NASA-CR-195732

MUADEE

Mars Upper Atmosphere Dynamics, Energetics, and Evolution

Discovery Mission

Final Report: Executive Summary Volume

March 15, 1994

(NASA-CR-195732) MUADEE: MARS UPPER ATMOSPHERE DYNAMICS, ENERGETICS, AND EVOLUTION DISCOVERY MISSION. EXECUTIVE SUMMARY VOLUME Final Report (Michigan Univ.) 100 p

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Mars Upper Atmosphere Dynamics, Energetics, and Evolution Mission

(MUADEE)

FINAL REPORT
EXECUTIVE SUMMARY VOLUME

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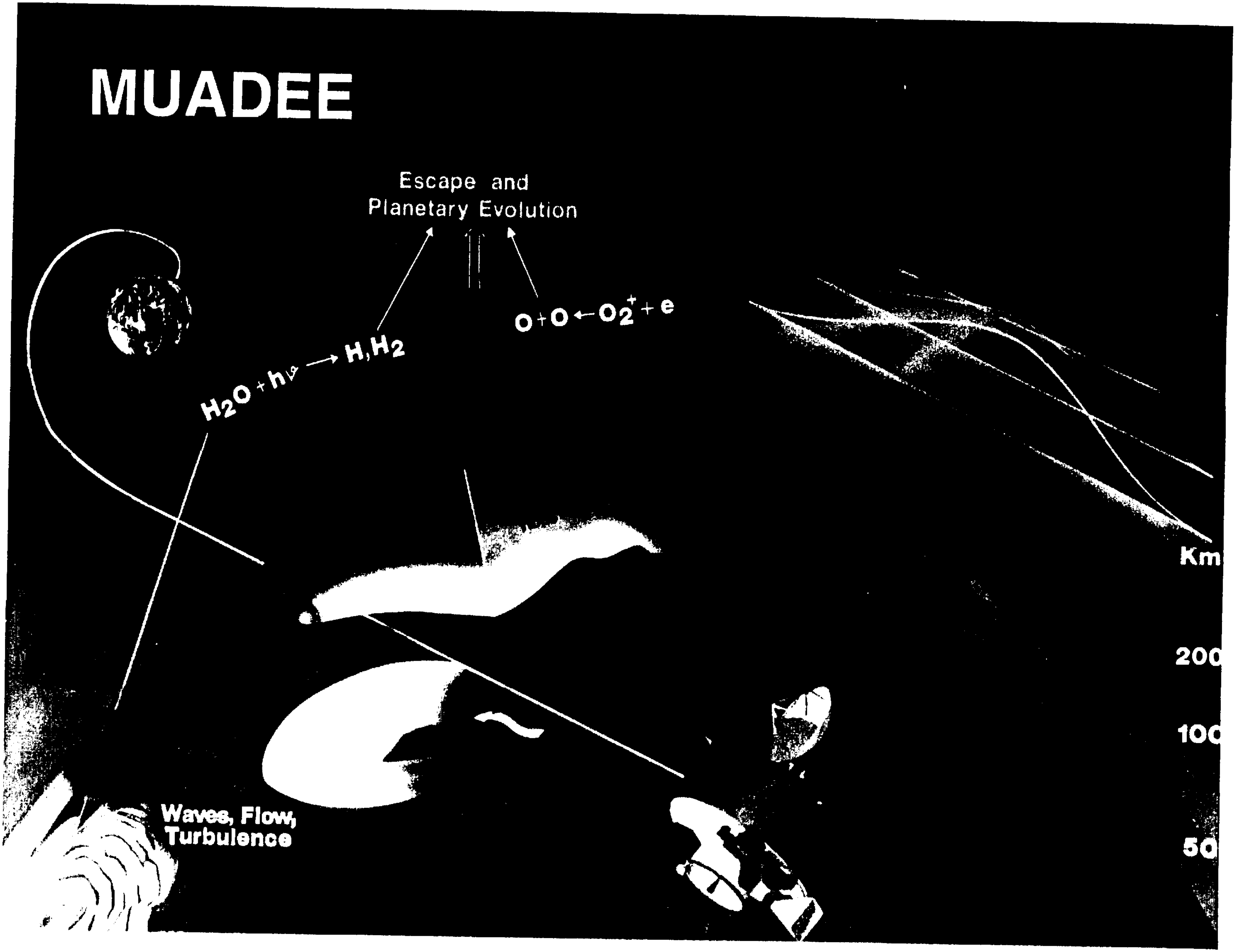
MUADEE
Escape and
Planetary Evolution
$H_2O + h\nu \longrightarrow H, H_2$
$O + O \leftarrow O_2^+ + e$
Km
200
100
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Waves, Flow,
Turbulence

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1.0 EXECUTIVE SUMMARY

A DISCOVERY MISSION

This document is the final report of the MAUDEE (Mars Upper Atmosphere Dynamics, Energetics, and Evolution) consortium. It describes a low cost Discovery mission to investigate the upper atmosphere of Mars and to understand the manner in which Mars has evolved over geologic time.

In keeping with the innovative philosophy permeating the Discovery Program and in order to minimize the burden of reading an extensive prose exposition, we have adopted a new presentation format. The format involves a series of view graphs with facing text. The view graphs form the basis of a complete oral presentation of the MAUDEE mission and the facing text provides more detailed, but still brief, explanatory descriptions. Readers can scan the view graphs and/or read the facing text at their discretion. The oral presentation of this study was given to code SL personnel at NASA Headquarters on February 23, 1994.

The MAUDEE consortium is led by the University of Michigan. The industrial partner is the Lockheed Missiles and Space Company, Inc. The teaming NASA Center is the Jet Propulsion Laboratory. Several other Universities and laboratories are also involved. The Consortium has completed a study of the MAUDEE mission to the Phase-B level of detail. The mission requirements have been frozen, instrument definition documents have been negotiated and finalized, a full mission scenario has been established, and a complete management plan is in place. In response to the upcoming Announcement of Opportunity, the MAUDEE consortium will propose near-term activities to mitigate and retire risk on the program, thereby further reducing development costs.

MAUDEE is an essential component of the Mars Exploration Program. It provides the information required to understand the evolution of the planet via the escape of volatiles. It provides the key measurements needed to understand the upper atmosphere of the last of the three terrestrial planets to be so studied. It connects and supplements investigations based on other Mars missions: Mars Surveyor, Planet-B and Mars-96.

The MAUDEE mission plan involves a combination of remote and in-situ sensors, housed in three instrument packages. The sensors make measurements of the atmospheric regions between ~60-200 km. These instruments are based on extensive heritage from Earth explorers and Pioneer Venus. The mission scenario has several phases and employs aerobraking maneuvers to lower initial apoapsis, thereby reducing fuel requirements.

The spacecraft has body-mounted solar cells, enabling deep diving into the Martian atmosphere. The orbital inclination allows for pole-to-pole latitudinal sweeps in an initial elliptical phase, followed by a circular phase affording detailed diurnal measurements. The nominal mission duration at Mars is one Mars year.

The MAUDEE Principal Investigator has full financial and technical responsibility for the mission. In order to ensure fiscal and technical responsibility, a detailed management plan has been developed, based on an Integrated Product Development Team approach. The plan incorporates mechanisms for oversight and financial reporting that enable NASA to monitor cost-to-complete in a rigorous fashion. To further control costs, descope plans have been adopted by the Consortium for instruments, spacecraft and the mission scenario.

The MAUDEE development costs are of the order of $100M, including fees and contingencies. Conservative margins in power, mass, telemetry, fuel, and cost have been identified and rigorously maintained. MAUDEE is ready to start development and will be available for a 1998 launch.

A *Discovery* Mission

Mars Upper Atmosphere
Dynamics, Energetics and Evolution

- Exploration and Coupling studies of the middle and upper atmosphere/ionosphere of Mars and its role in planetary evolution.
- Remote and In-situ measurements of regions between 60 and 200 km
- Deep diving (~110-120 km) permitted by body-mounted solar array.
- -82° inclination phased elliptical/circular orbit provides rapid local time precession, and full global coverage. Aerobraking orbit adjust, 26 month mission.
- 3 Heritage instrument packages, based on Earth explorers and Pioneer Venus.
- University-Lockheed-JPL Consortium

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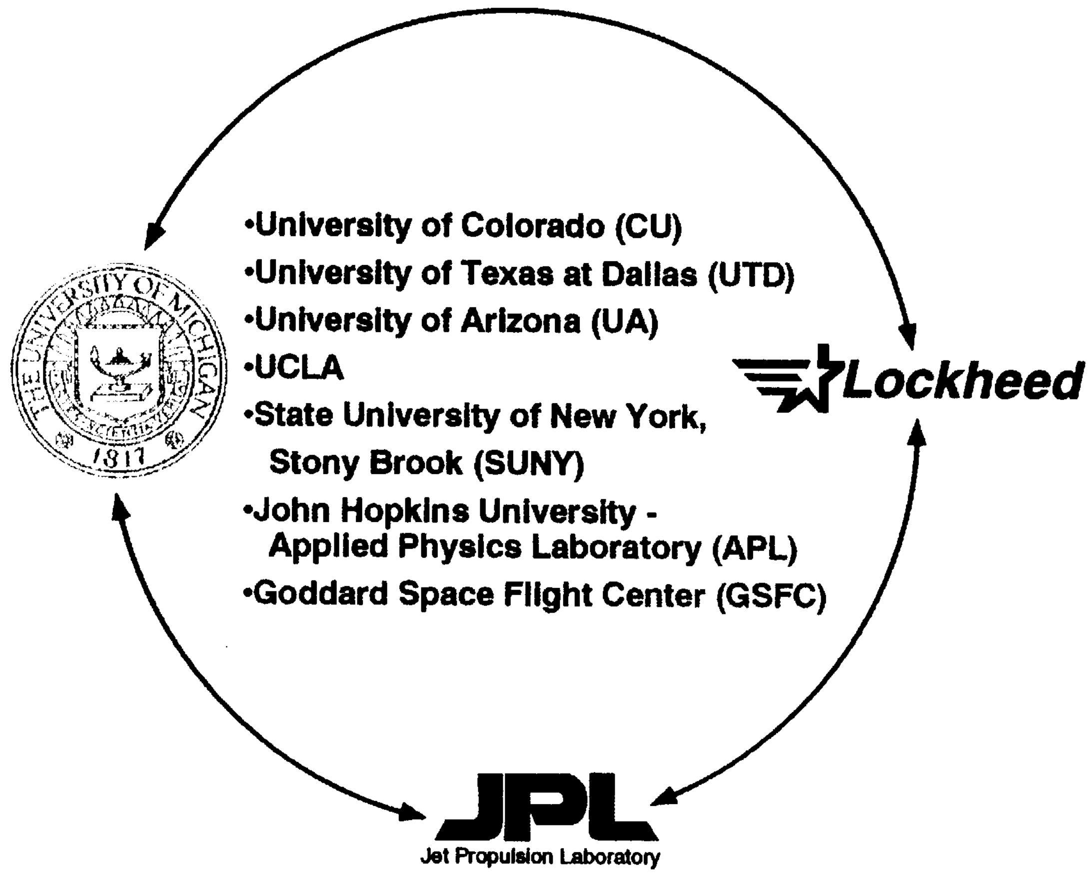
WHAT IS MUADEE?

The MAUDEE Consortium operates in a "badgeless" manner. That is, participants are MAUDEE team members first and foremost. They leave their institutional affiliations behind while working on the program. Individuals are chosen based on their expertise and long-term commitment to MAUDEE. In this approach, *designers become builders become operators*, eliminating the loss of corporate memory that often bedevils programs due to personnel changes.

An Integrated Product Development (IPD) team approach has been utilized for this study and will be retained throughout the program. Intensive, iterative interactions among MUADEE scientists and implementing engineers have led to a full specification of the mission. All important design trade studies have already been completed using this approach. Key individuals involved in this study are committed to follow through all later phases of the program.

WHAT IS MUADEE?

A "Badgeless" Consortium



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CJE Programmatics. 1

SCIENCE TEAM

The MAUDEE science team involves individuals with extensive experience with both planetary and terrestrial missions. The Principal Investigator has overall responsibility for all aspects of the program. Four Co-Investigators or team leaders are named. These individuals have specific responsibilities for the provision of instrument packages or for the (specified) science areas. Team participants are also listed.

Timothy L. Killeen is the Principal Investigator. He is the Director of the University of Michigan's Space Physics Research Laboratory, an institution that has been involved with the space program since its inception. Dr. Killeen is also the team leader for the Neutral Atmosphere Package. Roderick A. Heelis from the University of Texas at Dallas is the Team leader for the Plasma Instrument Package. Ian A. F. Stewart from the University of Colorado at Boulder is the Team Leader for the Scanning-Imaging Package. Stephen W. Bougher from the University of Arizona is the Team Leader for Studies of Upper Atmosphere Energetics and Dynamics. Bruce Jakoski is the Team Leader for studies of Martian Evolution.

The PI and the Science Team are also responsible for the interpretation and distribution of the mission data and for publication of the results in the open literature. While the number of Co-Investigators is kept small to control costs and to avoid diffusion of responsibilities, the MAUDEE science measurements will be of great interest to a much larger number of researchers. The Consortium has adopted an open data policy. Results will be made available through the Internet and the Planetary Data System without restrictions and immediately following validation work.

Science Team

Principal Investigator: T. L. Killeen
Professor and Director,
Space Physics Research Laboratory, University of Michigan

Team	Team leader Co-Investigator	Team participant
Neutral Atmosphere Package:	T. L. Killeen (UM) PI	H. Niemann (GSFC) P. Mahaffy (GSFC) G. R. Carignan (UM) J. H. Yee (APL)
Plasma Instrument Package:	R. A. Heelis (UTD) Co-I	L. H. Brace (UM) J. Slavin (GSFC)
Scanning-Imaging Package:	A.I.F. Stewart (CU) Co-I	S. Mende (LMSC) A. Binder (LMSC)
Energetics and Dynamics:	S. W. Bougher (UA) Co-I	J. Fox (SUNY) H. G. Mayr (GSFC) R. Zurek (JPL) A. Kliore (JPL) L. Paxton (APL) A. F. Nagy (UM) T. I. Gombosi (UM)
Evolution:	B. Jakosky (CU) Co-I	J. Luhmann (UCLA) R. Hartle (GSFC)

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BACKGROUND

The MUADEE mission is based on the recommendations of various advisory committees over the past 15 years. Some of these studies are listed here. They all set goals for a mission to study the Martian upper atmosphere and complete the exploratory investigation of the upper atmospheres of the three terrestrial planets: Earth (studied by numerous Explorer missions) , Venus (studied by Pioneer Venus) and Mars.

MUADEE is also directly related to the previously-studied Mars Aeronomy Observer (MAO) mission (JPL report, 1986). It is, however, is a much less ambitious mission than MAO. It focuses primarily on study of the evolution of the atmosphere. This will require a global exploration of the middle and upper atmospheres and the processes that couple these regions, including the escape of volatiles. It will be necessary to rely on cooperation with other international missions (Planet B and Mars-94) to fully address the questions relating to solar-wind interactions. MAUDEE is to be considered an integral part of an international program to study Mars (see later for letter agreement with Japanese collaborators).

A recent study of Mars, commissioned by the Committee on International Space Plans and Policies recommended six principal areas of study for Mars, listed here. MAUDEE results are critical for 4 of these 6 areas, specifically geological evolution, external processes, water in Martian history, and existence of past or present life (related to prior existence of water).

References:

1. Planetary Exploration Through the Year 2000, Part 2, Solar System Exploration Committee of the NASA Advisory Council, 1986.

2. An Implementation Plan for Priorities in Solar and Space Physics, Committee on Solar and Space Physics, Space Science Board, National Research Council, National Academy Press, Washington, D.C., 1985.

3. Mars Aeronomy Observer; Report of the Science Working Team, NASA Tech. Memo 89202, Jet Propulsion Laboratory, October , 1986.

MAUDEE

Background

Historical Perspectives:

- **COMPLEX (1978); SSEC (1983); CSSP (1985) all set similar goals for a Mars upper atmosphere mission:**

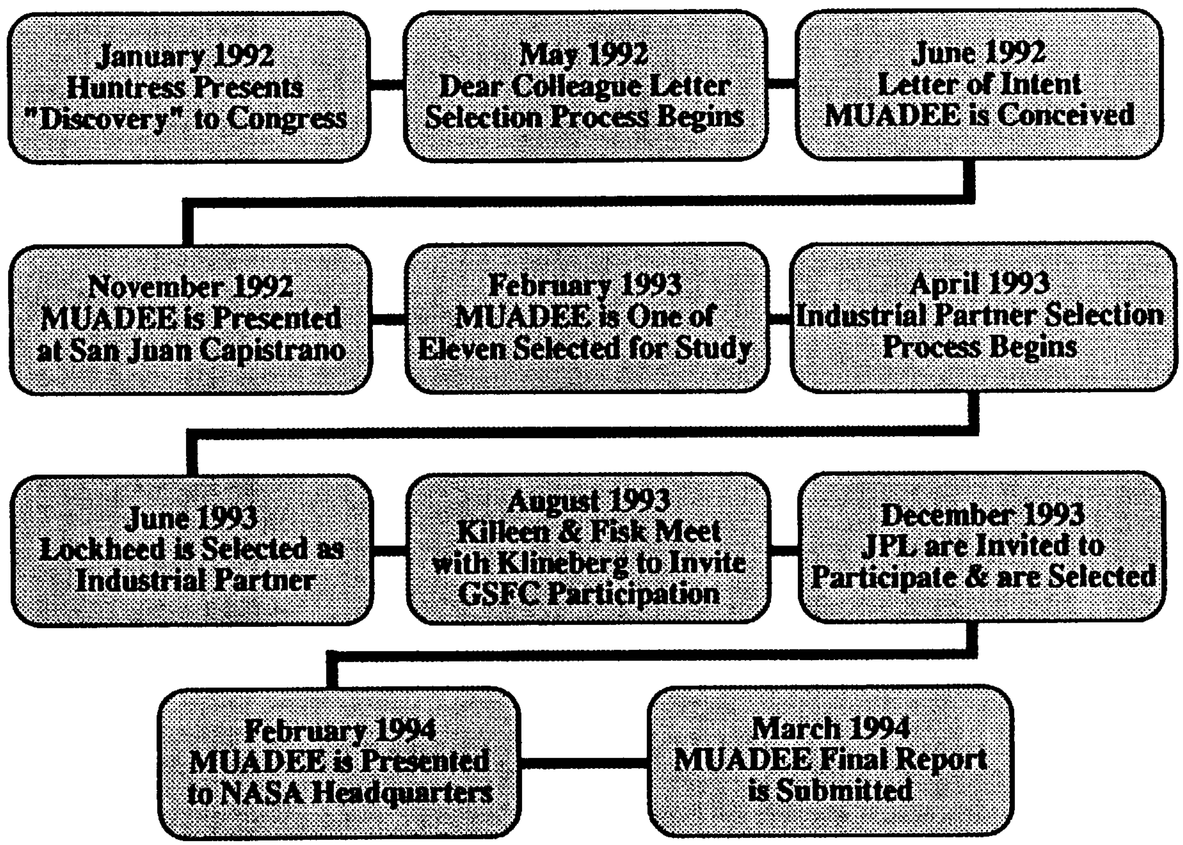
- **IAA Cosmic Studies, 1993: Committee on International Space Plans and Policies: International Exploration of Mars Principal areas:**
  - Composition and internal structure
  - Geological Evolution and ages
  - External Processes
  - Composition and dynamics of the atmosphere
  - Water in Martian history
  - Existence of past or present life

MAUDEE is critical for 4 of the 6 areas.

MUADEE HISTORY

The MUADEE Discovery mission concept grew out of NASA's Dear Colleague letter in May of 1992 indicating the possibility of a Discovery program which would fund a series of small planetary missions; follow-ons to the first two missions, Pathfinder and NEAR. MUADEE was one of 11 missions that was selected in the summer of 1993 for further definition. Since that time, The MUADEE science team has selected Lockheed and JPL as Consortium partners, has firmed up the scientific approach and mission plan, and has completed the definition of the mission, the instruments, and the spacecraft to the Phase B level. This document presents the results of that study. We now await NASA's issuance of the Discovery Announcement of Opportunity to which we are prepared to respond.

MUADEE History



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TWIN SCIENCE GOALS

The primary goal of MUADEE is to understand the evolution of the Martian atmosphere and, in particular, to understand how long-term changes in the atmosphere have affected the geomorphology of the surface, the existence of water on the planet, and the possible evolution of life on Mars.

This primary goal recognizes of the central role played by the Martian upper atmosphere in controlling and regulating the outflow of gaseous materials over long time periods. Without basic knowledge of the manner in which the upper atmosphere "throttles" volatile escape rates, we will never reach a quantitative understanding of Martian evolution. To achieve this primary goal, MUADEE measurements must characterize the Martian upper atmosphere well enough to permit our general circulation model (MTIGCM) to be used to identify the physical, chemical, and radiative processes that are now operating there.

MUADEE measurements of atmospheric variables, isotopic ratios and present-day escape rates of volatiles will provide the needed MTIGCM inputs to enable a quantitative analysis of planetary atmospheric evolution over geologic time.

The secondary goal of MAUDEE is to characterize the upper atmosphere of Mars and to understand the relevant physical, chemical, and radiative processes. The MUADEE observations of the basic state variables (circulation, thermal and constituent structures) will allow us to reach an improved understanding of not only the atmosphere of Mars, but also that of Earth and Venus.

Twin Science Goals

- To understand the evolution of the Martian atmosphere and how these changes have affected the geomorphology of the surface and the possible origin of life on Mars

- To characterize the upper atmosphere of Mars and to understand the relevant physical, chemical, and radiative processes

GOAL 1: KEY CONSTRAINTS

Martian surface morphology provides clear evidence of climate changes that must have been tied to the presence of water on the surface, probably early in the history of the planet, and perhaps returning episodically. The possibility of forming life is closely tied to the question of whether water was present for extended periods of time and, if so, how long it lasted. The history of water on Mars is inevitably connected with the history of escape of volatiles from the atmosphere to space. The key to understanding the history of atmospheric loss to space is an understanding of the physics, chemistry, and dynamics of the present upper atmosphere.

Goal 1: Key Constraints

Upper-Atmospheric Processes Provide Key Constraints on Fundamental Questions Related to the History of Mars:

- The Martian surface shows clear evidence of climate change that is tied to the presence of water on the surface.
- The possible formation of life on Mars, in early epochs or later in its history, is closely tied to the presence of water at the surface and to the history of the climate.
- Loss of volatiles to space is likely a major contributor to the evolution of the climate and atmosphere.
- Understanding the physics, chemistry, and dynamics of the upper atmosphere is key to understanding the history of loss to space.

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LOSS TO SPACE

Certain photochemical processes, such as dissociative recombination of N_2 and O_2, produce hot N and O atoms, some of which have sufficient energy to overcome the gravitation attraction of Mars. Solar wind interactions produce energetic ions via energizing collisions with the neutral gases. This sputtering process produces neutral escape. Another sputtering process involves the impact of hot oxygen atoms, produced photochemically, with cold neutrals like C and N. This type of sputtering is an additional cause of energization and escape. Finally, ionospheric ions are picked up by electromagnetic interactions at the top of the ionosphere between solar wind magnetic fields and cold ions and electrons. These processes produce direct escape of planetary ions down the magnetotail, an effect that has been observed by instruments on Phobos 2.

Each of these processes leaves characteristic signatures in the upper atmosphere (e.g., isotopic ratios) which can be detected by MAUDEE instruments. The relative importance of these processes to long term volatile escape is an issue to be directly addressed by this Discovery mission.

Loss to Space

Processes By Which Substantial Loss To Space Can Occur:

- Photochemical escape (N and O, especially)
- Sputtering by upper-atmospheric ions picked up by the solar-wind magnetic field (all species)
- Sputtering by fast-moving oxygen in the upper atmosphere (C and possibly N)
- Ionospheric ion escape

IMPORTANCE TO EVOLUTION STUDY

An understanding of the physics, chemistry and dynamics of the upper atmosphere, including the above escape-inducing processes, requires global scale measurements of the structure, composition and motion of the constituents, the isotopic ratios of several species, and the response of the upper atmosphere to solar EUV and solar wind energy inputs. With these measurements, we can deduce current and past escape rates of the various species

Importance to Evolution Study

- Understanding these processes and the role they have played depends on understanding the physics, chemistry, and dynamics of the upper atmosphere.

- Specifically, we need to determine:

  - Structure, composition, and dynamics of the upper atmosphere

  - Isotope ratios of species in the upper atmosphere and in escaping species

  - Escape rates of different species.

  - Dependence on solar EUV flux and solar-wind properties.

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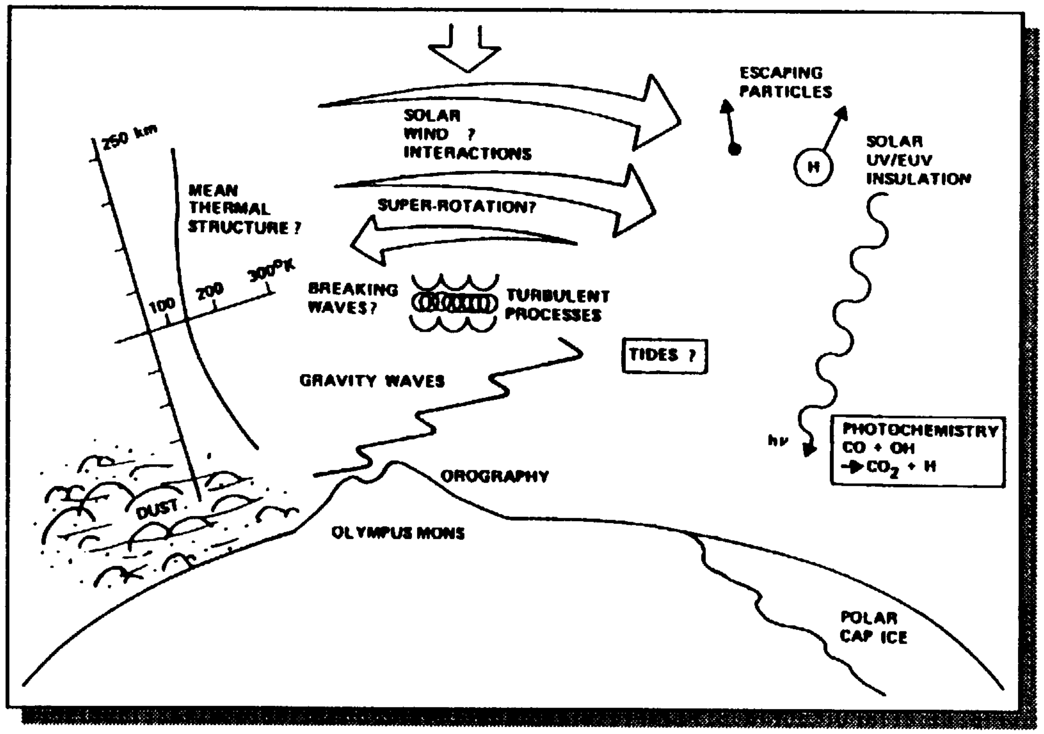
GOAL 2: UPPER ATMOSPHERE PHYSICS

While it remains almost entirely unexplored, there is a great deal of evidence that the upper atmosphere of Mars is the most dynamic of all of the terrestrial planets. Solar UV and EUV radiation ionizes, heats and dissociates the neutral gases and photochemical reactions produce a wide range of neutral and ion species. Owing to its rather weak ionosphere, the solar wind penetrates the ionopause and interacts with both ions and neutrals, energizing them and inducing planetary escape. Winds flowing over high relief topography generate dust storms and gravity wave activity which have profound effects upon the overlying atmosphere. The dust carried aloft is heated by the Sun and in turn heats the upper atmosphere. The gravity waves grow as they propagate upward, eventually breaking when their amplitudes become so large that the waves become unstable.

The dynamic and energetic state of the Martian upper atmosphere is likely to exhibit both similarities to and great differences from that of the Earth. By determining the basic state of the Martian upper atmosphere, MAUDEE will make an important contribution to the understanding of how atmospheres work in general. In many ways, Mars represents an ideal test bed for some of the theories developed for Earth. On Mars, the effects of "magnetosphere" forcing are likely to be small, implying that the gravity wave and tidal coupling from below may dominate the upper atmosphere. In the case of the Earth, the highly variable magnetospheric effects often mask the coherence of the wave and tidal forcings which are therefore not very well understood.

Goal 2: Upper Atmosphere Physics



- **The upper atmosphere of Mars is strongly influenced by conditions in the lower atmosphere and in the solar wind interaction region.**

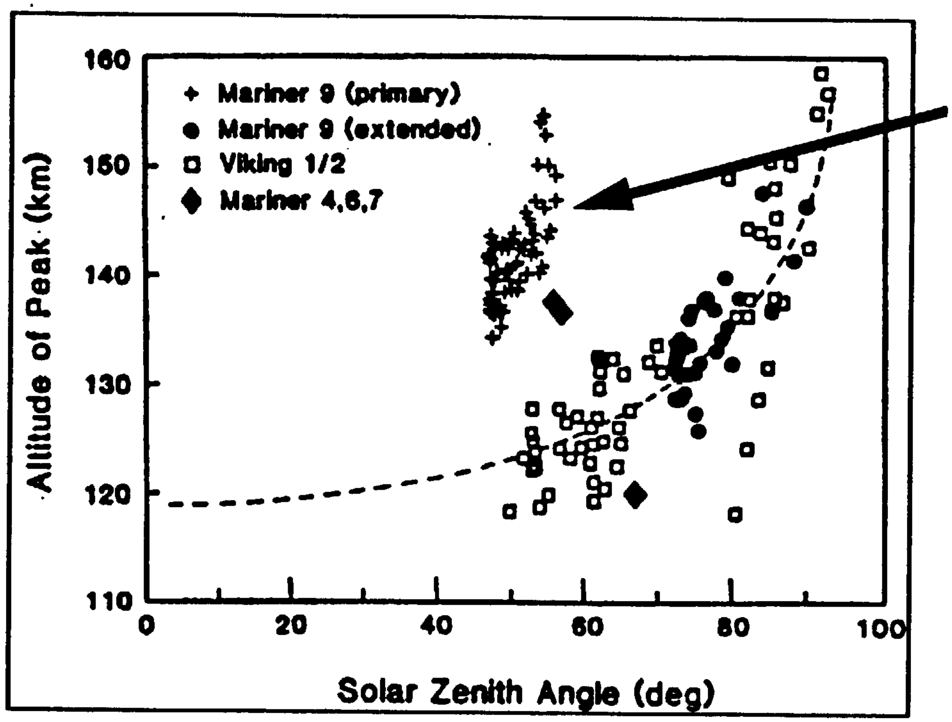
c. 3

DUST STORMS DRIVE ATMOSPHERIC STRUCTURE

The main evidence for the effects of dust storms on the upper atmosphere came from the Mariner 9 radio occultation measurements of the height of the ionospheric peak. The ionospheric peak occurs at a specific density level in the atmosphere. When Mariner 9 arrived at Mars, a major global dust storm was in progress. The atmosphere below about 100 km was being strongly heated by contact with the sunlit dust, causing the peak to move upward from its normal altitude near 125 km to altitudes in the vicinity of 145 km. This could only happen if the thermospheric density during the dust storm was increased by a factor of 3 or more. Global scale density enhancements of this magnitude do not occur at Earth or Venus.

The influence of dust storms on upper atmospheric structure is one of the most intriguing questions to be studied by MUADEE.

Dust Storms Drive Atmospheric Structure



A global dust storm occurred during the Mariner 9 primary mission. The atmosphere was greatly expanded due to aerosol heating, causing the height of the Ionosphere to rise by ~20 km.

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SCIENCE QUESTIONS

The scientific questions that MUADEE will answer involve three themes: What are the processes that lead to atmospheric evolution? What is the present state of the upper atmosphere? What is the relevant mix of processes that control the dynamics, energetics and chemistry of the upper atmosphere? These questions are inseparable. The answers obtained in the investigation of each of them carry the seeds of understanding the others.

An understanding of planetary escape requires a determination of the thermal escape of the lighter gases and, in general, the non-thermal escape of heavier constituents. Since lighter isotopes tend to escape more readily than heavier ones, measurements of the isotope ratios will provide present world boundary conditions on atmosphere evolution models.

The validity of current Mars thermosphere/ionosphere general circulation models (MTIGCM) has not been tested because we simply know almost nothing about the global distribution of chemically active species. We know nothing of the global distribution of even the major constituents, the global temperature structure or the wind patterns. We have no measurements of how the upper atmosphere responds to seasonal variations in solar UV and EUV. We also know little about the sources and sinks for energetics. Therefore our current understanding of the dynamics of the Martian upper atmosphere is based on untested theories.

Science Questions

(1) Investigate the processes that are responsible for the loss of the present atmosphere to space, and infer those that operated in the past.

- ***what is the thermal loss of hydrogen?***
- ***what are the escape mechanisms for heavier atoms such as O?***
- ***what do the present isotope ratios and rare gas abundances tell us about the past evolution of the atmosphere?***

(2) Determine the present state of Mars' upper atmosphere between 60 and 200 km.

- ***what are the distributions of the photochemically important species, and how do they vary?***
- ***what are the structure and composition of the thermosphere and ionosphere, and how do they vary ?***
- ***what are the temperatures, and how do they vary?***
- ***what are the zonal and meridional winds, and how do they vary?***
- ***what are the isotope ratios and the rare gas abundances?***

(3) Investigate the processes that control the dynamics and energetics of the region, and its chemistry.

- ***what are the sources of momentum and the dissipation processes?***
- ***what are the sources of energy and heat, and what are the cooling mechanisms?***
- ***what are the photochemical and transport processes that control the dissociation and recombination of molecular species?***
- ***what are the photochemical and transport processes that control the production and recombination of the ionosphere?***

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MEASUREMENT REQUIREMENTS

Only a combination of in situ and remote measurements of the altitude region between 50 km and 200 km can answer the above questions. The first order of business will be to determine the present state of the upper atmosphere with adequate spatial and temporal resolution and accuracy. These measurements include the concentrations of the neutrals and ions; the neutral, ion and electron temperatures and velocities; the isotope ratios and rare gas concentrations; the magnetic fields; and the solar EUV flux incident on the top of the atmosphere. The facing table lists the specific parameters of interest, the altitude range, resolution and accuracy required.

Measurement Requirements

MUADEE Science-Driven Measurement Requirements (1 of 2)

The Present State of the Atmosphere	Measured Parameters (Instruments)	Altitude Range (km)	Spatial Resolution	Temporal Resolution	Accuracy
Neutral and ion concentrations	n_n, n_e, n_i, CO_2, CO, O_2, O, N_2, N, C, D, H, CO_2^+, O_2^+, O^+, N_2^+, NO^+, He^+, D^+, H^+, etc. (NIMS, UVS)	115 - 250	1/2 scale height 10 km (waves) 100 km (tides)	~1 min (waves) ~1 hr LT (tides) ~1 hr (planetary waves) ~1 month (season)	5%
Neutral gas and plasma temperatures	T_g, T_i, T_e (NIMS, FPI, RPA, LP)	115 - 250	same as above	same as above	5%
Neutral and ion wind velocities	v_n, v_i (FPI, NIMS, RPA, IDM, IP)	50 - 250	sames as above	same as above	5%
Isotope ratios and rare gas concentrations	$^{15}N/^{14}N$, $^{38}Ar/^{36}Ar$, $^{13}C/^{12}C$, $^{18}O/^{16}O$, D/H (NIMS, UVS)	115 - 250	below homopause (~120 km) and in thermosphere (>120 km)	day and night	5%
Magnetic fields (ionospheric currents and solar wind IMF)	Bt, Bx, By, Bz (VMAG)	115 - 1000	1 km along orbit	1-2 second	5 nt abs. 5 nt rel.
Solar EUV (incident and absorption profiles)	Total EUV, Spectral variation with altitude (EUV)	incident>250 km, absorption profile, 115-250 km	5 km vertical resolution	~5 second	5% abs. 1% rel.

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MEASUREMENT REQUIREMENTS (CONT)

The processes that control the upper atmospheres of the terrestrial planets include; momentum generation and dissipation, heating and cooling, transport, dissociation, ionization, excitation, emission, and escape. Gravity waves and dust storms are sources of energy and momentum that seem to be more important at Mars than at the other terrestrial planets. We can expect them to have major impacts on all upper atmosphere and ionosphere processes.

MUADEE

Measurement Requirements (cont)

MUADEE Science-Driven Measurement Requirements (2 of 2)

Controlling Processes	Measured Parameters (instruments)	Altitudes (km)	Spatial Resolution	Temporal Resolution	Accuracy
Momentum & Dissipation Sources	v_n, v_i, n_n, n_i, (FPI, IP, NIMS, UVS)	50 - 250	1/2 scale height 10 km (waves) 100 km (tides)	~1 min (waves) ~1 hr LT (tides) ~1 hr (planetary waves) ~1 month (season)	5%
Heating and Cooling Sources	EUV, T_n, T_i, T_e, n_n, n_i, (EUV, FPI, NIMS, RPA, LP)	115-250 50 - 150	1/2 scale height 100 km (tides) EUV absorption	same as above	5% 1% rel.
Dissociation and Recombination	EUV, T_n, T_i, T_e, n_n, n_i, (EUV, FPI, NIMS, RPA, LP)	115-250 in situ	1/2 scale height 100 km (tides) EUV absorption	same as above	5% 1% rel.
Excitation and Emissions	$O(^1D)$, $O(^1S)$, $O_2(^1\Delta)$, etc.	50-150 remote (species-dependent)	1/4 scale height	~1 min (waves) ~1 hr LT (tides) ~1 hr (planetary waves) ~1 month (season)	10%
Escape and Atmospheric Evolution (atoms, ions, rare gases, isotope ratios)	n_n, n_i, n_e, T_n, T_i, T_e, v_n, n_i, super thermal ions and neutrals (IP,NIMS,FPI,LP,RPA)	115-250 in situ 50-150 remote	1/4 scale height 10 km horizontal	~1 min (waves) ~1 hr LT (tides) ~1 hr (planetary waves) ~1 month (season)	5%
Dust Storm perturbations	n_n, n_i, n_e, T_n, T_i, T_e, v_n, v_i (IP,NIMS,FPI,LP,RPA)	115-250 in situ 50-150 remote	1/4 scale height 10 km horizontal	~1 min (waves) ~1 hr LT (tides) ~1 hr (planetary waves) ~1 month (season)	5%
Gravity Wave perturbations	n_n, n_i, n_e, T_n, T_i, T_e, v_n, v_i (IP,NIMS,FPI,LP,RPA)	115-250 in situ 50-150 remote	1/4 scale height 10 km horizontal	~1 min (waves) ~1 hr LT (tides) ~1 hr (planetary waves) ~1 month (season)	5%

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SENSORS FOR MEASUREMENT GOALS

The history of upper atmosphere exploration has shown that many parameters must be measured simultaneously to gain an understanding of the underlying physics. Isolated measurements of a few parameters are not very useful in an atmosphere that is as spatially and temporally variable as that of Mars. The Atmosphere Explorer satellites carried 16 instruments, and the Pioneer Venus Orbiter carried 12. Owing to the more limited goals of MUADEE, only 7 sensors will be required, integrated together into three instrument packages.

The MUADEE instruments are based entirely on heritage from Earth Explorers and/or Pioneer Venus. They are inherently simple and inexpensive by comparison with typical planetary-class instruments.

The MUADEE sensors and their relation to the MUADEE goals are indicated in the table on the facing page. Most of them perform measurements that bear on two or more of the MUADEE goals; the present state, the controlling processes, and the effects of atmospheric escape on the evolution of the atmosphere.

Sensors for Measurement Goals

- Derived from Earth Explorers and Pioneer Venus

FPI :	Fabry-Perot Interferometer	LP/EUV:	Langmuir Probe/Solar EUV
UVS:	Ultraviolet Spectrometer	RPA/IDM:	Retarding Potential Analyzer Ion Drift Meter
NIMS:	Neutral mass spectrometer		
VMAG:	Vector magnetometer	IP:	Imaging photometer

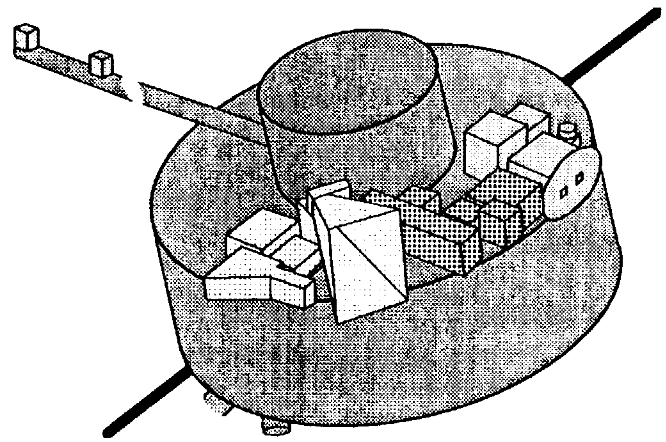
A. Escape and Evolution	
Thermal loss of H	NIMS, UVS, FPI
Escape of atoms & ions	NIMS, FPI, UVS, RPA/IDM, VMAG
Isotopes and rare Gases	NIMS
B. Present State	Sensors
Chemically important neutrals	NIMS, UVS, FPI
Ionosphere and magnetic fields	VMAG, NIMS, LP/EUV, RPA.
Temperatures	FPI, LP/EUV, NIMS
Winds	FPI, NIMS, RPA/IDM
Isotope Ratios and Rare Gases	NIMS
C. Controlling Processes	
Sources of momentum & dissipation	FPI, IP, NIMS, UVS
Sources of energy and heat, and cooling	LP/EUV, UVS, NIMS
Dissociation and Recombination	NIMS, FPI, UVS
Ionization & recombination	NIMS, LP/EUV, UVS, FPI

INTEGRATED PACKAGES

The 7 MUADEE sensors are repackaged into 3 Instrument Packages for purposes of mission simplification and to keep costs low. These packages are: the Scanning-Imaging Package (SIP), The Neutral Atmosphere Package (NAP), and the Plasma Instrument Package (PIP). Each sensor, and its peculiar circuitry, shares a common Data Processing Unit and Power Supply. While the sensors themselves differ from package to package, most of the supporting hardware (the DPU and the PS) will be identical, thus simplifying their integration into the spacecraft and simplifying the spacecraft design itself.

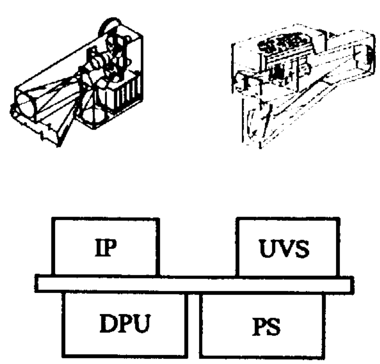
MUADEE

INSTRUMENTS



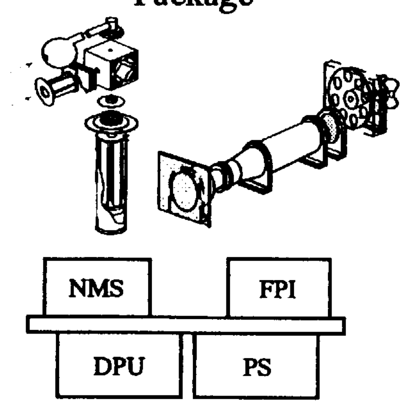
SIP

Scanning Imaging Package



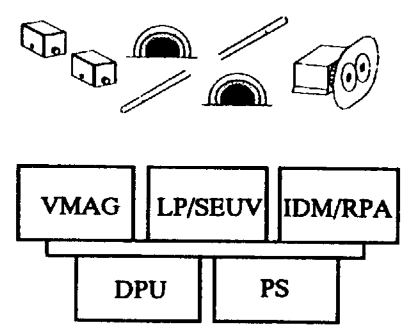
NAP

Neutral Atmosphere Package



PIP

Plasma Instrument Package

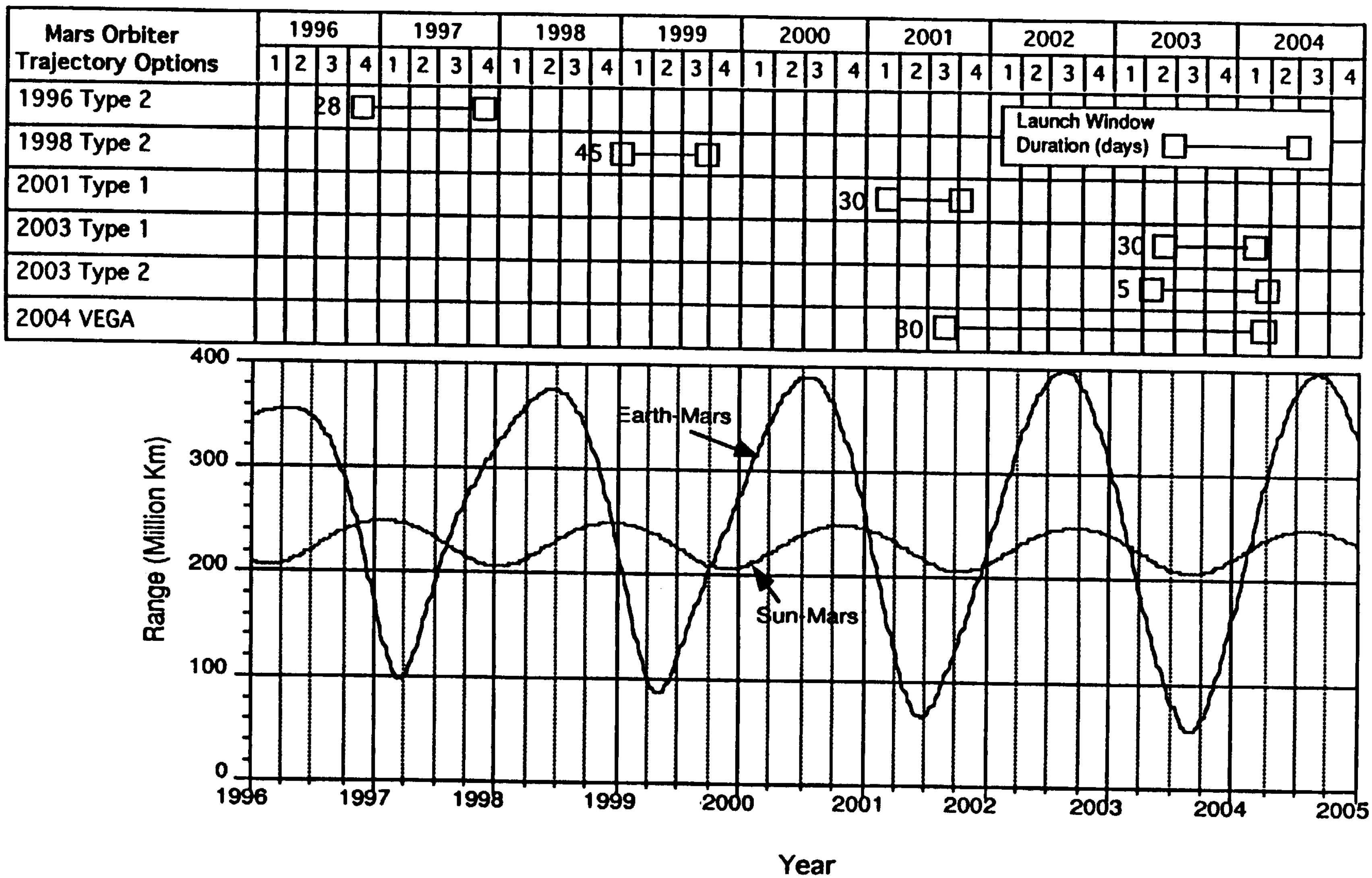


MUADEE_IntPkgs.cvs 03/10/94
2.3

LAUNCH OPPORTUNITIES

Launch opportunities occur at approximately 2 year intervals. The facing graph shows the opportunities between 1996 and 2003. The injection Δv differs, but the MUADEE design is sufficiently capable to use any of them. A 1998 launch is assumed in this study. The propulsion system is adequate to provide relatively long launch windows (order of 2 months). This will be important to avoid launch pad conflicts if other Mars missions are launched during this opportunity.

LAUNCH OPPORTUNITIES



ORBITAL SCENARIO

A multi-phased mission is required to achieve the measurement goals of MUADEE while keeping the costs low. After a 10 month cruise phase, the spacecraft will be injected into a 24-hour orbit having an inclination of 99.5° and periapsis and apoapsis altitudes of 250 km and 33,000 km, respectively. Periapsis is then lowered to the vicinity of 115 km to begin a 5 month period of gentle aerobraking toward the desired deep-diving orbit of 130x2500 km. (The use of aerobraking reduces the amount of spacecraft propellant required to achieve the initial orbit and then to get down to the desired orbit). Periapsis drifts repeatedly from pole to pole during the next 16 months, thus permitting a latitudinal survey of the upper atmosphere at several different local times. After completing the latitudinal survey, aerobraking and chemical propellant are used again to place MUADEE into a circular orbit that lies entirely within the thermosphere and ionosphere (alt.~200 km). The rapid orbital precession in this orbit permits a Global Survey (latitude, longitude and local time) to be conducted. Finally, the orbit is boosted to a 250x1000 km quarantine orbit to provide the required lifetime to impact.

MUADEE

Orbital Scenario

Mission Scenario Rationale

Injection into 24 hour orbit to reduce orbit injection delta v requirement

Aerobraking Phase (115x33,000 to 2500 km); 4-5 months
- In situ thermospheric measurements to lowest possible altitudes
- Visual imaging and remote sensing of middle atmosphere from low periapsis
- Global uv imaging from high altitude apoapsis.

Deep-diving Phase (elliptical, 130x2500 km); 16 months
- Increased apsidal drift rate provides latitudinal sweeps of periapsis at 4 different local times and wide range of Sun-Mars distances.
- Permits near-global uv imaging from apoapsis
- Low telemetry bit rate is compatible with brief periapsis data taking.

Global Survey Phase (circular ~200 km); 4 months
- Full orbit in situ and remote sampling of atmospheric latitude structure
- Orbit precession samples full local time variation.
- Start of circular phase is delayed until Aug, 2001 when higher bit rates are available for full orbit data recovery.

Quarantine Orbit (~250x1000 km); added science if mission is extended
- Full seasonal and dust storm responses of the atmosphere (mostly remote)
- Periapsis altitude to provide ~30 year lifetime during quarantine phase

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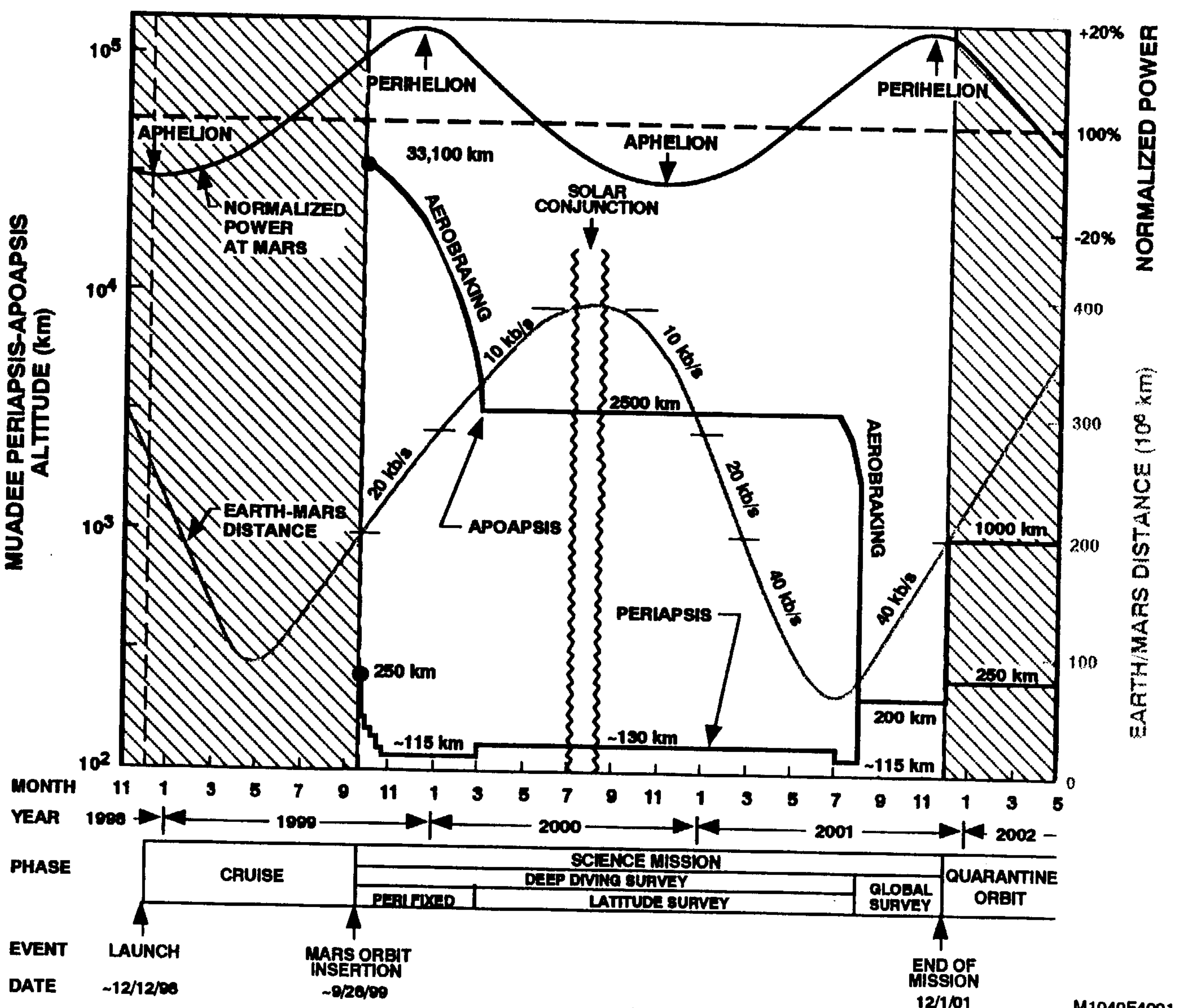
MISSION SCENARIO

A plot of the progression of apoapsis and periapsis (red) during the multi-phased mission. The variation in spacecraft electrical power (green) and the Earth-Mars distance (blue) are also shown. Injection into a 24 hour orbit is followed by aerobraking into the desired deep-diving orbit (130x2500 km). This orbit is desired because periapsis moves rapidly from pole to pole to provide height profiles of the atmosphere as a function of latitude, thus it is called the Latitude Survey Phase. Solar conjunction will interrupt contact with the spacecraft for about a month in July of 2000, however, the spacecraft will continue limited data taking autonomously during this period. After 7 pole to pole sweeps of periapsis, each at a different local time, the Latitude Survey will be considered completed, then aerobraking is again used to reduce apoapsis in preparation for a maneuver to begin the Global Survey from circular orbit at about 200 km. The rapid precession of this orbit will allow nearly all local times to be encountered within 4 months, using both the northbound and southbound halves of the orbit. The mission will end in December 2001 when MUADEE will be placed in an orbit which meets the planetary quarantine requirements.

MISSION SCENARIO



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SYSTEM REQUIREMENTS

The design presented in this report is compliant with all system requirements. The key system requirements are summarized in the following figure with design and performance margins identified. At the project level, the spacecraft requirements have been scoped to ensure compatibility with the overall discovery cost guidelines.

To minimize risk significant margins have been identified and maintained in all key areas. The overall mass margin of 33% is based on the Delta II 7925 launch vehicle with the 9.5 foot fairing. Because of the variation in Earth/Mars geometry , the lift capability of the launch vehicle is a function of launch date. The MUADEE system was designed for the worst case 2001 launch opportunity. The spacecraft was designed for a 3 year lifetime. This includes a 1 Earth year cruise to Mars and 2 Earth years of mission operations at Mars. All of the propellant load calculations were based on the spacecraft dry mass with contingency. An additional 8% contingency was then added to the propulsion mass.

The spin stabilized spacecraft includes a momentum wheel to operate the spacecraft in a despun-mode. The modest pointing accuracy and knowledge requirements are met with significant margins.

Aerobraking is used to minimize the propulsion mass required to achieve the science orbits after initial Mars orbit capture. Aerobraking is accomplished without the use of heat shields by maintaining modest heating levels and orienting the spacecraft tail first through periapsis.

For all communications modes, a 3 db margin is maintained. This includes both the high gain antenna science downlink mode, and emergency communications through the omni antennas. All communications are through the JPL Deep Space Network (DSN) system. Standard operation uses the 34 m antenna system and the emergency mode utilizes the 70 m DSN antenna when the spacecraft is furthest from the earth.

Accommodation of the scientific instruments includes the areas of mass, power, data rates, and fields of view. During all modes of operation, a spacecraft power margin of 25% is maintained. This includes the cruise, latitude survey, and diurnal mapping phases of the mission.

MUSE

SYSTEM REQUIREMENTS

REQUIREMENTS		COMPLIANCE	MARGINS/COMMENTS
• SCHEDULE	LESS THAN 3 YEAR SPACECRAFT DEVELOPMENT	YES	< 3 YEARS
• QUALIFICATION	PROTOFLIGHT	YES	PROTOFLIGHT MARGINS
• LAUNCH VEHICLE	DELTA II 7925	YES	33% MASS MARGIN
• LAUNCH DATE	1998, 2001, 2003	YES	2001 DESIGN CASE
• LIFETIME	LESS THAN 1 YEAR CRUISE, 2 EARTH YEARS IN MARTIAN ORBIT	YES	3 YEAR DESIGN LIFE
• MARS ORBIT	99.5° INCLINATION, CAPTURE: HIGH ELLIPTICAL 1 TO 3 DAY PERIOD, SCIENCE ORBITS: 130 KM X 2500 KM, 200 KM TO 250 KM CIRCULAR, PARKING ORBITS: 250 KM X 1000 KM	YES	ΔV BASED ON DRY MASS WITH 20% MARGIN ADDITIONAL 8% MARGIN ADDED TO ΔV
• TRAJECTORY CORRECTIONS	GROUND COMMANDED, TWO MANEUVERS, INJECTION ERRORS CORRECTED WITHIN 2 WEEKS PLUS MID COURSE CORRECTION	YES	INCLUDED IN ΔV BUDGET
• OPERATING MODES	SPIN STABILIZED @ 3 RPM DESPUN @ 1 REV PER ORBIT	YES	SPIN BALANCED S/C WITH MOMENTUM WHEEL
• POINTING CONTROL	ALL PHASES 0.5°, 3σ	YES	0.19° 3σ MARGIN
• POINTING KNOWLEDGE	ALL PHASES 0.3°, 3σ	YES	0.05° 3σ MARGIN
• AEROBRAKING	MAXIMIZE AEROBRAKING TO MINIMIZE DELTA V WITHOUT USE OF HEAT SHIELDS	YES	TAIL FIRST AEROBRAKING IMPLEMENTED
• COMMUNICATIONS	X-BAND, DSN	YES	3 DB MARGIN
• PAYLOAD ACCOMMODATION	MASS 44.0 KG POWER 36.6 WATTS DATA RATE 4,396 BPS	YES	30% SI MASS MARGIN 25% SI POWER MARGIN 3 DB COMM MARGIN

SYSTEM OVERVIEW

This figure outlines the contributions of the various members of the MUADEE consortium. Lockheed provides the spacecraft and integration and testing, the University of Michigan provides the instruments (with the support of the University of Texas and the University of Colorado) and operates the spacecraft after it has been injected into Mars orbit and checked out. JPL provides project management, DSN communications, navigation and orbit determination, and backup mission control after Mars orbit insertion. JPL controls the spacecraft through injection and initial operations. The PI at University of Michigan operates the mission control center there after initial checkout and operations at JPL.

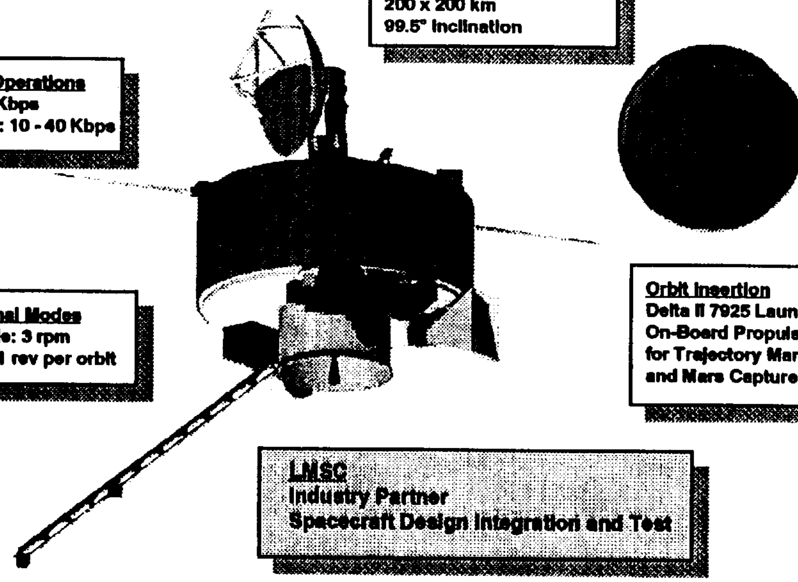
SYSTEM OVERVIEW

University of Michigan SPRL
MUADEE Discovery Team Leader
Scientific Instruments
MTOC: Mission Test Operations Center
Mission Control Functions
Testing, Training, & SOE Verification

Mission Operations
Uplink: 2Kbps
Downlink: 10 - 40 Kbps

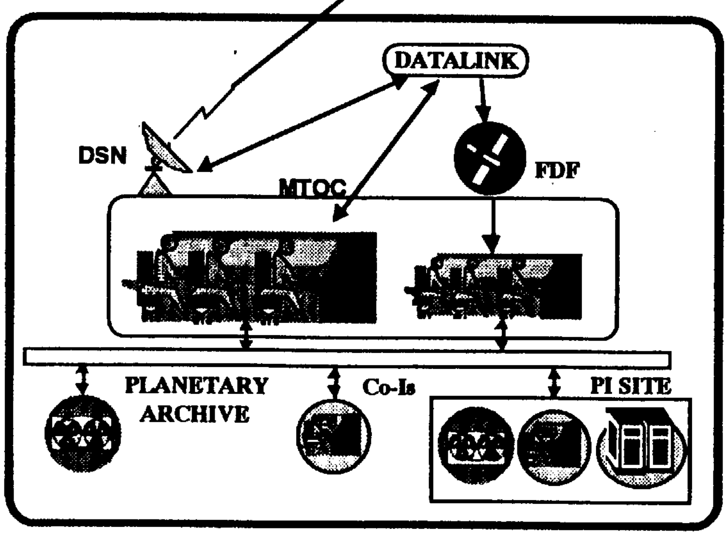
Operational Modes
Spin Mode: 3 rpm
Despun: 1 rev per orbit

MUADEE Science Orbits
130 x 2500 km
200 x 200 km
99.5° Inclination



Orbit Insertion
Delta II 7925 Launch
On-Board Propulsion
for Trajectory Maneuvers
and Mars Capture

LMSC
Industry Partner
Spacecraft Design Integration and Test



JPL
NASA Partner
Project Management Support
DSN Communications
Orbit Determination & Navigation
Back-up Mission Control

SPACECRAFT DESIGN DESCRIPTION

The three instrument platforms are mounted on the aft deck of the spacecraft bus structure. The spacecraft electronic components and propulsion tanks are mounted on the interior of the bus which consists of 6 internal bays.

The overall dry spacecraft mass is 477 kg with contingency and 897 kg fully loaded with propellant . The body mounted solar cells provide power to the spacecraft which has an orbit average power of 145 watts.

The pointing control system provides a pointing capability of 0.5° and pointing knowledge of 0.3°. Both values are 3σ numbers. The propulsion system provides up to a maximum of 1.98 km/s delta V impulsive capability.

SPACECRAFT DESIGN DESCRIPTION

• PAYLOAD	3 INSTRUMENT PLATFORMS PLASMA INSTRUMENT PACKAGE SCANNING INSTRUMENT PACKAGE NEUTRAL ATMOSPHERE PACKAGE
• BUS CONSTRUCTION	ALUMINUM HONEYCOMB WITH SIX INTERNAL BAYS
• MASS	477 KG DRY, 897 KG WITH PROPELLANT
• POWER	BODY MOUNTED GA/AS SOLAR CELLS, 145 WATTS ORBIT AVERAGER POWER
• POINTING CONTROL	DUAL MODE SPIN STABILIZED/MOMENTUM BIAS, 0.5° (3σ) POINTING, 0.3° (3σ) KNOWLEDGE
• PROPULSION	MONO / BI-PROP SYSTEMS, TOTAL ΔV 1.98 KM/S

SPACECRAFT KEY FEATURES

The MUADEE spacecraft design is based on the flight qualified Lockheed Pbus. This figure identifies several of the spacecraft design features. More detailed descriptions for each of the subsystems are included in the spacecraft design section.

The thermal design uses passive thermal control techniques to maintain all spacecraft equipment within required temperature limits for all mission phases. Heat rejection radiators are covered with high emittance materials to maximize heat dissipation to space. Surfaces not used as radiators are covered with Multi Layer Insulation (MLI) to minimize heater power requirements and temperature fluctuations . Heaters are used on temperature sensitive components such as batteries to supplement component dissipation in low power dissipation modes.

The electrical power system uses body mounted solar cells on both the cylindrical and top surfaces. Super NiCad batteries are used for peak power operation and eclipse periods.

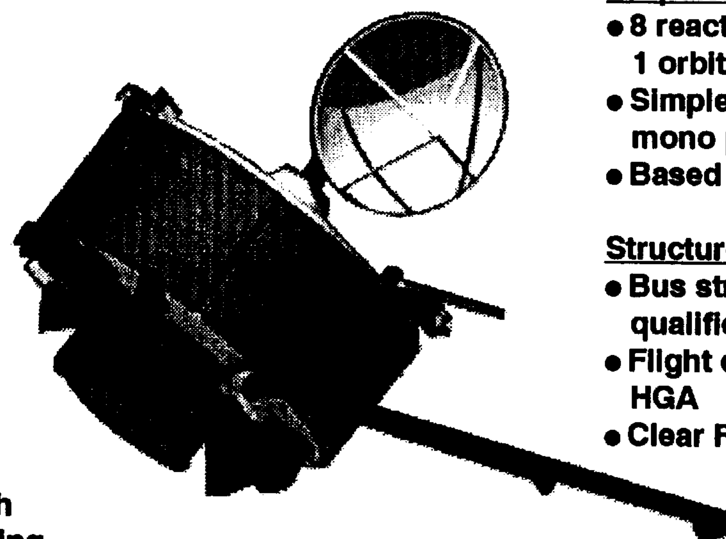
The attitude control system provides both spin stabilized and despun operational modes. The bus is spin balanced for the spinning mode and a momentum wheel is added to provide a despun operating mode. Attitude control sensors include star scanners, horizon sensors, and sun sensors.

The on-board propulsion system includes reaction control thrusters for orbit maintenance and a large orbit adjust thruster for orbit capture and other major orbit adjustments. The system uses both bi-propellant and mono propellant systems with simple blowdown configurations. This allows for simple operation of the propulsion system in both the spinning and despun operational modes.

The spacecraft structure is based on the Lockheed flight proven PBUS. The bus is constructed of aluminum honeycomb with aluminum facesheets. The high gain antenna is articulated by a two axis gimbal that provides pointing of the antenna during all operating modes. Use of the PBUS cylindrical geometry provides clear fields of view for all scientific instruments.

The command and data handling system is based on the Honeywell 1750A 16 bit flight computer. The system uses a data management unit that provides interfaces to all the scientific instruments and spacecraft components. A 2 Gbit solid state data recorder allows scientific data to be collected and then stored for transmission at a later time.

SPACECRAFT KEY FEATURES



Thermal Control
- Passive subsystem using FOSR, MLI
- Dedicated anti-sun radiators
- Minimum heaters (batteries)

Electrical Power
- Fixed body mounted solar arrays
- 25% contingency margin
- Based on flight qualified hardware

Attitude Control
- Simple spinner augmented with momentum wheel for de-spinning
- Spinning (3 rpm) or non-spinning (1 rev per orbit) modes
- Based on flight qualified hardware and software algorithms
- Simple safemode protective system

Propulsion
- 8 reaction control thrusters plus 1 orbit adjust thruster
- Simple blowdown bi-prop and mono prop systems
- Based on flight qualified hardware

Structures and mechanisms
- Bus structure based on flight qualified structure
- Flight qualified gimbal used for HGA
- Clear FOV for all instruments

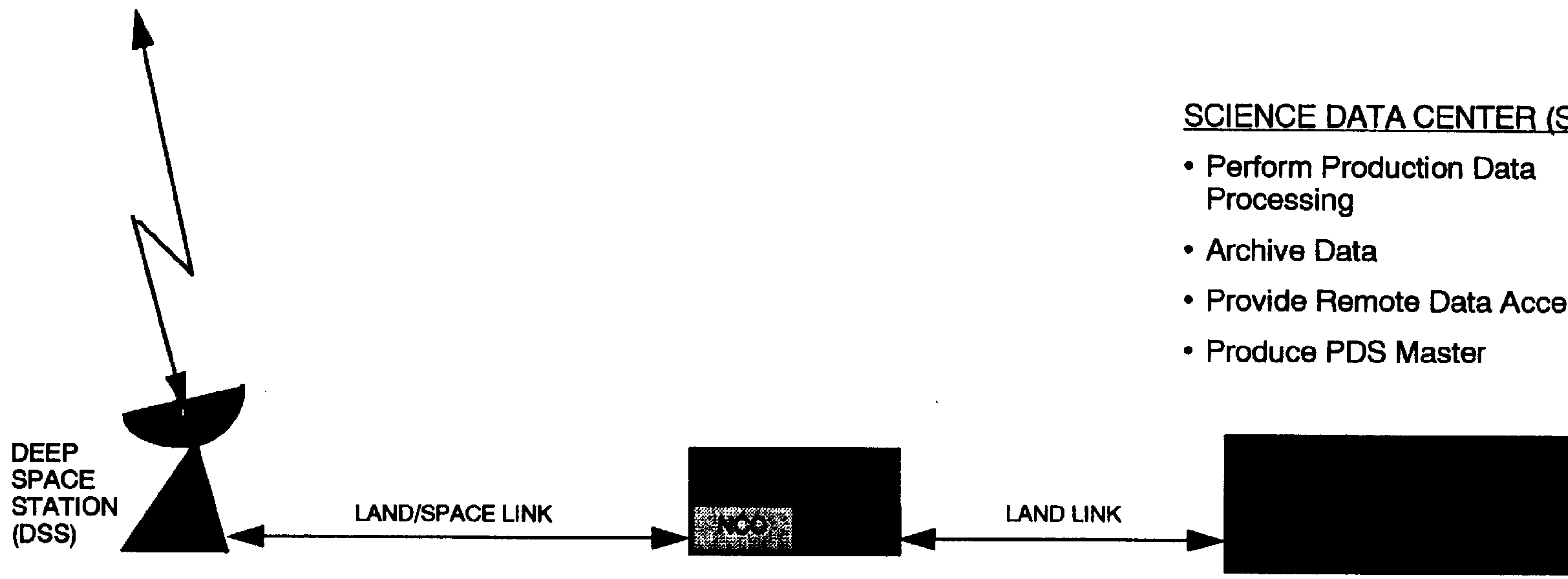
Data Handling & Communications
- Flight qualified data management system
- Solid state recorder
- X-band transponder based on flight qualified design
- 1.8m flight qualified HGA
- Fore and aft omni antennas
- Redundant system

GROUND SEGMENT OVERVIEW

The functions of DSN, JPL, the Science Data Center, and the MUADEE Test and Operations Center are outlined in the facing diagram.

The MUADEE data and commands are acquired and transmitted through the JPL Deep Space Network. JPL has the responsibility for orbit navigation and tracking and for back-up emergency functions. The MUADEE test and operations center (MTOC) is located at the University of Michigan and is staffed by Consortium members as appropriate for the given mission phase. The Science Data Center (SDC) is co-located at the University of Michigan and connected to Consortium institutions and the Planetary Data System via land links. More details on the ground segment are provided below.

GROUND SEGMENT OVERVIEW



SCIENCE DATA CENTER (SDC)

- Perform Production Data Processing
- Archive Data
- Provide Remote Data Access
- Produce PDS Master

DEEP SPACE NETWORK

- Acquire and Communicate with MUADEE Spacecraft
- Receive telemetry and tracking Data
- Transmit Command Loads
- Communicate with JPL via Land or Space Link

JPL SUPPORT

- Perform Network Control Functions and Command/ Tlm Delivery
- Perform Orbit Determination and Navigation Functions
- Perform Back-up (Emergency) Mission Control Functions

MUADEE TEST & OPERATIONS CENTER (MTOC)

- Perform Mission Control Functions (cmd, display)
- Perform Simulation Function for testing, training and verification
- Perform Necessary Support Functions

SYSTEM MARGINS

The MUADEE Consortium has taken very seriously the preservation of significant, conservative design margins in all aspects of the mission. For the margin calculations, worst-case conditions were assumed (end-of-life for solar cells, worst case launch window, worst case communications link, etc.)

The mass margin of 30% is conservative given the high heritage of all sensors and the use of an existing bus design. This margin and the relatively small size of the Lockheed P-Bus enables MUADEE to be accommodated securely within the Delta-II launch vehicle envelope.

The 25% power margin was the most difficult margin to sustain through the study, due to the body-mounted solar cells and the scientific requirement for a circular orbital phase late in the mission when extended eclipse periods occur. The MUADEE Consortium went to considerable effort defining and tuning the power system requirements. The 25% power margin was maintained by adjusting the mission scenario to take into account the complex trades involving the Mars-Sun geometry, Earth-Mars distance, telemetry bandwidths, etc.

The other margins (communications link, pointing, and propulsion) are all based on worst case scenarios and are considered conservative.

SYSTEM MARGINS

PARAMETER	REQUIREMENTS / RECOMMENDED MARGIN	CURRENT MARGIN	COMMENT
MASS	30%	33%	DRY S/C MARGIN 20% + 13% WET S/C MARGIN
POWER	25%	25%	@ FURTHEST MARS/SUN & MARS/EARTH DISTANCES
COMM LINK	3 DB	3 DB	@ 10 KBPS HGA WORST CASE 8 BPS EMERGENCY OMNI
POINTING	0.5°, 3σ	0.19°, 3σ	@ 2500 KM IN 1 RPO MODE
PROPULSION	1548 M/S	210 M/S	@ WORST CASE INSERTION ΔV BASED ON DRY MASS WITH CONTINGENCY

INTERNATIONAL MARS PROGRAM

MUADEE is a natural and essential part of a comprehensive international mars program, due to the importance of the upper atmosphere for any detailed study of Martian evolution. It complements and extends the Mars Surveyor program which will focus on the surface and perhaps the lowest part of the atmosphere. Surveyor's sun-synchronous orbit (fixed local time) will preclude measurements of the diurnal variations.

Mars-94/96 carries both remote and in situ devices, but the high periapsis altitude (300 km) precludes in situ measurements at the altitudes of interest to MUADEE. Also, its highly eccentric orbit will cause periapsis to be almost fixed in latitude, thus not able to provide the kind of global coverage required.

Planet B primarily focuses on the plasma environment of Mars above about 150 km and solar wind interactions with the upper ionosphere. Its equatorial orbit precludes the global coverage that will be provided by MUADEE's near polar orbit. Also, its use of deployed solar arrays and sounder antennae increases the atmospheric drag and precludes operations at altitudes near the ionospheric peak and within the fully mixed region of the atmosphere below 125 km. This altitude region is of primary interest to MUADEE's in situ measurements. MUADEE's surface-mounted array will permit operation down to about 110-115 km without undue spacecraft torquing or aerodynamic heating.

Because of their different instrument complements and orbits Planet B, Mars Surveyor, Mars 94/96, and MUADEE are more synergistic than duplicative. An actively coordinated measurements program is being planned with Planet B investigators, and a similar program will be conducted with Mars Surveyor and Mars 94/96 if their lifetimes overlap.

International Mars Program

- **Mars Surveyor**
  - focus on planet and lower atmosphere. Aeronomy was specifically excluded
  - sun-synchronous orbit (fixed local time) excludes measurement of diurnal variations by remote measurements
- **Mars 94/96**
  - Periapsis of ~300 km does not allow for thermosphere/ionosphere in situ measurements
  - Highly elliptical orbit allows little local time and latitude movement of periapsis
  - mission status uncertain
- **Planet B**
  - Current selected payload focuses on plasma measurements at altitudes > 150 km. Extended aeronomy instruments "under consideration" exclude remote wind measurements. 33 kg payload limit.

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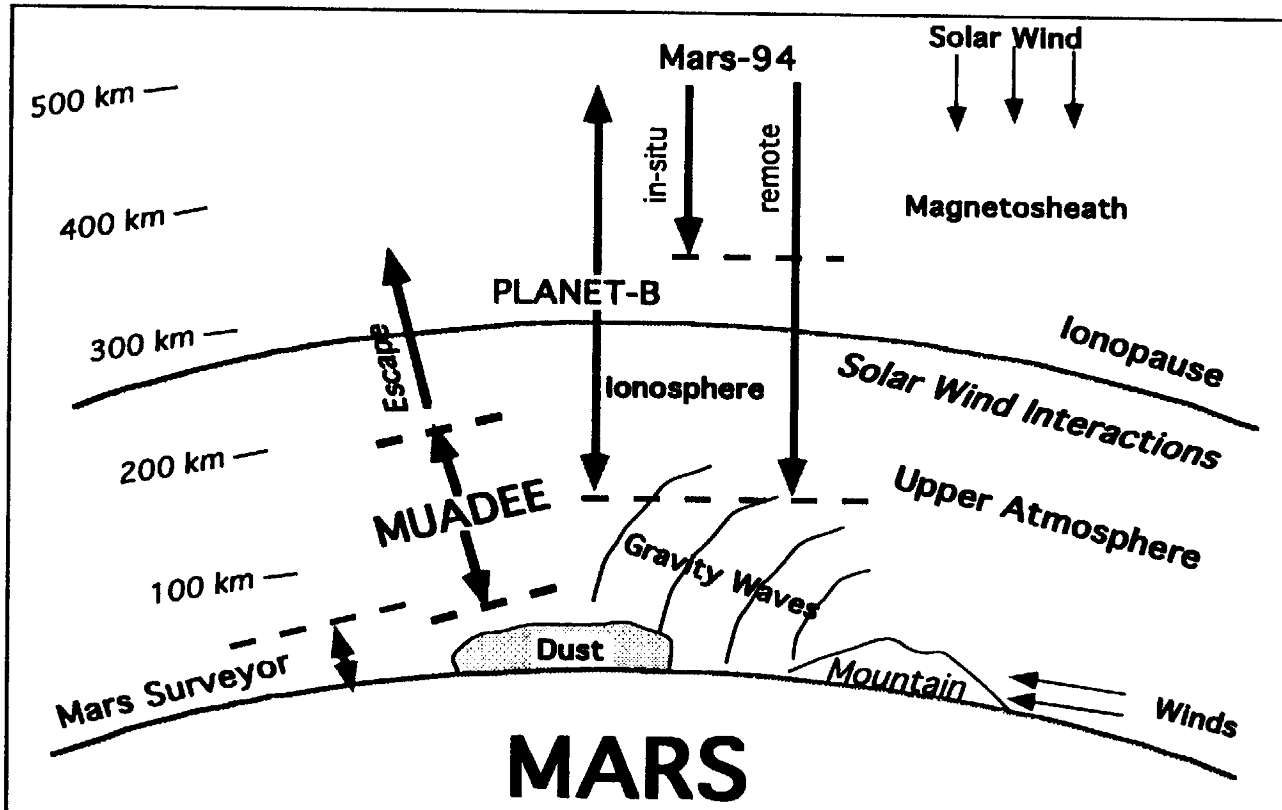
RELATIONSHIPS WITH OTHER MISSIONS

The synergism between the various planned Mars missions is illustrated below. Mars 94/96 and Planet B will investigate the upper ionospheric and its interactions with the solar wind. MUADEE will measure both the neutral and ionosphere parameters at altitudes down to 115 km via in situ measurements and down to perhaps 50 km via remote measurements. It will also directly measure escape fluxes and isotopic ratios as a function of altitude. MUADEE's measurements will elucidate the interactions that occur within the middle and upper atmosphere and ionosphere. It will not, however, duplicate the types of energetic plasma instruments that Mars 94/96 and Planet B have to permit the study of solar wind interactions. Mars Surveyor, as we now understand it, will focus on the Martian surface but will retain one instrument which can provide information on the temperature of the lower atmosphere.

Collectively, this group of spacecraft will enable an understanding of the Martian environment from the surface to the solar wind.

The MAUDEE Consortium has also considered several possible augmentations to the mission that include: 1) use of the MUADEE bus as a communications orbiter for Mars Surveyor; 2) added high spatial resolution visible imager; 3) added microwave atmospheric sounder; 4) possible hardware exchange with the Japanese Planet-B mission. These possible augmentations are discussed in order to provide NASA with potential options to improve the overall Mars Exploration Program.

Relationship With Other Missions



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PLANET-B LETTER AGREEMENT

The MUADEE and Planet B teams have agreed to collaborate and form an axis of a new International Program for Mars Exploration. The vehicle for the planned collaboration is a (draft) Letter of Agreement to be finalized through NASA's office of International Affairs. In the draft letter, MUADEE and Planet B teams have agreed to exchange data and to coordinate operations through a series of planned regular interactions. By means of this agreement, U.S. investigators will have full access to Planet-B data and Japanese investigators will have full access to MUADEE data. Joint scientific activities, involving workshops are planned. The two teams will investigate the desirability of providing backup DSN support for the acquisition of Planet B data and NASDA support for the acquisition of MUADEE data. The possible exchange of Co-investigators and/or limited hardware will be discussed at future meetings.

The MUADEE Consortium will pursue a similar collaborative agreement with the Mars Surveyor investigators and Mars 94/96 investigators. Three MUADEE scientists are already collaborating US scientists in the Mars 94/96 mission.

PLANET-B Letter Agreement

- Together MUADEE and PLANET-B provide complementary data needed to understand the origin, evolution and dynamics of the martian atmosphere. (e.g. MUADEE measures isotopic ratios, while Planet-B measures solar wind interactions and ion escape). Planet B is equatorial, MUADEE polar.
- Types of collaboration:
  - Coordinated operations: (weekly exchange of operational modes and orbit-crossing information on common E-mail network and dedicated line).
  - Exchange of science data: (key parameters in near-real time, final data PI to PI).
  - Joint science activities (via workshops and joint sessions at symposia).
  - Possible exchange of MUADEE and Planet-B Co-Is.
- Under Discussion:
  - Possible hardware exchange (e.g., mass spectrometer and solar wind monitors)
  - DSN support for Planet-B and NASDA support for MUADEE for critical operations. (possible auxiliary data acquisition)

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ATMOSPHERIC KNOWLEDGE FOR FUTURE MISSIONS

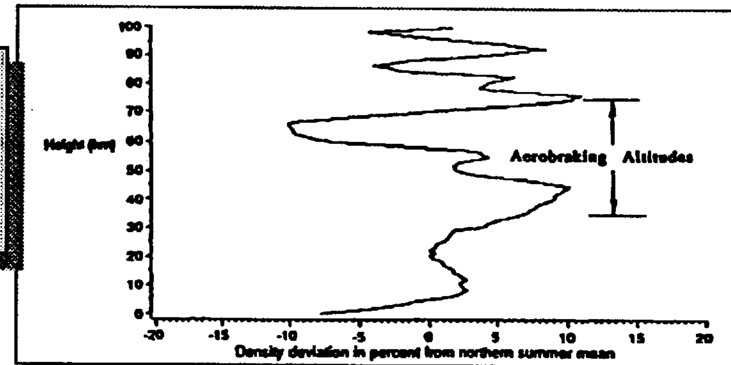
The use of aerobraking, particularly aerocapture, during future Mars missions will require better knowledge of the Martian upper atmosphere than is currently available. But better knowledge of the atmosphere (the other half of the aerobrake) will be required before aerocapture designs can be considered safe and reliable without considerable over design to make up for atmospheric uncertainties.

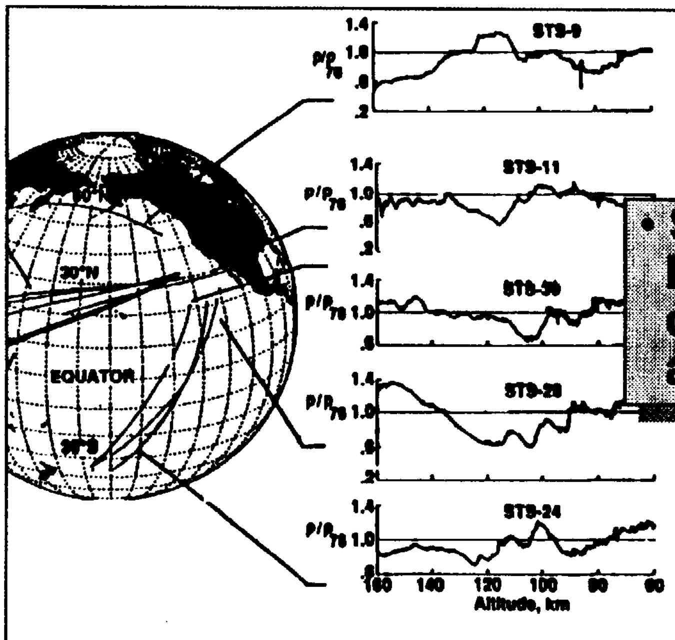
Uncertainties exist in both the mean global structure of the atmosphere and in its transient response to dust storms and gravity waves. The mean density variation with altitude, latitude, local time, and season are probably represented reasonably well by the COSPAR Mars Reference Atmosphere and the Mars-Gram Model, although MUADEE will certainly provide significant improvements in these mean models. However, little is known about the transient response of the upper atmosphere to dust storms and gravity wave disturbances. We do know, however, that the gravity waves are real and probably common, since they appeared at aerocapture altitudes in both the Viking 1 and 2 Lander density profiles of the day side atmosphere of Mars. Accelerometer measurements made during Space Shuttle reentry show the same type of density waves at the same density altitudes. Atmosphere Explorer and Dynamics Explorer mass spectrometer measurements have shown that the most wave-active regions at Earth to occur at high latitudes, and one expects them also to be large in the middle atmosphere in the vicinity of large mountain ranges.

It is clear from Pioneer Venus measurements that the most dynamic regions of the Venus atmosphere are the dawn and dusk sectors, just nightward of the solar terminators. We do not know where the most active regions occur in the Martian atmosphere, although it might be reasonable to expect them to be associated with the highest relief surfaces. MUADEE, particularly in its Global Survey phase, will identify the wave-active regions at Mars. The Neutral Mass Spectrometer will measure the waves that reach orbital altitudes, while the Imaging Photometer will detect the waves remotely as they propagate upward through the underlying atmosphere. The waves will show up as interference patterns in the visible airglow images, and these patterns will yield information on the amplitude and scale sizes of the waves down to aerocapture altitudes. It will be important to identify these wave-active regions so they can be avoided in future planning of aerocapture maneuvers, or accounted for in the dynamic range of the aerobrake design.

MUADEE Atmospheric Knowledge for Future Missions

- Viking 1 and 2 Lander measurements showed the presence of large waves - only current evidence





- Shuttle re-entry measurements have indicated large anomalies, due to gravity waves, particularly at high latitudes

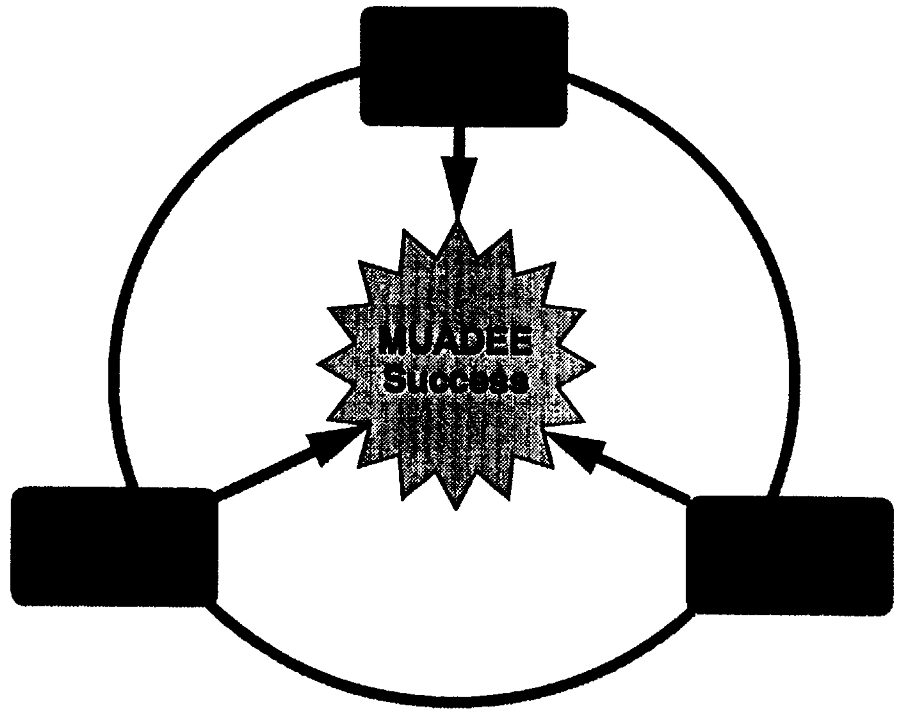
MUADEE will:
- Determine low Mars orbital environment
- Measure gravity waves
- Identify most active regions
- Determine atmospheric drag

MEMORANDUM OF UNDERSTANDING

The University of Michigan, Lockheed, and JPL have signed a Memorandum of Understanding that defines the key roles to be played by each of the MUADEE Consortium members. The theme of the Consortium is that the talent available within these organizations will be co-located as required to follow the action. For example, the Project Manager from JPL will be co-located at Lockheed as required to oversee the spacecraft development and co-located at the University of Michigan to oversee the fabrication of the instruments and the Ground System.

The Memorandum of Understanding is appended to this report. Some of its principal features are summarized in the next few view graphs.

University of Michigan - Lockheed - JPL Memorandum of Understanding (MOU)



- MOU Guides joint activities in support of the MUADEE mission
- Defines key roles, relationships, and arrangements for management of MUADEE

MOU - ORGANIZATIONAL ROLES

The PI has overall responsibility for the business, financial, technical and scientific management of the MUADEE project. An Executive Committee consisting of senior officers of the University of Michigan, JPL, and Lockheed will exercise high level oversight of the project. The Executive Committee, chaired by the PI, will assure that the proper level of attention is given to any problems that may affect the cost-to-complete or the scientific success of the mission. An external Non-advocate Review Board consisting of experienced program managers will review the project at critical times and will report to the NASA Headquarters Discovery Program Office on the status of the MUADEE project and will recommend any corrective measures that may be needed.

MOU - Organizational Roles

- PI has overall responsibility, accountability, and decision authority for MUADEE
  - Business, Finance, Technical, Scientific Management
- Executive Committee
  - Comprises senior members from each consortium partner
  - Chaired by the PI (also representing Science Team)
  - Operated by consensus
  - Approves appointments of key personnel assigned to PI
    - » Project Manager, Spacecraft manager, etc.
  - Exercises oversight over all aspects of MUADEE expenditures
  - Semi-Annual Cost-to-Complete Compliance Certification
- External Non-Advocate Review Board
  - Comprises experienced program managers, will advise both Program Manager and Program Office on Project Status and corrective measures

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MOU - SCIENCE TEAM RESPONSIBILITIES

The MUADEE Science Team is chaired by the PI and consists of the Co-investigators and any colleagues that have been assigned science-related responsibilities in the project. The Science Team will specify the science requirements for the mission and, to control costs, assure that these requirements do not grow during the implementation. The Science Team will participate in all decisions which impact the scientific data return that is required to meet the scientific goals. The scientific goals may be scaled back during the implementation of MUADEE, if necessary to control the cost-to-complete, but the goals may not be expanded.

The Science Team will process, interpret and distribute mission data, and it will assure proper credit to NASA, The University of Michigan, JPL, Lockheed, and all team members.

MOU - Science Team Responsibilities

- Science Team chaired by by the PI
- Responsible for detailed specification of science requirements
  - Requirements to be frozen at time of NASA Discovery AO
- Participates in all decisions impacting mission science data return
- Interprets and distributes mission data
- Assures proper credit to NASA, Michigan, JPL, Lockheed, and all other team participants

MOU - JPL RESPONSIBILITIES

JPL will assign the MUADEE Project Manager who will be responsible to the PI, while reporting administratively to the JPL Office of Space Science and Instrument Discovery Office. The Project Manager is charged by the PI to deliver MUAUDEE on-time and within cost. He will be co-located both at Lockheed and at The University of Michigan as required during the development phase. After MUADEE has been delivered into Mars orbit and checked out, the Ground Segments Manager at the University of Michigan will become the Project Manager.

JPL will also perform the navigation, tracking, and data acquisition functions for MUADEE during the Mission Operations and Data Analysis phase of the mission. A more complete description of the management scheme is given below.

MOU - JPL Responsibilities

- **Assign Project Manager to MUADEE**
  - Will be directly accountable and responsible to PI
  - Will report administratively to JPL Office of Space Science and Instrument Discovery Office
  - Charged by the PI to deliver MUADEE mission on-time and within cost
    - » University of Michigan Project Manager (Ground Segment Manager) assumes responsibility during MO & DA Phase
- **Provide navigation, tracking, and data acquisition functions during MO & DA Phase**

TLK Exec. 34

LOCKHEED RESPONSIBILITIES

Lockheed will provide the spacecraft bus, based on the existing P-BUS design. It will integrate the instruments and test the spacecraft, then deliver it for launch to the Eastern Test Range. Lockheed will also provide launch and operations support.

Lockheed Responsibilities

- Spacecraft Development
- Spacecraft Integration and Testing
- Spacecraft Launch Operations

MOU CONTRACTS

The prime contract for MUADEE will be between NASA and the University of Michigan. Michigan will write subcontracts to all other MUADEE Team participants. The Lockheed will receive an Award Fee type of contract.

MOU - Contracts

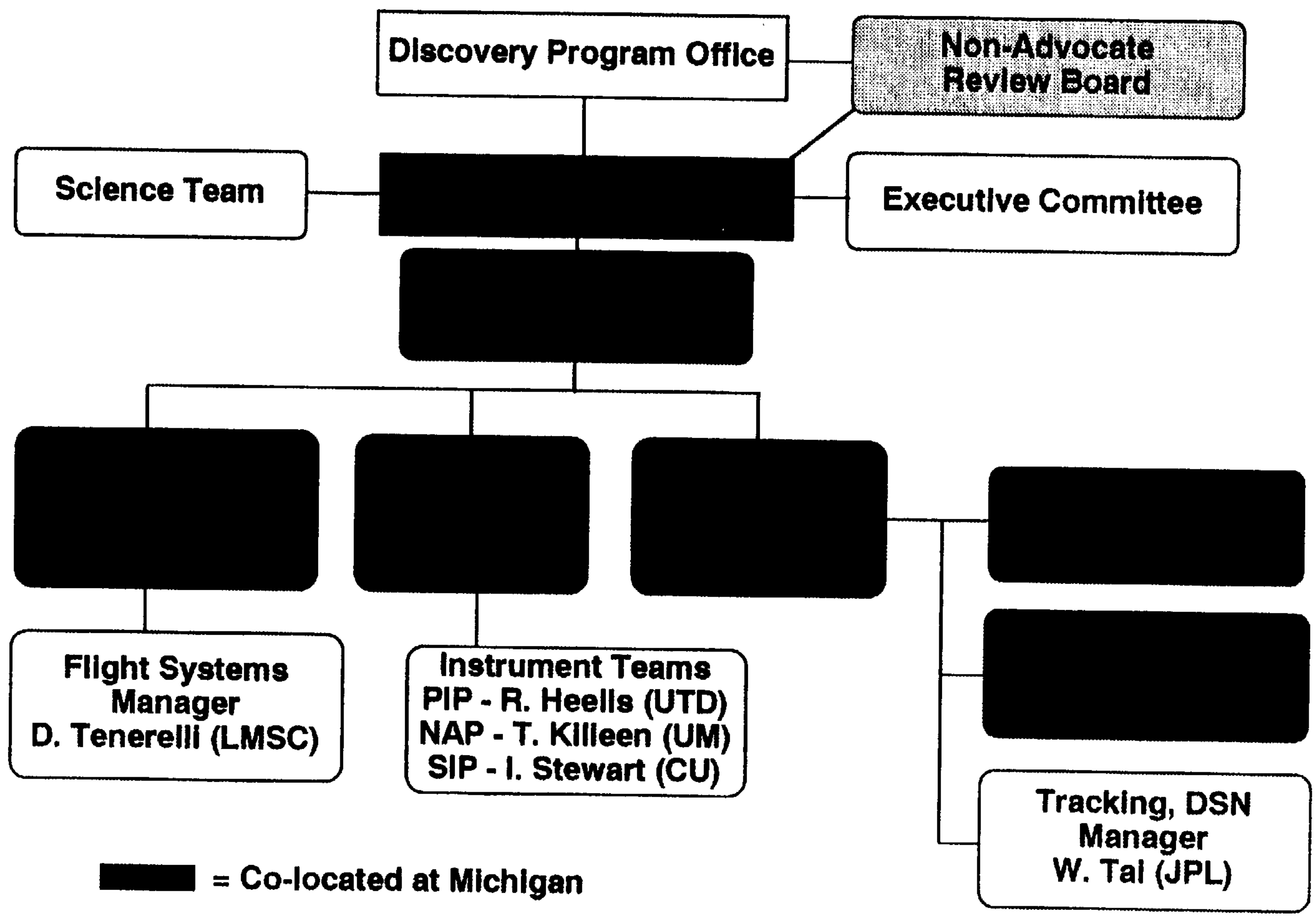
- Primary contract written from NASA to Michigan
- Sub-contracts written from Michigan to team institutions
- Lockheed contract type will be Award Fee

PHASE C/D ORGANIZATION

The facing page shows the proposed management arrangement for the Implementation phases (Phase C/D) of MUADEE. The key difference between MUADEE and previous missions that have been implemented by NASA Centers is evident here. Key members of the Michigan-Lockheed-JPL Consortium co-locate at the University as required to perform the needed functions involving test and integration. The low overhead associated with co-location at Michigan reduces both the spacecraft and integration costs. After launch, the University of Michigan Ground Segment Manager, who will have been involved in the development and testing, takes over the responsibility of operating the satellite. The Project Manager and some of the Lockheed engineering team go back to California. All consortium members remain on-call for support if on-orbit operations problems arise, and to support planned critical maneuvers.

A more detailed description of this and other mission phases is given below.

Phase C/D Organization



TLK Exec. 23

MISSION SCENARIO DESCOPES

If further mission definition during Phases C and D indicates that the Mission Scenario, if implemented, would drive costs beyond present expectations, the Global Survey (circular orbit phase) would be eliminated. This phase requires greater operational support than does the elliptical phase because the MUADEE spin axis must be torqued more frequently to keep it perpendicular to the orbit plane.

If additional cost reductions are required, the Latitudinal Survey (elliptical orbit phase) can be shortened by reducing the number of pole-to-pole periapsis sweeps. Each sweep requires 2.3 months, so a reduction from 7 sweeps to 5 sweeps would reduce the Latitudinal Survey phase from 16 months to less than 11 months.

Mission Scenario Descopes
(Order of Action)

- Remove circular orbit phase (5 months)
- Remove latitude sweeps of elliptical phase one at a time (2 sweeps deleted reduces mission duration to 1.5 years)
- Return to Pioneer-Venus-like spinner (remove momentum wheel)

TLK Exec. 41

INSTRUMENT DESCOPES

A number of instrument deletions and simplifications are available if mission scenario descopes are not adequate to contain cost-to-complete caps. The first option will be to remove the magnetometer from the Plasma Instrument Package. This will de-emphasize the solar wind interactions and Joule heating aspects of the MUADEE science goals.

The second option will be to delete the Imaging Photometer from the Scanning Imaging Package. This will de-emphasize MUADEE's study of the role of gravity wave propagation from the underlying atmosphere on the energetics and dynamics.

The third option will be to delete the Langmuir Probe sensors from the LP/EUV instrument in the Plasma Science Package. This will de-emphasize the role of electron-ion and electron-neutral heating in the thermospheric energy balance. However, the EUV capability of the instrument will be retained, since the EUV is the main heat source in the energy budget of both the thermosphere and ionosphere and it should be measured simultaneously with the atmospheric parameters.

The final instrument descope option that will be implemented will be to remove one of the two Fabry-Perot etalons, thus reducing the ability to obtain neutral gas wind directions.

This nested set of instrument descopes has been agreed to by all participants and is available for implementation as needed during the development phase. Instrument descopes will be activated by the Principal Investigator on the recommendation of the Project Manager.

Instrument Descopes
(Order of Action)

- Remove Magnetometer channel
- Remove Imaging Photometer channel
- Remove LP capability from LP/EUV sensor
- Descope FPI channel to single etalon implementation

SPACECRAFT DESCOPES

The first spacecraft descope option will be to reduce the data rate capability; including the communications subsystems and the onboard memory. This will reduce the electrical power requirements and the size of the body-mounted solar array and the external structure that supports it.

If further reduction in mission costs are required, the momentum wheel can be omitted from the spacecraft design, thus returning the mission to a pure spinner. This would be similar to the Pioneer Venus Orbiter design, except that the spin axis would be maintained perpendicular to the orbit plane to permit cartwheel-like scanning of the limbs for the remote instruments and full ram angle sweeps for the in situ measurements.

Spacecraft Descopes (Order of Action)

- Reduce science data throughput, down size comminication subsystem and electrical power subsystem requirements
- Return to Pioneer-Venus-like spinner, remove momentum wheel

SPACECRAFT BUS ADVANCED TECHNOLOGY PLAN

A significant goal of the MUADEE project will be to explore and demonstrate spacecraft implementation approaches that will reduce costs for future NASA missions. A related goal will be to transfer this technology to the aerospace industry where it can be used to benefit future commercial applications in space. The facing page lists the major aspects of this plan.

SPACECRAFT BUS
ADVANCED TECHNOLOGY PLAN

- <u>SPACECRAFT ADVANCED TECHNOLOGY IMPLEMENTATION PLAN</u>
  - ESTABLISH VIRTUAL SPACECRAFT DEVELOPMENT ENVIRONMENT
    - INTEGRATION PRODUCT TEAMS
    - CONCURRENT ENGINEERING
    - STANDARIZED DATA FORMATS
    - AUTOMATION TOOLS
    - SPACECRAFT TESTBED
  - LEVERAGE ONGOING ADAVANCED TECHNOLOGY
    - COMPOSITE STRUCTURES, HIGH STREGTH AND THERMAL CONDUCTIVITY WITH LOW MASS
    - MINIATURE LOW POWER/COST STAR TRACKER
    - RISC PROCESSORS, 1773 DATA BUS, 3-D SS MEMORY
    - HIGH EFFICIENCY SILICONE CELLS
    - LITHIUM POLYMER BATTERIES
- <u>SPACECRAFT TECHNOLOGY TRANSFER PLAN</u>
  - DEVELOP TECHNOLOGY IMPLEMENTATION PLAN BASED ON BENEFIT TO FUTURE MISSIONS AND COMMERCIAL PAYOFF
    - ASTROPHYSICS
    - EARTH SCIENCE
    - COMMERCIAL REMOTE SENSING
    - COMMUNICATIONS
    - SPACE PHYSICS
    - PLANETARY MISSIONS
    - COMMERCIAL INDUSTRY

PAYLOAD ADVANCED TECHNOLOGY

The MUADEE scientific instruments involve several technological developments that may prove useful for later NASA mission or for commercial applications. These include the high sensitivity CCD detector that will be used by the Fabry-Perot Interferometer. The SEUV sensor represents a new low-cost and simple approach to making measurements of the solar ionizing radiation environment in which all spacecraft must operate. Use of this new sensor in orbit will allow calibration against the more established Langmuir Probe method of measuring the UV and EUV total incident radiation, as demonstrated at Venus on the Pioneer Venus Orbiter.

Packaging technology will reduce the cost and size of the scientific instruments. The new ERIM (Environmental Research Institute of Michigan) Multi-chip Module Technology will be used in some of the instruments. The integration of the 7 instruments into 3 Instrument Packages which share common power supplies and DSUs offers a demonstration of another approach to cost reduction.

PAYLOAD ADVANCED TECHNOLOGY

- FABRY-PEROT INTERFEROMETER CHANNEL (FPI)
  - High-Sensitivity CCD Detector.
- SOLAR EXTREME ULTRAVIOLET CHANNEL (SEUV)
  - New sensor design used in conjunction with proven mature Langmuir Probe (LP) electronics.
- PACKAGING
  - ERIM Multichip Modules.
  - Integrated Instrument Electronics approach.

EDUCATION PLAN

MUADEE will make major contributions to education in Michigan and elsewhere. Engineering and design courses will be offered to undergraduate and graduate students who are interested in focusing on the design and implementation of a scientific satellite mission. Student research projects will be conducted in parallel with, and in support of, MUADEE instrument and spacecraft development efforts by co-located professional staff from Michigan, Lockheed, and JPL. We expect there to be about 20 graduate student thesis projects. Students will also participate in the mission operations under the supervision of professional spacecraft controllers.

A primary and secondary school outreach program will be undertaken expanding upon the Blue Skies and Weather Underground programs developed by Professor Samson at the University of Michigan. These programs will make current MUADEE insitu data and images available via INTERNET to thousands of students. We expect this program to attract many scientifically oriented students to engineering programs around the country and to expand interest in NASA science missions.

Education Plan

- University of Michigan College of Engineering Design Courses - supported by LMSC and JPL personnel, focusing on MAUDEE topics (parallel efforts, non critical)
- Undergraduate student research projects
- Mission Operations crew supported by students
- Graduate Student Thesis Projects (~20)
- Elementary-High School:
  - Expand on the Michigan "Blue Skies" and "Weather Underground" Internet Systems developed by Prof. Samson at University of Michigan.
  - System is accessed by over 300,000 students per week interested in "real time" weather data. MAUDEE will provide an on line capability enabling Martian "weather" to be used in the K-12 curriculum. Dust Storm flash news, with "real-time" images from Mars!

MUADEE IN THE NEWS

MUADEE has already generated a great deal of public attention both in the Ann Arbor press and nationally. The headers on the facing page indicate the interest and excitement that our work thus far on MUADEE has engendered.

MUADEE in the News

Space: U-M aims high — for Mars

From page 1B

that are built into the larger-cost missions."

MUADEE and the other Discovery missions would be limited to $150 million and must be off the ground in

NASA Culls Discovery Missions While Seeking Program Funds

By LEONARD DAVID
Special to Space News

WASHINGTON — NASA has taken another step in one of its

project can be started every year. If all projects require the maximum development cost of $150 million, then the interval between

manage a project."

Richard Vorder Bruegge, staff scientist for Science Applications International Corp. in Washing-

NASA selects U-M team to work on 1998 Mars expedition

By Sally Pobojewski
News and Information Services

NASA has chosen a team of U-M

Dynamics, Energetics and Evolution) Mission. Killeen will direct the work of a 17-member scientists consortium from six

from NASA's Kennedy Space Center.

"MUADEE is one of 11 new Discovery Program science missions selected by

ble launch date would be

A new NASA progra

Mission development m

U-M could be 1st to lead space quest

■ If U-M beats competition, it would oversee Mars mission

By DAVE WILKINS
NEWS STAFF REPORTER

The University of Michigan could become the first university to oversee a space mission, as NASA explores new ways of doing business.

U-M Professor Timothy Killeen is leading a project that would send a spacecraft

U-M team aims high — for Mars

■ Mission: NASA considers university's proposal to launch a cheaper spacecraft.

By Hugh McCann
and Paige St. John
THE DETROIT NEWS

Timothy Killeen. "There are only eight or 10 universities that could take on something like this."

MUADEE mission

U-M atmospheric scientists are developing plans for an unmanned mission to Mars in 1998. MUADEE's (Mars Upper Atmosphere Dynamics, Energetics and Evolution) goal is to explore the upper atmosphere of Mars in a two-year mission. Here's a look at the spacecraft:

Magnetometer: Imaging photometer:

M-EDITION/CAMPUS

MARS

U-M's MUADEE is considered front-runner for NASA funds

whether MUADEE will get a green light. It is considered a front-runner.

"We have a really great shot at it. This is a mission with a lot of academic support," said

MUADEE would explore for the first time the

NASA's Goddard Space Flight Center, UCLA, Johns Hopkins and the universities of Arizona, Colorado and Texas at Dallas.

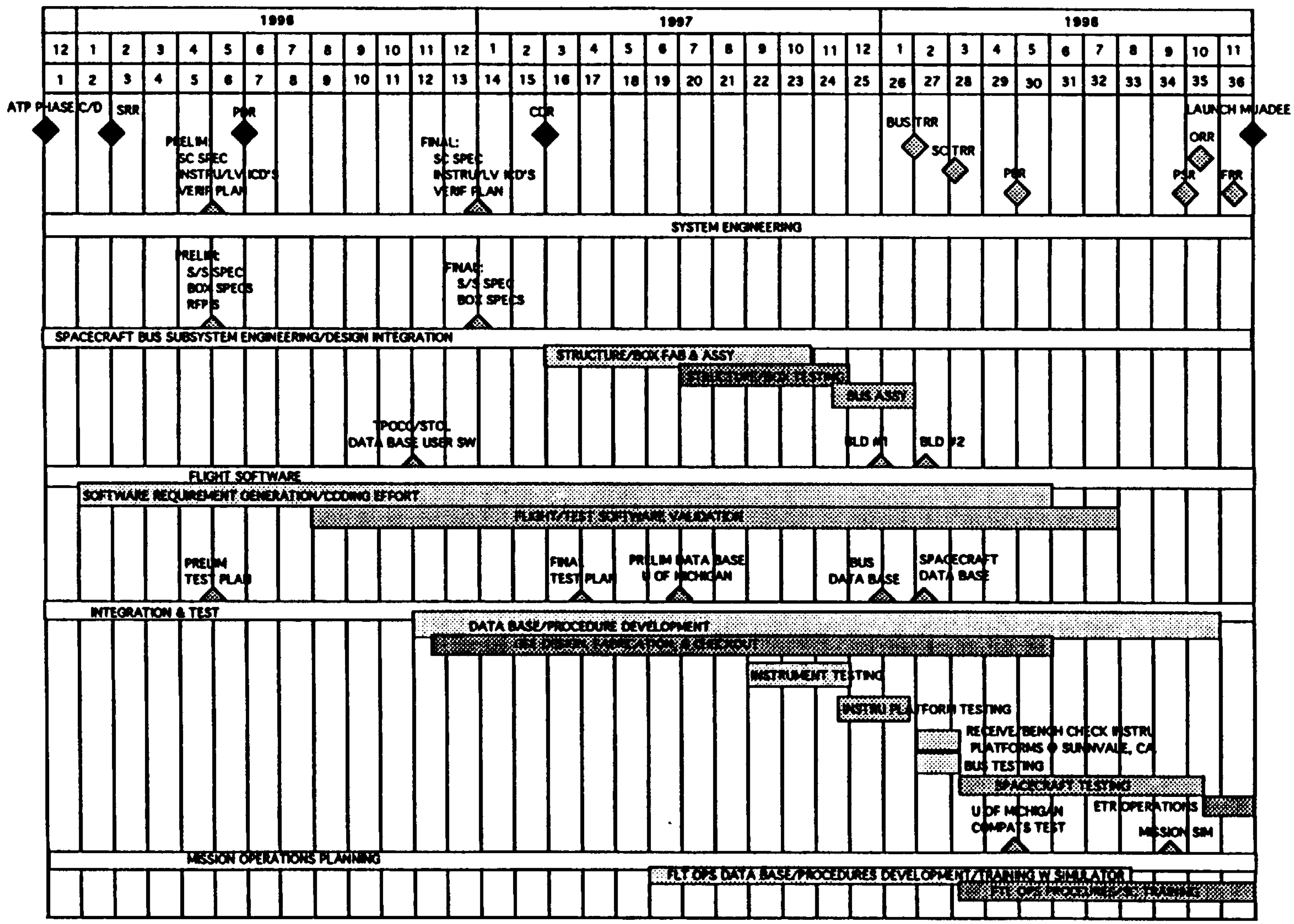
PROJECT SCHEDULE

The total time span for all hardware and software development period is less than three years as directed by the discovery guidelines. The ability to perform to this type of schedule is based on Lockheeds' previous performance. Lockheed has performed spacecraft bus design, integration with multiple complex scientific instruments, and systems level test in less than 3 years and maintained cost performance requirements. Cost and schedule data are available for these projects and will be provided with the past performance portion of the proposal submission.

The first project milestone is the System Requirements Review. At this time all the system requirements are frozen and flown down to the individual subsystems. The Preliminary Design Review (PDR) is held six months after project start. The Critical Design Review (CDR) is then held 9 months after PDR. Based on the work already performed and contained in this document, the accelerated PDR/CDR schedule can be met without increasing project risk and will result in project cost savings.

After spacecraft bus assembly the Bus Test Readiness Review is held. The bus is functional tested and integrated with the scientific instruments. A Spacecraft Test Readiness Review is then held prior to system level testing. After system level functional and environmental testing is performed the Final Readiness Review is held prior to shipping the spacecraft to the launch facility. Spacecraft launch is scheduled for the 1998 Mars opportunity at the end of the year.

PROJECT SCHEDULE



C-2

AUXILIARY SCIENCE AND OTHER OPTIONS

The MUADEE tracking and radio occultation data will make very important contributions to Mars science, some of it of great interest to upper atmosphere science and some of it of intrinsic interest to Martian geology. JPL and Goddard have great experience in the use of tracking data to investigate planetary gravity fields and to measure atmospheric densities via aerodynamic drag effects. In addition, telemetry occultation has been used extensively to obtain height profiles of ionospheric electron density at Venus, Mars and the outer planets.

During the MUADEE mission, Dr. Dave Smith at Goddard will collaborate with his counterparts at JPL to model the Martian gravity field and to separate the effects of atmospheric drag on the orbit. The very low periapsis altitude in the Latitude Survey phase, and the low circular orbit of the Global Mapping phase will provide unique opportunities to define the higher order gravitational terms that are particularly difficult to determine because they fall off rapidly with altitude. The drag component will be used to calibrate the total densities derived from the neutral mass spectrometer measurements. Both will be used to guide the adjustments of periapsis during the Aerobraking phase. This approach was used successfully at Venus during the Magellan deep-diving operations in 1993, and Dr. Smith is responsible for the gravity studies from the Mars Surveyor mission. The MUADEE orbit provides the best opportunity of any planned Mars mission for detailed gravity gradiometry.

Dr. Arv Kliore of JPL will employ the MUADEE X-band occultation data to obtain height profiles of electron density. The variations in peak height will be of particular value as they provide a direct measure of the enhancements in thermospheric neutral gas density that occur because of dust storm heating of the atmosphere or the heating associated with gravity wave breaking. These density profiles will be particularly valuable during the Global Mapping phase of MUADEE because they will provide the only source of information on the ionospheric peak height. Dr. Kliore has performed the radio occultation analysis on many planetary missions; including the Mariners, the Viking orbiters, Pioneer Venus Orbiter, and Magellan.

Additional capabilities for MUADEE have been considered by the Consortium in order to provide NASA with possible options for the overall Mars program. These options are discussed in greater detail in Section 14. Options include: a visible imager with 5 m/pixel resolution; a microwave atmospheric sounder for tropospheric temperature measurements; use of the MUADEE spacecraft as a communications orbiter for the Mars lander program.

AUXILIARY SCIENCE AND OTHER OPTIONS

- Gravity Gradiometry (Dr. David Smith, GSFC)
- Radio Science (Dr. Arv Kliore, JPL)
- Visible Camera: 5 m/pixel
  - low cost, minimal impact on spacecraft mission
  - imagery of selected targets
  - 2.9 kg; 0.2 Watts average when on; 271 bps
- Microwave Sounder
  - atmospheric temperature and water vapor
  - global synoptic measurements
  - 15 kg; 10 Watts average when on; 100 bps
- Communications Orbiter for Lander Program
  - MUADEE orbit compatible
  - 40 kg increase; 60 Watt increase needed

SUMMARY

- Essential Science for MARS Program
- Under $100 Million Including Contingency
- Unique Management Approach - and It's Working
- Educational Impact
- Significant Progress - Can Launch in 1998