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AIRLOCK & CONNECTIVE TUNNEL DESIGN AND AIR MAINTENANCE STRATEGIES FOR MARS HABITAT AND EARTH ANALOG SITES

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ABSTRACT

For a manned mission to Mars, there are numerous systems that must be designed for humans to live safely with all of their basic needs met at all times. Among the most important aspects will be the retention of suitable pressure and breathable air to sustain life. Also, due to the corrosive nature of the Martian dust, highly advanced airlock systems including airshowers and HEPA filters must be in place so that the interior of the habitat and necessary equipment is protected from any significant damage. There are multiple current airlocks that are used in different situations, which could be modified for use on Mars. The same is true of connecting tunnels to link different habitat modules. In our proposed Mars Analog Challenge, many of the airlock designs and procedures could be tested under simulated conditions to obtain further information without actually putting people at risk. Other benefits of a long-term study would be to test how the procedures affect air maintenance and whether they need to be modified prior to their implementation on Mars.

INTRODUCTION

One of the most important factors in the Mars Habitat design involves maintaining the air pressure within the habitat. Preservation of breathable air will be an extremely vital part of the mission, as very little can be found in situ. Since Mars surface expeditions will be of such long duration, it is imperative that the airlock designs incorporate innovative air maintenance strategies. For our proposed Earth Analog Site competition, many of the components of these designs can be tested, as can the procedures required for long-duration habitation on Mars.

CURRENT PERSONNEL AIRLOCK DESIGNS AND MODIFICATIONS FOR MARS USE

Many types of airlocks are currently in use on Earth and in orbit, each of which incorporate factors that would be required on Mars. The closest analog is probably the Space Shuttle/ Spacelab/ Space Station airlock. This airlock is sized to fit two astronauts simultaneously, with an interior volume of 150 cubic feet, although the inside diameter is only 63 inches and the length is 83 inches. The D-shaped doors both have a 40-inch diameter and are 36 inches across. The airlocks are designed so that the higher pressure on one side aides the pressure seals by having the interior door open into the interior of the module and the exterior

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door open into the airlock.[1] The pressure seals are certified for vacuum use; therefore they would also be acceptable for use on Mars where the ambient pressure is approximately 0.005 atm. However, as this airlock is employed solely in null-g environments, it would need to be modified for ease of use in 0.33 g. For example, an inside diameter of at least 72 inches and doors of 65 inches in diameter would greatly improve the maneuverability of astronauts suited up to go through the door. Figure 1 details a sketch of the proposed Mars personnel airlock door dimensions.

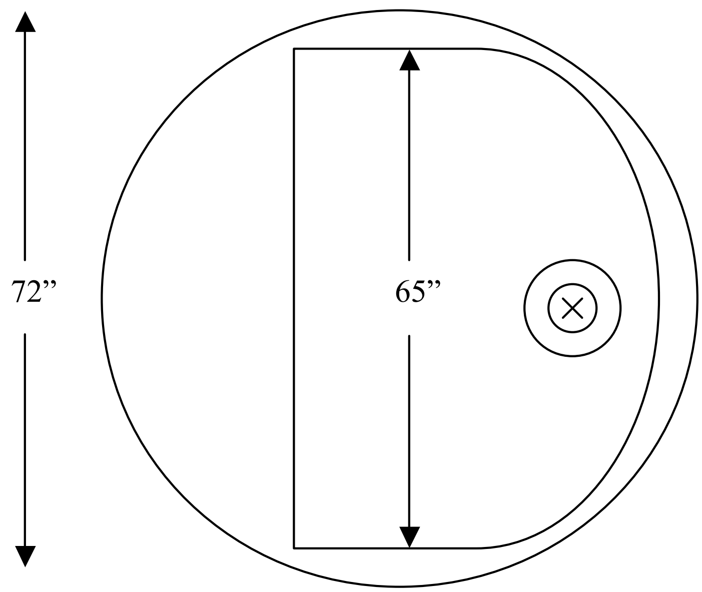

Figure 1. Personnel Airlock Front View

The most basic and important type of lock is the personnel airlock that will connect the interior of the habitat to the Martian atmosphere. This lock will most likely be a Space Station derivative in design, as the pressure requirements are operationally similar. Modifications, however, will be necessary to accommodate this new application. Due to the corrosive nature of the Martian dust, it is imperative that as little as possible be allowed to enter the habitat. One method that could be used to prevent this would be to have a cleanroom airshower with incorporated HEPA filters placed directly in front of the exterior door to remove dust down to 10 parts per million, or whatever is deemed appropriate. This airshower could also be used to remove any human particles from the suits prior to leaving the habitat so as not to contaminate the Martian atmosphere. Additionally, the air pumps would be incorporated into this system to return the air to the habitat as the airlock is depressurized. Airshowers can be manufactured to keep contaminants to ensure a maximum of one particle larger than one-half micron in one cubic foot of air, with the appropriate HEPA filter. The optimal configuration for the airshower would be to place the fan in the ceiling and the HEPA filters in the floor for Vertical Laminar Flow.[2] Another use of the personnel locks will be the storage of the EVA suits, with enough space so

[1] NASA website, http://www.shuttle.nasa.gov/shuttle/archives/sts-78/shutref/sts-eclss-airlock.html
[2] Servicore, Inc., http://www.cleanroom.com/learning_center/partone.html

that up to four astronauts can don their suits easily and simultaneously. This implies a length of approximately 120 inches. Figure 2 shows a sketch of the proposed Mars personnel airlock.

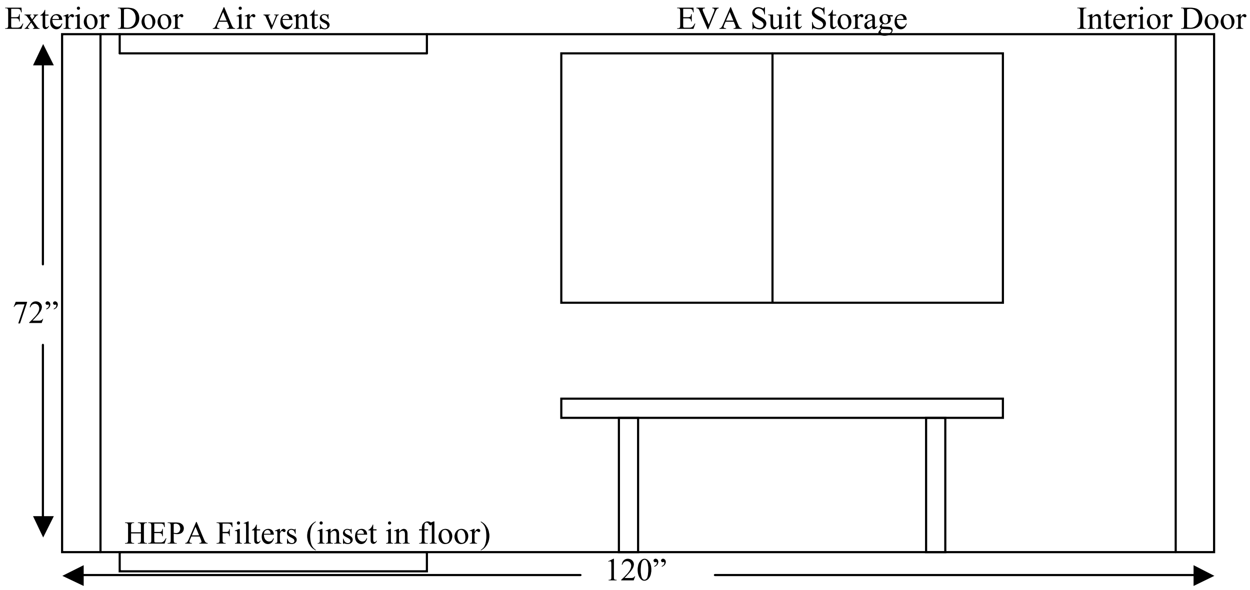

Figure 2. Personnel Airlock Cut-Away Side View

The same type of personnel airlock could be used in the rover, as the entry from both the habitat and the Martian atmosphere. This airlock would also double as the emergency pod for the vehicle. Therefore, in addition to the airshower, filtration system, and suit storage, the airlock must also have its own stores of emergency rations, water and medical supplies, communication equipment, and air scrubbers. This would be most efficient if these systems were situated in the walls or floor of the airlock so that they could not be cut off during an emergency where the crew was forced to remove themselves from the main part of the rover.

OTHER AIRLOCK TYPES FOR USE ON MARS

So far, this has been a discussion of personnel EVA airlocks. On Mars, there will be uses for up to four different types of airlocks as the habitat structure is diversified. Current proposals state that the habitat would be started with only one type of personnel airlock, and as the structure is made more complex, other types of more specialized locks would become more suitable. A different airlock for scientific samples would be beneficial in maintaining the safety of the habitat by keeping samples isolated until they are examined in the scientific section. If a sample airlock were to be found in the science section, it would be easier to simply place the samples into the lock from the outside and retrieve them on the inside. This type of airlock might not even need to equalize pressure, if the analysis were to be done under normal Martian conditions. However, the lock still must have two sets of pressure doors and the ability to be pressurized, if necessary. I propose a size of approximately two feet in diameter and three feet in length for a scientific sample airlock.

Once the station is more established and complex, a third type of personnel intra-habitat airlock would become quite useful. High importance must be placed on the independence of each area in the habitat so that in case one module experiences a leak or is suddenly depressurized, the atmosphere can be contained in the other modules, minimizing the air loss and crew danger. Therefore, smaller airlocks must exist at every exit from the habitat into the tunnels connecting to other habitat modules. These locks could consist solely of two pressure doors and enough interior space for four astronauts to pass through simultaneously, with a smaller pressurization system required as the pressure is anticipated to be the same on both sides of the lock under normal conditions.

The fourth airlock type would be used to enter the greenhouse or vehicle garage, if it is decided that these structures be kept at a lower pressure than the habitat modules. Our current garage design specifies that vehicles should be able to back up to the habitat module in order to mate the airlocks and allow the astronauts to enter or leave the habitat without needing to suit up. However, it must also be possible to maintain and clean the rovers without going into the Martian atmosphere, and it would be better for the vehicles if they were stored in a protected environment away from the corrosive dust. Therefore, we suggest that an inflatable garage system with an airlock is devised that could easily be sealed by an astronaut in a suit and then inflated to a pressure lower than that in the habitat, but high enough so that astronauts can work there in only protective suits and oxygen masks. NASA has proposed a retrofitted airlock for this purpose that would be inexpensive, simple to assemble, adaptable to any terrain and size required, and require no external power.[3] Similarly, our greenhouse proposal indicates that it should be inflated to the same lower pressure, along with the connective tunnels leading to the greenhouse. These airlocks must also have space for storage of the protective working suits and air systems, as well as an airshower to remove any dust that attached to the suits after working with the vehicles. Figure 3 shows the artist Carter Emmart's impression of the habitat's layout, including views of the different airlocks connecting the greenhouses and garage to the main habitat modules.

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[3] NASA website, http://technology.nasa.gov/scripts/nls_ax.dll/w3TechBrief(15;NPO-15415-1;20076886;1)

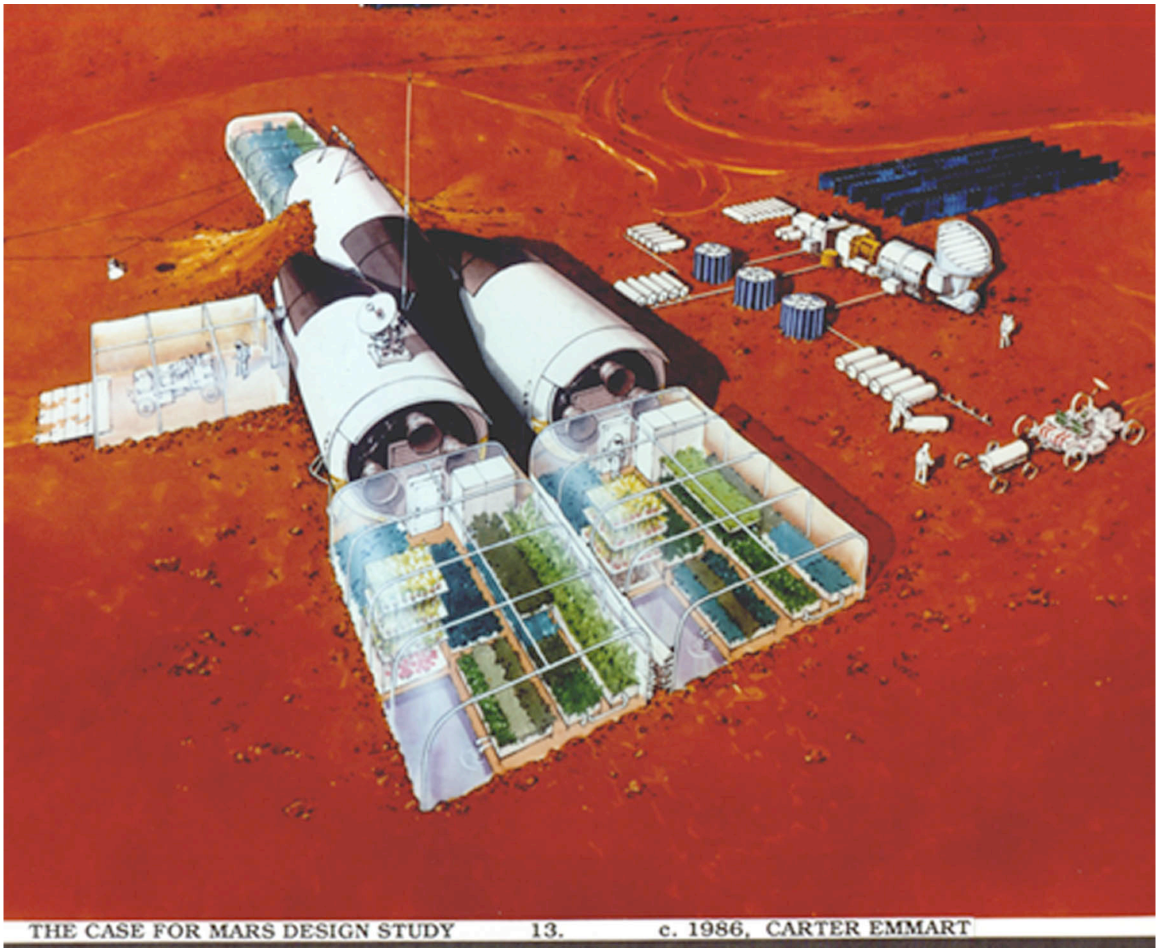

Figure 3. Artist’s Conception of Mars Base Layout

Figure 4 details the anticipated locations of all types of airlocks.

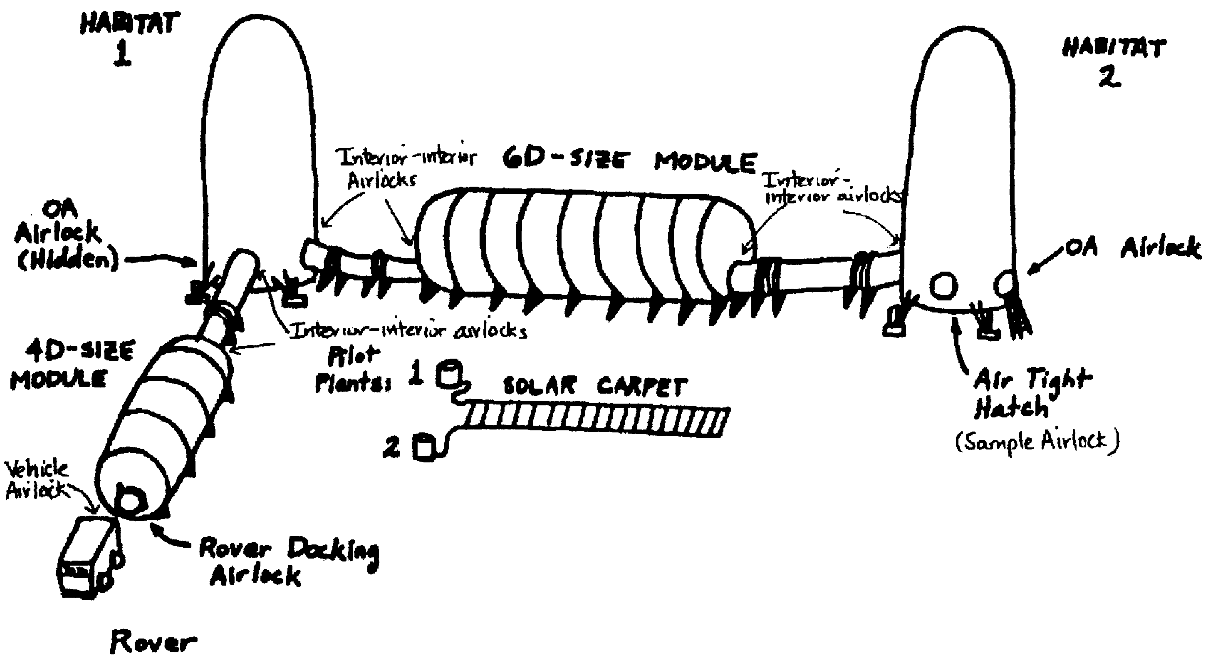

Figure 4. Suggested Airlock Locations[4]

CONNECTIVE TUNNEL IMPLEMENTATIONS

The connective tunnels mentioned will also be designed to be inflated, so that they will have a cylindrical shape of the same size as the entry airlock, and be reinforced with ribbing along with a grated walkway along the bottom to help secure the tunnel to the ground. If they can be kept at a lower pressure relative to the habitat, this will induce smaller stresses on the walls as well as reduce the amount of atmosphere lost in the case of an air leak. The most common current application of a similar type of connective tunnel is found on the Space Shuttle. This tunnel was used as a transfer tunnel from the shuttle to Spacelab, which was housed in the shuttle payload bay. The tunnel was constructed from welded 2219 aluminum with exterior exposed structural ribs of 2.4 x 2.4-inch aluminum as well as external waffle skin stiffening. The interior diameter was 63 inches, which tapered to two D-shaped openings that had a 40-inch diameter and were 36 inches across.[5] The very high strength and stiffness was required for safety in orbit; whereas, on Mars, possibly a strong polyethylene that is sufficiently resistant to puncture plus layers of Nextel, spaced between several-inches-thick layers of open cell foam would be suitable

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[4] Stanford US/USSR Mars Exploration Initiative Final Report Vol. 1 (1992) pg. 523

[5] NASA website, http://www.shuttle.nasa.gov/shuttle/archives/sts-78/shutref/spacelab.html#spacelab

for the connective tunnels. These layers would provide the necessary protection from meteorites as well as reduce heat loss from the structure.[6]

RELATED MARS ANALOG CONTEST GOALS AND RULES

The main goal of this analysis is to find appropriate methods for simulating Martian atmospheric responses at Earth analog sites so that the procedures and mechanisms can be tested for safety and ease-of-use over the long term. Examples of airlocks that would be useful for a Mars analog study include the pressure doors found on all Navy ships and the anterooms of cleanrooms. In both of these cases, the interior is also at a higher pressure than the exterior ambient pressure for safety reasons. As a minimum requirement on all sites wishing to enter the Mars Analog Site Contest, the structures must be able to tolerate an overpressure differential of 0.05 atm above ambient pressure. The systems need not be closed, but there must be a continuous-speed fan capable of maintaining this overpressure at all times. Differential pressure sensors must be placed within the habitat as well as the airlocks and rovers. Such sensors that are accurate to at least 0.0001 atm can be bought off the shelf for less than $100. Any pressure change greater than 0.01 atm should sound an alarm to indicate a leak.[7] An emergency situation requiring the astronauts to wear pressure suits within the habitat would arise if the pressure differential dropped below 0.035 atm.

The airlock simulators need not be along the designs of the Mars-ready airlocks. An appropriate analog for the minimum requirements would simply be a room with close-fitting doors that lead both into the habitat and outside, space to store outerwear and suits, a constant-speed fan, a vent to simulate pressure equalization, and a differential pressure sensor. For the interior-interior locks, the only requirements would be two doors and a small space for transit. See the Appendix for more detail into the components and procedures governing analog airlock construction and use. Figure 5 shows sketches for a possible analog airlock design.

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[6] Emmanuel, R. (2000) *Structures for Mars and Mars Analog Sites.*
[7] NASA website, http://www.shuttle.nasa.gov/shuttle/archives/sts-78/shutref/sts_eclss.html#sts_eclss

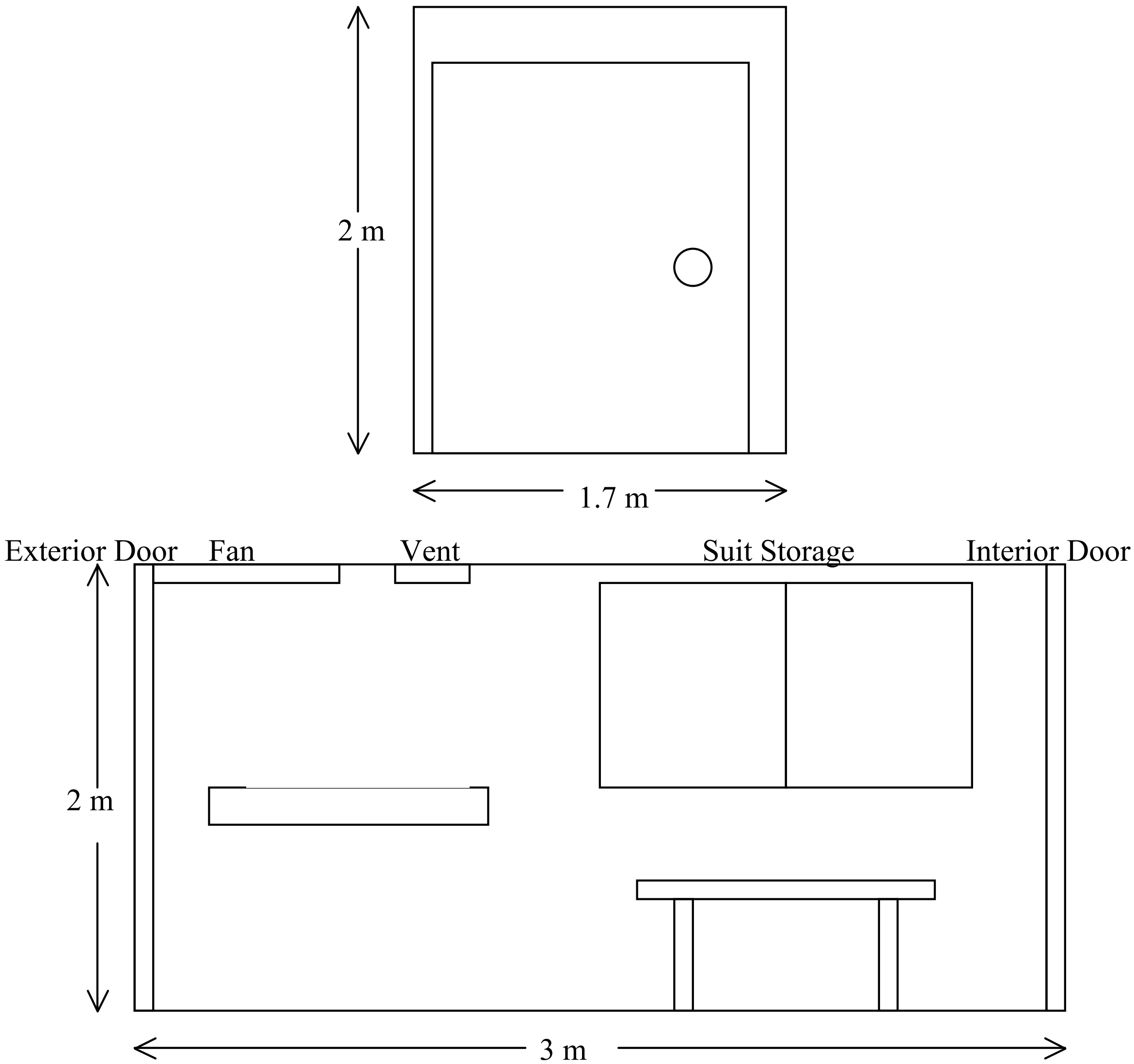

Figure 5. Analog Airlock Design Front and Cut-Away Side Views

If a certain site, such as the Biosphere, chooses to concentrate data gathering on air maintenance in a closed system, more stringent rules can be created to better simulate the pressure differential and procedures that will be found on Mars. The maximum analog pressure differential advised is 0.2 atm above ambient pressure. At this same analog site, excursion suit components as well as other vehicle designs can be tested under higher-pressure conditions. Also, with true pressure-sealed airlocks, the long-term use of air pumps and air scrubbers can be tested to ensure that the extra pressure within the airlock is removed to the interior when equalizing to the ambient pressure, as the air pumps are a vital part of the air maintenance cycle.

Another system that could be tested either simultaneously or at a different analog site would be the air maintenance system, including the HEPA filters in the airlock area, CO_2

scrubbers, and O_2 production components. In such an experiment, the habitat would need to be entirely closed and sensitive air quality sensors placed in all areas so that poor circulation or O_2 production would trigger an alarm. Normal procedures for all of these analog experiments as well as on Mars must be very strict, as the air maintenance is quite important. First of all, the system controls must not allow both sides of the airlock to be open at the same time, even interior-interior locks. This is required so that in any emergency, such as a leak of pressure, the entire habitat will not depressurize. Under normal circumstances, when exiting from the habitat to the outside, a suited astronaut must wait for the extra pressure to be pumped out of the lock and back into the habitat before opening the outer door and vice versa. However, both doors must be equipped with emergency overrides so that if the occasion arises, the doors can be opened before the pressure is equalized. This cannot be a common practice, as too much air volume would be lost in such an episode. See the Appendix for more detail into emergency airlock procedures.

In a simulation containing airshower and HEPA filter-equipped locks and pressurized EVA suits, procedures to use the airshowers when re-entering the habitat to remove as much dust as possible should be followed. One way to test the efficacy of these systems would be to place sensors on the habitat side of the airlock to check the air quality for particle influx when the airlock is used. Additionally, EVA suits should remain in the airlock storage area at all times to minimize particulates in the habitat modules.

Inflated connective tunnels can also be tested at an analog site by using an appropriately sized cylinder of polyurethane sheeting and attaching it to two sets of pressure doors before inflating it to a higher pressure. Emergency testing can be accomplished by creating small punctures in any pressurized surface connected to the habitat to examine the sensitivity of the barometers and to determine procedures to deal with such occurrences.

For all of these purposes, analog sites will be quite beneficial in determining daily and emergency procedures for the Mars habitat. Many different components of the airlock and air maintenance systems can be tested either separately or together at a number of sites. Equivalent systems in most cases can be constructed from materials acquired at the local home improvement center. Thus, the use of analog sites will be able to furnish very important long-term data to indicate how well the air maintenance systems will function on Mars.

APPENDIX - Airlock and Pressure Rules for Mars Analog Sites

4.2.3 Habitat

As a minimum requirement for the contest, all parts of the habitat should be overpressurized to 0.05 atm above ambient outside pressure by use of fans situated throughout the structure that continuously blow in fresh air.

4.2.3.1 Pressure Systems

The overpressure of the habitat, rovers, and personnel suits must be maintained at all times. At a minimum, this can be accomplished by placing multiple fans connected to the outside that run at a constant speed, to be determined before the contest begins by evaluating the leakage of the habitat structure. There must also be differential pressure sensors situated around the habitat capable of signaling an alarm if the pressure differential goes outside of 0.05 ± 0.01 atm. The daily monitoring and maintenance of these sensors should be a part of Normal Activities. If any alarms go off or pressure sensors indicate a pressure loss, emergency procedures should be followed until the situation is resolved.

4.2.3.2 Airlocks

All habitat areas and rovers must have airlocks with close-fitting doors that can hold 0.05 atm above ambient pressure. At a minimum, this should consist of a prefab compartment with two sealing doors. For safety reasons, the exterior door should open into the airlock, while the interior door should open into the habitat or rover. Since it is assumed that in the minimum configuration, the structures will not be airtight, a vent must be situated in the airlock such that the pressure can be increased and decreased at will, by either opening or closing this vent to multiple positions. The apparatus can be either manually or computer-controlled, and it must be controllable from both sides of the airlock as well as inside.

The airlock should also be used for storage of the EVA suits, and the rover airlock can also double as the emergency pod for the vehicle.

For grading purposes, surveillance cameras should be placed to ensure that the competitors are adhering to the rules and procedures.

One or more sites can use a higher differential pressure in order to test different components of the site design as monetary and structural loads allow. The differential must be within the range of 0.05 – 0.2 atm above ambient pressure.

4.2.3.3 Airlock Procedures

To pass through the airlock, the astronaut must first check the pressure sensor readout to ensure that the airlock is fully pressurized. After unsealing, traversing, and resealing the first door, the excursion suit can be removed from storage and put on. Once all requisite procedures are completed regarding the suit, the vent should be opened to equalize pressure with the outside, determined by looking at the readout. (For analog purposes, the vent simulates the pump that will be removing the excess air from the airlock back into the habitat. In order to keep from losing precious breathable air on Mars, these procedures must be strictly adhered to.) When the pressures have equalized, the vent should be closed, and the outer door may be opened, traversed, and resealed.

For the reverse procedure, many of the steps are the same, except that the vent must be closed fully until the pressure differential is reacquired, when it is returned to its resting state.

During normal procedures, the airlock shall remain "depressurized" while the astronauts are in the local area near the habitat (or outside of the rover) for safety reasons and to facilitate ease of reentry unless other astronauts are also preparing to exit. Similarly, it should be pressurized when all participants are inside the structure.

4.2.3.4 Emergency Procedures

In the case of an emergency, some of these airlock procedures can be broken with only minor loss of points (assuming the emergency can be verified by the grading authority.) In such cases, it is possible to open the second door before full repressurization or depressurization has been accomplished. However, both doors can never be open at the same time as this would simulate an explosive decompression of the habitat.

In the event of a pressure alarm or other indication of a leak, all available personnel should immediately begin searching for the cause of the problem while monitoring the pressure within the structure. If the pressure differential drops to 0.035 atm or less, the pressure suits should be worn within the structure until the leak can be fixed.