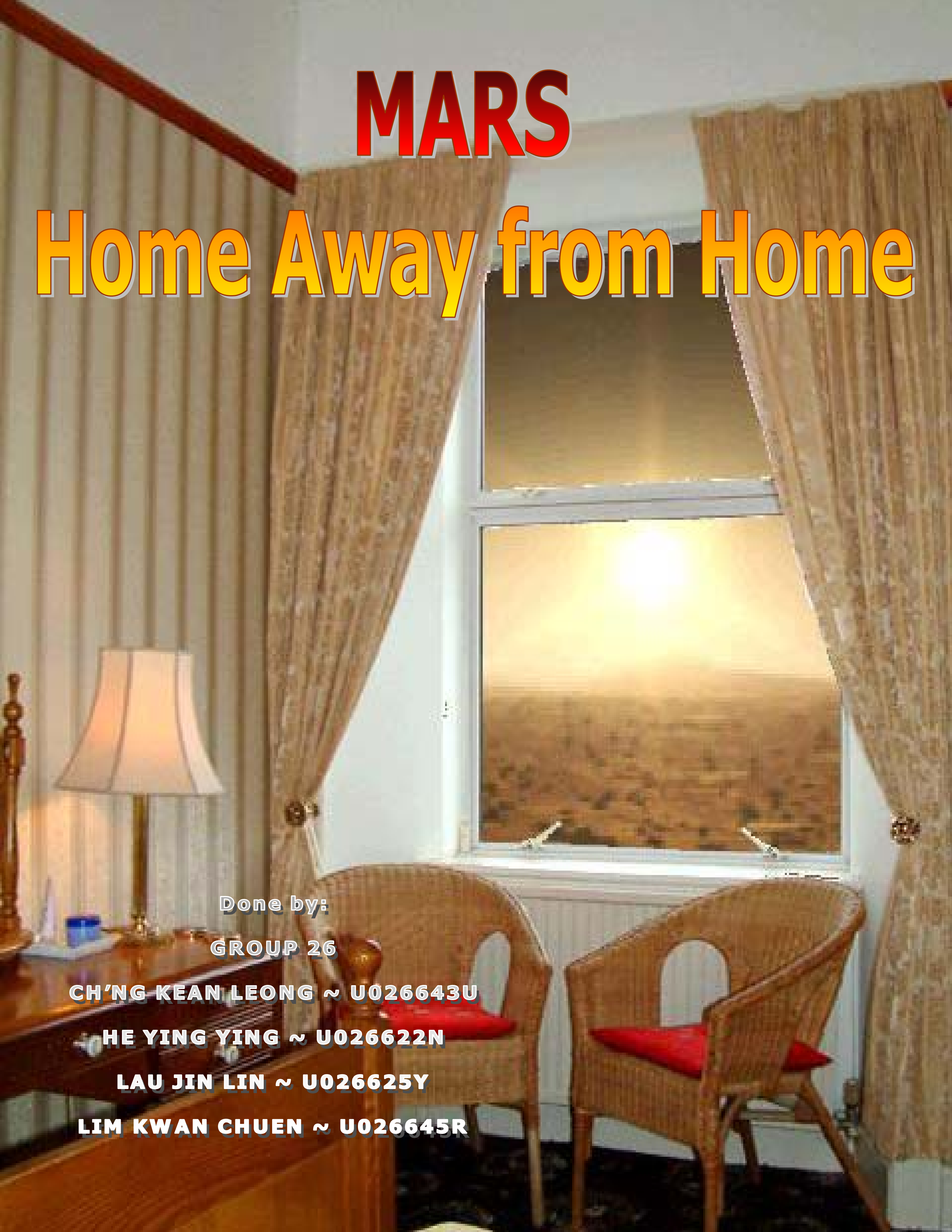

MARS

Home Away from Home

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Table of Contents

Executive Summary

Mars is the fourth planet from the Sun and is commonly referred to as the Red Planet. Before space exploration, Mars was considered the best candidate for harbouring extraterrestrial life. Visible to the ancients, and distinctly reddish in the night sky, the next planet has always been an attractive subject for imaginative science fiction. Despite various evidences now revealed that there is no living organism in Mars, the spirit to explore Mars has never ceased, realizing that overcrowding and exhaustion of resources on Earth may one day force human to make their way outward into the cosmos. While this is not realizable in near future, it is worthwhile imagining the life in Mars, and most importantly, what would the calendar look like in Mars!

The project looked into the reasoning behind Mars exploration for inhabitancy. Why Mars and not other planet? We examined the physical aspects of Mars, the possibility for human to live in Mars. Cultural astronomical aspect of Mars in notably was explored. Attempts were made to answer typical questions of seasons, sun and moons in Mars – Do we have seasons in Mars? How will the two moons appear in Mars?

Highlights of the project would be the construction of Mars calendar. Various versions of Martian calendar have been developed by one party or another. The project has underlain the basic principles behind the construction of Martian calendar based on definition of time system in international solar standard. Differences between different versions were contrasted and investigated.

Martian calendar developed was compared with Gregorian calendar commonly adopted by us on the Earth. The project has also developed a model to convert Gregorian date into a Martian date based on the Martian calendar constructed.

The project concluded with the problems living in Mars, and constraints and limitations of current technology in overcoming them. Hence, the project addressed astronomy aspect of Mars, its calendar, and the possibility for inhabitancy.

Chapter 1: About Mars

1.1 How its name come about

Mars, a bright "star" in the night sky, is the fourth planet from the sun in the solar system. It is named after a Roman god of war because of its red colour – the colour of fire, blood and war. However, its colour does not really come from blood or fire; it comes from oxidised iron - rust. Much of its surface is covered by reddish-orange rocks or a powdery orange soil. Its fiery red colour in the night sky has also earned itself a name called "The Red Planet"

Talking about the name of "Mars", different cultures had different names for it. The Chinese, Japanese and Korean called it the "*fire star*". The Egyptians called it "*Her Deschel*" or "*the Red One*". The Babylonians called it "*Nirgal*" or "*the Star of Death*" whereas the Greeks called it "*Ares*", their god of war. To the Greeks, *Ares* was a cowardly god. But to the Romans, Mars was one of the greatest gods, and it was an honour to follow him into battle or to fall to his sword.

The astronomical symbol for Mars is ♂ This symbol represents the shield and spear of the god, Mars. Since the god is a male, this symbol also represents men and masculine energy.

References: [1-1], [1-2]

1.2 How Mars was discovered

Since prehistoric times, Mars has been seen by skygazers. This is due to its brightness and closeness to Earth (less than 45 million miles away). However, Galileo is the first person to see Mars through the telescope in 1610. Later, in 1659, Christian Huygens was the first person to draw stretches of Mars, which were useful to astronomy. He also deduced that the rotational period of Mars is about 24 hours.

Till now, numerous spacecrafts have been sent to Mars. Some of them include the orbiters, landers and rovers. A few of the most successful missions include the Viking programs, Mars probe program and the Mariner.

References: [1-1], [1-2], [1-5]

1.3 Reasons to explore Mars

The single most important reason is human-centred - that it will definitely benefit humanity. If there is a day when Earth can no longer support the huge population, or that the environment becomes too bad for living, civilisation can continue to survive in the Martian colonies. Moreover, Earth might also be destroyed in the hand of warfare, diseases or other types of catastrophe.

The nature of humanity is to expand. However, the technology results in contraction instead. According to a sociologist, this will results in more environmental crimes, such as technological deceleration, pollution, economic and social collapse, because there is no place to go. Thus, if we were able to colonized Mars one day, this new world could aid in the advancement of society by providing a place for the expansion.

Moreover, human beings are naturally curious. They like to discover and explore the unknowns. Thus the exploration of Mars will indeed provide great satisfaction for them, since homesteading Mars will present many intellectual and engineering challenges.

Richard Poss, a humanities professor at University of Arizona, suggested that Mars exploration could provide a moral substitute for war. Currently, many youths joined the military to challenge and test themselves. With space exploration, these youths can switch their focus to the challenges, dangers and proving ground for Mars exploration. In addition, there is a probability that resources will be allocated away from military and weapons to the Martian project.

In addition, the exploration of Mars can results in increased employments and new technologies and discoveries. These discoveries and the knowledge learnt could also aid in allowing us to better understand, protect and control our planet – Earth.

All these reasons and many others prompt quite a number of companies, both public and private, to explore on the possibility of living in Mars, either to go there for a holiday or to live there permanently. For instance, 4Frontiers Corporation is aiming to open a small human settlement on Mars within 20 years.

References: [1-3], [1-6]

Chapter 2: Physical Characteristics of Mars

Mars is considered a relatively small planet. It has a diameter about half the diameter of Earth. The surface area of Mars is only one quarter of the Earth’s surface area. It only has one-tenth the mass of Earth. However, because Mars do not have oceans, its surface area corresponds to the Earth’s dry land.

2.1 Its Atmosphere

The atmosphere of Mars is relatively thin compared to that of Earth. This can be confirmed by the fact that the air pressure in Mars is only 750 Pascals while the air pressure in Earth is 10^5 Pascals. However, Mars has a higher atmosphere scale height than the Earth (11km versus 6km). The thin atmosphere of Mars has resulted in lower atmospheric temperature since it cannot hold heat. The highest temperature it can reach is about 20^{o}C. The composition of Mars atmosphere is as below:

95% - Carbon Dioxide
3% - Nitrogen
1.6% - Argon
0.4% - Traces of Oxygen and Water

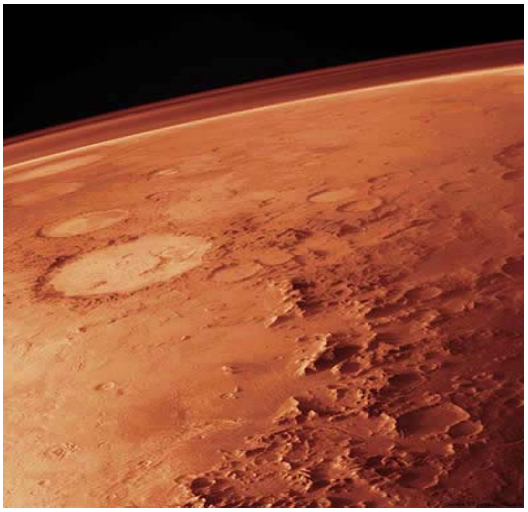
Figure 2.1 the atmosphere of Mars

However, it was discovered in 2003 that methane was also present in the atmosphere. The composition of methane was about 11±4ppb[1] by volume. The possible sources of this unstable gas were comet impacts, volcanic activity and the existence of microorganisms.

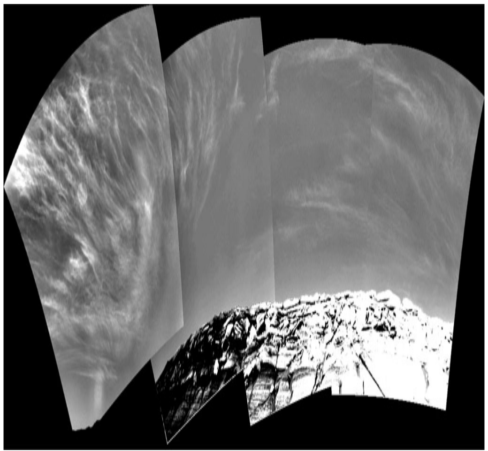
Figure 2.2 Clouds of water-ice

During the winter months, where the poles are in continual darkness, the temperature gets so low that about 25% of the atmosphere snows out into dry ice (solid CO_2) of a few metres thick. During the summer months, when there is sunlight, these dry ice sublimines. This results in strong winds with a high speed of 250 mph[2]. Large quantities of water vapour and dust are transported, giving rise to large cirrus clouds and Earth-like frost.

References: [1-1], [1-2]

Figure 2.1: taken from http://library.thinkquest.org/03oct/01858/aboutmars.html

Figure 2.2: taken from http://en.wikipedia.org/wiki/Mars_(planet)

2.2 Topography

Mars has an interesting topography. The southern part is characterised by highlands cratered and pitted by ancient impacts whereas the northern part consist of plains flattened by lava flows.

There are many mountains on Mars. The highest mountain in the whole solar system, at 27 km, is an extinct shield volcano, named *Mount Olympus. It is* more than twice as high as Earth's Mount Everest and covers an area about the size of Missouri. It is situated in a vast upland region called Tharsis which is 10 km high and 4000 km wide. Some examples of these large volcanoes

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[1] Parts per billion

[2] Meters per hour

include Pavonis Mons, Arsia Mons, and Ascraeus Mons. However, none of the volcanoes are active presently.

Interestingly, the largest canyon system in the whole solar system is also found in Mars. Named *Valles Marineris* or the *Mariner Valley*, it is 4000 km long and 7 km deep. There are also many impact craters on Mars; the largest of them is the *Hellas impact basin*. Some other craters include Agassiz, Calahorra and Halley.

The difference between the top of *Mount Olympus* (highest point on Mars) and the bottom of *Hellas impact basin* (lowest point) is roughly 31 km. This difference is much larger than that of Earth (19.7 km), which means that Mars is about three times “rougher” than Earth.

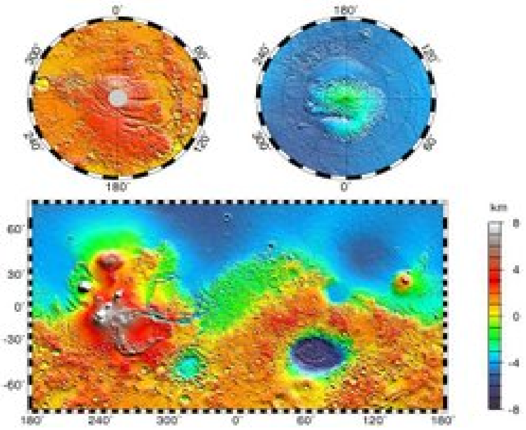

Figure 2.3 Mars Topographic map

This photo is taken by NASA/JPL-Caltech. Notable features include the Tharsis volcanoes in the west, including *Mount Olympus*, *Valles Marineris* in the East of Tharsis and *Hellas impact basin* in the Southern hemisphere.

References: [1-1], [1-2]

Figure 2.3: taken from http://en.wikipedia.org/wiki/Mars_(planet)

2.3 Areology

It has been observed by the Mars Global Surveyor spacecraft that part of the Martian crust has been magnetised in alternating bands, about 160 km wide by 1000 km long, which is similar to those bands found on the Earth's ocean floor. It is hypothesized that these bands could provide evidence that there were plate tectonics on Mars. If this is really the case, these plate movements can help to sustain an Earth-like atmosphere by transporting carbon-riched rocks to the surface. The magnetic field can also protect Mars from cosmic radiation.

Figure 2.4 Microscopic rock forms indicating past signs of water

It is discovered that hematites are present on Mars in the form of small spheres with a diameter of a few millimeters. These hematites are believed to require water for their formations. Minerals containing iron, sulphur or bromine were also discovered. Because of all these evidences, many scientists believed that water was present in the past.

Researchers also did experiments on a few meteorites believed to have been originated from Mars. Two of the meteorites seemed to show signs of ancient bacterial activity.They also found features which they believed are caused by the microfossils left by life on Mars. However, this theory has not been confirmed to be true.

References: [1-1], [1-2]

Figure 2.4: taken from http://en.wikipedia.org/wiki/Mars_(planet)

2.4 The interior of Mars

Based on the density of Mars (which is about 30% less than the density of Earth) and its gravitational field, scientists deemed that Mars' interior could consist of crust, mantle and core, just like Earth's interior. They suggested that Mars' mantle and core contribute a smaller fraction of its volume as compared to that of Earth. Martian core is believed to be made up of mainly iron, with traces if nickel and maybe even sulphur.

References: [1-2]

Chapter 3: How would life be on Mars?

3.1 The two moons

There are two moons on Mars – Phobos and Deimos. Both are relatively small and have an odd shape. Both always point the same face towards Mars. The table 3.1 below shows some of the properties of the two Martian moons.

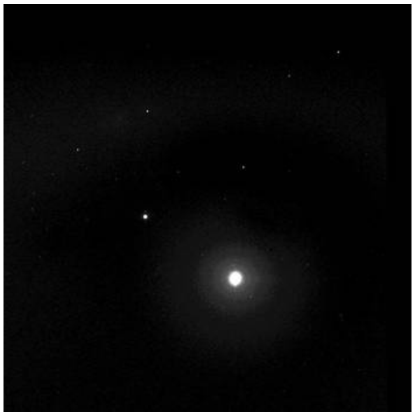

Figure 3.1 The 2 moons as seen from Mars

Mars' Moon				
Name	Diameter (km)	Mass (kg)	Mean orbital radius (km)	Orbital period
Phobos	22.2 (27 × 21.6 × 18.8)	1.08×10^{16}	9378	7.66 hours
Deimos	12.6 (10 × 12 × 16)	2×10^{15}	23,400	30.35 hours

Table 3.1 Properties of Mars’ moon

3.1.1 Phobos

Phobos, named after the son of Ares (Mars) from the Greek Mythology, is the larger and innermost of Mars' two moons. Its orbit is less than 6000 km above the Mars' surface. Phobos was discovered by an American astronomer Asaph Hall in the year 1877. He also discovered Deimos.

It is predicted that Phobos is composed of the C-type surface materials.[3] It's relatively low density suggests that it is not a pure rock. It probably consists of a mixture of ice and rock. One Soviet astronomer suggested that it might be hollow since it has a low density. The images obtained from Mars Global surveyor indicate that Phobos might be covered with a layer of fine dust, similar to the regololith on the Earth's moon.

Figure 3.2 the actual telescope used to discover Phobos

Phobos has a shape intermediate between an oblate and prolate spheroid. It is non-spherical, with dmensions of 27 × 21.6 × 18.8 km. Moreover, it is cratered. The most prominent one is the large Phobian crater called *Stickney*. The impact that resulted in the formation of Stickney, and probably the grooves and streaks on Phobos' surface, must have almost shattered Phobos.

Figure 3.3 A montage of three separate images taken by Viking 1 on October 19, 1978. The large on the upper left of the image is Stickney

It is widely believed that Phobos might be an asteroid captured by Mars gravitational pull. Some speculated that it comes from other solar system instead of the main asteroid belt. On a few

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[3] C-type asteroids are carbonaceous asteroids. They form 75% of known asteroids and are extremely dark.

occasions during the 19th century, astronomers with a more powerful telescope than that of Asaph Hall were unable to detect that Mars had satellites. Thus it is spectulated that both Phobos and Deimos only start to orbit around Mars during the 1870s!

Phobos moves around Mars faster than the rotation of Mars. This is because the orbit of Phobos around Mars is below the synchronous orbit radius.

It appears to rise in the west, took about 4 hour 15 min or less to move across the sky and sets in the east, usually about twice a day (every 11 hr 6 min). Since it is very close to the Martian surface, it cannot be seen above the horizon for latitudes greater than 70.4°.

This low orbit of Phobos also means that it will eventually be destroyed. This is because the tidal forces are lowering its orbit by about 1.8 meters per century. It will take about 50 million years for Phobos to either impact the surface of Mars or break up into a planetary ring.

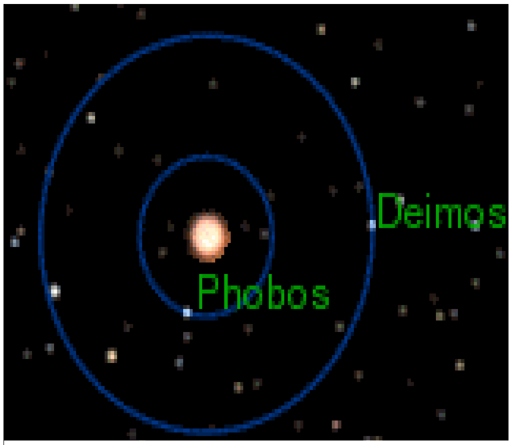

Figure 3.4 Orbits of Phobos and Deimos (to scale), seen from above Mars' South Pole

Modeling Phobos as a Mohr-Coulomb[4] body (a pile of rubble), it is shown that Phobos is stable with respect to the tidal forces. However, when its orbital radius drops to below 8400 km (pass the Roche Limit[5] for rubble pile), it is likely that it will break up.

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[4] **Mohr-Coulomb Theory** is a mathematical model describing the response of rubble piles to the shear forces produced by gravity.

[5] The **Roche limit** is the distance within which a celestial body held together only by its own gravity will disintegrate due to a second celestial body's tidal forces exceeding the first body's gravitational self-attraction.

Phobos' diameter when viewed from Mars' equator = $\frac{1}{3}$ * angular diameter of the full moon as seen from Earth. Due to its closeness to the Martian surface, its apparent size varies by up to 45% as it passed overhead. Thus for an equatorial observer, Phobos will be about 0.14^o upon rising and swell to 0.2^o when it reaches zenith.

The occurrence of eclipses in Mars is much more common then on Earth. It occurs a few times each day whenever Phobos passes over Mars sunlit side.

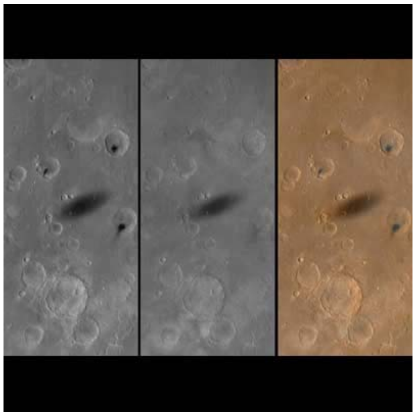


Figure 3.5 Shadow of Phobos

3.1.2 Deimos

Deimos is the smaller and outermost of Mars' two moons. It was also being discovered by Asaph Hall in the year 1877, as mentioned above. It is nonspherical with dimensions of 15×12×10 km.

Deimos is composed of both the carbon-riched rock (similar to the C-type asteroids) and ice. Similar to Phobos, Deimos is also cratered. However, its surface is relatively smoother than Phobos' surface. This is because of the regolith that is partially filling up the craters. *Swift* and *Voltaire*, the two largest craters, is about 3 km apart.

It is believed that Deimos is an asteroid which is perturbed by Jupiter into an orbit where it is captured by Mars. However, there is still some dispute regarding this hypothesis.

The angular diameter of Deimos' is less than 6.35 cm. Thus it appears like a star to the naked eyes. When it is at its brightest ("full moon"), it will correspond to the brightness of Venus as seen from Earth. At its 1st and 3rd phases, it will have similar brightness to Vega as seen from Earth.

Unlike Phobos, Deimos rises in the East and sets in the West. The orbital period of Deimos is about 30.5 hours. This exceeds the solar day of Martian which is about 24.5 hours. Thus it takes about 2.7 days between the rising and setting for an equatorial observer. Deimos' orbit is relatively close to Mars. Thus with this small inclination with respect to Mars' equator, the Deimos cannot be seen from Martian latitudes larger than 82.7^o.

References: [1-1], [1-2], [1-9]
Figure 3.1: taken from http://www.physorg.com/news6550.html
Figure 3.2: taken from http://en.wikipedia.org/wiki/Mars_(planet)
Figure 3.3: taken from http://en.wikipedia.org/wiki/Mars_(planet)
Figure 3.4: taken from http://en.wikipedia.org/wiki/Mars_(planet)
Figure 3.5: taken from http://pds.jpl.nasa.gov/planets/captions/mars/marssp.htm
Table 3.1: taken from http://en.wikipedia.org/wiki/Mars_(planet)

3.1.3. Transits of Phobos and Deimos from Mars

The transits of Phobos are also known as partial eclipses of the Sun because the angular diameter of Phobos is half of that of the Sun. It takes place when Phobos bypass directly between the Sun and a point on the surface of Mars, blocking a bulk portion of the Sun's disc from someone standing on Mars. When the transit takes place, Phobos, as seen on Mars, is a big black disc moving across the façade of the Sun.

The penumbral shadow of Phobos shifts quickly over the surface of Mars. Figure 10 shows Phobos's shadow, indicated by the arrows.

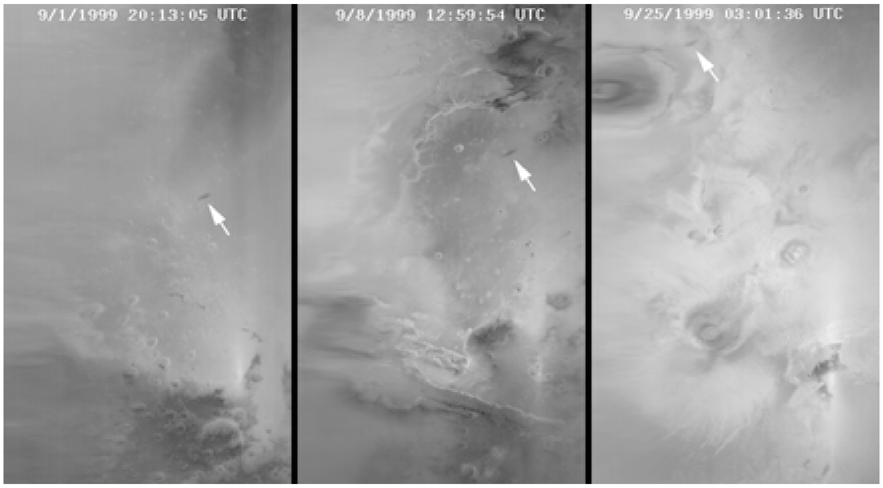


Figure 3.6 Phobo's shadow on three occasions

Phobos has a very short orbital period of 7.6 hours; consequently, a transit of Phobos has duration of about thirty seconds. Deimos has a very short orbital period of 30.3 hours; consequently, a transit of Deimos has duration of about a minute or two.

For Deimons, it would only be right to use "transit" because the angular diameter of Deimos is about 1/10 of the angular diameter of the Sun as observed from Mars.

The transits of Deimos takes place when Deimos bypass directly between the Sun and a point on the Martian surface, blocking a minute portion of the Sun's disc from someone standing on Mars.

When the transit takes place, Deimos, as seen on Mars, is a miniature black disc moving across the façade of the Sun rapidly.

Due to the low-inclination of the equatorial orbits, the shadows of Mars' moons as projected on the Martian surface display a seasonal distinction with latitude. The shadows of Phobos or Deimos will pass through the same Martian latitude during two periods in a Martian year. The situation is similar for Deimos, except that during each period, about six transits of Phobos can be seen from Mars, whereas almost none of Deimos can be seen.

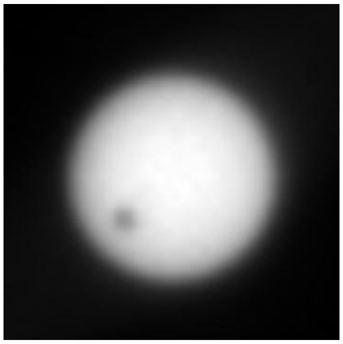


Figure 3.7 Transit of Deimos from Mars

Besides the vernal autumnal equinoxes, the shadow of Phobos always falls in "winter hemisphere". Therefore, the transits of Phobos occur during Martian autumn and winter in the northern hemisphere and the southern hemisphere, approximately symmetrically around the winter solstice. When near the equator, transits occur around the autumnal equinox and the vernal equinox; further from the equator, the transits will be nearer to the winter solstice.

Transits of Phobos and Deimos are on Mars on the majority of the Martian year. Nonetheless, there are some intermissions when the shadow passes north or south of Mars. Since Phobos revolves in close proximity to Mars, and it cannot be seen north of 70.4°N or south of 70.4°S; we would not be able to observe transits at such latitudes. Similarly for Deimos, which cannot be seen north of 82.7°N or south of 82.7°S.

Reference: [1-16], [1-17], [1-18]

Figure 3.6 taken from http://mars.jpl.nasa.gov/mgs/msss/camera/images/11_1_99_phobos/index.html

Figure 3.7 taken from http://hallencyclopedia.com/Astronomical_transit

3.2 Seasons on Mars – Equinoxes and Solstices

Two factors influence the temperature variation of a planet – the distance from the sun and the tilt of the Mars axis. Mars has an axial tilt of 25^{o}. It has the second highest orbital eccentricity. This results in the sun - Mars distance that varies from 1.36 to 1.64 AU over a year. These two factors give rise to seasons in Mars.

The temperature is influenced by the amount of sunlight falling on that location. Due to the axial tilt, the angle at which the sunlight falls on a point changes throughout the year.

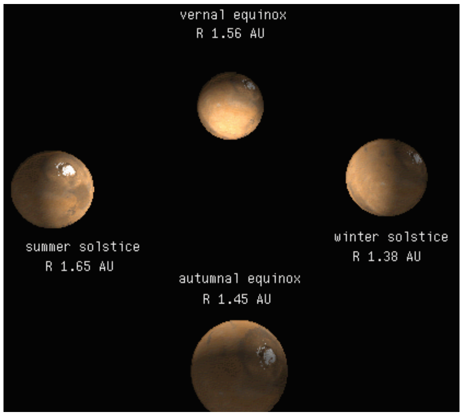


Figure 3.8 Planetary positions of Mars for each season

The top image shows the start of spring in the Northern hemisphere – Vernal equinox. During this period, the sun falls directly at the equator.
The left image shows the summer solstice, where the North Pole experience mid-night sun (have sunlight during the entire day). The bottom shows the autumnal equinox where the sun falls directly at the equator.

The right image shows the winter solstice, where there is no sunlight (total darkness) during the entire day. The above description is for the Northern hemisphere. The opposite will happen in the Southern hemisphere. The mean repetition intervals for the vernal equinox, summer solstice, autumnal equinox, and winter solstice are 668.5906 sol, 668.5880 sol, 668.5940 sol, and 668.5958 sol, respectively.

During the winter solstice, when there is total darkness, the CO_2 deposits out as dry ice, resulting in a 25% decrease in the global atmospheric pressure. This atmospheric pressure is controlled by a complex balance between the warm and cold poles. This means that when the North Pole is in total darkness, the South Pole is having midnight sun, so it is expected that the pressure will remain almost constant throughout the year. However the high orbital eccentricity of Martian orbit causes the solar input to be significantly different when one pole is in sunlight than when the other pole is in sunlight.

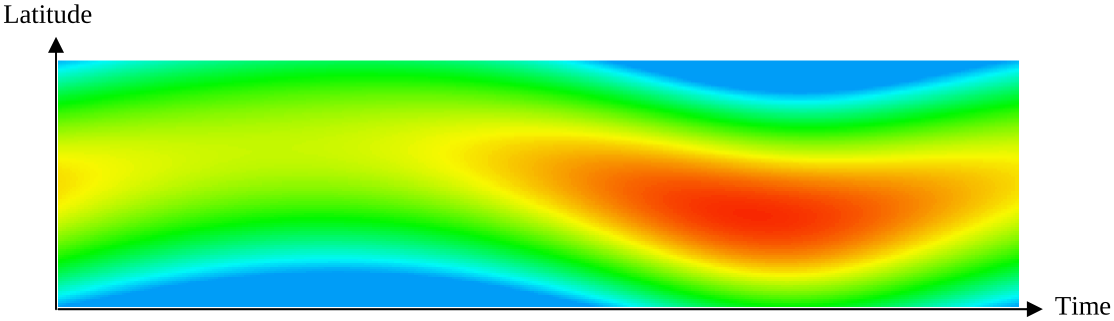


Figure 3.9 solar input graph

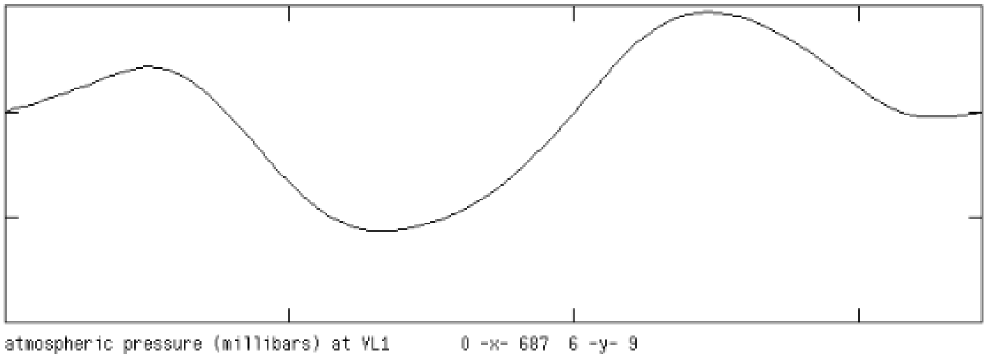


Figure 3.10 the variation of atmospheric pressure

The northern spring is at the start of the time axis, while the South Pole is at the bottom of the vertical axis. The blue colour in the graph indicates the least solar input while the red indicate the most solar input. Thus from the graph, we can observed that summer in the Northern hemisphere is much cooler than the summer in the Southern hemisphere. This is due to the fact that Mars is closer to the sun in the Southern hemisphere. In general, winters in the northern hemisphere are warm and short because Mars is at perihelion, thus it is moving relatively faster. Winters in the southern hemisphere are long and short because Mars is at aphelion, thus it is moving slower. Due to the same reason, summers in northern hemisphere are long and cool, while summers in the southern hemisphere are shorter and hotter. Therefore, the difference in temperature is wider in the south.

References: [1-1], [1-7], [1-14]

Figure 3.8: taken from http://www.msss.com/http/ps/seasons/seasons.html

Figure 3.9: taken from http://www.msss.com/http/ps/seasons/seasons.html

Figure 3.10: taken from http://www.msss.com/http/ps/seasons/seasons.html

3.3 Dust storms

During the spring and summer where it is warmer, the poles are exposed to sunlight causing the dry ice to melt. This in turn, creates an enomous wind that has a speed as large as 250 mph. These winds transport huge amout of dust and water vapour, giving rise to dust storm.

Figure 3.11 Dust devil on Mars, photographed by the Mars rover Spirit

The largest storms can last for several months and cover the entire Mars. One of them occurred in 2001. However, smaller regional dust storms can occur at any time during the Martian year.

References: [1-1], [1-2]

Figure 3.11: taken from http://en.wikipedia.org/wiki/Mars_(planet)

3.4 Sun as seen from Mars

Similar to Earth, Mars orbit around the sun in a counterclockwise direction as seen from the Northern hemisphere. The orbit is approximately circular. It has a radius of about 1.5 AU. The maximum angular distance of the ecliptic from the celestial equator is 25^o.

There is also the occurrence of midnight sun in Mars. This is due to the tilt of the Mars axis. Since the tilt of Mars axis is about 25^o, we expect that areas of latitude above 25^o north and south will have midnight sun for certain period of the year.

References: [1-1], [1-15]

3.5 The colour of the sky

Figure 3.12 Mars's sky turned violet by water ice clouds

Figure 3.13 Close-up of Mars skies at sunset, showing more colour variation

Figure 3.14 Mars sky at sunset, as imaged by Mars Pathfinder

Figure 3.15 Mars sky at local noon, as imaged by Mars Pathfinder

As seen from the Figure 15, the Martian sky is pinkish in colour, while in the vicinity of the sun, the sky is blue. From figure 17, it is seen that the colour of the sky during the mid-day is yellowish brown. It is believed that the colour of the sky is caused by the presence of trace amount of magnetite in the dust particles. At other times, the colour of the sky can be violet, which is caused by the scattering of light by small water ice particles in the clouds. The dust particles in the atmosphere cause twilight to last a long time before the rising of the sun and after the setting of the sun.

References: [1-14]

Figure 3.12 to 15: taken from http://en.wikipedia.org/wiki/Astronomy_on_Mars

Chapter 4   Definition of Time System

4.1 Introduction

The Earth revolves around the Sun and rotates on its axis. How long does it the Earth to complete the above tasks? Since the question involves the concept of “how long”, we use time as a ‘tool’ in order to quantify the answer.

For centuries, philosophers and scientists have been trying to give clear definitions of time. As a tool for astronomical studies, we would only define time in a physical sense. This guides to the definition of time of “which quantifies or measures the interval or duration between events” or “A number, as of years, days, or minutes, representing such an interval”. Such physical quantification of time leads us further into defining the concept of year, day, and minutes etc from an astronomical point of view.

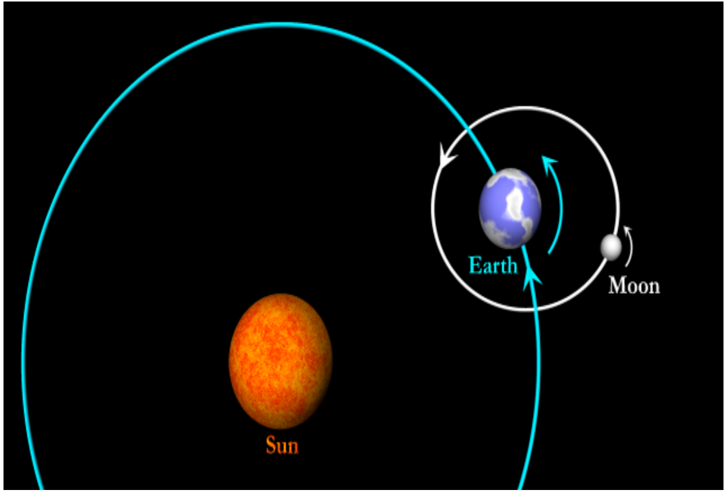


Figure 4.1 Movement of the Sun, Moon and Earth

We require a system to keep track of time. Hence the need for calendars arises. There is a list of calendars which are in current use, was used in the past or proposed for future usage. For instance, calendars which are still in use in today’s society are the Gregorian calendar, Chinese calendar, Islamic calendar, Hindu calendar. The most commonly used is the Gregorian calendar.

References: [4-1], [4-2]

Figure 4.1: taken from http://www.hermit.org/Eclipse/why_solsys.html

4.2 Year

A year is the time between a repetitions of an occasion associated to the path of the Earth around the Sun. Similarly, this can be functional to any planet: for example, "Martian year". For astronomical years, there are two ways to quantify the astronomical year, namely, tropical year and sidereal year.

A tropical year (also known as seasonal year) is the time the Earth takes to complete one revolution from one equinox to the next. This is the traditional definition. A modern definition would be the time it takes for the Sun's mean longitude to increase by 360°. Depending on the reference point chosen, the precise length of a tropical year will vary. Usually, the March equinox is use as a reference point. In this case, such tropical year is named as vernal equinox year.

The mean tropical year (averaged over all ecliptic points) is 365.24218967 days (365d 5h 48m 45s). It has been observed that the Sun "moves" from south to north and back, hence giving rise to the name "tropical year". The word, tropic originates from Greek: *tropos,* which means "turn".

On the other hand, a sidereal year is actual time the Earth takes to revolve round the Sun and go back to the same position relative to the stars. The sidereal year is about 365.2564days (365d6h9m10s).

The pull of the Sun and the moon on the Earth causes the Earth's axis to rotate clockwise gradually over a period of about 25 800 years. As a result, the position of the March equinox moves backwards along the ecliptic. Such a phenomenon is known as precession. Consequently, the Earth will complete a tropical year earlier than a sidereal year since the equinox will arrive earlier. The tropical year is 20mins shorter than the sidereal year.

A calendar year is defined as the time between two dates with the same name in the calendar. Generally, a calendar year is the period between the New Year's Day to the day before the following New Year's Day.

The seasons are commonly associated with the seasonal markers, i.e. the equinoxes and solstices. Hence, most calendars designed their calendar year as an approximation of the tropical year. An example of such is the Gregorian calendar, which is a solar calendar.

A solar calendar uses days to approximate the tropical year. An example is the Gregorian calendar. The number of days or months in an astronomical year does not have an integer number of days or months. Therefore, in order to predict an astronomical year as accurately as possible, calendars usually have a system of intercalation. That is, the addition of an extra day (or month). For the Gregorian calendar, the leap year is intercalated, i.e. an extra day is added to February, making it to 29 years, every 4 years. Calendar years have 365 days, whereas leap years have 366 days. Leap years are divisible by 4 but not by 100. Alternatively, they are divisible by 400. For e.g., year 2000 is a leap year, whereas year 1900 isn't. Each cycle of the Gregorian calendar is 400 years, the average year is 365.2425. The present value of the tropical year is 27 seconds shorter than the average Gregorian year. There are a variety of approximations as to when the above will accumulate to a day. However, as the tropical year gets shorter, it would not be possible to forecast how the inaccuracy will accumulate. Some suggested changing the rules to stating that years divisible by 4000 are not leap years.

References: [4-3], [4-4], [4-5], [4-6], [4-7], [4-8], [4-9]

4.3 Months

The month is a unit of time used in calendars, of which, the moon is used as a convenient time keeper.

The sidereal month is the actual time period of the moon’s one complete orbit around the earth. The length of one sidereal month is approximately 27d7h43m11.5s (27.3217 days).

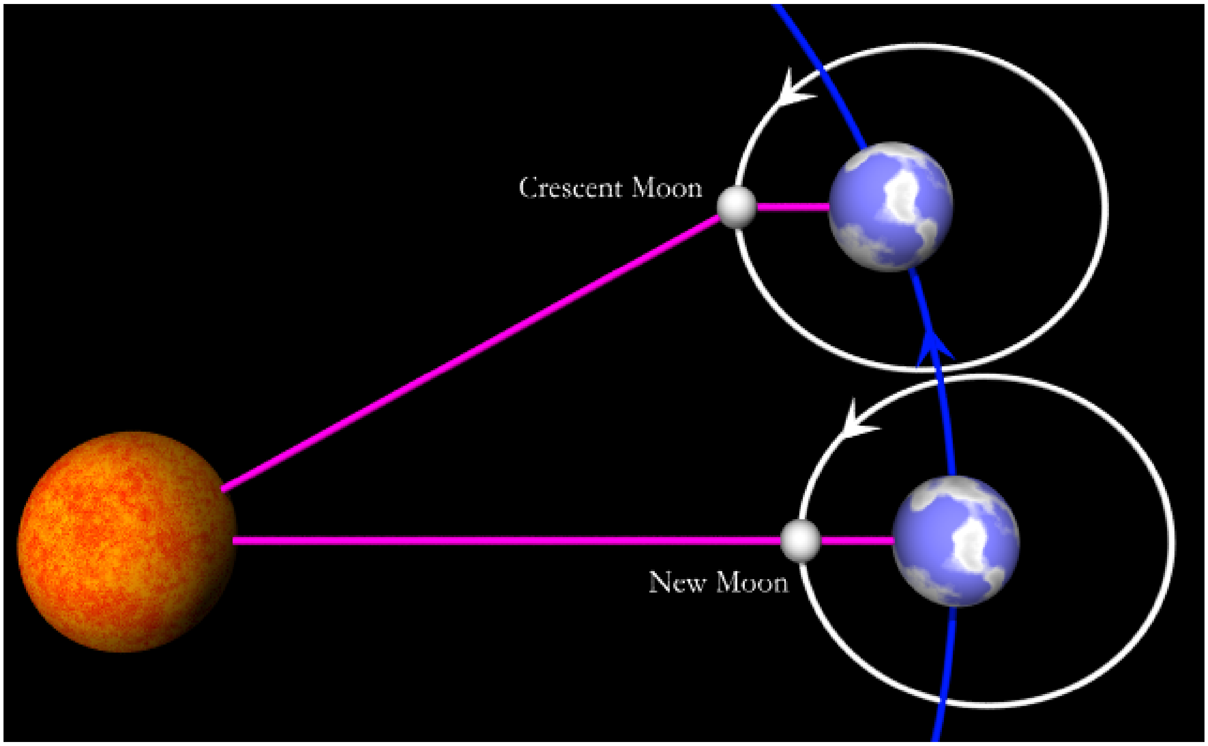


Figure 4.2 illustrating sidereal month

The earth-moon system has revolved 27° around the Sun. The moon has not completed a once full revolution.

The period between two successive new moons (as illustrated by Figure 4.3) is the synodic month. The average length of the synodic month is 29d12h44m2.8s (29.5306 days). Since the orbits of the earth and moon are slightly parabolic, they do not have a constant speed. Thus, the synodic month may be between about 29.27 to about 29.83 days.

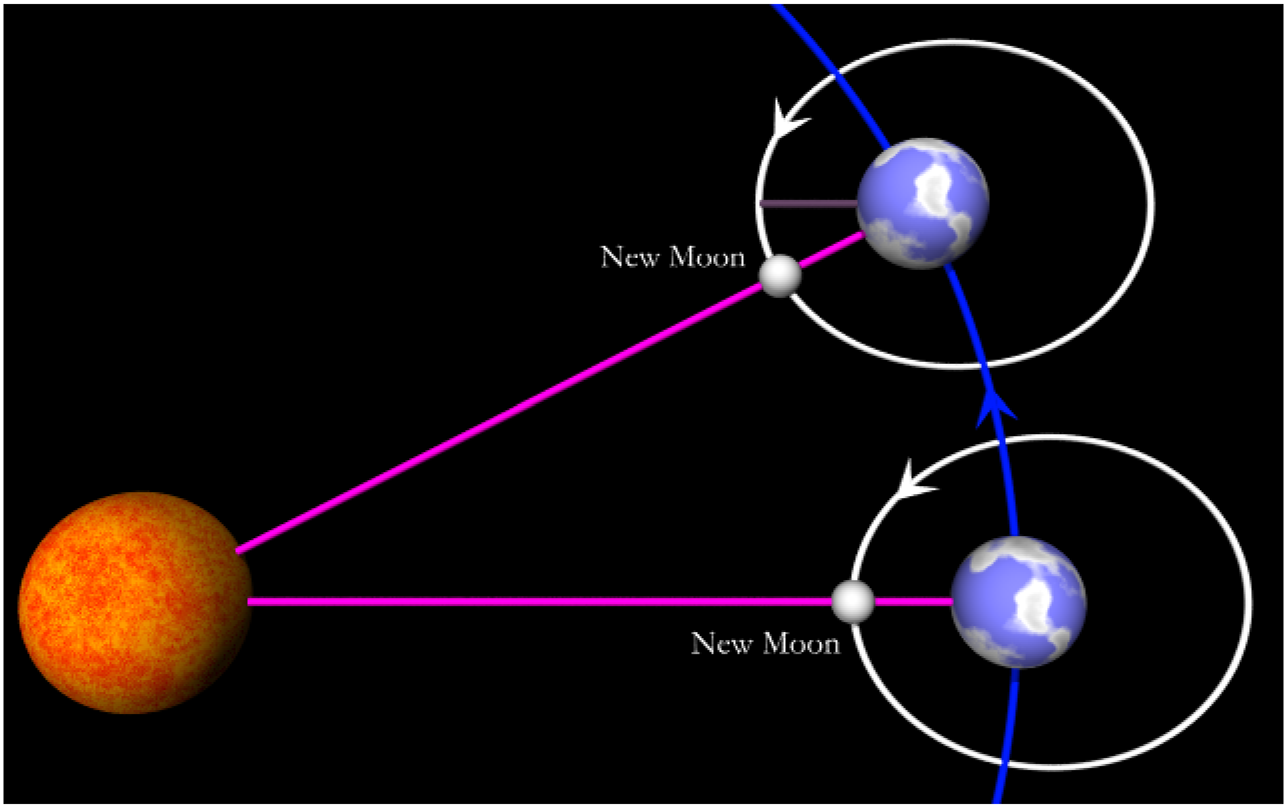


Figure 4.3 illustrating synodic month

In line with the concept of the tropical year, is the tropical month. Due to the wobbling of the earth's axis, precession, and hence the backwards shift of the equinox along the ecliptic, the moon would take less time to return to the same equinox. The length of a tropical month is 27.321582 days ($27^{d}7^{h}43^{m}4.7^{s}$).

References: [4-6], [4-10], [4-11]

Figure 4.2 & 4.3: taken from

http://66.102.7.104/search?q=cache:SkPPXZ4E74oJ:www.hermit.org/Eclipse/why_months.html+&hl=en

4.4 Days

A day may consist of numerous units of time. A day may refer to the period of sunlight, such that the Sun is above the horizon; or it may refer to one complete length of time, darkness and daylight.

The mean solar day is the time between two successive noons. The length of the mean solar day is a 24 hours, although, the amount of daylight varies throughout the year at different latitudes.

The actual solar day varies because the Earth’s path around the Sun is an ellipse (Kepler’s first law: *The orbit of a planet about a star is an ellipse with the star at one focus)* According to Kepler’s second law, *a line joining a planet and its star sweeps out equal areas during equal intervals of time.* The motion of the Earth is thus the fastest at perihelion (point closest to the Sun) and slowest at aphelion (furthest away from Sun).

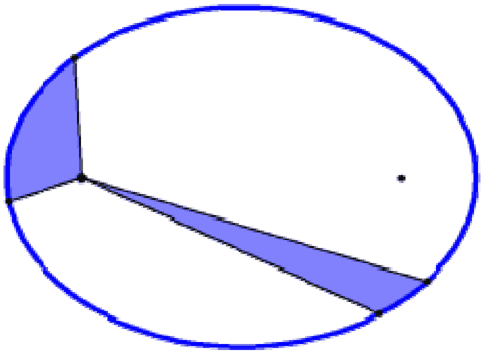


Figure 4.4 Kepler's second law of planetary motion aka law of equal areas.

Another effect for the variation in the length of the solar day is that the ecliptic is tilted with respect to the celestial equator. Thus the apparent motion of the Sun moves eastwards faster than during other times. Combination of the above two effects results in the differences between the actual and mean solar day and is related to the equation of time.

The sidereal day is the time taken for the Earth to complete one true rotation. It has a length of 23 hours 56 minutes on each day of the year. This remains unchanged. The mean solar day is thus 4 minutes longer than the sidereal day.

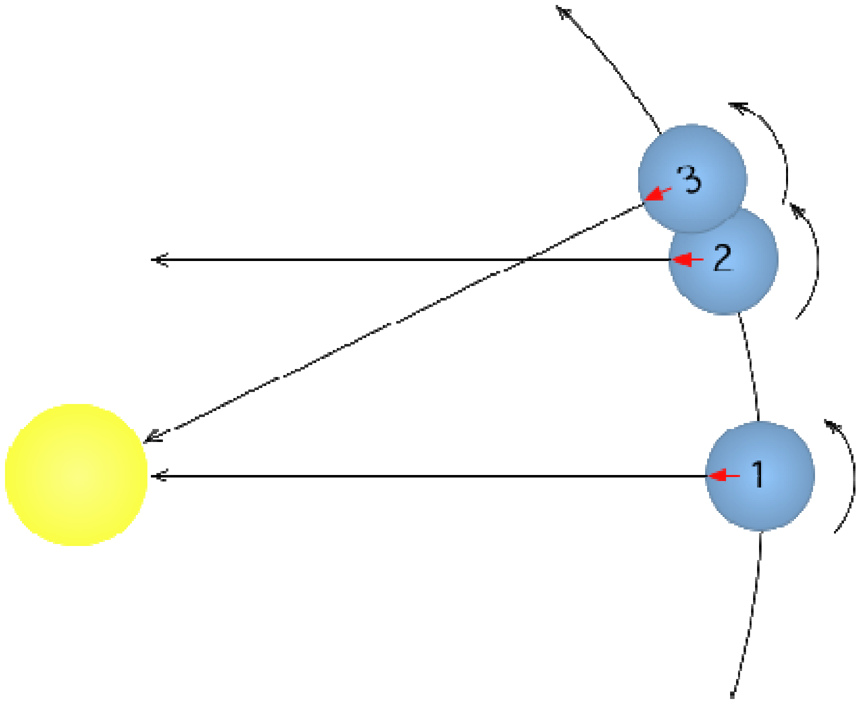


Figure 4.5 Sidereal day compared to solar day

From Figure 4.5, the sidereal day is shorter than the solar day. The Sun is right overhead at position 1. When the earth reaches position 2, it has rotated 360°. One sidereal day is from position 1 to 2.However, for the Sun to be overhead once again, the earth has to rotate slightly more to position 3. One solar day is from position 1 to 3.

Reference: [4-5], [4-6], [4-11], [4-12], [4-13]

Figure 4.4: taken from http://en.wikipedia.org/wiki/Image:Kepler-second-law.png

Figure 4.5: taken from http://en.wikipedia.org/wiki/Image:Sidereal_day_%28prograde%29.png

4.5 Weeks

A week is a unit of time; its length is between that of a day and a month. Weeks has no astronomical basis even though it is commonly used as a unit of time. By convention, there are seven days in a week. This approach is adopted by modern calendars like the Gregorian calendar. There are several possible origins of a seven day week. E.g. Biblical creation, the ancient Babylonians, Hindu civilization, etc.

If we follow the Gregorian calendar,
1 week = 7days
1 week = 7 days × 24 hrs /day
= 168 hrs
= 10080 mins
= 604,800 seconds

1 year = 52 weeks + 1 day = 365 days for a common year
1 year = 52 weeks + 2 days = 366 days for a leap year

Over a cycle of 400 years, a mean Gregorian year will have 365.2425 days, thus,
Number of weeks = 365.2425 days / 7 days per week
= 52.1775 weeks

4.6 Hours, Minutes and Seconds

Hours, minutes and seconds are all units of time. 1 h = 60mins = 3600 s. Seconds is used as an SI unit. One degree is divided into 60 minutes (minute of arc) and one minute is further divided into 60 seconds (minute of arc).

Leap seconds are introduced to adjust universal time coordinated (UTC) so that the time calculated by atomic clocks can match that of the Earth’s rotation. Such a measure is needed because the speed of the Earth’s rotation changes slightly.

Reference: [4-15], [4-17]

4.7 The Gregorian calendar

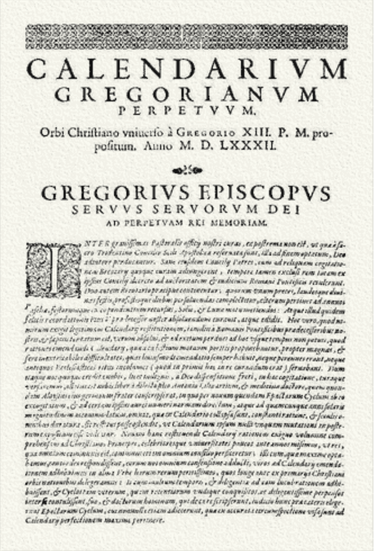
Years, months and days are the basic structure towards designing a calendar. However, none is a multiple integral of the other two. This results in the formation of various calendars in many different civilizations over centuries.

	Arithmetical	**Astronomical**
Solar	Gregorian	French Revolutionary
Lunisolar	Jewish	Chinese
Lunar	Civil Muslim	Religious Muslim

Table 4.1 Classifications of some calendars

A solar calendar uses days to approximate a tropical year and arithmetical calendars uses arithmetical rules and formulae as a basis of formation. The Gregorian calendar is both a solar calendar as well as an arithmetical calendar.

The Gregorian calendar is one of the widely used calendars in the world today. It is sometimes referred to as the "Christian calendar". It was proposed by Aloysius Lilius, a physician from Naples. Pope Gregory XIII convened a commission to consider reform of the calendar.The Gregorian calendar was introduced because the old Julian calendar approximated the tropical year to be slightly longer, causing the swift of the vernal equinox to an earlier date. It was declared by Pope Gregory XIII in a papal bull in February 1582 (Figure 4.6). [4-14] The modern Gregorian calendar is agreed on by scientists and not by religious authorities.



CALENDARIVM
GREGORIANVM
PERPETVVM.
Orbi Christiano vniuerso à GREGORIO XIII. P. M. propositum. Anno M. D. LXXXII.

GREGORIVS EPISCOPVS
SERVVS SERVORVM DEI
AD PERPETVAM REI MEMORIAM.

Figure 4.6 Inter Gravissimas

A common year consists of 365 days and a leap year consists of 366 days. February 29 is introduced as an intercalary day. Previously mentioned in section 4.2, Leap years are divisible by 4 but not by 100. Alternatively, they are divisible by 400.

There are 12 months in the Gregorian calendar, count of days start on the beginning of each month. The sequence of the months and number of days were adopted from the Julian calendar.

No.	**Month**	**No. of Days**	**No.**	**Month**	**No. of Days**
1	January	31	7	July	31
2	February	28 (29 on a leap year)	8	August	31
3	March	31	9	September	30
4	April	30	10	October	31
5	May	31	11	November	30
6	June	30	12	December	31

Table 4.2 Months of the Gregorian calendar

The Gregorian calendar is based on a 400 year cycle which consists of
400 x 365 + 97* = 146 097 days.
* Note: 97 leap years in every 400 years.

The average length of one Gregorian calendar year
= 146 097 days / 400
= 365.2425 days per calendar year

Compare the above with the mean tropical year of 365.24218967 days; it is a rather close approximation. However, there is still a slight error which will accumulate in the course of 2500 years. There are various suggestions to rectify this error through the system of leap year, but none has been implemented.

As the Gregorian calendar is meant to be an approximation of the tropical year, equinoxes and solstices will stay almost constant. Since a common year consists of 365 days while a tropical year has 365.24218967 days, we examine the March equinox and find that it will move 0.25 days forward in the Gregorian calendar for 3 consecutive years. By the time of the leap year (4th year), the March equinox can then be even out and thus adjusted back by one day in the calendar. This results in the equinox performing a “4 step dance”, 3 backwards steps and one forward step. The old Julian calendar will keep such a rhythm whereas the Gregorian calendar misses a beat three times every 400 years.

Some claim the Ecclesiastical Rules for computing Easter, however, Gregorian calendar is mainly used for civil use. In fact, many Eastern Europe countries use the Eastern Orthodox rules for computing Easter.

Reference: [4-14], [4-15], [4-16]

Figure 4.6 taken from http://webexhibits.org/calendars/year-definitions.html

Table 4.1 taken from http://www.math.nus.edu.sg/aslaksen/teaching/heavenly.html#Lectures

Chapter 5: Martian Calendar

5.1. Introduction

"What day is it? Do days exist without calendars? Does time pass when there are no human hands left to wind the clocks?" -- Howard Koch, *Invasion from Mars,* the 1938 radio play based on H. G. Wells' *The War of the Worlds*

The questions raised by Howard Koch may seem trivial. Who cares about time when there is no human in the first place? In fact, they project deeper philosophical significance. Had we one day manage to settle in other extraterrestrial planets in the cosmos, a time keeping system will be indispensable for human in that planet.

Human has been accustomed to time keeping system of day, month and year. These concepts hinges upon the natural rhythmic of Earth's interaction with the Sun, Moon or both. Essentially concept of time was developed through our civilization to enable convenient tracking of our position in the cycle of Earth-Sun-Moon interaction. This prompts us to attempt to extend our civil time on Earth to Mars, the planet with highest possibility for human inhabitancy. This seemingly simple idea may have belied the difficulty of its implementation. This is because Mars has its own distinct natural cycles, and the impact of these cycles on human activities cannot be simply neglected. Daily routine will be synchronized with the Martian day, not the Earth day. Similarly, it is the annual passing of Mars along the orbit, not that of Earth, that marks its seasons. Therefore, while basic principles on how terrestrial time was defined can be extended, Mars will need its own time and calendar.

5.2. Defining the Martian Day

5.2.1 Solar day

A solar day on Earth, as described in earlier chapter, is the length of time between two successive noons. It is equivalent to the beautiful number of 24 hours that we are accustomed to.

Therefore, applying similar understanding, a Martian solar day will be the length of time between two successive noons in Mars. This period is equivalent to 24h 39m 35.244s on Earth. This means that if we bring a watch to Mars and track the period from one noon (Sun at its highest point as seen from Mars) to the next similar occurrence, it will be longer than 24 hours on Earth. For example, if Sun is spotted at its highest point from Mars at 12.00PM Earth time (the time our watch shows), the next time we will observe Sun at its highest point would be 12:39:35.244PM as shown by our watch.

To avoid confusion of Martian solar day with Earth solar day, a Martian solar day has been coined “sol”. The word “yestersol” was then used by NASA to refer to the previous sol (the Mars version of "yesterday") and came into fairly wide use within that organization during the Mars Exploration Rover Mission of 2003.

Simple mathematics can be done to find the equivalence of sol to Earth solar day.

1 solar day on Earth = 24 h

1 sol on Mars = 24 h 39 m 35.244 s

Therefore,

$$1 \text{ sol on Mars} = \frac{24 + (39/60) + (35.244/3600)hrs}{24hrs} = 1.02749125 \text{ Earth solar days}$$

5.2.2 Sidereal day

A sidereal day on Earth is defined as the length of time for Earth to complete one true rotation of 360 degrees. Again, similarly, a Martian sidereal day would be the period of time for Mars to rotate 360 degrees.

One sidereal day on Earth is slightly shorter than solar day (24h), and is equivalent to 23h 56m. One sidereal day on Mars is equivalent to 24h 37m 22.663s. With the same reasoning as that of Earth, Mars sidereal day is shorter that its solar day (24h 39m 35.244s).

To find the equivalence of Mars sidereal day to Earth sidereal and solar day:
1 solar day on Earth = 24 h
1 sidereal day on Earth = 23h 56m
1 sidereal day on Mars = 24h 37m 22.663s

Hence,

$$1 \text{ sidereal day on Mars} = \frac{24 + (37/60) + (22.663/3600)}{24} = 1.02595675 \text{ Earth solar days}$$

Alternatively,

$$1 \text{ sidereal day on Mars} = \frac{24 + (37/60) + (22.663/3600)}{23 + (56/60)} = 1.0288 \text{ Earth sidereal days.}$$

(long decimals are kept to preserve precision in subsequent calculations)

5.3 Defining Martian Time

To ease communication and reference of shorter period of time, human has created time system of hour, minute and second. 1 solar day on Earth is divided into 24 hours, each hour consists of 60 minutes, and each minute further divided into 60 seconds.

Therefore, the same can be applied to Mars, but the basic unit for division must be sol.
Hence,
1 sol on Mars is divided into 24 Martian hours,
each Martian hour consists of 60 Martian minutes, and
each minute further divided into 60 Martian seconds.
To avoid confusion, different terms can be used to denote Martian hour, minute and second, just as sol depicts Martian solar day.

To find the equivalence of Martian time to Earth time
1 solar day on Earth = 24 h
1 sol on Mars = 24 h 39 m 35.244 s

Therefore,

1 Martian hour $= \dfrac{24+(39/60)+(35.244/3600)hrs}{24hrs}$ = 1.02749125 hours

1 Martian minute = $\dfrac{1.02749125\times 60\min}{60}$ = 1.02749125 minutes

1 Martian second = $\dfrac{1.02749125\times 60s}{60}$ = 1.02749125 seconds

Note that all the ratio is same as that of sol-to-days. The reasoning is simple. The basic unit of division is sol, therefore, all subsequent division of similar pattern will churn the same ratio. Had one sol not equals to 24 Martian hours, or one Martian hour not equal to 60 Martian minutes, or one Martian minute not equal to 60 Martian seconds, one or all of the ratio will be different.

5.4. Defining the Martina Year

5.4.1 Tropical year

A tropical year on Earth is the period of time from one season and back to the same season.
Mean tropical year on Earth is 365.2422 solar days.

Tropical year on Mars should also be defined in the same way.
It has been found out that on Mars
1 Martian tropical year is equivalent to 686.9725 Earth solar days.
This means that 1 Martian tropical year = $\frac{686.9725}{365.2422}$ = 1.88 Earth tropical year
Martian tropical year is almost twice as long as Earth tropical year!

To find Martian tropical year in terms of sols
1 Martian tropical year = 686.9725 Earth solar days
1 sol on Mars = 1.02749125 Earth solar days

Therefore,
1 Martian tropical year = $\frac{686.9725 days}{1.02749125 days}$ = 668.5921 sols

In fact, the break down of tropical year from season to season is as follows:
The northward (vernal) equinox year = 668.5907 sols
The northern (summer) solstice year = 668.5880 sols
The southward (autumnal) equinox year = 668.5940 sols
The southern (winter) solstice year = 668.5958 sols.
Averaging out over an entire orbital period gives a Martian tropical year of 668.5921 sols

5.4.2 Sidereal year

A sidereal year is actual time the Earth takes to revolve round the Sun and go back to the same position relative to the stars. For earth, one sidereal day is 365.2564 solar days. This is slightly longer that tropical year of 365.2424 solar days.

Following the same definition, one sidereal year of Mars is the time it takes to make 360 degrees of revolution around the Sun. It has been found out that on Mars
1 Martian sidereal year = 686.9797 Earth solar days
Note that for the same reasoning as Earth, Martian sidereal year is slightly longer that its tropical year of 686.9725 Earth solar days.

Converting Martian sidereal year in terms of sols

$$1 \text{ Martian sidereal year} = \frac{686.9797 days}{1.02749125 days} = 668.5991 \text{ sols}$$

5.5. Construction of Martian Calendar

Ideas to construct Martian calendar is no longer new. Tonnes of model have been proposed to serve as Martian calendar. The underlying difference is due to different division used to partition one Martian tropical year. The number of months, number of sols per month, number of sols per week, frequency of leap years and number of leap sols are all the degree of freedom of the calendar “creator”. Agreement has yet to be reached as of which version should serve as the standard. Each version has its own pros and cons and will be presented in the next chapter. In this section, we will attempt to construct a Martian calendar, along the way demonstrating and explaining the principles in the calendar construction.

It should be mentioned that the calendar to be constructed is not the original idea of the team. Instead it is an assimilation of different versions, presented to provide easy understanding on how a Martian calendar can be constructed. Nevertheless, care has been exercised to absorb ideas that to the opinion of the team make sense, reasonable and easy to follow. This understanding will then be extrapolated to examine various versions of Martian calendars and analyze their justifications. By no intention the team seek to advocate a particular version of Martian calendar. The major objective is to render demonstration and understanding of key areas to be considered in the construction.

While the construction of Martian calendar may seem a daunting task beyond our capability to most of us, it is in fact not. Knowledge we know about the Earth Gregorian calendar (most commonly adopted) can conveniently be applied to construct a Martian calendar. The construction will also demonstrate the greater philosophical idea of applying what we know to the unknown.

5.5.1. The month

5.5.1.1 Number of months per year

From above discussion, we know that

1 Martian tropical year = 668.5921 sols

Our calendar will be based on Martian tropical year, similar to Gregorian calendar which tracks Earth tropical year.

In Gregorian calendar, each common year is 365. Leap year occurs once every four years, except for century years non-divisible by 400. This is to take into account the mean tropical year of 365.2424. Therefore, for Martian calendar, we can take the one non-leap or common Martian year to be 668 or 669 sols, and the remaining discrepancy to be accounted through leap year. This will be addressed later in subsequent section.

Here, we would pick one common year of Martian calendar to be 668 sols. This is because we are accustomed to "adding days in leap years". So, in order to preserve the similar trend, 668 sols for non-leap year is reasonable. Loosely, it can be understood as follow: the "shortage" of taking 668 instead of 668.5921 (668-668.5921 = -0.5921sols/Martian year) will be added back in leap years. Had we chosen 669 sols, we will have "excess" of 669-668.5921 = 0.4079 sols/Martian year. This "excess" will then have to be subtracted in leap years.

Defining the number of months is a trickier question. Basically, we seek to address: How should we partition the 668 sols? Various versions of Martian calendar diverge in this aspect, and will be presented in more detail under comparison in the next chapter.

Dr. Robert Zubrin, the president of The Mars Society (an international organisation advocating a manned Mars mission as a goal), presented his version of Martian calendar with 12 Martian months. This is reasonable as it relates closely to the Gregorian calendar which also has 12 months per year. For discussion and demonstartion sake, we shall use this as our basis.

5.5.1.2 Names of months

Now we have defined how many Martian months in a Martian year. Next is the naming the twelve months. Of course, we would not want the Martian months to be termed the same as Gregorian months as this will be very confusing. For example, if we study “abroad” in Mars and we tell our parents that we will be returning to home on Earth in January, the immediate response of our parents will definitely be: Do you mean January on Earth or January on Mars? Naming the months as Martian January, Martian February.. Martian December is not fancy either, not to mention that it is troublesome and somewhat confusing.

Since there is no generally accepted standard, the naming is basically arbitrary and the creator can essentially name the month to his or her own likings. However, by doing this, name of the months will lose its significance. One way of resolving this is to use the name of the constellations of zodiac. This makes very good sense as the signs of zodiac not only bear physical significance to our solar system, they have long and profound history in human civilizaiton.

Therefore, the name of the months will consist of Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius and Pisces.

Next is the orientation for such a naming. Should the naming be done according to areocentric (planet-centered) point of view or heliocentric (sun-centered) point of view? Ancient astrologers, having a geocentric (Earth-centered) point of view, named the months for whatever zodiacal constellation the Sun appeared to be located in as viewed from Earth. Some versions advocate that a heliocentric point of view may present a more plausible system for interplanetary culture, leading to the naming of Martian month to follow the constellation that Mars can be found in as seen from the Sun.

Here, we would like to choose the areocentric view for Martian months naming to preserve the ancient geocentric view of Earth which in many instances helps in the understanding of cultural astronomy till today. Therefore the naming will follow the constellation the Sun appeared to be located in when viewed from Mars.

5.5.1.3 The starting month

Now we need a starting point for the month. Which point along the orbit of Mars carries more significance over the rest? Definitely it will be the equinoxes and solstices. In fact, it is now customory to define vernal equinox as the start of a year for any planet. Therefore, vernal equinox of Mars should mark the beginning of the month. Currently, vernal equinox of Mars occurs when Mars is at Gemini when viewed from the Sun (heliocentric view). The sun will therefore appear to be located at Sagittarius when viewed from Mars (areocentric view). Therefore Sagittarius would be the first month of the calendar. Naturally, first day of the month Sagittarius will be the vernal equinox.

It should be mentioned that due to precession, location of vernal equinox will shift. This does not mean that we will have to redefine our starting month. Once it has be defined that Sagittarius is the starting month as at the point of calendar creation, the Sun is located in Sagittarius at vernal equinox, it no longer matter if vernal equinox is no longer at Sagittarius after many years. Sagittarius will always be the first month of the calendar. The origin of such a definition can then be traced back as vernal equinox was “once” at Sagittarius. This is very much similar to the naming of “Tropics of Cancer” and “Tropics of Capricorn”. 2000 years ago, when summer solstice occurs, the Sun can be spotted at Cancer; and during winter solstice, Sun is at Capricornus. It does not matter to us now even if solstices do not happen in Cancer or Carpricornus.

5.5.1.4 Slight modification to naming of month

We forsee one complication of using the zodiac constellations for naming the month. In the month of Sagittarius, the Sun will not be at the zodiac Sagittarius forever.

Recall that the period of time for two successive occurrences of the Sun to be spotted at zodiac Sagittarius is the sidereal year, when Mars has made one full revolution along the orbit. However calendar is based on tropical year. Therefore from year to year as marked from calendar, Sun will appear to shift westward slowly with respect to the stars due to precession.

The length of the precession cycle on Mars is 93,000 Martian years, or 175,000 Earth year. After 46500 Martian years (or 87,500 Earth years), in the month of Sagittarius, Sun will be at Gemini. Now this poses considerable confusion. It is the month of Sagittarius and yet the Sun is close to Gemini. Therefore naming system which is free from the zodiac constellation could be a better option. This may seem insignificant at the moment as precession cycle on Mars is very long. However to the least, using a single name to resemble two meanings may not be so ideal either.

Hence, upon this point, we would like to propose a slight modification to the naming. The naming should preserve the significance of zodiac constellations. On the other hand, it should be differentiated from the zodiac constellations. We would like to put forth an idea of using abbreviation for all the months as
Sag, Cap, Aqua, Pis, Ari, Tau, Gem, Can, Leo, Vir, Lib, Sco.
Therefore, when one says Sagittarius, one really refers to the star Sagittarius; when one says Sag, one will then refer to the month Sag of the Martian calendar.

Does that solve the entire problem? No. What is the remaining problem then?
Leo still contains double meaning as month and constellation. Probably we can change the first letter to other letter. Again, this is pretty arbitrary. Since it is a Mars month, Meo, Aeo, Reo or Seo are the likely names. Out of personal liking, we would pick Reo.

So finally, the names of the months will be
Sag, Cap, Aqua, Pis, Ari, Tau, Gem, Can, Reo, Vir, Lib, Sco

5.5.2. The sols

A little recap of what has been presented thus far.
A Martian year will consist of 12 Martian months
Name of the months would be Sag, Cap, Aqua, Pis, Ari, Tau, Gem, Can, Reo, Vir, Lib, and Sco.
Sag is the first month of the year, and 1 Sag marks the vernal equinox.

Our next task is to determine how many sols in a month and how many sols in a week.

Again, there are different views on the number of sols to put in a month. Essentially after fixing the number of month, we are left with two choices of fixing the sols in a month: equal-angle or equal duration. In an equal-angle month, every month will be of different sols. An equal-arc month essentially tracks equal angular distance travelled along the orbit. Due to the eccentricity of Mars orbit, every month will therefore be of unequal length. In equal-duration month, every month will be equally allotted with same number of sols.

In Gregorian calendar, every month is of equal duration. In fact, due to low eccentricity of the Earth orbit, every month is also of equal angular distance. To a common civilian, which are we more familiar with? Unless one has taken a course on astronomy, we will not realize the fact that each month is of equal angle of Earth orbiting around the sun. However, we will definitely know that each month is of equal duration. Hence, equal-duration month pose a more “user-friendly” option and we shall choose this for our construction. A more detailed discussion on equal-angle month can be found in next chapter.

Each common Martian year consist of 668 sols. To find the average number of sols per month, a simple division reveals that

Average number of sols per month = 668 sols / 12 = $55\frac{2}{3}$ sols

Therefore, each month contains either 55 sols or 56 sols.

Since 668 sols = (56 sols × 8) + (55 sols × 4),
there will be 8 months of 56 sols and 4 months of 55 sols.
Spreading out equally month of 55 sols, we obtain

	Month	Sols
	Sag	56
	Cap	56
■	Aqua	55
	Pis	56
	Ari	56
■	Tau	55
	Gem	56
	Can	56
■	Reo	55
	Vir	56
	Lib	56
■	Sco	55

Month of 55 days occur once every 3 months. Month divisible by 3 will have 55 days. Therefore month 3, 6, 9, 12 (Aqua, Tau, Reo, Sco) will have 55 days.

The simplest way of defining a Martian week would be to follow 7 days per week on Earth. Therefore, one Martian week will consist of 7 sols. Each Martian month will therefore consist of 8 Martian weeks. Month Aqua, Tau, Reo and Sco which have 55 days will then fall short of 1 sol to 8 Martian weeks. One week will have 7 sols strictly, flat throughout the year. Other way of defining a Martian week would be 7 sols week for month of 56 sols, and 6 sols week for month of 55 sols. Pros and cons of this alternative option will be presented in next chapter.

5.5.3. The seasons, solstices and equinoxes

Having defined the month and sols, and the date of vernal equinox, we are ready to determine when to expect solstices and equinoxes, and its corresponding seasons.

Duration of seasons in Mars has been found as follows:

Seasons	*No. of sols*	*Fraction per year*
Spring	193.30 sols	0.2891
Summer	178.64 sols	0.2672
Autumn	142.70 sols	0.2134
Winter	153.95 sols	0.2303
Total	668.59 sols	1

As opposed to Earth, the duration of season is

Seasons	*No. of days*	*Fraction per year*
Spring	92.764 days	0.2540
Summer	93.647 days	0.2564
Autumn	89.836 days	0.2460
Winter	88.997 days	0.2436
Total	365.244 days	1

It can therefore be clearly seen that the length of season in Mars varies considerably. The fraction can range from 0.21 to 0.29. This is in contrast to the situation on Earth where each season is of almost equal length, as depicted by the fraction of almost 0.25 throughout. This is due to the higher eccentricity of Mars orbit (0.0943) compared to Earth orbit (0.0167). Therefore the effect of Kepler’s second law will be stronger in Mars. Seasons tend to be long when it is far from the Sun and tend to be short when it is close to the Sun.

As our Martian tropical year consists of only 668 sols, duration of each season will approximate as follow:

Seasons	*No. of sols*
Spring	193 sols
Summer	179 sols
Autumn	142 sols
Winter	154 sols
Total	668 sols

Spring or vernal equinox has been defined as the first sol of the year.

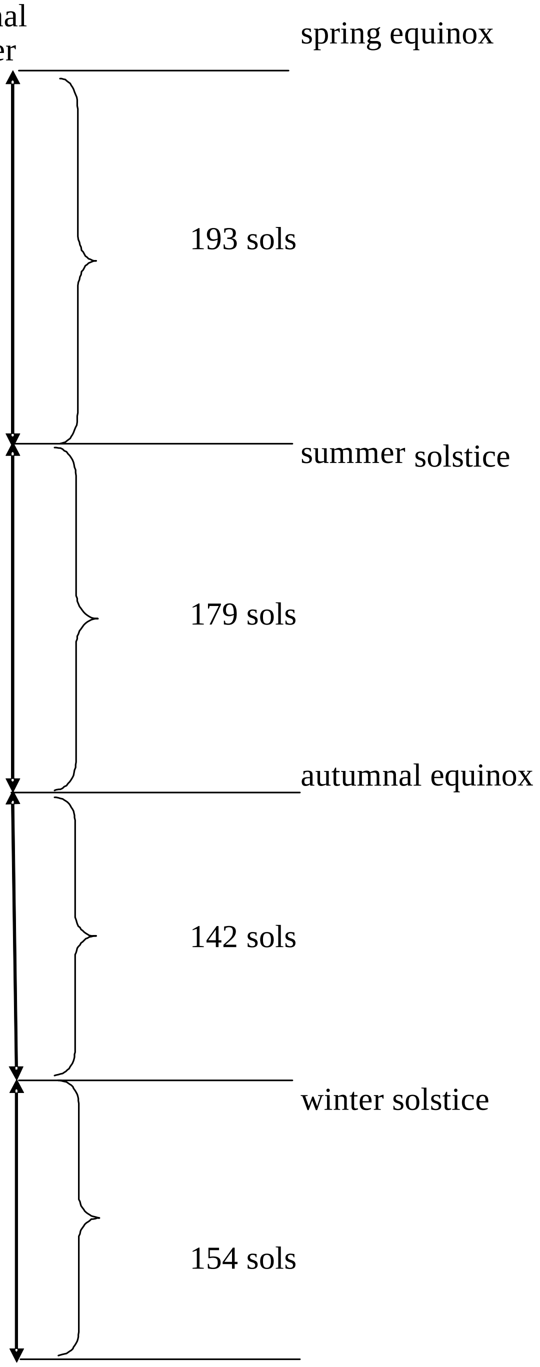
Summer solstice will occur in sol no. (193+1) = 194th sol of the year

Autumnal equinox will occur in sol no. (193+179+1) = 373rd sol of the year

Winter equinox will occur in sol no. (193+179+142+1) = 515th sol of the year

Hence, the position of solstices and equinoxes on the Martian calendar will be as follow:

	Month	Sols	Cumulative sols till month end	Seasonal Marker
	Sag	56	56	1
	Cap	56	112	
¦	Aqua	55	167	
	Pis	56	223	194
	Ari	56	279	
¦	Tau	55	334	
	Gem	56	390	373
	Can	56	446	
¦	Reo	55	501	
	Vir	56	557	515
	Lib	56	613	
¦	Sco	55	668	



The dates of solstices and equinoxes will therefore be as follows:

Spring equinox occurs on 1 Sag (from definition)

Summer solstice occurs on the 194th sol of the calendar
End of month Aqua marks 167th sol of the year
End of month Pis marks 223rd sol of the year
194 falls in between 167 -- 223, therefore summer solstice will occur in Pis
The date is calculated as 194-167 = 27
The date of summer solstice is therefore 27 Pis

Autumnal equinox occurs on the 373rd sol of the calendar
End of month Tau marks 334th sol of the year
End of month Gem marks 390th sol of the year
373 falls in between 334 -- 390, therefore autumnal equinox will occur in Gem
The date is calculated as 373-334 = 39
The date of autumnal equinox is therefore 39 Gem

Winter solstice occurs on the 515th sol of the calendar
End of month Reo marks 501st sol of the year
End of month Vir marks 575th sol of the year
515 falls in between 501 -- 575, therefore winter solstice will occur in Vir
The date is calculated as 515-501 = 14 Vir

To summarize, the date of seasonal markers are

Spring equinox	1 Sag
Summer solstice	27 Pis
Autumnal equinox	39 Gem
Winter solstice	14 Vir

5.5.4. The Year

Final aspect of the construction is concerning the year. Two issues will need to be addressed:
When should we start counting the year?
How should leap years be accounted in Martian calendar?

5.5.4.1 Epoch

The first question seeks to set an epoch for Martian calendar. Basically, we need to define when Year 1 is. Numerous ideas have been proposed to set the epoch of Martian calendar, some bear astronomical significance, while others resemble the date of spacecraft landing on Mars.

We shall adopt Dr. Robert Zubrin’s epoch for Mars. On 1 January 1961, Mars was at vernal equinox. Recall that vernal equinox marks the first day of the year. It so happen that first day of 1961 coincides with first day of Mars. Therefore, 1961 will serve as the starting year on Earth when we start counting the year on Mars as Year 1.

The reasoning behind our adoption of this epoch is that it allows reasonably easy conversion of time between Mars and Earth as first sol of Gregorian year coincides with first sol of the Martian year (conversion to be shown later). Besides, all important dates of human exploration to Mars occur after 1961. Hence, all the equivalent dates on Mars will have a positive year. For example, Viking I landed on Mars on 20 July 1976. Had this is chosen as Year 1, some important dates like 15 July 1965 when Mariner 4 flew by Mars will have a negative year in Mars. This is because 1976 is set as Year 1 of Mars, 1965 which precedes 1976 will therefore have its equivalence that precede Year 1 of Mars, leading to negative year on Mars and this is undesirable.

5.5.4.2 Intercalation

The second aspect pertaining to the year that should be addressed is the intercalation, where we seek to account for leap years in Martian calendar.

Mean tropical Martian year is 668.5921 sols. As briefly described earlier, a common Martian year of 668 sols are used. This is to allow addition of sols during leap years as 668 sols per common year fall short of 0.5921 sols/Martian year. In order to correct the error and therefore reflect the mean tropical Martian year, these “shortage” will be accumulated for a number of years and then added back in a present cycle. This therefore resembles the practice of Gregorian calendar, where we add 1 day during leap year.

We shall first understand how intercalation was determined for Gregorian calendar.
Mean tropical year of Earth = 365.24 days
1 common year in Gregorian calendar = 365 days
Hence, after each common year, the error would be -0.24 days / year.

It is desirable to correct the tropical year before the error accumulates to large discrepancy. Intuitively, we would want to correct the error once every four years. This is because after four years, the error would be -0.24*4 days / year = -0.96 days / year, which is close to 1 day. Therefore, we add 1 day once every 4 years.

However by adding 1 year, we are adding more days that we should, introducing error of
(1-0.96) days / 4 years = 0.04 days / 4 years = 0.01 days / 1 year
Hence, after 100 years, the accumulated error would be 1 day.
We therefore correct this by subtracting one day once every hundred years. Note that now we are subtracting one day from a leap year, since we have already added one day once every 4 years even in 100th year. So essentially, we are maintaining the number of days in a common year and not doing any subtraction. Therefore, for leap years, we add one day. No subtraction actually takes place.

In summary,

$$365.2425 = 365 + \frac{1}{4} - \frac{1}{100} + \frac{1}{400}$$

In every 4 years, 1 day will be added. Hence year divisible by 4 will be leap year.

Years divisible by 100 will not be leap year, but years divisible by 400 will be leap year.

Applying similar understanding, a basic intercalation can be developed for Mars.

Mean tropical year of Mars = 668.5921 sols

1 common year in Martian calendar = 668 sols

Many different forms of intercalation have in fact been proposed. The simplest model would be that of a Darian system. We shall incorporate that into our Martian calendar. It can easily be understood as follow:

$$668.592 = 668 + \frac{6}{10} - \frac{1}{100} + \frac{1}{500}$$

Hence in every 10 Martian years, 6 sols will be added.

Now we need to define Martian leap year. In Gregorian calendar, we add one day for leap year. If we maintain similar rule, then 1 Martian leap year will have additional 1 sol.

Thus, there will be a total of 6 Martian leap years in the course of 10 Martian years

(This is to make up additional 6 sols in 10 Martian years).

Therefore, leap years will be odd number Martian years, plus a Martian year divisible by 10.

(For example: Year 1, 3, 5, 7, 9, 10)

Further, Martian years divisible by 100 will not be leap year but Martian years divisible by 500 will be leap year. Leap days can be added in the month Sco (the last month) of the calendar.

The remaining error will therefore be 668.5921-668.592 = 0.0001 sols. This error will accumulate into 1 sol in 10000 Martian years. An extended intercalation scheme can be adopted to correct this. However this will require more extensive analysis and shall not be presented in this project.

5.6. Conversion of Dates between Martian and Gregorian

Having constructed Martian calendar, definitely we need a system to convert the dates between Gregorian calendar and Martian calendar. This will allow easy communication between inhabitants in two planets.

Principles of conversion can be understood as follow:
1 Jan 1961 is our starting date of counting day or year in Mars.
1 Jan 1961 therefore corresponds to 1 Sag Year 1
Hence, given any date on Gregorian calendar, what we need to do is to calculate the duration between the given date with 1 Jan 1961.
This duration in terms of Earth solar day can then be converted into sols in Mars
Duration in terms of sols in Mars will then be added into 1 Sag Year 1
Martian Date can then be determined.

To illustrate the idea, it is best demonstrated via an example
Viking I lands on Mars on 20 July 1976. What date does it correspond to in Martian calendar?

<u>First step: Calculate duration between the date and 1 Jan 1961</u>
(a) Calculating number of years from 1 Jan 1961 to 1 Jan 1976:

Number of years = 1976-1961 = 15 years

(b) Calculating number of days from 1 Jan 1976 to 20 July 1976:

Average days per month = 365.2422 / 12 = 30.43685

Number of days = (7 – 1) x 30.43685 + 20 = 202.6211

Number of years in this duration = 202.6211 days / 365.2422 = 0.5547582

(c) Calculating total duration from 1 Jan 1961 to 20 July 1976

Number of years = 15 + 0.5547582 = 15.5547582 years

Second step: Converting duration into Martian units

From step (C) above, duration between two dates = 15.5547582 years

Recall that

1 Martian tropical year = $\frac{686.9725}{365.2422}$ = 1.8808684 Earth tropical year

Therefore, 15.5547582 years = $\frac{15.554782}{1.8808684}$ = 8.270000 Martian years

Third step: Determining the Martian Date

The duration between the two dates is equivalent to 8.27 Martian years

(a) Determining the Martian Year

Starting from Year 1, 8 Martian years are added

The Martian year will then be Year 9

(b) Determining the Martian Month

After adding 8 Martian years the remaining duration is 8.27 – 8 = 0.27 Martian years

Converting 0.27 Martian years into Martian months

0.27 Martian years = 0.27 x 12 = 3.24

Starting from Month Sag, 3 Martian months are added

The Martian month will then be end of Aqua, or the start of Pis.

(c) Determining the Martian Date

After adding 3 Martian months the remaining duration is 3.24 – 3 = 0.24 Martian months

Average sols per month of Mars = 668.5921 / 12 = 55.71601

Converting 0.24 Martian months into sols:

0.24 Martian years = 0.24 x 55.71601 = 13.37184

Starting from end of Aqua, 13.37184 days will be added

The Martian Date will then be 14 Pis

Finally, 20 July 1976 is equivalent to 14 Pis Year 9.

It is customary to develop a generalized formula for conversion

Duration in years $= (Year - 1961) + \dfrac{(Month - 1) \times 30.43685 + Date}{365.2422}$ = P

Duration in Martian years = $\dfrac{\text{P}}{1.8808684}$ = Q

Two simple functions will be defined to determine Martian Date. It is self-explanatory from the example:

Integer(123.456) = 123;	Integer(0.789) = 0	Integer(234) = 234
Decimal(123.456) = 0.456;	Decimal(0.789)=0.789	Decimal(234) = 0

Martian Year = integer(Q) + 1

Example: Q = 8.27, integer(Q) will be 8

Martian Year = 8+1 = Year 9

Martian Month = 1 + integer[decimal(Q) x 12]

Example: Q = 8.27, decimal (Q) will be 0.27

decimal(Q) x 12 = 0.27 x 12 = 3.24

integer[decimal(Q)x12] = integer(3.24) = 3

Martian Month = 1 + 3 = 4

Martian Day = 1 + integer{decimal[decimal (Q) x 12] x 55.71610}

Example: Q = 8.27, decimal (Q) will be 0.27

decimal(Q) x 12 = 0.27 x 12 = 3.24

decimal[decimal(Q)x12] = decimal(3.24) = 0.24

decimal[decimal(Q)x12] x 55.71610 = 0.24 x 55.71610 = 13.4

Martian Day = 1 + integer(13.4} = 1 + 13 = 14

5.7. Important Dates in Mars

Applying the above formula, all important dates on Mars are calculated and summarized in the table below.

In tandem with this, a spreadsheet has been developed to ease the conversion procedure. Guidelines are provided on how to use the spreadsheet. With that tool, we can convert any date (Public Holidays, Birthdays) on Earth to a Martian Date very easily.

	Gregorian				**Martian**			
Occasion	Earth Date	Day	Month	Year	Year	Month	Sol	Mars Date
Calendar begins	1 January 1961	1	1	1961	1	1	1	1 Sag Year 1
Mariner 4 flyby	15 July 1965	15	7	1965	3	5	55	55 Ari Year 3
Mariner 6 flyby	31 July 1969	31	7	1969	5	7	44	44 Gem Year 5
Mariner 7 flyby	5 August 1969	5	8	1969	5	7	48	48 Gem Year 5
Mariner 9 in orbit	14 November 1971	14	11	1971	6	10	21	21 Vir Year 6
Mars 2 and 3 land	02 December 1971	2	12	1971	6	10	39	39 Vir Year 6
Viking 1 arrives n orbit	19 June 1976	19	6	1976	9	3	39	39 Aqua Year 9
Viking 1 lands	20 July 1976	20	7	1976	9	4	14	14 Pis Year 9
Viking 2 lands	3 September 1976	3	9	1976	9	5	1	1 Ari Year 9
Mars Observer disappears	21 August 1993	21	8	1993	18	5	14	14 Ari Year 18

Chapter 6: Variations in Martian Calendars

6.1 Overview of Various Versions

In the last chapter, the team has developed a Martian Calendar by carefully absorbing feasible time keeping concepts employed in various versions of Martian Calendars. In this chapter, pros and cons of the other proposed Martian Calendars will be discussed by contrasting various distinguishable features in each version. Practicability of the different features introduced in each version will also be looked into. The chapter serves primarily to analyze alternative ways of constructing a Martian calendar apart from those adopted and presented in earlier chapter.

Dr. Robert Zubrin

The main distinguishable feature of Dr. Robert Zubrin's model of calendar is that the number of sols per month are defined based on the duration of 30^o travel of the Mars along the orbit around the Sun. Hence, the 12 months in the proposed Martian Calendar will have varying length of sols per month with each month representing 30^o of travel of the Mars around the Sun, as opposed to the equal duration month presented in earlier chapter. However there are some inherent problems with such a definition and will be discussed in more detail in section 6.2.

Thomas Gangale

Darian Calendar is proposed by Thomas Gangale. He divided a year in a different way from that of Dr. Robert Zubrin. In Darian Calendar, a year is divided into 24 equal-duration months, with each month consists of either 27 or 28 sols. Intuitively, this poses less problem and is indeed more user friendly. While both Darian calendar and our model share the same concept of equal-duration month, number of months per year is different. Recall that our model consists of 12 months, each month of 55 or 56 sols.

Another feature of the Darian Calendar worth mentioning is that the first sol of every month will also be first sol of the week. This is equivalent to saying 1st Jan, 1st Feb..

1st Dec will be Monday. Therefore, Martian inhabitants would never face the dilemma we have with the Gregorian calendar: “What day is it on 25 December?”. However, as each month is of either 27 or 28 sols, there are months with one sol less than others. Therefore, in order to make every month to begin with first sol of the week, 27-sol month will have the last week of the month one sol short, hence a missing “Saturday” for last week! What more, this occurs almost four times per year! Greater details of Darian Calendar will be scrutinized in section 6.3.

Frans Blok

In the Darian Calendar, the 24 months are named after the Latin names and the Sanskrit names of the constellations of zodiac. This may appear too parochial, not to mention they take good brains to remember them.

Therefore, Frans Blok designed an innovative nomenclature system to name the 24 months, which he called the Rotterdam System. Each name of the 24 months is fixed with simple rules which can be easily memorized. However for the convenience of pronunciation, some alphabets of the name are not fixed by the rule. Hence, this system is still partially arbitrary in principle. Greater problem is that some of the names churned out by the Rotterdam system appeared to be pretty indecent in certain language. More details can be found in section 6.4.

Mark Knoke

One of the methods to reduce the complaints of the inconvenience of having to remember too many names for months is probably to reduce the number of the months. The names to be remembered are indeed the least if number of months is reduced from 24 to 12. The number of sols within a month, on the other hand, increases when the number of months reduces and not all will be so keen on a month of too long.

Mark Knoke struck a balance between these two aspects. He proposed Vophik calendar with 16 months, each of 41 or 42 sols each. In this approach, months are divided into average length. Note that this is yet another gyration of how to divide a year. Thus far, we have came across martian year with 12, 16 and 24 months. These are just a few of the many other various ways of dividing a year in equal-duration manner.

Intercalation introduced in Vophick Calendar inserts fewer leap years into the calendar, thus common year still deserves its name as “Common Year”. Besides, it is able to correct the accumulated error up to 10000 year. In addition, Mark Knoke adopted a different epoch for the calendar. The system together with its pros and cons will be discussed in further detail under section 6.5.

Others

Finally, the team have also encountered some proposed Martian Calendars where the principle in the division of a sol into smaller units is completely different. In one particular case, a sol is divided into 100 units which the author, Manfred Krutein, named “Centisol”. In another case, as proposed by Ander Ström, the terrestrial second is still in used in the time keeping system of the Mars. Therefore, a clock designed by Ander Ström will run from 00:00 to 24:39:35.244 daily. Both designs have their pros and cons.

References: [6-1], [6-2], [6-3], [6-4], [6-5], [6-6], [6-7], [6-8]

6.2 The Martian Calendar by Dr. Robert Zubrin

The basic unit is sol, or the Martian day. In Dr. Robert Zubrin's proposal, a Martian year is devided into 12 months, with each month representing the duration of 30^o revolution around the orbit.

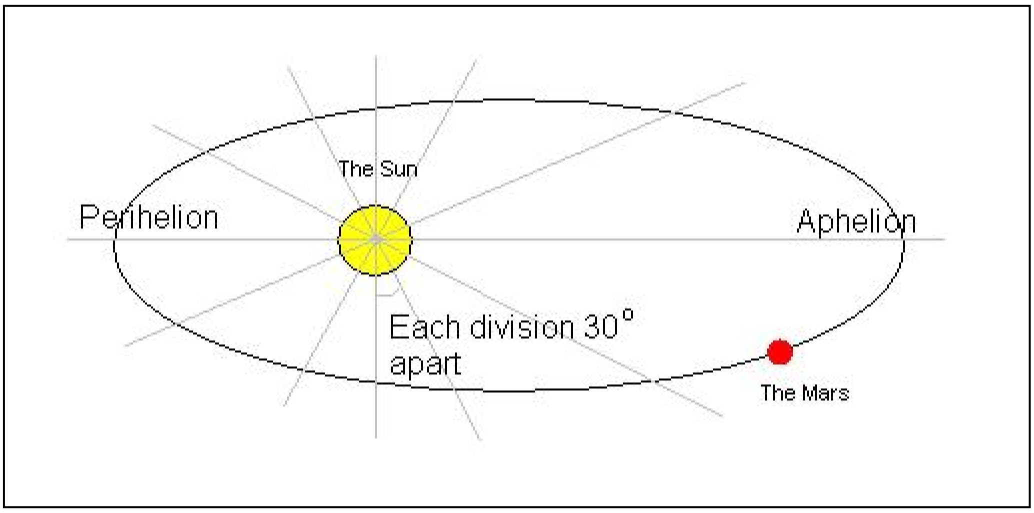


Figure 6.1 Division of year into 12 months with equal degree (30^o)

The figure above illustrates the idea of deviding a year into 12 months with equal degrees of travel around the Sun.

Note that to revolve 30^o degrees along the orbit, the arc length varies, with longer distance when Mars is futher away from the Sun (close to aphelion). Coupled with the lower speed of revolution when Mars is close to aphelion (recall Kepler's second law), Mars essentially takes longer time to travel 30^o around the Sun when it is close to the aphelion.

Similarly, shorter arc length and higher speed of revolution enable shorter travelling time of 30^o along the orbit when Mars is close to the perihelion. Therefore, follwing this definition, months of varying lengh are produced. Months close to aphelion are longer while the months close to perihelion are shorter. When Mars is close to aphelion, it takes long time to travel 30^o along the orbit. Thus, a month, which is equivalent to the duration of 30^o travel, will also be long. The converse is true when Mars is close to the perihelion.

The following table shows calendar constructed by Dr. Robert Zubrin

Month	**Sols**	**Begins on Sol**	**Notes**
Gemini	61	1	Gemini 1 - vernal equinox
Cancer	65	62	
Leo	66	127	Leo 24 - Mars at aphelion
Virgo	65	193	Virgo 1 - summer solstice
Libra	60	258	
Scorpius	54	318	
Sagittarius	50	372	Sagittarius 1 - autumnal equinox
Capricorn	47	422	Dust storm season begins
Aquarius	46	469	Aquarius 16 - Mars at perihelion
Pisces	48	515	Pisces 1 - winter solstice
Aries	51	563	Dust storm season ends
Taurus	56	614	Taurus 56 - Martian New Year's Eve

Table 6.1 The 12 months of the Martian Calendar as proposed by Dr. Robert Zubrin

From the table, it can be seen that the longest month has 66 sols (month Leo), when the Mars is close to aphelion. Shortest month has 46 sols (month Aquarius), when Mars is close to perihelion. Therefore, Mars's seasons are still 3 months long each, although the duration of each month is different. The advantage of having months partitioned in such a way is that one could easily estimate the position of the Mars in the orbit, without any sophisticated device to calculate its distance from the Sun.

The purpose of a calendar is to match the tropical year. Due to precession, the season markers (says vernal equinox) shift earlier year by year. A good calendar would eliminate the shift and estimate the seasons to fall invariantly at the same date in any year of the calendar. No one would intend to design a tropical calendar whereby the seasons’ shift is accumulated overtime. This is achieved via intercalation by introducing leap year.

Unfortunately, the division of the sols of a month as defined by this model does not always reflect the reality and the calendar would lose its ability to reflect the aphelion and the perihelion as intended. For instance, if currently the Mars faces its northern hemisphere to the Sun when the planet is at aphelion, 46500 Martian years later (half of the precession cycle), the Mars would face its northern hemisphere to the Sun when it is at perihelion. Therefore, it implies that if the northern hemisphere of the Mars is experiencing long summer in present, 46500 Martian years later the northern hemisphere of the Mars would experiencing short summer due to the coupled effects of precession and the eccentrictity of the Mars.

However, this shorten summer can not be reflected in the calendar. As precise intercalation is used, summer solstice will always fall on Virgo 1. The current duration of 3 months from Virgo 1 to Saggitarius 1 is however a long one (reflecting a long summer). This would mean that in order to make Saggitarius 1 the autumnal equinox, the period of Virgo 1 to Saggitarius 1 has to be redefined to make it shorter in an attempt to match duration of summer after half a cycle of precession. Alternatively, autumnal equinox will no longer occur in Saggitarius 1.

Basically, the problem is due to two contradicting objectives that the author seeks to achieve. Precise intercalation calulation is introduced in the model to match the Martian tropical year, such that seasonal markers will always occur at the same date. Meanwhile, the months are partitioned into different lengths to reflect the corresponding location of the Mars in its orbit, such that long months indicate a location close to aphelion and short months reflect a location close to perihelion.

However, both these two aspects can only be satisfied together for some years, meaning the date will indicate the season, and the length of the month will indicate the position of Mars or the duration of a season. Due to the precession of the Mars, in order to always match the tropical year, the months have to give up their ability to reflect the corresponding location of the Mars in its orbit, meaning the date will still mark the season, but the length of the month will no longer reflect the position or the duration of season. Therefore, while the months with different duration is very useful for present, it would lose its intended meaning after several thousand years.

Secondly, it is hard to plan for activities when the months are not equally long. For instance, one is worse off to work on the long months if the salary is on monthly basis, but better off if it is on the short months. Therefore, many activities cannot be done based on months, but they have to be done based on sols.

Reference: [6-1]

Table 6.1: Taken from http://users.ameritech.net/kroche/zubrin.html

6.3 The Darian Calendar by Thomas Gangale

The Darian Calendar was designed by an aerospace engineer and political scientist, Thomas Gangale, in 1985 to serve the possible future need for a time-keeping system in Mars. He named the Darian Calendar after his son, Darius.

In the Darian Calendar, the basic unit is sol. One Martian tropical year in the Darian Calendar is devided into 24 equal-duration months. Each quarter consists of six months with 28 sols for the first five months and 27 sols for the sixth month. This essentially eliminates the long sols per month in a 12 month system. While a 12 month system matches the Gregorian system in terms of number of months per year, a 24 month system matches more closely of the Gregorian system in terms of number of days per month. Therefore, tradeoff exist.

The Darian Calander attemps to preserve the seven days week concept of the Gregorian Calendar. As the first five months of any quarter are 28 sols long, which can be evenly devided into 4 weeks, it turns out that the date on any months is invariably linked to a fixed sol of the week. This means that every 1st sol, 8th sol, 15th sol, or 22nd sol is the first sol of the week, and it can be deduced that every 7th sol, 14th sol, 21st sol and 28th sol is the seventh sol of the week, as can be referred from figure 6.2. The sol of the week is directly indicated by the sol of the month. Such regularity in date is also one of the fascinating features of the Darian Calendar. However, the sixth month of a quarter is a 27 sols month (except for the last month of the leap year), and its final week is only 6 sols long. To preserve the regularity, the last sol of the final week is omitted. Therefore, if today is the sixth sol of the 4th week of the 6th month, tomorrow will be the first sol of the first week of the 7th month. The seventh sol of the 4th week of the 6th month does not exist.

The regularity of the Darian Calendar is no doubt interesting, but there is a payoff for it. If a Martian tropical year is not a leap year, there will be one short weekend once every six months. Considering the 5-days working week system which are commonly implemented in the developed countries on the Earth nowadays, the community in the Mars will lose four sols once every year which are equivalent to be the weekends!

Besides, it would also be unacceptable for some religions whereby the seven-day week is one of the important components of their belief.

Sagittarius

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Dhanus

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Capricornus

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Makara

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Aquarius

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Kumbha

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	

Pisces

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Mina

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Aries

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Mesha

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Taurus

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Rishabha

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	

Gemini

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Mithuna

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Cancer

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Karka

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Leo

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Simha

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	

Virgo

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Kanya

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Libra

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Tula

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Scorpius

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Vrishika

So	*Lu*	*Ma*	*Me*	*Jo*	*Ve*	*Sa*
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	**28**

Figure 6.2: the Darian Calendar (The last day of Vrishika is an intercalary day.)

The months of the Darian Calendar was named after the Latin names and the Sanskrit names of constellations of zodiac. It makes sense to name the months after the constellations of zodiac. However it might be difficult for some people to remember 24 names of the months, not to mention the name itself are difficult to memorize.

The sols of the week are named after the long known seven heavenly objects in the sky. They are Sol, Luna, Mars, Mercurius, Jupiter, Venus and Saturnus. However, the Moon is terrestrial and it is therefore inappropriate to be named as a sol of the Martian week. Secondly, it is impossible for one to see the Mars in the sky when he is on the surface of the Mars. Hence, shouldn't the third sol of the Martian week to be named after the Earth instead of the Mars. (In the earlier paper, the author did indeed name the second sol and the third sol of the Martian week after the Mars's natural satellite Phobos and the Earth respectively, instead of the Moon and the Mars.)

After the creation of the Darian Calendar, many modified versions have been proposed. These modified versions still employ the underlying concept of the Darian Calendar, but with alternation to the nomenclature of the months and the sols of the week. The following section is one of the examples of the modified Darian Calendar.

References: [6-2], [6-3]

Figure 6.2: courtesy of http://en.wikipedia.org/wiki/Darian_calendar

6.4 The Rotterdam System by Frans Blok

Frans Blok modified the Darian Calendar by implementing an innovative nomenclature system to replace the former one. A totally new nomenclature for the Darian months and the sols of the week was developed to avoid the naming being too parochial. He designed 24 completely new names for the months and 7 completely new names for the sols of the week, with certain rules for the nomenclature. He called it the Rotterdam System.

Month	**Season north/south**	**Name**	**Syllables**	**Characters**
1	Spring/fall	ADIR	2	4
2		BORA	2	4
3		COAN	2	4
4		DETI	2	4
5		EDAL	2	4
6		FLO	1	3
7		GEOR	2	4
8	Summer/winter	HELIBA	3	6
9		IDANON	3	6
10		JOWANI	3	6
11		KIREAL	3	6
12		LARNO	2	5
13		MEDIOR	3	6
14	Fall/spring	NETURIMA	4	8
15		OZULIKAN	4	8
16		PASURABI	4	8
17		RUDIAKEL	4	8
18		SAFUNDO	3	7
19	Winter/summer	TIUNOR	3	6
20		ULASJA	3	6
21		VADEUN	3	6
22		WAKUMI	3	6
23		XETUAL	3	6
24		ZUNGO	2	6

Table 6.2 Nomenclature of the 24 months of the Darian Defrost Calendar

The first letters (in red) of the 24 months' names are arranged in alphabetical order, with 'Q' and 'Y' omitted from this order. The author claimed that 'Q' is omitted because it resembles the consonant 'K' and it always need vowel 'U' in its vicinity. 'Y' is omitted because it is hard to classify it between a consonant and a vowel. The last letters (in either blue or green) are arranged in a repetitive form of 'R', 'A', 'N', 'I', 'L', and 'O'. Therefore, the 24 months are group into 6 groups, for example, a month that ends with alphabet 'R' is either the 1st, 7th, 13th or the 19th month in the Darian Calendar. Besides, the 24 months are also grouped into 6 groups of 4 months, whereby the first month of each group of 4 months have a 'D' in between the first letter and the last letter in their names (in orange). The author designs these groupings of months by making use of the fact that 24 can be evenly devisable by 4 and 6.

The seasons of fall and winter in the Northern hemisphere can be told from the name of the months by the letter 'U' (in yellow). Also, the number of letter of the months' name can indicate the seasons. For instance, the months with 4 letters in name are the months with the long season (spring in northern hemisphere), the months with 8 letters in name are the months with short season (fall in the northern hemisphere) and the months with 6 letters in name are either the summer or the winter. In addition, months that are 27 sols long (except for the final month) are recognized by having 1 letter less in their names as compared to their counterparts in the same season. In other words, months that have even number of letter in their name are 27 sols long and 28 sols otherwise.

The names of the sols of the week are also designed with similar method, but less sophisticated.

Sols of the Martian week	**Terrestrial counterpart**
AXATISOL	SUNDAY
BENASOL	MONDAY
CIPOSOL	TUESDAY
DOMESOL	WEDNESDAY
ERJASOL	THURSDAY
FULISOL	FRIDAY
GAVIOSOL	SATURDAY

Table 6.3 Nomenclature of the 7 sols of the week of the Darian Defrost Calendar

The first letters in the names of the sols of the week are also arranged in alphabetical order, from ‘A’ to ‘G’. The number of letters in their names differentiates between working days and weekends, whereby working days are 7 letters in length while weekends are 1 letter longer.

Despite the creativity of the nomenclature designed by Frans Blok, there are still too many of them. While it is convenient to know the season of a hemisphere by just looking at the name of the month, this feature will lose its functionality due to precession. For example, spring will not always be the long season in northern hemisphere. The ability of the name of the month to tell the season might be helpful for some years, but not always true. Furthermore, the naming of the months and the sols of the week is not completely fixed by rules. When there is no rule to fill in the gap between the letters that had been fixed by some rules, an arbitrary letter is used to fill in the gap for pronunciation convenience. As the nomenclature is still partially arbitrary, it is hard to convince the whole community to accept it. This is especially true when “ULASJA” means “son of a bitch” in Russian and “WAKUMI” means “oral sex” in Japanese.

Reference: [6-4]

Table 6.2 & 6.3: taken and modified from http://www.geocities.com/fra_nl/rotmonth.html

6.5 The Vophick Calendar by Mark Knoke

In time keeping system with 24 months, there might be too many months within a year. In time keeping system with 12 months, there might be too many sols within a month. To seek a balance between the two, Mark Knoke designed a time keeping system for the Mars, which has 16 months in a year, and each month is either 41 sols or 42 sols long.

Month	Name	Sols
1	January	42
2	February	41
3	March	42
4	Geldof	42
5	April	42
6	May	42
7	June	41
8	Yorte	42
9	July	42
10	August	42
11	September	42 (41 in leap years)
12	Herjber	42
13	October	42
14	November	41
15	December	42
16	Vidman	42

Table 6.4 16 months of the Vophick Calendar

As Mark Knoke's proposal aims to strike a balance between the calendar that is designed with more months within a year and the calendar that is designed with more sols within a month, Mark Knoke's calendar has the average advantages and disadvantages between the two kinds of calendars.

Despite the confusion that might arise when the names of Gregorian months are reused in the Vophick Calendar, 16 is indeed a good number, which can be evenly devisable by 2, 4 and 8. Hence, a Vophick year can be easily grouped into quarters, halves and even eighths.

In Vophick Calendar, year 1 was started with the year of the landing of Viking I onto the Mars surface, 20 July 1976. This choice of epoch is different from Dr. Robert Zubrin's, who recommended that year 1 should start on 1 January 1961, when the vernal equinox of the Mars coincided with the vernal equinox of the Earth. Many proposed Martian Calendars have adopted Mark Knoke's choice of epoch because it marks the year when mankind's technology first reached the Mars successfully. Had 20 July 1976 chosen as the epoch, some important dates like 15 July 1965 when Mariner 4 flew by Mars will have a negative year in Mars. In fact, we used to count years negatively as BC (abbreviation of Before Christ) for the events that occurred before the epoch of the Gregorian Calendar. Therefore, will the presence of negative years in the Martian history affect the future life of the Martian community? Both choices of epoch are reasonably important. Hence, the choice of epoch for the Martian Calendar is left to be an agreement of the whole community.

Besides the difference in the choice of epoch, Mark Knoke had also counted leap years differently from our team. He had viewed the average tropical year of the Mars as the following,

$$668.5921 = 669 - \frac{2}{5} - \frac{1}{125} + \frac{1}{10000}$$

In every 5 years, 2 will be leap year, which have been chosen to be the first quarter year and the third quarter year in the interval of five years. Years divisible by 125 will be leap year, but years divisible by 10000 will not be leap year. By following the rule, a common year consists of 669 sols and 1 sol is subtracted if it is a leap year. Although this is an unconventional method of defining a leap year (since we used to add one day for the Gregorian leap year), it indeed generates fewer leap years than common years as opposed to the method that was employed by our team. Therefore, common year still deserves its name as “Common Year”. Furthermore, the error that occurs once every 10000 years as mentioned in the previous chapter will be eliminated by Mark Knoke’s intercalation. The only disadvantage of this intercalation is that we can no longer easily treat every odd year as leap year, since the leap year will be the year ends with 2, 4, 7, and 9.

References: [6-1], [6-5]
Table 6.4: http://www.geocities.com/sotosoroto/vophick.html

6.5 Other proposals

6.5.1 100 Primary Division Day by Manfred Krutein

In this proposal, one Martian year is called “Orb”, as the abbreviation of orbit. One Orb is the time when the Mars complete one cycle of revolution around the Sun. Thus, one Orb is corresponding to the Martian sidereal year. A calendar that counts year based on the sidereal year cannot estimate seasons since seasons shift their time along the calendar. Therefore, one of the pitfalls of the Martian Calendar proposed by Manfred is that it has no relationship with the seasons.

Next, Manfred has eliminated the division of year into months and weeks with the claims that there is no comparable influence of a large Moon around the Mars. However, months do not necessarily have to reflect the cycles of the Moon. Their role is more significant in breaking a year into smaller divisions that facilitates the activities planning. In fact, the Gregorian months have no relationship with the cycle of the Moon. Eliminating months and weeks has indeed made a year more difficult to be grouped into smaller division, and thus it makes the planning of activities becomes more difficult.

Manfred eliminated the 24 hours system and devided a sol into 100 units of “Centisol”. Decimal time system is easy to be computed. However, it is not easy to devide a full circle (360^o) into 100 units, since 360 is not evenly divisable by 100. Upon division, 1 Centisol is coresponding to 3.6^o, which makes the computation in degree tougher and offsets the convenience of computation in time.

References: [6-6], [6-7]

6.5.2 Terrestrial Time Based Clock by Ander Ström

The basic unit used is the terrestrial second. Since 1 Martian day is about 39 minutes 35.244 minutes longer than 1 terrestrial day, the extra 39 minutes 35.244 seconds is append to the Martian clock after 24:00:00. On the Earth, the clock runs from 00:00 to 24:00 per day while on the Mars, the clock runs from 00:00 to 24:39:35.244 per sol.

The pros of this system are that terrestrial second is retained in the Martian time system. The community on the Mars can relate to the terrestrial community with the same basic time unit. 8 working hours in Martian time is still the same as the terrestrial time, thus one does not need to work extra minutes to satisfy the 8 working hours as compared to the terrestrial counterpart.

However, Martian time is devided unevenly by this system. The uneven length of Martian day, 24 hours 39 minutes 35.244 seconds, is very hard for computation by the local community on the Mars. Confusion might also arise because the interval from a given time to the same given time of the next day is 24 hours on the Earth, says from 12:00 p.m. day 1 to 12:00 p.m. day 2, but it means 24 hours 39 minutes and 35.244 seconds on the Mars. Furthermore, the abbreviation p.m. to indicate “Post Meridian” is no longer meaningful for this system because at 12:00 p.m. of any place on the Mars, the local Sun has not reached the Prime Meridian yet.

References: [6-6], [6-8]

Chapter 7: Problems

The main problems stem from the Martian gravity. Mars' gravity is only about 38% of Earth's gravity. With lesser gravity, the gases will easily float away from Mars. Thus Mars cannot maintain as much atmosphere as Earth.

As a result of this, the atmosphere is not thick enough to create the pressure required to keep water in the liquid state. This posts one of the major problems to be solved if we were to colonise Mars.

Moreover, the atmosphere of Mars is not enough to trap the heat from the sun light striking the surface. The heat quickly radiate out into space. Thus the temperature on Mars is very low except during summer at the equator. The average temperature is about -50^{o}C.

The lower gravity on Mars also causes our bones to get weaker and thus more easily broken. This is because, when the stress on the human skeleton is decreased, calcium will leach out, making it more brittle. Thus if you live on Mars for a few years, your bone density will decrease rapidly to less than 50% of the regular density. The decreased gravity will also result in the weakening of muscles and connective tissues.

At the moment, Mars is barren with no vegetations. That will mean that there will not be any food there. Unless we are able to bring huge quantities of food to Mars, scientists have to come up with ways to grow vegetables there. Currently, they are looking into using greenhouse method.

There is also static electricity on Mars, where it is more serious than on Earth. This is because the soil there is so dry and insulating that if you walk on it and later returned to the habitat and reached out to open the airlock, the lightning bolt might zap the critical electronics.

The above mentioned are just a few of the many possible problems that we have to face in order to colonise Mars. It is not quite possible to colonise Mars unless we first develop artificial gravity and solve the food problems. Thus there is still a long way to go before human beings can actually live in Mars.

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Appendix Mars/Earth comparison

Bulk parameters

Properties	**Mars**	**Earth**	**Ratio**
Mass (1024 kg)	0.64185	5.9736	0.107
Volume (1010 km^3)	16.318	108.321	0.151
Equatorial radius (km)	3397	6378.1	0.533
Polar radius (km)	3375	6356.8	0.531
Volumetric mean radius (km)	3390	6371	0.532
Core radius (km)	1700	3485	0.488
Ellipticity (Flattening)	0.00648	0.00335	1.93
Mean density (kg/m3)	3933	5515	0.713
Surface gravity (m/s2)	3.71	9.8	0.379
Surface acceleration (m/s2)	3.69	9.78	0.377
Escape velocity (km/s)	5.03	11.19	0.45
GM (x 106 km3/s2)	0.04283	0.3986	0.107
Bond albedo	0.25	0.306	0.817
Visual geometric albedo	0.15	0.367	0.409
Visual magnitude V(1,0)	-1.52	-3.86	-
Solar irradiance (W/m2)	589.2	1367.6	0.431
Black-body temperature (K)	210.1	254.3	0.826
Topographic range (km)	30	20	1.5
Moment of inertia (I/MR2)	0.366	0.3308	1.106
J2 (x 10-6)	1960.45	1082.63	1.811
Number of natural satellites	2	1	-
Planetary ring system	No	No	-

Orbital parameters

Properties	Mars	Earth	Ratio
Semi major axis (106 km)	227.92	149.6	1.524
Sidereal orbit period (days)	686.98	365.256	1.881
Tropical orbit period (days)	686.973	365.242	1.881
Perihelion (106 km)	206.62	147.09	1.405
Aphelion (106 km)	249.23	152.1	1.639
Synodic period (days)	779.94	-	-
Mean orbital velocity (km/s)	24.13	29.78	0.81
Max. orbital velocity (km/s)	26.5	30.29	0.875
Min. orbital velocity (km/s)	21.97	29.29	0.75
Orbit inclination (deg)	1.85	0	-
Orbit eccentricity	0.0935	0.0167	5.599
Sidereal rotation period (hrs)	24.6229	23.9345	1.029
Length of day (hrs)	24.6597	24	1.027
Obliquity to orbit (deg)	25.19	23.45	1.074

Mars Observational Parameters

Discoverer:	Unknown
Discovery Date:	Prehistoric

Distance from Earth	
Minimum (106 km)	55.7
Maximum (106 km)	401.3
Apparent diameter from Earth	
Maximum (seconds of arc)	25.1
Minimum (seconds of arc)	3.5
Mean values at opposition from Earth	
Distance from Earth (106 km)	78.39
Apparent diameter (seconds of arc)	17.9
Apparent visual magnitude	-2
Maximum apparent visual magnitude	-2.91

Mars Mean Orbital Elements (J2000)

Semimajor axis (AU)	1.5236623
Orbital eccentricity	0.0934123
Orbital inclination (deg)	1.85061
Longitude of ascending node (deg)	49.57854
Longitude of perihelion (deg)	336.04084
Mean Longitude (deg)	355.45332

Satellites of Mars

Properties	**Phobos**	**Deimos**
Semi-major axis* (km)	9378	23459
Sidereal orbit period (days)	0.31891	1.26244
Sidereal rotation period (days)	0.31891	1.26244
Orbital inclination (deg)	1.08	1.79
Orbital eccentricity	0.0151	0.0005
Major axis radius (km)	13.4	7.5
Median axis radius (km)	11.2	6.1
Minor axis radius (km)	9.2	5.2
Mass (1015 kg)	10.6	2.4
Mean density (kg/m3)	1900	1750
Geometric albedo	0.07	0.08
Visual magnitude V(1,0)	11.8	12.89
Apparent visual magnitude (V0)	11.3	12.4

*Mean orbital distance from the centre of Mars.

Martian Atmosphere

Surface pressure:	6.36 mb at mean radius (variable from 4.0 to 8.7 mb depending on season) [6.9 mb to 9 mb (Viking 1 Lander site)]
Surface density:	~0.020 kg/m3
Scale height:	11.1 km
Total mass of atmosphere:	~2.5 x 1016 kg
Average temperature:	~210 K (-63 C)
Diurnal temperature range:	184 K to 242 K (-89 to -31 C) (Viking 1 Lander site)
Wind speeds:	2-7 m/s (summer), 5-10 m/s (fall), 17-30 m/s (dust storm) (Viking Lander sites)
Mean molecular weight:	43.34 g/mole
Atmospheric composition (by volume):	
Major :	Carbon Dioxide (CO2) - 95.32% ; Nitrogen (N2) - 2.7% ; Argon (Ar) - 1.6%; Oxygen (O2) - 0.13%; Carbon Monoxide (CO) - 0.08%
Minor (ppm):	Water (H2O) - 210; Nitrogen Oxide (NO) - 100; Neon (Ne) - 2.5; Hydrogen-Deuterium-Oxygen (HDO) - 0.85; Krypton (Kr) - 0.3; Xenon (Xe) - 0.08

Reference: [1-12]

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http://www.broom-lodge.co.uk/pics/LargeImages/BroomLargeDoubRoom5.jpg

http://orion.ramapo.edu/~kfowler/marssurface.jpg