1. Introduction

1.1 The Mars Environment

Mars, the fourth planet from the Sun, is one of the terrestrial planets and Earth's outer neighbor. Throughout history, stargazers often referred to Mars as the Red Planet because its bright appearance and reddish color stand out in the night sky. The rocks, soil, and sky have a red or pink hue. Impressive surface features, such as enormous volcanoes and valleys, are frequently obscured by huge dust storms. Mars is only about half the diameter of Earth. Although the length of the Martian day is almost the same as Earth's, its mass is only 11% of Earth's. Some of the basic Mars statistical data are listed in Table 1-1.

Table 1-1. Mars Statistical Parameters

Parameter	Value
Diameter	6,785 km (4,217 miles)
Length of Day	24 hr 37 min
Mass	0.11 x Earth
Length of Year	687 Earth days
Density (water=1)	3.9
Tilt of Axis	25° 12"
Minimum Distance from Sun	205 million km (128 million miles)
Maximum Distance from Sun	249 million km (155 million miles)
Surface Gravity	0.38 x Earth
Temperature	–82°C to 0°C (–116°F to 32°F)
Minimum Distance from Earth (opposition)	55 million km
Maximum Distance from Earth (superior conjunction)	~400 million km
Satellites	Deimos (8 km) Phobos (28x20 km)

Before space exploration, Mars was considered the best candidate for harboring extraterrestrial life because the Martian environment was expected to be the most similar to Earth. In July of 1965, Mariner 4 transmitted 22 close-up pictures of Mars. All these pictures showed a surface containing many craters and naturally occurring channels. In July and September 1976, Viking Landers 1 and 2 touched down on the surface of Mars. The three biology experiments aboard the landers discovered unexpected and enigmatic chemical activity in the Martian soil, but they provided no clear evidence for the presence of living microorganisms in the soil near the landing sites. However, recent examination of the 12 Martian meteorites collected from Antarctica found carbonate minerals. Fossilized organic materials associated with these carbonates provided evidence for possible past life on Mars.

Recently, scientists using data from Mars Global Surveyor (MGS) have observed features that suggest there may be current sources of liquid water at or near the surface of Mars [Malin and Edgett, 2000]. Many images show gullies formed by flowing water and the deposits of soil and rocks transported by these flows. The evidence makes it much more likely that life could exist or could have existed on the planet. Future exploration of Mars will not only help us answer questions such as whether life exists on Mars, but it will also help reveal the origin and evolution of the Solar System [Carr, 1981; Kieffer et al., 1992; Kliore, 1982; Luhmann et al., 1992; Golombek et al., 1997; Albee et al.,1998].

The Martian climate and surface features are more significantly influenced by the shape of the Martian orbit than Earth because Mars has a more elliptical orbit. The Martian orbit eccentricity is 0.093, in contrast to the near-circular Earth orbit (0.017). This high eccentricity affects Mars in a number of ways, as show in Figure 1-1. When Mars is at its perihelion (closest point to the Sun), the southern Martian hemisphere tilts toward the Sun. Thus, the southern hemisphere has a relatively hot and short summer. When Mars is at its aphelion (farthest point from the Sun), the northern Martian hemisphere tilts toward the Sun. Thus, the northern hemisphere has a relatively cold and long summer. A similar effect on Earth causes only a 3-day difference because of the low eccentricity. For this reason, the Martian southern summer peak temperature is ~ 30°C higher than the northern peak temperature. These differences have generated profound effects on Martian atmospheric circulation patterns, surface geomorphologic change, dust storm and polar ice cap formation, etc. Mars also has a higher inclination angle (25° 12") of its rotation axis relative to the normal to its orbital plane (Earth's inclination is 23.5°). However, the effect due to this difference is small.

American and Russian spacecraft have made a steady stream of exploratory flights to Mars with both successes and failures in the past thirty years [Kliore, 1982; Blamont, 1991; Breus, 1992; Golombek et al., 1997; Albee et al., 1998]. Table 1-2 is a subset of the missions that have returned valuable data and of planned future missions.

Recently, the U.S. National Aeronautics and Space Administration (NASA) launched a series of missions in a coordinated program to explore Mars. Both successful missions of Mars Pathfinder (MPF) and Mars Global Surveyor (MGS) greatly enhanced our knowledge and public interest in Mars [Golombek et al., 1997; Albee et al., 1998]. NASA is accelerating the pace of Mars environmental studies and will be sending spacecraft to Mars more frequently.

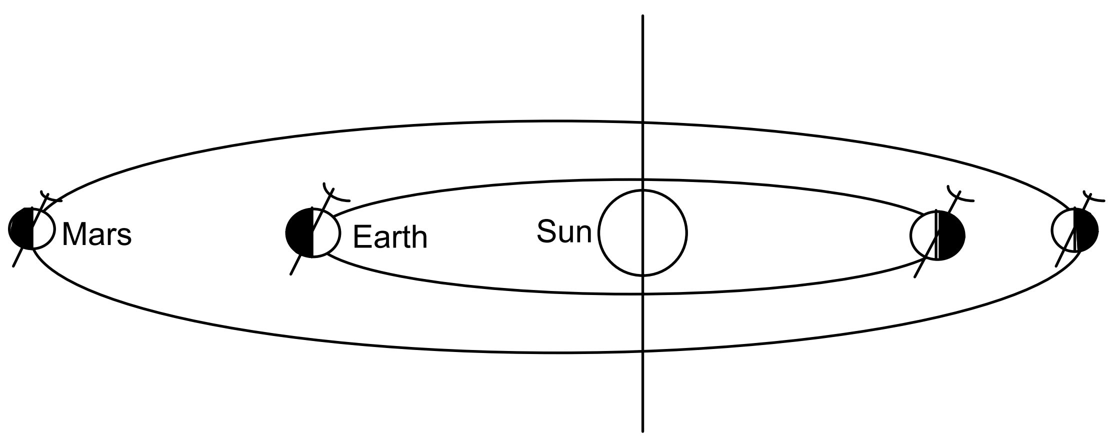

Figure 1-1. Mars Orbit and Relative Distance from Sun. Mars has a more elliptical orbit, as compared with Earth's orbit. There is a 44 million kilometer difference between its aphelion and perihelion.

Table 1-2. Mars Exploring Missions and Active Dates

Missions	Active Date
Mariner 4, 6, 7, and 9 (U.S.)	1964, 1969, 1971
Mars 2 and 3 (Russ.)	1971 & 1972
Mars 4, 5, and 6 (Russ.)	1974
Viking I and II (U.S.)	1975
Phobos (Russ.)	1989
Mars Observer (U.S.)	1993
Mars Pathfinder (U.S.)	1997
Mars Global Surveyor (U.S.)	1998
Mars '98 (Polar Lander and Deep Space II) (U.S.)	1999
Nozomi (Planet-B) (Japan)	1999
Mars Odyssey Orbiter (U.S.)	2001
Mars Exploration Rover (U.S.)	2003
Mars Express Orbiter (ESA) and Beagle II Lander (UK)	2003
Comm Orbiter (U.S.)	2005
Mars Reconnaissance Orbiter (U.S.)	2005
Mars 2005 (Sample Return) (U.S.) and 4 Netlanders (CNES)	2005
Mobile Science Laboratory (U.S. and ESA)	2007
Scout Missions (U.S. and ESA)	2007
Mars Aircraft (Kitty Hawk) (U.S.)	2010
Mars Human Exploration Program (U.S.)	2020

Through cumulative effects, the instruments carried by all Mars missions have provided precise and definitive measurements and analysis. Today our knowledge about Mars has been greatly enhanced in a range from its surface rocks to its atmosphere. The atmosphere of Mars is quite different from that of Earth [Keating et al., 1998]. While the Earth atmosphere is composed mostly of nitrogen and oxygen, the Martian atmosphere is composed primarily of carbon dioxide with small amounts of other gases. The six most common components of the Martian atmosphere are the following:

(1) carbon dioxide (CO_2): 95.32%;
(2) nitrogen (N_2): 2.7%;
(3) argon (Ar): 1.6%;
(4) oxygen (O_2): 0.13%;
(5) water (H_2O): 0.03% and
(6) neon (Ne): 0.00025%.

The Martian atmosphere contains only about 1/1,000 as much water as Earth's, but even this small amount can condense out, forming clouds that ride high in the atmosphere or swirl around the slopes of towering volcanoes. Local patches of early morning fog can form in valleys. At the

Viking Lander 2 site, a thin layer of water frost covered the ground each winter. Local and global dust storms, which occur frequently in certain areas, contribute to the atmospheric hazes [Martin, 1984].

The Martian sky usually appears as a reddish color. This is because the blue light is absorbed by the dust, but the red light is scattered throughout the sky. By contrast, the molecules in the Earth's atmosphere intercept about as much of the blue sunlight as the Martian dust does because blue light is scattered easily by Earth's atmosphere, but the red light is neither absorbed and scattered, giving the Earth its blue sky.

On the basis of previous missions and the recent Mars Pathfinder measurements, there is evidence that in the past a denser Martian atmosphere may have allowed water to flow on the surface. Physical features closely resembling shorelines, gorges, riverbeds, and islands suggest that great rivers once marked the planet. The average recorded temperature on Mars is –63°C (–81°F) with a maximum temperature of 20°C (68°F) and a minimum of –140°C (–220°F). Carbon dioxide, the major constituent of the atmosphere, freezes out to form an immense polar cap, alternately at each pole. The atmospheric pressures at the Viking Lander 2 site were 7.3 and 10.8 millibars (1 mb = 100 Pa). In comparison, the average atmospheric pressure of the Earth is 1000 millibars.

The Martian ionosphere also has some differences and similarities with respect to the Earth's ionosphere [Acuna et al., 1998]. Basically, the Martian ionosphere is a single layer with relative low plasma density. Because Mars has little or no intrinsic magnetic field, ionized gas can directly interact with the solar wind to form a comet-like ionotail in the nightside.

1.2 Radio Wave Propagation Parameters

Telecommunication with the spacecraft is crucial to secure the success of each mission. Thus, we need to study the effects of Martian environments on radio wave propagation and any potential impairment to communication.

Because the environment of Mars is significantly different from Earth's in many aspects from its surface to its outer ionosphere, the effects of the Martian environment on radio wave propagation may be also different. Our understanding of radio wave propagation needs to be expanded based on data from the various Mars missions.

From the viewpoint of classical radio wave theory, radio wave propagation at Mars is controlled by both its ionospheric (plasma) refractive index and its tropospheric (atmosphere) refractive index. These indices govern the propagation direction, the intensity, and the polarization of radio waves.

For low-frequency waves, the refractive index of a medium containing free electrons, with a superimposed static magnetic field, is given by the Appletion-Hartree formula [Budden, 1961]:

$$n^2 = 1 - \frac{X}{1 - iZ - \frac{Y_T^2/2}{1-X-iZ} \pm \sqrt{\frac{Y_T^4/4}{(1-X-iZ)^2 + Y_L^2}}} \tag{1-1}$$

where n is the refractive index, $X = \frac{\omega_p^2}{\omega^2} = \frac{f_p^2}{f^2} = \frac{N_p e^2}{\varepsilon_0 m \omega^2}$, and $Y = \frac{eB}{m\omega}$, $Y_L = Y\cos\theta_{Bk}$, which is the longitudinal component of Y, while $Y_T = Y\sin\theta_{Bk}$ is the transverse component of Y. $Z = \nu/\omega$. Furthermore, ω is the radio wave angular frequency, ω_p is the plasma frequency, ν is the plasma collision frequency, B is the background magnetic field, and θ_{Bk} is the angle between the magnetic field and the wave propagation direction. Thus, the refractive index is mainly a function of electron density and background magnetic field.

For high frequency waves (> 1 GHz), the radiometeorology has some effects on the wave propagation. These effects mainly occur in the lower portion of the atmosphere, the troposphere. Because the tropospheric radio refractive index is slightly greater than unity, it is convenient to define [Bean and Dutton, 1966]:

$$N = (n-1)\times 10^6 \quad \text{(N unit)} \tag{1-2}$$

We usually use N (refractivity) to describe the spatial and temporal variation of the air refractive index. In general, the dry part of the refractivity (N_d) can be expressed as:

$$N_d = Q\frac{P}{T} \tag{1-3}$$

where $Q = 0.269\sum_i q_i f_i$ and q_i is the refractivity at standard temperature and pressure (S.T.P.) of the *ith* constituent gas of the atmosphere (cf. Essen and Froome, [1951]; Newell and Baird, [1965]), and f_i is its fractional abundance (by volume). P is in millibars, and T is in Kelvins. Thus, we have the Martian radio refractivity:

$$N = 130.6\frac{P}{T} + 3.73\times 10^5 \frac{P_{wv}}{T^2} \tag{1-4}$$

Thus, the tropospheric radio refractivity is a function of atmospheric pressure, absolute temperature, and water vapor pressure, P_{wv} (mb). Note that this expression is different from that on Earth because the Martian atmosphere has a different composition than that of Earth.

Besides ionospheric and tropospheric refractive index effects on the wave propagation, the gaseous attenuation of high frequency radio waves is another important factor [Waters, 1976]. Martian dust storms and atmospheric aerosols are the dominant factors in wave scattering. Even though Mars has a very low water vapor content, Martian cloud and morning fogs may also have some impact on radio waves. Some special Martian geological and geomorphologic features, such as polar ice caps, canyons, and crater domes, can also cause wave reflection and diffraction.

In the following chapters, we review all related previous measurements and analysis. We apply the radio wave theory to these environmental parameters and study their effects from outer space to the Martian surface over all related topics.

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