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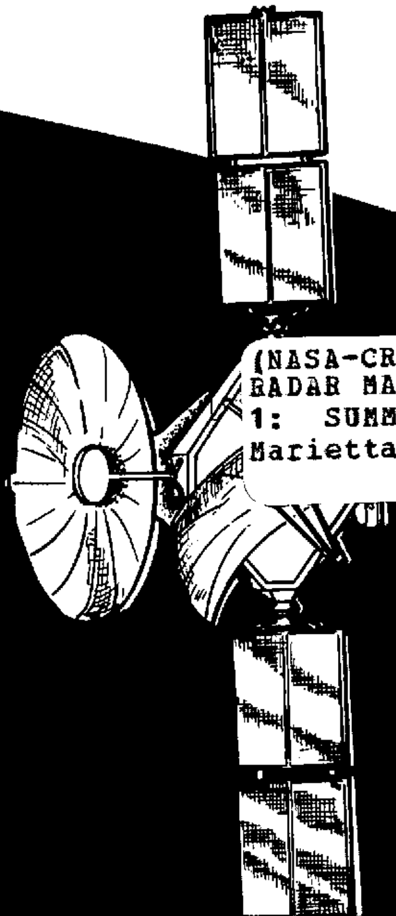
Final Report

A Study of an Orbital Radar Mapping Mission to Venus



Volume I

Summary

September 1973

NASA CR 114640

A STUDY OF AN ORBITAL RADAR MAPPING MISSION TO VENUS

FINAL REPORT

VOLUME I SUMMARY

September 1973

Approved

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Program Manager

D. B. Cross
Technical Director

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER

FOREWORD

This report has been prepared in accordance with the requirements of Contract NAS2-7204 and under the direction of the NASA Contract Monitor John S. MacKay. The data and conclusions are the result of a nine month technical effort conducted for the Ames Research Center by the Martin Marietta Aerospace, Denver Division and the Environmental Research Institute of Michigan (ERIM) as a subcontractor. The report is divided into the following volumes:

Volume I	Summary
Volume II	Configuration Comparisons and System Evaluations
Volume III	Parametric Studies and Subsystem Comparisons

The report is arranged so that Volume I provides a concise overview of the study, Volume II provides an appreciation of the major mission and system integration considerations as well as cost and schedule implications and Volume III provides the detailed supporting tradeoff studies down to the subsystem level.

ACKNOWLEDGEMENTS

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I. INTRODUCTION

Venus, the nearest of Earth's planetary neighbors and the planet most like the Earth in many respects, remains a mystery because of its thick layers of clouds. If good resolution images of the Venusian surface were made available, it is reasonable to expect that exciting discoveries would emerge.

Since energy in the visible or IR wavelengths does not reach the surface without appreciable attenuation, photographic images equivalent to the Mariner 9 returns from Mars will not be possible at Venus. However, since RF energy at wavelengths of 5 cm or longer will penetrate the Venus atmosphere, radar imaging of the Venus surface is a real and exciting possibility. Recent applications of fine resolution, side looking radar imaging at Earth have demonstrated the value of this technique in revealing topographic data and geologic information under difficult "seeing" conditions. Figure I-1 is an example of the effectiveness of synthetic aperture, side looking radar imaging. This mosaic was made over Venezuelan terrain that, when not covered with dense clouds, is blanketed with obscuring foliage. While much of the imaging detail is in fact radar return from the tops of the trees, the contours of the underlying surface are much more evident than they would be in normal photographs.

With the powerful imaging tool available, NASA made an appropriate and responsible decision to look into its application to the mapping of the Venus surface.

Several studies of the Venus radar mapping mission have been completed: Planetary Imaging Radar Study (JPL); A Preliminary Analysis of a Radar Mapping Mission to Venus (SSD, Ames Research Center); and Venus Orbiting Imaging Radar Study (JPL). These

Figure I-1 Radar Imaging of Venezuelan Terrain, 3 cm wavelength, 10 meter resolution
(Courtesy Goodyear Aircraft Corp.)

studies have concentrated on different aspects of the mission and systems requirements, with each making reliable contributions to the understanding of the complete mission. The study reported here was directed by the Ames Research Center with the objective of tying together the mission features and alternatives so that overall feasibility, effectiveness and technology problems could be assessed.

II. STUDY APPROACH

The study objective as established by the NASA Technical Monitor, Mr. John S. MacKay, was to develop a preliminary design of a Venus radar mapping orbiter mission and spacecraft to identify and evaluate the important technological problems. Thus, the work involved trading off alternate ways of implementing the mission and examining the most attractive concepts in detail to assess technology requirements. Figure II-1 outlines the sequence of study events. A sample mission was first evaluated using "best guess" assumptions on spacecraft and mission parameters so that the interactions among these parameters could be understood. The sample mission became the baseline for more detailed studies of science, mission and spacecraft subsystem alternatives. These alternatives were then sorted into compatible groupings or alternative mission/spacecraft concepts for further study. Twenty-six compatible groupings were analyzed by examining the interaction of their functioning elements and assessing their overall cost/effectiveness in performing the mapping mission. Three preferred candidate designs were finally selected for more detailed definition. Cost, schedule and performance information was compiled for one recommended mission/spacecraft concept. Recommendations for further technology development were made in support of the

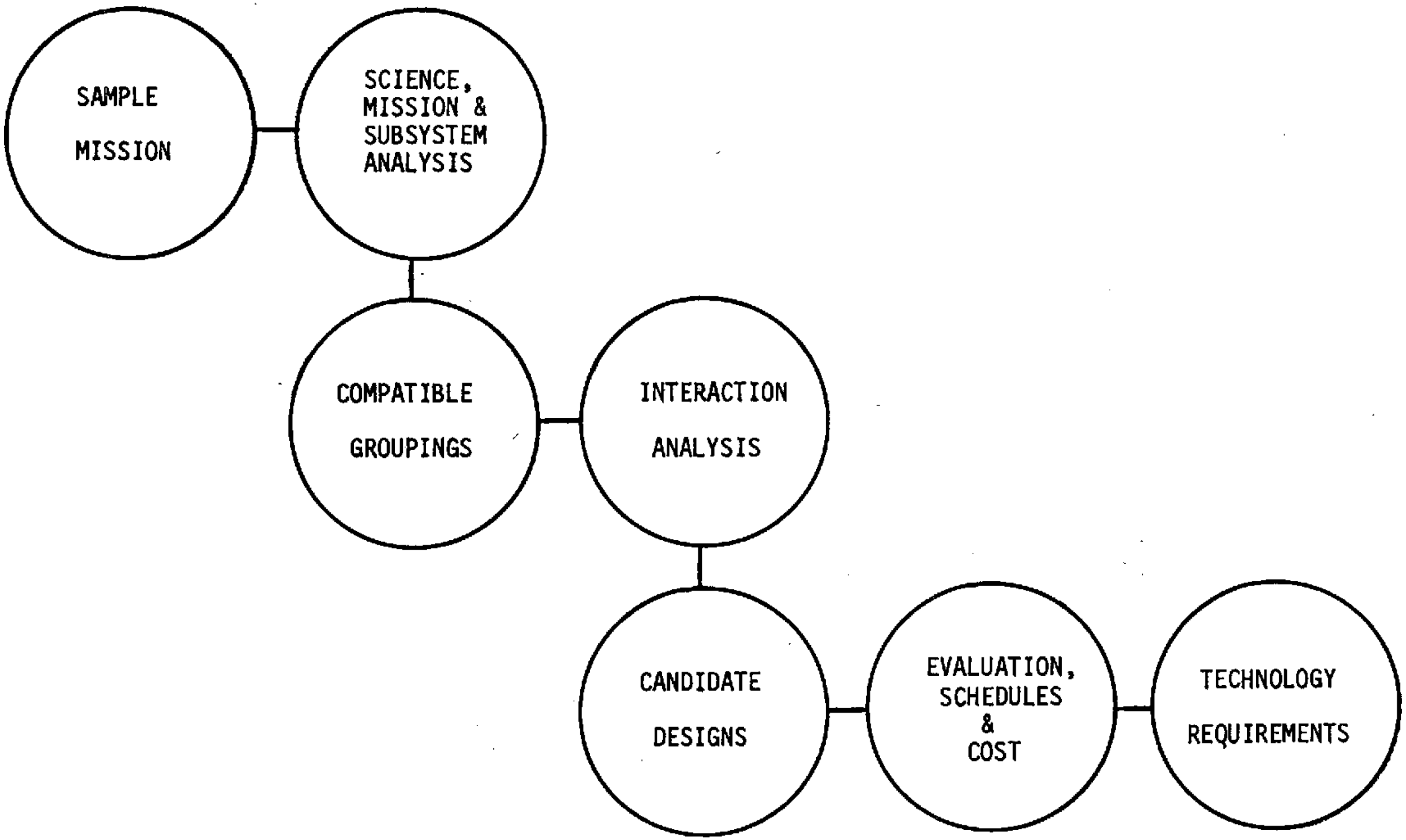


Figure II-1 Study Flow

recommended configuration and a number of potential enhancement features that could be added to that baseline.

The basic mission features common to all concepts studied are:

1. Injection to Venus of a spacecraft in the 2000-3000 kg class (including propellants) on a Type I or Type II trajectory.
2. Insertion into a polar or near-polar orbit at Venus with eccentricity from 0 (circular) to 0.5, and periapsis altitude approximately 400 km.
3. Useful weight in orbit (not counting propulsion system weight) of 700-1000 kg.
4. Three-axis stabilized orbiting spacecraft carrying a side looking radar and antenna (peak transmitted power in the 200 to 1000 W range), on-board data processing, storage and transmitting equipment (raw data from the radar at 6 to 12 megabits/sec; data storage of 1000 to 3000 megabits; data rates to Earth of 80 to 250 kilobits/sec), and supporting subsystems.
5. Complete or near complete mapping coverage of Venus at resolutions of 30 to 200 meters.

Figure II-2 shows the mission heliocentric geometry for typical launch years (in 1983 and 1984). Figure II-3 is a view of the typical orbital geometry at arrival. Figure II-4 shows the recommended mapping spacecraft concept developed in this study. This spacecraft is a derivative of the Viking '75 Orbiter design to which has been added the radar system and antenna, a new communication system and antenna, articulated solar panels, and supporting modifications and additions. These mission features will be summarized in more detail later in this volume.

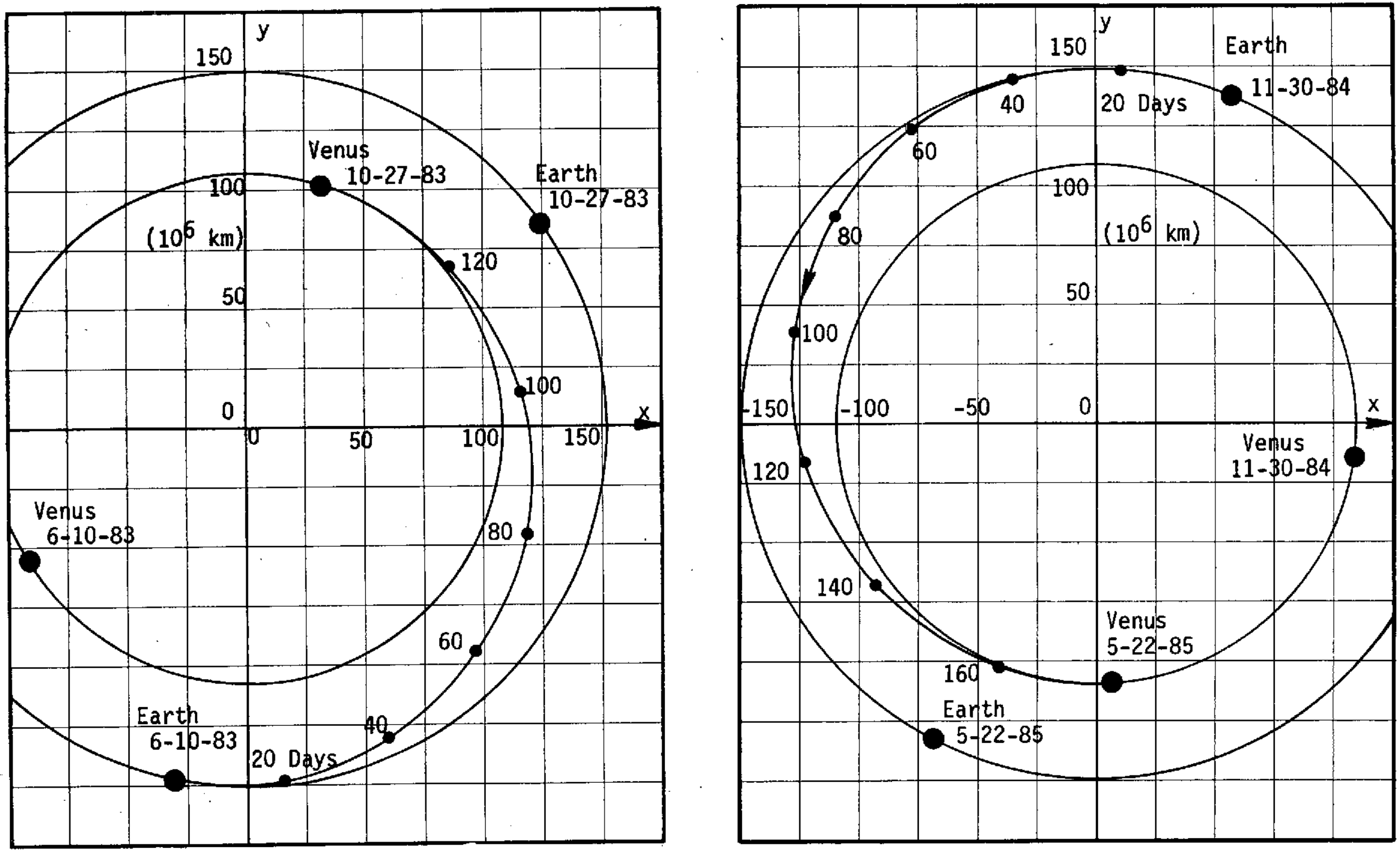


Figure II-2 Mission Heliocentric Geometry for Typical Launch Years (1983 & 1984)

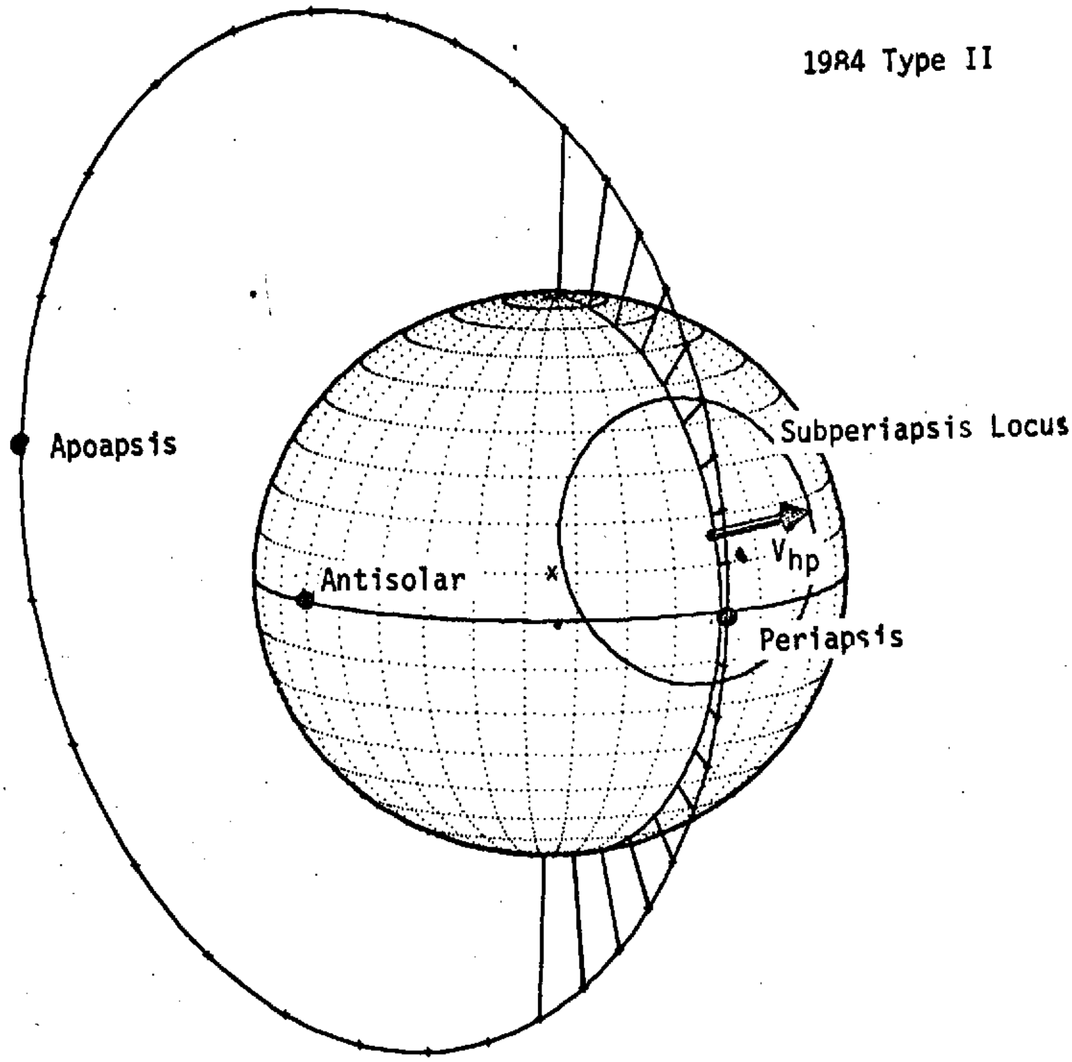


Figure II-3 Typical Orbital Geometry at Arrival

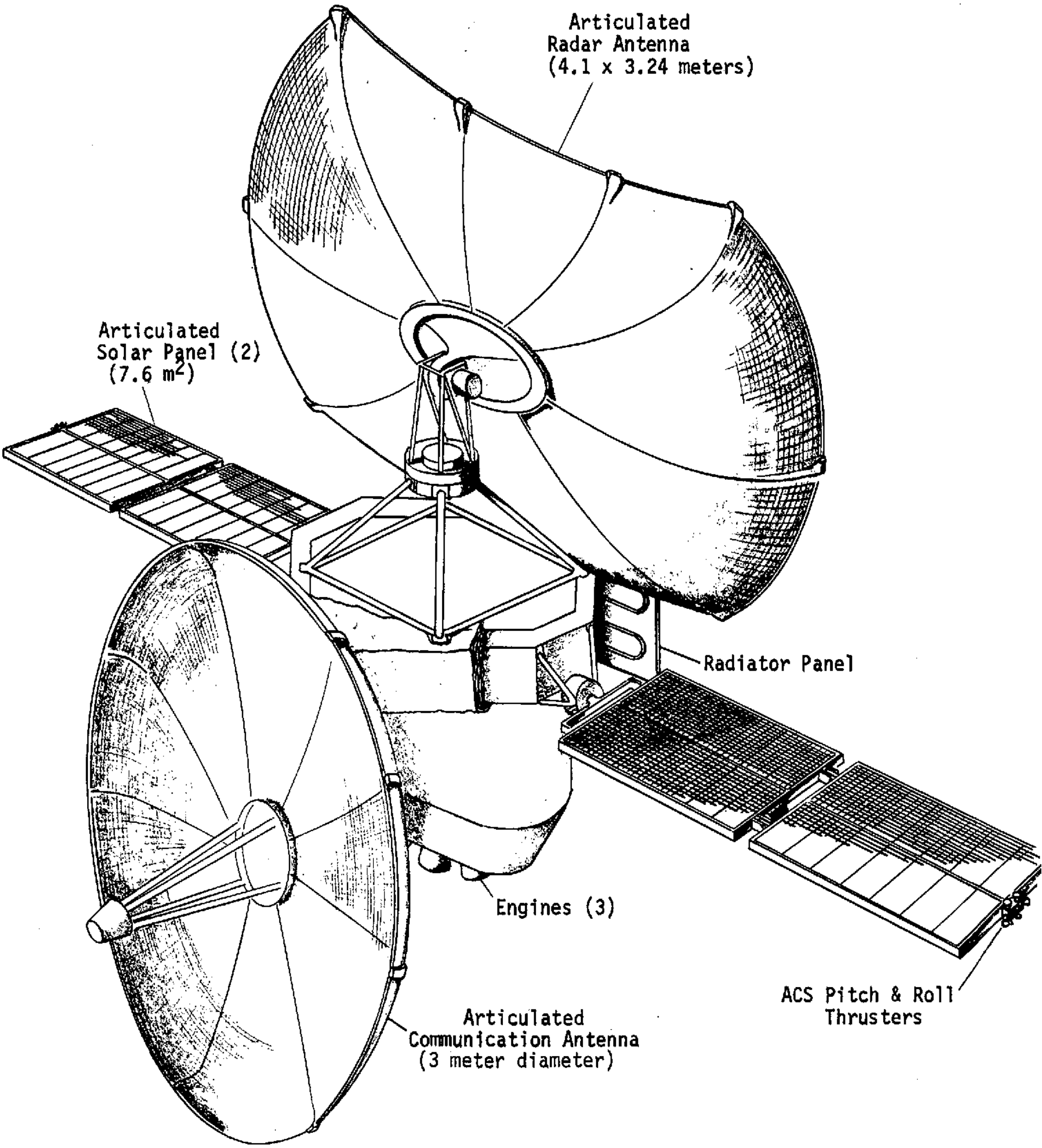


Figure II-4 Recommended Mapping Spacecraft Concept (Configuration C)

III. MAJOR STUDY CONCLUSIONS

Three important conclusions emerged from this study:

1. The basic technology required to do a scientifically useful Venus orbital radar mapping mission is available today.
2. Special radar and data processing operational techniques can be employed that will produce mapping coverage and resolution from an elliptical orbit as good as that attainable from a more difficult-to-achieve circular orbit.
3. The function that has the greatest influence in the mission/spacecraft design is the return data link.

A number of technology advancements have been identified in this study that would enhance the performance, versatility and scientific value of the mapping mission. However, the basic science objective of covering at least 80 percent of the surface at 1 km resolution and at least 20 percent at 100-meter resolution can be met without need for new technology breakthroughs or state-of-the-art advancement. In fact, concepts developed in this study have dramatically exceeded these objectives, providing for a nominal 100-meter resolution (50-meter at equator to 200-meter at poles) augmented by a significant amount of 33-meter resolution data. This means that scientifically reliable missions could be planned for as early as a 1981 launch with good confidence of success.

Prior to this study there had been some debate over the relative merits of circular and elliptical (eccentricity of 0.2 to 0.5) orbits for the mapping mission. The circular orbit offers constant range and range rate conditions, simplified radar pointing requirements, low radar power, and the ability to map the full 360^{o} of the orbital period. This last feature permits the coverage of the entire Venus sphere in 120 days. The elliptical orbit, on the other hand, requires significantly lower spacecraft propulsion system performance and allows better balanced time sharing between the mapping and data return activities. However, the varying range and range rates as seen from the elliptical orbit degrade resolution, increase radar power requirements, and introduce signal ambiguities unless compensating operational and hardware techniques are used. Such compensating techniques have been identified in this study. Methods for implementing variable side-look angles, variable antenna beamwidths and variable pulse repetition frequency (PRF) have been shown to eliminate range ambiguities and maintain power requirements within acceptable limits. With such features, the elliptic orbit mapping system can produce full planet coverage at resolutions varying from 30 meters at periapsis to 200 meters at the planet poles. Furthermore, it can deliver those results using a modified Viking '75 Orbiter spacecraft, or equivalent, meaning that program costs should be significantly lower than if new, higher performance propulsion systems were required. Because mapping can only be done during half of the period of the elliptic orbit, the full mapping mission requires twice as much time as the circular orbit case or approximately 240 days.

The problem of returning the radar imaging data to Earth is one that offers few opportunities for short-cut or compromise. If there is to be full coverage of the planet at a nominal 100-meter resolution with data fidelity suitable for good scientific interpretation, then the total number of bits returned during the mission becomes an essentially fixed number. The available communications windows, then, dictate the required data rates. The study has shown that power is available to relay 100-meter resolution data even during orbits experiencing Earth occultations; additional capability is available during periods of no Earth occultation. These rates are relatively high. For the 240-day elliptical orbit missions the data rates can go as high as 250 kbps which is the current limit for the Deep Space Network. For the 120-day circular orbit missions, the rates are typically higher due to the greater data volume per orbit and the significantly greater impact of Earth occultations on communications windows. The planned DSN upgrading becomes mandatory in this case. This then becomes a case where the apparent disadvantage of the elliptic orbit converts to an advantage.

There are, of course, methods for on-board processing that can reduce the volume of data returned. These include presumming (averaging) data from a number of radar pulses, and on-board image formation. These techniques are described in this report and useful strategies are recommended. Although increasing the amount of on-board processing does increase the spacecraft complexity, it enhances the image content (fidelity or "shades of gray") available to the scientist at Earth. At the same time, however, it reduces the capability for later study of the raw data in response to new discoveries about the planet surface.

IV. SUMMARY OF RESULTS

The results of this study are presented in three volumes. Volume III documents the outputs of parametric trade off analyses conducted at the spacecraft subsystem and mission event level. Volume II evaluates and compares spacecraft/mission configurations at the overall system and mission performance level. This summary, Volume I, covers the highlights of the total effort and describes the recommended mission/spacecraft concept. Much of the work accomplished in the areas of radar and data processing is due to the efforts of the Environmental Research Institute of Michigan (formerly the Willow Run Research Laboratory of the University of Michigan). ERIM served as subcontractor to the Martin Marietta Corporation.

MISSION DESIGN

The direction by the NASA Technical Monitor was that missions in the 1980s were to be considered, with emphasis on the middle portion of that period. The basic mission geometry shown in Figures II-2 and II-3 is typical for all mission years.

In general, periapsis will always occur during Earth occultation and the insertion maneuvers will be out of sight of Earth stations. The periapsis insertion maneuver will establish an orbit with a periapsis altitude of 400 km and an eccentricity of 0.5. The 400 km altitude assures a lifetime of one year with minimum trim maneuvers and the 0.5 eccentricity permits the use of a conventional Viking class propulsion stage. The impact of eccentricity on the insertion propulsion requirements is shown in Figure IV-1.

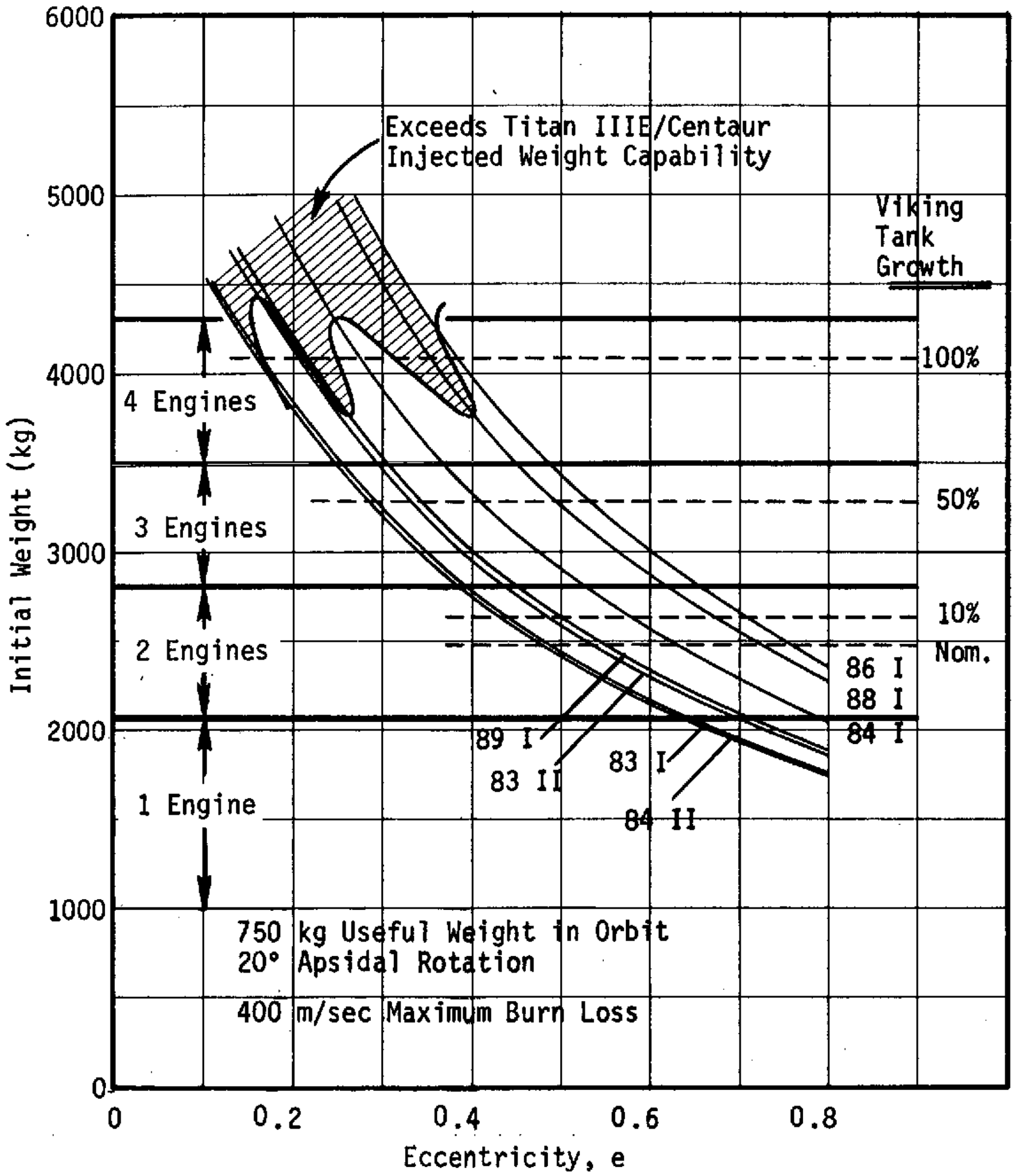
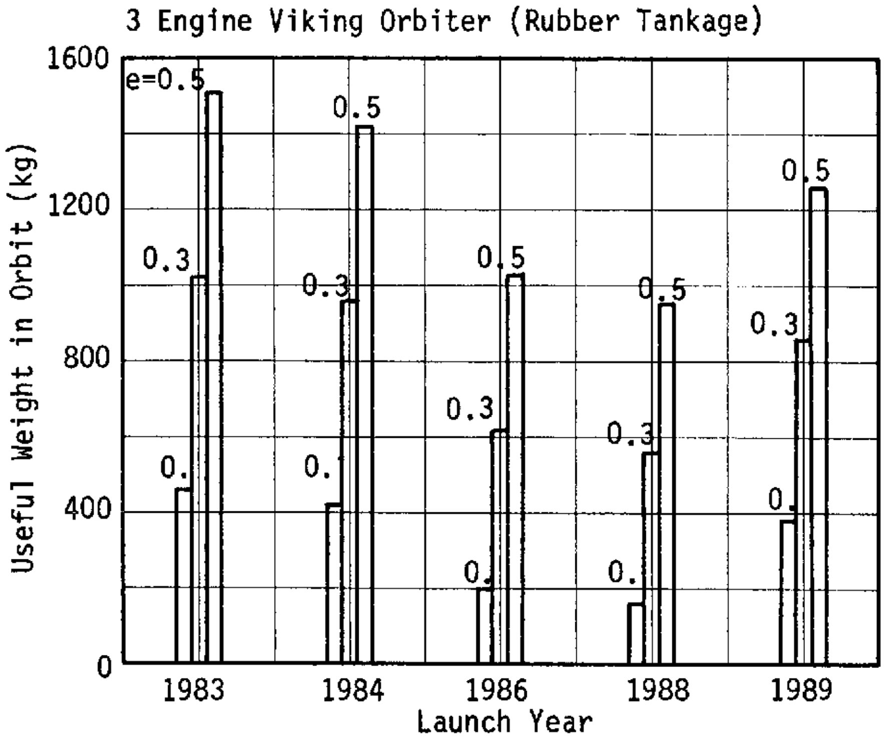
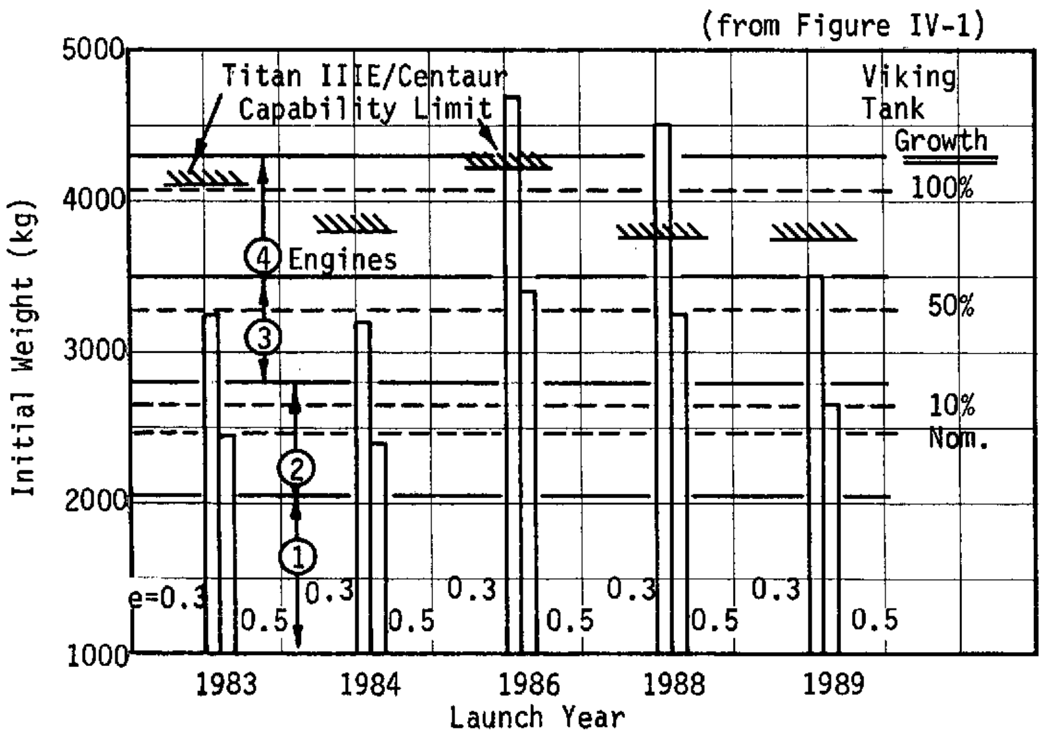


Figure IV-1 Insertion Propulsion Requirements

Figure IV-1 is based on the assumptions of a 750 kg useful weight in orbit, a 20^{o} apsidal shift capability and a 400 m/sec maximum finite burn loss. With these assumptions an upper limit on initial weight can be established as a function of initial thrust-to-weight ratio or number of engines (thrust level) as shown in the figure. Hence, a 3 engine Viking insertion stage or its equivalent in thrust capability is required to achieve eccentricities of 0.5 or greater for all mission opportunities. Similarly, if tankage growth is considered, then, a 3 engine Viking insertion stage with current tankage sizes can be used for the more favorable years. In this configuration the two outboard engines are not gimballed and are used only for the insertion maneuver. Simple propellant isolation assemblies can be employed and the basic midcourse maneuver strategy can remain the same. Hence, a space storable propulsion system is not required to accomplish the mission. Eccentric orbits pose no other major operational problem or system impact. However, circular orbits may permit the mission duration to be shortened from 240 to 120 days.

The performance as a function of mission year is presented in Figure IV-2 and includes ΔV provisions for a 20^{o} periapsis shift (apsidal rotation) and a maximum 400 m/sec finite burn loss. The allowance for a 20^{o} apsidal rotation would permit placement of the periapsis on the equator regardless of the mission year. The finite burn loss value was arbitrarily established as a manageable value. Shuttle Centaur launch capabilities are approximately double the Titan III/Centaur capabilities and would permit the possibility of a dual spacecraft mission.


3 Engine Viking Orbiter (Rubber Tankage)
Useful Weight in Orbit (kg)
1600
1200
800
400
0
e=0.5
0.3
0.5
0.3
0.5
0.3
0.5
0.3
0.5
0.3
1983
1984
1986
1988
1989
Launch Year


(from Figure IV-1)
Initial Weight (kg)
5000
4000
3000
2000
1000
Titan IIIE/Centaur
Capability Limit
Viking
Tank
Growth
100%
50%
10%
Nom.
4 Engines
3
2
1
e=0.3
0.5
0.3
0.5
0.3
0.5
0.3
0.5
0.3
0.5
1983
1984
1986
1988
1989
Launch Year

RADAR AND ANTENNA SYSTEM

The recommended radar design is an S-band side looking synthetic aperture system. The antenna is an articulated truncated parabolic design of mesh grid construction. Its size is 4.1 x 3.24 meters. It requires a 360° level of azimuth gimbal and a few degrees of deviation gimbal for the variable side look angle. The system requires a maximum of 340 watts of input power to the radar during mapping and weighs 67 kg. A variable side look angle is utilized to control ambiguities and reduce power requirements. An eccentric offset clutterlock pointing control technique is used to map at large true anomalies. In this way, mapping of the entire planet surface can be accomplished. The mapping strategies, mapping sequences and alternate approaches to variable side look angles are presented in Volumes II and III. The options include a fixed side look angle and variable beamwidth that sacrifices some surface coverage and a fixed side look angle and squint mode operation that appears to be able to map the entire surface.

The basic system assumes a single frequency and a single polarization but can readily provide part-time dual polarization by adding an electronic switch and an additional feed. A simple radar altimeter is included to provide basic data for image rectification, stereo imagery and limit sounding. The altimeter will use a separate small antenna and to utilize existing systems will operate at L-band frequencies.

DATA HANDLING AND COMMUNICATIONS

The radar data processing, data storage and the return data link are the most sophisticated and demanding parts of the radar mapper system design. The recommended strategy for on-board processing involves receiving raw data from the radar at 6 to 12 Mbps, presumming or averaging to approximately 500 to 1000 kbps, storage capacity of approximately 1100 Mbps and transmission to Earth at 80 to 250 kbps. A block diagram of the basic data handling system is shown in Figure IV-3.

Because of the variation in Venus-Earth range during the mission and the resulting variation in possible data link rates, several alternative strategies can be employed. During the long range portion of the mission, presummed azimuth and unprocessed range data can be transmitted to yield 100 x 100 meter resolution. At shorter range, when available data rates go up, the additional capacity can be used for finer azimuth resolution or for mixed integration ground processing. Other implementation approaches would allow mixed integration image formation on-board the spacecraft. Mixed integration provides image enhancement by noncoherently summing data from the surface as seen in several successive azimuth "looks" through multiple azimuth channels. Figure IV-4 is an example of the image enhancement possible with noncoherent or mixed integration.

Data storage requirements can be met with a tape recorder of the Viking '75 Orbiter class. A number of alternative mass storage concepts were examined in the strategy with advanced hybrid film techniques and magnetic bubble systems indicating promise and future technology benefits.

The recommended communication system uses a 3 meter parabolic antenna articulated in two degrees of freedom ($\pm$10 in elevation and

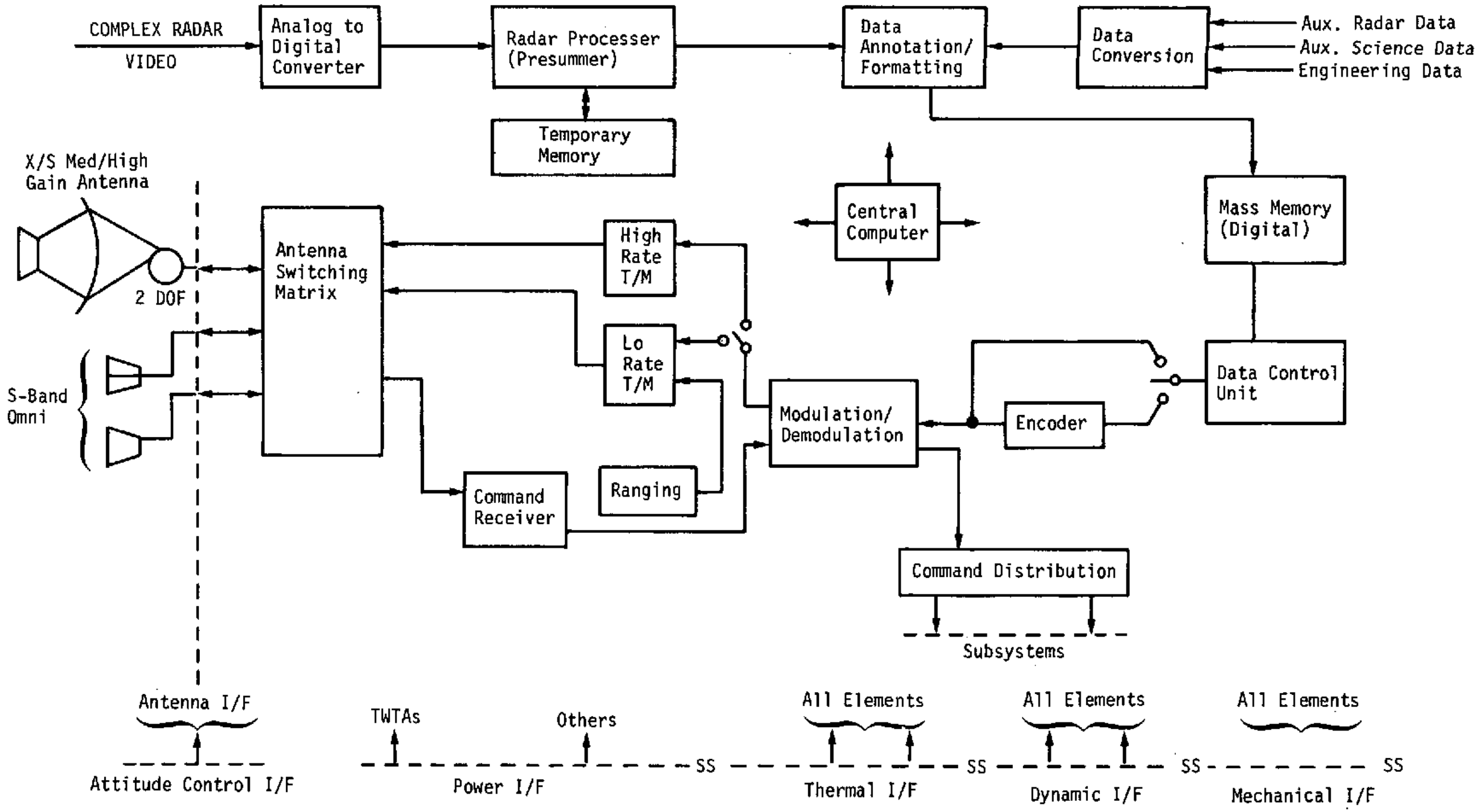
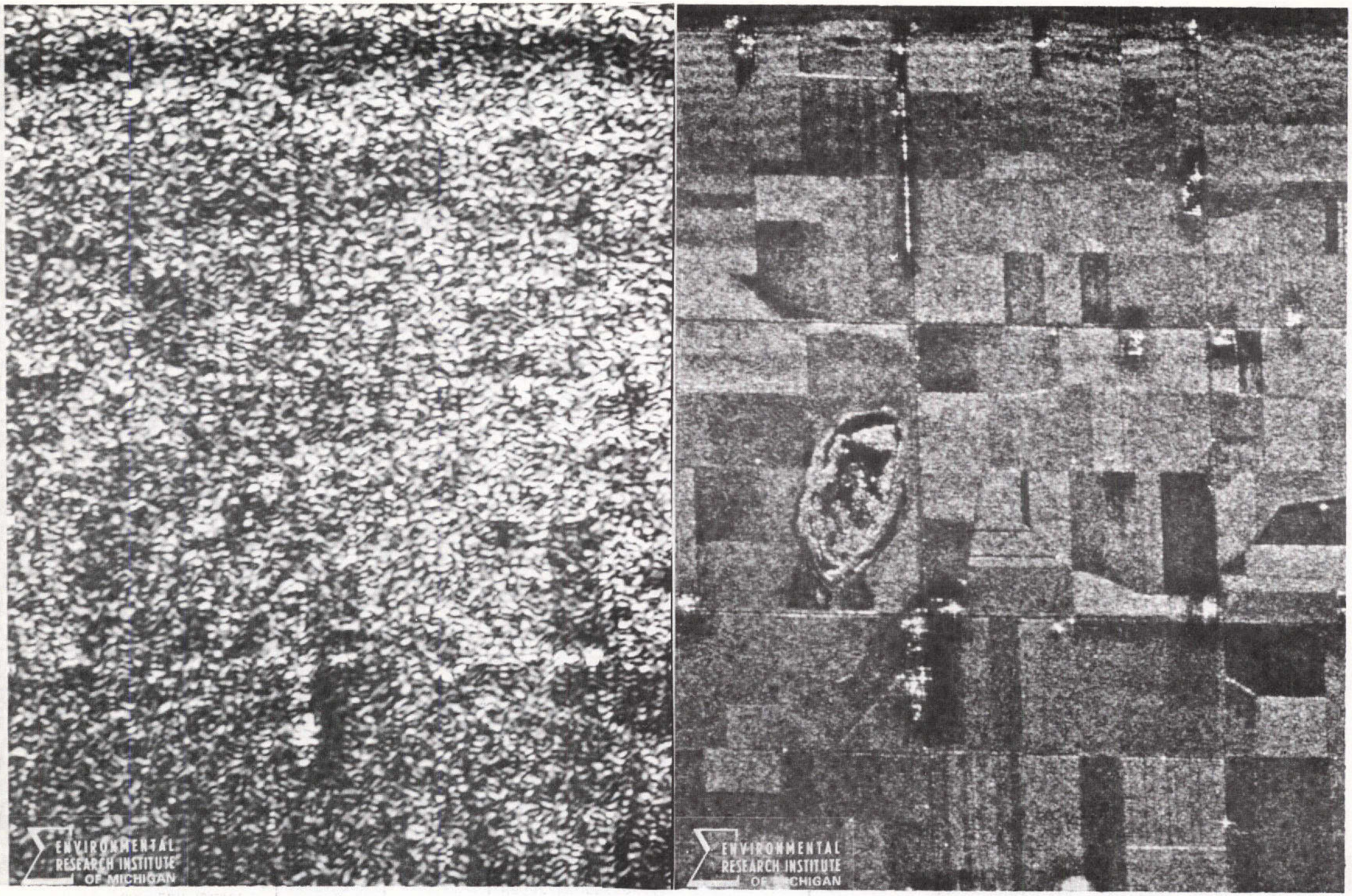


Figure IV-3 Data Management/Communication Basic Block Diagram



COHERENT INTEGRATION NON-COHERENT INTEGRATION

Figure IV-4 Image Enhancement Possible with Noncoherent vs Coherent Integration (30 m resolution)

$\pm$ 45 in azimuth). The system operates at X-band with 50 watts of output power and a coded data channel providing high quality returned data over the entire mission distance.

OTHER SPACECRAFT SYSTEMS

The spacecraft subsystems required to support the radar and data handling functions can be relatively straightforward derivatives of Viking '75 Orbiter designs utilizing current technology. The recommended spacecraft configuration is shown in Figure II-4. The estimated mass statement for this configuration is shown in Table IV-1.

Table IV-1 Recommended Spacecraft Configuration Mass Statement

	Mass (kg)
Structure, Mechanical Devices and Thermal Control	227.9
Radar and Antenna	71.2
Communications/Command Rec/Mod Demod	53.2
Processor/Recorder	54.4
Attitude/Articulation Control	56.5
Attitude Control Gas	8.7
Command Computer	56.6
Power/Pyro	121.1
Contingency	66.8
Spacecraft Mass (useable mass in orbit)	734.5
Propulsion Inerts (including contingency and trapped propellant)	247.2
Propellant	1026.4
Injected Mass	2008.1

The propulsion system is the Viking '75 Orbiter system with two additional fixed 300-lb thrust engines (same as currently used) mounted on the thrust structure to reduce finite burn losses during the Venus orbit insertion burn.

Spacecraft attitude control can be handled by a nitrogen cold gas system equivalent to the Viking '75 Orbiter design but capable of carrying 19 kg of gas instead of 14 kg. Total ACS impulse requirements for the mission are 5524 Newton-seconds (compared to 3000 Newton-seconds for Viking Orbiter).

Adequate spacecraft power can be supplied by two Viking '75 Orbiter sized panels. Because the recommended spacecraft remains inertially fixed during the complete orbit period, the solar panels will have to be articulated (rotatable). Average power requirements for the mission will be approximately 600 watts.

The thermal control design for the recommended configuration uses an internal heat pipe for temperature equalization and a reductor/heat pipe assembly to reject heat to space. This is a conservative design based on worse case thermal problem expectations. Subsequent analysis and test may indicate that a simpler thermal control design is adequate.

TECHNOLOGY REQUIREMENTS

All of the subsystems used in the recommended spacecraft configuration use current technology. While develop testing will be required to verify adequate performance margins under the conditions of the Venus mapping mission, no extensions of the state-of-the-art appear to be required.

A number of potential enhancement features were identified in the study and are described in Volumes II and III. Some require additional development work. Examples are:

- control moment gyros and reaction wheels for the ACS system
- on-board mixed integration image formation system
- advanced low power, long life mass storage systems
- high power X-band radio frequency amplifiers
- high data rate, high code rate convolutional decoders
- furlable, articulated large diameter X-band antenna
- space storable propulsion system
- study of ambiguity elimination and power reduction methods to be used for radar mapping in elliptical orbits
- image content (especially topographic data) as a function of frequency, polarization, resolution, side look angle and stereo enhancement

COST AND SCHEDULES

The estimated run out costs of the Venus radar mapping mission were compiled by two independent approaches. First, a cost model based on the accumulated experience of a number of unmanned space programs was applied (Planning Research Corporation Model). This yielded a total cost of $200 million. The second estimating technique made direct comparisons between the changes and associated costs required to evolve the Viking '75 Orbiter from the Mariner 71 Orbiter with the equivalent changes required to evolve the Viking '75 Orbiter to a Venus Radar Mapper. This approach indicated a total cost of $255 million. These estimates are in FY 73 dollars and do not include launch vehicles, DSN costs or other NASA support costs. A two-launch mission is assumed.

Figure IV-5 is a simplified program schedule showing major events and span times leading to a 1981 launch mission. This early launch date was chosen to demonstrate that the Venus

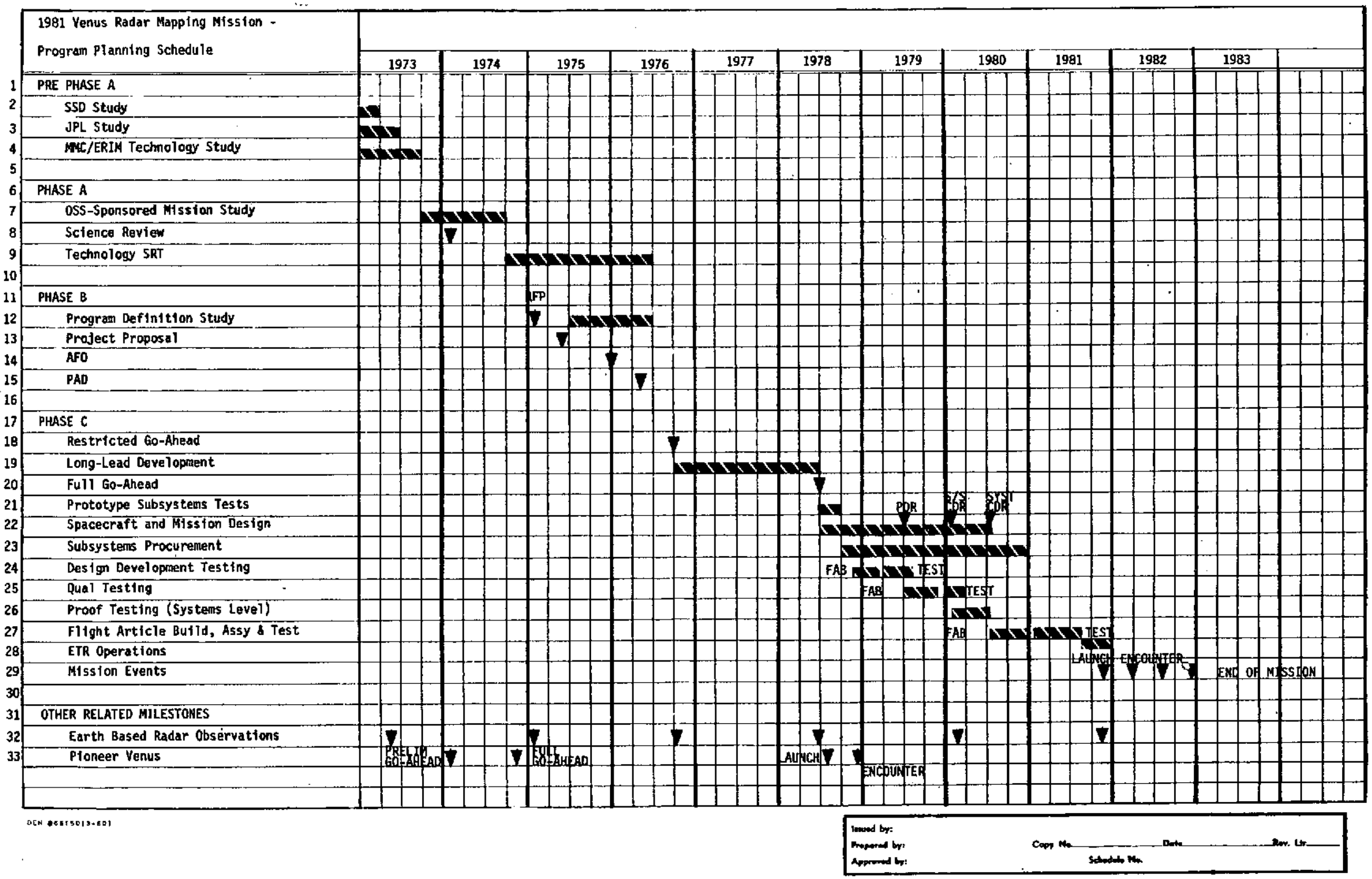


Figure IV-5 Venus Radar Mapper Program Schedule orbital radar mapping mission can be considered as a near-term reality that fits well into this nation's evolving program for exploring our nearest planetary neighbor.