MARS AQUARIUS MISSION AND TITAN EXPLORER

U. S. NAVAL ACADEMY

MARS AQUARIUS MISSION

Philosophy

The Mars Aquarius Mission is designed to carry out several scientific studies of the surface and subsurface of Mars with an emphasis on locating subterranean water. This mission is a precursor to a manned mission to Mars. A manned mission will require an extended stay on the planet's surface, and an accessible source of water will greatly simplify life support requirements. Using data from previous Mars observations, four sites have been selected as possible locations of subsurface water. The Aquarius spacecraft carries one penetrator for each of these sites.

Penetrators

Two hundred and fifty-five days after launch, all four penetrators will be simultaneously released from the spacecraft and injected on hyperbolic trajectories toward their respective landing sites. Upon atmospheric entry, each has a heat shield and a parachute that will decelerate the penetrator into a ballistic approach. Landing accuracy is approximately 5 km. Impact will occur at velocities from 80-100 m/s. Depending on the composition of the landing site, at impact the lower housing of the penetrator will be blasted 4-6 m further into the soil.

The penetrators carry instruments to carry out several experiments. The neutron spectrometer and alpha-backscatter/XRF spectrometer will detect the presence of water throughout the surface, subsurface, permafrost layers, and atmosphere. The gamma ray spectrometer will determine the abundance of most major and minor elements, as well as a few trace elements, near the surface of Mars. Temperature probes will measure the planet's temperature-depth profile. Accelerometers and a seismometer will analyze the structure of the planet and seismic activity. Also, a 360° camera/imager will provide visual data on landing sites.

Each penetrator carries a 2-W microradioisotope thermoelectric generator, as well as lithium batteries for power. Data is relayed up to the orbiter via a half-wave dipole antenna and a 0.5-W transmitter at a maximum rate of 11.1 kbytes/s at 220 MHz. A diagram of the penetrator is shown in Fig. 1.

Communications

The Mars Aquarius communications system must be able to receive commands from Earth, transmit signals to the penetrators to initiate their transmission of data, receive and store this data, and telemeter both this data and status reports back to Earth. Basic components of the communications system include a 3-m Earth-pointing dish and a half-wave turnstile reflector Mars-pointing antenna, each used for both transmitting and receiving. Both antennas are mounted on the despun section of the spacecraft. The groundbased component of the communications will involve the use of a 70-m dish, part of NASA's Deep Space Network (DSN).

A 500-km orbit was chosen for the spacecraft orbiter. This orbit provides for low path loss for the uplink, and also provides the necessary overhead time of three minutes needed for data reception from the penetrators. Upon reception of data from the penetrators, the orbiter will store it in memory until a predetermined time to downlink via DSN. The orbit is designed so that any given penetrator can uplink four times a day. This requires maximum storage of 31.9 kbits. Downlink will take 30 minutes at 19 kbps and 8.4 GHz.

Power and thermal control

The power system chosen for the Aquarius is a solar array of eight panels. This system met the requirements of vehicle weight, power required, and safety. Maximum power needed

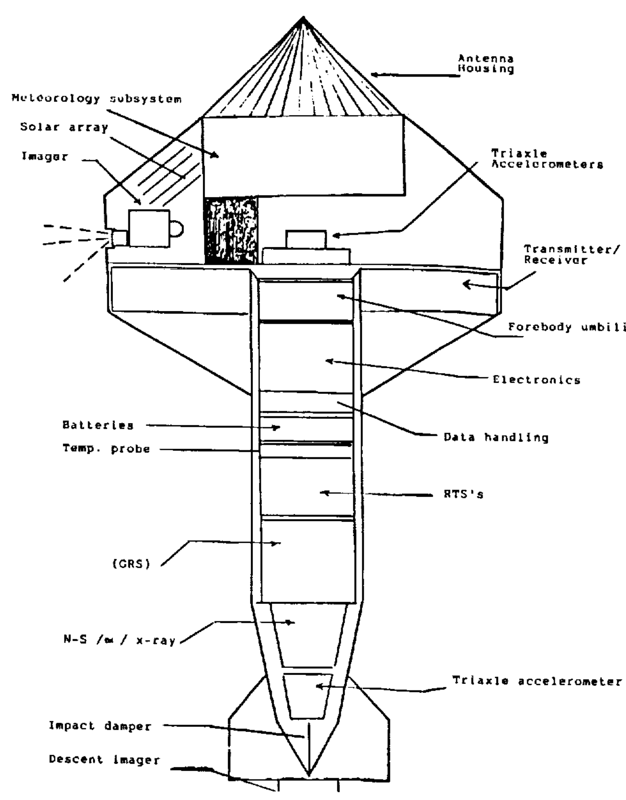

Fig. 1. Aquarius Penetrator.

onboard the spacecraft is 340 W. Each panel is 5.747 m^2, and each panel alone is capable of producing the 340-W requirement. Since the spacecraft is spin stabilized, however, the panels are wrapped around it so that enough solar cells are always in maximum incidence. Due to the polar orbit of the orbiter, there will be times of solar eclipse. Maximum eclipse time will be 41.03 min. Power during these times will be provided by 22 NiCd batteries in series, which will be reconditioned after each period of use in eclipse.

Thermal constraints onboard are nearly entirely determined by the batteries. The NiCd cells must be kept within -10° to 25°C. The spinning spacecraft otherwise allows the sun to evenly heat the orbiter against the cold of outer space. Both active and passive temperature regulation are employed on the spacecraft. Multithermal insulation blankets used on the despun section, black paint on the antennas, aluminum on the propellant tanks, and a stainless steel heat shield over the 490-N engine comprise the passive portion. Active systems include two heaters for eclipse periods when no sunlight can provide heat, and an active louver system for heat dissipation should temperatures rise too high. Figures 2 and 3 show top and side views of the Aquarius spacecraft and include elements of the communications, propulsion, power, and thermal systems.

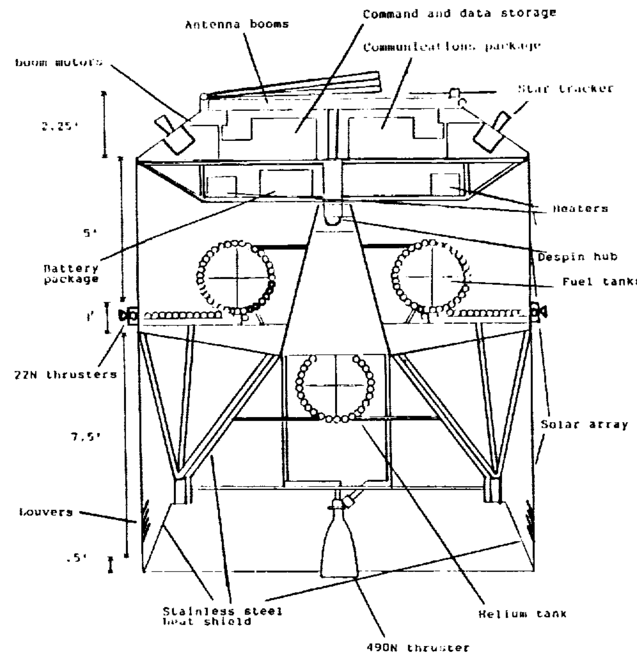

Fig. 3. Aquarius Spacecraft, Side View.

Astrodynamics and aerobraking

To conserve spacecraft weight, a minimum energy transfer is utilized. The spacecraft will begin the Mars transfer from an Earth parking orbit of 300 km. A 3.696-km/s ΔV will place the spacecraft on a Hohmann transfer to Mars. The thrust vector will also place the spacecraft in Mars' ecliptic plane. This is a plane change of 6.5° from the parking orbit's 28.5° inclination. The entire transfer will take 258.96 days. Three quarters of the way to Mars, the 490-N engine will impart a ΔV of 0.459 m/s, placing the spacecraft on a path that will result in a polar martian orbit. Mars capture will be accomplished using aerobraking. This greatly reduces fuel requirements for the spacecraft. The spacecraft will enter the martian atmosphere at a flight path angle of -20° with a velocity of 4.159 km/s. The aerobraking maneuver will slow the spacecraft by 0.6323 km/s, resulting in an elliptical orbit with a periapsis of 100 km and an apoapsis of 500 km. At apoapsis a ΔV of 27.6 m/s will place the spacecraft in a circular orbit. The aerobrake is a blunt body with a lift-to-drag ratio of 1:2. It is composed of an isogeometric grid of ceramic tiles and unfolds after the spacecraft is removed from the shuttle bay. The optimum launch date has been calculated as April 26, 2001.

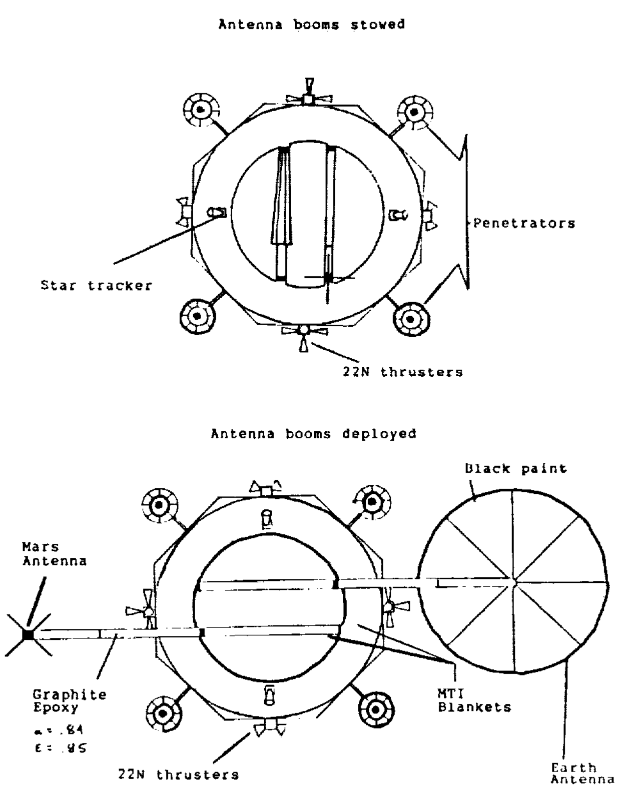

Fig. 2. Aquarius Spacecraft, Top View.

Propulsion

The propulsion system must provide for the transfer of the spacecraft from Earth orbit to Mars, and for stationkeeping once the martian orbit is attained. The space shuttle will deploy the Aquarius spacecraft with its transfer kick motor into a 300-km Earth orbit, positioning it in the proper attitude for transfer. At this time the aerobrake will be deployed and the 3-m Earth communications dish extended. The 3.696-km/s ΔV is provided by the Orbus 21 Transfer Orbit Stage (TOS), a solid rocket booster that will carry 5347 kg of propellant. The TOS uses three-axis stabilization. During transit the spacecraft's y axis will be perpendicular to the Sun, allowing the solar panels to achieve maximum incidence. Three-axis stabilization will be used at this time. The spacecraft has four star trackers onboard for this purpose. Attitude control is provided by a bipropellant system of one 490-N engine and twelve 22-N thrusters. Upon achieving Mars orbit, the despin hub will be unlocked and the spacecraft will be spun up to 25 rpm. Star trackers on the despun section will provide stationkeeping data. The Aquarius spacecraft has sufficient fuel onboard for a minimum of two martian years of service, after which time the spacecraft will be placed in planetary quarantine for probable future restart. The spacecraft can then be used again as a communications relay for future missions.

TITAN EXPLORER

The Titan Explorer is a scientific research probe consisting of an orbiter and a lander designed to travel to Saturn's largest moon, Titan, to conduct various experiments, make observations, and send data back to Earth. The probe will be placed in a circular orbit around Titan and will make preliminary estimates of Titan's atmospheric composition and structure, measurements of magnetic fields, observations of the dynamics of Titan's atmosphere, and radar observations of the topography of Titan.

The lander will be deployed by the probe after the orbit around Titan has been established. It will attempt to measure the composition and variations of the atmosphere as it descends, land on either a solid or liquid surface, and determine the conditions and composition of Titan's surface.

The Titan Explorer is 10 m long and octagonal in shape along its main axis. A high-gain dish antenna, folded and stored on the top of the spacecraft makes its height 2.4 m. The total mass of the spacecraft without fuel is 2743 kg. It will be launched by NASA's space shuttle in the year 2015 and will use a nuclear propulsion system to send it on a six-year journey to Titan. Upon reaching Titan, it will use at least 15 different scientific instruments to accomplish its objectives of studying Titan's emissions, magnetic field, atmosphere, weather systems, and surface composition and conditions.

Saturn's distance from Earth and the Sun makes just reaching Titan a significant problem. Titan Explorer will get to Saturn using a gravity assist flyby of Jupiter. It will first be launched into a 300-km-altitude Earth orbit by the shuttle. A velocity change of 3.8 km/s will be used to move it to the plane of the ecliptic. Another ΔV burn of 6.3 km/s will put the spacecraft approximately on a Hohmann transfer orbit to Jupiter, which will take approximately 2.7 years. It will fly past Jupiter at a distance of 206,700 km, gaining about 10.0 km/s from this flyby. It will travel for another 2.8 years and then use a 5.87 km/s burn to reach a parking orbit with a radius of 1.3 million km around Saturn. It will then use a Hohmann transfer around Saturn to get to its circular orbit around Titan, 2000 km above its surface. The launch window for this trajectory is primarily constrained by the angular relationship between the Sun, Jupiter, and Saturn. The first practical launch window would open late in 2015.

In order to use this trajectory, a propulsion system significantly better than those available today will be needed to avoid having to carry extremely large amounts of fuel. It was assumed that by the proposed launch in 2015, such a system, specifically a nuclear thermal rocket, could be developed to provide all of the velocity changes necessary for this trajectory. Recent studies have proposed such a system that would use a particle bed reactor made up of uranium and carbon alloy pellets. The reactor will be used to heat hydrogen gas to temperatures of 2400-3000 K and then eject it through an exhaust nozzle. With a specific impulse of roughly 1000 s, preliminary estimates have proposed a rocket 3.05 m $\times$ 1.22 m that would have a mass of 1134 kg and would deliver over 34,000 kg of thrust. This rocket would require 10,580 kg of fuel to complete the proposed trajectory. Six hydrazine thrusters are also located at various places on the spacecraft, but these will be used primarily for maintaining and altering its orientation.

Power for the main spacecraft will be provided by radioisotope thermoelectric generators (RTG) which use thermoelectric couples to produce electrical energy from the heat given off by the natural radioactive decay of radioisotope fuel. The RTGs will be used to power the scientific instruments, command and data handling system, communications systems, heaters, pumps, and electric motors. The total estimated power requirement for the orbiter is 390 W. The most recently developed RTG is the General Purpose Heat Source (GPHS)-RTG. Its high specific power (54.4 W_e/kg) make it a good candidate to provide the large amount of power required by this mission. The Titan Explorer will use two such RTGs that will be deployed on extendable booms after launch. They have the capacity to provide 580 W at the beginning of the mission. After the six-year transit to Titan, their total output will have decayed to 475 W.

Attitude determination and control will be performed by Sun sensors and star trackers supplying data to a three-axis stabilization system with momentum wheels. The momentum wheels provide the spacecraft with some gyroscopic stiffness while three-axis corrections and adjustments will be made by six hydrazine thrusters. The Titan Explorer's orbiter carries six scientific instruments to gather preliminary information concerning Titan's atmospheric composition and dynamics, surface topography, and magnetic field. A solid-state imaging camera will be used to determine atmospheric structure, motions, and radiative properties and will study relative cloud motions. A photo-polarimeter-radiometer will measure the temperatures and energy balance of the atmosphere, as well as cloud characteristics and composition. An ultraviolet spectrometer will use spectra to study the atmosphere above the clouds. The orbiter also carries a gamma-ray spectrometer which will attempt to investigate the composition of surface elements by measuring gamma-ray emission characteristics. A radar altimeter will be used to provide some topographic mapping of the surface in an effort to determine the amount of liquid and solid surface and possibly adjust the entry trajectory of the lander. A magnetometer, extended from the spacecraft by a boom, will measure any magnetic field that exists around Titan. These six instruments require approximately 77 W of power.

Communications with the spacecraft will be conducted through DSN. It is assumed that DSN's current transmission/receiving rates of up to 12 GHz will be improved to allow a rate of 15 GHz by mission launch time. The primary communications system onboard the spacecraft uses a 5.8-m-diameter parabolic dish high-gain antenna that will require

118 W of power and will broadcast at a frequency of 15 GHz to meet the required data transfer of 135 kbps. A secondary system will consist of two parabolic dish low-gain antennas. They are each 1.35 m in diameter and will operate at frequencies of 14.9 GHz and 14.8 GHz. During the probe's journey to Titan, the high-gain antenna will be folded along the top of the spacecraft and covered by a protective shroud. Until it is deployed when the probe reaches Titan, the secondary antennas will be used. When the lander is deployed, the orbiter communications systems will act as a communications relay between the lander and Earth. Two dipole antennas will be used to communicate with the lander.

The lander is designed to survive entry into Titan's atmosphere, safely land on either a solid or a liquid surface, and float if the latter situation is encountered. It is made up of a 1-m-diameter spherical housing mounted on a flat, 1.3-m platform base. The bottom half of the lander is surrounded with a vacuum-filled shroud. While attached to the orbiter, the lander is encased in a conical atmospheric-entry aeroshell and is carried on the front of the spacecraft. It will be deployed once the orbit around Titan has been established and preliminary observations have been made by the orbiter's scientific instruments. Four hydrazine thrusters mounted in the atmospheric entry shell will be used to maneuver the lander out of the path of the orbiter, adjust the lander module's orientation, and start it on its entry trajectory. Once the lander unit has entered the atmosphere, a pilot chute will be deployed, which will pull off the aft cover which, in turn, releases the main parachute. Once the main chute has been deployed, the conical heat shield will be jettisoned and the lander will drift slowly to Titan's surface, studying atmospheric composition and conditions as it descends.

Power for the lander will be provided by a scaled-down version of the GPHS-RTG. This smaller version will be a little more than half the size of a normal GPHS-RTG. It will provide an estimated power output of 136 W after six years. Multilayer Kapton blankets will be used to insulate the RTG from other lander systems and a double closed loop system will transfer excess heat from the RTG to an atmospheric radiator. Mylar and Kapton multilayer blankets will also be used to insulate the lander from the extremely cold temperatures of Titan's surface (estimated to be about 94 K).

The lander will carry scientific instruments to be used during the descent phase and others to be used while on the surface. The atmospheric structure experiment will study the variation with altitude of the temperature, pressure, and density of the atmosphere as well as conditions of cloud levels, internal cloud structure, and the depths and altitudes of cloud layers. A net flux radiometer will provide a better understanding of Titan's radiation budget. A neutral mass spectrometer will be used to determine the abundances of the major components of the atmosphere at different altitudes and will also analyze samples of the surface of Titan. A nephelometer will be carried to locate cloud layers, make direct measurements of cloud structure, and determine the character of the particles in the main clouds. The camera and navigation system determines characteristics of surface topography and morphology. The lander will carry a cryogenic xenon sample collector and an alpha-particle instrument and an *in-situ* chemical analysis instrument will be used to analyze collected samples. A micro gas chromatograph will determine the distribution and molecular forms of the biogenic elements (C,H,N,S,O,P).

Communications with the orbiter will be conducted via the lander's two omnidirectional, quarter wavelength, dipole antennas. The orbiter will use a beacon system to let the lander know when it is within sight and able to receive data. The lander's system will have a maximum data transfer rate of 50 kbps. The command and data handling system can store up to 3 Gbits of data, which equals 9.5 orbits of data.

The goals of the Titan Explorer mission are to reach and successfully establish an orbit around Titan, enter Titan's atmosphere, safely land on its surface, and survive to send back enough data to answer many of the basic questions about this planet-like moon. To complete such a mission, some assumptions had to be made concerning technological advances achievable by the year 2015. Provided such advances can be made, Titan Explorer should be able to successfully perform its mission.

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