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The Mars Aerial Platform Mission: A Global Reconnaissance of the Red Planet Using Super-Pressure Balloons

Robert Zubrin†, Steve Price†, Terry Gamber† and Ben Clark†
Martin Marietta Astronautics
PO Box 179
Denver, CO 80201

Jim Cantrell†
Space Dynamics Lab
Utah State University
Logan, Utah 84322-4140

Abstract

The Mars Aerial Platform (MAP) mission is a conceptual design for a low-cost, Discovery class mission whose purpose would be to generate tens of thousands of very high resolution (20 cm/pixel) pictures of the Martian surface, map the global circulation of the Martian atmosphere, and examine the surface and sub-surface with ground penetrating radar, infrared spectroscopy, neutron spectroscopy, and other remote sensing techniques. The data would be acquired by instruments which are carried by balloons flying at a nominal altitude of about 7 km over the Martian surface. Because new balloon and micro-spacecraft technology is now available, the balloon probes could be quite long-lived, lasting hundreds or even thousands of days, producing an immense science harvest in the process. Together with the Mars Environmental Survey (MESUR) surface network science mission, MAP would revolutionize our knowledge of the Red Planet.

Mission Description

The MAP mission will be carried out as follows: A low-cost launch vehicle such as a Delta 7925 (1000 kg TMI) is used to propel a small spacecraft carrying 8 entry capsules onto trans-Mars injection. Approaching Mars, a spinner is used 10 days prior to arrival to release the capsules outward so that they enter Mars' atmosphere at widely dispersed locations. Each capsule then enters the atmosphere, and deploys a parachute which slows it down to the point where a balloon can be inflated. The inflation is accomplished during descent, so that no landing system is required (the practicality of accomplishing this has been demonstrated on Earth at altitudes of up to 150,000 feet, where atmospheric density is similar to Mars). After the balloon is inflated, the parachute, capsule, and inflation equipment is jettisoned, and used to land a meteorology package consisting of pressure and temperature sensors, battery and transmitter on the surface. Each of the balloon probes will then commence their float around Mars at a altitude of about 7 km (23,000 ft) above the mean surface level. The probes, which will never land in the course of their long duration aerial cruise, will carry a gondola payload of 8 kg, which includes 2 cameras, 1 kg of atmospheric science and additional instruments, data recording and transmitting equipment, a rechargeable battery and solar array.

When it is daylight two pictures are taken simultaneously every 15 minutes. One is taken with a high resolution CCD black and white camera with a nominal resolution of 20 cm per pixel; with a 1024 x 1024 pixel field, this gives a field of view 204 m on a side. The other is taken with a color camera at a moderate resolution of 10 m per pixel; this gives a field of view 10.2 km on a side. The two cameras are aligned so that the high resolution image is located at the center of the medium resolution picture, whose features in turn can be used to locate the region studied on a map of the planet. The data is stored and then is periodically uplinked to an orbiting satellite, which could either be Mars Observer or the MESUR comsat, and is then transmitted back to Earth.

It is anticipated that the science return of this mission will be large, with 32,000 high resolution pictures returned to Earth for each 100 days of operation of an eight balloon fleet, plus an equal number of pictures at resolutions superior to the best Viking images. The high resolution pictures will have a factor of 7 greater resolution than the best pictures returned from Mars Observer. Additional science return will result from use of other instruments, such as a ground penetrating electromagnetic sounder. Tracking the balloons will yield knowledge of Mars' global atmospheric circulation. The cost of the mission is anticipated to be low, falling below the $150 million (without launch) ceiling of the Discovery-class guidelines.

A mass breakdown for the mission is given in the tables below. As can be seen in fig. 1, each probe can be packaged in a 1.1 meter diameter aeroshell, and 8 such probes together with their carrier spacecraft can be fitted into the launch fairing of a single Delta.

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Fig. 1 The MAP entry capsule has a diameter of 1.1 meters. Eight such capsules together with their spinning carrier vehicle can be fitted into a Delta fairing and launched to Mars. Shown within capsule, from top, is the parachute container, the balloon container surrounded by gas cans, and the gondola.

Mission Mass Breakdown

Delta 7925 Launch

(8) Probes	728 kg
Spacecraft	150 kg
Margin	122 kg

Probe Mass Breakdown

Aero-Shield	12.9 kg
Base cover and Drogue	9.5 kg
Main Parachute System	15.9 kg
Surface Meteorology Package	3.0 kg
Despin Device	1.0 kg
Tanks, lines valves	18.3 kg
Balloon Container	3.7 kg
Balloon and Associated Systems	16.5 kg
Gas Mass	2.1 kg
Gondola Payload	8.0 kg
Total	90.9 kg

Gondola Payload Mass Breakdown

Battery (Nickel-metal Hydride, 18 W-hrs)	0.5 kg
Solar Array (40 W-hrs, 0.22 m^2)	0.5 kg
Radio Transmitter	1.1 kg
Computer	1.0 kg
Thermal Protection and misc structure	1.5 kg
Science	
Cameras	0.6 kg
Atmospheric monitors	0.1 kg
Other Instruments (EMS, Neutron Spec, IR Spec, etc.)	1.3 kg
Cabling	0.3 kg
Contingency	1.1 kg
Total	8.0 kg

Science Return

The MAP mission has high potential for a large science return. Some of the areas that will be benefited include:

1. Geologic Science: The greatest benefit from high resolution images is the information that could be gained on surface processes. In contrast to Mars Observer, whose highest resolution images will show objects as small as a mid-sized car, the cameras

Fig. 2 The MAP mission will explore the Red Planet with imaging, meteorological measurements, ground penetrating radar, and other techniques. Tracking the balloons will reveal Mars' global atmospheric circulation.

on the MAP gondola will be able to reveal surface features the size of a cat. such images will give us submeter surface morphology, block size distributions, and surface textures, all of which provide insight into volcanic processes, sedimentary deposits, fluvial history, and aspects of impact cratering. in addition, aeolian features such as ripple fields, individual dunes, small channels, etc., will be visible, providing direct evidence for the link between the atmosphere and the surface. The scale of some of these is below Mars Observer resolution. Assessment of these and other features that are submeter in size will provide a whole new suite of information on surface/atmosphere interactions.

2. Atmospheric Science: The MAP mission provides a unique in-situ platform for atmospheric science. Each balloon will float at a fixed density level (0.008 kg/m^3, or about 7 km above the mean surface) for at least 100 days. If the balloons were to average 10 m/s, a conservative value, then thousands of kilometers will be traversed. Depending on the circulation, it is possible that some of the balloons will circumnavigate the planet several times. thus global sampling of the atmosphere is possible.

Measurements that can be taken aboard the MAP balloons include temperature, pressure, horizontal wind speed and direction (via tracking), dust size and composition, and water vapor concentration. Atmospheric science goals that could then be addressed include the critically important surface boundary layer and its diurnal variability, atmospheric dynamics, circulation systematics, aerosol composition and properties, and the seasonal cycles of dust and water. Tracking of the balloons would give information on winds and circulation systems which could be used to test the computational global circulation models currently being developed by NASA. Slope wind systems may be particularly important on Mars and the MAP balloons should be able to help characterize their structure and dynamics. Aerosols, dust in particular, are known to be ubiquitous in the Martian atmosphere, yet their composition, size, and shape are uncertain. MAP balloons could measure these properties directly and thereby greatly increase our understanding of these climatically significant particles. Water vapor concentrations could be measured, furthering our understanding of the nature and distribution of near surface water reservoirs.

3. Exploratory Science: Infrared detectors on the balloons would be able to detect local geothermally heated hot-spots on the Martian surface, should any exist and fall within several kilometers of the probe's ground track. Neutronic devices would be able to detect local concentrations of ice, hydrated minerals, or deposits of carbonates. Ice layers 10 meters or more below the surface may also be revealed by electromagnetic sounding using the radar altimeter, which can function as a simple ground penetrating radar. The discovery of such features would be of very high value for exobiological investigations.

4. Development of Mars Engineering Models: Numerous U.S. and international groups have a high interest in developing engineering models of the Martian surface. A recurring theme is the need for imaging of the surface at the scale that could be provided by MAP. In particular, knowledge of size-block distributions, slopes, surface discontinuities, etc., at a scale important to landers, roving vehicles and other landed mission operations is of high interest. The advantage of MAP is that a wide variety of terrains could be sampled to provide input to engineering models. The sub-meter scale imaging provided by MAP is also important to assess landing hazards to certify safe sites for future landers. The Mars Observer camera has a resolution of about 1.5 m/pixel, allowing it to resolve features about 4 m across. Such resolution is too gross for use in assessment or avoidance of landing hazards facing Mars surface science missions. Submeter scale imaging is also needed to provide context for the activities of a landed rover mission. This context would permit significantly richer surface operations activities, and a concurrent improvement in the caliber of science conducted.

The results from the MAP aerostats will be obtained concurrently with data returned by the meteorology packages delivered to the surface by the entry probe parachutes. This will enhance the potential science return by the synergy that will result from concurrent measurements from the surface network with the drift measurements on the balloons. This will provide more information on the atmospheric structure than could be obtained by either a balloon network or a surface network acting alone.

The large array of potential science instruments that could be carried by MAP are summarized in the table below. There are far too many to be all carried in the same gondola, however if the probes sent to Mars are divided into 4 "science sets" (which we label

Candidate MAP Instruments

Instrument	Mass (kg)	Power (W-h/sol)	Data (Mb/sol)	Science Set (example)
Camera BW or 3-color	0.6	10	26.0	A,B,C,D
Temp and Pressure	0.1	0.01	0.02	A,B,C,D
Sun Sensor	0.1	0.01	0.02	A,B,C,D
Accelerometer	0.1	0.1	0.2	A, C
Neutron Spectrometer	0.2	0.03	0.06	A,B,C
Gamma Ray Spectrometer	1.0	2.0	5.0	B
Electromagnetic Sounder	0.4	8.0	1.0	A, C
Microwave Radiometer	0.3	0.1	0.02	A
Magnetometer	0.2	2.0	0.02	A, D
Infrared Radiometer	0.1	0.01	0.02	A, C,D
Infrared Spectrometer	0.5	2.0	5.0	C
Nephelometer	0.2	0.5	1.0	D
Hygrometer	0.2	0.02	0.02	D
Dust Composition Analyzer	0.4	0.1	0.02	D

"A,B,C, D,") with 2 probes per set for a Delta launch, then the full range of potential investigations could be carried out. To minimize instrument and computer power, all instruments would be cycled on and off once every 15 minutes in coordination with the camera operation.

The Camera

The primary instrument carried by the probe will be a CCD camera such as that currently under NASA-sponsored development by Malin Space Science Systems (Fig.3). This camera has a mass of 1.0 kg, including two sets of optics (additional sets can be added for 0.3 kg each), all electronics, data compression, and 40 MBytes of data storage. (In the candidate instrument table above, part of the camera mass is accounted for by the gondola computer.) The compressor reduces the data so that 0.6 bits are required for each pixel of black and white photography, and 0.7 bits for each pixel of color. Thus a pair of pictures, each 1024 x 1024, one color and one black and white will require a total of 1.3 Mbits and each balloon probe can store a maximum of 248 pairs of pictures at a time.

To enable a significant advance in the understanding of Mars surface geology, a resolution about an order of magnitude better than Mars Observer (20 cm/pixel) is desired. As it is not possible to find an area only a few 100 meters across in orbiter images, a "context" or low resolution frame is also needed. This context image must be around 10 km on a side, based upon attempts to locate the highest resolution Viking Orbiter frames (about 10 m/pixel, 1200 pixels across) in the Mars Global Digital Image Mosaic (250 m/pixel resolution).

The baseline MAP camera system consists of two camera heads bore-sighted to take simultaneous high and medium resolution images. The camera heads are placed on a pan with 1 degree of freedom to allow downward looking pictures to be obtained, horizontal pictures (allowing the observation of sedimentary layers), or any angle in between. The medium resolution camera can also be used to acquire images of the Sun to determine atmospheric opacity and dust particle size information.

Fig. 3 A miniature CCD camera such as that designed by Malin Space Science Systems would be the primary instrument carried by the MAP probe. This camera has a mass of 1.0 kg, and a volume of 400 cc, including 2 sets of optics and a computer for data compression and storage. Drawing shown is full scale.

Data Retrieval and Power Budget

The aerostat transmitter system is generally kept silent while its radio receiver is cycled on and off listening for a beacon on the orbiting communications satellite. Once such a beacon signal is acquired, the gondola computer is awakened and a return signal is sent up to the orbiter, allowing a communications link to be established.

Using 18 watts of power, 5 watts of UHF (401 MHz) can be produced, which will result in a transmission rate of 64 kb/s to the Mars Observer uplink, or to a similar relay carried by a MESUR comsat. Processing of data requires about 0.4 W-hr per picture pair, while transmission to the comsat requires about 0.1 W-hr. Thus a total of 0.5 W-hr is required for the processing and transmission of each pair, with 80% of this expended during the daytime when the pictures are taken.

The balloon probe carries a power system with a storage of 18 W-hrs, and a solar array that can produce 43 W-hr/sol (a sol is a Martian day of 24.6 hours) under moderately below average Martian conditions (100 W/m^2 diurnally averaged solar incidence.) If half of this power is available for image processing and transmission, then each probe can transmit 40 picture pairs per sol. The total link time to Mars Observer required for this transmission is about 813 seconds per sol, which is only about half of what will be typically available to each aerostat on a daily basis.

Of the aerostat's remaining power, 8 W-hrs/sol is can be used in the ground penetrating radar, 3 W-hrs/sol for the computer, and 10 W-hrs/sol is extra and available for contingency utilization. The thermal protection power needed by the MAP gondola is provided by 3 Radioisotope Heating Units (RHUs). These require no electric power. Thus the gondola is survivable even if solar incidence should drop far below anticipated levels for an extended period. Should solar levels drop, it simply means that imaging activities will be curtailed in accord with a reduced power budget; should solar levels rise, imaging can be expanded beyond the 40 picture-pairs/sol baseline.

Balloon

Recent advances in balloon materials and micro-electronics give us the hitherto impossible prospect of building lightweight, high-altitude super-pressure balloons that would last at least two Martian years. Balloons of this nature are being currently flown on Earth and most of the technologies needed to fly these balloons on Mars (remote inflation equipment— and descent modules) have already been demonstrated.

The balloons required by the MAP probes would be 9.1 m in radius and made of a new biaxial nylon 6 film, 12 microns thick, that is much stronger than the 6 micron mylar used in the French Mars 96 balloon and guaranteed by the nature of its manufacturing process to be free of pores. Superpressure balloons made of this material are currently being manufactured by Winzen Balloons of San Antonio Texas. Because the balloon material is so much stronger, venting will be unnecessary (i.e. the fabric can react to the pressure differential caused by day-night temperature changes), and according to Winzen, the estimated mean life of the balloon (before leakage caused sufficient buoyancy loss to terminate flight) would be many years. Since the balloons in the MAP mission avoid the surface, unlike the French Mars 96 balloon which will land its snake every night, the probability of crash or snag is much lower. Mission termination for each probe is thus most likely to occur as a result of failure of the instrument package. Such packages can be designed for lifetimes of thousands of days; we assume a conservative average mean time to failure of 100 days. This is in contrast to the payload on the French Mars 96 Balloon, which is powered by a primary battery which limits mission life to 10 days, even in the absence of a balloon mishap.

To date, Winzen has constructed and successfully flown super-pressure balloons made from biaxial nylon 6 on two separate flights. More long-duration testing is needed, however. Plans for such a series of long duration tests are currently being developed by NASA's Jet Propulsion Lab.

The MAP baseline balloon design assumes an atmospheric density of 0.008 kg/m3. This corresponds to a seasonal minimum geometric altitude of 7 km which will clear 93% of the terrain on the planet. The baseline design also assumes a floating mass of 26.5 kg and a 12 micron thick biaxial nylon balloon material. This design was analyzed using Global Circulation Model data over all latitudes and solar longitudes (seasons). Balloon super-temperature, relative balloon skin stress, and lifetimes were all calculated. Based on this data, the balloon can be expected to operate satisfactorily anywhere on the planet. The northern hemisphere yields the most temperate conditions (showing a large operational margin) and the southern atmosphere yields less margin. Lifetimes are also maximized in the northern atmosphere, around 3000 sols.

Fig. 4. The entry and balloon inflation sequence that will be used on the MAP mission. Such dynamic inflation techniques have been demonstrated by the French Mars 96 team on Earth at altitudes of 150,000 feet using a larger balloon made of weaker material than will be employed on MAP.

Balloon Deployment and Inflation

Remote inflation of balloons is a challenge, but it has been successfully demonstrated at Venus and on Mars-like conditions on Earth by the French Mars 96 project. The procedure used (Fig.4) , in both cases, is to use the combination of an aero-shield and parachute to decelerate the vehicles to about 35 m/s, after which the balloon is deployed out of the bottom of the descent module by the gondola and entry-shield. The balloon is then inflated from the top, first slowly (20 g/s), to prevent erosion damage to the adjacent balloon fabric and then 20 seconds later at a faster rate (170 g/s) to quickly inflate the balloon.

Once the balloon is inflated, the balloon and inflation equipment is separated. Due to the relative size of the parachute (20.8 m diameter), the inflation equipment slows compared to the balloon which still has the aero-shield attached. After a waiting period of about a minute, the balloon drops the aero-shield and the balloon attains its stable float altitude. The inflation equipment, having been at a different altitude, will have experienced a different wind shear pattern and will not directly fall onto the balloon when their altitudes cross again.

Balloon Flight Profile

At the time of entry, the balloons may be targeted to widely dispersed locations, typically spread over 130 degrees of latitude. The balloons will then commence to float at the velocity of the Martian winds at their altitude. Current models suggest that the wind will carry the balloons primarily in the West-East direction with typical velocities on the order of 30 to 60 km per hour. At such speeds each aerostat could be expected to circumnavigate the planet every 10 to 30 days. There will also be some North-south migration which will probably cause some balloons to wander into and out of Mars' polar regions during portions of the mission. This may afford an opportunity to examine regions of the planet that cannot be targeted for direct probe entry during a given launch opportunity. If an aerostat should wander into a polar region during the Arctic night, gondola operations will be curtailed until it leaves. Characteristic aerial velocities of the balloons suggest that such a shutdown should last no more than a few days at most.

The balloons have a nominal float altitude during the Northern summer of 7 km, with a diurnal altitude variation of a few hundred meters. However because of the evaporation of CO_2 from Mars' south polar cap, the average atmosphere during the course of the year is thicker than that of the northern summer, and so the balloons on the average will actually float at a typical altitude of about 8.5 km, clearing over 97% of all Martian terrain. Having such a large fraction of the planet safe for travel gives each balloon fair odds for a long duration flight. Although an eventual crash is certainly possible, chances for balloon loss through collision with terrain obstacles is diminished by the tendency of balloons to follow the streamlines of air which must, of necessity, go around all obstacles the airflow encounters.

Probe Navigation

For science purposes, it is important that the sites photographed by the MAP probes be identifiable.

Latitude can be determined by the time of comsat overpass. In addition, the perpendicular distance of the probe from the comsat groundtrack can be determined by the Doppler shifting of the signal the comsat receives from the Probe. Thus a navigational fix for each probe can be determined 2 to 5 times each sol. In addition, longitude can be determined twice a day by noting the time of sunrise and sunset. If longitude is known, then a sun-sensor can be used to determine latitude and gondola orientation. As a third navigation technique, the aerostat location can be determined by comparing its 10 km x 10 km medium resolution images with Mars Observer and Viking surface imagery. Since the position of the probe is periodically known precisely, either by comsat tracking or identification of surface features, the position of the probe at all times can then be known precisely if overlap can be maintained between the areas captured by the medium resolution images. Since the probe can know its own location using such techniques, probes can be pre-programmed to take horizontal photographs when they find themselves in a certain region and pointing (the balloons are expected to slowly rotate) in a given direction. thus it will be possible to obtain horizontal or oblique panoramic images of many of the major sights on Mars, such as Olympus Mons or the Valles Marineris.

Conclusion

The MAP mission will produce a glorious science return for Mars geology and meteorology, and provide engineers with the knowledge of the surface of Mars needed for the design of rovers and safe landers. It will provide future explorers with information about where precious water may be found, and may identify locations that offer improved prospects for a search for indigenous life. By charting the planet's winds, MAP will provide the routes for future mobile science missions - for the skies of Mars are its highways. But perhaps the greatest return from the MAP mission will be the least tangible - its impact on the intellectual life of humanity at large. Today, nearly 500 years after Copernicus, most people still think of Earth as being the only world in the universe, and the other planets, despite academic knowledge to the contrary, as mere points of light in the sky. The MAP aerostats will take humanity's eyes to another planet in a way that has never been done before. Through the gondolas' cameras, we will see Mars in its spectacular vastness - its enormous canyons, its towering mountains, its craters, its plateaus, its dried up lakes and rivers, its rocky plains and frozen fields of water and dry ice. We shall see that Mars is truly a world, and for the first time, our knowledge that the Earth is not unique shall really be made tangible. What finer return can a mission have?

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