fourteen documents (Bibliography Items 38-50) were critically reviewed. There were various mateials used in these studies including gem and industrial quality diamond bits (Bibliography Item 39) for lunar drilling. Tungsten, cobalt and molybdenum tool steels have been evaluated for permafrost drillings. Austenitic manganese steels have also been used for cryogenic applications. There is a wide variety of proven materials available: however, evaluation of these materials will require an estimate of the hardness of the Titan rocks.

No work is presently being performed that can be directly used for the Titan Probe drill bit. The present work on ion implantation to improve bit surface hardness and wear properties is directed toward ambient or elevated temperature applications. Their suitability at $70^{o}K$ will have to be evaluated.

3.3.2.4 Metal Matrix Composites - The key terms used for this literature search were Aluminum Matrix Composites, Metal Matrix Composites and Titanium Matrix Composites. Descriptors for 124 documents were received and studied. Eleven documents (Bibliography Items 10-13, 51-57) were critically reviewed.

Currently there are many on-going activities to evaluate Metal Matrix Composites (MMC) in spacecraft applications. One of the studies, "Development of Graphite/Metal Advanced Composites for Spacecraft Applications" (Bibliography Item 13) is being performed by Lockheed Missiles and Space Company under Air Force Contract F33615-78-C-5235. The study consists of material development work, data generation, preliminary design, design development, fabrication technique developemnt and component/subcomponent testing necessary to establish firm performance predictions for graphite/magnesium and graphite/aluminum metal matrix composite spacecraft components.

Rockwell International Corporation has recently concluded a study, "Satellite Applications of Metal Matrix Composites" (Bibliography Item 10) for the Air Force. Various components were considered from space programs such as; the P80-1 spacecraft, the Global Positioning System Satellite, the ADOPT Satellite System, and the HALO Vehicle System. In most cases MMCs were proven to be the best materials choice. (The results on the P80-1 spacecraft study are presented in Table 3-5.)

Hughes Aircraft Company (Bibliography Item 12) evaluated physical properties, availability, cost and workability of various MMCs. Finally, three components, a Syncom IV satellite equipment mounting shelf, a

D-band planar array antenna and a telescope mirror were fabriated from MMC and critically tested. The study showed that MMC provides significant advantages over conventional construction materials for selected satellite components.

The literature search concluded that significant mechanical properties data are available; however, not enough data are available regarding long-term vacuum effects, contamination, fabrication technology and nondestructive inspection techniques.

3.3.3 Materials Technology Development Plan

3.3.3.1 Nonmetallic Materials - Nonmetallic materials currently being evaluated by Martin Marietta Corporation for NASA-MSFC will provide a base for Titan Probe materials technology development plan for the nonmetallic materials (excluding lubricants). The nonmetallic materials include; sealants, potting compounds, paints and finishes, inks, films, fabrics, encapsulants, elastomers, structural plastics, ablatives, adhesives, electrical and thermal insulations.

The objective of this part of the plan is to establish the degradation in critical design properties when exposed to space vacuum for 10 years. Vacuum effects will be studied by established techniques of Thermogravimetric Analysis (TGA), Residual Gas Analysis (RGA) and Quartz Crystal Microbalance (QCMB).

The steps required to carry out the proposed plan involve:

- Selection of candidate materials;
- Determination of isothermal weight loss in vacuum for the selected materials;
- Determination of outgassing rate and contamination characteristics;

- o Evaluation of long-term space vacuum effects on critical design properties.
- o Development of analytical techniques to predict long-term effects based on short-term experimental data.
- o Formulation of relationship between chemical changes and physical properties.

The determination of acceptance criteria for the contamination level of the Titan Probe materials will involve the following:

- o Determination of condensible degassing rates.
- o Estimation of contamination levels from the condensible degassing rates.
- o Prediction of long-term outgassing behaviour from short-term experimental data.

The critical material properties to be tested, along with the required conditioning and environments, are listed in Table 3-10.

Implementation of this long term effects plan for nonmetallic materials will take at least 3 years to complete. The rough order of magnitude cost is estimated to be $250 thousand.

3.3.3.2 Lubricants - The technology development plan for lubricants will be performed using the same steps described for nonmetallic materials. The critical properties to be evaluated are shown in Table 3-11. The most important test in this evaluation process is the assembly test. Assemblies simulating Titan Probe applications are tested in vacuum and hours-to-failure, or maximum life will be recorded.

The recommended plan for lubricants will take at least 3.5 years and the rough order of magnitude cost is estimated to be $200 thousand.

TABLE 3-10 Nonmetallics and Adhesives - Test Matrix

Test Identification	Preconditioning Environment					Test Environment		
	Ambient	Heat Sterilization	Thermal Cycling	Thermal Vacuum	Aging	Ambient	In-Situ Vacuum	Titan Environment
I. Mechanical Properties								
Tensile Shear	X	X	X	X	X	X	X	X
Flexture	X	X	X	X	X	X	X	X
Peel (180o)	X	X	X	X	X	X	X	X
Creep Rupture	X	X	X	X	X	X	X	X
Fatigue Strength	X	X	X	X	X	X	X	X
II. Standard Adherence	X	X		X				X
III. Electrical Properties								
Dielectric Strength	X	X		X		X	X	X
Surface Volume and Resistivity	X	X			X	X		
Dielectric Constant and Loss Factor	X	X		X	X	X		
Corona Initialization Voltage		X		X				X
IV. Thermal Properties								
Thermal Conductivity	X	X				X		
Coefficient of Thermal Expansion	X	X				X		
V. Chemical Characterization								
Isothermal Weight Loss	X	X					X	
TGA, DTA, RGA	X	X					X	

Table 3-11 Lubricating Materials - Test Matrix

Test Identification	Test Evnironment	
	Ambient	Thermal Vacuum
I. Mechanical Properties		
o Compressive Strength	X	X
o Creep (Stress Relief)	X	X
o Coefficient of Friction	X	X
II. Chemical Characterization		
o Isothermal Weight Loss	X	X
o TGA, RGA,	X	X
o Corrosion Characteristics	X	X
III. Thermal Properties		
o Thermal Conductivity	X	X
o Coefficient of Thermal Expansion	X	X
o Specific Heat	X	X
IV. Assembly Test	X	X

3.3.3.3 Drill Bit Material - The objective of this technology development plan is to find material suitable for hard rock drilling at 70°K. The steps to accomplish the objectives are:

- Selection of candidate materials.
- Evaluation of impact strength and hardness at ambient and 70°K temperatures.
- Simulation test of rock drilling at 70°K.

The impact strength and hardness of the candidate material will be determined at 70°K. The successful materials will then be tested by simulating the actual rock drilling operation. Table 3-12 shows the test parameters and environments for each test that is required.

TABLE 3-12 Sampler Drill Bit Material - Test Matrix

	Test Environment		
Test Identification	Ambient	70°K	Titan Environment
Impact Strength	X	X	X
Hardness	X	X	X
Simulated Rock Drilling Test	X		X

This technology development of the drill material will take approximately 1.5 years to complete and should be completed in time to start the Sample Drill Technology plan described in the Sample Acquition section. The rough order of magnitude cost is estimated at $90 thousand.

3.3.3.4 Metal Matrix Composites - As discussed earlier, mechanical properties data for the selected MMCs (i.e, graphite/magnesium, graphite/aluminum and silicon carbide/aluminum) is very well established. The primary objective of this plan is to fully evaluate the vacuum stability and other Titan Probe application related properties. The items required to accomplish this knowledge development are the same as listed for the nonmetallic materials. The critical material properties to be tested, as well as the and test environments, are presented in Table 3-13.

The metal matrix composites development, for Titan Probe application will take approximately 3.5 years to complete and the rough order of magnitude cost is estimated at $200 thousand.

Table 3-13 Test Matrix For Metal Matrix Composites

	Test Environment		
Test Identification	Ambient	Thermal-Vacuum	Heat Sterilization
Tensile Strength & Modulus	X	X	X
Compressive Strength & Modulus	X	X	X
Flexture Strength & Modulus	X	X	X
Bearing Strength & Modulus	X	X	X
Inter Laminar Shear	X	X	X
Thermal Conductivity	X	X	X
Coefficient of Thermal Expansion	X	X	X
Solvent Compatibility	X	X	X
Moisture Absorption	X	X	X
Chemical Characterization a) TGA, RGA, in Vacuum b) Isothermal Weight		X	
Emittance	X		

3.3.4 Bibliography - Materials

The data sources identified and evaluated in the materials study are listed below:

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3.4 Magnetic Bubble Memories (MBM)

3.4.1 MBM Technology Development Required - The previous Pre-Phase A feasibility study traded-off the various storage devices and determined the MBM as the viable device for the Titan Probe mission. The requirements for data storage were identified as:

- 1×10^6 Bits - Class B Probe
- 14×10^6 Bits - Class C Probe

Tradeoff studies show that the MBM (compared to the tape recorder type storage devices) have a greater potential of surviving for 10 years in space. Tape recorders have mechanical moving parts which make them susceptible to long-life problems, as well as wearout. The MBMs, in comparison to solid state devices, are preferable since their memory is nonvolatile, whereas the CMOS and I^2L devices need power to maintain their memory.

The mission conditions to be assessed for the Titan Probe are:

- Ionization radiation,
- Sterilization temperatures,
- 300-g shock,
- 10-year dormant life in space vacuum.

3.4.2 MBM Technology Status - MBMs are relatively new and no history of space usage is available. The MBMs presently on the market are intended for commerical use and are available over the operating temperature range of -10°C to +70°C. Maximum extension of this range is expected to encompass -50°C to +100°C within the next several years.

The approach taken to obtain information consisted of a telephone survey of persons knowledgeable in the areas of MBMs. Both suppliers and potential users were contacted (see contact list in Section 3.4.4). The telephone survey was followed with an industry-wide data search for published papers that could possibly contain information pertinent to the above environments.

3.4.2.1 Ionizing Radiation - Telephone discussions with people knowledgeable in space radiation environments and effects on piece parts were conducted. Persons at Rome Air Development Center (RADC), Jet Propulsion Labs (JPL), Rockwell International, and the Aerospace Corporation were contacted. Results of these discussions indicated that MBMs are relatively insensitive to the levels of radiation normally encounted in space environments.

MBMs will be at least as tolerant of space radiation environments standard piece parts such as resistors, capacitors, and semiconductors.

Literature regarding space radiation-hardness of MBMs substantiates the above results. Recent interest has centered upon nuclear radiation-effects and survivability. Several tests have been reported in the IEEE Transactions on Nuclear Science. One paper (Bibliography Item 2), "Radiation Tolerance of Bubble - Domain Materials and Devices," published in 1973, reports no significant degradation of a variety of magnetic film types at radiation levels up to 5×10^7 rads. This radiation level is approximately three orders of magnitude higher than the levels anticipated for the Titan mission and demonstrates that MBMs can tolerate the mission radiation environment.

3.4.2.2 Sterilization Temperature - Assuming the sterilization bake will be similar to the Viking Lander requirement, a temperature of 130°C to 150°C can be expected. The length of the bake may be as long as 72 hours. Telephone discussions with knowledgeable persons provided insufficient information or data that could be used to evaluate the anticipated time-temperature effects on MBMs. In general, most persons contacted had no information regarding the effects of the high temperature bakes. Only Intel Reliability Report RR-22 indicated that ten type 7110, one Megabit MBMs, were exposed to 150°C for 168 hours without experiencing failures.

Discussions with contacts (Bibliography Item 16) at Rockwell, Texas Instruments, and Western Electric indicate all three have concerns about the effects of high temperature on their units. All indicated that scrambling of the memory contents could occur. Also, all were concerned as to what effect the temperature would have on the permanent magnets used to supply the Z-field magnetization. Concerns were expressed that the level of magnetization would shift to the point where the memory functions would be affected or would not operate reliably. Setting of the magnetic field prior to assembly is required to assure reliable operation. Extreme temperatures are used to form the garnet film; the persons contacted, therefore, prognosticated that the films would not be seriously effected or degraded as a result of the sterilization bake.

3.4.2.3 <u>300g Shock</u> - Information was received from Texas Instruments and Intel that they had performed shock testing on their MBMs at 300g's and 200g's respectively. No information was provided concerning the length of the shock pulses used in the test; nor is the pulse characteristic for the Titan Probe clearly defined. Therefore, no direct comparison could be made. Concern about the Titan Probe shock level on MBMs re[illegible] from the construction of the packages and due to the permanent ma[illegible] used therein. The packages are a much larger mass than standard [illegible]onic parts generally used in aerospace electronics, and would probably re[illegible] special consideration during packaging design.

Since magnetics are sensitive to high levels of shock, and the operation of MBMs is very dependent on the Z-level magnetic field, concern is expressed regarding the expected shock level and lack of information on existing MBMs. This concern is only an engineering concern and can probably be alleviated with special mounting techiques.

3.4.2.4 Dormancy Life - No information was obtained concerning the performance of MBMs after 10 years of dormant life. However, it should be noted that the packages for MBMs to date are generally molded plastic packages (Rockwell uses Hysol MH-19F-01). Packages reviewed indicate that the garnet film and field coils are molded together in a plastic encapsulent. The top and bottom of the packages are recessed to allow placement and alignment of the permanent magnets. The entire assembly is enclosed within a magnetic shield.

Review of the latest report on dormancy effects "Storage Reliability of Missile Material Progarm; Missile Material Reliability Prdiction Handbook, Parts Count Prediction", (Bibliography Item 2), and discussions with Maurice Bahan of the Redstone Arsenal, indicate that plastic encapsulated semiconductors have a higher failure rate than heremetically sealed units. Concern is expressed for MBMs since the construction techniques uses thin film aluminum conductors and wire bonding similar to semiconductors and integrated circuits. These construction techniques could be subject to degradation due to absorption of moisture. Future effort should be expected to improve the packaging technique to obtain hermetically sealed MBMs.

3.4.2.5 Current Program - Development of the MBM system is being worked by NASA-LRC/GSFC. Systems with capacity of 10^8 bits have been delivered by Rockwell. Initial problems have been solved and a followup program to develop a system, using IBM Bubble Lattice, with more than 10^7 bits/chip is being initiated. Results are anticipated in the 1985 time-frame.

Rockwell, Western Electric, and Intel are working to develop more efficient weight, power, and volume densities per bit of storage. These manufacturers are responding to RFPs from DOD Agencies to develop and deliver mass storage systems.

For the Titan Probe mission time-frame a high density MBM system will be available, with $14x10^6$ bits of storage. Controlling electronics can be expected to be reduced to below 1 kg of weight and less than 4 watts power consumption (this low power is achieved by strobing the system).

3.4.3 <u>Magnetic Bubble Memory Development</u> - Presently no data or information is available to assess the effects of high temperature sterilization requirements on MBMs. The concern is that the temperature may scramble the memory or cause long-term degradation. Similarly, there is a lack of data needed to predict long-term dormant life. A test program should be initiated on viable MBM candidate parts to provide this information. The test approach to be used should consist of a step-stress approach to determine if these concerns are justified and if so, to define threshold levels. The objective of the test program is to derive temperature-time relationships for both operating and non-operating conditions.

A typical test program would consist of performing at least two operating life tests at different elevated temperatures until 50% failures occur. Measurements would be conducted logarithmically in time. Another test would be performed by incremental increases of temperature for at least two different times until 50% failure was obtained. All data would be analyzed and presented in accordance with MIL-STD-883, method 1016. The above data would result in information that would predict the useful temperature ranges of operation and storage for the MBMs. Additionally, failure analysis of representative failures would be performed to identify and understand the physics of the degradation of parameters.

The test program consists of the following steps:

- Choose two candidates from available parts;
- Perform part anatomy analysis;
- Perform operating life test;
- Perform nonoperating test;
- Perform dormant storage test;
- Perform long life prediction.

This test plan is estimated to require a total time span of approximately 3 years. A rough order of magnitude cost estimate for this test procedure is $150 thousand and assumes that two MBM part types are evaluated. This evaluation ideally should be completed prior to the PDR milestone in the Concept-Validation phase (Phase B of the A-109 Acquisition Cycle) of the Titan Probe program.

3.4.4 BIBLIOGRAPHY - MAGNETIC BUBBLE MEMORY

The data sources identified and evaluated as part of this Magnetic Bubble Memory technology development study are listed below:

1. Notes on "Bubble Memory Seminar" at Stanford Univeristy (Lead by Dr. R. L. White); Phil Adams April 21, 1980.

2. Reliability Prediction Modeling of New Devices R. G. Long, M. Cohen : Arthur D. Little, Inc. February 1980

3. Intel Magnetics Reliability Report, RR-22, Sept. 1979.

4. Intel Magnetics Bubble Memory Design Handbook May 1979.

5. "Current-Access Magnetic-Bubble Circuits" A. H. Bobek et al. : The Bell System Technical Journal March 1979.

6. TIB0203 Magnetic Bubble Memory Systems Application Manual March 1979.

7. An Early, 1978, Seniconductor Memory Technology Survey J. E. Goodwin June 1978

8. Introduction to Magnetic Bubbles R. M. Gilbert : Harry Diamond Labs November 1975 (AD-A021 982)

9. Exploratory Developm,ent of Magnetic Bubble Domain Material for Application in Air Force Solid State Mass Memory Systems D. M.Heinz, et. al. : Rockwell International Corporation March 1975 (AD-A014 364), August 1973 (AD-775 715)

10. "Radiation Induced Mobility Changes In Bubble-Domain Materials," N. D. Wilsey & H. Lessoff: IEEE Trans. on Nuclear Science Dec, 1974.

11. Radiation Tolerance of Bubble-Domain Materials and Devices R. A. Williams, et al: IEEE Trans. on Nuclear Science Dec., 1973.

12. "Bubble Memory Characterization Study, Phase I" W. D. Williams NARC 78-175-50.

13. "Bubble Memory Device Characterization Study"
A. C. Gerhardstein
NADC 78-170-50.

14. Magnetic Bubble Error Correction Study
A. C. Gerhardstein
AFAL TR-79-1229.

15. Texas Instruments Reliability Report; Bulletin CA-200.

16. PERSONS CONTACTED

a. Stewart Cummins; Air Force Avionics Lab; (513) 225-5362.
Has contract to build & evaluate breadbond systems.

b. Pat Vail, Rome Air Development System; (617) 861-3047
Radiation Testing & Effets on MBM.

c. Ross Williams; Rockwell Int; (714) 632-1976
Radiation Testing on MBM

d. Bill Alexander; Texas Instruments; (214) 238-5195
MBM Capabilities and Reliability Testing

e. Garner Jones; Western Electric; (919) 697-6587
Reliability Data on MBM.

f. Al Karlin; Aerospace Corp; (213) 648-5527
General information on SAMSO interest in MBM

g. Patty Buchman; Aerospace Corp; (213) 648-5527
Radiation Effects on MBM.

h. Kamal Saliman; JPL; (213) 354-5622
Ratiation Effects on MBM.

i. Kevin Kennelly; JPL; (213) 354-5622
Ratiation Effects on MBM.

j. Jeff Love; Intel Corp., (303) 321-8086
Intel MBM Capabilities and Reliability Data.

k. Andy Elder; Rockwell Micro-electronics; (714) 623-3729
General information concerning status and capability of MBM.

l. Chuck Colabrese; Naval Air Research Center, (215) 441-2332
Temperature effects on MBM.

m. Tony Gerhardstein, Texas Instruments; (214) 980-6083
Information on magnet characteristics.

n. Burt Kahren; Texas Instruments; (214) 238-2872
Temperature effects and magnet characteristics.

o. Roy Sligh; Rockwell Autonetics; (714) 632-2180
Information on characterization testing of MBM.

APPENDIX A

APPENDIX A STUDY PROGRAMMATICS

A-1 Study Objectives

The objective of this study was to determine if technology advances are needed to accomplish the Titan Probe mission. If a technology advancement is required, then Technology Development Plans will be developed for those technology areas. The Statement of Work for the contract requires completion of the following tasks:

- o Define the technology advances required to permit a Titan Probe mission to be launched in 1989.

- o Define a technology development plan for each of the technologies found to be required.

The study was conducted using the schedule shown in Figure A-1.

A-2 Study Ground Rules

The study ground rules and assumptions were defined in the Contract Statement of Work and they were amended as a result of the kick off meeting of 6 November 1979. These rules and assumptions are:

- o Project start in fiscal year 1984, launch in 1989, and go into Saturn orbit in 1997. Assume 10 years in space for life considerations.

- o The Class B Probe is a hard lander that performs upper atmosphere, atmosphere, and surface science. The baseline is defined in the Pre-Phase A Study Report (MCR-79-518), "Study of Entry and Landing Probes for Exploration of Titan." This configuration is described in Section 3.0 of this report.

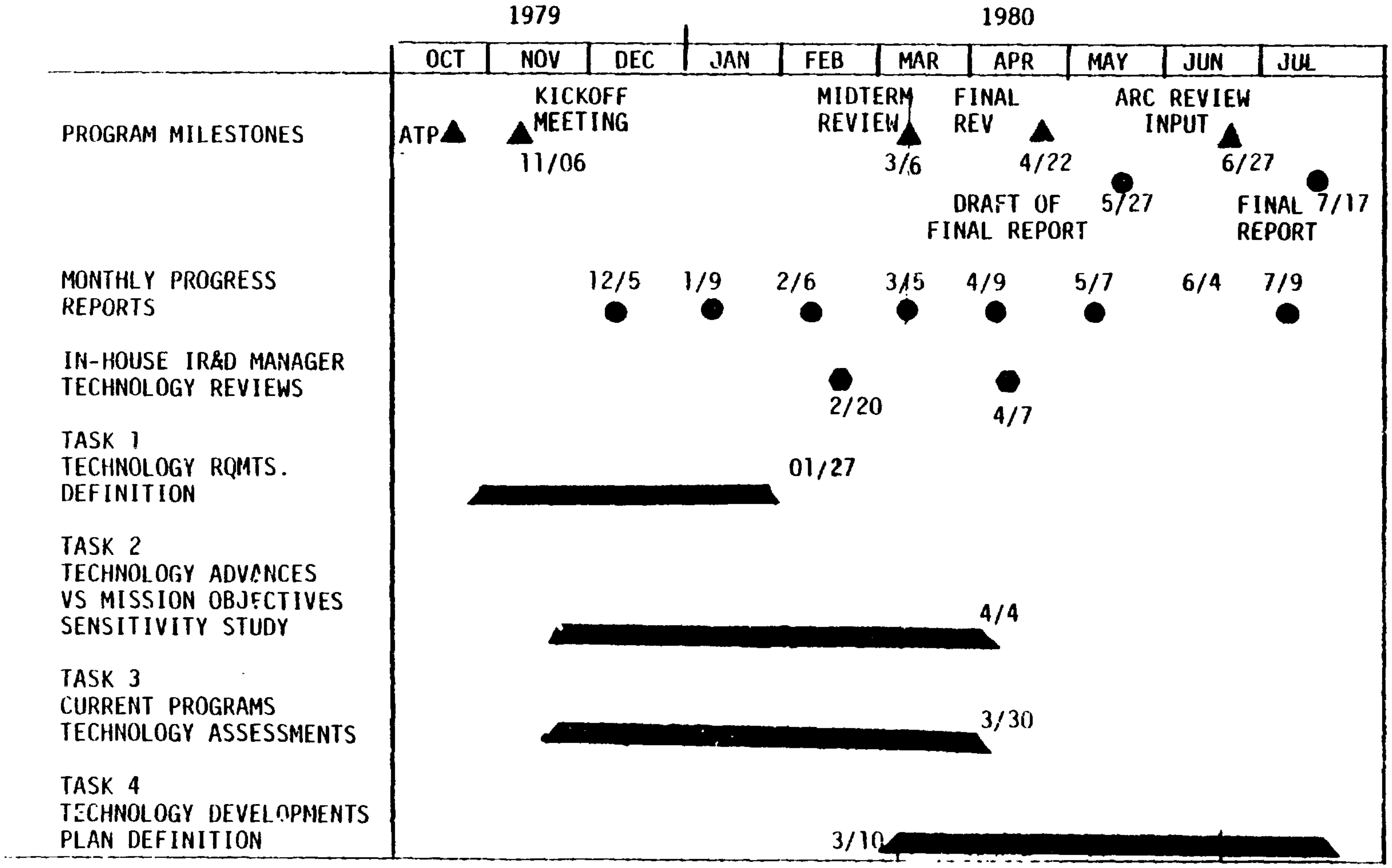


Figure A-1 Titan Probe Technology Study Schedule

- The Class A Probe is a non-landing probe that conducts only atmosphere science. The Class C Probe is a Class B Probe with added surface science and the capability to operate on the surface for greater than 32 days. The Class A and C configurations were analyzed, in this study, to assess only the hardware unique to these configurations.

- The science experiments were not examined in this study, but the accommodations and interfaces were studied for any required technology advances.

- The previous study cousidered entry from orbit primarily, and also presented a variation on this configuration for direct entry from an approach trajectory. Both configurations were evaluated in this study.

- A contamination requirement was added for this study. A mission probability of contamination of no more than 10^{-4} with a microbial reduction to 10^4 was used as mission driver.

- The weight goal for the Class B configuration is 225 kg.

- Surface sample acquisition requirements are per memo LXE:239-1 (Related Document 4 in Appendix C).

- Consider single string subsystems used in the baseline (i.e., do not add redundancy for reliability).

A-3 Study Task Flow

Figure A-2 diagrams the tasks used to perform this study. The approach used was to first perform a System Requirement Analysis (SRA) in Task 1. The documentation from this analysis was then used by the subsystem specialists to analyze the implementing baseline hardware and determine the technology developments required. The technology items

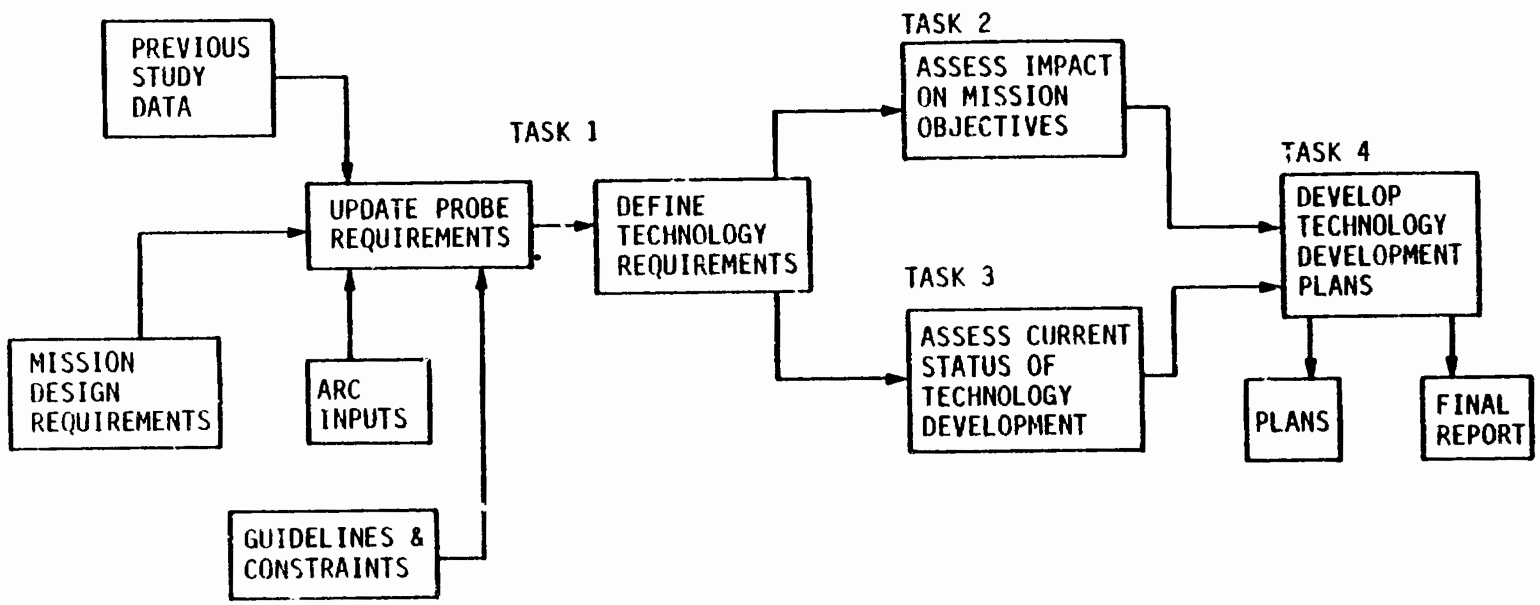


Figure A-2 Titan Probe Technology Study

from Task 1 were then ranked in Task 2 to assess the impact of each technology requirement on the mission objectives.

Assessment of the current technology status was accomplished in Task 3, and in Task 4 we prepared a technology development plan for those technology items found to require technology advancement.

A-4 Tasks 1 and 2 - Results and Products

The SRA developed the outputs used to systematically develop the hardware subsystem requirements. These product items consisted of:

- Mission Objectives - The mission objectives were drawn for the original mission documentation and resulted in the hierarchy diagram of Figure A-3.
- Function Flow Diagram - From these mission objectives, a top level and lower level function flow diagrams was developed Figures A-4a through 4k.
- Mission Drivers - Table A-1 lists the environments and conditions that could drive the hardware toward technology advancement. These items are defined in the design criteria document.
- Design Criteria Document - Document TPT-MA-04-1 was developed as a specification for the subsystem specialist to use for the technology analysis.

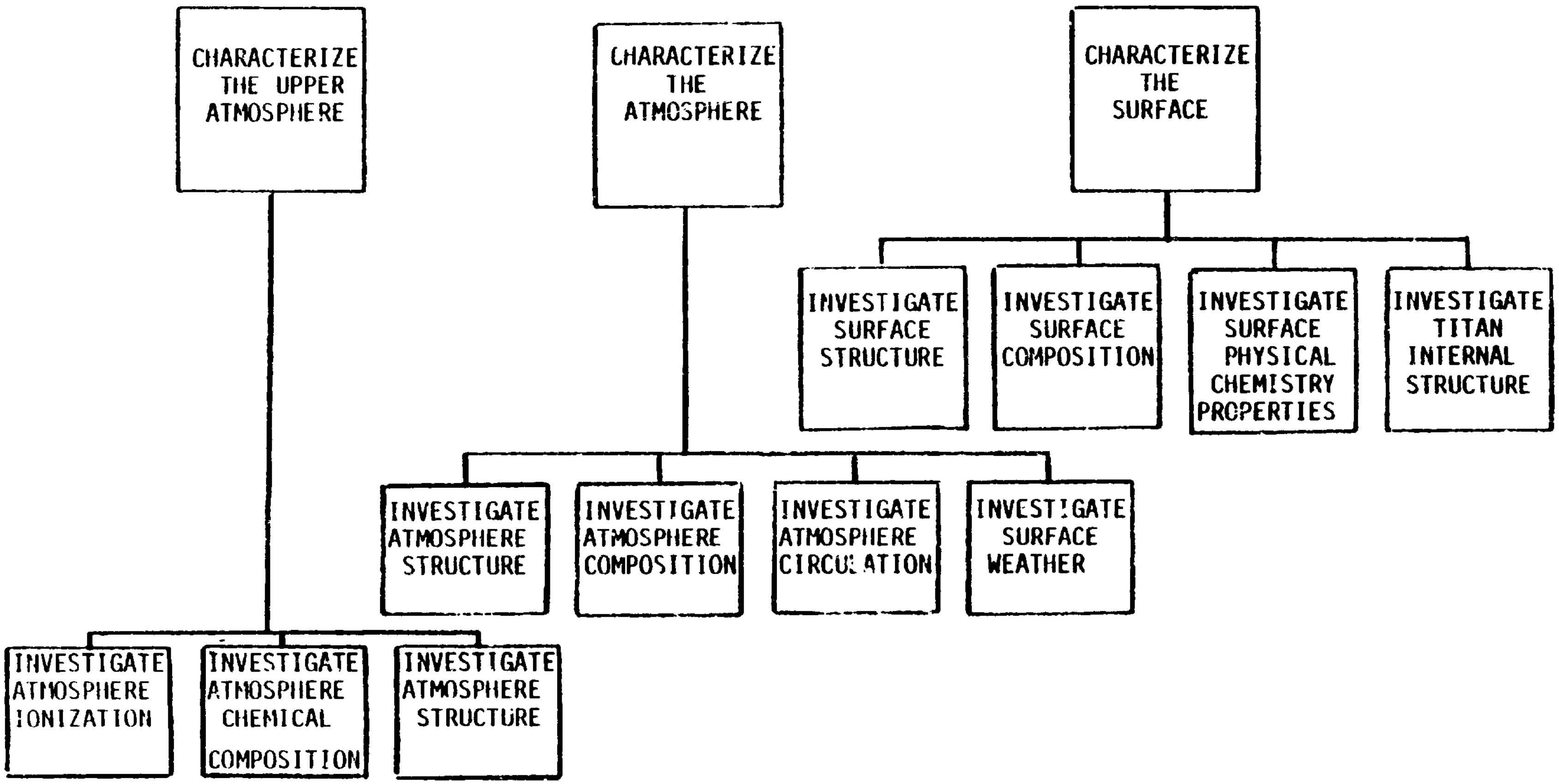


Figure A-3 Titan Probe Mission Objectives

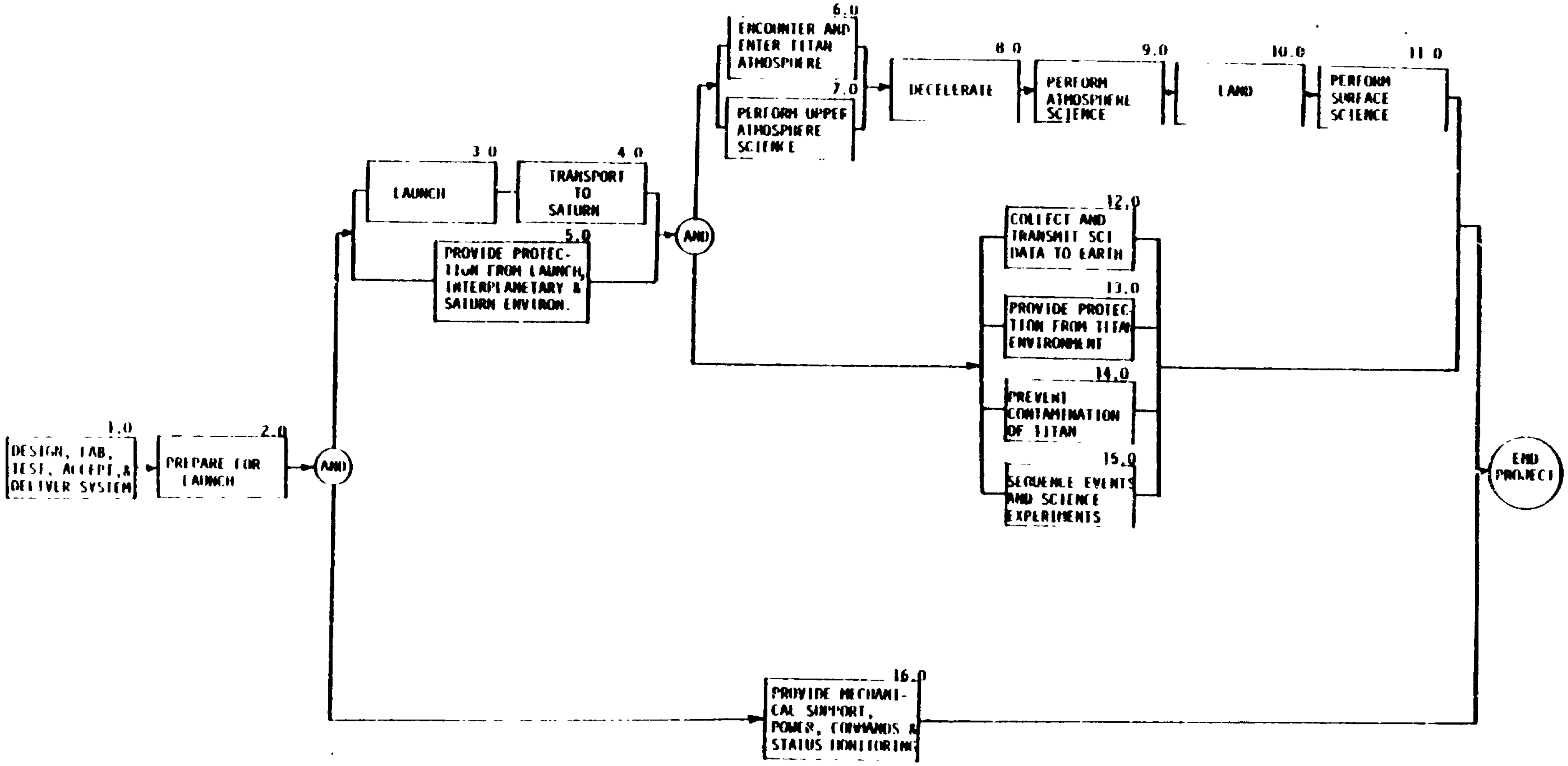


Figure A-4a Titan Probe Functional Block Diagram

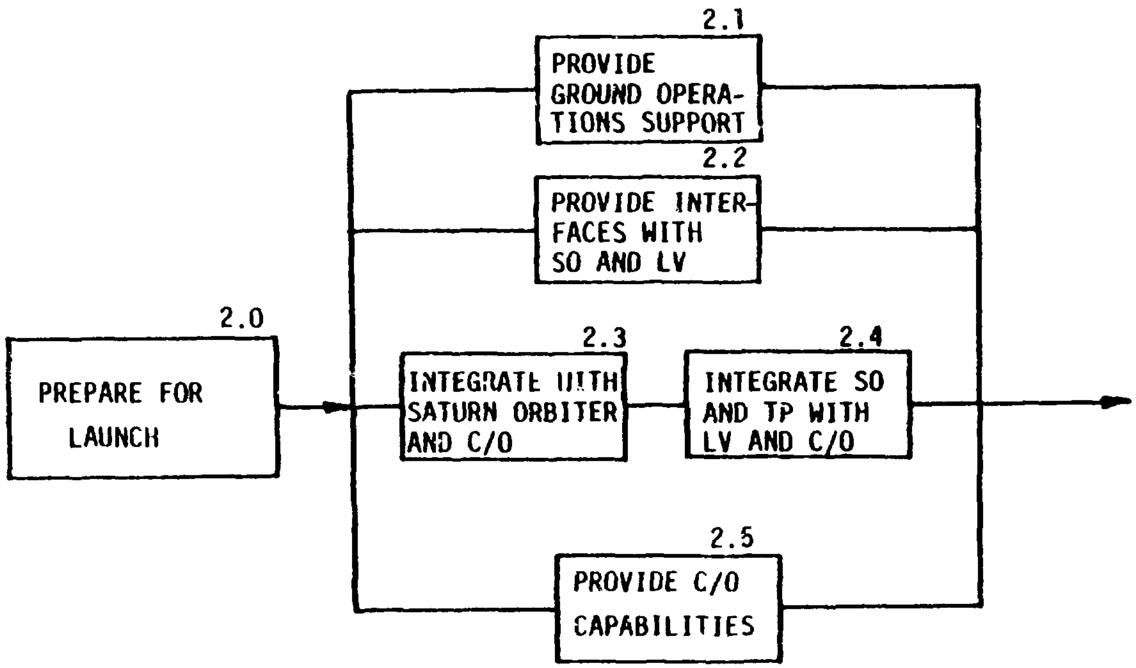


Figure A-4b Titan Probe Functional Breakdown

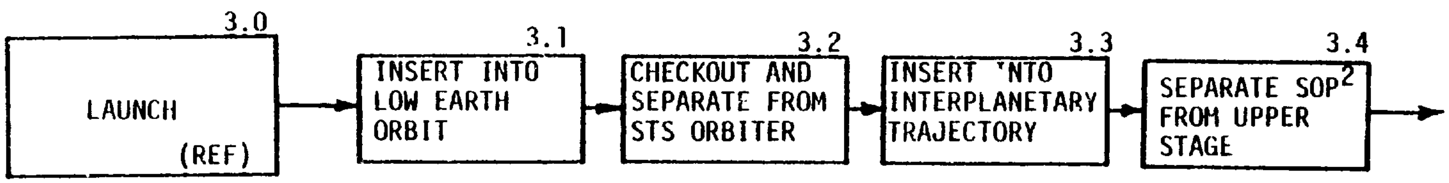


Figure A-4c Titan Probe Functional Breakdown

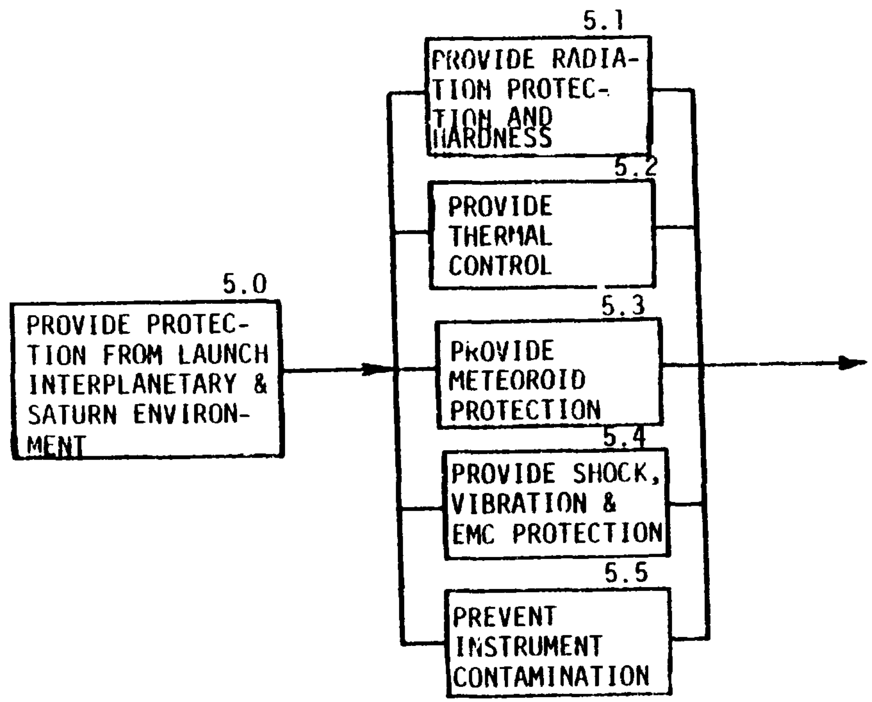


Figure A 4d Titan Probe Functional Breakdown

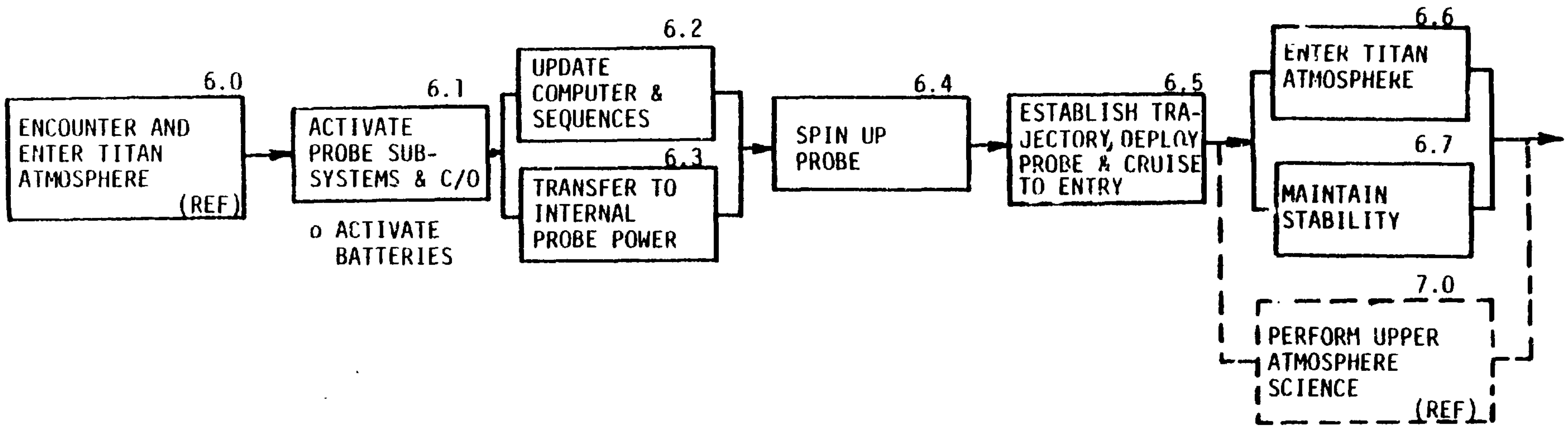


Figure A-4e Titan Probe Functional Breakdown

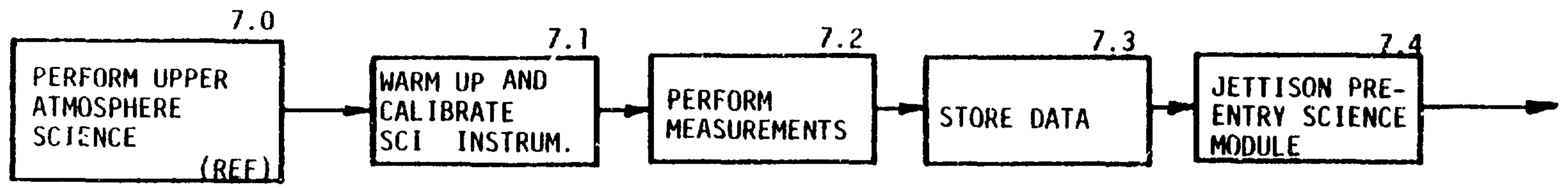


Figure A-4f Titan Probe Functional Breakdown

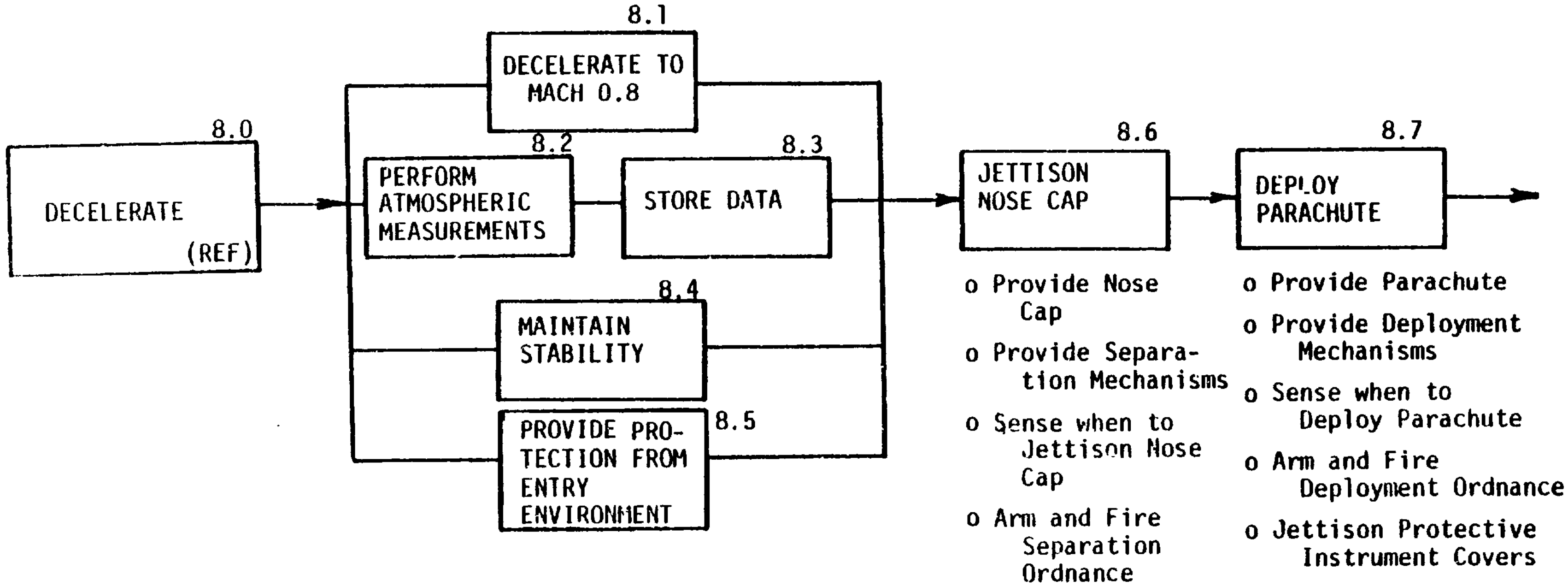


Figure A-4g Titan Probe Functional Breakdown

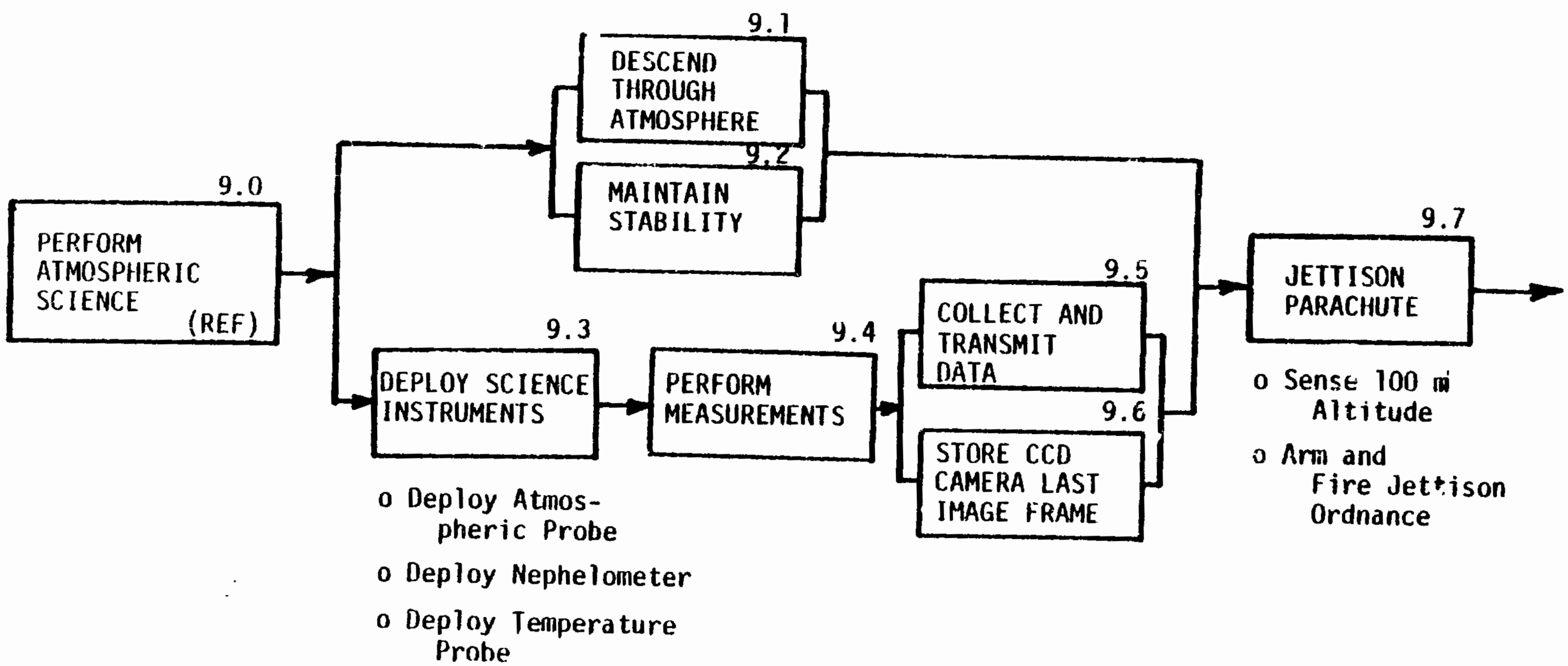


Figure A-4h Titan Probe Functional Breakdown

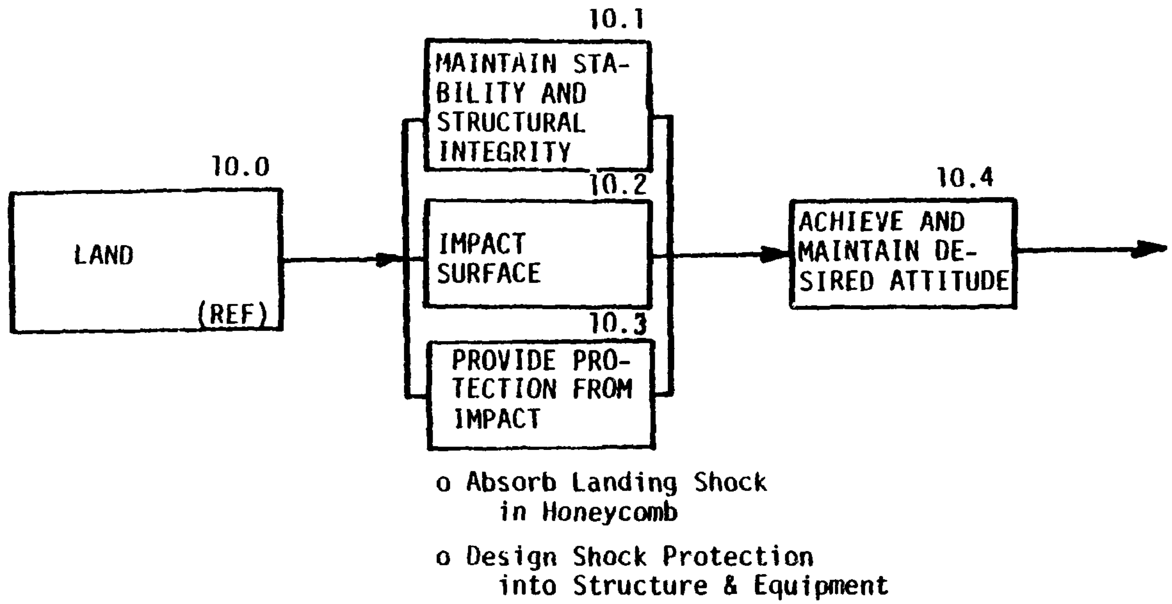


Figure A-41 Titan Probe Functional Breakdown

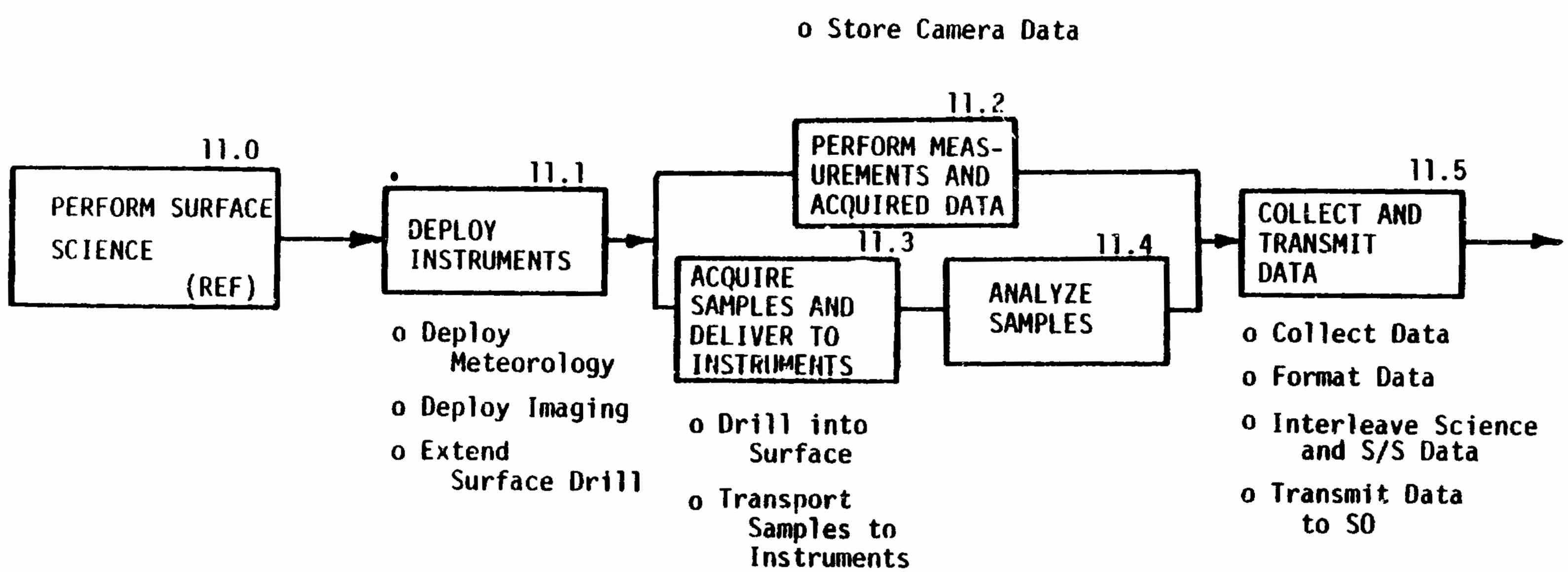


Figure A-4j Titan Probe Functional Breakdown

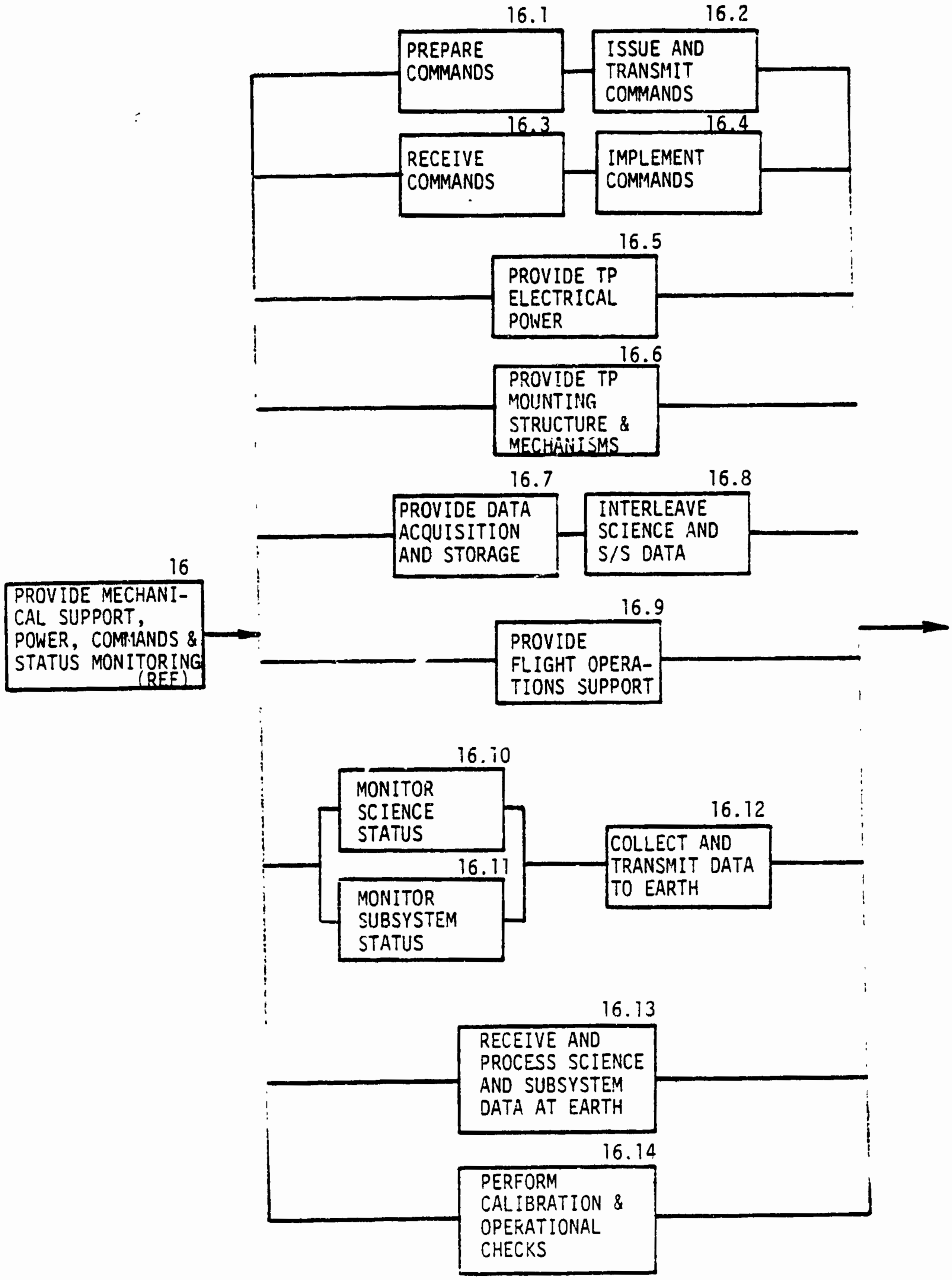


Figure A-4k Titan Probe Functional Breakdown

Table A-1 Titan Probe Technology Study-Mission Drivers

Surface Properties o 2658 km radius o Solid/semi-loose material/liquid surface o 300g impact o 1.25 m/sec^2 gravity
Surface Temperature o 70°K to 100°K
Atmosphere o 100% methane and 100% nitrogen o Surface pressure 0.2 to 2 bars
Total Probe Mass o 225 kg max
Mission Lifetime o Mission Life: 9 years minimum o Useful Life: 10 years minimum o Project Start: FY 1984 o Launch: FY 1989
Science Accommodation o Surface sample acquisition o Jettison of pre-entry science o Science deployment o Prevent contamination of science instruments
Planetary Quarantine o Microbial reduction to 10^4 o Bioshield enclosure of Titan Probe

The technology requirements were determined by the subsystem specialist. The subsystem hardware in the baseline configuration was examined against the system documents. The subsystem specialists documented their findings in the subsystem reports, and produced the technology requirement tables (Appendix B) as a working tool. These tables provide the means of tracing the functional requirements through the hardware to the technology requirement for the hardware. This output was the first estimate of the technology requirement based on the specialist's knowledge, and was prior to literature searches for technology status. The left-hand column in these tables is the function identification number that correlates with the functions numbered in the functional flow diagram, of Figure A-4a.

In Task 2, it was required to assess the impact of the technology required to the mission's successful completion. This was accomplished by counting the number of mission objectives (refer to Figure A-3), that are supported by each of the functions shown in Figure A-4a. Table A-2 is the function value list that resulted. This value for the function was then carried to the technology requirement tables annotated with the value. The technology requirements, found in the last columns of the table, were then evaluated for its impact on the mission. The list of ranked technology requirements was then tabulated (Table A-3) and presented at the mid-term review. This process considered all mission objectives to be of equal importance to the mission and technologies were counted only once against each mission objective.

The evaluation was not carried to a strict quantitative ranking since the technologies required were found to be generic to the mission completion and a more rigorous mathematical analysis would not significantly affect the outcome of the study.

Table A-2 Function Value List

	Function	No. of Objectives Supported
6.0	ENCOUNTER AND ENTER TITAN ATMOSPHERE	11
16.0	PROVIDE MECHANICAL SUPPORT, POWER, COMMAND, & STATUS	11
12.0	COLLECT AND TRANSMIT SCIENCE DATA TO EARTH	11
13.0	PROVIDE PROTECTION FROM TITAN ENVIRONMENT	11
15.0	SEQUENCE EVENTS AND SCIENCE EXPERIMENTS	11
8.0	DECELERATE	8
9.0	PERFORM ATMOSPHERIC SCIENCE	—
	9.1 Descend Through Atmosphere	8
	9.2 Maintain Stability	8
	7.4 Jettison Pre-entry Science Module	8
	8.6 Jettison Nose Cap	6
	9.7 Jettison Parachute	5
	9.7.1 Sense 100m Altitude	5
	9.7.2 Arm and Fire Ordinance	5
10.0	LAND	
	10.1 Maintain Stability and Structural Integrity	5
	10.2 Impact Surface	5
	10.3 Provide Protection from Impact	5
	10.4 Achieve and Maintain Desired Attitude	5
11.0	PERFORM SURFACE SCIENCE	
	11.5 Collect and Transmit Data While on Surface	5
	9.5 Collect and Transmit Atmosphere Science Data While on Parachute Descent	4
	11.1.2 Deploy Surface Imaging	4
	9.0 Perform Upper Atmosphere Science	3
	9.6 Store Descent Imaging CCD Camera Last Frame	2
	9.3.1 Deploy Atmosphere Probe	2
	9.3.2 Deploy Nephelometer	2
	9.3.3 Deploy Temperature Probe	2
	11.1.1 Deploy Meterology	2
	11.1.3 Extend Surface Sampler	2
	11.3 Acquire Surface Samples and Deliver to Instrument	2
	11.4 Analyze Surface Samples	2

Table A-3 Ranked Technology Requirements - Tasks 1 and 2 Results

Rank	Item	Technology Development Required
Higher	Batteries	1) Life 2) 300g Impact 3) Sterilization 4) Design Concept
Higher	Materials	1) Life 2) Temperature
Higher	Bubble Memory	1) Life 2) 300g Impact 3) Sterilization
Higher	Mechanisms-Flight	1) Life
Higher	MicroStrip Antenna	1) Temperature 2) 300g Impact
Higher	Landing Integrity	1) Stability 2) 300g Impact Analysis 3) Sample Ability
Lower	Sample Acquisition/ Delivery	1) Surface Uncertainty 2) Temperature
Lower	Mechanisms-Landed	1) Life 2) 300g Impact
Lower	RTG	1) Environment 2) Life 3) 300g Impact
Lower	Radioisotope Thermal Unit	1) 200 to 250 Watts

A-5 Task 3 Method

Under Task 3 we conducted a survey with the objective of assessing the development status of required technologies. The method used for the status survey was a synergistic process, (see Figure A-5). The initial step established the state-of-the-art using the specialist's knowledge as the baseline from which to make contacts in government agencies and industry. Literature searches were made through the National Technology Information Service (NTIS), the Defense Technical Information Center (DTIC) and the NASA Remote Console System (RECON). These searches are enumerated, by search control number, and the search terms, used for retrieval of documents from the data banks, are listed in Tables A4 through A9. These report bibliographies contain abstracts which were reviewed, and the pertinent documents were requested and analyzed.

Reports, papers and information from personal contacts, conference proceedings, and professional journals were also collected and reviewed. This screening process resulted in the bibliographies for each technology that are in Section 3.0 of this report.

This method of obtaining documents was slow and not always complete. There were some papers that were categorized as limited access that we could not obtain. There were some classified papers we could not get and there are IRAD documents from industry that we did not attempt to obtain.

Similarly, the assessment of current activities is not readily available. The Martin Marietta Library staff searched through NASA-RECOM and it did not bring out the latest RTOP activities. Similarly we found a government group that is not available to industry. The Interagency Advanced Power Group (IAPG) is the group that periodically publishes a list of current programs taking place in various power areas. In this case we were able to obtain a listing and have included this information in our survey. We became concerned knowing many such groups were not uncovered

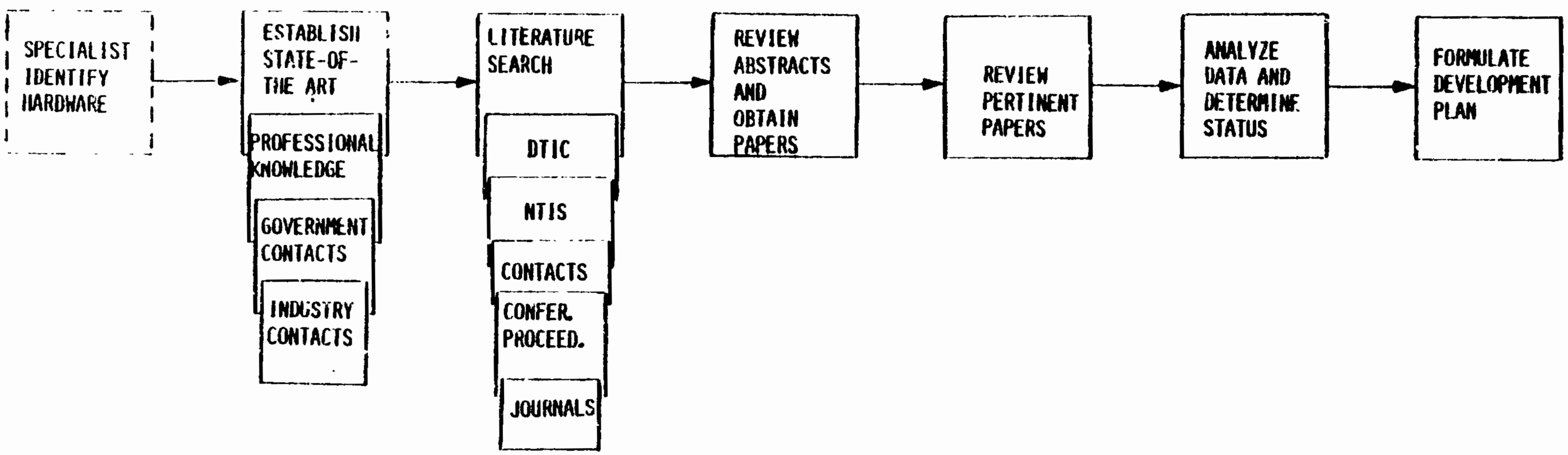


Figure A-5 Technology Status Evaluation Method

Table A-4 Terms for Surface Sampler Literature Search

Lunar Composition
Lunar Craters
Moon
Lunar Crust
Lunar Dust
Lunar Soil
Lunar Geology
Lunar Rocks
Lunar Surface
Lunar Core
Planetary Surfaces
Mars Surface
Surface Properties
Mars (Planet)
Drills
Drill Bits
Drilling
Sampling
Samplers
Samples
Specimens
Data Samkpling
Chemical Analysis
Chemical Tests
Concentration
Exploration
Specimens

Table A-5 Terms for Battery Literature Search

First Level Search Terms	Second Level Search Terms
Alkaline Batteries	Lithium
Battery Chargers	Silver
Battery Compartments	Zinc
Battery Components	
Battery Separators	**Third Level Search Terms**
Dry Batteries	
Electric Batteries	Silver Zinc Batteries
Guided Missile Batteries	Sulfur
Lead Acid Batteries	Sulfur Compounds
Low Temperature Batteries	Sulfur Dioxide
Magnesium Batteries	Thionyl
Mercury Batteries	
Metal Air Batteries	
Meteorological Batteries	
Mine Cadmium Batteries	
Primary Batteries	
Radioisotope Batteries	
Reserve Batteries	
Sea Water Batteries	
Silver Zinc Batteries	
Storage Btteries	
Thermal Batteries	
Water Activated Batteries	
Wet Cells	

Table A-6 Terms for Space Vacuum Effects Literature Search

First Level Search Terms

Acetal Resins
Acrylic Resins
Airplane Engine Oils
Amino Plastics
Antiseize Compounds
Butyl Rubber
Carbon Phenolic Materials
Cellulose Acetates
Cellulose Ethers
Cellulosic Resins
Cutting Fluids
Dacron
Delrin
Ebonites
Elastomers
Epoxy Resins
Ethyl Cellulose
Expanded Plastics
Foam Rubber
Furan Resins
Glass Reinforced Plastics
Graphited Materials
Greases
Halocarbon Plastics
Heat Resistant Plastics
Instrument Greases
Laminated Plastic
Latex
Low Temperature Lubricants
Lubricant Additives
Lubricants
Lubricating Films
Lubricating Oils
Methyl Cellulose
Mineral Wool
Natural Fibers
Natural Rubber
Nitrile Rubber
Nylon
Orlon
Phenolic Plastics
Plastics Coatings
Plastics
Plexiglas
Polyacrylamides
Polyacrylates
Polyamide Plastics
Polyester Fibers
Polyester Plastics
Polyethylene Plastics
Polyethylene Terephthalate
Polyimide Resins
Polymethyl Methacrylate
Polyoxyethylene
Polypropylene
Polypropylene
Polystyrene
Polyurethane Resins
Polyvinyl Alochol
Polyvinyl Chloride
Polyvinylidenes
Quartz Phenolic Materials
Rayon
Reinforced Plastics
Rubber
Silastic Compounds
Silicone Plastics
Solid Film Lubricants
Solid Lubricants
Styrene Plastics
Synthetic Fibers
Synthetic Rubber
Thermoplastic Resins
Thermosetting Plastics
Vinyl Plastics
Vinyl Rubber

Second Level Search Terms

Aerospace Environment
Deep Space
Interplanetary Space
Interstellar Space
Low G
Outer Space
Space Environments
Weightlessness
Zero G
Zero Gravity

Table A-7 Terms Used for Lubricants Literature Search

First Level Search Terms

Aerospace Environment
Deep Space
Interplanetary Space
Interstellar Space
Outer Space
Space Environments
Weightlessness
Zero G
Zero Gravity
Zero-G

Second Level Search Terms

High Vacuum
Ultrahigh Vacuum
Vacuum

Third Level Search Terms

Airplane Engine Oils
Antiseize Compounds
Cutting Fluids
Graphited Materials
Greases
Instrument Greases
Low Temperature Lubricants
Lubricant Additives
Lubricants
Lubricating Films
Lubricating Oils
Solid Film Lubricants
Solid Lubricants

Table A-8 Terms for Drill Bit Materials Literature Search

First Level Search Terms

Drilling
Drilling Machines
Drills
Rock Drilling

Second Level Search Terms

Astronomical Bodies
B Type Stars
Basalt
Binary Stars
Boulders
Char Oil
Clay
Clay Minerals
Coal
Cryogenics
Cryopumping
Deep Space
Dwarf Stars
Fullers Earth
Granite
Gypsum
Igneous Rock
Infrared Stars
Interplanetary Space
Interstellar Space
Kaolinite
Limestone
Lunar Probes
Magma
Mars Probes
Metamorphic Rock
Montmorillonite
Moon
Novae
Outer Space
Pegmatite
Peridotite
Quartizite
Rock
Rock Drilling
Rock Mechanics
Rock Salt
Sandstone
Schist
Sedimentary Rock
Shale
Space Environments
Space Exploration
Space Objects
Space Probes
Space Tools
Stars
Sun
Supernovae
Talc
Titan Moon
Variable Stars
Venus Probes
Wolf Rayet Stars

Table A-9 Terms for Memory Literature Search

First Level Search Terms

Bubble Domain

Bubble Memory

Bubble Storage

Magnetic Bubble

In spite of a concern for not having reached each and every player in the technology area, we feel the assessment of the status report is basically correct. The activity list may not be complete, it does, however, represent the type of activity presently taking place.

The technology development plans recommended in Section 3.0, are not dependent on completeness of this activity list since an updated technology survey will be performed as the first task in the execution of the plan.

APPENDIX B

APPENDIX B HARDWARE TECHNOLOGY ANALYSIS

This appendix documents the products from Task 1 and describes the baseline configuration from the previous study (Related Document No. 1).

B-1 Titan Probe Capsule Configuration

The Titan capsule to be carried in the Saturn orbiter is configured as shown in Figure B-1. Its elements are:

- o Bioshield - base and cap;
- o Titan Probe;
- o Pre-entry Module.

The bioshield protects the sterilized descent capsule from biological, chemical, and particulate contamination before and during launch. The bioshield cap is jettisoned during the cruise to Saturn. The inner descent capsule is comprised of the Titan Probe and the Pre-Entry Module.

The reference set of science instruments are listed in Table B-1. No technology assessment was attempted of these instruments.

Figure B-2 depicts the Titan Probe mission entry and descent sequence. The Pre-Entry Module is jettisioned as the probe is decelerated by the denser atmosphere. After deceleration to about Mach = 0.8, a parachute is deployed (in the thin methane reference atmosphere) to slow the descent through the atmosphere. Near the surface, the parachute is jettisioned and the probe falls to a hard landing (20 meters per second).

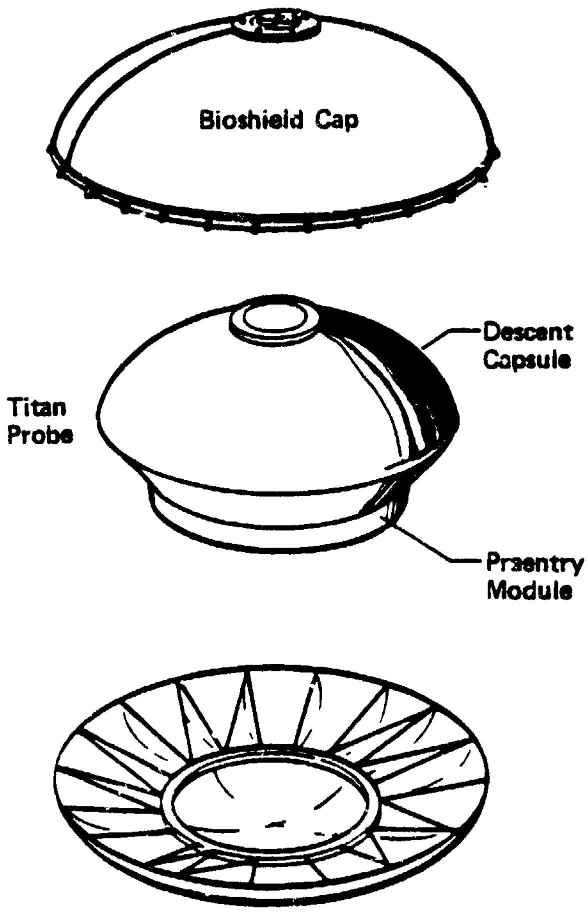


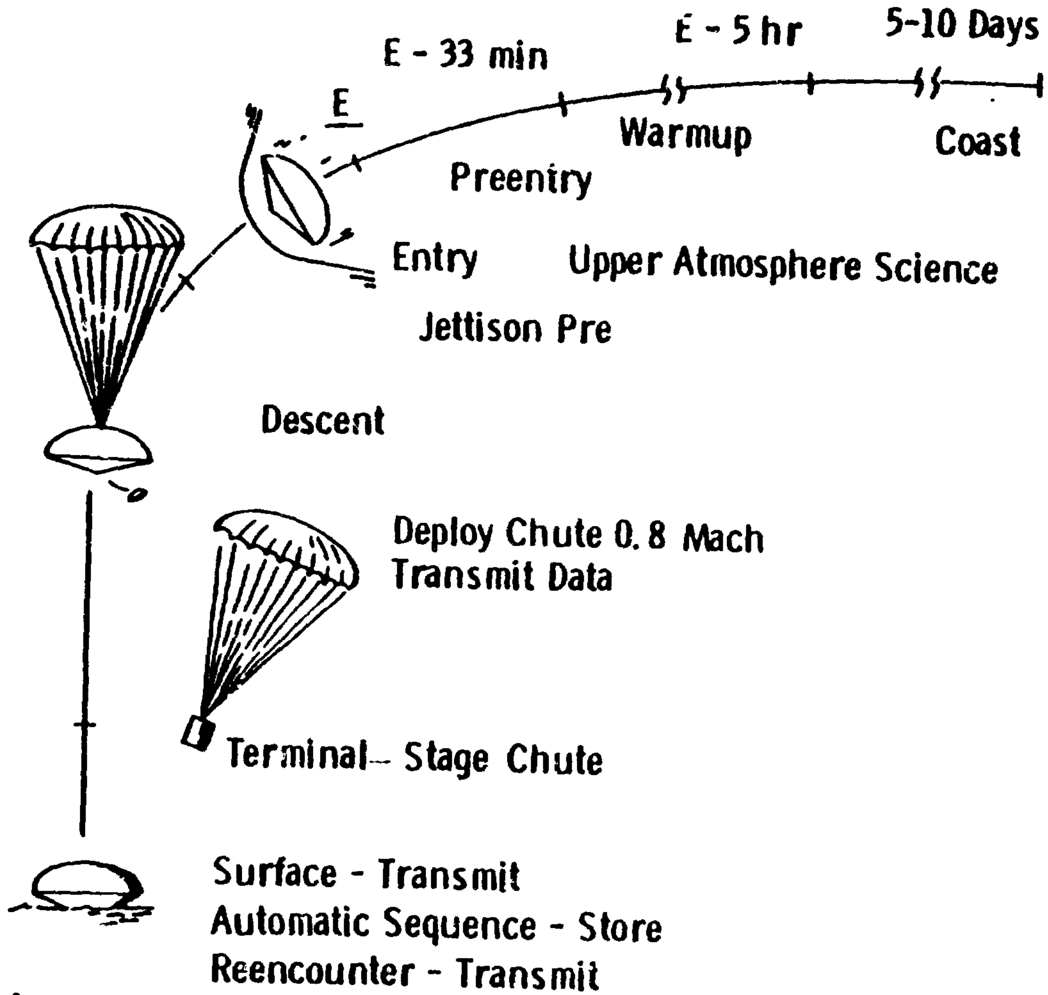
Figure B-1 Titan Probe Capsule

Table B-1 Titan Probe Science Payload Complement by Probe Class

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

* Class B and C uses surface GCMS for atmosphere measurement.

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



*Percent probability of surface location.

Figure B-2 Typical Titan Probe Mission Entry Descent Sequence

B-2 Bioshield

The bioshield prevents recontamination of the sterilized Titan Probe with earth organisms by completely encapsulating it during and after sterilization. It consists of three major subassemblies - the cap, base, and equipment module. The equipment module provides a bulkhead through which pass the electrical and instrumentation harnesses, and other interfacing functions. The base provides the support structure for attaching the Titan Probe and interfaces with the Saturn orbiter structure adapter. Ejector devices separate the cap from the spacecraft after insertion into trans-Saturn trajectory, and another device spins the Titan Probe prior to release from the Saturn orbiter.

B-3 Pre-entry Module

The Pre-Entry Module (shown in Figure B-3) is positioned on the leading cone of the entry probe to allow the upper atmosphere science instruments to sample free space. The module is therefore required to be jettisoned prior to entering significant atmosphere. The baseline concept for jettison is a split module held together by a tension link and strapped to the cone by hold down straps.

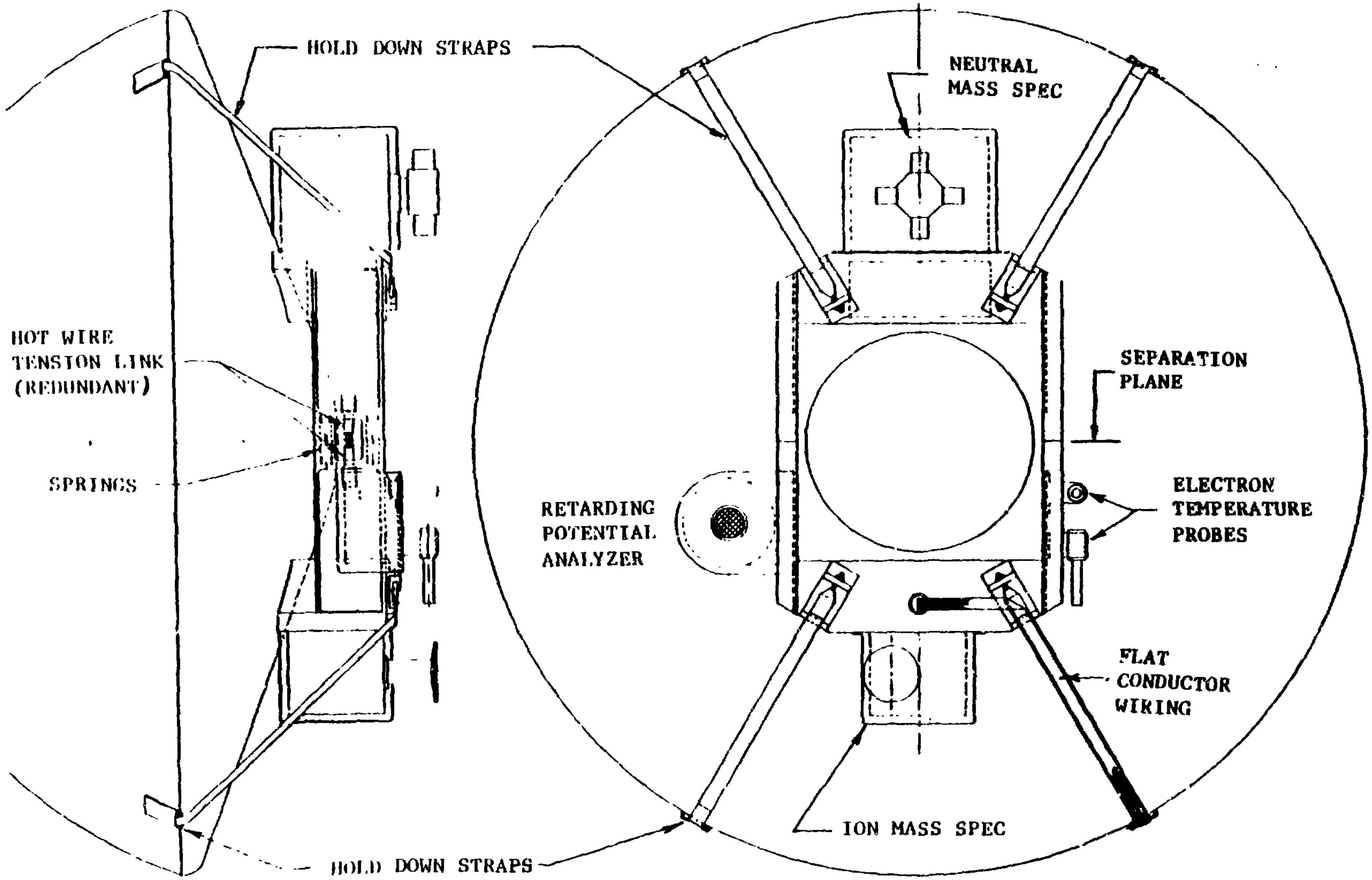


Figure B-3 Titan Probe Pre-Entry Science Module

The mechanism for jettison is comprised of springs, links, and associated electronics. Design considerations will be required for spring materials and materials with surface-to-surface contact to prevent electro-chemical reactions from degrading the separating mechanisms. The hot wire tension links have supporting data available to assure operation after 10 years dormant life.

B-4 Titan Probe System

The Class B probe (see Figure B-4) is a combination atmosphere and lander vehicle. The external configuration uses a 20-degree half angle cone aeroshell and ablator, while the aft cover is a segment of a sphere. When designed for a thin methane Titan atmosphere, it requires a parachute to slow its descent. For the thicker nitrogen atmosphere model, transit through atmosphere is sufficiently slow to enable all required science investigations. A hard landing of less than 300g deceleration is required for either atmosphere mode. The surface mission lasts until the Saturn orbiter passes out of communication range approximately 2.7 hours after impact. Operational duration is approximately 249 hours from separation from the Saturn Orbiter, and 10 years from launch.

The subsystem elements of the probe include structures and mechanism, telecommuication, data handling, electrical power, and thermal control.

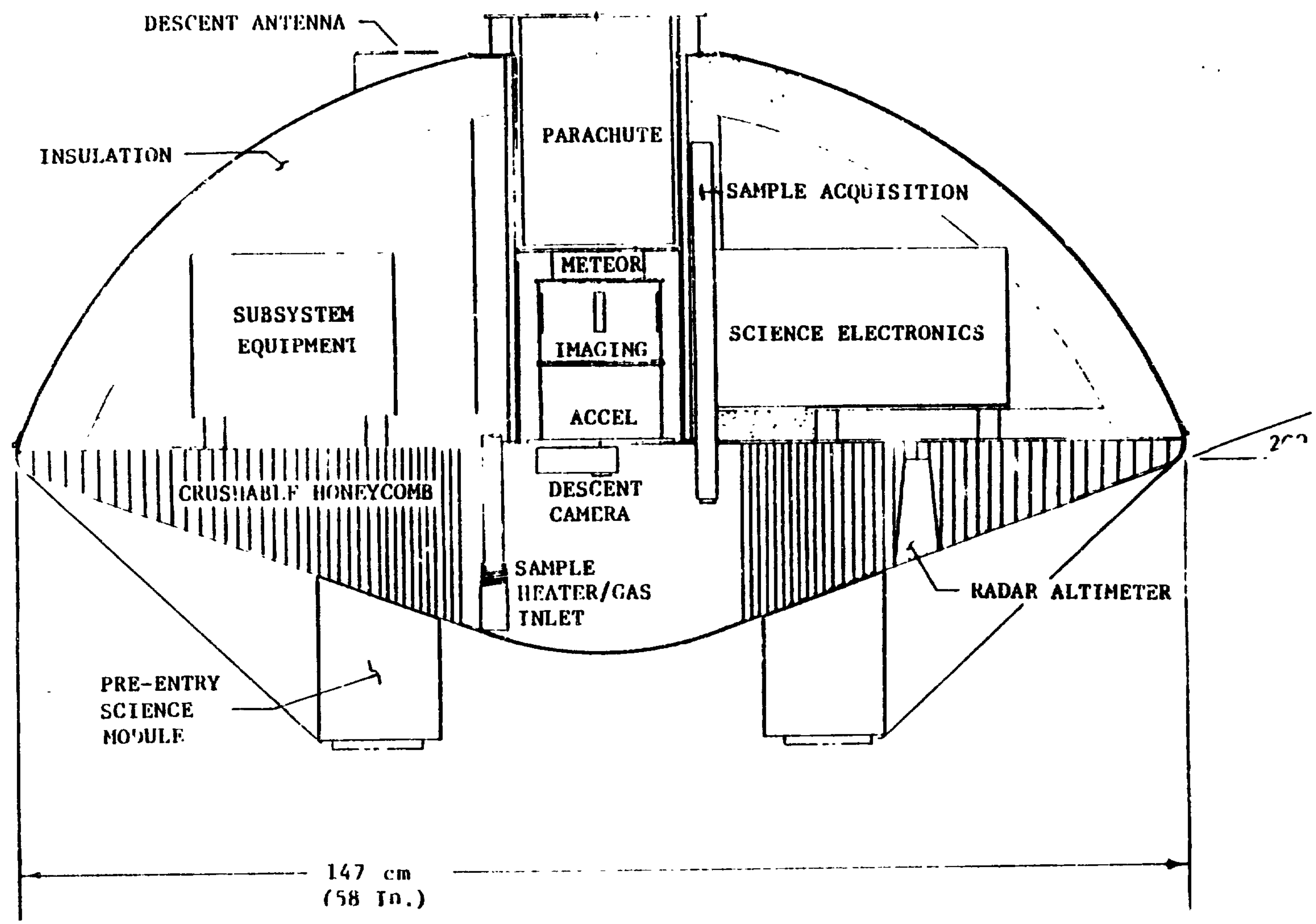


Figure B-4 Class B - Probe/Lander Configuration

The Titan Probe system block diagram is shown in Figure B-5. All support functions are supplied by the Saturn orbiter until immediately prior to probe spin-up and release. From release through entry into the atmosphere and subsequent landing, data is stored and/or relayed to the Saturn orbiter for retransmission to Earth. All pre-entry science data is stored for later transmission. During the entry phase, the atmospheric structure instrument data is stored, and also transmitted throughout entry and possible blackout to provide a signal using the ultra stable oscillator to gain Doppler tracking data and signal degradation data. Real-time engineering data, science data, and previously stored calibration, pre-entry, and entry data are interleaved and transmitted to the orbiter during the descent period and following landing.

The probe is designed with subsystem and science equipment within an environmentally controlled compartment as much as possible. Compartment temperature is maintained with electrically controlled heaters, isotope heaters, and equipment electrical dissipation.

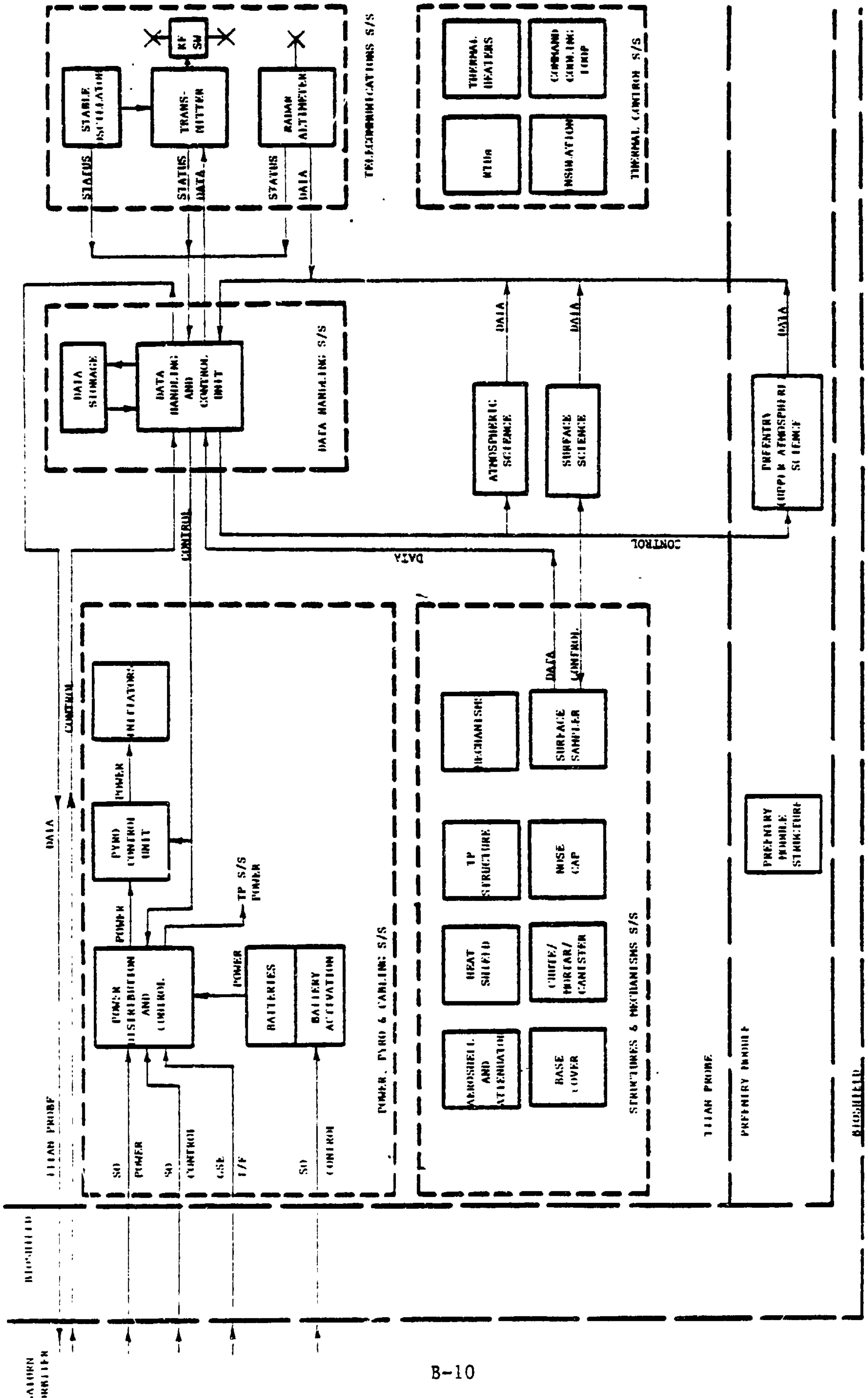


Figure B-5 Titan Probe System Block Diagram

B-5 Structure and Mechanism Subsystem

The Class B structure subsystem is defined in Figure B-6. The aerodecelerator for the thin methane atmosphere requires a parachute to slow the descent rate. The parachute is inserted at the top of a central structural tube that encloses the extendable science mast. This mast deploys meteorology and imaging experiments after landing. The parachute is jettisoned at 100m altitude, and the probe free-falls for a relatively hard landing.

The aeroshell and heat shield are combined with a honeycomb structure impact attenuator. These limit the impact deceleration to less than 300g with an impact velocity of 20 m/sec. Good attitude stability and small surface penetration are obvious goals.

Uncertain surface characteristics (irregular or liquid) combined with low surface temperatures (70^{o}K to 100^{o}K) and a spacecraft that has survived 10 years of interplanetary travel create a difficult landing problem. The study assumed a flat hard surface for landing impact. While no critical problems have been identified, this area requires further study and design consideration.

The baseline configuration is designed to land on a flat surface with the impact energy applied to the tip of the probe. A conceptual design should be pursued that will account for slopes, rocks, and wind forces by being capable to absorb vertical and lateral impact energy.

CLASS B PROBE/LANDER CONFIGURATION

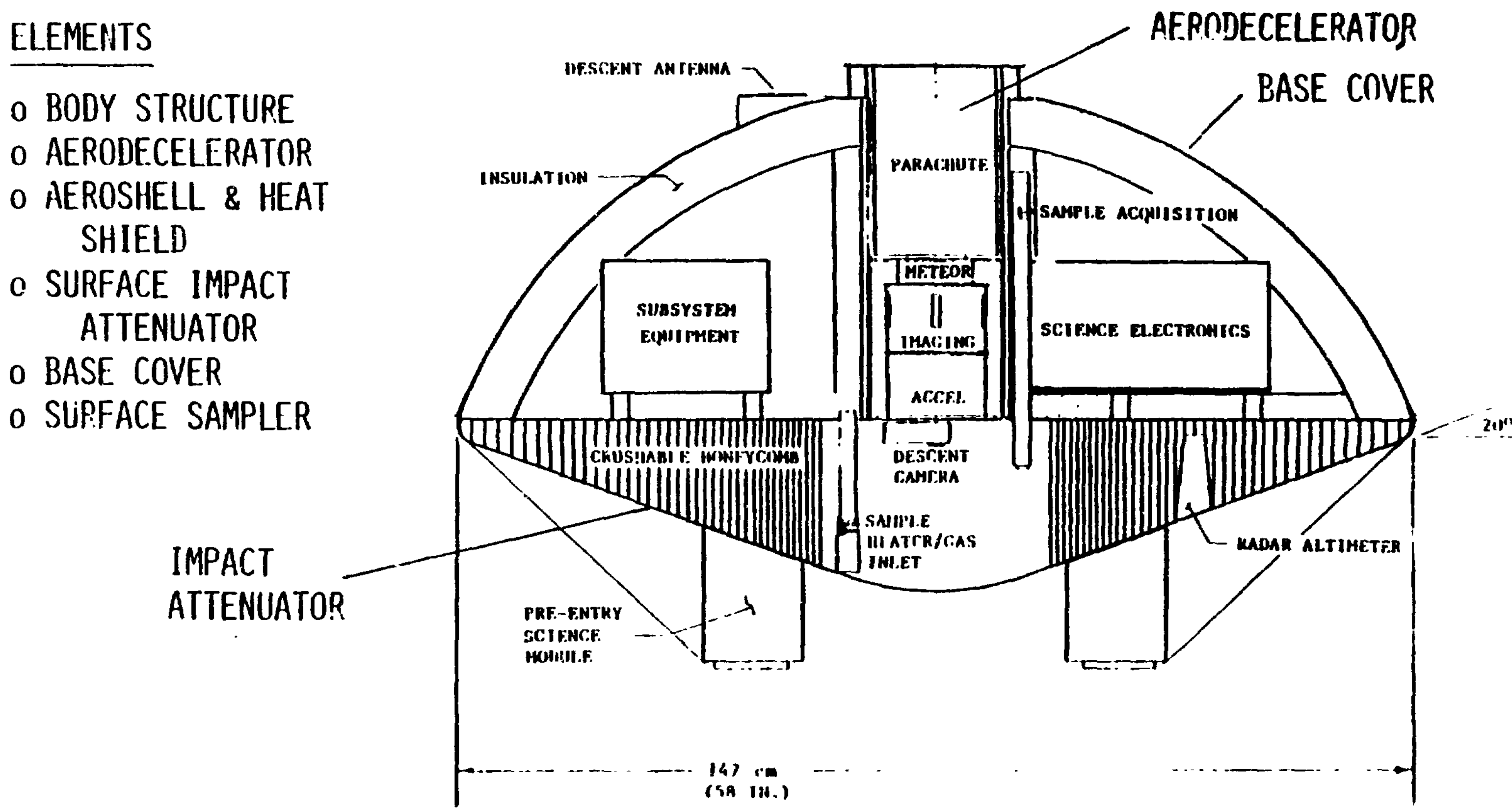


Figure B-6 Structures and Mechanisms Subsystem

The design study should include a reliable method to maintain a clear area for the sample acquisition device to reach the surface. Similarly the design must find a means to preserve the surface material chemical composition by not:

- o Introducing contaminant materials from the ablative shield or from the structure;
- o Significantly changing the temperature of the surface;
- o Changing the chemical composition of the sample area.

The effect of the impact energy on the dynamics of the probe should be analyzed to put criteria on the design of structure, subsystem, and parts. A fundamental dynamic analysis of the baseline configuration indicates that the impacted shock from the 20 meter per second landing, will be in the form of a terminal peak sawtooth that peaks at 300g after 0.010 second. Equipment can then experience amplification factors up to 30, depending on the mounting techniques, natural frequencies, and structural damping characteristics.

During descent, the nose cap is jettisoned to provide an opening for atmosphere to reach the atmospheric composition instrument and for light to impinge on the camera (Figure B-7. The baseline design jettisons the nose cap using hot gas actuated pin retractors. The ability for these devices to work after being dormant for 10 years in the space environment has been verified. A technology verification by analysis and test will be required during the design phase.

The mechanism required to deploy the meteorology and camera mast after landing can be developed during the program design phase providing that consideration is given to materials, lubricant selection, and landing shock. These technology requirements are discussed in greater detail in the materials section.

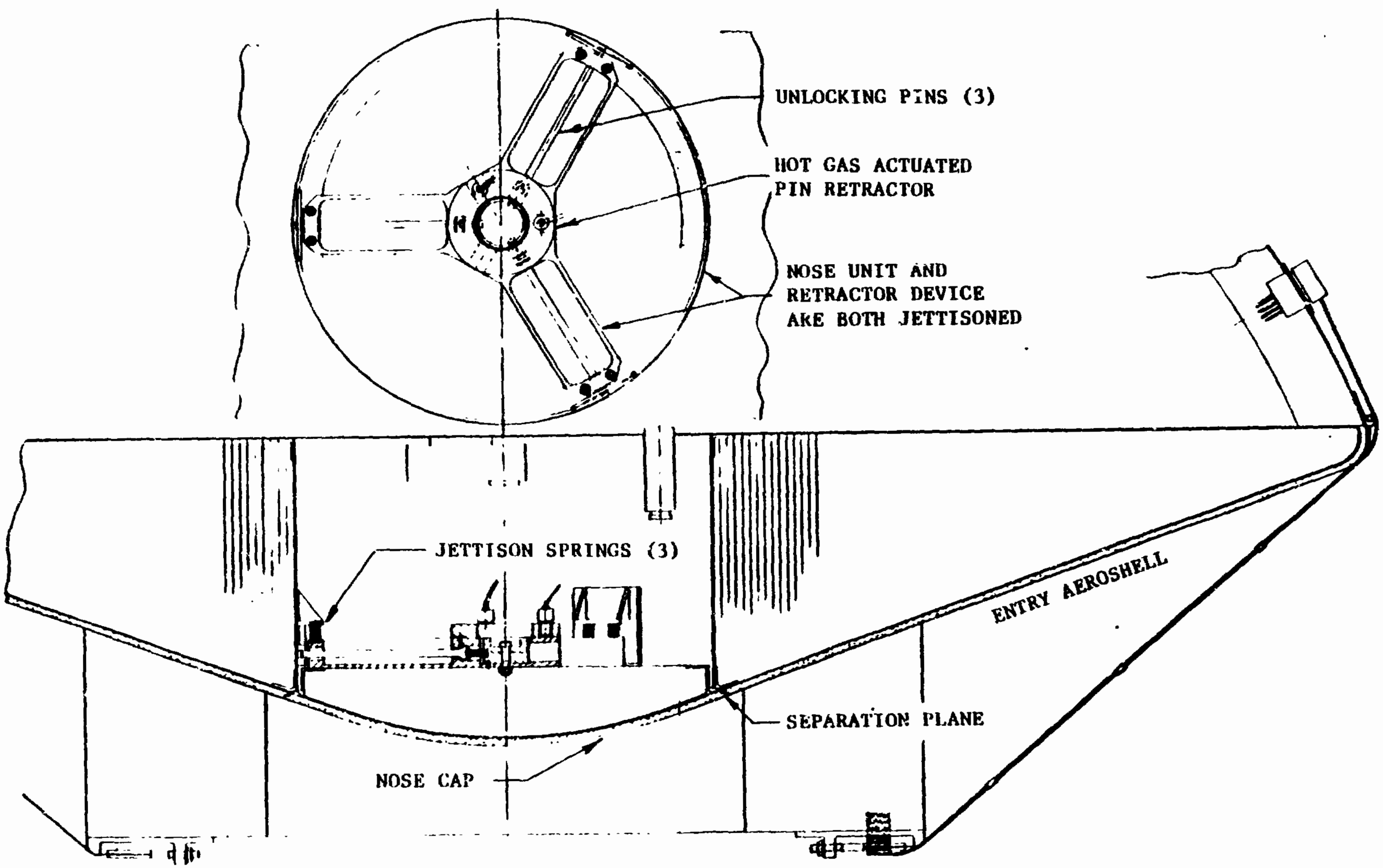


Figure B-7 Titan Probe Jettisonable Nose Cap Detail

B-6 Telecommunications Subsystem

B-6.1 Requirements Analysis

The required major functions of the baseline telecommunications subsystem for a Titan Probe are to:

- Provide a stable oscillator transmitter frequency source to allow wind/Doppler measurements during the probe descent period.
- Maintain a communications link to transmit coded science and probe subsystems status data to the Saturn orbiter during descent and for a short period of time after probe impact (the Class C probe would require communications with the orbiter 32 days later).
- Provide a radar altimeter to trigger release of the descent parachute at 100 meters or less altitude above the landing surface (this is for the thin atmospheric model only).

Detailed requirements for the subsystem are yet to be developed; however, the major characteristics have been determined such that an evaluation of the extent of development needs can be made.

A review of the telemetry transmitter requirements shows that a very stable frequency source is required (3×10^{-10} frequency stability as specified by NASA Ames) for wind/Doppler measurements. The required transmitter output power varies from 2.5 watts at 1400 MHz for the Class B probe entering a thin atmosphere from orbit around Saturn to 6 watts RF output for a thick atmosphere. For direct entry, using a separate probe carrier, the transmitter output power goes up to as much as 20.8 watts at 1400 MHz for the thin atmosphere and 21.8 watts for the thick (30%) atmosphere.

Desired characteristics for the telemetry antenna include a peak gain of 4.4 dBi on axis with a 140-degrees half-power beamwidth (HPBW) and axial ratio of 3 dB or less out to the half-power points.

The radar altimeter is required to operate over a relatively short range (detect 100-meter altitude above the surface). It is estimated that detection of a 90-meter altitude ±10 meters should be sufficient for a preliminary performance requirement.

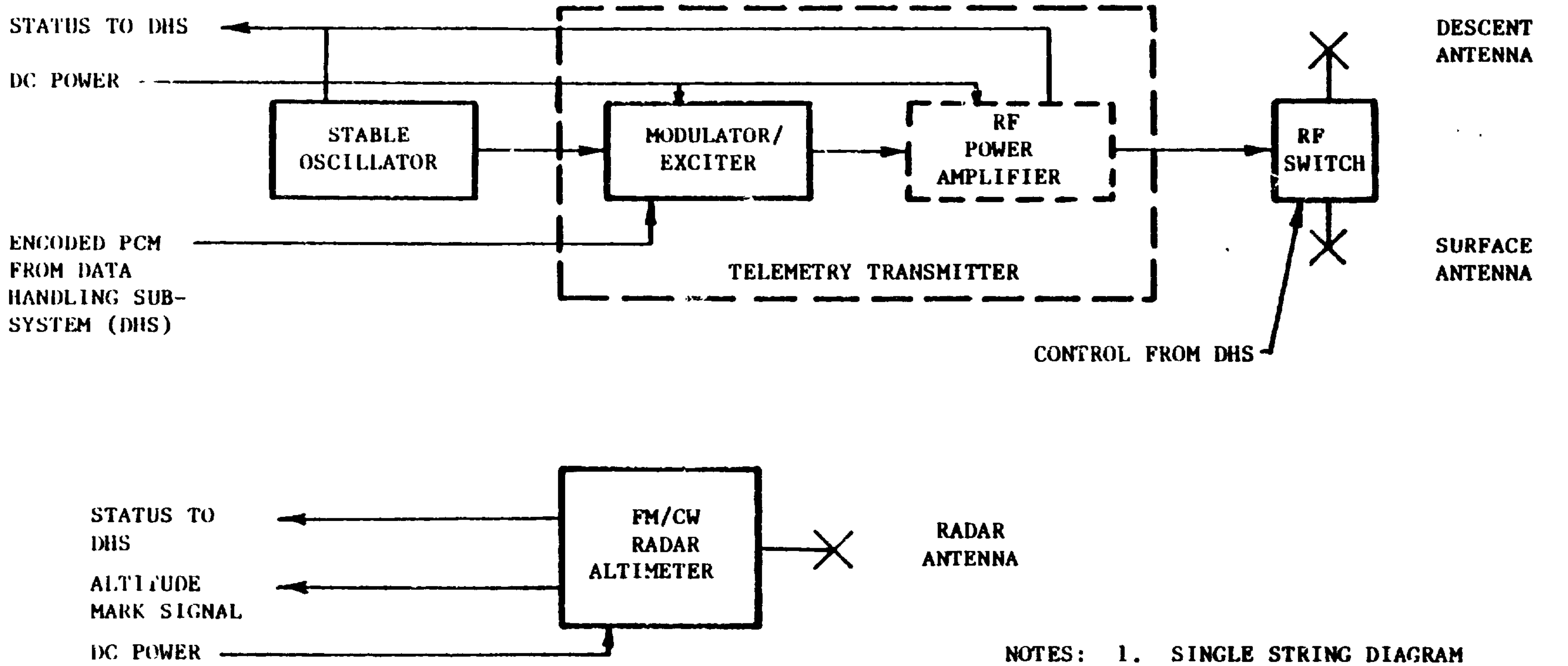
A review of the communications link parameters and proposed subsystem implementation given shows that some soft spots exist in the design. Specifically, the performance quoted for the communications antenna is somewhat optimistic for a microstrip antenna and no performance parameters were given for the radar altimeter other than size, weight, and primary power allocation.

The microstrip antenna was characterized as having a peak gain of 4.4 dBi and half-power beamwidth of 140-degrees with an axial ratio of 3 dB or less in the HPBW. A closer look at some recent designs by Martin Marietta shows that HPBW beyond 100-degrees is not very practical with the microstrip antenna suggested, and the axial ratio at the half-power can be expected to approach 10 dB. Also, care must be taken to limit the temperature excursions of the antenna to prevent detuning and/or delamination. An alternate antenna that can meet the beamwidth/gain objectives for the hard lander is a turnstile-over-cone antenna as shown for the soft lander configuration. However, this antenna has the disadvantage of excessive thickness compared to the thin dimension of the microstrip antenna. Replacing the two microstrip antennas with the turnstiles would require a new probe layout due to the thicker turnstile antennas. To avoid a completely new probe design layout, it is recommended that the antenna be considered a design item needing further investigation and development. If the gain/beamwidth cannot be obtained for the required temperature range for the microstrip antenna, either the alternate antenna must be used or the transmitter output power must be increased from 2.5 watts to 5 watts. The Galileo Probe antenna HPBW is 56-degrees, which is too narrow for our mission.

The radar altimeter can be either a pulse type or FM/CW type. The latter is preferable from the standpoint of simplicity and power consumption. A simple dipole or slotted waveguide antenna for the altimeter would provide a beamwidth wide enough to handle specular reflections from the surface. (Specular is typical of moons and planets other than Earth.) It could be built to collapse upon probe impact at the surface. Viking Lander altimeter components or equivalent hi-rel parts technology could be used for the altimeter and little development effort would be required, other than the usual design for reliability and test for compliance. A frequency of 13.3 GHz is typical for the FM/CW unit and about 100 milliwatts of output would be required. If a pulsed radar technique were used, a 1-MHz frequency (Viking Lander) would be considered. The altimeter and its antenna are not considered technology development items since both the Lunar Excursion Module and the Mars Viking Lander used similar technology for altitude measurement during decent. Due to the short radar range requirement for the Titan Probe mission, the weight, size, and power of the radar altimeter should be compatible with the estimate of 1 kg, 1133 cm^3, and 1 watt, respectively.

The telemetry transmitter technology (exciter and power amplifiers) can be based on the Galileo Probe design, which is expected to provide 24 watts output at each of 2 adjacent frequencies for redundancy and withstand a 425g force for 30 seconds. The stable oscillator designs now being successfully developed (by Frequency Electronics, Inc. of New Hyde Park, New York) as the stable frequency source for the Galileo Probe can serve equally well as the technology base for the Titan Probe, except (i.e., the transmitter) weight becomes a problem when redundancy is considered.

A block diagram of the telecommunications subsystem as presently conceived for the single string baseline is given in Figure B-8. This subsystem consists of a stable oscillator, a telemetry transmitter, two telemetry antennas, an RF antenna selector switch, a radar altimeter transceiver, a radar altimeter antenna, and RF cabling. The stable oscillator is temperature controlled using a double oven and proportional control. The crystal is an SC cut selected for reduced shock susceptibility. The unit being developed for the transmitter in the Galileo Probe features a Dewar flask and welded titanium construction. Some of the major characteristics are given in Table B-2.



NOTES:
1. SINGLE STRING DIAGRAM
2. TELEMETRY RF OUT
   2.5W RF BASELINE
   24W RF DIRECT ENTRY
   6W RF (THICK 30% FROM ORBIT)
3. RADAR ALTIMETER NOT USED FOR THICK NITROGEN ATMOSPHERE

Figure B-8 Telecommunications Subsystem Functional Block Diagram

Table B-2 Stable Oscillator Characteristics

Power Output:	+1 dBm cw
Nominal Frequency:	23 MHz
Crystal:	SC cut
Frequency Stability:	3×10^{-10} after 5 hours warmup
Phase Stability:	(See Galileo procurement spec)
Temperature Control:	Double oven with proportional control
Construction Features:	Titanium Dewar Flask
	Welded construction
Size:	4.45 cm dia x 14 cm (1.75 in. dia x 5.5
Weight:	0.6 kg (20 oz)
Input Power:	5W warmup, 2W operate
Special Environment:	400g acceleration

The baseline transmitter requires a minimum of 2.5 watts RF output at 1400 MHz for the thin atmosphere and entry from orbit around Saturn. For thick 30% atmosphere or direct entry options, the power output requirement varies from 6 to 21.8 watts. The Galileo Probe transmitter output is 24 watts, thus it could be used for the high power options. For the baseline, the power amplifier section of the transmitter can be simplified to provide the lower output. Typical transmitter characteristics are given in Table B-3.

The telemetry antennas to be built by Martin Marietta are microstrip "patch" antennas with estimated performance characteristics as given in Table B-4. The design is based on the principles summarized in the baseline study. It remains to be seen whether the beamwidth can be broadened to a more desirable 120-degrees HPBW.

The radar altimeter is conceived as an FM/CW type using Viking and Lunar Excursion Module (LEM) parts technology. Estimated performance characteristics for the altimeter are given in Table B-5. The altimeter antenna to be built by Martin Marietta is a simple low gain type having a HPBW of about 90°. Teledyne Ryan, manufacturer of the Viking and LEM altimeters, is a good source for the transceiver. The altimeter must be designed and tested specifically for this mission to obtain the minimum size and weight required for the simple function of providing an altitude mark. No altimeter is required for the thick atmosphere model since a parachute is not required.

Table B-3 Telemetry Transmitter

Frequency:	1400 MHz
Output Power, min:	2.5 watts (24 watts option)
Frequency Source:	External stable oscillator (See Table B-1)
Output Impedance:	50 ohms
Modulation:	BPSK of carrier
Input Signal (PCM):	Convolutionally encoded K-7, Rate 1/2 at up to 4200 symbols/sec
Size:	8.6 cm x 10.7 cm x 12.2 cm (3.4 in. x 4.2 in. x 4.8 in.)
Weight:	1.6 kg (3.5 lb)
	28 watts (109 watts option)
Typical Source:	Motorola Government Electronics Division - Scottsdale, Arizona

Table B-4 Telemetry Antenna Characteristics

Type	Microstrip
Peak Gain	4.5 dBi
Half-Power Beamwidth	120 deg.
Axial Ratio	2 dBi on axis, 10 dBi at half power points
Input Impedance	50 ohms
Polarization	RHCP
Size	6 in. x 6in. x 0.6in.
Weight	1.0 kg
Power Handling	30 watts

Source: Martin Marietta, Denver, Colorado

Table B-5 Radar Altimeter Performance

Type	FM/CW
Output Signal	Altitude Mark at 90 ± 10 km
Nominal Frequency	13.3 MHz
Range	Over 200 meters
Range Accuracy	± 5% at 100 meters ± 10 meters
Output Power	100 milliwatts
Antenna	Dipole
Nominal S/N	TBD at 100 meters
Signal Detection & Ranging	Center of power tracking
Size	1130 cm^3
Weight	1 kg including antenna
Input Power	1 watt

For an extended 32-day mission it is assumed that the rendezvous time with the returning orbiter can be preset in the probe so that the probe is not required to receive commands from the orbiter to start transmission. If the probe is required to receive commands, a major change would be required to add a diplexer, receiver, and command demodulataor to the telecommunications subsystem. Also, a command transmission system would be required in the orbiter.

For a Class A probe, the basic difference in design is deletion of one of the telemetry antennas since no transmissions from the Titan surface is required.

The probe telecommunications telemetry link design is based on an orbiter receiving system having a pointable 12.8-degrees HPBW antenna and a system noise temperature of $380^{o}K^{+100}$ with the major contributor being the noise figure of the receiver. A $50^{o}K$ antenna temperature and $100^{o}K$ brightness temperature are assumed. A 3 dB pointing loss is assumed for the orbiter antenna.

B-6.2 Technology Requirements - Table B-6 lists the specific technology requirements related to the subsystem's hardware. Common to all the items are: (1) equipment survivability for 9 to 10 years in space required to perform the mission; (2) the thermal protection problem since they must be external to the metal protective shell of the probe to function; and (3) the requirement to function after experiencing the relatively high landing force of the probe on the surface of Titan (except the radar altimeter and its antenna).

Technology for the telemetry antennas is associated with obtaining the gain/beamwidth characteristics required for the mission in a lightweight compact design such as a microstrip antenna. These characteristics, including virtual standing wave ratio, must be maintained within reason (using the material selected) over a relatively wide temperature range - a range whose severity will depend on the success in designing a radome and thermal protection to limit the temperature excursions.

The telemetry transmitter being built for the Galileo Probe is designed to withstand 20 bars atmosphere pressure and an impact acceleration equivalent to the Titan missions. The output power for each channel is 24 watts, adequate for our worst case mission, but weight is the dominant problem especially for a dual redundant system. Likewise, the exciter (used to drive the transmiter) is designed for the 20 bars and high-acceleration entry. It also represents a weight problem for Titan Probe since the weight is 1.6 kg each. Assuming that the Galileo oscillator/driver/transmitter effort is successful in meeting the performance under adverse environment, and a successful weight reduction

Table B-6 Technology Requirements Table

12.1 Provide Telecommunications

Functional Requirements	Baseline Subsystem	Device Type	Required Elements	Technology Requirements
12.1.1 Maintain a communications link to orbiter transmitting science and subsystems status data	Telecommunications	Low Gain Antenna	Microstrip Connector Hybrid	Thermal protection (Radome, etc.)
		Transmitter		Temperature Compensation
			Electronic Components	Prevent Board Delamination and Detuning
			Amplifiers	Materials Selection
			Filters	10 Years in Space
			Multipliers	Weight Reduction
			Modulators	High g Loading
			ICs	Pressurization and Seal
			Power Supply	High Efficiency
			Transformers	Thermal Protection
			Isolator	Atmos Pressure
				10 Years in space
		Antenna Switch	Switch Contacts	High g Loading
			Actuator	Temperature Extremes
				Power Handling
				Pressurization and Seal
				10 Years in Space
		Coaxial Cable and Connectors	Conductors	High g Loading
			Insulation	Thermal Protection
				Low Noise and Loss
				10 Years in Space

Table B-6 Technology Requirements Table (concl)

12.1 Provide Telecommunications

	Functional Requirements	Baseline Subsystem	Device Type	Required Elements	Technology Requirements
12.1.2	Provide a stable frequency source for wind/doppler measurement during probe descent	Telecommunications	Ultra Stable Oscillator	Radio Crystal Oscillator CKT buffer amp double Oven Dewar Flash Voltage Reg. Oven Controller	Frequency Stability High g Loading Pressurization and Seal Weight Reduction 10 Years in Space
12.1.3	Sense a 100 meter altitude and initiative parachute jettisoning	Telecommunications	Radar Altimeter Antenna	Dipoles Feed Line	Temperature Compensation or Thermal Protection and Material Selection 10 Years in Space
			Radar Transceiver	Power Ampl Low Gain Ampl IF CKTS Detector Oscillator CKT Modulator CKT Power Supply CKT Filter	Pressurization and Seal Minimize Weight 10 Years in Space

effort can be implemented, this technology can be used for the Titan transmitter. For the thin atmosphere model both the pressure seen by the case and the transmitter output power will be much less. This should help substantially in reducing weight.

The stable oscillator, being designed for the Galileo mission, can be used as-is for the Titan Probe since both the expected performance and the weight are compatible.

The radar altimeter transceiver can be easily designed using today's technology. Since the design will be unique for this mission, a minimum weight approach can be stressed at the inception of the design. The radar antenna must be protected thermally as discussed above.

Both weight and volume become factors when considering a dual redundant approach. Depending on the atmosphere model and the type entry, a dual redundant approach is expected to increase the telecommunications weight by a factor of from 74 to 90%.

In summary, the dominant drivers in the probe telecommunications technology area are life in space, antenna design/thermal protection, and weight reduction for the driver/transmitter.

An item not directly related to the probe but to the probe interface is the receiving equipment on-board the relay craft. The receiver must be designed to handle up to 2084 information bits/second (4168 symbols/second) as determined in Reference 1 report. It is understood that the receiver in the Galileo program is designed for a 256 symbol/second rate. Further, the receiving antenna HPBW is assumed to be 12.8 degrees 20.5 dBi gain on axis and pointable whereas the Galileo antenna is fixed and has a HPBW of 20-degrees or 17 dBi gain. The significance of the lower gain of the actual Galileo receiving antenna versus that assumed in baseline study is that if we use the actual Galileo antenna, the stated probe transmitter powers would have to be increased by 3.5 dB, or 2.24 times, to maintain the stated link margins.

B-7 Power

B-7.1 Requirements Analysis

The baseline functions of the power, cabling and pyro subsystem are to:

- o Provide power during entry, descent and landed phases of the mission.
- o Provide pyrotechnical devices for jettisoning and deployment operations.
- o Provide interconnections between the various probe subsystems.

In addition to fulfilling these functions the power, cabling, and pyro subsystems must satisfy these mission drivers and constraints:

- o 7-year cruise life;
- o Survive sterilization procedures (150°C bake);
- o Withstand 300g landing impact;
- o Have high power/weight and power/volume ratios;
- o Supply high peak/average power ratios;
- o Withstand 10-year exposure to space conditions;
- o 11 days active life (107 days Class C).

To satisfy the power needs and constraints, a variety of factors must be considered. Atmosphere, temperature, and probe type all serve to control the amount of power needed by the probe. The battery capacity varies over a 95 to 104 W-hr range for the Class A probe and a 263 to 812 W-hr range for the Class B probe. The Class C probe would use RTGs to supplement battery power.

Pyrotechnical initiators are used to eject the nose cap; to deploy and jettison the parachute; to activate the probe and release the data gathering equipment. These initiators are fired by discrete signals sent from the data handling and command subsystem. The major requirements of the pyros is to survive the 150°C sterilization and retain their vitality for the 7 to 10-year space voyage.

B-7.1.1 Power

The power source on-board the probe needs to satisfy some very stringent requirements indeed. At this time, only two battery types satisfy the power-to-weight ratio requirement; lithium and zinc-silver oxide (Zn-AgO). Of these two battery types, the lithium cell has higher power-to-weight and power-to-volume ratios. Zinc-silver oxide batteries have the enormous advantage of being remotely activated and rechargeable. This makes the Zn-AgO battery eminently more practical than the lithium battery for use on the probe.

Detailed analysis on Zn-AgO batteries reveals that current battery technology is not sufficiently developed at this time to meet the needs of the probe. Zinc-silver oxide batteries typically have only a 6-hour wet life after activation and can supply 5-15 W-hr/lb. Minimum probe requirements indicate a need for an 11 to 107-day wet life and a minimum of 30 W-hr/lb. Information collected on Zn-AgO batteries indicates, however, that this technology should exist in the 1985-1987 time-frame.

The battery is required to withstand 300g impacts; this does not pose a severe problem. Tests run in a centrifuge show that Zn-AgO batteries maintained both structural and electrical integrity after exposure to a 500g force. This far exceeds the expected 300g impact of the probe and gives a wide margin of safety.

A Class C probe would not be able to carry a sufficient number of batteries alone to complete the mission. For this probe type an RTG would then be used to recharge the batteries during low demand periods (when transmitter and heating units were off) and to supplement the battery during peak demands. Table B-7 shows a requirements summary for the power subsystem.

A technology status investigation was conducted on the use of lithium batteries. The results of this study are included in the battery technology discussion (Section 3.2).

Table B-7 Electrical Power Subsystem Requirements

	Thin Atmosphere			Thick Atmosphere (30% Surface)		
Probe Class	A	B	C	A	B	C
Requirements						
Energy (W-hr)	95	263	322	404	812	938
Peak Power (W)	73	103	127	73	125	127
Active Mission Duration (Days)	11	11	107	11	11	107
Implementation						
Battery Type	Zn-AgO	Zn-AgO	Zn-AGO	Zn-AgO	Zn-AgO	Zn-AgO
Required Total Capacity (W-hr) (W-hr)	162	451	552	693	1392	1608
RTG Power (BOL) (W)	-	-	25	-	-	25
Weight (kg) (Includes Batteries, PCDA, Control Assemblies & RTGs	17	29	41	25	44	57

B-7.1.2 Pyros - Pyrotechnical initiators perform several ejection and deployment operations. These include:

- o Pre-Entry Operations
  1. Activation of Zn-AgO batteries
  2. Jettisoning of pre-entry science package upon entry
  3. Total of five initiators needed

- o Entry and Descent Operations
  1. Nose cap ejection at Mach 0.8
  2. Parachute deployment at Mach 0.8 (then atmosphere only)
  3. Jettison parachute at 100m
  4. Release nephelometer
  5. Operation of GCM and neutral mass spectrometer valves
  6. Total of 18 initiators needed

- o Landed Operations
  1. Deployment of equipment mast
  2. Release of sample drill
  3. Uncage seismometer
  4. Total of six initiators needed

This list applies to the baseline Class B probe only. Obviously, other class probes would require different numbers of initiators.

B-7.2 Technology Requirements

Batteries and RTUs are the only technologically immature portions of the power, cabling and pyro subsystem. Both cabling and pyros use well established and tested technologies. Studies show low temperature, long inactive periods and a 300g impact to be the only requirements for cabling and pyros. Table B-8 shows a summary of the technology analysis.

In all three probe classes, the batteries must be able to supply high current levels for short times without appreciably reducing cell life due to

Table B-8 Technology Requirements Table

16.5 Provide Electrical Power

	Functional Requirements	Baseline Subsystem	Device Type	Required Elements	Technology Requirements
16.5.1	Supply regulated 22-32 Vdc Vdc power while attached to Saturn orbiter	Electrical Power	Staging Electrical Interface Power Distribution and Control Assembly	Staging Connector Interface Cable Magnetic Latching Relays Relay Driver Electronics	Long Shelf life High Reliability
16.5.2	Supply 28V power while separated from the Saturn orbiter through end of mission	Electrical Power	Battery Power Distribution and Control Assembly RTG (Class B Extended and Class C Probes)	Secondary Zn-AgO Batteries Remote Actuator Devices Selenide RTG with PnO_2 Fuel Capsule	Long Shelf Life 300g Impact Sterilization Temperatures Low Degradation Low Weight 11 Day Active Life (Class B Probe)
16.5.2	Conduct power, signals, data between experiments, subsystem equipment	Electrical Power	Wiring Harness	Cables Connectors	Low Temperature (70°K to 1000°K)
16.5.4	Provide control of safe, arm, & firing of ordnance	Electrical Power	Pyro Control Unit	Relay Drivers Relays Initiators Pyro Ordnance	Long Shelf life 300g Impact
16.5.5	Provide protection from EMC	Electrical Power	Shredding (radiated EMC) Filtering (Conducted EMC)	Cable Shield Filters Single Point Ground	Long Temperature 300g Impact Long Shelf life

Table B-8 Technology Requirements Table (concl)

16.5 Provide Electrical Power (Continued)

	Functional Requirements	Baseline Subsystem	Device Type	Required Elements	Technolocy Requirements
16.5.6	Activate Batteries	Electrical Power	Pyro Activated Gas Generator	Pyro Ordnance Gas Source Ordnance Initiators Electrolyte Reservoir Electrolyte	Low Weight High Reliability/ Long Shelf Life
5.7	Transfer to Internal Power	Electrical Power	Motor Driven Switch	Motor-Driven Switch	Long Shelf Life
16.5.8	Provide Under Voltage Protection	Electrical Power	Sequential Load Shredding Control	Relays Voltage Sensors	Long Shelf Life 300g Impact
1C.5.9	Provide Short Circuit Protection	Electrical Power	Fuses (Redundant)	Fuses Single Point Ground	High Reliability 300g Impact
16.5.10	Provide power, signal and data interfaces to the pre-entry science module	Electrical Power	Electrical Interface	Pyro Operated Cable Cutters Dead Facing Relays Interface Cables	Long Shelf Life

passivation. Improvements in cell life foreseen in the next 5 to 7 years are primarily a result of more efficient activation procedures. During activation the electrolyte (stored in a sealed tank during the space flight) is dumped into the battery by ignition of pyros. As these techniques improve, batteries with a wet life of 107 days, and are able to withstand a 10-year space flight, should become available.

The RTG problem is somewhat more complex. Thermoelectric generators have been built using a wide range of technologies. Materials such as Bi_2Te_3, PbTe, A_sSnTe and SiGe operating from 500 to 1000°C have been used. Low temperature generators, such as the Snap 19, operate with an internal gas pressure caused by helium being released from the plutonium fuel. Multi-hundred watt generators vent their interiors to space after liftoff, thus operating in vacuum conditions.

During space flight, all power to the probe is supplied from the Saturn orbiter. At the time of separation, the batteries must take over this job and supply power for the 249-hour probe life. Activation procedures must commence 6 hours before probe release to ensure the probe's power system is operating satisf to. ily.

The RTG produces 25 watts of power for the Class C probe. A dc-to-dc power converter raised the RTG output voltage high enough to charge the batteries. Figure B-9 shows block diagrams of the A, B, and C class probes.

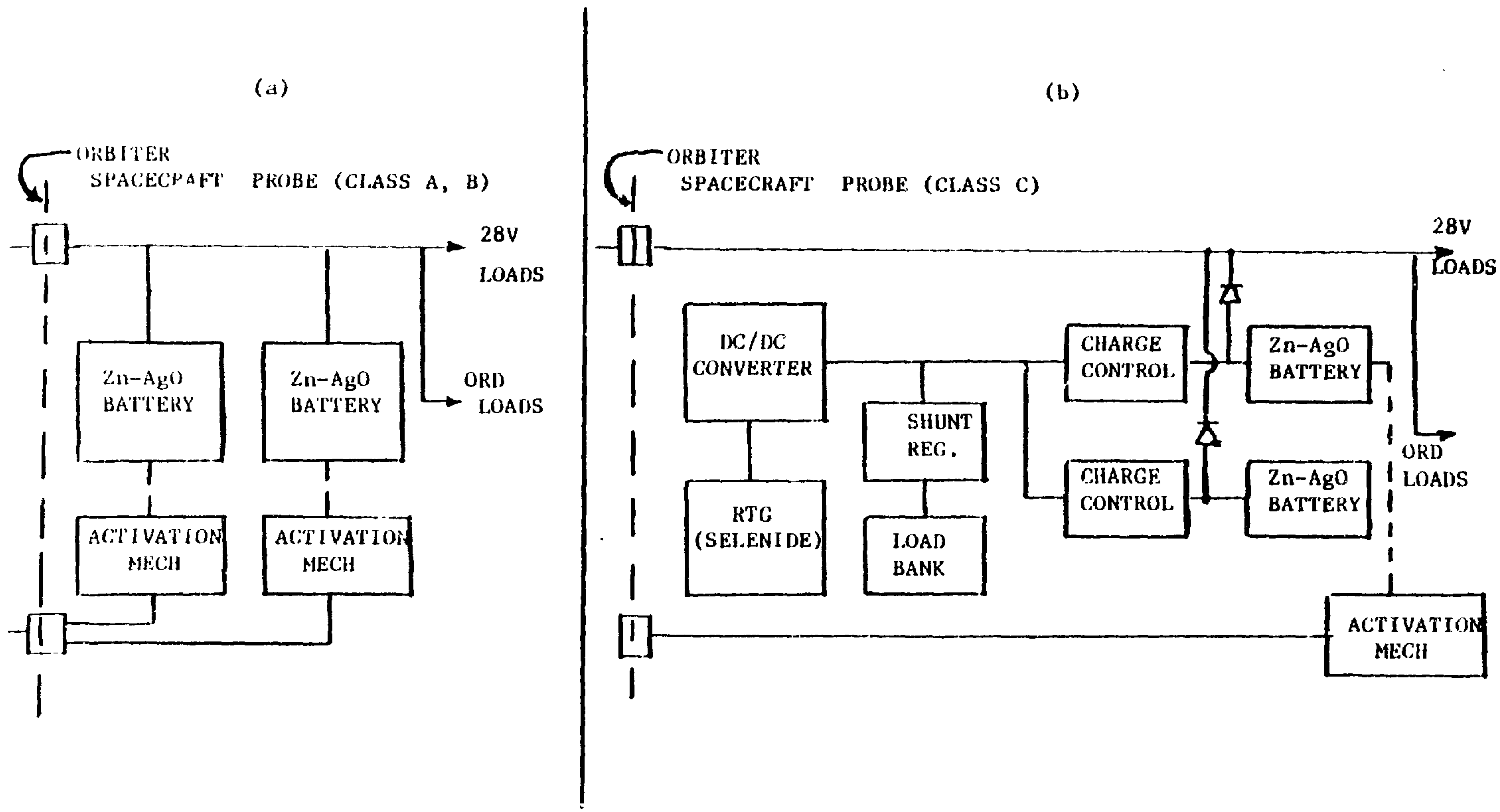


Figure B-9 Electrical Power Subsystem Functional Block Diagram

B-8 Data Handling and Command

B-8.1 Requirements Analysis

The functions required of the baseline data handling and command (DH&C) subsystem are to:

- o Provide on-board checkout for both preflight and preseparation configurations through the orbiter interface.
- o At separation, provide a timer for probe activation prior to entry.
- o At probe activation, provide sequences for science instrument warmup and calibrate and store the calibration data.
- o Provide sequencing of pre-entry science through an umbilical to the pre-entry module.
- o At the deceleration signal, activate the pre-entry module jettison sequence.
- o Provide sequencing and data storage of entry science measurements.
- o At deceleration and/or time signal, sequence pyros for parachute release, nose cap release, and instrument deployment functions.
- o Provide sequencing of descent science measurements and interleave stored data with real-time data for transmission to orbiter.
- o At an altitude of 100m, receive the radar signal to release the parachute (thin atmosphere only).

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

- Format and interleave the science and subsystem data and route this data to the telecommunications subsystem for transmission to the orbiter.

No detailed requirements, and thus design features, have been developed at this time for the DH&C subsystem. However, the basic design philosophies have been reviewed as defined in Reference 1, and determined to be adequate. No major design changes from the baseline subsystem described in that reference are recommended. Table B-9 shows the basic technical requirements of the DH&C.

The referenced study identifies the interface between the Titan Probe and the Saturn orbiter as being RF. This type interface requires a RF demodulator on both the Titan Probe and Saturn orbiter to demodulate and detect the signal so that the DH&C subsystems on the Titan Probe and Saturn orbiter can accept and respond to the commands/data, respectively.

The biggest drawback to this type interface is that the transmitters on the Titan Probe and Saturn orbiter must be turned on to communicate with each other. This operational mode can cause both thermal and prelaunch operational constraints. It is recommended that video (digital) interface be evaluated for at least part of these mission requirements. This type interface allows direct entry into the DH&C subsystems on the Titan Probe and Saturn orbiter.

A review of the DH&C subsystem revealed that the subsystem can be broken down into two major functional blocks, the data processor and the mass storage device. Both these blocks interface with the science experiments. The processor controls the experiments (and can, during entry, accept and store science data), and the mass storage accepts and stores surface science data.

Table B-9 Technology Requirements Table

16.0
15.0 Provide Data Handling and Control

Functionsl irements		Baseline Subsystem	Device Type	Required Elements	Technology Requirements
16.7.1	Collect data from science instruments	Data Handling and Control	Data Processor	CMOS: Gates, registers Crystal Oscillators	Radiation Hardening Long Shelf Life
16.7.2	Store data as required				
	- Pre-entry science	Buffers	Data Processor Storage	CMOS: Gates, Registers	Radiation Hardening Long Shelf Life
	- CCD Camera	Buffers	Analog Delay Line	CCD Bubble Memory	Sterilization Tempera-tures
16.12	Collect subsystem status data	Data Handling and Control	Data Processor	CMOS: Gates, Registers	Radiation Hardening Long Shelf Life
16.8	Interleave science and data and send to telecom-communications subsystem	Data Handling and Control	Data Processor	CMOS: Gates, Registers	Radiation Hardening Long Shelf Life
16.5	Provide on-board science data processing as required	Data Handling and Control	Data Buffer	Operational Amplifiers, Re-sistors, Capa-citors, CMOS Gates, Shift Registers, Crystal Oscillator	Radiation Hardening Long Shelf Life

Table B-9 Technology Requirements Table (cont)

16.0
15.0 Provide Data Handling and Control

	Functional Requirements	Baseline Subsystem	Device Type	Required Elements	Technology Requirements
15.0	Provide sequencing for experiment and probe subsystem events	Data Handling and Control	Data Processor (Sequence System)	CMOS Gates, Registers	Radiation Hardening Long Shelf Life
16.14	Initiate and accomplish instrument warmup and calibration	Data Handling and Control	Data Processor (Timing and Control)	CMOS Gates, Registers, Crystal Oscillator	Radiation Hardening Long Shelf Life
16.3	Accept updates to sequences and computer stored instructions	Data Handling and Control	Data Processor (Data Memory)	CMOS Gates, Registers	Radiation Hardening Long Shelf Life
16.3	Accept (and accomplish) commands (via hardware) from Saturn orbiter and GGSE	Data Handling and Control	Data Processor (Data Memory)	CMOS Gates, Registers	Radiation Hardening Long Shelf Life
15.1	Activate and checkout probe subsystems and experiments	Data Handling and Control	Date Processor (Timing and Control, Sequence System, Data	CMOS Gates, Registers, Crystal Oscillator, Operational Amplifiers, Resistors, Capacitors	Radiation Hardening Long Shelf Life

Table B-9 Technology Requirements Table (concl)

16.0
15.0 Provide Data Handling and Control

	Functionsl Requirements	Baseline Subsystem	Device Type	Required Elements	Technology Requirements
16.10	Provide status data to Saturn orbiter	Data Handling and	Data Processor	CMOS Gates,	Radiation Hardening
16.11		Control		Registers	Long Shelf Life
16.14	Perform calibration and operational checks of subsystems	Data Handling and Control	Data Processor (Sequence System, Timing, and Control, Data Buffer, Formatter	CMOS Gates, Registers, Crystal Oscillator, Operational Amplifiers Resistors, Capacitors	Radiation Hardening Long Shelf Life
16.4	Prepare, format, and issue commands to subsystems and experiments	Data Handling and Control	Data Processor (Data Memory, Timing and Control, Sequence System)	CMOS Gates, Registers Crystal Oscillator	Radiation Hardening Long Shelf Life
16.16	Provide a compatible data interface with Saturn orbiter and GSE	Data Handling and Control	Data Processor (Formatter, Scratch Pad, Timing and Control	CMOS Gates, Crystal Oscillator	Radiation Hardening Long Shelf Life
16.4.1	Accomplish transfer to internal power and separation commands	Data Handling and Control	Data Processor (Timing and Control)	CMOS Gates, Crystal Oscillator	Radiation Hardening Long Shelf Life
16.7.1	Provide a compatible data interface with the pre-entry science module	Data Handling and Control	Data Processor (Sequence System, Data Buffer)	CMOS Gates, Operational Amplifiers, Resistors, Capacitors	Radiation Hardening Long Shelf Life

The baselined data system processor was based on a preliminary design performed by Hughes Aircraft Company for the Galileo Jupiter atmospheric entry probe. The format is programmable and would be useful to update the descent sequence, if required, due to updated Titan atmospheric data gathered during flyby encounters by the orbiter prior to the Titan Probe release. Features of the data processor are shown in Table B-10.

Table B-10 Data Processor Features

- (Class B, C - 135k) Memory (Control, Data Storage, Format, Sequence, Scratch Pad)
- Class B, C - 97k) Bits of Storage in Memory
- Fixed and Programmable Formats
- Fixed or Programmable Descent Sequence
- 254 Available Command Channels (from Orbiter)
- 96 Discrete Command Lines (from Sequencer)
- 79 Output Commands (from DH&C)
- 6.2 kg; 6556 cm^3; 6 Watts

For this study, two levels of data storage are required for the Titan Probe mission depending on probe class. Emphasis was given to the Class B probe but impacts caused by the Class C probe were also considered.

In addition to the data processor storage capacity, supplemental storage capability is required for the surface science, primarily for imagery data. Storage requirements by probe class and mission phase are as follows:

Probe Class	Maximum Storage (Bits) Entry	Surface
B	97,000	1.08×10^6
C	97,000	14.2×10^6

While the data processor storage is adequate for both probe classes during entry, considerably more capacity is required for both probe classes, as mentioned above. This capability is to be provided by means of bubble memory discussed elsewhere in this report.

The data processor uses CMOS technology and is considered to be state-of-the-art for this mission. It can be broken down to several major functional blocks, as shown in Figure B-10.

The heart of the data processor is the timing and control circuitry. This circuitry generates the data clock which is used to time all functions performed, including clocking data into memory, exercising the sequence system, and updating the scratch pad, The clock will be crystal controlled and the crystal will oscillate at a frequency at least an order of magnitude higher than the data clock rate in order to enhance frequency stability. See Table B-11 for data requirements.

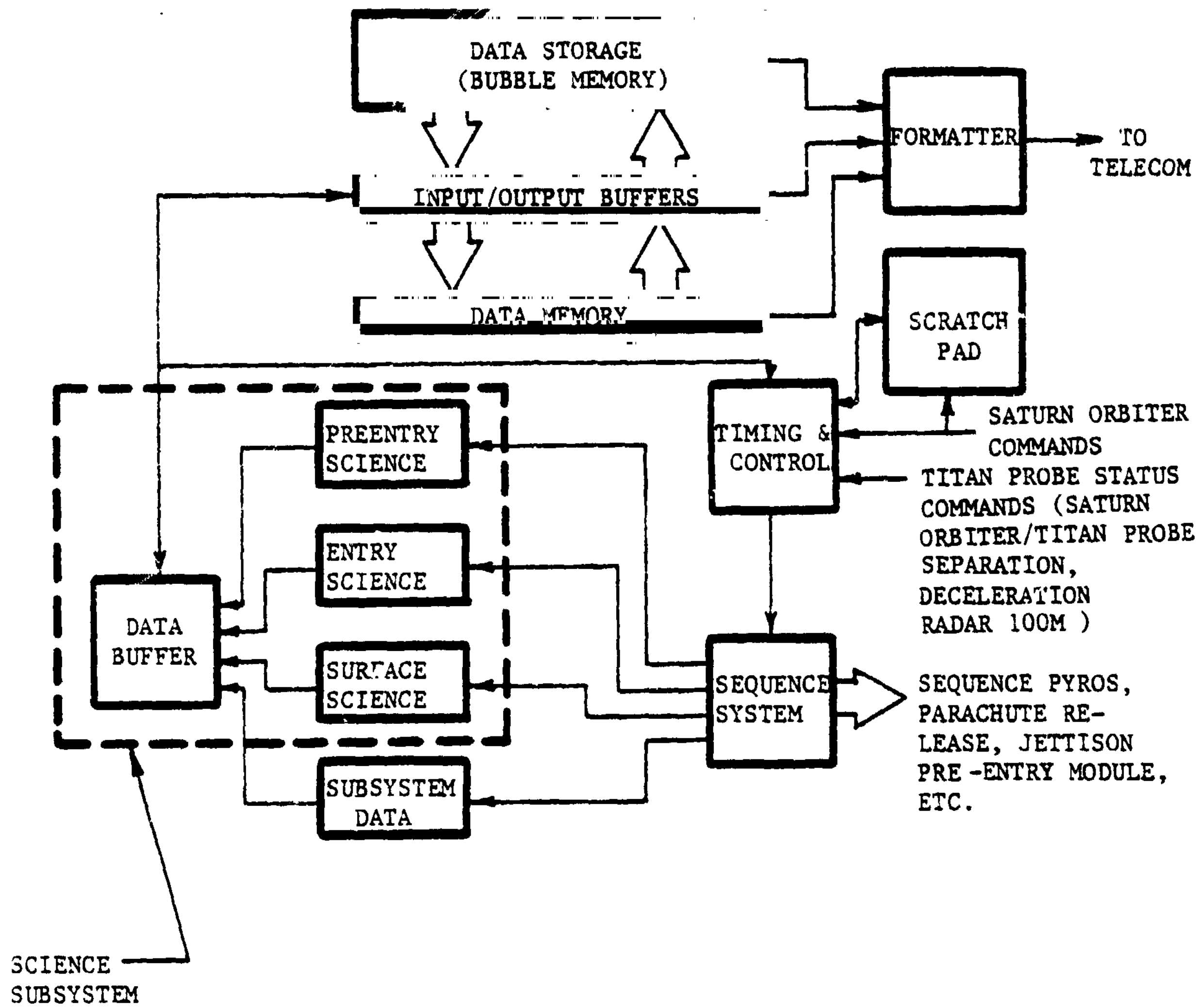


Figure B-10 Data Handling and Command Subsystem Functional Block Diagram

Table B-11 Baseline Probe Data Requirements by Mission Operational Phase

PROBE DESIGN		WARM-UP CALIBRATE	PRE-ENTRY	ENTRY	DESCENT	TOUCHDOWN INITIAL SURFACE		EXTENDED SURFACE	RE-ENCOUNTER
THIN ATMOSPHERE, TIME, MIN		10	33	11	25	90		(32 Days)	90
Class A									
o Total Bits	bits	10,000	-	15,345	50,720	-		-	-
o Data Rate	bps	Store	-	Store	96 (1)	-		-	-
						30 M	60 M		
Class B									
o Total Bits	bits	10,000	72,000	15,345	2.3×10^6 (2)	4.1×10^6	2.2×10^6	-	-
o Data Rate	bps	Store	Store	Store	1,560	2,284	630	-	-
						60 M	30 M		
Class C									
o Total Bits	bits	10,000	72,000	15,345	2.56×10^6 (2)	4.6×10^6	1.1×10^6	14.2×10^6	14.2×10^6
o Data Rate	bps	Store	Store	Store	1,722	1,283	660	Store	2,625
THICK ATMOSPHERE, TIME, MIN		10	33	8	283	60	30	(32 Days)	90
Class A									
o Total Bits	bits	10,000	-	12,960	120,500 (1)	-		-	-
o Data Rate	bps	Store	-	Store	21	-		-	-
Class B									
o Total Bits	bits	10,000	72,000	12,960	12.7×10^6 (3)	4.1×10^6	1.1×10^6	-	-
o Data Rate	bps	Store	Store	Store	750	1,142	600	-	-
Class C									
o Total Bits	bits	10,000	72,000	12,960	17.3×10^6 (4)	4.6×10^6	1.1×10^6	14.2×10^6	14.2×10^6
o Data Rate	bps	Store	Store	Store	1,018	1,283	600	Store	2,625
Class B to 10% Surface									
o Total Bits	bits	10,000	72,000	12,960	12.7×10^6	5.2×10^6		-	-
o Data Rate	bps	Store	Store	Store	750	960		-	-

NOTES

(1) Multiple playback of entry data

(2) Two descent images

(3) Eleven descent images

(4) Fifteen descent images

The timing and control responds to various commands, such as orbiter-to-probe "health" checks, orbiter/probe separation command/indication, deceleration and radar 100-meter indication. Each of these commands or discrete events causes the timing and control to either activate a sequence or input/output to memory.

One primary function the timing and control performs is to provide a timer to activate the probe after 5 to 10 days following separation from the orbiter. The discrete signal issued to activate ("warmup") the probe is derived by counting down an extremely slow clock (1 pulse per second). These clock pulses can be derived from either the basic data clock or a separate less complex clock since precise timing should not be required.

The other various probe status discretes, (i.e. deceleration and the radar 100-meter altitude indication) cause ignition of pyros, parachute release, and the jettison of pre-entry module at approriate times.

The interface between the sequence system and the science subsystem consists merely of the probe/orbiter separation bi-level signal since each instrument will be designed to sequence itself after receiving the separation indication. An alternative approach to sequence the science subsystem could be to use the timer in the timing and control circuitry. Also, in reference to the timer, this same circuite could be used to provide sequence commands to turn the transmitter on or off as required for the Class C probe, since the RF telemetry is required only when the orbiter is in sight.

The science subsystem's data buffer supplies a single multiplexed data stream containing science and subsystem data to the input/output buffers, which either load the data into memory or directly to the formatter, and thus, to the telecommunication subsystem for real-time transmission.

The input/output buffers control the flow of data to either the processor memory or mass storage as required during the descent and surface phase of the mission.

The formatter accepts data from either data memory or mass storage or directly for real-time transmission and then converts the data to the proper PCM format. The data is then routed to the telecommunications subsystem for transmission.

The mass storage concept baseline is bubble memory. Table B-12 presents a summary of the storage characteristics. Previous studies showed that space qualified bubble memories of the capacity required for this mission would be state-of-the-art by the early to mid-1980s. several industry and government sources were contacted for this study to update the information previously gathered and to obtain projections for the development of bubble memories. Each of these sources were very optimistic as to the future use of bubble memories in space. They were also consistent in their predictions of package size and power consumption for the memory capacity required.

Table B-12 Data Storage Summary

Mass (kB)	Volume (cm^3)	Power (W)	Total Bits
10	7,200	20	14×10^7

Requirements:

Class B Probe: 10^6 bits for science including imagery

Class C Probe: 14.2×10^6 bits over 32-day period for surface science

B-9 Thermal Control

B-9.1 Requirements Analysis

The required functions of the baseline Thermal Control System (TCS) for the Titan Probe are to:

- o Maintain all probe components within storage temperature limits during the prelaunch, launch, cruise, and coast phases of the mission.
- o Maintain all probe components within operational temperature limits during the warmup, pre-entry, entry, descent, and landed phases of the mission.

The TCS must perform these functions while satisfying the following mission drivers and constraints:

- o Maintain structural integrity and operational capability under a 300g impact load.
- o Provide thermal protection from an uncertain environment on the surface of Titan as follows:
  1. Temperature
     a. $70^{\circ}K$ to $100^{\circ}K$
  2. Atmosphere
     a. 100% methane or nitrogen
     b. 0.2 to 2 bars pressure
     c. Wind velocity TBD m/sec
- o Limit the weight of the TCS to a maximum of 21.0 kg (does not include ablative heat shield).

- o Satisfactorily perform a mission life of approximately 10 years.

- o Hold contamination of the Titan surface to specified limits.

The TCS described in the baseline study consists of a 7.6-cm thick layer of insulation inside the spherical aft cover; thermal isolation standoffs to mount components on the honeycomb backplate; insulation between the honeycomb backplate and the components; and insulation around the central structural tube, thus enclosing the components. Radioisotope thermal units (RTUs) are used within this enclosure to replace the heat lost through the insulation and probe structure to the Titan environment during the warmup, pre-entry, entry, descent, and landed phases of the mission. ground cooling loop is provided to reject the RTU heat load during the prelaunch phase. Heat pipes conduct the RTU heat load to a spacecraft-mounted radiator during the cruise phase and to a probe-mounted radiator during the coast phase.

A review of this passive TCS shows that it does not provide the control necessary to account for the following uncertainties in the Titan environment:

- o Temperature is predicted to be in the range of 70°K to 100°K.

- o Atmospheric composition may range from 100% methane (baseline) to 100% nitrogen at pressures from 0.2 bar to 2.0 bars. Insulation performance will vary significantly over this range of conditions due to "poisoning" by the atmosphere.

- o Winds may result in high convective losses at exterior surfaces of the probe.

To account for these uncertainties, it is proposed that the described passive TCS be designed with a cold bias for the cruise and coast phases. It is also proposed that the RTU thermal output be supplemented by thermostatically controlled electrical resistance heaters to control the compartment temperature within specified limits during the landed phase of the mission. Figures B-11 and B-11a show a functional block diagram of this system.

An alternate design may be required if better definition of the Titan environment and component operational temperatures indicates the necessity to reject rather than add heat during the landed phase. In this event, mechanisms would be provided to move the RTUs in or out of the probe interior, as required, to control compartment temperature within specified limits during the landed phase of the mission. Figure B-12 shows a functional block diagram of this alternate system.

An undesirable feature of the TCS described in the baseline configuration is the spacecraft-mounted radiator which requires the use of heat pipes that cross the Solar orbiter-Titan Probe interface. These pipes must be vented and cut prior to probe separation, thus presenting some very serious problems like:

- Single point mission failure should any one of the pipe cutters fail to function properly.
- Containment of the pressurized working fluid to prevent probe contamination.

To avert these problems, the Saturn orbiter-Titan Probe configuration should be designed such that the probe-mounted radiator can reject the RTU heat load during the cruise phase as well as the coast phase of the mission, thus eliminating the need for heat pipes across the Saturn orbiter-Titan Probe interface.

In addition to the TCS described in the baseline, thermal control is required for the pre-entry science module and for the components within the central structural tube. Also, the antennas may require special thermal control to prevent detuning and/or delamination caused by excessive temperature excursions.

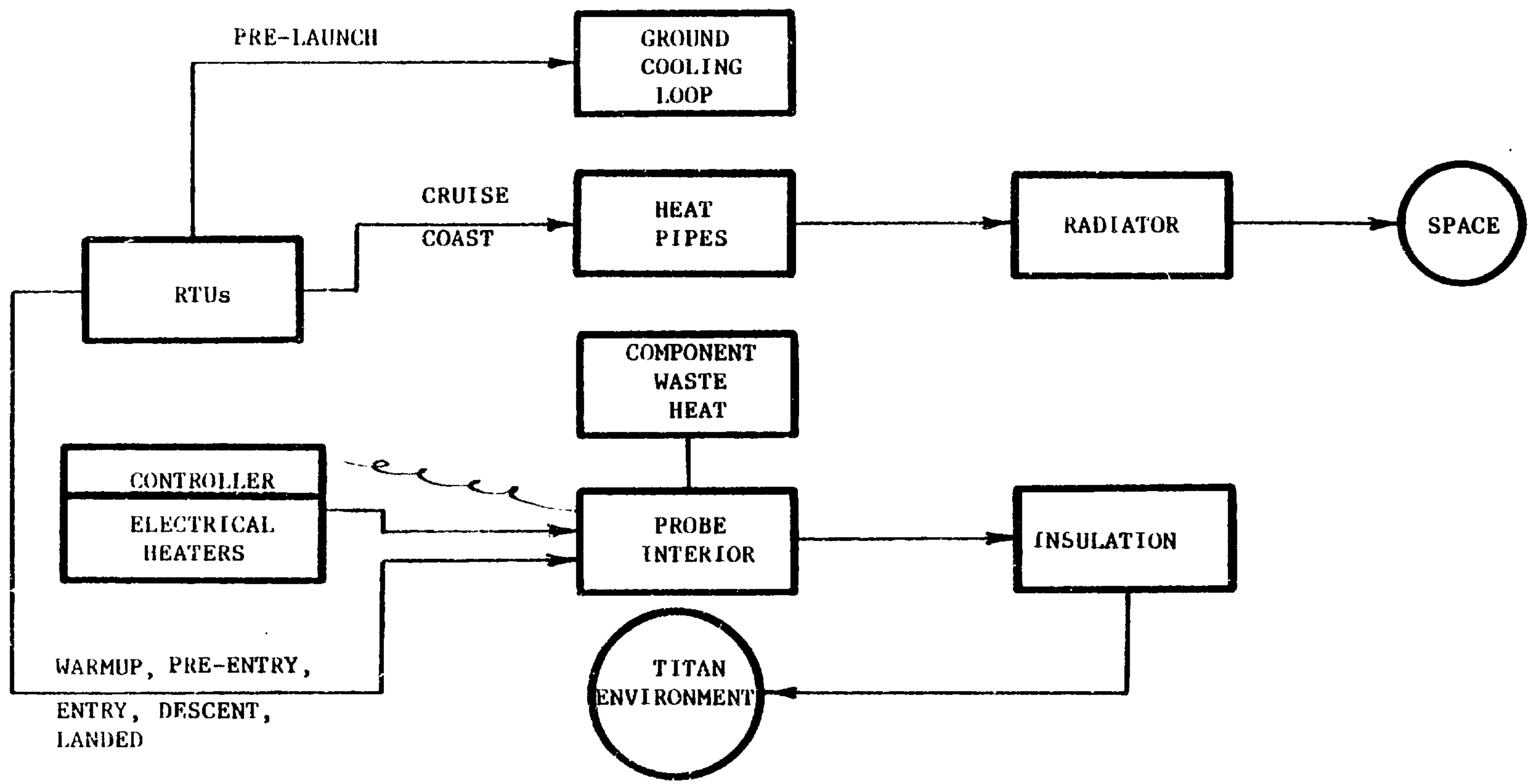


Figure B-11 Thermal Control System Functional Block Diagram with Electrical Resistance Heaters

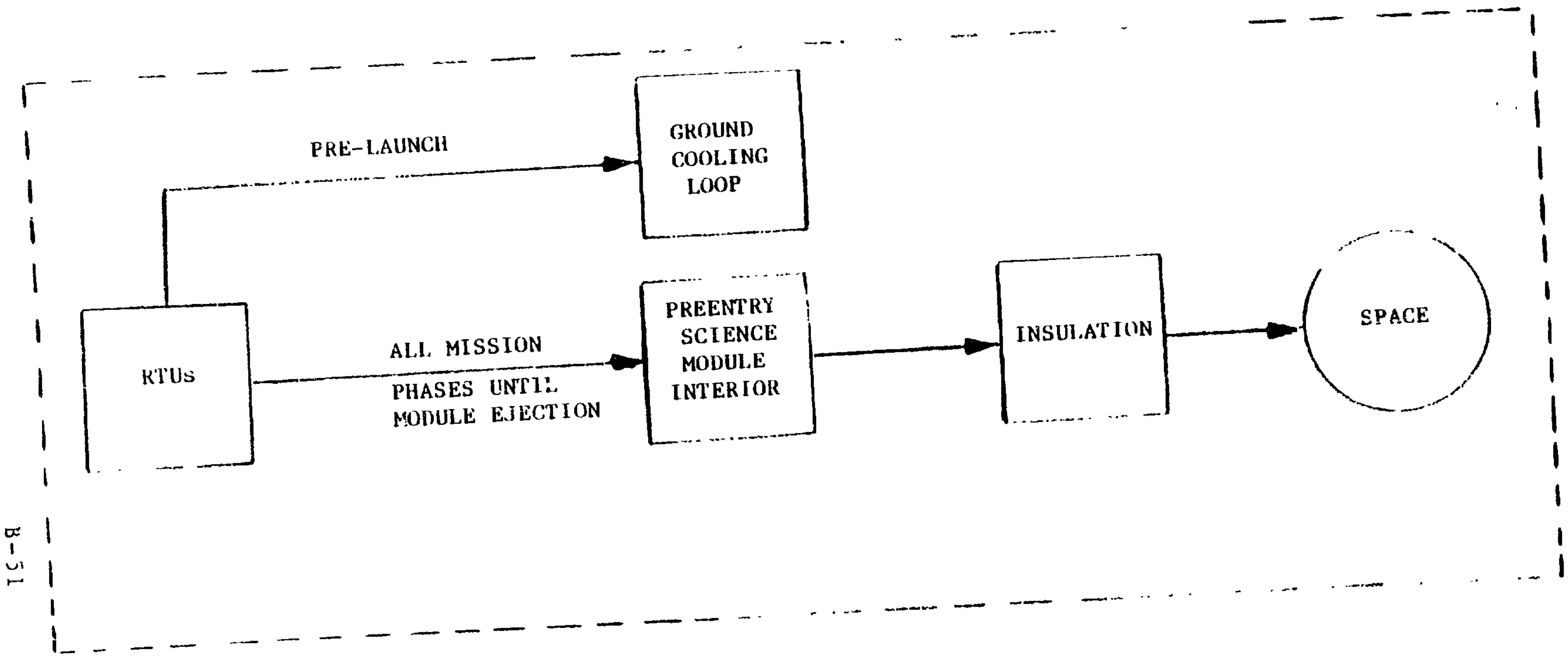


Figure B-11a Thermal Control System Functional Block Diagram for Pre-entry Module

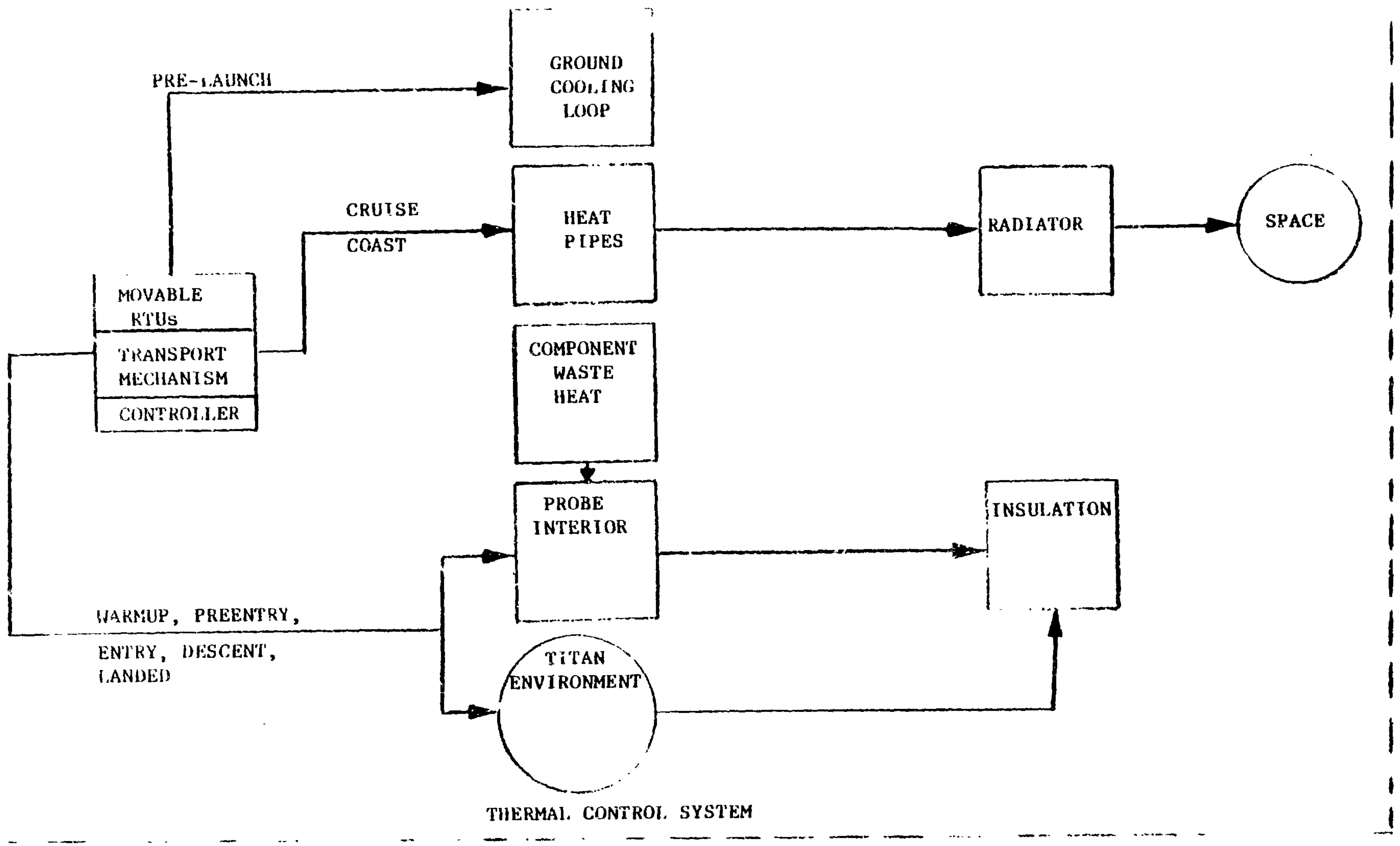


Figure B-12 Functional Block Diagram of Alternate TCS with Movable Isotope Heaters

Since the pre-entry science module will be subjected to a fairly constant and predictable environment, its components can be maintained within specified limits by a passive TCS consisting of insulation enclosing the module interior and electrical heaters to supply the heat losses.

The central tube TCS will be designed as an integrated part of the probe interior TCS.

B-9.2 Technology Requirements - The technology requirements for the TCS are shown in Table B-13 and discussed in the following paragraphs.

The ground cooling loop must be capable of rejecting 200 to 250 watts thermal to the ground cooling system while maintaining the probe interior at approximately 278°K (40°F). It must also have the capability of heating the probe interior by high temperature fluid flow (TBD °K) to aid in the sterilization process. The ground cooling loops are similar to those used on the Viking Landers. This technology is considered to be well within present state-of-the-art.

The probe-mounted radiator system is required to reject 200 to 250 watts thermal to space while maintaining the probe interior at approximately 278°K (40°F) during the cruise and coast phases (10 years). The technology for the use of heat pipes and radiators in a zero-g environment is well established and is, therefore, within the present state-of-the-art.

Fiberglass insulation must be capable of limiting heat losses to 250 to 300 watts thermal with the components at operational temperatures and the exterior surfaces subjected to the uncertain conditions on Titan's surface. Studies are required to establish insulation fabrication techniques and construction details to prevent contamination of the probe interior with insulation particles and to maintain the structural integrity of the insulation under a 300g impact load. This is not considered to be a technology development item.

Table B-13 Technology Requirements Table

5.0
13.0 Provide Thermal Control

Functional Requirements	Baseline Subsystem	Device Type	Required Elements	Technology Requirements
5.1 Maintain equipment and science at the desired temperature range prior to launch	GSE Cooling System	Ground Cooling Loop	- Material	Configuration GSE Interface High Temp Capability to aid sterilization State-of-the-art
5.2 Maintain desired temperature range during cruise and coast phases	Probe-Mounted Radiator System	Heat Pipes	- Pipe - Wick - Working Fluid - Materials	 Configuration Zero-g Operation
		Radiator	- Material	Lightweight State-of-the-art
13.1 Maintain desired temperature range during warmup, pre-entry, entry, descent, and landed phases	Insulation	Insulating Blankets	- Fiberglass - Lightweight	High efficiency in Titan Atmosphere Configured to withstand 300g load Heater penetrations (Alternate System)
		Isolation Standoffs	- Material	Low Temperature Strength
	RTU	RTU	- Materials	Configuration Thermal Output
		Transport Mechanism	- Materials	Design to survive 300g impact and provide positive positioning of RTUs
	(Alternate System)	- Controllers	- Temperature Sensor	
	- Actuator			

Table B-13 Technology Requirements Table (concl)

5.0
13.0 Provide Thermal Control

Functional Requirements	Baseline Subsystem	Device Type	Required Elements	Tehcnology Requirements
13.1 (Continued)	Thermostatically controlled eletric heaters	Controllers Resistance Heaters	- Materials	Design to survive 300 g
	Aeroshell	Ablator	- Material	Jettison prior to impact to prevent contamination of area

The 10-year life requirement of the Titan Probe dictates the use of RTUs to provide a relatively constant passive heat source for the cruise and coast phases of the mission. The RTUs must be sized (approximately 200 to 250 watts thermal) to maintain the probe components near their minimum storage limits (cold bias). This is considered to be a technology development item due to the comparatively high thermal output requirement for the RTUs. The Galileo Probe uses small (1 watt) RTUs that are jettisoned with the aeroshell prior to entry.

In addition, should it be determined that the RTUs must be moved to obtain the necessary thermal control, studies would be required to develop simple reliable mechanisms to provide positive movement and positioning of the RTUs through penetrations in the probe insulation. In conjunction with the transport mechanism studies, controllers would have to be devised to sense the probe interior temperature and actuate the transport mechanisms. Also, the insulation penetrations would have to be designed to minimize losses and, at the same time, permit the RTUs to reject their heat either to the Titan environment or to the probe interior, depending on RTU position.

The thermostatically controlled electrical resistance heaters are required to supplement the cold bias RTU output to maintain the components within operational temperature limits by replacing the probe heat losses to the environment (250 to 300 watts total). The use of electric resistance heaters is well within the state-of-the-art. However, technology development is required to establish a design that will withstand the 300g impact load.

The use of ablative heatshields to dissipate the heat generated during entry and descent is a well established technology. In the Titan Probe application, however, the heatshield must either be jettisoned prior to probe impact or some other means employed to prevent contamination of the impact area on Titan by the charred ablator material.

Thermal control of the antennas may be required to maintain some specified operating temperature and to minimize temperature excursions to prevent detuning and/or delamination of the antennas. This is being flagged as a technology development item in both the thermal control and the telecommunications subsystems.

APPENDIX C

APPENDIX C RELATED DOCUMENTATION

1. Final Report Study of Entry and Landing Probes for Exploration of Titan
Contract NAS 7-9985, Martin Marietta MCR-79-519,
31 March 1979

2. NASA - Ames Research Center
Contract NAS 2-10380,
including Statement of Work No. 2-27857
September 17, 1979

3. Operation Directive - 203785 supl : 100
Titled: Titan Probe Technology Assessment and Development Plan Study
Contract NAS 2-10380, Martin Marietta,
29 October 1979

4. Letter, SPT : 244-7/203 dated 3 December 1979
Action Items from the Titan Probe Technology Study Kickoff Meeting, to A.J. Castro, Martin Marietta from J.P. Murphy, Ames Research Center (w/2 enclosures)

5. Mid-term Review
Titan Probe Technology Assessment and Technology Development Plan Study, Martin Marietta, TPT-MA-02-1,
Presented 6 March 1980

6. Final Review
Titan Probe Technology Assessment and Technology Development Plan Study, Martin Marietta, TPT-MA-02-2,
Presented 23 May 1980