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# Mountaineering and Climbing on Mars

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Initial human missions to Mars will be a precious commodity wherein a maximum amount of information is gathered by each crew. As was the case during innumerable terrestrial missions of exploration, the Martian terrain that visiting crews must traverse in order to gain an understanding will often be difficult. This is accentuated by the fact that Mars is a world of geology – one whose surface area is equal to dry surface on Earth. Human crews will be called upon to use a variety of skills and tools to traverse the Martian surface – including those often associated with hiking, mountaineering and technical climbing. While rovers and other mechanical devices will be employed, it should be assumed that skills commonly associated with rock climbing, caving, and mountaineering on Earth will also be required. This paper looks at the human factors associated with such activity on Mars: space suit design requirements, life support, tools and procedures, traverse planning, logistics issues and navigation. Implications for adaptation of terrestrial gear will be examined as will implications raised by planetary protection. Lessons learned during sorties conducted on the lunar surface during the Apollo program are discussed.

**Keywords:**

## 1. Introduction

While it is said that everyone climbs mountains for their own reason(s), there are three main reasons for climbing difficult, mountainous terrain in an expedition. All three are present in all expeditions, however the balance varies from one expedition to the next: covering territory so as to claim it for a national or economic use; going somewhere or doing something that no one has done before – and the human factors involved in so doing; and visiting a location to understand its unique characteristics – and how they relate to the rest of the world (planet).

Mars is a world to explore – indeed, we have been exploring for centuries – at first with our imagination, now with our robots, and soon with our own two feet. We will quickly find that many locations will only be accessible by mountaineering.

Unlike much of Earth these days, sophisticated medical assistance on Mars is not going to be a phone call and a helicopter ride away. Any risky activity – including mountaineering on Mars - must be done for a purpose resonant with overall mission objectives and the risk that goes with achieving these objectives.

In the early years of exploration before the local infrastructure is built up, access to some regions of interest may only be possible with mountaineering techniques. While some of this can be performed by robotic vehicles, there is a limit to their ability to cover certain types of terrain – even if controlled remotely by a human. While humans will be somewhat resource intensive to support on Mars, they are rather nimble and adept at climbing over – and up – difficult terrain. Humans will likely do much of the scrambling about because they are the best technology available.

We can get an idea [1] of what was considered part of a preliminary plan of exploration on another planet a generation ago, but never carried out. This occurred mostly as a result of the cancellation of Apollo missions 18, 19, and 20 and the need to refocus the remaining landing missions on other objectives. Had some of the original mission scenarios come to pass, there would have been some feats that certainly fall in the category of what is considered climbing and mountaineering. Apollo 18 would have landed next to the lava tubes that form Hyginus Rille. To examine these tubes close up, astronauts would have been lowered several hundred meters on a rope by winch to the bottom of the gorge.

The budget cuts also changed the original destination of the Apollo 16 mission - Tycho, a prominent crater 87 km across and 5 km deep with a central peak 2 km high. The crew planned to winch down the crater's side on the end of a rope. While these planned activities are rather tame inasmuch as humans would be lowered and raised at the end of a rope (no actual climbing involved), these are activities that are associated with "aid climbing" on Earth – the ascent and descent of exceptionally difficult peaks and cliffs. Apollo 20 was planned to land in the center of the immense crater Copernicus which has a large central peak. There may well have been at least a partial ascent of that peak.

## 2. Where Walking Stops and Climbing Begins on Mars

"Mountaineering" can be simply described as human locomotion over significantly inclined, difficult terrain, with some sort of artificial aids used to assist (boots, ropes, etc.). The word "climbing" tends to be used when the terrain is very vertical and the climber needs to use their arms during the ascent. Inclination isn't the only factor that defines difficulty. Some steep slopes with gentle terrain and certain types of surface features can be rather straightforward to ascend whereas much less steep slopes with difficult terrain can be much harder to traverse.

Altitude and weather can also affect degree of difficulty. On Mars, since life support is utilized, only the physiological effects of altitude are removed as a factor (unless something fails). All other factors common on Earth - plus some new ones unique to Mars - affect difficulty level of crossing a given expanse of Martian terrain. Given the hazards of the Martian environment, plus the operational burden of functioning inside a spacesuit, most traverse activities beyond simple sorties on non-difficult terrain from Base Camp or from a Rover can be considered to fall under conditions associated with mountaineering. As such, 'climbing' and 'mountaineering' will be more a matter of degree, than kind, on Mars.

## 3. An Operational Definition of Martian Climbing and Mountaineering

For the sake of this discussion, "climbing and mountaineering on Mars" will cover activities that involve one or more of the following:

- Human crews are required to traverse terrain because automated (robotic) vehicles or motorized human transport cannot
- Terrain is inclined (either up or down) such that motorized transport cannot efficiently traverse so as to reach target location(s)
- Surface composition is of a nature that is fragile, of low friction, or of a composition that mechanical aids or specific equipment is required for humans to traverse it
- Trips are of a length that sleep periods and or bivouac are required
- Distance to base camp or rover cannot be reached without a substantial rest period
- A surface excursion is made with the clear intent of climbing difficult terrain primarily for the purpose of doing so (gear or operations testing)

## 4. Reasons to Engage in Climbing and Mountaineering on Mars

Examining stratigraphy is one way of re-constructing a planet's history - therefore Mars surface teams will need to climb up and descend down a variety of features - taking samples and measurements in the process. Mountaineering skills will be needed in such situations. Some of the most interesting features on Mars will no doubt be some of the most difficult to reach. In many cases only human locomotion will allow access. Targets of opportunity will also present themselves which are best handled by human access. Mountaineering may also be employed in contingency situations wherein a rover becomes incapacitated and direct human access may be the only way to meet mission objectives.

## 5. The Overlap Between Mountaineering, Climbing, and Other Exploration Activities on Mars

Spacesuits used on Mars will need to be robust, flexible, easily repaired, and designed for the widest possible range of human activities. Indeed, given the length of potential missions and the potential for damage, each crew member may have more than one spacesuit – and will be able to substitute all or some parts from other crew member's suits. Life support systems will need to adapt to a wide range of external environmental conditions by providing humans with a tolerable range of internal conditions. Although lighter Martian gravity will serve to make many tasks easier, having to carry around a lot of gear may reduce such an advantage significantly – if not make them more difficult than they would be on Earth. In addition, mountaineering is going to require a certain amount of exertion that is likely to exceed the range currently considered in spacesuit design. This exertion is likely to continue for prolonged periods.

Communications and navigation will be required for virtually any activity out side of base camp –

including mountaineering. Various solutions to this issue range from a Martian GPS-like system, to more localized systems composed of a series of ground-based repeaters.

Tools and equipment will be required not only to assemble, but to maintain and repair structures and machinery. It is almost a certainty that all crew members will need to have a demonstrated proficiency not only to repair equipment, but to improvise when the proper tools or materials are not available. Given the nature of hiking and climbing, unexpected circumstances are certain to arise wherein the gear at hand needs some augmentation in order to deal with such events.

All crew will be required to have medical proficiencies as well as operational capabilities that include rescue and contingency scenarios. At an absolute minimum one should assume that crew members have the skills of an Emergency Medical Technician. Moreover, they will need to have the tools at hand during any mountaineering activity whereby injuries can be handled. By its very definition, mountaineering calls for people to be far away from their base camp in locations that are difficult to reach if a contingency arises. Therefore the crew needs to be self-sufficient in this regard – more gear to carry.

## 6. Logistics

How much gear one uses, how you position it ahead of time, and what you carry with you is both a matter of style as well as one driven by the nature of a climb. Expeditions in the Himalayas can easily involve dozens of people to support a few climbers as they reach the summit. This approach provides a capability to make repeated attempts, endure long periods of bad weather and other risks that might threaten a climb. It is also resource intensive.

Another approach involves reducing the logistics to an absolute minimum and dashing for the summit. While retaining a level of safety, such an approach reduces the ability of a expedition to tolerate delays. It also limits the ability of the team to deal with contingencies. The benefits are primarily the ability to move fast – which can sometimes be the key to taking advantage of windows of opportunity that a more ponderous logistics set up might now be able to respond to.

Large mountain assaults (be they traditional or reduced) require a lot of people and the ability to support them. There are not going to be a lot of people on Mars for quite some time to come. Regardless of which mission scenario you prefer (intermittent sorties versus building up a permanent presence by overlapping missions) nearly all activities on Mars will be performed with a small number of people. Dash assaults using a small number of people are likely to be the norm on Mars. One way to maximize the ability of smaller groups to attain a mountaineering goal is to make repeated sorties along the route, leave supplies, fix ropes, etc. in caches and then retreat back to a base camp. Over time the logistics are moved along a series of stops or caches such that things are in place to allow climbers to move swiftly along a route without having to carry a large amount of material with them.

## 7. Shelter and Food

Mountaineering on Earth usually involves travel to remote locations and at least an overnight stay – usually many more. Shelter (or to ‘bivy” i.e. bivouac) is usually required to keep out inclement weather, to provide warmth, and occasionally to keep dangerous animals away. On Mars, (minus the concerns about wildlife), shelter will be required during any mountaineering activity requiring more than a day’s trek away from normal shelter (rover or base).

The need for shelter on Mars derives from the need to get out of a spacesuit – in both normal and contingency situations more than it does to protect anyone from the elements. Although activity at night on Mars will be limited, suits will need to be able to function in low temperatures. Night activity will need to be possible inasmuch as solar flare alerts or injury may force a climbing team to be on the move in the dark. Also, although prevalent, Martian dust storms are more than a nuisance and source of reduced visibility and gear maintenance than anything else. Again, the need of shelter is going to be driven by the need to get out of and then back into suits. It also makes sleeping, large meals, and using the latrine less of a chore.

Since it is obvious that there will need to be a regular means whereby people get out of their suits (sleep, waste removal, first aid concerns), this will need to be done in a way that adheres to planetary protection requirements. If a shelter can be carried and erected, the issue of whether you enter the enclosed volume and get out of your suit – or attach your suit to the enclosed volume and then exit the suit – becomes an issue. If the space suit never enters a pressurized environment where terrestrial life forms could adhere to its outer surface, or putative Martian life forms could do the opposite, you have a complicated clean up protocol to follow before you can go back outside. If there is a way to "dock" the suit and then step (or crawl) out of it, inside and outside environments can be kept from being exposed to one another. Russian ORLAN EVA suits in use on the International Space Station are constructed somewhat in this way. However, it is one thing to float into or out of such a suit in microgravity – and quite another to do so in a significant gravitational field. Of course there is an issue as to how you create a portable shelter that is, on one hand large enough to hold the climbing team, robust enough to be pressurized, and sophisticated enough such that multiple suits can dock with it – all this while being light enough to be carried and simplified enough such that it can be erected and taken down quickly. These structures (with supply caches) might be forward positioned along the expected route for use by a mountaineering team. Of course this only simplifies the front end of such an activity – the structures would probably need to be retrieved at some point because in the early stages of Mars exploration gear is unlikely be considered expendable.

In a nominal or routine situation, this 'docking' could be considered. However if an individual is injured, or repairs need to be made to the suit, then alternatives must be available whereby people enter and exit their suits inside a pressurized enclosure. Again, the driver here is whatever planetary protection protocols are in force during the time people are on Mars and how much complexity can be carried along on a mountaineering expedition. If a portable shelter cannot meet planetary protection protocols, then such sorties may be limited to the amount of terrain someone can cover and then return from while wearing a suit. This would severely limit what could be climbed on Mars.

There is no shortage of tents available today that are light and easy to set up. The challenge will be to add all of the functionality that such a shelter would need on Mars. Given that there are many other non-mountaineering scenarios wherein such a shelter would be required (e.g. a breakdown in a pressurized rover's life support) it is probable that something will be considered for inclusion in the baseline gear inventory for human expeditions.

There are going to be other reasons to seek shelter while out on the Martian surface: solar radiation events. What would people do if they were caught by a solar storm while out on a mountaineering traverse? The structures one would need to provide pressurized shelter (for reasons previously mentioned) would not be the same as what you would need to protect people during a heightened radiation event. If the crew is required to endure a solar radiation event, they will either have to get back to their rover or base or make do with what they have at hand. If a shelter has been forward positioned then it is possible that the tools needed to build a soil barrier and/or tanks of water to act as shielding may be provided. As there might be some advance warning (but not a lot) mountaineering teams might be able to make it back to adequate shelter. Depending on the terrain, caves or rock outcroppings may be available for use as shelter - or, with some work, modifiable into stone shelters. Trenches might also be dug and climbing gear used to build a platform atop which soil could be placed and underneath which the crew could wait out the storm in their suits.

Rock climbers are notorious for their peculiar eating habits. Power bars, cookies, complex carbohydrate gels and various sports drinks can be used to power their activities for days. Climbs, even multiday ones, are more like vertical marathons than anything else wherein hydration and fuel are consumed and utilized at a frenetic pace. Mountaineering is also strenuous, but usually entails stretching out the effort over prolonged periods - often weeks. Climbing peaks over 7,000 meters takes humans close to and into the "death zone" wherein they are chronically deprived of oxygen, cold, and burn calories like a furnace. In such prolonged activities, properly chosen food and the ability to get enough water must be assured.

Eating inside space suits is problematical. Current capabilities include food sticks and fluid bladders with straws. These suits are designed, however, for use in microgravity for no more than 6-8 hours. Suits used on the surface of Mars will need to have the ability to support their occupant for many days at a time. Climbing and being away from a rover or a base – and temporary shelter – will necessitate that sufficient caloric intake, balanced with other nutritional needs, is available. There will also need to be an ability to administer pharmaceutical agents which may be used as part of any countermeasures program adopted to ameliorate the effect of lowered gravity, radiation, etc.

## 8. Planetary Protection

Mars may have once harbored life. It may still harbor life. We don't know. That is one of the reasons we want to go there. Alas, the act of going to Mars to search for life brings the risk that we will inoculate the planet with terrestrial life forms by virtue of our presence there. It is almost a certainty that there will be very specific and strict planetary protection protocols in place for all human activities on Mars - as there already are for dealing with unmanned spacecraft.

These measures would serve to prevent both forward contamination (by Earth life of Mars) and reverse contamination (of Earth life by putative Martian life). Even if humans do not come in contact with Martian life, there will be hazardous materials to deal with from surface materials. Moreover, humans are also likely to shed living matter in a way that could contaminate the planet. By the hazardous nature of what is involved in terms of exposure to Mars itself, this risk is enhanced – to say nothing of the enhanced complexity in terms of hardware and procedures required to deal with these risks.

The challenge is to build a space suit – and accompanying systems and procedures – that keeps Mars and humans apart. Apollo surface missions simply ignored the issue altogether. Humans were exposed to unfiltered lunar material the moment they climbed out of their suits after their first EVA. Some crew members reported the smell of lunar soil as being like “gunpowder”. Although the risks had been studied in advance, the crews were nonetheless breathing in the unfiltered soil (regolith) of a planet they had just landed on. It is improbable that anything like this will be allowable on Mars for many, many years to come until such time as the chemical nature of Mars’ surface and subsurface and the existence of any indigenous life is known with some certainty.

## 9. Equipping Humans to Climb on Mars

Climbing involves use of hands, feet, and body parts in frictional and counterbalanced positions. Can gloves, boots and helmets (and suit fabrics) stand up to this sort of abuse? There is a wide body of terrestrial mountaineering, climbing, and spelunking experience - as well as geology fieldwork expertise to draw upon. Existing gear and techniques can be adapted for use on Mars however some new things may need to be developed taking the Martian environment into account. Below some of the challenges facing designers of such gear and procedures are discussed.

### 9.1 Spacesuits

When it comes to building a pressure vessel within which humans can move (sometimes known as a space suit) there are gross and fine issues that need to be addressed. The motions involved in moving around, bending, etc. all involve large limbs and muscles which can move suit components more easily than smaller body parts such as feet, and most critically, fingers. Current space suits are designed for use in microgravity - the range of motion they need to provide are far different than those you would need on a planetary surface. These suits are also designed for usage times measured in hours with refurbishment by a large team back on Earth. Apollo suits were designed to last a few days and were then thrown away. Suits to be used on Mars will need vastly greater usage times. They will also need to be much more flexible, particularly for mountaineering, and be maintained only by the people wearing them with the tools at hand.

### 9.2 Boots

Boots used on Mars will need to work in a wide range of temperatures from almost warm (from a terrestrial standpoint) down to more than –100°C. They will have to deal with warm ground temperatures at the soles of boots and sub-arctic temperatures a meter away. They will also need to be designed such that they do not shed too much warmth to the cold surface. Too much heat shed while walking across frozen volatiles on or within the Martian surface could cause the ground to suddenly become unstable.

Boots will also have to function at the low ambient pressure on Mars. They will need to be both flexible and yet strong enough to retain the proper internal environment. While the flexibility issues are not as daunting as they are with gloves, people are going to be doing a lot of walking on Mars. Climbing and mountaineering will simply exacerbate any problems that might exist with boot design.

Like any boot used for rough activities such as climbing, boots used on the Martian surface will need to be wear resistant – possibly with outer coverings that can be replaced or discarded. The soles will need to provide friction and grip. They will also need to be non-reactive with the surface chemistry and be able to be cleaned prior to entry into any pressurized environment. Given the extended duration of Mars surface missions, the soles will also need to be replaceable when they have worn down or become damaged. As is the case with better brands of terrestrial climbing boots, there will need to be fittings to allow the attaching of crampons, extra-rugged cleats – or perhaps even snowshoes in a secure and easily removed fashion.

When tacking vertical smooth surfaces on Earth, climbers wear shoes covered with extra-sticky rubber. Such materials are also useful on regular boots when some vertical surfaces are expected. It should be assumed that as materials are designed for the outer surface of Martian boots that such sticky properties will be considered.

### 9.3 Gloves

Gloves are probably the most critical item – and the most difficult to create. Climbing and mountaineering require the use of a variety of tools, direct contact with a variety of surfaces and materials (rock and ice) – all while keeping hands from getting tired. Current spacesuit designs don't even come close when it comes to the sort of gloves that will be needed on Mars – even if no climbing and mountaineering whatsoever is contemplated.

As part of a larger, overall space suit, gloves require some level of stiffness so as to retain their shape and a pressurized inner environment. The higher the pressure, the stiffer the pressure vessel (spacesuit and gloves). While a certain amount of stiffness can be endured for larger limbs, such rigidity can make gloves hard to use – and very tiring. Fingers are small appendages and the muscles are not used to working against a great amount of resistance (such as that from spacesuit gloves) for many routine activities. When they are called upon to do so they tire easily.

One way to make gloves extra dexterous is to reduce the amount of material – and thus some of the glove stiffness - so as to allow fingers to move more easily. However, by decreasing suit mass insulation properties suffer, as does its ability to retain a shape under pressure. This was an issue in Shuttle EVA gloves until heated gloves were introduced in the late 1990's. Still, no one is threading sewing needles with spacesuit gloves just yet – even if they are heated.

In order to be useful on Mars, regardless of the activities contemplated, gloves will need to be changed out due to wear as well as have addition of special coverings or outer glove liners for rough duty and the use of climbing gear such as belay devices and ropes.

### 9.4 Helmets

Helmets will need to offer maximum visibility while filtering out unwanted light and radiation. As is the case with current space suits, visors and flaps may be one answer. Use of materials which respond to certain wavelengths (e.g. glasses that darken when you go outdoors) or can be controlled with the application of an electrical charge may also be considered. Options that don't require power or automation, or at least will not hinder other aspects of helmet use if they do fail, would be preferable from an operational and reliability point of view. Faceplates need to offer maximum visibility and optical clarity at the same time that they shelter the wearer from harmful radiation. Faceplates need to be resistant to scratches and abrasions and either be designed for refinishing (buffing) or replacement when surface damage impairs their ability to allow wearers to see what they are doing – safely.

Since climbing and mountaineering will put all gear under additional risk of damage, extra protection for helmet faceplates will be required. One solution might be to use an external framework similar to that used on American football helmets. Helmets also need to be exceptionally resistant to damage from falling objects or from falling astronauts. Not only will the material used to construct helmets need to be robust, the inside of the helmet must also be padded to provide cushioning while preserving wear ability and visibility.

It is also certain that helmets will be equipped with a variety of audio and perhaps visual communications systems (heads up displays). These systems need to be robust enough that they can withstand some punishment. They also need to be unobtrusive: climbing can often require 100% of the climber's attention. If all else fails, one would hope that one astronaut could hold their helmet up to another's and be heard by simple sound conduction between helmets. This could be critical should someone have a fall and all suit systems become inoperative.

## 10. Suit Construction

Spacesuits are fabric sandwiches of various materials – each with different functions. Once weaved together the layers are not designed to be separated. Since wear and tear is likely to happen under even the mildest surface operations, to say nothing of mountaineering and climbing, thought should be given to suit design where things on the exterior of a suit can be easily repaired or replaced, thus allowing the suit proper to be protected. One way to protect clothing during outdoor activities such as climbing and mountaineering is to layer – and wear a covering or "bib" designed to take much of the abuse and then either be discarded (or repaired) and replaced with a new covering. Such outer coverings could afford protection from damaging UV radiation. They could also be used to enhance radiation protection, and even thermal properties. Repairs might require repair to multiple layers or the replacement of entire parts in extreme cases. While people vary in their dimensions, space suit parts can be made to be somewhat interchangeable. This should be considered to the maximum extent possible. Too many tailored parts will result in more logistics than might otherwise be the case.

## 10.1 Dust, Moving Parts, and Flexibility

The dust being blown around on Mars presents many possible hazards not just to mountaineers but to crew in general. Power systems utilizing solar photovoltaic panels run the risk of having light collecting surfaces covered up. They also run the risk of being eroded by sand blasting. Cooling radiators run the risk of becoming covered with insulating levels of dust, thus decreasing their heat shedding efficiency and the performance of systems that depend on the shedding of this heat. Dust also complicates any gas intake that might be used by in situ atmosphere or chemical production. Care must also be taken to make certain that any optical surfaces - cameras, sensors - are resistant to dust erosion, that they can be protected during surges in dust, and cleaned readily.

Filters can keep dust out, but they have to be maintained. Blowers and wipers can clear off dust but they require power. Joints can be lubricated but they require lubrication. In other words each solution has an operational cost to consider. As was the case with the Apollo missions, dust also presents a hazard to the joints and other moving surfaces within a pressure suit. In addition to being inherently resistant to such events, there needs to be a way that joints and other moving surfaces can be accessed while the wearer is still in their suit. Having an internal pressure volume (liner) over which the suit is worn is one approach that might be considered.

## 10.2 Maintenance

Suits will need to be designed such that they can be totally disassembled and repaired by the crew. This needs to be the case not only in routine situations, but also in contingencies. Given that everyone's life will depend on these suits every time they walk on the surface, the care and maintenance of suits will need to be seen as a capability not unlike the ability of a soldier to disassemble, clean, and re-assemble their gun. This will be especially important for anyone contemplating climbing or mountaineering on Mars.

Space suits will require liners that can be washed since humans exude a constant amount of oils and moisture which can not only become noxious, but can also provide a rich medium for the growth of pathogens and undesirable organisms. This would mean that some sort of washing machine is going to need to be aboard.

In addition to all of the things that will be needed for routine, non-mountaineering activities, suits will need to be designed such that they can interface with equipment used in climbing. They will need to have the ability to be connected to harnesses, ropes, belay devices, hoists, and other gear. They will also need to be able to carry various pieces of gear that will be used, removed, stored, and reused again (pitons, carabiners, slings, camming devices, etc.). Use of special 'bibs' or overalls will probably be needed so as to not only protect the suit and attachments during climbing but also to reduce the snag hazard i.e. the propensity for objects to get stuck on each other or the climbing surface.

Suits will also need to be designed such that the large loads that climbers will need to carry (gear, shelter, food etc) can be attached and that the change in center of gravity can be safely accommodated by the wearer of a suit – something which already has a substantial mass of its own. While the gravity at the surface of Mars is 0.38 g, it is almost certain that the mass of suits plus the gear that needs to be carried will quickly approach the same sort of "felt weight" or burden one would experience walking on earth. The notion of climbers leaping about on Mars is likely to occur only during rest stops when all the gear is off – assuming that people have the energy to do so.

## 10.3 Life Support

In terrestrial climbing and mountaineering, life support issues focus generally on food and water supplies, waste storage or disposal, and body temperature control (through clothing). Atmospheric concerns only become an issue on Earth at altitudes of 1,829–2,438 m (6,000–8,000 ft) when individuals unacclimated to lowered oxygen levels start to exhibit symptoms of acute mountain sickness (AMS). As one ascends, and air becomes thinner, this can progress to life threatening conditions – if not treated promptly.

One of the most common ways to treat this is to either descend promptly or place the affected individual(s) into an environment where the amount of oxygen available is increased. This can be done either by putting someone into a pressurized chamber ("Gamow bag") or by delivering oxygen directly from a tank via a face mask. Since mountaineering is strenuous by its very nature, climbers require additional atmospheric supplies - as well as cooling, hydration, and food – more than would be required if they were simply be standing at high altitudes.

Since all surface activities on Mars are going to require pressurized suits, the issue of altitude sickness during routine use is not of special concern since suits will be used at all times regardless of what a person is doing. The issue of diminished atmospheric pressure and composition is, none the less, a real hazard and must be taken into consideration as is the case when humans depend on a life support system to survive. Exceptions to otherwise normal life support operations would be damage to a suit so that life support systems were incapable of retaining optimal pressure and/or gas mixture. Another scenario involves alterations in the normal breathing mixture made deliberately in situations where supplies needed to be stretched due to injury, inability to traverse, or some other operational emergency.

In either case, the affected individuals will need to be treated. Short term assistance could be provided in the form of input from emergency supplies (small gas cylinders) or via "buddy breathing" (cf. SCUBA) from another person's life support system. This would necessitate the provision of emergency supplies and the ability to connect these supplies - or the life support system from another suit. In addition, however, chronic exposure of substandard atmospheric conditions can result in serious – even lethal – physiological conditions such as edema, loss of consciousness, and neurological deficits. These symptoms can be treated with medications which will need to be administered.

While most surface activities will occur within close proximity to supplies (a base or a rover), situations could arise where individuals might be required to live in their suits for prolonged periods of time – perhaps days.

Suits will also need to have their power storage systems (batteries) recharged periodically. Since carrying additional storage batteries becomes a weight issue (and also a logistics limiting issue since you eventually run out of new batteries) some thought would need to be given to in situ recharging via solar cells.

In addition to the routine recharging of suit life support systems, at some point waste in the form of urine and feces will need to be dealt with. The "diapers" currently used by both genders in space suits aboard the International Space Station and Space shuttle are designed to accommodate EVAs of no more than 8 hours or so. Moreover, the users of these suits, while they are active, are not required to be walking and carrying gear in a gravity field. The waste is removed when they take the suits off. Apollo EVA suits, designed to be used for several days on the lunar surface for EVAs up to 7 hours in length, also used diapers. While EVAs were accomplished according to plan, the fecal collections systems and the way that feces were handled afterwards left a lot to be desired. In a Martian surface suit, while urine could be handled for longer periods using tubes and cups, feces will likely force wearers to taken their suits off at least every day or so. Once suits are cleaned, there is the issue of storing waste and cleaning materials for return to base for recycling and all of the attendant planetary protection issues that would accompany this. One way to deal with carrying waste around is to have a portable means of incinerating material. Water could be reclaimed for reuse in the process. However, this is rather energy intensive, and the same ethic that proper climbers adhere to – i.e. "pack it out" will apply on Mars as well.

## 11. Medical Issues

Climbing and mountaineering are dangerous activities on Earth. They will be even more hazardous on Mars. One would assume that the *in situ* medical capability would include the ability to handle broken bones, lacerations, and dislocations – even if overt mountaineering were not a sanctioned mode of exploring the surface.

### 11.1 First Aid

In terms of general first aid needs, teams out on the Martian surface – whether they are climbing or doing routine, more pedestrian exploration, will need to carry a robust first aid capability - or be close to one – at all times. Given that access to a patient's body – either by themselves or by someone who will treat them – necessitates removal of part or all of their suit, most treatment is likely to occur within a pressurized volume – such as a long range rover, a temporary shelter, permanent base, or landing/ascent vehicle. Generally, first aid will need to attend to routine issues such as scrapes, burns (cold), solar event radiation exposure, blisters, insomnia, and general soreness. It will also need to provide treatment for sprains, breaks, lacerations, trauma (conditions that can result from falls or loosened material falling on someone), and consequences of life support malfunction (anoxia, decompression, bends, etc.)

## 11.2 Treating the Patient

Suppose someone falls and breaks their leg or arm while climbing. Assuming that their suit is intact, the injured limb can be splinted and/or immobilized. Not much else can be done without removing their suit. If injuries require access to the person's unsuited body (lacerations, protruding compound fractures, etc.) a sheltered environment sufficient to enclose the number of people required to deal with the injury – plus the patient - must be available. Moreover, the gear required to diagnose and then treat the injury must also be available.

In treating all conditions, an operational triage of sorts needs to be performed wherein those involved decide between treating a situation in situ or seeking outside help. If outside help is needed, a balance needs to be weighed between the risk inherent in providing assistance and amount of gear required to reduce that risk. In the case of parties engaged in climbing or mountaineering on the Martian surface, this becomes especially important. This medical capability can either be carried by the crew as part of their provisions, prepositioned in a supply cache along the route ahead of time, or delivered by some means (human or robotic) when needed from a remote location (base camp, rover, etc.).

Let us assume that an injury is serious enough to require evacuation. Let's also assume that the other members of the climbing team are able to stabilize the injured person such that they can be moved. Assuming they are in a remote location, how do they get the inured member of their party out? If the patient can walk (with or without assistance) and perform basic mountaineering skills, then the issue is more one of persistence than anything else. But what if they cannot move on their own? Will materials be on hand to create a litter or stretcher? Various *ad hoc* capabilities have been created by ingenious mountaineers on Earth using climbing ropes, packs, skis, and walking sticks. Will this be considered acceptable on Mars, or will evacuation gear need to be provided?

Of course, some injuries are so severe that the person cannot be moved. This would require that significant medical capabilities be brought to the patient. Again, given that they are in a remote location as mountaineers because it is hard to get there otherwise, the same issues facing evacuation are confronted. Does the mission have rocket planes or rovers that can get close enough?

## 11.3 Dealing with Death

Mountaineering and climbing can also be fatal. While death certainly reduces the complexity of what needs to be done, it does present vexing issues. While science fiction often portrays burial on another world in romantic terms, it is rather unlikely that this will be allowed (at least deliberately) during early phases of human exploration – while Mars's biota (or lack thereof) is still an open issue. If the body of a Martian mountaineer is to be brought back (and can be brought back) then the issue is one of simply moving perhaps 50-100kg from point A to point B. Mountaineers on Earth have been doing this for centuries. A sled could be made out of gear and dragged, or the body could be carried on a litter.

If the body cannot be retrieved or the issue of removing it is impossible (without risking the remaining team) then the issue becomes problematical. Given the ambient temperature on Mars, it is almost certain that a dead human inside a spacesuit will quickly lose all heat and freeze solid. This would reduce the changes that can transform a body during decomposition (bloating, etc.). Assuming that the suit retains structural integrity (or is repaired such that it is sealed) any biological agents within the suit (flora and fauna on or within the body) will likely remain isolated from the Martian environment for a prolonged period of time. While this may not be enough to satisfy planetary protection protocols long term, it could solve the problem in the short term.

If the victim's suit was somehow breeched during the accident, which leads to their death, the issue becomes more complicated – and gruesome. As noted earlier, one would certainly assume that rigorous planetary protection measures would be in place. If human remains (and the biota that reside on and within the human body) come in contact with the external Martian environment, there may be an issue of sterilizing the regions where contact was made. The sort of injuries which could lead to suit rupture and death would likely deposit tissue no more than a few meters from the point of impact. The low temperatures would cause tissue to freeze dry rather quickly thus limiting the ability of anything within that tissue from setting up home. Clean up and/or decontamination is not likely to present an impossible task. Biocidal wipes and sprays will likely be included as part of any standard mission. As for collecting remains inside a container that could be carried back or left behind, a body bag could be provided – perhaps serving double duty for hauling gear needed by the climbing team.

Death during a space mission is an issue that has been faced by current space explorers. While the means of dealing with a dead comrade in space are rather closely held, NASA does have procedures in place for everything from unexpected pregnancies to restraining and sedating delusional crew members. Moreover, the design for the (now cancelled) X-38 crew return vehicle required that crew could be returned in a reclined (injured) position if need be. It is likely that any vehicle developed in the future will have similar requirements levied upon its design and operations. As for dealing with a corpse, again, these procedures are rather closely held, but I can say from personal experience, i.e., working on the Space Station Freedom program, that an option for placing corpses in body bags and storing them outside the space station, attached to the truss (until such time as they could be returned to Earth) was discussed.

### 11.4 Dust

There is also a health risk from dust. The NRC expressed a strong concern that the composition of the dust might pose a health hazard [2]. In particular they urged that surface analyses be done to accurately define the nature of any materials that might become airborne or adhere to surfaces. Of particular concern was the presence of hexavalent chromium in Martian dust. Exposure to hexavalent chromium is a known health risk on Earth. There is also the health risk that accompanies the inhalation of dust in general and the need for the respiratory system to eliminate it. There is also a possible hazard from dust reacting with moisture within the respiratory system and the compounds that could form as a result. If crew members are going to be in the presence of suits that have been worn outside, this hazard will need to be handled on a routine, perhaps daily basis in a way that minimizes direct exposure. This assumes, of course, the planetary protection protocols do not preclude the direct exposure of humans to Martian material.

## 12. Martian Climbing Gear

Several centuries of climbing and mountaineering have produced a wide variety of tools, aids, and other gear. While the basic devices have all remained somewhat constant in their gross performance, their capabilities have seen constant increases in capability (flexibility and strength) while also seeing decreases in weight. In both cases this is the result of a synergy in design and a constant influx of new (lighter and stronger) materials. While computers and handheld calculators constantly zoom ahead in capability with order of magnitude increase on a regular basis, human fingers remain unchanged. Keyboards on these devices have only managed to shrink to the point that they are able to be manipulated by humans hands – and no further. While materials advances will continue to be applied to climbing gear, it has to be used by human hands. Climbing and mountaineering gear in the future is probably going to be very familiar to those who use it today, whether it is used on Earth or elsewhere. Modern climbing gear, when properly used, can dramatically reduce the risks associated with falling such that falling is something that can be dealt with in a routine fashion. This allows many routes to be attempted that might not have been considered feasible prior to the invention of this gear. This does not mean that falling is something that can be taken less seriously – rather, that it is something that can be prepared for.

### 12.1 Climbing on Mars

One's first reaction to the notion of climbing on a planet with a gravitational field of 0.38 g would be that it would be easier to climb there and that gear would not need to be robust. This is not necessarily the case. While Mars will offer a two-thirds decrease in weight as perceived by an unencumbered human, this advantage will be almost instantly eclipsed when space suit and life support gear mass – plus adaptations to Martian conditions – are factored in. Given that a fully outfitted climber on Mars is going to "weigh" a fair fraction of their weight as felt on Earth, and that Martian mountaineering gear will have a long tradition of terrestrial specifications to meet, it is logical to assume that terrestrial loads will be the design point. If nothing else, added capacity translates into a safety margin. This can be useful when fatigue sets in or usage either exceeds design specifications in terms of usage or the amount of damage it is supposed to sustain. Also, using existing terrestrial standards and test systems on Earth will simplify the process of certifying gear.

Since any human surface exploration plan for Mars is likely to include a heavy regime of geology and sample acquisition, the tools needed to carry out this important aspect of the mission's science objectives will require tools that overlap with those tools and gear needed for climbing and mountaineering. Use of climbing gear for scientific field activities is not without precedent on Earth. Ornithologists use climbing descent and ascent devices to observe nesting birds. Archaeologists use climbing and spelunking devices to enter and leave tombs. Astrobiologists use climbing (and caving) gear when they explore deep caves looking for extremophiles. And of course, geologists would be unable to gain access to many areas without using a wide array of climbing and mountaineering gear.

## 12.2 Maintenance and Safety Margins

When repair is required, the gear should be designed to facilitate – not complicate – repairs. Parts that can wear out from abrasion (Mars dust)– hinges, springs, fabric surfaces – must be able to be replaced. Items needing cleaning and or lubricating, such as carabiner gates, ascent/descent devices, camming devices, need to be similarly accessible. Lastly, given the extreme isolation of humans on Mars, and that this environment is likely to throw a few surprises (despite whatever detailed analysis is done before hand), gear should be very forgiving in terms of ease of use and safety margins (strength). Luckily this ethic has been inherent in gear design for many years.

In addition to the ability to fix things, there will need to be an ability resident in the crew's skill mix for improvisation. Moreover, since many pieces of climbing and mountaineering gear automate functions that humans can do with much simpler devices, it will be incumbent upon the crew to know how to do body delays, rappels and "know their knots" when the fancier gear breaks or is not available.

## 12.3 Ropes and Belaying

Climbing on Earth involves the "belay" of one climber by another. One person climbs while the other maintains a protection system wherein they can intervene and stop the climber from falling more than a short distance. This system involves a rope and a series of anchors placed along the way by the climber. The person belaying a climber is, himself, anchored to the ground or the object being climbed. His anchor is independent of the belay system wherein another climber is being protected. As a climber ascends, they pause at certain intervals determined by the nature of the climb as much as the distance traversed and place a piece of gear for protection. This can be a piton driven into the rock, a wedge that is worked into a crack or fracture in the rock or a synthetic fabric sling that is worked around a feature in the rock. A rope attached to the climber is then run through a loop attached to this piece of protection. This loop normally takes the form of a "carabiner". Carabiners are strong metallic oval-shaped objects with a spring-controlled gate that springs open to admit the rope and then closes to prevent its exit. Carabiners in use today are rather strong and have strengths rated at 2,000 kg or more.

The other end of the rope is held by the belayer. The belayer can be above as well as below the climber depending on the course of the climb. In either case, the rope is worked through a belay device – a system that imparts friction on the rope, as needed, in a way that can be accurately and quickly controlled by the belayer in case the climber falls. Some devices function nearly automatically and lock up when sudden tugs initiated by a fall occur (much like the seat belt in a car). Others require the undivided attention and intervention of the belayer. While fancy devices have been created that serve to back up human intervention with some amount of automation, many climbers prefer systems that are simple and easy to operate.

There are other occasions where it is difficult or impractical to stop and set up a complicated anchor system. In these cases climbers can use their own bodies as friction devices - a so-called "body belay" and use their stance to help anchor them in place in case of a fall. In other cases, all involved are in motion – as is the case when crossing ice or snow fields. Climbers are tied onto one another. Should someone fall, climbers employ a wide range of actions – including falling to the ground and using an ice ax to anchor themselves in – arresting the fall of someone ahead (or behind them). It may sound odd that you could just stand somewhere with a rope around your body and stop someone from falling, but a little basic physics, some muscles, quick thinking, and your body, and it is rather straightforward to do. Basic mountaineering and climbing skills will have a wide applicability on Mars - not just in climbing, but routine activities such as being lowered into a canyon to collect samples.

## 12.4 Gear Considerations for Mars

On Mars, where gear will need to be maintained and repaired, a balance will need to be struck. When the fancy gear fails or is inoperable, back-up systems (belay plates, figure 8's or groups of carabiners) will need to be employed. While traditional alpine roped climbing systems might well work on Mars, care must be taken not to damage a spacesuit's integrity or the life support system it is carrying. Mechanical systems which do not impart significant wear and tear on the user's spacesuits need to be considered and employed wherever possible. Suits should be designed so as to allow easy connection to harness, anchors, belay devices and to allow the stresses from the uses of these devices to be safely distributed through the suit.

## 12.5 UV Exposure

Many of the synthetic materials currently used for ropes, slings and harnesses are sensitive to UV radiation exposure on Earth. Significant degradation can occur from UV exposure in a very short time leading to a decrease in strength and resiliency. In addition to UV, wet and frozen ropes can lose up to a third of their strength. This is why climbers are always wary of using fixed ropes - or slings they find already in place - unless they have a clear knowledge of when the rope or slings were put in place (and by whom). Some much more UV resistant materials will need to be developed for use on Mars while retaining the flexibility that current materials have. In some cases, gear (such as ropes), which have synthetic, flexible coverings may have a limited life time because of UV degradation. The faster that outer sheath (which only provides 5 % or so of the rope's overall strength) degrades, the faster its ability to protect the interior of the rope declines. Given that the outer sheath of a rope is something that is impractical to try and replace, much more UV-resistant external coverings need to be developed.

## 12.6 Ropes and Slings

Modern climbing ropes are "kernmantle" (jacketed-cored) in construction and are comprised of a woven nylon sheath which surrounds a braided core. Modern climbing ropes are so reliable that except for instances where a sharp object has damaged a rope in use, no one has apparently ever had a modern climbing rope fail on them as the result of a fall. Ropes are made of nylon, perlon, or similar polyamide fibers woven into varying patterns with each fiber running as one continuous strand for the entire length of the rope. The most common lengths for climbing ropes are 45 and 50 meters. Common diameters range between 9 mm (two of these ropes are used in tandem) to 11 mm (used alone). A rating system for kernmantel ropes has been established by the Union International des Associations d'Alpineisme (UIAA). A standard 11mm rope is required to hold a minimum of 5 UIAA falls without breaking using an 80 kg falling test mass. A 9 mm rope is required to hold a minimum of 5 UIAA falls without breaking using a 55 kg falling test mass. The force this test places on a rope is around 1,000 kg. These ropes are strong and can absorb an immense amount of fall–generated energy without breaking.

In addition to large climbing ropes smaller ropes and woven slings (similar to automotive seat belts) are used to attach a variety of mechanical devices to the climbing surface. These materials are similarly vulnerable to UV degradation. Current ropes derive their strength from their inherent molecular structure. Factors that affect that structure (heat, mechanical, chemical) degrade performance. UV issues aside, on Mars, the low surface temperatures, low atmospheric pressure, constant chance of possible contact with solid carbon dioxide and a Martian surface whose surface is still only poorly characterized all serve to threaten the inherent strength and usability of modern ropes. At the same time, ropes and associated slings will need to be used in a manner very similar to current gear – that is they need to be of similar diameters and need to be capable of handling by gloved hands. In cases where climbing is not involved, such as being lowered over a cliff or into a cave (spelunking) it is possible that winched cable systems could be used instead.

## 12.7 Metal Gear

Ropes and slings need a way to connect to the climber – and to anchors placed along the course of a climb. This is done principally by use of a variety of metal objects: carabiners and an innumerable array of pitons, wedges, and other devices. Modern metallurgy has taken basic designs which have existed in some case for more than a century and made them stronger, lighter, more reliable, and easier to use. Carabiners are commonly made from aluminum – a metal which is strong, easy to manufacture, and light. While it is perfectly adequate for terrestrial climbing, it may not be on Mars. Aluminum has an inherent tendency to corrode. Normal use results only in a thin aluminum oxide layer which actually serves to protect the remainder of the aluminum underneath. Over time, however, pits and scratches can render the carabiner useless. On Mars, moving climbing gear from the heavily oxidized surface into a pressurized environment and then back out again would likely expose aluminum gear to a significant corrosion risk. An alternative would be titanium.

While titanium has made an appearance in climbing gear - including carabiners – it has yet to rival aluminum in use in carabiners. Titanium is remarkably resistant to corrosion. Moreover, it does not suffer any loss in strength at low temperatures –and actually becomes stronger as the temperature reduces. Other gear used in climbing involves placing a metallic object in ("protection") an existing crack or other feature in the surface and positioning it such that it becomes firmly anchored. A carabiner is then attached to this object and a rope is then run through the carabiner. Some of the devices used are simple shaped pieces of metal with a sling attached. Fancier pieces of gear use spring-loaded cam gears, which are retracted as the piece is inserted and then expand when the piece is set.

## 13. What to Climb?

Now that all of the gear, logistics, and medical issues have been discussed, what will it be like to climb on Mars? Given that a lot of gear will need to be carried in order to provide supplies and safety capabilities, it should be anticipated that grand feats of mountaineering may have to wait for a few years until such time as the infrastructure is in place on Mars to handle the logistics. Even fast dashes for peaks on Earth require several dozen people and a lot of prepositioned supplies such that such a dash can then be mounted at an opportune place and time.

While there are mountains and canyons of similar variety to those found on Earth, there are many more features that have little or no terrestrial counterpart. If one were to contemplate climbing the largest peak on Mars – and in the solar system – Olympus Mons, you would need to plan for a long walk instead of an arduous climb. The slope is very gentle - assuming you take the route that offers the least obstacles. This mountain is 480 km across at its base, 27 km high with a caldera composed of nested craters 80 km across and 3 km deep at its summit. Conditions at its summit are not unlike those in space. For almost its entire circumference, O. Mons is encircled by a series of cliffs and scarps ranging in height from 4 to 6 km.

Given the amount of gear required to climb big walls on Earth, it will be quite some time before anything of this nature is attempted on Mars. If anyone is going to try and climb this mountain I suspect they will use satellite imagery and find the easiest route imaginable. As is the case on Earth, people who climb things are going to want to name them – and the names may not fall within the boundaries of what the planetary nomenclature committees would like.

Eventually, people will start to produce guide books and rating systems for climbs on Mars. A variety of rating systems currently exist, some with American and some with European origins. Some systems are hybrids. Some rating systems apply only to climbs where human muscle and skill are concerned. Others have to do with "aid climbs" where a variety of mechanical aids are put in place and people hoist themselves up and down. No doubt on Mars, a totally Martian rating system will soon emerge, one that takes into account the ease or difficulty of a climb while wearing a spacesuit.

## 14. What Will it be Like to Climb on Mars?

I wrote a short fiction piece [3] for the National Space Society's Magazine Ad Astra in 1992 titled "Oh Mons! The first ascent of Olympus Mons". In it I chronicled a slightly illegal ascent of the mountain.

> "For all intents and purposes I am in space. Funny thing - on Earth back in the 1900's, to get to the same relative height above one's planet required riding in an experimental rocket-powered airplane. Only when the altimeter read "50 MILES" (80 km), and at no small risk of injury, did one qualify for astronaut wings. Mars has half the diameter of Earth and a surface gravity of 0.38g. I have almost reached an equivalent level above Mars to qualify for those hard-earned wings simply by climbing a volcano. Wild."

One thing that may not be apparent on smaller peaks on Mars is the fact that the climbers realize that they are on another planet. When some of the more spectacular features on Mars are conquered, some rather novel sights will be there to greet the climbers. Will humans climb such things on Mars? Yes. I think it is inevitable – and it will happen sooner than people expect.

## References

1. K. Cowing, "Everest On Orbit", *Climbing*, No. 135, February/March 1993.
2. National Research Council, "Safe on Mars", 2002.
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