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Final Report of the Ad Hoc Mars Airplane Science Working Group

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FOREWORD

The concept of an airplane capable of flying at Mars arose during a broad options study of Mars exploration vehicles in 1978. It was based on a small, remotely piloted airplane powered by a reciprocating hydrazine engine that was capable of flying to 100,000 ft at Earth. Under the advocacy of V. C. Clarke, Jr., of JPL, a preliminary Mars airplane design was established by Developmental Sciences, Inc. This design, based primarily on high performance gliders, supported the feasibility of a Mars airplane. Landing and takeoff systems based on vertical takeoff and landing systems were considered as well as continuous flight.

As the engineering work progressed, it became evident that the airplane was a potentially useful exploration vehicle. However, little consideration had been given to its scientific use. Consequently, a small ad hoc working group of scientists was established to undertake a preliminary assessment of the utility of the airplane. Because time was short, a thorough evaluation of all the potential capabilities of the airplane--aerial surveys, instrument deployment and sample return -- was impossible. Therefore, the ad hoc working group considered primarily the use of the airplane in the aerial survey mode. Five areas of interest in this mode were considered as being fundamental in establishing the scientific usefulness of the airplane. The working group was chosen to have members familiar with Mars scientific objectives and with practical experience with orbital or aerial survey type measurements. The members were:

John Minear	Chairman, Johnson Space Center, Houston, TX
Donald Davies	Deputy Study Scientist, JPL, Pasadena, CA
Michael Malin	Visual Imaging, JPL, Pasadena, CA
Michael Gaffey	Gamma Ray and IR Spectroscopy, Univ. of Hawaii, Honolulu, HI
Sheldon Buck	Gravity, Draper Laboratory, Cambridge, MA
David Strangway	Magnetic Field and Electromagnetic Sounding, Univ. of Toronto, Mississanga, Ontario, Canada
Ronald Prinn	Atmosphere Composition and Dynamics, MIT, Cambridge, MA

Each Working Group member prepared a short paper assessing the airplane's capability in his respective area of interest. Preliminary design specifications of the airplane furnished by JPL were used in this assessment. The group then met at JPL on May 8-9. At this meeting JPL and Developmental Sciences Inc. presented the latest airplane design and specifications, members of the Working Group discussed capabilities of the airplane, and the general scientific usefulness of the airplane operating in the aerial survey mode was evaluated. Design and mission operations requirements levied on the airplane by experiments were also discussed. A draft of this report was then prepared and circulated to all members for their comments and additions.

ABSTRACT

This report documents the findings of the Ad Hoc Mars Airplane Science Working Group, which was formulated in early 1978 to assess the utility of a remotely piloted airplane for scientific exploration. Although an airplane can be used in several modes, e.g., aerial survey, landing science instruments for in situ investigations, deploying network science by air drop, or sample collection and transport to a central site, only the aerial survey mode was considered in detail. Five experiment areas were chosen to evaluate the airplane's capability in this mode: visual imaging, gamma ray and infrared reflectance spectroscopy, gravity field, magnetic field and electromagnetic sounding, and atmospheric composition and dynamics. The Working Group concluded that the most important use of a plane in the aerial survey mode would be in topical studies and returned sample site characterization. The airplane offers the unique capability to do high resolution, oblique imaging, and repeated profile measurements in the atmospheric boundary layer. It offers the best platform from which to do electromagnetic sounding. It is an adaptable vehicle that has the potential to offer many promising options, such as the possibility of deploying instruments and sample collection in the polar regions, which are inaccessible with soft landers or rovers.

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SECTION I

INTRODUCTION

A. MARS AIRPLANE HISTORY

The concept of a Mars airplane arose directly from a small, remotely piloted airplane developed by D. Reed at the NASA Dryden Flight Research Center. This small airplane, the Mini-sniffer, is a high-altitude powered glider designed to conduct stratospheric sampling above 20,000 meters (70,000 feet). The plane's power is provided by a hydrazine (non air-breathing) piston engine developed by J. Akkerman of the Johnson Space Center.

Studies by D. Reed and Developmental Sciences Inc. established the feasibility of airplane flight in the thin Mars atmosphere and of deploying airplanes into the Mars atmosphere from an orbiting spacecraft. Subsequent studies have resulted in the design of a Mars airplane capable of flying for periods up to 25 hours with payloads of 40 kg. Table 1-1 gives the basic flight characteristics that are of interest to scientific investigations from the airplane. More detailed information about the airplane design and operation is given in Appendix A.

B. OPERATIONAL MODES OF THE AIRPLANE

Three different operational modes of the airplane can be considered: delivery of science packages, sample collection, and as an aerial survey platform. Although different airplanes could be used in different modes on any one mission or one airplane could be used in several modes, it is worthwhile to consider the modes separately. This provides the simplest and operationally least demanding base from which to make evaluations.

The important unique features of the airplane are its capability to travel long distances (several thousand kilometers) in short times (<25 hours) at low altitudes and to traverse dangerous terrain that may be of high geologic interest. These attributes provide advantages to the airplane over other vehicles in all three of its operational modes. Given this inherent advantage in speed, range, and site availability, the usefulness of the airplane operating in the deployment mode depends on the science packages that can be deployed. Considerable attention has already been given to deployed science packages, in situ surface analysis, and surface networks (A Mars 1984 Mission, 1977; Final Report and Recommendations of the Ad Hoc Surface Penetrator Science Committee, 1976). Other vehicles (penetrators, hard landers and soft landers) also offer the capability to deploy scientific instruments. The main advantage of the airplane is its potential for reaching sites that cannot be reached safely by the other vehicles (e.g., polar regions, canyons and scarps).

Given that the airplane can land and take off, an obvious and valuable use for the airplane would be for sample collection. Sample retrieval, however, is demanding on airplane design and operations (repeated landing and takeoff, precise navigation, and sample acquisition devices).

Table 1-1. Mars Airplane Characteristics

Cruise speed	60 - 90 m/s (216-324 km/h)
Cruise duration	13 - 25 h (18 - 31)[a]
Deployment altitude	7.5 km
Flight altitude	0 - 15 km
Payload	40 - 100 kg
Maximum range	6000 km (10,000)[a]

[a]After completion of the working group considerations it was discovered that high energy density batteries were available that make an electric airplane feasible. This longer lifetime does not affect the conclusions about the general utility of the airplane as a Mars exploration vehicle.

C. SCOPE OF THE WORKING GROUP EVALUATION

The Working Group considered the airplane primarily as an aerial survey platform because of the short time available and because the usefulness of this mode had not been evaluated. Seven possible experiment areas were chosen as the basis for evaluating the airplane's science capability in the aerial survey mode:

(1) Visual imaging.

(2) Gamma ray spectroscopy.

(3) Infrared reflectance spectroscopy.

(4) Gravity field.

(5) Magnetic field.

(6) Electromagnetic sounding.

(7) Atmosphere composition and dynamics.

SECTION II

EXPERIMENT ASSESSMENT

A. VISUAL IMAGING

Historically, the treatment of the geology of the planets has, in many ways, been opposite that of the Earth. On Earth, we have grown to understand our planet first in a local sense through field studies, then in a regional sense with the advent of aerial photography, and finally in a global sense through the increasingly popular use of satellite images. On the other planets, particularly Mars, we have initiated our studies with a global perspective and are working our way toward a finer view. As imaging is the only sense that humans and their robot surrogates share, it becomes an important medium for communication and investigation.

1. Experiment Description

An airborne imaging system on Mars would present an extremely valuable opportunity to address major questions of Martian geology. The experiment would presumably acquire both high- and moderate-resolution images from near-normal and oblique viewing directions.

The airplane's proximity to the surface allows high-resolution imaging, and its range allows access to large tracts of land. Both points are important when one recognizes the extreme diversity of the Martian surface, at least at image resolutions obtained from orbit. The superficial absence of diversity at Viking lander image resolution has two contributing explanations: the Viking landing sites were chosen in areas specifically devoid of large-scale relief (primarily for safety reasons), and on flat, relatively uncratered surfaces, few processes compete with the homogenizing effects of eolian deflation. An important airplane observation would be the scale at which the Martian surface changes from one characterized by complex and diverse landforms to one of relatively homogeneous aspects.

There exist at present (or will soon exist) a number of imaging systems that could be used aboard the Mars Airplane. Many different types of vidicon systems are currently used on DOD remotely piloted vehicles. NASA has developed and flown a number of slow-scan vidicons, and is currently developing charge-coupled devices (CCD's) for spaceflight. Many of these systems have very low masses (except for optics) owing to rapid advances in electronic component miniaturization. As will be discussed shortly, optics on a Mars Airplane need not be very large. Thus, the imaging system may be relatively simple to implement.

Figures 2-1, 2, 3 present several oblique aerial photographs of terrestrial features that are likely to have Martian counterparts. The principal asset of an airplane imaging system is its ability to return such views.

Figure 2-1. Meteor Crater, Arizona. An oblique view of Meteor Crater, Arizona, taken from an altitude of about 1 km above the surface. Meteor Crater, formed by an impact, is about 1.2 km in diameter, and is markedly polygonal in outline. The image has a field-of-view of about 40 x 60 deg, centered about 60 deg from the vertical. Resolution is about 4 m (~2m/pixel). Note the mass movements within the crater, the slope drainage, ejecta outside the crater, and the large blocks (the largest in the foreground is 16 m across!).

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Figure 2-2. Kilauea Caldera, Hawaii. Oblique view of Kilauea Caldera and Mauna Kea (horizon) as seen in 1954. The caldera is roughly 3 x 4.5 km. Halemaumau, the inner pit, is about 1 km in diameter. The caldera is 120 m deep. This image was taken from an altitude of about 1.2 km above the surface, at approxiamtely 60 deg emission angle. Resolution is about 4 m (near-field). Note the 1954 lava flow, the numerous fault blocks and the pit crater in middle foreground. Also note the cones on the flanks of Mauna Kea.

Figure 2-3. Wright Dry Valley, Antarctica. Aerial view of the Labyrinth region of the Wright Dry Valley. Upper Wright Glacier is in the lower left; McMurdo Sound and Mount Erebus (a 13,200-ft volcano) are in the distance. This oblique photo was taken by the U.S. Navy on November 14, 1959, from an altitude of 6 km above sea level. The resolution is about 20 m in the near-field. The troughed terrain may have been produced by subglacial erosion, by a catastrophic flood, or by salt weathering and eolian erosion.

2. Most Important Measurement

The most important type of measurement to be made by the airplane imaging system is oblique photography. Oblique images convey much more information than vertical images for two reasons: first, the oblique perspective is one most interpretable by humans because our visual perception is oriented obliquely (i.e., from standing, standing on a mountain, or looking out from an airplane); and second, the oblique view conveys part of the topographic relief in the projected plane of the viewer. In the following paragraphs the capability of an airplane imaging system will be evaluated and compared to current or prospective orbital systems and to an orbital system of comparable capabilities. For this comparison, any new system will be assumed to utilize an 800 x 800 element CCD with 15.24-micron element spacing. It is important to note that, for vertical imaging, a line array system may be more valuable than one that frames. However, for oblique photography line array systems do not work well. Thus, this treatment has been limited to framing cameras.

A reasonably low-resolution system would consist of a relatively short focal length lens. For example, a 15-mm focal length lens would provide a 50 deg (0.88-rad) field of view. At 1 km altitude, this translates to an 880-m-square area viewed vertically, with a resolution of about 2.5 m (1.2 m/pixel).

A high-resolution system might consist of a 150-mm focal length lens, which would give a 5 deg (0.09-rad) field of view. Again, at 1 km altitude and looking vertically, this translates to a 90-m field of view and a resolution of 0.25 m (0.10 m/pixel).

Before these values can be given further consideration, the smear limitations must be assessed. Assuming the highest ground speed (90 m/s) and a smear limit of 0.5 pixel, the exposure interval for the low-resolution mode must be less than 6 ms. For the high-resolution mode, an exposure interval of 0.6 ms would be required. The former can be achieved with available shutters. However, the latter is beyond simple technology, and thus image motion compensation would be required. Such image motion compensation could be electronic (i.e., shifting the charges within the CCD during the exposure) or mechanical (shifting the position of the image on the CCD, shifting the optics, or the CCD). In this latter case the movement is small (0.5 mrad) but relatively easy to accomplish.

Exposure times of 6 ms are reasonable for f-numbers of about 9.5 or lower. An available lens has a zoom capability from 15-150 mm and a 79-mm lens aperture, yielding a maximum f-number of f/1.8. Thus, exposure rates are not limited by available light until late afternoon hours. For night-time viewing, image intensifiers or active IR imaging systems (currently used by DOD) may permit daytime/nighttime aircraft operations.

For oblique viewing conditions, the resolutions are reduced and the fields of view (in km) are increased. Assuming a horizon-viewing image with 10 deg of sky above the horizon and an altitude of 1 km, the image would be centered at an emission angle of 73.6 deg, with the near-field at 48.6 deg. The resolution of images of this type would be, for the low resolution system, 3.7 m (1.7 m/pixel) near-field, 7.7 m (3.5 m/pixel) center-field, and, given a smooth surface to the horizon (82 km distant), 200 m (90 m/pixel) at the horizon. The field of view would be some 1.7 km wide in the near-field, 3.5 km at the center, and 73 km at the horizon.

For the high-resolution system, owing to its more limited field of view, three separate images would be needed to look at: 48.6 ± 5, 73.6 ± 5, and 88.6 ± 5 deg. The resolution would be: 0.3 m (0.1 m/pixel) at 48.6 deg, 0.7 m (0.3 m/pixel) at 73.6 deg, and 20 m (9 m/pixel) at the horizon. Image size at the center of each frame would be about 118 m, 250 m and 7.25 km, respectively.

Pictures of high resolution can also be taken from orbit. Viking cameras, used with Mariner 10 or Voyager high-resolution optics, would have pixel resolutions of 8 μrad and a field of view of 0.5 x 0.56 deg. From 300 km altitude, this would yield a resolution of 5.5 m (2.4 m/pixel) and a field of view of 2.5 x 2.8 km. Oblique views of the horizon would have a resolution of 25 m (12 m/pixel) and width of 13 km. Exposure times would have to be small (less than 300 s) to limit smear - too short for existing shutters. Thus, image motion compensation of extremely small values would be needed (~70 μrad).

Unfortunately, Viking-type vidicons are deficient in sensitivity, and other factors have all but eliminated their use in planetary exploration. A more likely camera would use a 800 x 800 CCD, with a resolution of about 10 μrad per pixel. The vertical viewing resolution and field of view would then be 7 m (3 m/pixel) and 2.4 km square. At the horizon, these values would be 32 m (15 m/pixel) and 12 km.

Although these comparisons (Table 2-1) show that it is possible to acquire high-resolution images from orbit, a major deficiency is in data rate and contiguous coverage. For the airplane flying at 90 m/s at an altitude of 1 km, one vertical, low-resolution image every 5 seconds would provide 48% overlap and a 24 deg steroconvergency angle. Assuming 8-bit encoding, this translates to an average bit rate of 1 Mbit/s. Special coding schemes could lower the bit rate by at least a factor of 2. To acquire high-resolution vertical images in a contiguous strip overlapped by 48% would require a data rate of about 9.8 Mbits/s. To acquire observations from orbit similar to the low-resolution airplane images would require a data rate of 14.6 Mbits/s.

No-overlap images would reduce the above data rates to (1) airplane, low-resolution, 525 kbits/s, (2) airplane, high-resolution, 5 Mbits/s, orbit, high-resolution, 7.6 Mbits/s.

3. Airplane Requirements

Assuming an 800 x 800 element CCD array and 8-bit encoding, each airplane imaging frame would consist of 5.12 Mbits. At the highest aircraft velocity, the data system would have to handle data rates between

Table 2-1. Comparison of orbital and airplane imaging systems

System	Altitude, km	Focal Length, mm	Vertical FOV km	Vertical m/pixel	45 deg m/pixel	horizon, m/pixel	Data Rate (no-overlap), Mbits/s
Viking	300	475	7.9 x 8.7	7.5	11.0	37.0	4.0
Galileo CCD	300	1500	2.4	3.0	4.4	14.6	7.6
Airplane (low resolution)	1	15	0.9	1.2	1.7	90	0.5
Airplane (high resolution)	1	150	0.09	0.10	0.14	9	5.3

0.53 kbits/s to as high as 10 Mbits/s (depending on overlap and resolution). An operational scenario can only be constructed around a given data rate.

4. Problems

Pointing the camera at interesting things will be a major problem, given the time delay to receipt of data and round-trip light-time to Mars. Oblique views need not be taken as often as vertical views in order to assure overlap. Thus it may be feasible to program the camera to take "helical" panoramas. Data rate appears to be the major limitation.

5. Recommendations

An imaging system appears fundamental to a Mars Airplane. Thus pre-mission development of bit-encoding schemes, variable focal length optics, and, especially, image motion compensation should be given high priority.

B. GAMMA-RAY SPECTROSCOPY

Gamma-ray spectroscopy provides information on the surface elemental abundance.

1. Experiment Description

Gamma rays with characteristic energies are emitted from three sources:

(1) The decay of naturally radioactive isotopes and daughter products of uranium, thorium and potassium.

(2) The decay of cosmic-ray-induced radionuclides (neutron or proton capture).

(3) The de-excitation of nuclei resulting from the scattering of high-energy cosmic ray particles.

Comparison of the relative intensities of the gamma ray lines produced by each element permits the determination of elemental abundance. The basic theory has been described by Reedy et al. (1973).

The gamma rays are detected by interaction with a crystal which produces a pulse of visible light proportional to the energy of the incident gamma ray. A photomultiplier tube coupled to the crystal measures the intensity of the light pulse. The system can be collimated to measure gamma rays from a restricted solid angle by surrounding the primary detector with a second detector in all but the desired direction. Any gamma ray photon detected by both is eliminated, as are high-energy particles incident on the detector.

Two detector systems are available:

(1) A thallium-activated sodium iodide crystal (NaI(Tl)) which has relatively low-energy resolution (~50 keV at 0.66 MeV) and relatively high sensitivity. This type of gamma-ray spectrometer was flown on the Apollo 15 and 16 Command and Service Modules (CSM) in orbit around the Moon, and has been described by Harrington et al. (1974).

(2) A lithium-doped germanium crystal (Ge(Li)) which has high-energy resolution (~1 kev) but is about a factor of 4 less sensitive than the NaI(Tl) detector. Although such an instrument has not yet been flown on spacecraft, a discussion and performance evaluation of a Ge(Li) system is provided by Metzger et al. (1975). Since the determination of the intensity of descrete gamma ray lines is the primary purpose of the instrument, the higher energy resolution of the Ge(Li) system more than overcomes its lower sensitivity relative to the NaI(Tl) system. The Ge(Li) gamma ray spectrometer should be considered as the preferred version of this experiment for any future flight missions.

2. Most Important Measurement

Deployed on a Mars Airplane, the gamma-ray spectrometer has the potential of determining the abundance of the natural radioactive elements (U, Th, K) and of some of the more common or "radioactively select" elements in the surface material of the planet (Fe, Ti, Si, O, Al, Mg, Ca, C, H, Na, Mn, Ni, S, Cl, Lu, Cr, Sr, Ba, and Gd). Since each element is detectable when its descrete gamma-ray emission lines(s) can be isolated from the general background flux of gamma radiation,

Table 2-2. Gamma-ray spectroscopy sensitivity limits for a lithium-doped germanium crystal detector, lunar orbit (100 km)

	Observing time		
Element	1 h 3-δMDL	10 h 3-δMDL	100 h 3-δMDL
Th ppm	0.52	0.17	0.052
U ppm	0.12	0.039	0.012
K%	0.028	0.0087	0.0028
Fe%n	2.2	0.70	0.22
Ti%n	0.90	0.28	0.090
Si%	3.4	1.1	0.34
O%	6.5	2.1	0.65
Al%	5.5	1.8	0.55
Mg%	3.0	0.95	0.30
Ca%n	20.0	6.2	2.0
C%	5.4	1.7	0.54
H%n	0.75	0.24	0.075
Na%	1.0	0.32	0.10
Mn%	1.8	0.56	0.18
Ni%	1.2	0.38	0.12
Cr%	4.1	1.3	0.41
S%	7.3	2.3	0.73
Cl%	0.26	0.081	0.026
Lu ppm	11	3.5	1.1
Gd ppm	250	80	25

the limiting sensitivity and the precision of the determination depends on the counting time. The longer the counting time in a particular region of the planet, the lower the detection limit and the higher the precision of the elemental abundance determination. Metzger et al. (1975) have calculated the detection limits for a number of elements with a Ge(Li) system in orbit around the Moon (100-km altitude) and Mars (1000-km altitude). The calculated values of elemental sensitivity limits as a function of three different counting intervals are given in Tables 2-2 and 2-3 (from Metzger et al., 1975).

The effects of the Martian atmosphere, both in attenuating (primarily by Compton scattering) the gamma rays and in attenuating the energetic cosmic rays which serve as an excitation and radionuclide production mechanism, are clearly evident from the increased counting time needed in the Martian case to approach the same detection sensitivity.

The sensitivity limits given for the Mars orbiting gamma-ray spectrometer are not directly applicable to the Mars airplane-borne system, nor is any simple conversion to precise airborne sensitivity

Table 2-3. Gamma-ray spectroscopy sensitivity limits for a lithium-doped germanium crystal detector, Mars orbit (1000 km)

Element	Apollo 11 basalt (mean)	Sensitivity (3δ)					
		Uncollimated			Collimated		
		1 h	10 h	100 h	1 h	10 h	100 h
Th ppm	2.1	1.5	0.5	0.15	2.7	0.9	0.27
U ppm	0.55	0.9	0.3	0.10	1.7	0.5	0.17
K%	0.12	0.11	0.03	0.011	0.19	0.060	0.019
Fe%	12	4.4	1.4	0.44	8.7	2.7	0.87
Ti%	5	1.8	0.57	0.18	3.6	1.1	0.36
Si%	20	11	3	1.1	22	7	2.2
O%	42	13	4	1.3	27	8	2.7
Al%	7.1	-	9	2.9	-	16	5
Mg%	4.6	-	4.0	1.2	-	7	2.2
Ca%	8.6	-	-	6.6	-	-	12
C%	(30)[a]	12	4	1.2	-	8	2.4
H%	(5)[a]	2.4	0.75	0.24	4.1	1.3	0.41
Na%	0.3	-	3	1.1	-	-	1.9
Mn%	0.2	-	1.1	0.35	-	-	0.69
Ni%	0.024	-	0.11	0.23	-	1.4	0.45
S%	0.10	-	4.8	1.5	-	-	3.1
Cl%	0.003	-	0.17	0.052	-	-	0.10
Li ppm	2	-	-	17	-	-	29

Cr, Sr, Ba and, Gd may also be detectable at the longer observing times.
[a]Projected polar cap concentrations for Mars.

limits possible. In the case of an orbiter, the full atmosphere must be traversed by a gamma ray (~19 gm/cm^2 from the 7-m bar level) which would tend to decrease the gamma-ray flux from any small solid angle element as compared to a detector in the atmosphere. Moreover, the whole planet subtends a solid angle of about 100 deg (~2.5 steradians) as seen from the spacecraft in a 1000-km orbit, while a detector (uncollimated) near the planetary surface views a solid angle of 2πsteradians. However, most of the gamma-ray flux which reaches the orbiting detector is derived within about 40 deg (viewing angle from orbit) of the subspacecraft point and has transversed (and has been scattered by) only a slightly longer average atmospheric path than that of a normal to the planetary surface. By contrast, a near-surface detector would be expected to receive much of its flux from surface elements in the far field. Since the mass in an atmospheric path goes as 1/cosine of the angle to the normal while the scattering goes as the exponential (-1.0 x mass x scattering efficiency), where the scattering efficiency of the Martian atmosphere varies significantly over the gamma-ray energy region of interest (0.087 cm^2/gm at 0.50 MeV, 0.020 cm^2/gm at 10.0 MeV), the far-field surface elements will contribute gamma-ray flux with significantly different spectral energy distributions than the near-field elements.

For our purposes here, we can assume that the Mars orbital sensitivity levels for the Ge system provide reasonable lower limits on the sensitivity of an airborne system; that is, the detection thresholds should be lower and the precision of abundance determinations should be higher for a gamma-ray spectrometer on a Mars airplane.

3. Airplane Requirements

The major advantages of a mobile low-elevation gamma-ray spectroscopy experiment are two-fold. First the spatial resolution of the surface is much greater with a surface or near-surface gamma-ray system than with an orbital system. As is evident from the conclusion of the preceding secton (and from Metzger et al., 1975), typical minimum integration times for the Ge(Li) system are on the order of one-half to one hour. For a fixed or very slowly moving carrier (e.g., static lander or rover), the surface resolution is on the order of a few hundred square meters, depending on the specific placement of the spectrometer. For a Mars airplane system cruising at approximately 200 km/h and at an altitude of 1, 2, 5 and 10 km, the surface resolution would be about 400, 800 2000 and 4000 km^2, respectively. A flight of 10-h duration would provide about 10 such resolution units, somewhat less or more depending on the particular element being studied. By contrast, the gamma-ray spectrometer in a 1000-km orbit would have a surface resolution element of about a million square kilometers. Clearly the airborne gamma-ray spectrometer would provide a valuable intermediate resolution to complement the ground-based and orbiting systems.

In order to optimize the scientific return from an airborne Martian gamma-ray spectrometer, three factors should be taken into account:

(1) Flight elevation.

(2) Flight path.

(3) Duration and sequencing of experiment operation.

The flight elevation will have an effect on the total surface area sampled by a given integration interval. However, since the area being sampled will be of an extremely elongated form (~2-10 km x 200 km), this should not be a major consideration in flight elevation selection. Of much more significance is the effect of flight elevation on the necessary counting time for system. Figure 2-4 shows the gamma-ray flux received by an uncollimated detector at several elevations above the Martian surface. Atmospheric scattering and geometric effects are taken into consideration. It is evident that at higher elevations one suffers a significant loss of signal, expecially in the lower energy region (0.5-2.0 MeV) of the gamma-ray spectrum. Figure 2-5 exhibits the effect of flight elevation on signal intensity for several gamma-ray photon energies. Thus a low elevation flight line will enhance the sensitivity

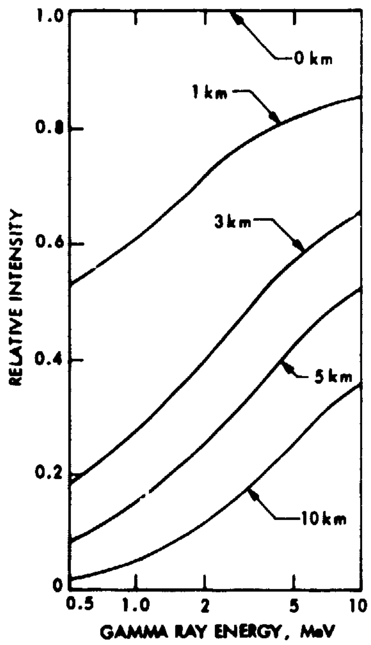

Figure 2-4. Gamma-ray flux vs energy for five flight elevations

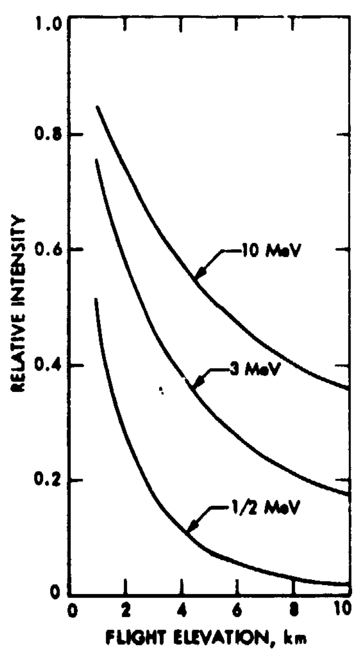

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Figure 2-5. Gamma-ray flux vs flight elevations for three energies of this instrument and/or increase the number of resolvable surface units.

The flight path to optimize the scientific return of a gamma-ray spectrometer cannot be defined a priori, but several guidelines can be stated. First, the flight path should attempt to maintain position within the boundary of each significant surface unit (identified by other means) for at least the minimum integration interval. Second, the flights should be concentrated in regions with a number of identifiable surface units. The available spectral evidence (McCord et al., 1977) indicates that the Martian dark areas exhibit significant mineralogical variations (apparently from the types of exposed rock fields seen on the Viking lander images) while the bright areas are spectrally very uniform (presumably dust and weathering products homogenized on a planetary scale). Therefore, it would be most useful to concentrate the bulk of the flight time in the dark areas of Mars.

The gamma-ray instrument should never be turned off once it is deposited in the Martian environment. Since the detection sensitivity of the experiment and the precision of elemental determinations are proportional to counting time, the experiment should be turned on at all times. If, for example, the airplane is configured to survive a Martian night (when imaging and reflectance spectrometer experiments cannot be used) by landing, every effort should be directed toward maintaining the gamma-ray instrument in an operational state, taking data. Moreover, thought should be given to taking data for as long an interval as possible after the airplane has exhausted its fuel and is no longer mobile.

4. Recommendations

A gamma-ray spectrometer utilizing a germanium detector deployed on a Mars Airplane would provide significant surface elemental abundance determination capability with both mobility and surface spatial resolution at two different resolution scales: (1) a few hundred square meters in the stationary surface mode, and (2) a few hundred square kilometers in the flight mode.

To optimize scientific returns from the airborne gamma-ray instrument, (1) flight elevation should be at a minimum altitude, (2) flight paths should be concentrated in regions of maximum geologic (mineralogic) diversity, most probably the Martian dark regions, and (3) the instrument should be maintained in a data-taking mode at all times during the life of the aircraft and as long as possible after termination of its mobile phase.

C. INFRARED REFLECTANCE SPECTROSCOPY

The purpose of this experiment is to provide surface mineralogy and mineral abundance information.

1. Experiment Description

When visible and near-infrared light interacts with minerals, a variety of photon absorption mechanisms give rise to diagnostic features in the spectrum of the reflected light. Electronic transitions of outer shell electrons (particularly among the transition metals: Fe, Ni, Ti, Co, Cr, etc.) produce absorption features which are directly related to the absorbing cation and to the crystallographic location in which it resides. Interionic or charge transfer absorptions in which electrons are exchanged between adjacent ions dominate the blue and UV portion of the spectrum and are responsible for the characteristic red color of iron oxides and Martian surface materials. The specific nature of the ionic arrangement governs the energy and intensity of these absorption features. In the near-IR portion of the spectrum (1-4 μm), absorption features arise from combinations or harmonics of the bending, stretching and rotational modes of OH, CO, CH and other molecules. For example, the several "water" features between 1.4 and 3.2 μm shift their positions and relative intensity depending on the state of the water (liquid, ice, vapor, bound water, water of hydration, etc.). These features thus can be used to identify and characterize the hydrates, carbonate and "organic" minerals. The basic theory underlying this work has been outlined by Adams (1975).

Extensive ground-based telescopic, visible and near-IR spectral studies of Mars have been carried out in the last few years. This work has been described by McCord et al. (1977, 1978) and Huguenin et al. (1977). Absorption features attributed to atmospheric CO_2, solid H_2O, ferric oxides (of several types and hydration states), and several types of ferrosilicates have been identified in these ground-based spectra. These studies also indicate that the bright area and dust cloud material is quite uniform and apparently represents a planet-wide homogenization of weathering products. The Martian dark areas exhibit a range of spectral features attributed to exposed rock of varying type mixed with the ubiquitous bright dust (an interpretation consistent with the images returned by the Viking 1 and 2 landers).

Two visible and near-IR reflectance spectrometers have been designed for deployment in spacecraft missions: the LPO spectrometer and the Galileo mapping spectrometer. Both systems utilize a small telescope to collect and collimate the light from a surface spot, dichroic mirrors to divide the spectrum into different orders, and prisms or gratings to disperse the light onto linear arrays of solid state (CCD, PbS) detectors which simultaneously sample all wavelengths. Typical spectral resolution is about 0.5-1% and integration time is about 0.5 s for the lunar case. The Galileo system builds up a linear array of spectra at right angles to the line of flight by using a mirror in the system to displace the spot being measured. Motion along with flight path produces a 2-dimensional spectral image.

An alternate spectral imaging system would involve the dispersion of an entrance slit (normal to flight direction) on a 2-dimensional detector array (e.g., CCD). Such detector arrays are available which are sensitive over the ~0.3-1.1 μm spectral region. Such a system was proposed for LPO in conjunction with the reflectance spectrometer.

2. Most Important Measurement

Deployed on a Mars Airplane, the reflectance spectrometer has the potential of determining the mineralogy and abundance of a number of oxide, silicate, carbonate and hydrated minerals present on the Martian surface as well as determining the presence and/or abundance of H_2O and CO_2 frosts, ices or clathrates. The airborne system would provide both increased areal coverage over either a rover or fixed lander and higher resolution than an orbiter. In the nominal LPO and Galileo instruments, the field of view subtends an angle of about 0.01 rad, corresponding to a 10-km resolution element from a 1000-km orbiter or 10-100 m from a low flying airplane (1-10 km). With a ground speed (minimum) of 60-90 m/s and an integration time of 0.5 s, the length of the resolution element along the ground track would be about 50 m. The field of view of the spectrometer might be increased to increase the signal-to-noise level or to increase the speed of the system slightly (0.25 s).

Spectral imaging is important since it permits the extent of characterized mineralogical units identified in detailed spectra to be mapped. The areal extent of mineralogically characterized surface units as well as their stratigraphic or areal relationships is an important datum in understanding the processes which form and degrade the surface material of Mars. Such detailed spectral maps would be a major new contribution to Mars science. Unfortunately, the only spectral imaging system currently under development (Galileo) is not suited for mapping from a rapidly moving platform. The spectral imager (imaging a spectrally dispersed slit on a 2-dimensional detector array) proposed as part of the LPO experiment would provide the needed speed but is not currently a developed system.

An alternative approach is to use a filter wheel combined with the existing imaging system on the airplane. The advantage of such a system is that it requires only a minimal addition to the camera weight. The major disadvantage of a filter system is that it slows down (increases the smear limit) the imaging system. Relatively broad bandpass filters (-1000 Å) would minimize the increase in exposure time. Major consideration should be given to the selection of filters for such a system. The appropriate filters should be selected only after a detailed consideration of the spectral properties of Martian materials. The filters should also have relatively high, uniform (rectangular passband) transmission near their nominal wavelength as well as very low transmission (<0.01%) outside their nominal passband. The scientific return from spectral images will be directly proportional to the amount of reasoned consideration given the selection of filters. These are not going to be off-the-shelf items!

For regions with material distributions similar to the Viking 1 and 2 landing sites, that is, discrete distributions of rocks, soil and dunes on a scale of 10 cm or larger, special spectral deconvolution techniques can be utilized to isolate the spectral signature of the dune or rock population. A single spectrum (with a high signal-to-noise level) could be resolved into 2 or more discrete spectra of the individual distinct units within the resolution element.

3. Airplane Requirements

Of course, the reflectance spectrometer can only be operated during the Martian day, but to minimize phase angle effects most measurements should be taken at high sun angle (i.e., near noon local time). Flight elevation is not a critical factor in the data taking.

4. Problems

The problems are minimal. A system using either filter wheels or an LPO type spectral imaging system could be readily developed.

5. Recommendations

A visible and near-IR (~0.4-4 μm) reflectance spectrometer deployed on a Mars Airplane would provide significant mineralogic information about the surface material of the planet, which would, in turn, provide insight into the formation and weathering processes active on the Martian surface. A spectral imaging system (most probably a filter system attached to the imaging system, unless development funds for a true high-speed spectral imaging system are forthcoming) would provide a means of mapping out the areal extent of the materials characterized from the detailed spectra. The Galileo or LPO spectrometer could meet the needs of the airborne system.

A strong recommendation is made that, if a filter system is to be utlized to produce spectral images, detailed consideration be given to optimizing the number of filters, their wavelengths and bandpasses to the special spectral properties of Martian surface materials.

D. GRAVITY FIELD

The gravity field of Mars has been observed using doppler tracking of both the Mariner 9 spacecraft and the Viking Orbiters (Reasenberg, et al. 1975; Sjogren, 1978). This tracking data has been used to construct spherical harmonic representations of the gravity field through degree six. This low-resolution representation provides no information about the short-wavelength gravity variations which may constrain models of near-surface density variations or crustal structure (<50 km depth). A gravity survey from a Mars Airplane would be very useful for measuring short-wavelength gravity anomalies associated with crustal density variations.

1. Experiment Description

Two different instruments can potentially measure the Mars gravity field from the airplane: an airborne gravimeter and a gravity gradiometer (which measures the components of the spatial gradient of the gravity vector). The torsion balance developed by von Eötvös in the 19th century was actually the first gravity gradiometer. However, this instrument can only be operated on a fixed base. Instruments to measure gravity gradients from an airplane or other moving vehicle (i.e., an acceleration-filled environment) are currently being developed by the Charles Stark Draper Laboratory, Bell Aerospace Co., and Hughes Research Co. Each of the designs requires a triad of three gradiometer instruments in order to determine all components of the gravity gradient, insofar as any individual instrument measures only two components. A complete determination of the gradient tensor would require three gradiometers in addition to a stable platform. For such a state-of-the-art, 3-component system, one might obtain noise levels as low as order 10^{-1} EU (fundamentally limited by thermal noise), and 10-s (1-km) sampling intervals. This system would have substantial size and weight, probably in excess of Mars Airplane mission capabilities.

A single gradiometer measuring components $\partial g_z/\partial x$ and $\partial g_z/\partial y$ would be sufficient for the mission's purpose, as one needs only to measure $\partial g_z/\partial x$ to integrate along track and recovery scalar gravity anomalies. A single gradiometer package would require averaging (smoothing) of platform jitter, and the sampling interval would be reduced to 30 s (3 km). Reduced gradiometer size (increased thermal noise) could still result in resolution of order 1 EU. Spatial resolution of the single gradiometer option can be expected to be approximately comparable with that of he gravimeter.

The alternative way to measure gravity is the gravimeter. The logical choice for a sensor would be the sort of aerospace accelerometer which is used for inertial navigation purposes. The sensing device is basically a magnetically suspended coil with an accompanying proof mass. After averaging the inertial accelerations out of the measurements, one is left with the scalar gravity anomaly.

For the Mars Airplane mission, the gravity gradiometer has some obvious advantages over the conventional gravimeter. The gradiometer is not sensitive to vertical accelerations nor does it require an Eotvos correction. Furthermore, the reference gravity field determinations are strongly degraded by altitude uncertainty. The vertical gradient (free-air correction) of the Mars reference gravity field is 0.2 mgal/m or 1 mgal for every 5 m. Insofar as uncertainties in Mars' gravitational equipotential surface (geoid) from existing models (Reasenberg et al, 1975) are on the order of 100 m, altitude uncertainties are on the order of 100 m. In comparison, the variation of the Martian reference gravity gradient with altitude is slight (2×10^{-3} EU/m).

In spite of the aforementioned disadvantages of the gravimeter, it should be considered as a mission option. The gravimeter package would have the advantage of compactness. As discussed above, altitude uncertainties are roughly 100 m, implying gravity errors of at least 20 mgal. Gravimeters of the LaCoste-Romberg type would have seriously degraded resolution in the dynamic, airplane environment. However, force-feedback aerospace-type gravimeters (accelerometers) would be suitable and capable of resolution on the order of 20 mgal, which is all that is required. Vertical accelerations of the airplane can only be separated from gravity determinations by averaging them out over rather long intervals (at least 10 s or 1 km). Eotvos corrections are of course required.

2. Most Important Measurement

The most important contribution of an airplane gravity survey would be to provide high-resolution (a few kilometers) gravity profiles over selected surface features of Mars. These profiles would provide information on shallow crustal density variations and isostatic compensation. Such gravity information would provide a strong complementary set of data to be used with seismic data in estimating the crustal thickness of Mars. One possible investigation might focus on the Tharsis topographic high, in order to determine the amount of crustal thickening (as proposed by Phillips et al., 1973), if any, in this region. On the other hand, it is possible that portions of the uplift in this region may be due to thermal expansion as seen on the Earth of mid-ocean ridges. The Coprates Chasma - which appears to be related tectonically to Tharsis - would also merit the shorter wavelength gravity survey that the Mars Airplane mission could provide.

Another possible investigation might attempt to resolve the gravity effect associated with apparent lava flows observed photographically (Viking Orbiter I) near volcanos such as Arsia Mons. For example, an abruptly terminated lava flow which is 500 m thick and possesses a 0.1 gm cm^{-3} density contrast with respect to the adjacent country rock would generate gravity gradients dg_z/dx approaching 10 EU at 0.5-km height above ground. A Mars Airplane equipped with a gradiometer could measure such gravity gradients.

A large gravity high (wavelength 500 km) has been observed (Sjogren, 1978) over the Isidis Planitia, a basin or topographic low. This mascon-like feature may be due to a high-density crustal intrusion or updwelling mantle plug. A gravity survey from the Mars Airplane would help constrain the shape, size, and position of this density anomaly.

3. Airplane Requirements

Essential supporting measurements can be provided by navigation equipment which is necessary for the overall mission. For both the gradiometer and the gravimeter options, position and altitude are required and can be obtained respectively from a visual imaging system and a radar and/or barometric altimeter.

As one gravimeter option, a strapdown accelerometer package could be used for both inertial navigation purposes and gravity measurement (with inertial accelerations averaged out). Alternatively, a single accelerometer can be used as a gravimeter by mounting it on a stable platform. To obtain desired resolution (see above) a two-axis platform with 10^{-3} radian level of certainty would be sufficient.

The gradiometer on the other hand would require a three-axis stable platform with a 10^{-5} radian level of certainty.

4. Problems

Gravimeter options do not present substantial engineering or feasibility problems for the mission. Development of a sufficiently stabilized platform for the gradiometer mission option could present some difficulty.

5. Recommendations

The salient scientific needs as outlined above favor the inclusion of the described gradiometer package in the Mars Airplane over gravimeter packages. However, the severe mission constraints on payload size and weight and the development of a stable platform for the gradiometer make the gravimeter the more feasible package.

E. MAGNETIC FIELD

The magnetic moment of Mars as reported by the Russians is low compared to that of the other planets (Dolginov, 1973). The extrapolated surface field is 60γ and it may be less than 6γ (Russell, 1978). This implies that at present Mars does not have a significant internal field. However, earlier epochs of planetary magnetism may have produced magnetized surface features on Mars (e.g., lava flows from the volcanoes and stream deposits). Measurement of the pattern of surface remnant magnetism is of interest because of its implications for the evolution of Mars' magnetic field.

1. Description of Experiment

The typical magnetometers that are used on spacecraft and on aircraft for terrestrial exploration are in general capable of operating at a level of about 0.1 gammas. This level of sensitivity is readily achieved by any of a number of systems. Perhaps for the present application, a three-component fluxgate system to clearly track all three components of the surface field would be most appropriate. Because of the need to clearly separate time and spatial variations in the field it would be useful to have a surface or an orbital system operating at the same time. Since it will be desirable to operate at the 0.1-gamma threshhold for mapping and correlation with geologic and/or topographic features it is essential to keep the sensors of the system as far as possible from the magnetic aircraft components. This might be most effectively done by a wing tip or tail installation and it would be quite desirable to have an inboard sensor to detect the effect of the aircraft if it becomes necessary to separate out the effect.

2. Most Important Measurement

Mapping of the local Martian magnetic field is of considerable interest since one can expect to find anomalies on Mars associated with major geological features. The airplane offers the best platform (the only other is a rover) from which such high-resolution magnetic field measurements can be made. Although Mars has at best a weak surface field, the materials of the solar system consistently record a memory of early solar system fields. Mars may once have had a fluid core and dynamo. If such once existed, those geologic units which were formed early in the history of Mars may well carry a memory of this effect. In the older, heavily bombarded surfaces these fields may well be randomized and preserve no effect. Or magnetic effects may be associated with the somewhat deeper and undisturbed crust. The accretion process of Mars may have permitted its cooling crust to have acquired a remanent magnetization in the presence of early solar system fields. In either case, there may be large volumes of material present which were magnetized early in Martian history. Subsequent volcanic activity may have taken place after the dynamo stopped or after the early solar system fields died out. This would mean that young volcanic constructs would at best be very weakly magnetized. The hypothesis may be right or wrong, but the experiment of magnetic mapping over a variety of well-mapped geological features of varying age could reveal a great deal about the history of any Martian field as well as being a useful mapping device in its own right.

In addition to the volcanic features that have been recognized, are there major dike swarms, as we find terrestrially, reflecting tensional periods in the Earth' crust? How deep is the Curie point is therm? Can fault structures be mapped by offsetting magnetic features? Can the direction of remanant magnetism be determined from examining the correlation of topography and magnetic fields?

We know from Viking that there are magnetic minerals on Mars, undoubtedly in oxidized state, and if any magnetic field was present while these were forming or cooling there will be magnetic anomalies on Mars. The presence of extensive reddening in itself quite clearly implies the presence of hematite, which while weakly magnetic, would in a Martian condition give recognizable anomalies.

3. Airplane Requirements

Optimally one would fly the Mars Airplane at a low elevation, perhaps nominally 1 kilometer, and one would fly a grid pattern with a flight spacing of about 5 km. (Terrestrially the usual mapping is done at 500-1000 ft with 1/2 mile flight line spacing). It would be essential to recover this flight path, which would be designed to cover a variety of major geologic and topographic features in a uniform manner. This flight path recovery and visual imagery over the same path would be most important for anomaly interpretation.

Requirements on the aircraft are essentially those of magnetic cleanliness ($\sim 0.1\gamma$) at the detector and a system for transmitting bits/s.

4. Problems

There are a limited number of problems with the experiment. Spacecraft magnetometers have been flown many times and no particular difficulty is foreseen, other than having a magnetically clean location for the sensor. Anomalies are certain to be present, although we do not know the magnitude. It is thus important to have a large dynamic range to cover the possibility that there are very large local anomalies. It is also desirable to have a reference magnetometer available in orbit or on the surface to separate out time variations in the field. If flying can be adequately controlled, this effect is often detected by flying a cross line to the grid to provide a reference at each end of each profile.

5. Recommendations

A magnetometer for geophysical mapping of Martian surface fields should be flown on an aircraft capable of flying a long-range grid over the Martian surface. This grid should be placed to cover the contacts between adjacent geologic and/or topographic features where significant magnetization contrasts may be expected. The study of these contrasts in remanent magnetization will be useful for mapping geologic features and for reconstructing the history of any Martian fields.

F. ELECTROMAGNETIC SOUNDING

Electromagnetic sounding appears to have an important role in the study of the surface layers of Mars. This is because very dry soils and rocks and those containing frozen water tend to be transparent to radio frequencies. On this basis it has been possible to map the thickness of ice caps to depths of several kilometers. The use of pulses in the radio frequency range and the time for the return of reflections can be used to get the depth at which water is present in the unfrozen state. The technique that would be the most useful then would be to transmit a conventional pulse at several megahertz and to measure the time to reflected arrivals.

Electromagnetic systems are used on earth conventionally for exploring for highly conducting massive sulphide deposits. More recently these systems have developed to the point where they can be used to map resistivity from airborne platforms. The electrical resistivity of rocks and soils is largely determined by the amount and state of the water present. When water is frozen the resistivity drops sharply as ions are no longer able to migrate freely. On the other hand because of the presence of salts it is often necesary to freeze materials to far below the freezing point to inhibit ion migration altogether. Terrestrial deserts for example almost always have very low resistivities because the fluids present are very heavily enriched in salts.

Pure ice is an excellent insulator, with the result that mapping from aircraft systems can be used to determine the thickness of glaciers by measuring the travel time for an electromagnetic pulse to be returned (Gudmandsen, 1971). There seems to be little question that Mars will have a very large range in its electrical properties owing to the presence of a range of temperatures, above and below freezing, a range of salt contents and a range of moisture content.

1. Description of Experiment

There are many possible configurations that could be used to conduct these measurements. These vary from deploying a large dipole antenna to operate over a swept frequency range to individual radar transmitters and receivers using dishes (Watts and England, 1974). Systems were built for topside ionosphere sounding which would have many of the required characteristics (Franklin and Maclean, 1969). Systems have been used in aircarft for radar altimetry and some of these may be readily adaptable to the purpose. A sophisticated imaging package was carried on board Apollo 17, although this was much more complex than required for the present purpose. Further research is required to settle on a specific configuration, but this is because of the need to choose among many options and not because of the lack of basic components.

2. Most Important Measurement

The most important measurement is clearly the one which detects the base of the frozen layer. This means a series of profiles run over specific features to map the depth to this horizon. It is likely that this measurement will be useful in constraining the interaction between the soil and the atmosphere. Variations in this thickness from place to place will provide constraints on the near-surface temperature regime over the history of the surface features.

3. Airplane Requirements

A transmitter operating at a mean power of a few watts for a 1-km flying height is likely to be adequate. Either a dish antenna or a dipole antenna mounted on the airplane should be adequate to radiate this power and to permit a subsurface reflection to be detected. Flying a path at a height 1 km and a grid at a spacing of a few kilometers should provide useful 3-dimensional information on the subsurface.

4. Problems

The problems are minimal. Some instrument development is clearly required and care will have to be taken to ensure that the pulses transmitted do not interfere with the magnetometer. Returns from a very irregular surface with many scattering objects either on or in the regolith could make interpretation difficult. This can be minimized by operating at as low a frequency as possible. If there is no fluid present in free form at depth there will be no reflection. However, the lack of a return could be used to assess the limit of the free water contact.

5. Recommendations

It is recommended that an electromagnetic sounder be incorporated on a Mars Airplane for the purpose of mapping the depth to any water-bearing horizon. This instrument should be used to map the thickness of the frozen and/or dry layer over specific geologic and/or topographic features. There is need to examine in detail the capabilities of currently existing systems to determine the optimum operating configuration.

G. ATMOSPHERIC DYNAMICS AND COMPOSITION

There are some very useful atmospheric science objectives requiring experiments that might be highly compatible with an aircraft platform. These experiments could provide data for global circulation models and for understanding the photochemistry of the atmosphere. Such experiments are commonly flown in aircraft-based studies of the Earth's atmosphere.

1. Description of Experiment

Measurements of temperature, pressure, dust concentration, and horizontal and vertical winds at various heights in the boundary layer (e.g., 0 - 5 km) would prove very useful in developing atmospheric circulation models. Of specific interest in elucidating the boundary layer are studies of:

(1) The mechanical and thermal forcing by the substantial Martian topography.

(2) The effects of surface roughness on vertical mixing.

(3) The effects of dust concentration on local buoyancy effects.

Horizontal and vertical winds could be obtained from aircraft navigation. Temperature and pressure could be measured with thermocouple thermometers and the aircraft barometric altimeter. Dust density and particle size could be measured with a Knollenberg forward scattering laser with a nephelometer for optical properties.

Measurement of vertical profiles of time-dependent or short-lived atmospheric species would prove invaluable in better understanding the photochemistry of the atmosphere and the chemical interaction of atmosphere with surface minerals.

Suggested instruments and the species to be measured (all instruments have been flown on the National Center for Atmospheric Research airplane) are as follows:

(1) O_3 - 2537 Å photometer.

(2) H_2O - 1216 Å photometer.

(3) NO_2 - scanning UV spectroscopy.

(4) NO - chemiluminescence.

(5) OH - laser-induced fluorescence.

Specific experiments for H_2O_2 and H_2O need to be devised and better sensitivity then exists for the UV spectroscopy may be required. Further development of scanning instruments such as mass spectrometers and/or gas chromatographs is also emphasized. A lightweight scanning instrument capable of ppb measurements on an aircraft would seem feasible and would add the possibility of discovering new and unexpected species.

2. Most Important Measurement

The most important measurements are profiles of temperature, pressure, and wind velocity in the boundary layer.

3. Airplane Requirements

Multiple profiles through the boundary layer are needed. Because of the efficiency of the gliderlike design of the Mars Airplane, a flight path with up and down variations of less than ~1 km requires very little more energy than does horizontal flight. Ascents to altitudes >~1 km will require powered climbs that will decrease the overall range of the airplane.

4. Problems

There appear to be no problems except those noted above with regard to specific instrument development.

5. Recommendations

A Mars Airplane would provide a useful platform from which to make atmospheric boundary layer measurements and vertical profiles of certain atmospheric chemical constituents.

SECTION III

ASSESSMENT OF SCIENTIFIC USEFULNESS OF MARS AIRPLANE IN SURVEY MODE

A. UNIQUE CAPABILITY OF THE AIRPLANE

Operating in the aerial survy mode, a Mars Airplane has unique capabilities as a Mars exploration vehicle. It can (1) travel large distances in short times (see Fig. A-5), (2) fly at low altitudes, (3) traverse rough areas that may be of high scientific interest (e.g., canyons, craters, volcanoes, polar regions). These vehicle capabilities provide the capability to make measurements over limited areas almost anywhere on Mars at spatial resolutions intermediate to those obtainable from orbiters and surface landers. This strongly suggests that the two most important scientific uses of the airplane operating in the aerial survey mode will be for topical studies and characterization of sample return sites. Examples of topical study problems are the following:

Is Valles Marineris a rift valley (gravity traverses)?
Is a specific crater isostatically compensated (gravity)?
What is the chemical and mineralogic variation across a basalt flow (IR and gamma ray spectroscopy)?
What is the scale of surface magnetic field variations (magnetic)?
What is the depth to free water (electromagnetic sounding)?

Site characterization is extremely important for placing returned samples into their local and regional geologic contexts. Imaging measurements made from a lander extend out only a few tens to a few hundred meters and provide little information on the geologic setting because they are too close. Orbital data provide broad-scale coverage, but the resolution is too coarse to be able to correlate with lander imaging. The intermediate scale of resolution for visual imaging and geochemical and mineralogical measurements attainable with the airplane is needed to make the extension from the local to the regional and global context.

The usefulness of the increased resolution in combination with the limited areas that can be covered is one of the two key factors on which the airplane must be evaluated scientifically. The other factor is the ability of the airplane to make unique measurements. The airplane provides the only way of obtaining atmosphere boundary layer profiles, the best way of doing electromagnetic sounding from the standpoint of traversing large distances, particularly over the polar regions, and the best way of doing high-resolution magnetic mapping.

B. RELATION TO OTHER VEHICLES

In assessing the role of the Mars Airplane in a Mars exploration program it is useful to compare its capabilities with other vehicles. Although it can obtain higher-resolution measurements than a polar orbiter, it cannot provide the global coverage -- coverage that is essential to addressing the major scientific objectives of Mars exploration.

Operating in the deployment mode, the airplane could deliver network science packages (seismometers and meteorology instruments) as hard lander, penetrators or soft landed packages. Although airplane deployment could improve targeting of the packages and perhaps provide a broader range of available sites, these are not deciding issues in how network science is to be done. Orbitally deployed penetrators or hard landers are capable of establishing adequately located networks on Mars (Mars Surface Penetrator - System Description, 1977). A wide range of latitudes are available, and the targeting accuracy with hard landers or penetrators is sufficiently good for the basic network measurements.

Airplanes offer the greatest competition to the survey mode of a long-range roving laboratory. Operating in the aerial survey mode they can perform many of the survey-type measurements suggested for a roving laboratory (Mars 1984 Working Group report) over a much more extensive area than can a rover. For example, an airplane with 2000-km range could cover a 100 x 100-km area with 5-km flight path spacing in a few hours. A rover might traverse the area only once in its lifetime. Areas of potentially high scientific interest (polar regions, canyons, craters) either too remote or too rough for a rover could be traversed by the airplane.

The airplane offers no advantage over short-range "minirovers" designed for sample acquisition within a few hundred meters of a sample return lander. In fact, the airplane is less desirable becaue of the many takeoffs and landings that it would have to accomplish to compete with a minirover sample collector.

It is not, however, in the one-on-one comparison with other vehicles that the airplane fares best. Rather it is an adaptable vehicle that has the potential to offer many promising options. As pointed out at the beginning of this report, the airplane could function to deploy instrument packages, to collect samples and to perform aerial surveys. Different airplanes could be used to perform different tasks or individual airplanes could perform multiple tasks. For example, each airplane might carry aerial survey instruments, deployable science packages and a sample collection device. As the airplanes fly and land they could deploy the science packages and collect samples for eventual return to Earth. Alternatively, different airplanes could be used for aerial surveys, science package deployment and sample collection.

A unique advantage of the Mars Airplane in deploying science packages or in sample collection is its ability to reach the polar regions. Polar regions above 60 deg latitude are not generally available for surface operations (landers or long-range rovers) because of frozen CO_2 coverage during the winter or cloud cover over the north pole during much of the year (see Table 3-1).

In sample acquisition, the airplane would need the same general capability for sample selection as would be required at a soft lander sampling site. A grab sample from an airplane is no more acceptable scientifically than is a grab sample from a soft lander (Mars Steering Group recommendations). A prime reason for sampling the polar regions is to obtain a stratigraphic core. Therefore, an airplane sampling the polar region would need a coring device.

Table 3-1. Latitude range for sample return missions

Launch year	L_S at landing	Latitude constraints: Geometry		CO_2	Frost	North hood	Combined	
		N	S	N	S		N	S
85	182	67	-78		-55,-90	90,55	55	-55
86	343	75	-90	90,55		90,50	50	-90
87	160	54	-90		-55,-90	90,70	54	-55
88		76	-70	90,50		90,55	50	-70
89	212	43	-90	90,60	-50,-90	90,50	43	0[a]
90	155	90	-62		-55,-90		90	-55

[a]The southern hemisphere is eliminated because of the possibility of a major dust storm.

C. PRIORITIZATION OF AIRPLANE EXPERIMENTS

The seven airplane experiments considered by the airplane working group are shown vs the major scientific objective that they address in Table 3-2. (Full scientific objectives as adopted by the Mars Science Working Group are given in Appendix B.)

The working group prioritized the basic airplane experiments as to their relative importance as airplane aerial survey experiments. This does not imply a prioritization of the experiments for the overall exploration of Mars. Three criteria were used in the prioritization: (1) uniqueness of the measurement, (2) probability of meeting the prime objective of the measurement, and (3) the contribution of the measurement to the scientific objectives of Mars exploration. Priorities are listed in Table 3-3.

Visual imaging was given first priority because the airplane is the vehicle from which the highest-resolution oblique images of volcanic constructs, polar regions and canyon walls can be obtained. These images could provide basic stratigraphic information for addressing the geologic evolution of the Martian crust and climatic changes (stratigraphy of the polar regions).

Table 3-2. Airplane experiments vs scientific objectives

Scientific objective	Aerial-survey experiment
Internal structure	Gravity, magnetic field
Global-scale composition	IR and gamma-ray spectroscopy, electromagnetic sounding, multispectral imaging
Detailed composition and age	N/A
Volatile composition and distribution	Electromagnetic sounding, atmospheric composition
Atmosphere dynamics	Atmosphere sounding
Magnetic field	Magnetic field
Landform processes	Visual imaging, gravity
Biology	N/A

Table 3-3. Priority of aerial survey experiments

Airplane measurement	Scientific priority
Visual imaging	1
P, T, $\overline{V}$ sounding	2
E-M sounding (polar regions)	2
Magnetometer	2
Gravity field	3
IR spectroscopy	3
γ-ray spectroscopy	3
EM sounding (nonpolar)	3
Multispectral imaging	4
Atmosphere composition	4
Humidity and dust opacity profiles	4
Airplane assumed to have:	
Radar altimeter	
Barometric altimeter	
Inertial system	
Terrain following sensors	

Pressure, temperature and wind velocity sounding, low-altitude magnetic field measurements, and electromagnetic sounding of the polar regions are second-priority measurements. Atmospheric sounding, particularly in the boundary layer, would contribute data necessary for understanding the global circulation of Mars' atmosphere. Boundary-layer sounding can practically be done only from the airplane.

A prime objective of low-altitude magnetic field measurements is to delineate possible local patterns in shallow remanant magnetic fields. As has been demonstrated with the lunar magnetic measurements, the scale of magnetic anomalies can be quite small (down to less than a kilometer), and these anomalies often show correlations with such geological features as maria and rilles. Correlation of local magnetic patterns with geologic features on Mars could lead to a delineation of past global magnetic patterns that relate to past planetary magnetic field activity. Low-altitude measurements from an airplane would provide the best method of obtaining high-resolution magnetic measurements.

The prime importance of electromagnetic sounding measurements is in determining the depth at which water may be present. This depth would be a strong constraint on the thermal evolution of the planet. Without a surface heat flow measurement the depth of the 0 deg isotherm is the next best thing to determine. Our knowldge of the properties of the Martian subsurface is extremely limited. Thus the probability of obtaining this depth is essentially unknown. The experiment was given a second priority only because of this uncertainty. Used as an experiment to provide information about shallow layering (nonpolar regions), the electromagnetic sounding experiment becomes a third-priority experiment.

Gamma-ray and reflectance IR spectroscopy measurements were classed as third priority because it was thought that global coverage was the essential element in geochemical and mineralogic mapping of Mars, considering our current level of knowledge about the planet. Resolution from orbit was felt to be adequate particularly in the case of IR measurements to address important regional variations. The prime use of airplane measurements would be to address topical problems and in the characterization of sample sites.

Gravity field measurements would contribute to the understanding of the shallow crystal structure. The perceived difficulty of doing airborne gravity surveys, and in particular the development of a gradiometer system for a Mars Airplane produced little confidence that a useful survey could be accomplished. The remaining experiments were judged to be investigations that would probably be done if an airplane were developed.

As discussed previously, one of the two most attractive uses of the airplane is in sample site characterization. Assuming this objectve for the airplane, the essential and desired payloads are listed in Table 3-4. The essential payload would provide the data base for placing the sample site in its regional geological setting.

Table 3-4. Airplane payload for sample site characterization

Essential	Desirable
Visual imaging	Electromagentic sounding
IR spectroscopy	Gravity field
Gamma-ray spectroscopy	
Multispectral imaging	
Magnetic field	

D. TERRESTRIAL APPLICATIONS

A small, remotely piloted airplane could have important scientific applications on Earth regardless of its use on Mars. Two such applications are as a stratospheric research platform and as a means of doing mineral exploration reconnaissance surveys. Clearly, the aircraft would be capable of meterological and chemical composition measurements in, say, the 20- to 40-km-altitude region, and its potential as an easily launched and recoverable observational platform for studies of the circulation and chemistry of the ozone layer ought to be carefully assessed. At present, experimenters rely primarily on expensive balloons to study these altitudes, at least as far as compositon is concerned. These balloons are restricted in their usefulness by weather conditions.

In the exploration for mineral deposits on the Earth there is a wide variety of geophysical methods used from aircraft. These methods are used both for direct exploration as well as for geological mapping. The commonly used devices are magnetic field sensors, electromagnetic systems and gamma-ray spectrometers. Other methods are occasionally used, but these three form the basis for hundreds of thousands of line miles of surveying every year. It is common to do this surveying at flight elevations ranging from 100 to perhaps 500 m, but in general the lowest elevations provide the most detailed information. It is also common to fly the selected area on a uniform grid with flight lines spaced at intervals ranging from 100 m to perhaps 5 km for reconnaissance studies. A small, remotely piloted airplane could offer significant cost savings and operational advantages over conventional aircraft.

SECTION IV

CONCLUSIONS

A Mars Airplane can operate in three modes; as a vehicle for deploying science packages, as a sample collector, and as an aerial survey platform. There does not appear to be any significant advantage in using the airplane to deploy network science packages over hard landers or penetrators deployed from orbit unless it can land and take off repeatedly. Then the airplane might be capable of carrying more sophisticated instruments and one plane could service several widely spaced areas. It is not clear, however, that this would be more cost-effective than several relatively simple Surveyor-type soft landers.

The airplane offers an attractive potential for sample collection. However, the technology requirements are the most demanding - repeated landings and takeoffs, sample selection and acquisition devices mounted on the airplane, and survivability during Martian nighttime.

As an aerial survey platform the most important use of the airplane would be in topical studies and returned-sample site characterization. Essential experiments for site characterization are visual imaging, gamma-ray spectroscopy, infrared reflectance spectroscopy, multispectral imaging, and magnetic field measurements.

Operating in the aerial survey mode with a landing and takeoff capability, the airplane must be considered superior to the long-range roving laboratory.

The airplane offers the unique capability to do high-resolution oblique imaging and repeated profile measurements in the atmospheric boundary layer. It offers the best platform from which to do electromagnetic sounding. It offers the possibility of deploying instruments and sample collection in the polar regions, which are inaccessible with soft landers or rovers.

A critical requirement is that the airplane system have the navigational capability to rapidly (within a few hours) locate an airplane and then guide the airplane to predetermined geologic features. This seems to require some autonomy in the airplane guidance system and relatively little feature identification through "real-time" interactions with the airplane.

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APPENDIX A

MARS AIRPLANE SPECIFICATIONS

Table A-1. Mars Airplane mass breakdown, kg

	Cruiser		Lander	
	Hydrazine engine	Electric engine	Hydrazine engine	Electric engine
Airframe	50	50	50	50
Powerplant and fuel system	13	20	13	20
Solar cells and rechargeable battery	0	0	8	8
Landing system	0	0	27	27
Navigation, guidance, Mission computer and flight control	30	30	30	30
Miscellaneous systems (communication, antenna, environmental control, etc.)	20	20	20	20
Subtotal	113	120	148	155
Payload	40-100	40-100	40-100	40-100
Dry weight	153-213	160-220	188-248	195-255
Fuel	147-87	0	112-52	20-20
Batteries	0	140-80	0	85-25
All up weight	300	300	300	300

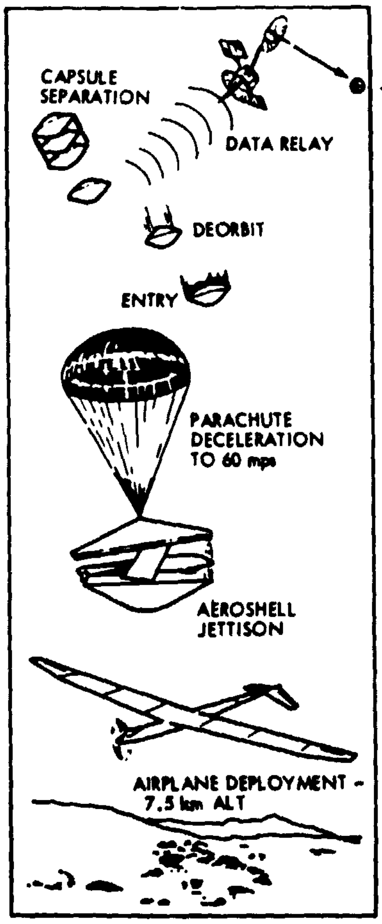


Figure A-1. Mars Airplane descent system

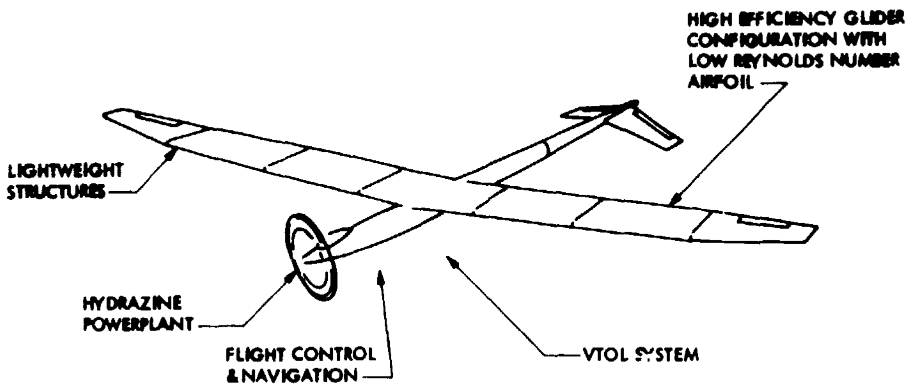


Figure A-2. Mars Airplane system

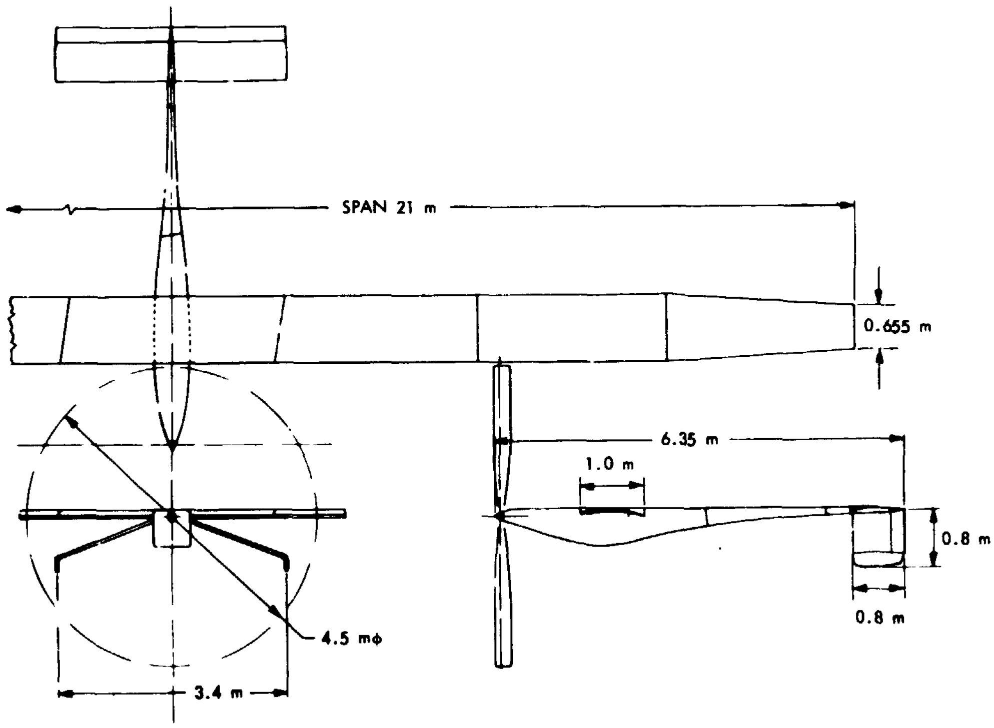


Figure A-3. Mars Airplane

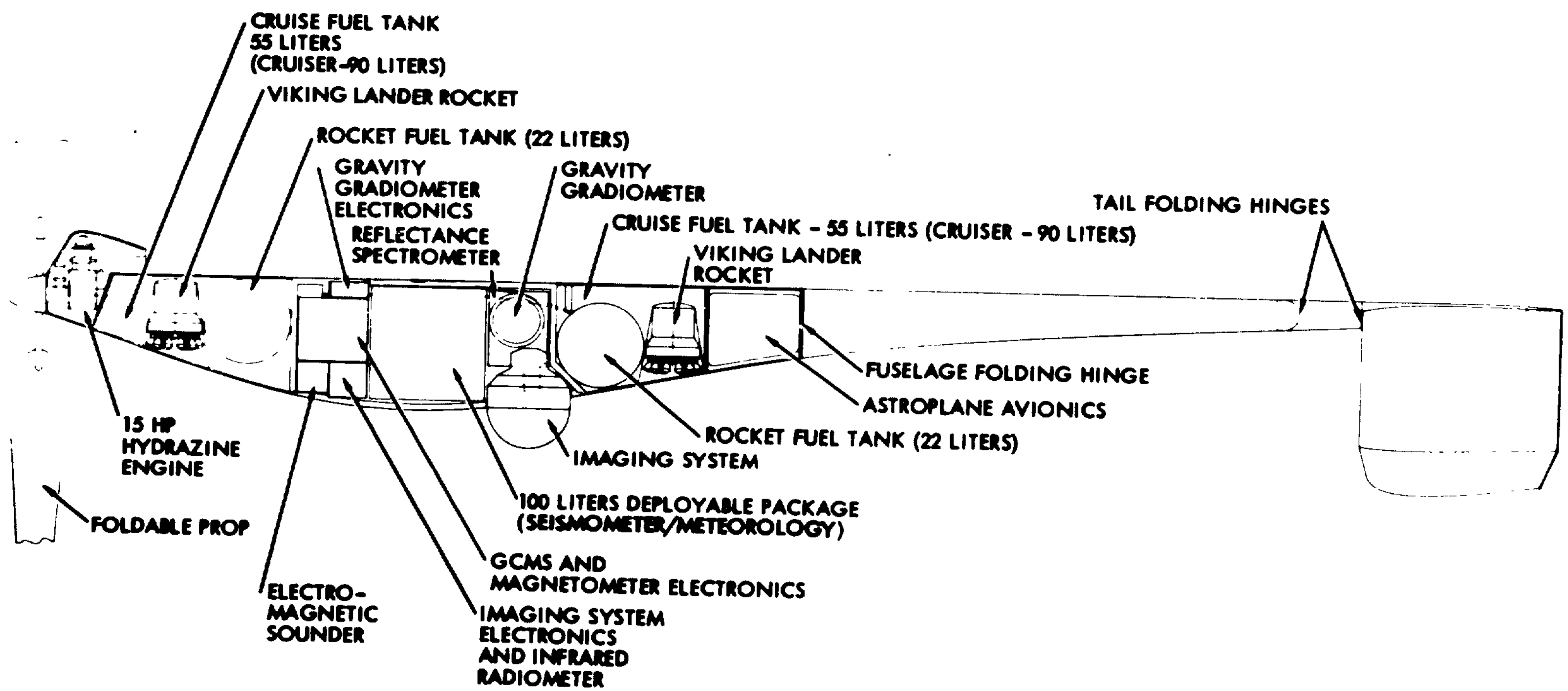
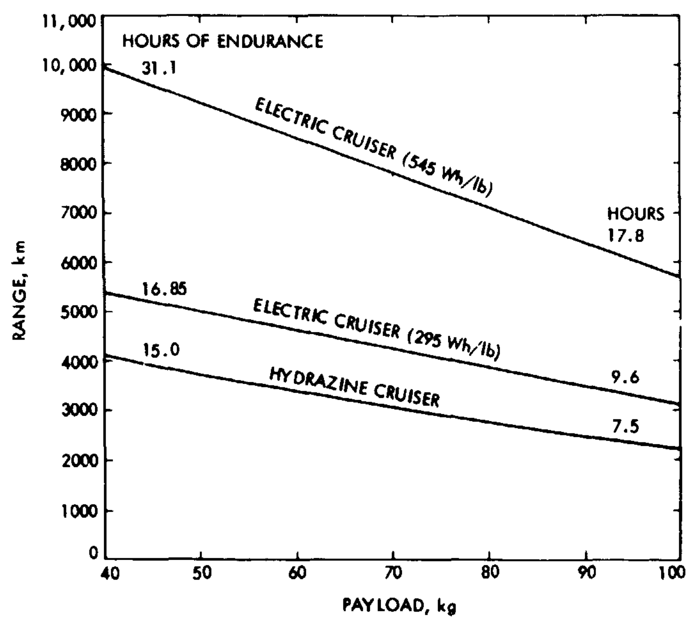


Figure A-4. Mars Airplane inboard profile



AUW	300 kg	PROP EFFICIENCY	0.85
WING SPAN	21 m	HYDRAZINE ENGINE CRUISE SFC	4.85
WING AREA	20 m^2	ELEC MOTOR EFFICIENCY	0.85
CRUISE ALTITUDE	1 km	AUX POWER CONSUMPTION	0.4 kW
LIFE/DRAG AT 300 kg	27.75		

Figure A-5. Mars Airplane cruise performance

APPENDIX B

SCIENTIFIC OBJECTIVES OF MARS EXPLORATION
(listed without order of priority)

1. Characterize the internal structure, dynamics and physical state of the planet.

2. Characterize the chemical composition and mineralogy of surface and near-surface materials on a regional and global scale.

3. Determine the chemical composition, mineralogy and absolute ages of rocks and soil for the principal geologic provinces of Mars.

4. Determine the chemical composition, distribution and transport of volatile compounds that relate to the formation and chemical evolution of the atmosphere; determine the interaction of the atmosphere with the regolith.

5. Characterize the dynamics of the atmosphere on a global scale.

6. Characterize the planetary magnetic field and its interaction with the upper atmosphere, solar radiation, and the solar wind.

7. Characterize processes that have produced the landforms of the planet.

8. Determine the extent of organic chemical and biological evolution of Mars and elucidate how the history of the planet constrains these evolutionary processes.