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The Architecture of Time: Design Implications for Extended Space Missions

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ABSTRACT

Architecture is about designing space for people to live and work in. Horology and calendrics are about designing time systems for people to live by. They could collectively be called "time architecture." To understand the design implications of the architecture of time requires a working knowledge of astronomy and mathematics, as well as a thorough understanding of how cultures have designed and used time throughout history. Time architecture is at the intersection of the space, the biomedical, and the social sciences.

Timekeeping issues of human activities on the Moon and on Mars bring the considerations of time architecture into focus. The length of the Martian sol is close enough to that of the Earth day to serve as a useful regulator of the diurnal rhythms of humans on Mars, as well as other species we will bring with us. This is in stark contrast to the Moon's 29-day cycle of day and night, which is far too long to serve such a purpose. Also, having an axial tilt similar to Earth's, Mars proportionately experiences seasonal changes on approximately the same scale, albeit on a much colder end of the scale. (The seasons on Mars have been described as winter, WINTER winter, winter WINTER winter, and yet more winter.) Still, this is a factor that must be addressed in system design, and will also affect human populations on Mars, both operationally and—eventually—culturally.

INTRODUCTION

This report concerns itself in the main with timekeeping issues of human activities on Mars, addressing design on a grand scale. Such issues become immediate concerns the moment there are humans living and working on that planet. The study of extraterrestrial social measurements of time has been confined almost entirely to Mars, although systems have recently been proposed for the Galilean satellites of Jupiter and for Titan. There are a number of reasons why Mars has dominated the subject. First of all, Mars is one of the nearest planets to Earth, and therefore one on which humans are likely to establish themselves in advance to voyages to other worlds. Furthermore, in the past half-century, while we have come to know both Venus and Mars as being less hospitable environments than pre-spacefaring civilization had hoped, Mars has clearly emerged as the better prospect for humanity's second home. Finally, the cycles of Mars are Earthlike enough that humans living there will find it terribly inconvenient to ignore them. Living and working by Earth's 24-hour day, humans would find themselves rising 39 1/2 minutes earlier each Martian sol. The Gregorian calendar will be useless for marking the regular passage of the Martian dust storm season and other annual weather phenomena, much of which has yet to be discovered. Martian society—including the micro-societies of the first long-term missions—will require a Martian clock and calendar for their own specific, localized purposes, and will refer to Earth's Universal Time and the Gregorian calendar only as its off-world interests require.

While more than 40 clock systems and more than 80 calendar systems are known to date to have been invented for Mars since 1880, a seldom considered aspect of timekeeping as an academic study is its social component. There are a great many mathematically valid solutions for a Martian clock and calendar, based on the planet's period of rotation and revolution; however, time architecture, including both horology and calendrics, is where the space, biomedical, and social sciences intersect. Although time is a physical phenomenon, how humans design and use time is a function of physiological needs and culture; time—in this sense—is socially constructed.

How prescient it has been that in the past 125 years, nearly 80 authors have published ideas for the architecture of time on Mars, describing how to divide the Martian day and Martian year into smaller units. The Martian prime meridian was established in the early 19th century, and the design of the Martian clock has been standardized at least since the Viking missions of the 1970s. Scientists can tell time on Mars; however, despite the constant stream of data that is downlinked from Mars these days, there is still no standardized system of expressing the date on Mars. Establishing a standard epoch—at a specific time of year on Mars, and a specific Martian year—should be the next priority in Martian timekeeping as a minimal system required for the physical sciences. More elaborate ideas, including the number and length of weeks and months, and names thereto, belong more to the realm of the social construction of Martian time, which will become important as humans make a presence on Mars.

THE SOCIAL CONSTRUCTION OF MEASUREMENT

Our concept of time has been fundamentally shaped by the natural rhythms of Earth's interactions with the Sun and the Moon: the day, the month and the year. These are the natural units of time. All others—the second, minute, hour, week, quarter, decade, century, and millennium—are derived from these three. As the cultures of the world have become more integrated, a common system of timekeeping has been universally adopted for civil purposes. The 24-hour clock, with its further divisions into 60 minutes per hour and 60 seconds per minute, is used exclusively throughout the world. The Gregorian calendar has become the international standard for civil time, although a number of other calendars—such as the Julian, Chinese, Jewish, Islamic, and Hindu calendars—continue to be used for cultural and religious purposes.

A clock or a calendar does more than "tell time;" it measures the measurers, it tells the story of those who constructed it and where they came from. Measurement and all who do it are part of human culture (Sydenham 1979, p. 29). The roots of measurement are in the social process itself—even when it strives to be precise, scientific, and abstract. The study of the history of measurement has demonstrated that the procedures that natural and social scientists use in measurement were invented to solve problems of everyday life (Duncan 1984, p. 2). For instance, during the fifth millennium BC, Egyptian priest-astronomers recognized that the solar cycle heralded the rise and fall of the Nile. The Sun eventually became an all-consuming object of astronomical observation, entirely displacing the Moon in importance, which was the primary astronomical timekeeping device for most other cultures. The Egyptians were the first to develop a calendar based solely on the solar cycle, in which the months were uniform divisions of the year that were divorced from the phases of the Moon.

The history of the Gregorian calendar is a fascinating case study in the social construction of time played out over three millennia. The Roman calendar evolved as Rome grew from an obscure village on the edge of the civilized world into an empire encompassing the whole of Mediterranean and European civilization. At early stages it was sparse in detail, without even months for much of the winter, since no useful work could then be done in the fields. The calendar year originally started with the beginning of the planting season in the month named for Mars, a deity whose religious functions were then primarily agricultural. Mars is now chiefly remembered as a war-god, whereas the other Roman deities whose names still grace the calendar are long forgotten. At times the Roman calendar was based on the moon; however Julius Caesar's expedition in the East against Pompey and his subsequent stay in the court of Cleopatra acquainted him with Egypt's solar calendar. Caesar's reform of the Roman calendar, with the Alexandrian astronomer Sosigenes serving as technical advisor, included its transformation into a solar calendar, with a bissextile day inserted every four years. Thus, the Julian calendar was not just a revision of the Roman calendar, but a melding of the time-measurement heritage of two cultures, a melding made possible by Rome's expansion into an empire. The emperor Constantine I made the seven-day week an official feature of the calendar in the 4th century because of its significance to Christians; however, by then the seven-day week had been in common use throughout much of the Empire for several centuries. Its practice had been spread not only by Christians and Jews, but by other cultures that had long used it in Egypt, Mesopotamia, and the Hellenized eastern Mediterranean. Constantine merely ratified a practice that had previously been socially constructed. The historical pattern of the adoption of the Gregorian reform of the calendar is another example of social construction, in this case proceeding at various paces in different branches of Christendom. Catholic states readily accepted the new calendar, some Protestant nations such as Britain held out for nearly two centuries, and many Orthodox countries continued to use the Julian calendar into the 20th century (Steel 2000).

Examples of the failure to socially construct time abound. A decimal clock, based on powers of 10, was contemplated as part of the metric system, but had few supporters. The French Revolutionary calendar, consisting of three 10-day weeks per month as well as new names for the days and months, was eventually abolished by Napoleon because it never caught on. The Stalin government experimented with both a five-day week and a six-day week in efforts to increase productivity as well as to disrupt social cycles tied to religion. The idea of a calendar containing 13 months exactly four weeks in length has existed at least since the 18th century (Ap-Iccim 1745). In the 19th century such a calendar was promoted by Marco Mastrofini (1834) in Italy and Auguste Comte (1877) in France, and in the 20th century was championed by Moses Cotsworth (1927) in Britain and by George Eastman (1926), the founder of Kodak, in the United States. A few corporations even adopted the system as their accounting calendar for several decades, but it never seriously challenged the primacy of the Gregorian calendar. Another attempt to rationalize the relationship of weeks to months was the World calendar, invented by

Elizabeth Achelis in 1930. It divided the year evenly into 91-day quarters containing exactly 13 weeks distributed over three months, with the 365th day and the bissextile day left out of the 7-day weekly cycle. The World calendar received consideration by the League of Nations and the United Nations, but the movement collapsed in the 1950s when the Eisenhower administration declared its opposition to it (McCarty 1996).

Both the Julian and Gregorian reforms adjusted the length of the calendar year. This brings up an interesting question: what is a year? While there are several physical definitions of the terrestrial year (sidereal, anomalistic, tropical, *et cetera),* there are also socially constructed definitions of the year. Most of the world uses the Gregorian calendar, which is based on 365.2425 days (very close to the physically-defined vernal equinox year). However, eastern Christianity still uses the Julian calendar for religious observances, and even scientists sometimes use the Julian year of 365.25 days because of its simple fraction. As a case in point, Table 1, taken from Allison 2001, expresses the various physical years in terms of the Julian year, a social construct. The Islamic year is defined as 12 lunations, and is therefore 354.3663 days. Time certainly is universal in the physical sense, but how humans organize time measurement systems is socially constructed. These two principles coexist; they are not mutually exclusive.

The physical scientist usually comes into the picture when the measuring instrument needs to be improved. An excellent example is the idea of measuring temperature with a thermometer, a vague concept that was made less vague through instrumentation (Duncan 1984, p. 2).

We take our familiarity with the dimensions of Nature for granted. However, the historical study of measurement has revealed that the familiar units of mass, distance, and time are socially constructed, and have not always been conceived of in the same way throughout history (p. 14). There has been an evolution toward greater abstraction and standardization, but the fact remains that Nature does not dictate the duration of a second or an hour. The hour has not had a fixed duration over human history (p. 15). The duration of a second, until recent history, was not agreed upon. Until 1967, “time was bound up with the classical mechanics of Newton; today it is defined in terms of quantum mechanics, and it is not certain that the two are the same (Danloux-Dumesnils 1969, p. 64).” It is the quest for ever greater precision in measures which led to the discovery of their illusory character (Langevin 1961). In trying to tie the metric system to Nature, its creators discovered that the system was not so natural and immutable. The International Meter is 0.2 mm shorter than the Metre des Archives, based now on a different standard than a fraction of the arc of meridian (Duncan 1984, p. 22). By 1928, the distinguished physicist P.W. Bridgman wondered whether, “from a strict operationist standpoint, physics was justified in treating as one and the same concept the notion of length pertaining to ultramicroscopic dimensions, the tactual concept suited to everyday life, and the optical concept, which is required for astronomical measures of length (p. 15).”

The truth of the matter is that there is an “idealization of the measurement process” which our scientific method is so dependent upon (pp. 120-121). Much of the philosophy of science is a neat *ex post facto* rationalization (p. 120). Our definitions of physical measurements and our conceptualizations of the architecture of the Cosmos are only as solid as our experience of everyday life. As we move outward into the Cosmos, the new challenges we face as a people

Table 1: What is a Year on Earth and Mars?

Measured Year	Earth	Mars
Anomalistic (perihelion-to-perihelion)	1.0000264 Jy = **365.2596 d**	1.8808917 Jy = **668.6146 sol**
Sidereal (fixed star-to-fixed star)	1.0000174 Jy = **365.2564 d**	1.8808481 Jy = **668.5991 sol**
Vernal Equinox (repetition of L_S=0°)	0.9999791 Jy = **365.2424 d**	1.8808269 Jy = **668.5907 sol**
Summer Solstice (repetition of L_S= 90°)	0.9999771 Jy = **365.2416 d**	1.8808168 Jy = **668.5880 sol**
Autumnal Equinox (repetition of L_S=180°)	0.9999781 Jy = **365.2420 d**	1.8808336 Jy = **668.5940 sol**
Winter Solstice (repetition of L_S=270°)	0.9999800 Jy = **365.2427 d**	1.8808387 Jy = **668.5958 sol**
Tropical (repetition of mean solar longitude)	0.9999786 Jy = **365.2422 d**	1.8808284 Jy = **668.5921 sol**

Units: 1 Jy = 1 Julian Year = 365.25 d ; 1 d = 1 Earth solar day = 86400 SI sec;
1 sol = 88775.24409 sec = 24 hr 39 min 35.24409 sec =1.02749125 d

redefine our experiences. In seeking to accommodate this process, we will enhance our vision of the universe and invent new instrumentation to measure it. Time measurement, as any other of our measurements, illustrates how social needs and processes influence the framework and conventions of physical measurement. Timing, sequence, tempo, and duration are fundamental features of social events (Duncan 1984, p. 30, citing Zerubavel 1982). It is logical to expect that so long as those features remain tied to the everyday experiences of current terrestrial life, they will not change much; however, when the everyday experiences of humans range farther afield, those features will change. They may even begin to change as humans start to consider new data from possible human ecological niches elsewhere in the solar system.

So, it is no mere idle exercise in creativity to study issues in timing, sequence, tempo, and duration on Mars, even though no actual Martian settlers currently exist. We stand on the verge of the acquisition of the Red Planet, with new data being deposited periodically into the human collective consciousness regarding conditions there.

HISTORY OF IDEAS

The first ideas on Martian timekeeping arose 125 years ago as novelists began to speculate on the possibility of a Martian society. The earliest tales envisioned humans encountering indigenous Martian civilizations. Later, as our increasing scientific knowledge of Mars reduced the prospect of advanced forms of Martian life, the trend was toward stories about humans establishing their own cultures on Mars. As incidental minutiae in a fictional narrative, the subject of keeping time on Mars often received superficial treatment, lacking the detail to be a complete and useful system (Heinlein 1949; Clarke 1951; Piper 1957). Occasionally, such ideas were based on a faulty knowledge of astronomy (Burroughs 1913; 1914; Compton 1966; Lovelock and Allaby 1984). Even when complete systems were described that fairly accurately accounted for the orbital factors of Mars, they did not take into account all the timekeeping needs of a human society (Greg 1880).

The first complete Martian calendar was developed by an astronomer who was active in the calendar reform movement in the 1930s (Aitken 1936; 1936a). Another astronomer invented a complete timekeeping system in the 1950s, going so far as to have a functioning Earth-Mars clock-calendar constructed (Levitt 1954; 1955; 1956). Not only did these systems accurately reflect the astronomical cycles of Mars, but they also took into account many of the sociological aspects of timekeeping.

More ideas on Martian timekeeping have been generated as interest in sending humans to Mars has increased. The Case for Mars series of conferences included two presentations on Martian time (Mackenzie 1989; Gangale, 1997). In the 1990s, roughly 20 authors wrote on the subject. The first commercially printed Martian calendar was available for the Martian year bracketing the turn of the millennium on Earth (Graham and Elliott 1998; 1999). A number of real-time Martian clocks are currently posted on the World Wide Web. Links to more than a hundred online Martian timekeeping topics are available on the Martian Time website at http://www.martiana.org/mars/, along with an in-depth discussion of the systems that are known to the authors of this presentation.

AN ARCHITECTURAL HIERARCHY

As with the building of a physical structure, the architecture of Martian time has its foundation and various higher levels. We identify five major sets of ideas.

The first step was the establishment of a prime meridian. This was settled within the scientific community in the mid-19th century. Indeed, Mars had a universally standardized prime meridian several decades before this question was settled for Earth! Of course, the definition of the Martian prime meridian has been successively refined over the years, but it has remained near the location established by Beer and Madler on their 1830 map.

Once a standard reference meridian was established, the next question was how to divide the Martian solar day (sol) into subunits. The system that has arisen through long-standing custom and use is to divide the sol into 24 hours, each containing 60 minutes (Lowell 1895), and as more precision has become necessary, each minute has in turn come to be divided into 60 seconds. In essence, the 24:60:60 Earth clock has simply been stretched by 2.75 percent to fit the slightly longer Martian sol. The scientific world has a common means of expressing the time of day on Mars.

The third problem of Martian time is to establish a common scientific expression of the date on Mars. This requires agreement on a heliocentric longitude (L_S) defining the first sol of the Martian year, and also agreement on which specific revolution of Mars to define at the Martian year 0. This paper assumes that establishing the vernal equinox of the northern hemisphere (L_S=0) as Sol 0 is readily achievable, although this assumption may provoke an unexpected debate. The second part of this issue, standardizing an historical epoch, will generate more discussion, because it is not obvious that there is one best choice from the standpoint of astronomy. Thus, consideration of this question moves us further on the path of the social construction of Martian time, although, to some extent, all previous standards of Martian time have been socially constructed within the space science community.

The time for setting this third set of standards is upon us. With all of the data that has been and continues to be returned from the various instruments on the surface of Mars and in orbit around Mars, the correlation of data between various space missions, past present, and future, will be greatly facilitated by a common system of Martian dates—in essence, a rudimentary Martian calendar. Indeed, it is not a little surprising that this has not yet been accomplished. The current situation is analogous to the ships of each seafaring nation navigating on the basis of its own capital city as the prime meridian.

The fourth stage in the development of Martian time will be the promulgation of a fully characterized calendrical structure, including an intercalation formula, the number of months in the year and the number of sols per month, the number of sols per week, and whether such weeks should be integral to the months and the years or simply float through the months and the years as in the Gregorian calendar. This complete structural description of a Martian calendar must be arrived at via a social process. Perhaps, at first blush, this would place the discussion outside the scope of a physical science journal. Yet well-known names in the physical and life sciences have weighed in on these issues, and logical argument can and should be applied to the problem of constructing a Martian calendar.

Stage 5 in the development of Martian time belongs entirely to the realm of social and cultural considerations. This will be the debate over nomenclature. We have long had an accepted term for the Martian solar day, but what shall we call the Martian year, month, and week? What names shall we apply to the sols of the week and the months of the year? In general, such issues may not be of interest to researchers, although since we have a term for the Martian solar day, it may be convenient to the scientific community to coin a term for the Martian year.

WHY NOT EXPORT EARTH TIME TO MARS?

So what is the big deal with Martian time anyway? Since we have a standard for civil time on Earth, why not export it to Mars in order to maintain commonality? This straightforward idea overlooks the fact that the time standard we have adopted on Earth works for everyone only because we all live on Earth and are subject to all of the same natural cycles. The problem is that Mars has its own distinct natural cycles, and the impact of these cycles on human activities on Mars will be impossible to ignore. Our daily routine will be synchronized with the Martian day, not the Earth day, and it will be the annual passing of the Martian seasons, not those of Earth, that will have a significant effect on our activities.

How long is a day on Mars? Just about any astronomy book will tell you that the rotational period of Mars is 24.6229 hours, or 24 hours, 37 minutes. However, note that the same table also gives Earth's rotational period as 23 hours, 56 minutes. But isn't Earth's day 24 hours long? What happened to the missing four minutes? The difference is that the 23 hour, 56 minute figure is a sidereal day, i.e., Earth's rotation as measured from the point of view of a fixed reference angle. But as Earth turns once on its axis, it also moves along its orbit around the Sun, and the direction from the Earth to the Sun changes slightly. It takes Earth an extra four minutes to rotate through this additional angle, and so Earth's solar day, measured from the point of view of the Sun, is 24 hours. The same principle applies to Mars. Although its sidereal day is 24 hours, 37 minutes, its solar day is 24 hours, 39 minutes, 35.244 seconds (88775.244 seconds).

Humans have already experienced the need to work according to a Martian daily schedule at times during the past quarter century. During the Viking missions in the 1970s, operations teams had to schedule tasks for the two landers based on the daylight hours at the two sites. A new term—sol—was coined for the Martian solar day. The sol on which each lander touched down was designated "Sol 0," and each successive sol was numbered consecutively. In order to express the local time at each site, the sol was divided into 24 Martian hours, which were in turn divided into 60 minutes per hour and 60 seconds per minute, just as on Earth. This same system was later used during the *Mars Pathfinder* mission in 1997.

Notice that the system of time used during the Viking surface operations, and which was later adopted for the *Mars Pathfinder, Spirit,* and *Opportunity* missions, made use of only one natural Martian cycle: the solar day. What about the Martian year? *Viking Lander 2* operated for 1,280 sols (nearly two Martian years), and *Viking Lander 1* lasted even longer—2,244 sols, or more than three Martian years.

How long is a year on Mars? Just about any astronomy book will tell you that the orbital period of Mars is a bit less than 687 days. But this measurement is in 24-hour Earth days, not Martian sols, which are almost forty minutes longer. If you lived on Mars, you would count 668.5907 sols from one vernal equinox to the next.

On Earth, the vernal equinox (the beginning of spring) is used to define the beginning of the astronomical year. This occurs when the Sun is directly above the Earth's equator, and the daylight and night periods are exactly 12 hours each (the term equinox is derived from two Latin words and translates literally as "equal night"). In organizing data for Martian phenomena that are influenced by the annual cycle, scientists often use the Martian vernal equinox as the starting point of the Martian year. Data is then graphed on a time scale from 0 to 668.6 sols.

The question then arises, how does one refer to one specific Martian year versus another? How do we organize our description of annual phenomena? For the Viking era, this was easy. One could refer to Sol 207 of Viking Year 1, for instance, and compare conditions at a landing site then with the phenomena observed on Sol 207 of Viking Year 3, exactly two Martian years later. But the situation becomes more complicated when one wishes to compare data across two or more Mars missions. A researcher interested in global weather patterns might want to compare data from several orbiter missions obtained during a number of different Martian years. For instance, suppose one needed to refer to a data point on Sol 475 of the second Martian year of *Viking Orbiter 1* operations and compare that to a data point on Sol 475 of first Martian year of *Mars Global Surveyor* operations. This is a rather cumbersome way of expressing what are essentially two Martian dates. To simplify expressing Martian dates, we need to agree on a standard epoch, that is, a starting date from which we all agree to count Martian years.

So far, we have discussed some of the technical requirements for measuring time on Mars. That is a quite narrow perspective, and what we currently have on Mars is a fairly rudimentary time system that serves the needs of a specific community of space scientists. Even so, one can see that as more spacecraft are sent to Mars and as more data accumulates, the need for a more comprehensive Martian timekeeping system grows.

Let us fast-forward to a time in which there is an initial human presence on Mars. A system approaching the level of completeness of Stage 4 will probably become necessary once a long-term human presence is established on Mars, and depending on the mission profile that is ultimately selected, long-term presence may begin with the first mission. A conjunction-class mission, involving Hohmann minimum-energy transfer trajectories on the outbound and inbound legs, requires approximately a 470-sol stay on Mars to await the proper alignment of Earth and Mars for the return flight. This is 70% of a Martian year, and although the crew will be protected from the environment, they will not be oblivious to it. The changing of the seasons may have a significant impact on surface operations, and since the phasing of the seasons will be different from one mission to the next, planning for these environmental factors will necessitate the use of some sort of an annual Martian time-scale in addition to the Mission Elapsed Time traditionally used by NASA. Additionally, the psychosocial well-being of a micro-society operating with a high degree of autonomy (due to the communications time delay—as much as 40 minutes near solar conjunction) in an extreme environment will necessitate the use of familiar rhythms of work, rest, recreation, and cultural observances. These are the functions that are served by a calendar consisting of weeks and months. Since real-time communication with Earth will be impossible and messages from Mission Control will have the character of voicemail, there will not be the tight control of the scheduling of tasks that characterizes missions in near-Earth space. The organization of time will be more in the hands of the crew, and during their time on Mars, the central organizing principles of time will be areocentric, not geocentric. “You are in a different *time* from us,” intoned the president of the United States in a taped message to the crew of *Capricorn One.*

Let us fast-forward even farther ahead to a time in which there is a human society on Mars, with people from all conceivable walks of life, not just scientists, engineers, and technicians, but accountants, artists, and athletes. What sort of timekeeping system will these Martians need? In asking that question, one needs to understand that developing a timekeeping system to serve the broad spectrum of humanity and all of its activities is really not a technical problem. The astronomy of developing a clock and a calendar is relatively straightforward. Once the space scientists determine the length of the sol and the Martian year, their part of the job is pretty much done. Almost anyone can do the math; it’s only on the level of middle school algebra. However, the true scope of the problem goes far beyond that, because developing a comprehensive civil time system is mostly a human problem involving social necessity. One needs to understand how human societies organize themselves in the temporal dimension at various social levels. Also, since each human society has done it differently, each of us has a cultural bias when it comes to measuring time. Finally, since there is no obvious best way to organize time for a society, arriving at a universally accepted system of Martian timekeeping will involve developing a consensus via a social process.

METHODOLOGY

A common method in the social sciences is to choose baselines against which to examine patterns of data or opposing models. In the case of human diurnal cycles and dimensions of social life dependent upon long-standing systems of timekeeping, we may choose baselines from among the nearly 80 systems for keeping time on Mars that have been devised in the last 125 years. We chose as baselines two relatively modern and widely-published conceptualizations to use as our comparative.

Robert Zubrin published his ideas for a Martian calendar in the November/December 1993 issue of *Ad Astra,* the National Space Society’s magazine. He also described his calendar in his 1996 book, *The Case for Mars.* Due to his position as president of the Mars Society, Zubrin’s calendar proposal continues to attract the interest of the Mars enthusiast community.

The science fiction author Kim Stanley Robinson described both a Martian clock and a Martian calendar in his 1993 novel, *Red Mars,* the first in a trilogy of Martian novels that are probably the most widely read of that genre to ever be published.

We wondered how a society of Mars settlers would fare under the Zubrin and Robinson systems. Here is what we found.

THE ZUBRIN SYSTEM

The Zubrin baseline contains several technical errors. However, even if these flaws were corrected, the basic concept of his calendar is such that it would be very difficult for a society on Mars to put into practice, as we will demonstrate.

TECHNICAL ERRORS - Zubrin set the Martian vernal equinox as New Year's Sol on Mars. Also, he reasoned that it would be convenient to begin the Martian era on a date on which the Martian year and the Earth (Gregorian calendar) year began simultaneously. According to his calculations, the last time these two events coincided was on 1961 January 1.

Zubrin devised an algorithm for converting Earth dates to his Martian system, the heart of which is the following equation:

Mars date = (8 / 15) x (Earth date - 1961) + 1

In this equation, the Earth date is expressed as:

Year + [(the numeric value of the Gregorian month - 1) x 30.4 + (the numeric day of the month - 1)] / 365

The Martian date in year-month-day format must be extracted from the numeric value resulting from the basic equation.

Several approximations in Zubrin's algorithm accumulate to induce significant errors in his calendar. First of all, he derives the length of the Martian year from the ratio of 15 Earth years to 8 Martian years. This is not terribly accurate. Earth's year, measured from one vernal equinox to the next, is 365.2424 days. A Martian year, measured from one vernal equinox to the next, is 686.9710 Earth days. This means that in 15 Earth years, there are only 7.975062 Martian years. This doesn't sound like much of a discrepancy, but it is, as you will see in a moment.

Another error in Zubrin's calculations is that he assumes there are 365 days per Earth year, whereas the actual value is 365.2424. Since the length of the Martian year is tied directly to the length of the Earth year via the 15:8 ratio, this short value for the Earth year has the effect of further shortening the duration of the Martian year in Zubrin's algorithm. The combined error results in a Martian year of only 15/8 x 365 = 684.375 Earth days in Zubrin's calendar.

When considering a Martian calendar, one needs to talk in terms of the Martian sol, which is 2.75 percent longer than an Earth day. There are 668.5907 sols in a Martian year, measured from one vernal equinox to the next. Because he uses the inaccurate 15:8 ratio and assumes 365 days in an Earth year, Zubrin's calendar really has only 15/8 x 365/1.0275 = 666 sols in a Martian year. As the saying goes, "the devil is in the details."

The Gregorian calendar replaced the Julian calendar because the old calendar had three days too many in 400 years. By comparison, Zubrin's calendar is missing nearly three sols every Martian year. This adds up to a big problem over just a few years. One of the primary purposes of a calendar is to keep in step with the seasons. Zubrin's calendar is clearly intended to do this, since each year supposedly begins on the Martian vernal equinox. However, because it is based on a highly inaccurate formula, it fails to achieve this purpose.

For instance, although New Year's Sol may occur on February 15, 2004 according to Zubrin's calendar, the actual Martian vernal equinox occurs on March 5, nineteen days later. Researchers can confirm this by consulting that year's *Astronomical Almanac,* a joint publication of the Greenwich and U.S. Naval Observatories, or they can consult NASA Reference Publication 1349.

As another example of the calendar's inaccuracy, Zubrin's formula led him to believe that a Martian vernal equinox occurred on January 1, 1961. Zubrin used this date to begin counting Martian calendar years since, according to his calculations, the beginning of the Earth year and the beginning of the Martian year occurred simultaneously. However, the real Martian vernal equinox occurred 31 days (30 sols) earlier on 1960 December 1. Again, researchers can confirm this by consulting the *Astronomical Almanac* for that year.

To recap, New Year's Sol on Zubrin's calendar has gone from being 30 sols late in 1961 to being 19 sols early in 2004, a total discrepancy of 49 sols over that time. Indeed, Zubrin's calendar was only briefly in synch with Mars in 1993, when he published his original article in Ad Astra.

PRACTICAL PROBLEMS - Even if these technical defects were corrected, Zubrin's calendar would still be problematic to put into practice. He casually dismisses the idea of having months of equal duration. "Such equipartitioned months don't work for Mars because Mars' orbit is elliptical, which causes its seasons to be of unequal length." While it is true that Mars' seasons are unequal in length, it does not logically follow that "equipartitioned months don't work." For whom would they not work, and why? Zubrin does not explain this. Another vague assertion is, "In order to predict the seasons, a calendar must divide the planet's orbit not into equal divisions of days, but into equal angles of travel around the Sun." Why must it? Earth's Gregorian calendar does not divide the planet's orbit into equal angles. The arc of Earth's orbit that is represented by February is only 27.6 degrees, while March occupies 30.6 degrees, a variation of more than ten percent. Yet anyone can predict with great confidence that the first day of spring will occur on or about March 21 every year.

Zubrin declares that "if we want months to be useful units and choose to retain the terrestrial definition of a month as a twelfth of a year, then a month really is 30 degrees of travel around the Sun." Two observations can be made here. First of all, this is exactly the opposite logic from the design of the modern clock. One could argue that we should define an hour as one twenty-fourth of a day (or sol on Mars), in which case an hour is really 15 degrees of travel of the Sun across the sky during the day. The problem is that the terrestrial day (and the Martian sol, for that matter) varies in length in the course of the year, and so that 15 degrees of travel takes slightly longer at some times than at others. Of course, we don't have hours that are sometimes 59 minutes long and at other times 61 minutes long. This is because the modern clock is based on the length of the mean solar day averaged over the span of the entire year, rather that being based on the variable rate at which the Sun travels across the sky.

Secondly, one should ask, "For whom would Zubrin's equal-angle months be useful units?" Suppose you are living on Mars, and you just got paid for the month. You got by fairly well in late autumn in the northern hemisphere, when the months lasted less than 50 days, but now it is late spring, so you are going to have to make that paycheck last 66 days. The problem is, you can only buy enough heating fuel and food for about 50 days, and you will have to shiver and eat shoe leather for the last couple of weeks. There would be cold comfort in the fact that Mars traveled 30 degrees around the Sun that month, as every other month. People live from day to day and from paycheck to paycheck, not from angle to angle.

One could counter that Martians could get paid more at one time of the year than at another. Monthly rents could also be seasonally adjusted, along with a million other prices, just so we could have a diagrammed calendar that traces immaculate 30-degree angles in planetary space. One can only imagine the administrative costs that this would impose, not only on every commercial enterprise on Mars, but on every field of human endeavor on the Red Planet.

The success of sustained human habitation on Mars will depend on such settlements becoming self-sufficient as rapidly as possible. It is a matter of debate whether the first Martian colonies will be funded by terrestrial governments, private investors, or a partnership of both. In any case, the start-up costs leading to a sustainable Martian economy will be huge, and the patience of either taxpayers or investors will not be inexhaustible. In all realms, the critical concern will be the shortest path to profitability consistent with human safety. Profitability requires efficiency, which in turn requires that all things be made as simple as possible.

Zubrin's calendar is far from simple. Only two of the twelve months contain the same number of sols. Here on Earth, we use a short mnemonic poem to help us figure out which months on the Gregorian calendar have 30 days and which have 31. Imagine how long a poem describing Zubrin's calendar would be, how long it would take to memorize it, and how long it would take to mentally recite it each time one needed to determine how many sols were in a particular month. Imagine these mental exercises being performed over and over by every person on Mars, sol after sol, year after year.

A final criticism of Zubrin's work is that he never even mentions the concept of a week. This is a glaring oversight, for nearly every calendar ever used on Earth has included some unit of time shorter than a month, consisting of a handful of days, in order to regulate commercial and social activity. Without this, any description of a calendar is incomplete.

Table 2: The Zubrin Calendar

Days per Week	*undefined*
Days per Month	46-66
Months per Year	12
Leap Days	*undefined*
Leap Day Position	*undefined*
Basic Intercalation Formula	15/8 * 365/1.027491
Extended Intercalation Formula	*undefined*
Mean Length of Calendar Year	666.06
Base Astronomical Year	Vernal Equinox
Accuracy	<1 year
Mean L_S of Beginning of Year	0
Year Count Start	1
Epoch (CE)	1961 Jan 1

DISCUSSION AND CONCLUSION - Zubrin designed his calendar from the perspective of a space scientist. The irony is that space scientists do not even use the civil calendar in their work because it lacks the necessary precision. Knowing only the time of day and the day of the year, one can only determine the position of the Earth in its orbit to about one degree of solar longitude, because some calendar years have 365 days and some have 366 days. For this reason, space scientists instead use precise astronomical tables called ephemerides. In contriving to make all the months fit equal angles, Zubrin attempted a solution for which there never was a problem, and in so doing created a huge inconvenience for society at large. Furthermore, even as a work of space science, Zubrin's calendar fails "to predict the seasons," since the Martian vernal equinox slips nearly three sols every Martian year.

The available data strongly indicates that the Zubrin calendar is failing to be socially constructed (Gangale and Dudley-Rowley 2002; 2003) despite the fact that Zubrin's Mars Society is the nexus of the Mars enthusiast community. Online survey data collected between February 2001 and December 2003 shows a 4 to 1 preference for 24 months of approximately equal duration (discussed below) over Zubrin's scheme of 12 widely variable months.

THE ROBINSON SYSTEM

THE ROBINSON CALENDAR - Zubrin refers to "the terrestrial definition of a month as a twelfth of a year." More accurately, a month is the synodic period of the Moon in its orbit around Earth. This is a natural unit of time. Were that period ten days or a hundred days, that definition would be the same. It happens that there are 12.37 lunations in a year, and so in solar calendars there are 12 months. The definition of a month as a twelfth of a year is a derived unit of time.

If we apply the synodic period of the Moon (29.53 days) to Mars, we find that it is equal to 28.74 sols, or 1/23.26 vernal equinox years. Rounding down to 23 yields a prime number, which is an exceedingly inconvenient way to divide up the Martian year. On the other hand, rounding up to 24 yields a number that is divisible by 2, 3, 4, 6, 8, and 12. Dividing the 668.6-sol Martian year into 24 months also results in months slightly less than 28 sols in average duration, thus most months would be 28 sols each, or exactly four 7-day weeks, while a few would contain 27 sols.

The 28-sol month is preferable for another reason that has no obvious connection to astronomy. On Earth, the average menstrual cycle is 28 days, and there is at present no reason to expect that this cycle will be substantially different on Mars. Everyone recognizes the importance of the diurnal cycle in regulating human activity. We all need to get a good night's sleep and eat several meals a day. The other human cycle that is necessary to human existence is the menstrual cycle. Since this is a natural human cycle of time, incorporating this cycle into a Martian calendar is highly desirable. It is only prudent to consider human factors in the design of any system that has a human interface. A calendar is very obviously a system that has a human interface, and the menstrual cycle is very obviously a human factor.

Table 3: The Robinson Calendar

Days per Week	7
Days per Month	27-28
Months per Year	24
Leap Days	*Undefined*
Leap Day Position	*Undefined*
Basic Intercalation Formula	*Undefined*
Extended Intercalation Formula	*Undefined*
Mean Length of Calendar Year	*Undefined*
Base Astronomical Year	Winter Solstice
Accuracy	*Undefined*
Mean L_S of Beginning of Year	272.1
Year Count Start	1
Epoch (CE)	2026 Apr 30

Robinson did not explicate his rationale for devising his 24-month Martian calendar, but for all the reasons discussed above, he made a good choice. However, Robinson left a number of design details undefined. There is no specified intercalation formula to account for the fractional number of sols in the Martian year, nor is the position of the leap sols—whatever their number—in the calendar year defined. Thus there is no way to calculate the mean length of the calendar year, or to judge the accuracy of the calendar.

THE TIME-SLIP CLOCK - Zubrin supports the stretched 24:60:60 clock for Mars that has long been used by space scientists (1993):

> A time of day on Mars, say 9 a.m, would have exactly the same physical significance with regard to the orientation of the planet towards the Sun as it does on Earth. All the equations of celestial navigation would also remain valid, although stellar latitude measurements would have to be taken with respect to the Martian pole star…

In Part 1 of his 1993 novel Red Mars, Robinson describes the Martian clock devised by the first one hundred colonists:

> And then it was ringing midnight, and they were in the Martian time slip, the thirty-nine-and-a half-minute gap between 12:00:00 and 12:00:01; when all the clocks went blank or stopped moving.

The idea was a very effective literary device, as well as a nostalgic tip of the hat to science fiction author Philip K. Dick, whose novel Martian Time-Slip was published in 1964. Robinson "was unaware of the 'stretched 24/60/60' clock system" until one of this paper's authors discussed it with him via email in October 2003, and rather than intending it as a literary device to add drama to a scene, Robinson took the idea seriously:

> … I take it the second would be expanded just enough to make the Martian day add up to 24 hours there? That would be bad for sports records and various kinds of timing, in comparing them to Earth. I should think the inconvenience of our residual miles and inches would convince people that keeping to a single set of standards was good for science and many other things. In that sense, the time-slip would work better. One could always time those extra 39 minutes on the clockfaces, rather than blanking out, if people needed to be precise in the slip.

Now, in a venue requiring around-the-clock operations, the time-slip clock would present problems. For instance, with three 8-hour shifts, one shift would work through the 39-minute time-slip, while the other shifts would have this as free time, which would hardly be equitable, and would be a needless point of contention among the crew. Alternatively, each crew could work an 8-hour 13-minute shift, but this seems like an awfully clunky system.

Of course, the great disparity in surface gravity between Earth and Mars makes any comparison of sports records problematic—even given a 14.7-psi environment with atmospheric constituents in their normal proportion—so using a slightly different clock would hardly be a consideration. There would have be two sets of records, one for the Earth leagues and one for the Mars leagues.

Also, Robinson's comment that miles are inconvenient is puzzling. The nautical mile is used throughout the world for both sea and air navigation, because it is a natural unit for that application: a nautical mile is equal to one minute of latitude. This is very convenient indeed!

Which brings up the inseparable relationship between the way we divide up the day and the way we measure angles in spherical coordinate systems, both geographical (latitude and longitude in degrees, minutes, and seconds) and celestial (right ascension in hours, minutes, and seconds, and declination in degrees, minutes, and seconds). The time-slip would break this relationship, and make time-spherical coordinate calculations extremely awkward. To re-establish this relationship in the time-slip system, it would be necessary to have a spherical coordinate system containing 369 degrees 53 minutes 48.66 seconds around each axis! Imagine recalculating the coordinates of Martian surface features, or the coordinates of stars, using such a system.

It is important to recognize that science is being done on Mars (and always has been) by the stretched 24:60:60 clock—by people who fully understand that the SI second is the basis for many derived scientific units of measurement. However, there is a distinction to be made between the scientific use of time (in terms of metrology) and the operational (or "civil") use of time. They are situationally specific, need not be the same, and in practice are not. For instance, meteorologists often express wind speed in knots (nautical miles per hour). This is not an SI unit, but a civil unit for the convenience of navigators and aviators.

In an operations environment, it is far more convenient to retain the structure of the 24:60:60 clock and simply redefine the units. For instance, if a scientist is studying diurnal phenomena on both Earth and Mars, the time of day needs to mean the same thing on both worlds in terms of solar local hour angle, not in terms of elapsed SI seconds.

Translations from one system to another as convenience dictates occur all the time in mathematics and the physical sciences: using different number-base systems, using radians to solve integrals, et cetera. Of course, non-scientists on Mars will seldom be concerned with the time conversions that scientists will need to make between the civil and SI systems; rather, they will be content with the simplicity of the 24:60:60 structure.

Standards exist for the sake of convenience. It makes little sense to insist on a single set of standards when to do so would cause no end of complications. Rather, the rational thing to do is to design two systems (in this case, a second system—the first one is a given) such that the interface between the two is as operationally simple as possible. This fully explains why scientists have always used a time system on Mars that is not based on the SI second.

IMPLEMENTING A COMPREHENSIVE SOLUTION

Choosing the point in Mars' orbit for beginning the calendar year, and selecting the specific revolution for the epoch, establishes a minimum solution to the problem of a Martian date system. These are issues that can and should be resolved in the near term, just as the design of the Martian clock has long since been settled.

As briefly discussed earlier, there are other issues of Martian time. These involve establishing a system of weeks and months, together with a system of names for the sols of the week and the months of the Martian year, and even distinctive terms for the Martian week, Martian month, and Martian year as units of time. Weeks and months are units of time that are necessary to a functioning human society, but not to machines operating on the surface of Mars or in orbit around it. Even though we are decades away from the first human landing on Mars, and perhaps a century or more from the establishment of a human society on Mars, there is a rich body of literature regarding such comprehensive solutions to the Martian calendar problem, consisting of more than 80 proposals over the course of the past 125 years. While the consideration of these ideas can be a fascinating intellectual exercise at the confluence of the space sciences and the social sciences, is a full-blown Martian calendar really needed right now? Are the number of sols in a week, the number months in the Martian year, and the names associated them, issues that need to be decided in the near term?

One school of thought considers these to be issues best deferred until there is a sustained and abundant human presence on Mars requiring these social constructs of timekeeping. Others contend that resolving such issues expeditiously and promulgating a human-oriented timekeeping system for Mars could be an important symbol of humanity's aspiration to incorporate Mars into its ecology and culture, and might serve to hasten the human acquisition of Mars. These are matters of philosophy, politics, and culture, and are likely to provoke a lively and extended debate, especially in coming decades as the prospect of the human habitation of Mars becomes more real.

However, the discussion needs to be an informed one. Too often the authors of Martian calendars—some of them prominent scientists—have published their ideas while citing only one or two poor examples of previous works, or none at all, inviting readers to question how well they researched the topic. In spite of the advent of the Internet and readily accessible electronic library databases, reputable authors continue to publish work that is less than scholarly. In some measure, this is forgivable. One can imagine that the inventor of a Martian calendar believes his or her idea to be so futuristic that no one could have thought of it before. The primary author of this article freely confesses his own ignorance of the work of others at the time he published his first article on Martian timekeeping (Gangale 1986), which he came to realize shortly thereafter (Gangale 1988). Our purpose here is not to indict other authors who have committed similar oversights, but to raise awareness on this subject, so that the same wheels are not repeatedly reinvented, and the discussion can progress to new issues.

One can postulate that a comprehensive solution might be officially adopted by international agreement, either via an ad hoc conference involving NASA, RKA, ESA, NASDA, et cetera, or via existing mechanisms within the IAU. Such an international agreement would probably be decades—even centuries—in coming, however, since some nations will have more of an interest than others in implementing such a system. As a practical matter, the nation most involved in the exploration of Mars will have the greatest need for a comprehensive solution. A country could unilaterally implement such a solution, and as we mentioned earlier, there would be political and cultural components to such an implementation decision. Even in this case, such a decision might be a long time in coming. The political will to officially establish such a system would likely only come in the context of a substantial societal commitment to colonize Mars. There are political risks to such an implementation mandated from above, because it can easily flop. The lesson of history is that a comprehensive solution, i.e., a calendar consisting of weeks and months, complete with names of the days of the week and the months of the year, must be socially constructed if it is to be successful.

A more plausible and earlier scenario for implementing a comprehensive Martian timekeeping system is that some user community could implement such a comprehensive solution for its own purposes, and the practice might spread to other communities as they became more involved in the exploration of Mars. For example, the word “sol” originated somewhere within the Viking program circa 1975, and in the years since it has become the generally accepted term. The use of the word “sol” was not mandated from above; it propagated via a social process. In fact, three decades later, it is not known exactly where the term originated. Similarly, the stretched 24:60:60 clock for Mars was an idea that circulated in the scientific community for decades. Once it became necessary to operationalize a system during Viking missions on the surface of Mars, choosing the system that had already been socially constructed was a “no-brainer.”

With regard to implementations mandated from above, incremental solutions have historically met with more success. The Gregorian calendar was a small correction to the Julian calendar, whereas more sweeping reforms of the calendar have never received much support. A minimal solution for Mars along the lines we describe is thus the next logical step.

CONCLUSION

The Martian calendar problem may be considered by some to be a far-out, fanciful, futuristic topic, yet it has a long history. That history may have been sparse and sporadic in its early development, yet it has had its luminaries, and the discovery of forgotten work continues. To some it may seem as useful an exercise as medieval arguments over the number of angels dancing on a pin, yet we look forward to a future when humans walk on Mars. And more than just walk, but are born and learn to walk, grow up and get married, have children and mark all of the other human events that make a calendar necessary.

As we humans establish ourselves as a multiplanetary species, spreading throughout the Solar System during this new century, we will leave behind the 24-hour day and the 365-day year. These are cycles that are peculiar to Earth, and as a product of billions of years of evolution on this planet, we are designed to operate by them. Humans will have no use for diurnal periods that are hundreds of hours long. Similarly, years of 12 or 29 times the duration of the terrestrial year (the orbital periods of Jupiter and Saturn, respectively) will be of no practical use in human affairs. We define a standard unit—the second—in as abstract a way as possible for the physical sciences, but time is a social measurement, first and foremost. We awaken, we work, we eat, and we sleep. We gather to transact business and recreate. We are born, we mature, and we die. How will we measure ourselves, our biological and social needs, according to the passage of time on alien worlds? What social measurements of time will we bring with us from Earth to make our new homes less alien? To what physical cycles of these new worlds will we adapt ourselves and our new societies?

Zubrin acknowledges, “The idea of a Martian calendar and timekeeping system is not original, and many have been designed in the past.” This body of work should not be summarily dismissed; rather, it deserves to be carefully researched for the valuable ideas it may contain. A successful calendar cannot be a product of vague reasoning and approximate astronomy. Furthermore, a grounding in exact astronomical relationships, while a necessary starting point, is still not sufficient. The combination of calendrics and horology, which we call “time architecture,” is a subject where space sciences, social sciences, and biomedical sciences intersect. A Martian clock and calendar cannot simply be designed on the basis of the planet’s periods of rotation and revolution, nor on the uncritical adherence to pre-existing “standard” units of measure, but must be carefully crafted to serve the common needs of the many walks of life in an emerging society struggling to make a go of it on a new world.

We invite the researcher to visit the Martian Time website at http://www.martiana.org/mars/, where he/she will find information on more than 80 Martian calendars dating from 1880 to the present.

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