

DESIGN AND ROBOTICS TO REDUCE CHORE TIME ON MARS

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ABSTRACT

Some of the logs and reports from the crews thus far at the Mars Society's research stations have mostly skipped over it, and some have covered a common topic explicitly. That common topic is the time spent of necessity out of “sim” outdoors together with the personnel time spent doing chores outdoors and indoors. Taken together, those times when added to the time for human biological functions (such as sleeping, eating, etc.) reduce the time that can be devoted to research and exploration (“possible productive time”). Some improvements in productive time will be attained on Mars because Mars will be paperless, even though thus far, the research stations have not moved to going paperless. More than offsetting that improvement on Mars, however, will be additional chores time devoted to dust mitigation and to assuring life support integrity. And on Mars, personnel time spent in the equivalent of “out of sim” outdoors will be impossible. Hence, a realistic practical concern is how to increase the on Mars productive time while not reducing the time devoted to human biological functions.

Clearly, main solution directions have to target reducing the personnel time devoted to chores. A review of the logs and reports from the Mars research stations suggests two directions for action. One affects the design of the enclosures occupied by the personnel (habitat, rover, etc.) to eliminate the need for chores, and the other suggests the use of robots to do the more time consuming chores not eliminated by the adopted design of the enclosures. Because life support will be so critical for the on Mars personnel, six examples of leading candidate topics could be power creation and use, in-enclosure atmosphere management and maintenance, potable water supply and management, waste disposal processes, Mars suit cleaning, and restocking the rover with consumables.

Keywords: doing science on Mars, infrastructure chores, chores reduction, Mars information system, automating chores, robotic chores, paperless operations

PERSONNEL TIME USAGE

Detailed conscientiously acquired quantitative data on personnel time usage have not been consistently available from the reports and logs of the crews who have served in the Mars Society's analog research stations.¹ Nor are they available from the reports and logs of the crews of Mir and of the International Space Station. The personnel time usage data available from all of those sources are scattered, occasional, and primarily qualitative, such as “was late,” and often

lacking in relevant context details. What can be often inferred from the reports and logs is that the personnel usually had more to do than what could be accomplished in the time available, and that individually the personnel very rarely had spare time, either by happenstance or both scheduled and occurred. Usually doing fall back plans took over when unanticipated conditions occurred, such as from bad weather, equipment failures, rock slides, etc.

The reports and logs do give some qualitative data about the use of personnel time. A general summary of those qualitative data can provide a baseline view of the time usage.

Biological functions. To preserve life and functional competence, human beings have to devote time to the performance of common biological functions. Some biological functions usually take place concurrently with other functions, such as breathing, talking, digesting, circulating the blood, etc. Some usually do not occur well concurrently with other human activities and take time to be done, or are not as well done concurrently. Among those are sleeping, eating, urinating, bathing, resting, dressing, socializing, etc.

Habitat operation and maintenance. Preserving human life on Mars will critically depend upon maintaining the integrity of whatever be used as habitats by the on Mars personnel. Since crew health and welfare will, as a matter of realism, be the top priority, maintaining and operating the habitats will be the top claim on the time of the personnel.

Mission work. The nominal key reason for sending human beings to Mars will be to learn and report data back to Earth about Mars. That will likely be the official mission, and have a high priority, second only to crew health and welfare as a desired use of on Mars personnel time.

Mission overhead chores. To make possible the mission work, some mission support chores will have to be done. Among them will be keeping the mission tools and equipment in usable condition, expressing as data what the on Mars personnel find about the nature and properties of Mars, and then communicating those data. Emphasized most likely will be the results of doing Mars exploration beyond what could be accomplished by having only robots do the exploration.

“Living off the land.” For the first human explorers, Mars will be an alien and unforgiving environment, with a high cost of importing anything. Hence, as Robert Zubrin has pointed out, effort should be expended using equipment provided to turn to human use some of what Mars has.² A classic example is to produce fuel on Mars from what is available on Mars. While some of these efforts can be automated to minimize human involvement, some personnel time will be needed to get and keep “living off the land” processes working reliably.

“Out of sim” work. While these have been noted as occasional uses of major chunks of personnel time at the Mars Society research stations, on Mars they will be tiny uses of on Mars personnel time, and probably only under dire circumstances. The Mars environment will almost always rule out any attempts to have the on Mars personnel work “out of sim.”

The net effect of the differences between conditions on Mars and at the Mars Society research stations will be to increase the proportion of time doing chores on Mars, compared to conditions at the research stations. While “out of sim” time will drop very significantly on Mars, almost all of the other categories of chores time will tend to increase, and in aggregate increase more than the difference between the length of a day and of a sol. The one category that will not tend to

increase is mission work; out of its time will come the time increases in other categories. Yet the justification for or value of sending human beings to Mars is what the on Mars personnel will get done in mission work.

What is wanted and will be needed on Mars is to make the mission work productive, and to devote more on Mars personnel time in each sol to doing it. That is, the possible productive time of the on Mars personnel is what needs to be maximized, while preserving crew health and welfare. Two major avenues for increasing the overall productivity of the on Mars personnel are to reduce chores time and to go paperless. To reduce chores time will have to involving having fewer chores to do, and to do those chores faster and easier. Possible ways of doing that are offered later in this presentation. Going paperless, as has been described at prior conferences of the Mars Society, reduces the time spent in capturing, storing, communicating, and using data, both in mission work and in habitat operation and maintenance, while improving the accuracy, completeness, and accessibility of data.³

What action could be taken to reduce chores time for personnel on Mars, to have fewer chores to do, and to do those chores faster and easier? From studying the available logs and reports, three directions appear as prime targets for initial action:

Design considerations. Designs for habitats, rovers, mission work, Mars suits, tools, equipments, etc., could be reviewed to find or create new or revised designs that reduce the need for human-done maintenance or operation. Some alternatives are covered in the design considerations sections below.

Work practices. How could work practices for use on Mars be improved to make the work easier, more simple, and faster to do, while keeping accuracy and relevance high? An area of particular focus is likely to be work done while in Mars suits. Having available equipment and tools with multiple capabilities could save chore time while weighing less and taking up less space in the habitats and rovers, and costing less to send to Mars. Easy to use tools could include some automation, or tie in with paperless operations automatically, or both. Some possible improvement areas are covered in the work practices section below.

Robotic assistance. Instead of having a person do a chore, could a robot do it? Clearly, that would depend on what action was taken on design considerations. Some possibilities are covered in the robotic assistance section below.

DESIGN CONSIDERATIONS

Equipments and tools

For use by personnel on Mars, the most significant item of equipment will most likely be the Mars suit. Any presence by any person outside of a habitat or rover enclosure will require that person to be wearing a functioning Mars suit. Wearing a Mars suit should not in and of itself be a chore. But for that to be true, design action is needed on many points. Some examples of them are listed here. Mars suits should be easy and quick to put on, and to take off. The steps to get them functioning (turn on) and idled (turn off) should be automated, with indications visible both outside and within to the wearer about their suit's functioning status. Turn on and turn off processes should require only short waits by the wearer. The Mars suit should impose only

insignificant restrictions on the wearer, especially with regard to hand and finger movements and mobility.⁴ Since in use, Mars suits will get dirty rapidly with clinging dust and dirt, they should be cleanable by robotic means. In use, visors and hand coverings should be workably field cleanable by the wearer while wearing the suit. The suit's consumables (such as electric power) should not have to be replenished as another chore to be done by personnel. Whenever being worn, Mars suits should be tied in with the communication subsystem that is part of the paperless Mars system.

While in Mars suits, the personnel will often have to use tools and equipments. To save personnel time on Mars, those tools and equipments should be designed to be usable and effective within the restrictions imposed by the characteristics of the Mars suits. Especially helpful will likely be multipurpose tools and equipments tied in with the paperless Mars system. While requiring more training of the users, the savings in personnel time on Mars, in weight, in space taken up, and in quality and quantity of data obtained, will very likely more than justify their design and use.⁵ For best results, the design of such tools and equipments will have to involve consideration of the likely mission and habitat situations that may be encountered by the personnel on Mars.

Habitats

Habitats for the personnel on Mars are an especially important target area for chore reduction for two main reasons. Firstly, in the alien environment of Mars, the habitat provides the requisite approximation of the Earth conditions native to the human beings. Secondly, maintaining the health and welfare of the personnel on Mars will be realistically the top priority for action by the on Mars personnel. Hence, designing the habitats and their operations will be the prime area for achieving reductions in chores time in order to free up time for doing more mission work. Regrettably, it also is a difficult area for doing the design work because of the relatively broad choice of alternatives available. As Robert Zubrin has suggested, habitats might be “tuna cans” sent in advance from Earth.⁶ They might be at least initially (and intended only for temporary use), the space vehicles that transported the personnel to Mars. They might be inflatables brought deflated from Earth. They might be refurbished lava tubes or caves. While unlikely for initial personnel on Mars, they might be structures built mostly from “living off the land” materials available at or near the Mars landing site. Etc.

Whatever be the habitat choice, some critically important conditions on Mars will have to be dealt with by the design of the habitat. Some storage space and equipment space may for convenience be included within the habitat. The atmosphere in the habitat must be different from the normal atmosphere of Mars, in composition, density, pressure, humidity, and temperatures, and be maintained that way within relatively narrow bounds. That habitat atmosphere will also have to sharply limit the amount of dust, and isolate changes in it from the wide range of changes in the amount and kinds of dust occurring in the Mars atmosphere. The habitat will also have to block nearly all, except visible light, of the radiation that bombards Mars from the sun and from space. The habitat design chosen should require only very few and brief chores from the on Mars personnel in their use of it, require little set up or start up time, and be quickly and easily decommissioned when the on Mars personnel vacate it.

Since habitats require utilities, a key part of habitat design involves how the utilities are to be provided and maintained. What chores, what kinds of chores, and how the chores are to be done by the on Mars personnel are important parts of the design of habitats for human beings on Mars. Consider four utilities as examples:

Atmosphere. Ideally, keeping the habitat supplied continuously with a desired stable atmosphere should involve no chores for the on Mars personnel. Unfortunately, that will be difficult to realize, partly because of the dynamic demands on the use of the habitat. Those demands will affect the atmospheric composition (including humidity), pressure, temperature, and contaminants. The number of persons in the habitat will vary, as will what they are doing, and how often and when they go in and out. The external environment of the habitat will vary, in temperature and rate of heat loss to the habitats, and in dustiness. A fully automated system to provide and operate the habitat atmosphere would be best. But how are the filters to be cleaned, for example, since a big supply of replacement filters will be nonexistent?

Electric power. Electricity will also a dynamic utility, not only because of direct habitat uses, such as lighting, but also for stationary equipment uses, such as motors, radios, battery chargers, water pumps, etc. Who or what is to keep the electric power flowing reliably as needed and how needed, from generation to points of use? What will be the personnel chores involved, when and how often, and for how much time?

Potable water. What will be the water sources, the water storage, and the water distribution processes? What will be the initial water set up (start up) chores, and the routine repetitive water chores expected of the personnel? When and how often will they be, and how much time will they take? How can automation reduce such chores time on Mars?

Gray water. How automated will be the gray water collection and disposal and/or recycle processes? What will be the routine chores for the personnel to do, how often, and taking how much time? What about the reliability of the processes, and what possible additional chores might have to be done, as under infrequent circumstances?

The design of the habitat for use on Mars can affect the chores time of the personnel also in the biological functions area. For example, consider food preparation and the associated garbage disposal. For any specific habitat design, how much personnel time will be required in meal preparation? Obviously, this depends partly on what is to be the food supply and the forms in which the foods are supplied. What about a habitat design facilitating social interaction during the meal, and quick easy clean up afterward? Or for example, consider sleep. What habitat design characteristics will facilitate each person getting a restful full-duration regular sleep period, yet require little as chores time in turning in and in getting up? What will be the habitat characteristics on a paperless Mars to keep personnel chores related to toilet functions be easy and relatively quick?

A specialized Mars habitat is a crewed rover. To keep mass and transport to Mars space requirements low, a crewed rover will most probably be designed to operate on a replaceable consumables basis, such as on battery power, or “living off the land” fuel. In operation, the rover design might be open and require the personnel in it to be in Mars suits at all times. Or the rover could provide enclosed space for the personnel and tanks of compressed atmosphere to keep the enclosed area habitable for personnel not fully clothed in Mars suits. In either form, the rovers

like other Mars habitats on a paperless Mars, would be designed to provide continual data acquisition as well as communication with a base station and/or other rovers or relay stations, and on an as wanted basis, with individual on Mars persons and access to stored data.

WORK PRACTICES

Mission related chores

As has been partially covered in prior Mars Society conferences, the time needed in order to do some mission related chores can be reduced by going paperless.³ The kinds of chores benefitting from going paperless can be those involving the acquisition, storage, retrieval, and use of data. Going paperless relieves the on Mars personnel from having to spend time writing about the mission work they have done. Instead, they talk as they work, and what they say is converted automatically by the Mars information systems into computer accessible documents. This includes at the personnel's option, capturing and labeling images, such as of landforms, rock samples, microscope views, experiment set ups and results, etc.

An aspect of mission work less improved by going paperless is the handling of tools and equipment, including any laboratory equipment and supplies. As was noted above, some tools and equipments intended for mission use should be designed to save personnel time in their use and maintenance. An especially important item of equipment in this regard is a Mars rover. Specific work procedures and practices for most anticipated situations should be created in advance, and the personnel trained in their use so that rover use time can be done with little use of personnel chores time.

Habitat related chores

Whether the habitat be fixed location or mobile (such as a rover), the personnel on Mars can expect to spend time on habitat related chores in four stages of their time on Mars. The four stages are set up (start up or commissioning), operation and use, maintenance and repair, and shut down (decommissioning). To increase the personnel time available for doing mission work, habitat related chore time in all four stages should be reduced, such as using improved processes and procedures, and by built in automation.

Upon arrival on Mars, a prime concern will be putting a habitat into operation. What the specific set up chores will be, will depend upon what (if anything) has been pre-arrived at the landing site, and what is landed with the arriving crew. A likely situation will be that the arriving crew will initially work from, such as sleep and eat, from what they landed in, while they are setting up a fixed location habitat. That set up process should be fast and lean, but easy and effective. The objective of sending a human crew to Mars is to do mission work, not to put up or to make a habitat. The same principle applies to getting a rover ready for first use.

Once a rover is ready for use and the crew has moved into the fixed habitat, the operation and use stage gets underway and runs concurrently. Both for the habitat and rover, as was noted above, the habitat and rover designs should require but little chores time from the on Mars personnel. For example, the monitoring and recording of conditions should be automated and

connected to the paperless Mars system, for both the rover and the fixed habitat. The habitat and rover designs should incorporate automation for most of the routine conditions and situations that can be anticipated. Tools and equipments and spare parts suitable for aiding unanticipated but doable repair work, such as a broken wire or a loose nut or a shorted battery charger, should be provided to shorten repair chores. Unfortunately, the extent of the aid possible beyond that will depend upon how the crew are to be transported to and returned from Mars.

In preparation for the return of the on Mars crew to Earth, the habitat and rover should be decommissioned. For possible use by future missions to Mars, the decommissioning should be as much as possible, a reversible process. Some data gathering equipment will probably be deliberately left in operating condition and running, to transmit data selectively back to Earth automatically about conditions on Mars after the crew has left for Earth. Hence, the decommissioning chores should be kept brief, such as shutting down selected utilities. One main chore during decommissioning will be to load for transport to Earth the physical samples collected in the mission work. One new chore will probably be recommended in order to take back to Earth with the returning crew, a backup copy of the stored data held by the paperless Mars system.

ROBOTIC ASSISTANCE POSSIBILITIES

Some persons have taken the position that the on Mars exploration of Mars should be done only by robots, not by human beings.⁷ Other persons have taken the position that the on Mars exploration of Mars should also be done by human beings.⁸ Supporters of each position offer cogent reasons why their respective positions should prevail. This presentation takes a combination position, recognizing that people can do some tasks better than can be done by robots, and that robots can do some tasks done better than can be done by people. This presentation's position is that any on Mars exploration that includes having human beings on Mars be done collaboratively with human beings and robots each assisting the other.

Let us review briefly nine examples of tasks that could be done in whole or in part by robots to reduce chores time for on Mars personnel:

Battery recharge and test. Five likely examples of reliance on batteries for power are in Mars suits, in rovers, in backups of solar powered equipments (such as weather stations), in temporary communication relays, and in mobile robots. Equipments for use on Mars and relying on batteries for their electric power, should be designed to incorporate an acceptance of battery recharge and test processes done by robots. The on Mars personnel should be able to use battery powered equipment without personnel having to do the recharge and test chore.

Dust control. To protect on Mars personnel health and some tools and equipments in the rover and the habitat, the dust levels in the enclosed atmospheres will have to be controlled. If that process is not automated to work with the changing dust levels in the Mars atmosphere, then the dust control task should not be done by the personnel. For example, the personnel should not have to clean or replace any dust filters. Instead, have robots to do such chores.

Mars suit turnaround. In using the Mars suits, the on Mars personnel will get the suits soiled and will deplete the suit's consumables. The replenishment of the suit's

consumables, the cleaning of the suit, and the ready to wear testing should be chores done with robotic assistance. The personnel chore time involved should be brief and be mostly a check on the robotic turnaround work. Sometimes a Mars suit will suffer damage during use, and need to be either repaired or replaced by the personnel.

Rover restocking. Major parts of the actions needed to restock the consumables used by the rover should be done with robotic aid. To accomplish this, the design of the rover should be coordinated with the design of the robot or robots that could do parts of the restocking, and the design of the habitat utility systems. An example of affected consumables are the gases needed for maintaining the atmosphere in an enclosed rover. While the unloading of any samples transported by the rover could be robot aided, the storage of the samples in or near the habitat, however, could be robot aided but done cooperatively with the on Mars personnel as a mission chore to do at the end of each use of the rover.

Waste processing. The activities done by personnel in the Mars suits, the rover, and the habitat will routinely generate some waste materials. Some of these will be best handled by the atmosphere and gray water systems serving the habitat. Some may be more effectively handled with less personnel time with the aid of robotics. Waste processing tends to be demanding of personnel time in restricted environments, so processing needs to be adapted to fit the anticipated conditions and resources on Mars, including the disposal of discarded items, such as broken or worn out tools and equipment.

Fuel processing. Much of the fuel processing procedures can be addressed and some automated as a part of the utilities for the habitat and rover. These fuel generation, storage, and distribution procedures along with those associated with the atmosphere and water utilities, are expected to be tied to “living off the land” to a significant extent. Hence the possible contribution of robotic assistance to personnel chores time savings is closely tied to the habitat and rover designs. Since fuel processing tends to be among the more hazardous activities for personnel, attention to fuel processing will be important in mission planning in order to look for ways to save personnel chores time.

Potable water processing. Personnel procedures involved in the start up of potable water processing may be highly dependent on the available resources on Mars near the landing location. But once the supply has been started, the routine acquisition, storage, and distribution operations should take over. Then roles for automation and robotic assistance should be clearly defined and consistently used in order to reduce chores time for the on Mars personnel.

Atmosphere processing. The set up (commissioning) of the habitat will require prompt on Mars personnel attention to getting the automated atmosphere generation working. The processing will very likely have to include acquiring and mixing the gases, raising them to temperature and pressure, distributing the resulting atmosphere where and as needed to support the on Mars personnel activity, and removing the Mars carbon dioxide as well as the human generated carbon dioxide and other unwanted gases (such as odors) and dusts. Time saving from reduced maintenance and operation chores can be pressed for then, because in that stage robotic attention should be sufficient for doing any non-emergency work. Some personnel chores time will be needed during shut down (decommissioning) to enable a quick and easy restart at some future time.

Some “go for” robots. Using one or more relatively small mobile “go for” robots on Mars has the potential to be a big saver of personnel chores time. In endeavors on Earth,

having one or more “go for” persons saves time for the personnel directing or asking services from the “go for” persons (such as “Go refill this coffee mug for me.”). Their most common uses on Mars will likely be outside the habitat to fetch or deliver objects. On Mars, the “go for” robot responds to spoken directions from the on Mars personnel. This is made possible by including the “go for” robots within the scope of the paperless Mars system. Consider some examples of possible personnel time savings. On Mars, “go for” robots can sometimes save the need for personnel to change in and out of a Mars suit. They can be directed to go get a rock or soil sample, while the person is doing a different mission activity. They can be directed by a person within a rover to place a temporary communication relay at a specified location, and then later, go to retrieve it. Etc.

SUMMARY

If people are to go to explore Mars, their time on Mars should be productively spent, doing the exploration that actually does increase human knowledge about the planet Mars. If people are to go to explore Mars, their time on Mars should not be dribbled away doing mundane chores like cleaning dust filters, testing and recharging batteries, tinkering with the habitat heating equipment to get the air temperature adjusted, and trying to remember in the evening and write up in full detail about what they saw and did and learned about Mars during that sol.

One important way to help the on Mars personnel be more mission productive will be to slash the time required to do chores. Three main directions to cut chores time and increase mission productive time are these:

Design or select the habitat, rover, Mars suits, tools, and other equipment to be used on Mars to require less personnel time in initial set up, in routine operation and use, in maintenance and repair, and when they are no longer needed by the on Mars personnel, in decommissioning.

Have the on Mars personnel use lean efficient work practices both in doing their mission work activities, and in doing non-mission chores. The use of a paperless Mars system could be a very helpful aid.

Add robotic assistance for the on Mars personnel not only in doing their mission work activities but also in doing non-mission chores. Two examples are the use of a turn around robot processing of Mars suits between wearings, and the availability of mobile “go for” robots.

To improve, refine, and particularize specific items in order to implement action in these three directions, it would be helpful to have the Mars Society research stations capture and collect consistently and in detail, specific data on how the crew members use their time. Encouraging the crews at the stations to move more in going paperless, and to put a high priority on slashing personnel chore time, could also help increase the possible productive time of the personnel for accomplishing Mars mission goals.

ENDNOTES

The Mars Society provides access to much of the available data. Its Web site is: <http://www.marssociety.org>

Chapter 1 and pages 239–240 in Robert Zubrin, *The Case for Mars*, Touchstone, New York NY, 1996, 344 pp.

Presented in 2003 by Ned Chapin in the Mars Society Sixth International Convention and published in: Ned Chapin, “Information systems gear in Mars analog research,” *On to Mars: XXXXXXXXXXXXXXXXXXXX*, Apogee Books, Burlington ON, Canada, 200XXXX, pp. XXXXXX.

An advance on glove design is presented in 2008 by Gary L. Harris (Hydraulic antipodal focusing as a contributing factor to finger tip injury during the use of EVA gloves) in the Mars Society Eleventh International Convention and published in these proceedings.

While other Mars Society International Conventions have provided additional coverage, the Ninth Annual International Mars Society Convention in 2006 had ten presentations in its track 2A, but those proceedings have not yet been published. The Fourth International Convention in 2001 had four presentations in its Track 2B. Regrettably, none of those presentations appear in the published proceedings. The NASA work headed by William J. Clancy about communications is an example of work related to this area: William J. Clancy, “A closed Mars analog simulation: The approach of Crew 5 at the Mars Desert Research Station, April 8–20, 2002,” *On to Mars: XXXXXXXXXXXXXXXXXXXX*, Apogee Books, Burlington ON, Canada, 200XXXX, pp. XXXXXX.

Pictures and supporting text can be found scattered throughout in: Robert Zubrin, *The Case for Mars*, Touchstone, New York NY, 1996, 344 pp.

The literature seems scattered and piecemeal. Two relevant items are: Richard V. Morris and Doug W. Ming, “Mars robotic exploration,” ARES, NASA Johnson Space Center, 2007, available at: <http://research.jsc.nasa.gov/PDF/Ares-7.pdf> and Harry C. Holloway, “Human problems on a Mars mission (SDC 89-021),” *Proceedings of National Space Society’s Eighth Annual International Space Development Conference*, Space Development Conference, Ltd., Chicago IL, 1989, pp. 159–172. Session 2 of the NASA Mars Conference is entitled “The present and future unmanned exploration of Mars.” Also, eight presentations appear on pages 215–365 in *The NASA Mars Conference*, as Volume 71 in the Science and Technology Series of soft cover books published by Univelt, Inc., San Diego CA, in 1988.

The literature seems scattered and piecemeal. The 2005 plenary presentation by Scott Horowitz at the Eighth Annual International Mars Society Convention, entitled “The safe, simple, and soon plan to get humans to Mars” has regrettably not been published. An additional relevant item is the presentation by Marvin Hilton in Track 4B in 2006, entitled “The real reason for exploring Mars.” Regrettably, the proceedings of that Ninth Annual International Mars Society Convention have not yet been published. Session 3 of the NASA Mars Conference is entitled “Issues and options for the manned exploration of Mars.” Nine presentations appear on pages 375–534 in *The NASA Mars Conference*, as Volume 71 in the Science and Technology Series of soft cover books published by Univelt, Inc., San Diego CA, in 1988.