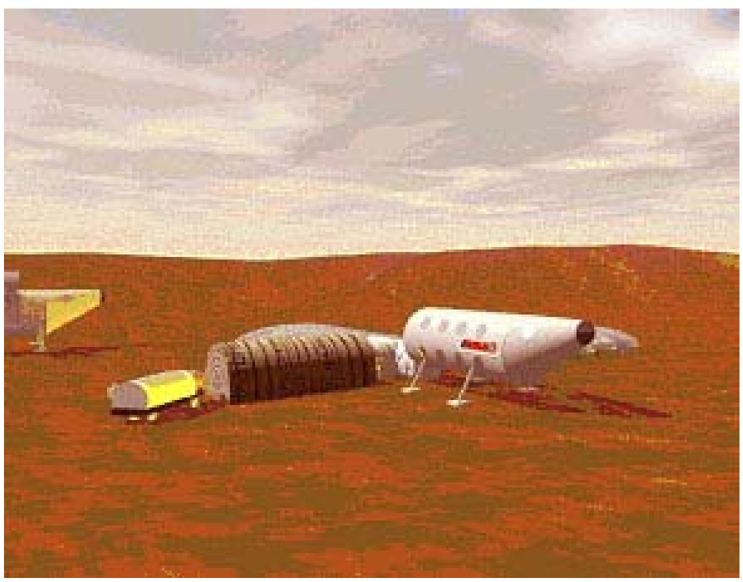
AN AUSTRALIAN MARS ANALOGUE RESEARCH STATION (MARS-OZ)

A PROPOSAL



Compiled by

Dr Jonathan Clarke

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1 INTRODUCTION

1.1 DOCUMENT SUMMARY

Mars Society Australia (MSA) has selected the Lake Frome Plains to the east of Arkaroola for the site of the Australian Mars Analogue Research Station (MARS-OZ). The station will provide a laboratory to study how humans will live and work on Mars, and will complement similar stations in Utah, Devon Island, and Iceland.

This document describes the selection process by which six regions, 200 km in diameter, were identified as potential sites and Arkaroola chosen as the preferred location for MARS-OZ. The Arkaroola region offers a wide range of terrain types, has a complex geology, is relatively easy to access logistically, has outreach opportunities, and includes a number of localities previously studied as Mars analogues.

The document reviews how and why MSA has chosen a different configuration for the MARS-OZ habitat to the “tuna can” chosen for the other localities. Our preferred sketch simulates a horizontally landed biconic. Horizontally landed biconics are attractive in an actual Mars mission over other configurations in terms of mission profile and surface operations. We believe this long thin horizontal configuration has considerable logistic advantages over the tuna can design. Furthermore, using a different configuration allows comparisons between different lander designs to be evaluated.

The habitat itself is part of a larger complex which will eventually include a simulated cargo lander, also of biconic design, inflatable structures and solar power systems. All operations will be carried out in conjunction with existing analogue research programs including the Marsupial Rover with its unique utility configuration, MarsSkin analogue mechanical counter pressure (MCP) space suit, and SAFMARS communications system.

These components together comprise a significantly different vision for an Analogue Research Station to those constructed or proposed to date. Together, they are shown in the cover illustration by Jozef Michalek. Potential research at the facility is multi-disciplinary. This document highlights engineering, science, information systems, environmental systems, and human factors as the key fields of research.

Finally, this document outlines further work necessary to transform the sketch into a detailed design proposal and possible costs of doing so. The only available costing is comparison with other Mars Analogue Research Stations. These comparisons, converted to Australian dollars, suggest a construction cost of the order of $700,000 and an annual operating cost of $120,000. We envisage the facility operating for a preliminary period of five years. A series of 8 program way points provide a guide to significant landmarks in the achievement of the goal of an operating MARS-OZ. They are the decision to commit to MARS-OZ, region selection, preliminary design, formal design, site selection, construction, deployment, and operation. This document marks the conclusion of the preliminary design phase.

2 OBJECTIVES FOR MARS-OZ

2.1 WHY BUILD MARS ANALOGUE RESEARCH STATIONS?

The nature and rationale for Mars Analogue Research Stations (MARS) are found on the Mars Society's (US) web page. [1]

"In order to help develop key knowledge needed to prepare for human Mars exploration, and to inspire the public by making sensuous the vision of human exploration of Mars, the Mars Society has initiated the Mars Analog Research Station (MARS) project. A global program of Mars exploration operations research, the MARS project will include four Mars base-like habitats located in deserts in the Canadian Arctic, the American southwest, the Australian outback, and Iceland. In these Mars-like environments, we will launch a program of extensive long-duration geology and biology field exploration operations conducted in the same style and under many of the same constraints as they would on the Red Planet. By doing so, we will start the process of learning how to explore on Mars.

"Mars Analog Research Stations are laboratories for learning how to live and work on another planet. Each is a prototype of a habitat that will land humans on Mars and serve as their main base for months of exploration in the harsh Martian environment…."

A further quote from the Mars Society (US) web page describes the operational philosophy of MARS:

"Each station will serve as a field base to teams of four to six crew members: geologists, astrobiologists, engineers, mechanics, physicians and others, who live for weeks to months at a time in relative isolation in a Mars analog environment. Mars analogs can be defined as locations on Earth where some environmental conditions, geologic features, biological attributes or combinations thereof may approximate in some specific way those thought to be encountered on Mars, either at present or earlier in that planet's history. Studying such sites leads to new insights into the nature and evolution of Mars, the Earth, and life.

"However, in addition to providing scientific insight into our neighboring world, such analog environments offer unprecedented opportunities to carry out Mars analog field research in a variety of key scientific and engineering disciplines that will help prepare humans for the exploration of that planet. Such research is vitally necessary. For example, it is one thing to walk around a factory test area in a new spacesuit prototype and show that a wearer can pick up a wrench - it is entirely another to subject that same suit to two months of real field work. Similarly, psychological studies of human factors issues, including isolation and habitat architecture are also only useful if the crew being studied is attempting to do real work."

The MARS are designed to meet three specific goals:

- "The Stations will serve as an effective testbed for field operations studies in preparation for human missions to Mars specifically. They will help develop and allow tests of key habitat design features, field exploration strategies, tools, technologies, and crew selection protocols, that will enable and help optimize the productive exploration of Mars by humans. In order to achieve this, each Station must be a realistic and adaptable habitat."

- "The Stations will serve as useful field research facilities at selected Mars analog sites on Earth, ones that will help further our understanding of the geology, biology, and environmental conditions on the Earth and on Mars. In order to achieve this, each Station must provide safe shelter and be an effective field laboratory."

- "The Stations will generate public support for sending humans to Mars. They will inform and inspire audiences around the world. As the Mars Society's flagship program, the MARS project will serve as the foundation of a series of bold steps that will pave the way to the eventual human exploration of Mars."

MSA's aim is to establish the MARS-OZ in the immediate future. It will be based near Arkaroola in the northern Flinders Ranges of South Australia and operate in conjunction with three other MSA programs: the Marsupial analogue pressurised rover with a unique utility configuration, the MarsSkin analogue mechanical counter-pressure space suit, and the SAFMARS satellite communications system[2].

3 SITE SELECTION

3.1 ASSESSMENT CRITERIA FOR ANALOGUE SITES

Australia is rich in locations geologists have identified as closely analogous to environments observed on the surface of Mars. Initial electronic discussion between members of the MSA identified many of these, which were found in most Australian States. Sites were nominated on the basis of scientific interest, range of environments suitable for testing equipment, and visual resemblance to Mars. The most attractive sites were in central Australia, and most could be visited in a single 4WD trek. The purpose of the Jarntimarra-1 expedition was to visit and evaluate these sites in terms of their Mars analogue potential.

3.2 EVALUATING THE SITES

Figure 1 Jarntimarra-1 expedition on location at The Breakaways, Coober Pedy

The Jarntimarra-1 expedition (October-November 2001, Figure 1) spent two weeks in the field and visited a wide range of sites. These are listed in
Table 1. The expedition route is shown in Figure 2. In undertaking this expedition, every effort was made to obtain permission from the stakeholders, owners or custodians of the selected land before the visit took place, though in all cases the visits were non-intrusive. A paper detailing the expedition and site selection process is in press[3].

At each site, the survey crew filled in a database information sheet. This was a set of 13 prompts for each field in the database: name, date, latitude/longitude, ownership, access, risks, maps, geology, climate, flora/fauna, history, analogue value and references. These provided for factual entries in the Jarntimarra database. To record comparative judgements with respect to the MSA's specific needs, there was a separate assessment sheet with a list of 8 scientific and 8 engineering criteria, favouring sites that have intrinsic scientific value and offering a range of conditions

Island Lagoon, Woomera, SA	Mt. Gason Bore, SA
The Breakways, Coober Pedy, SA	Mungeranie Bore, SA
Moon Plain, Coober Pedy, SA	Lake Eyre South, SA
The Painted Desert, SA	Milners Rock Pile, Birdsville Track, SA
Henbury Craters, NT	Coopers Creek, SA
Alice Well, NT	Mirra Mitta Bore, SA
Finke River Crossing, New Crown, NT	Mt. Gason Bore, SA
Mt. Hammesley Plain, SA	Mungeranie Bore, SA
Dalhousie Springs, SA	Sturts Stony Desert, SA
Lake Eyre South, SA	Clifton Hills dunes, SA
Milners Rock Pile, Birdsville Track, SA	Mt Gee, Arkaroola, SA
Coopers Creek, SA	Paralana Hot Spring, Arkaroola, SA
Lake Frome Plain outwash fans, SA	

Table 1 Sites visited during Jarntimarra-1

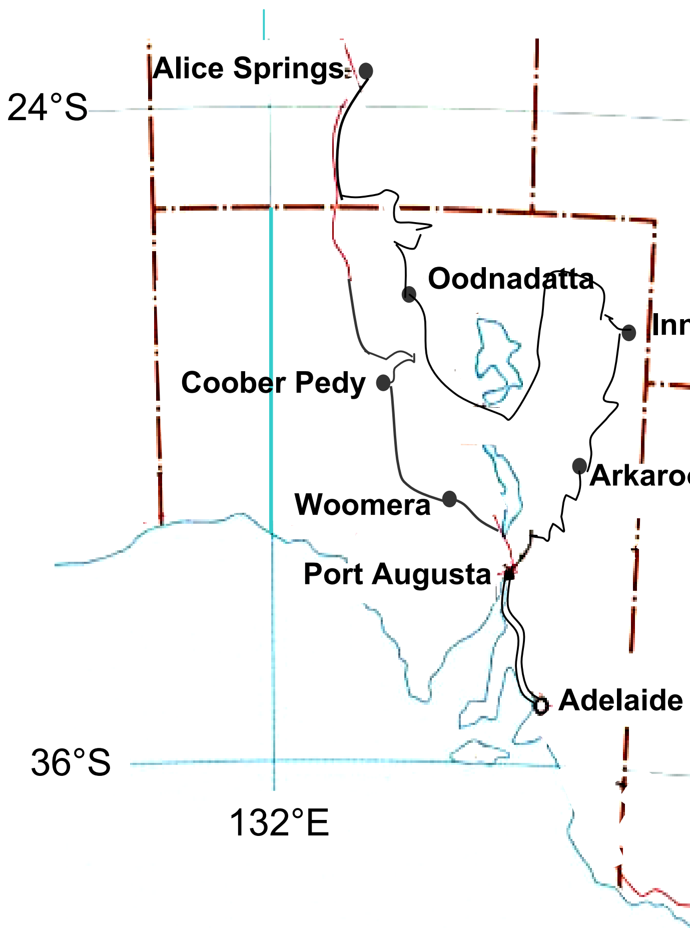


Figure 2 Route of the Jarntimarra-1 expedition

SCIENTIFIC CRITERIA	ENGINEERING CRITERIA	LOGISTIC CRITERIA	VISUAL CRITERIA

Bedrock geology	Rocky	Security	Climate
Geomorphology	Boulders	Accessibility	Surface water
Surficial deposits	Sandy	Infrastructure	Colour
Groundwater	Dusty	Land tenure	Vegetation
Weathering	Firm	Liabilities	Physiography
Palaeontology	Chemical Activity	Safety	Landscape process
Microbiology	Wind	Outreach potential	Cultural association
Extremophiles	Temperature variation		Cultural disturbance

Table 2 Ranking criteria for examined sites

in which to test analogue vehicles, spacesuits and other equipment. There was also a set of 7 logistical criteria relating to the distance from facilities and practical difficulty of operations and 8 visual criteria, reflecting the public relations requirement for the site to photograph as if it were the Martian surface (Table 2).

3.3 SELECTING THE REGIONS

A number of key issues for MSA were resolved during a three-day conference at Arkaroola village at the end of Jarntimarra-1. The expedition found that most of the assessed sites fell within the boundaries of only six 200-km diameter circles (Figure 3). The significance of these exploration zones is that each specifies a set of features within easy reach of one simulated Mars mission, given a vehicle capable of extended traverses. If the centre of a circle represents a habitat landing site, all the features within that zone would be accessible by sorties of no more than 100km. Each of these six centres represents a possible "landing site" for MARS-OZ.

Based on the collective experience gained while filling in the site assessment sheets, each zone was rated on a 5-point scale according to the above specific characteristics. Engineering and science scores then were doubled to reflect their importance relative to the other criteria in the total score. On this basis, the Moon Plain, Woomera and Arkaroola zones achieved equal ranking.

To support the goal of recommending a premier site for the 2002-2003 season, the tie was broken by considering the arguments of individual expedition members advocating each zone. Eventually the case for the Arkaroola region prevailed by virtue of its unique combination of logistical convenience (hospitable base at nearby Arkaroola village; 8 hours road travel from Adelaide; 1200m all-weather airstrip at Balcanoona), international scientific reputation and Mars-like geology.

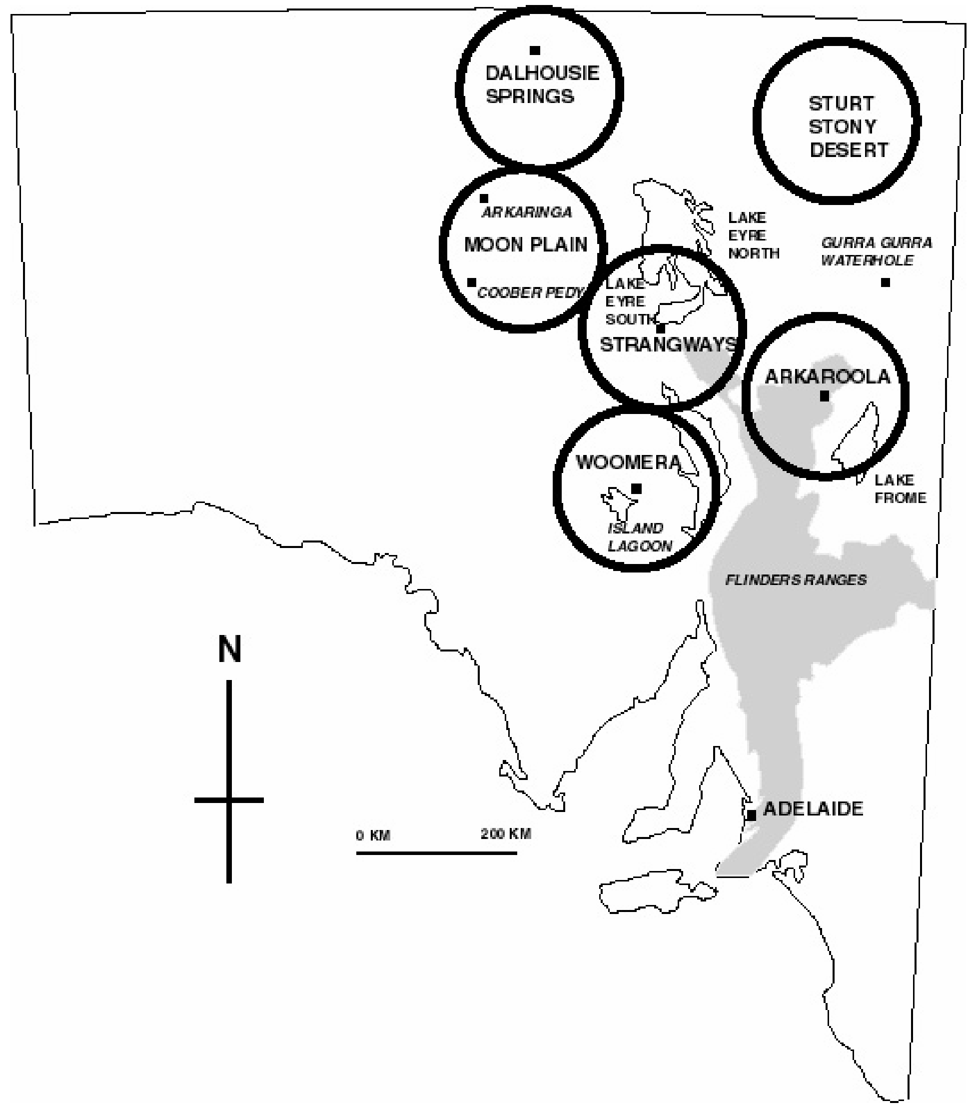


Figure 3 The six prime regions selected during Jarntimarra-1

Specific Mars analogue research in the region has been three-fold, focusing on aeolian landforms, extremophiles, and remote sensing. Studies of aeolian landforms compared Martian dunes at Nili Petra with terrestrial dunes at Gurra Gurra Waterhole in the Strzelecki Desert[4] [5]. The extremophile work found radiation-resistant thermophiles in the Paralana hot spring which is characterised by high levels of radon gas[6]. The area has been used in remote sensing experiments comparing hyperspectral imagery from the alteration halo surrounding the Mount Painter fossil hydrothermal system with ground truth from a hand-held spectrometer[7]. This last study is particularly relevant to detecting the presence of such systems on Mars, which are believed to be good localities to search for microfossils. Potential Mars analogue geoscience research in the area may include palaeontology, geomorphology and regolith studies. The Proterozoic sediments of the area are known to host silicified microfossils and the sinters of the Mt. Gee fossil hydrothermal system show potential for microfossil preservation. Geomorphological and regolith studies include evolution of the alluvial fans on the eastern flank of the Flinders Ranges, nature of mound springs of Lake Frome, and landscape evolution of the northern Flinders Ranges, where uplift has led to partial exhumation and dissection of ancient land surfaces buried beneath Cretaceous cover. Then finally, the area includes a wide range of surfaces, including boulder-strewn stream beds, gibber plains, salt lakes, sand dunes, gorges and very rugged hills.

An ideal site for the habitat was found on the gravel plains to the east of the Arkaroola zone's central point, between the eastern side of the northern Flinders Ranges and Lake Frome (Figure 4). This will allow easy access to sites in the Flinders Ranges proper and on the plains that surround Lake Frome. It will also simplify logistics, as a well-maintained, unsealed road runs up the eastern margin of the ranges, joining the Strzelecki Track to the north and the Barrier Highway to the south. The exact co-ordinates will be decided upon during a further expedition after discussion with the land holders.

Figure 4 Panorama of Lake Frome Plain southeast of Arkaroola, a potential site for MARS-OZ. The mountains in the distance are the northern Flinders Ranges near Arkaroola.

4 WHY SIMULATE A BICONIC LANDER?

4.1 BACKGROUND

FMARS and MDRS are based on cylindrical landers consisting of two circular decks 8 m in diameter (Figure 5). The European habitat (E-MARS or Euro-MARS) is of similar dimensions but consists of three decks[8] Discussions during Jarntimarra-1 highlighted the logistic challenges posed by assembling the Devon Island tuna can MARS on site. Transporting the MARS as a single unit to the chosen site seemed more attractive logistically. Road transport laws make it much easier to carry a long but comparatively low narrow structure than a high and wide one. This led to MSA considering building an analogue horizontally landed biconic (HLB) for MARS-OZ.

Figure 5 The MRDS under construction in SW Utah[9]

4.2 TYPES OF MARS LANDERS

There are two basic types of Mars landers, ballistic landers with low lift over drag (L/D) and biconic landers (high L/D). Ballistic landers are simpler to design, construct and fly, but have lower cross-range maneuverability and experience higher thermal and acceleration loads during entry. Biconics are challenging to design and fly, but have lower thermal and acceleration loads. Several lander configurations are possible with each type.

- Conical "headlamp" landers can be either ballistic, as in the Rockwell[10] and Energia studies of the 1960's[11] [12], or biconic, where the biconic aeroshell is jettisoned after entry, as with the Caltech mission (CMSM)[13]. These designs do not require attitude rotation during flight.

- Cylindrical tuna can landers, as with the Mars Direct (MD)[14] and NASA Design Reference (DRM) Mission version 1.0[15], which feature bioconic aeroshells. Both these studies required a 90-degree attitude rotation during flight.
- Open “coolie hat” landers where components are clustered behind a large open heat shield, as with early Energia studies[16 17]. These are ballistic landers and, like headlamp landers, do not experience attitude rotation. Some versions of MD feature an extendable coolie hat heat shield[18].
- Vertically landed biconics (VLB), as with the 1984 Case for Mars (CfM)[19] and DRM 3.0[20] studies. These studies also required a 90-degree attitude rotation during flight.
- Horizontally landed biconics (HLB). These also do not require attitude rotation during flight.

Unlike version 1.0 and 3.0 of the DRM and the MD studies, HLBs, in common with headlamp and coolie-hat designs, do not need to perform a highly dangerous attitude rotation maneuver. Compared with the vertical landed designs, HLBs also provide much better access to equipment when on the ground. This is their most attractive feature when considered as a Mars surface habitat.

4.3 BACKGROUND TO HLBS

Some of the earliest concepts for crewed missions to Mars used horizontally landing vehicles, typically gliders or flying wings. These included the von Braun studies of 1953[21] and 1956[22], and another by Bono in 1960[23]. These all assumed that the Martian atmosphere, was about 10% of Earth’s. When Mariner 4 showed that the correct figure was actually about 1%, interest in such landers initially evaporated, in favour of various ballistic designs. A partial exception was the CfM study which used vertical landing biconics as both ferries and cargo carriers. The cargo landers were lowered into the horizontal position after landing (Figure 6). Aspects of the CFM were influential in later ISU and Grover *et al*. studies.

Horizontally landing biconics have been part of a number of crewed Mars mission architectures from the 1980's and 1990's. They were favoured by RSC Energia in 1986-87[24 25] and 1989[26 27] studies, a similar design was used by Keldysh in 1989[28], and biconic/lifting body hybrids featured in the 1999 Energia studies[29]. Western studies include the Grover *et al*. 1996 study[30] and a 1991 International Space University (ISU) sketch[31]. The full ISU study is available only in print form[32]. The Energia studies were for nuclear electric or solar electric propelled sprint missions, the Keldysh design for a nuclear thermal sprint mission, the Grover *et al.* study for a long duration mission, and the ISU sketch was for both sprint and long duration missions. The Energia designs are shown in Figure 7, the ISU mission in Figure 8, Figure 9, Figure 10, Figure 11 and the Grover *et al.* concepts in Figure 12 and Figure 13.

All of these studies have biconics as the main landing vehicle; the Grover *et al.* study also uses a biconic for the Earth-Mars transfer vehicle, and the Keldysh study had a biconic as an earth entry craft. All cited studies except Scenario I in

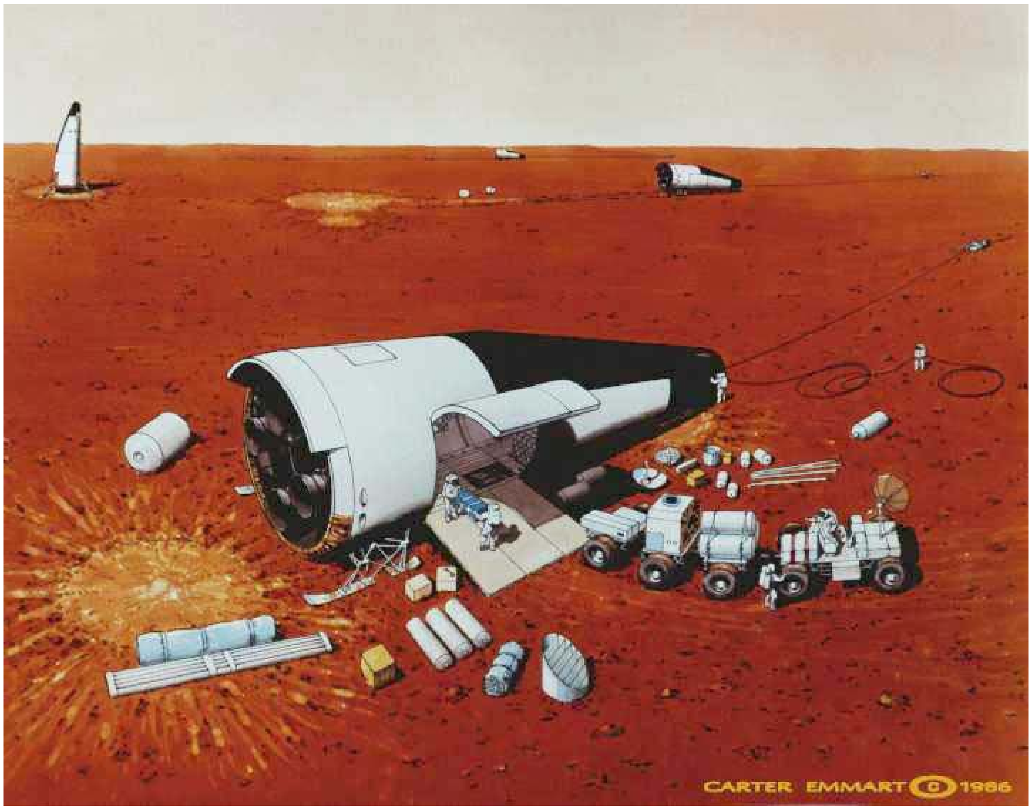


Figure 6 Unloading a CfM cargo lander with a tail-sitting ferry biconic in background (reference 19)

Grover *et al*. (which used a tail sitting biconic), and possibly one of the Energia 1999 designs and the Keldysh design where it is not clear how the ascent stage is placed), use a vertically launched ascent stage encapsulated within the biconic.

This arrangement should not be taken as definitive as other options are possible, such as inclining the bionic for launch (as in the 1960 Bono study), raising it to a vertical position (more or less as in the original von Braun approach) or using the descent engines for initial takeoff.

The 1986 Energia lander, referred to as the EA (Expeditionary Apparatus), or the MPK (Marsianskovo Posadochnovo Korablya) was a cylindrical spacecraft with a conical nose, 3.8 m diameter and 13 m long. The spacecraft masses 60 tonnes. The primary braking engine was housed in the rear of the spacecraft. A landing engine at the belly of the cylinder would then fire to bring the spacecraft to touchdown on four landing legs. The two-man crew rode to the surface in the return module contained within the cylinder. If difficulties arose during descent, doors would open in the spine of the cylinder and the return module would blast vertically from MPK and return to orbit. The crew would descend to the surface in a cylindrical inflatable airlock tunnel that deployed from the belly of the cylinder to the surface. The conical nose contained a crew living compartment. After a week on Mars the crew would return to the orbiting mother ship. The Energia design has been very influential on subsequent biconic landers, especially in the configuration of the ascent stage. The ISU and Grover *et al.* lander studies were at least partly inspired by the Energia landers.

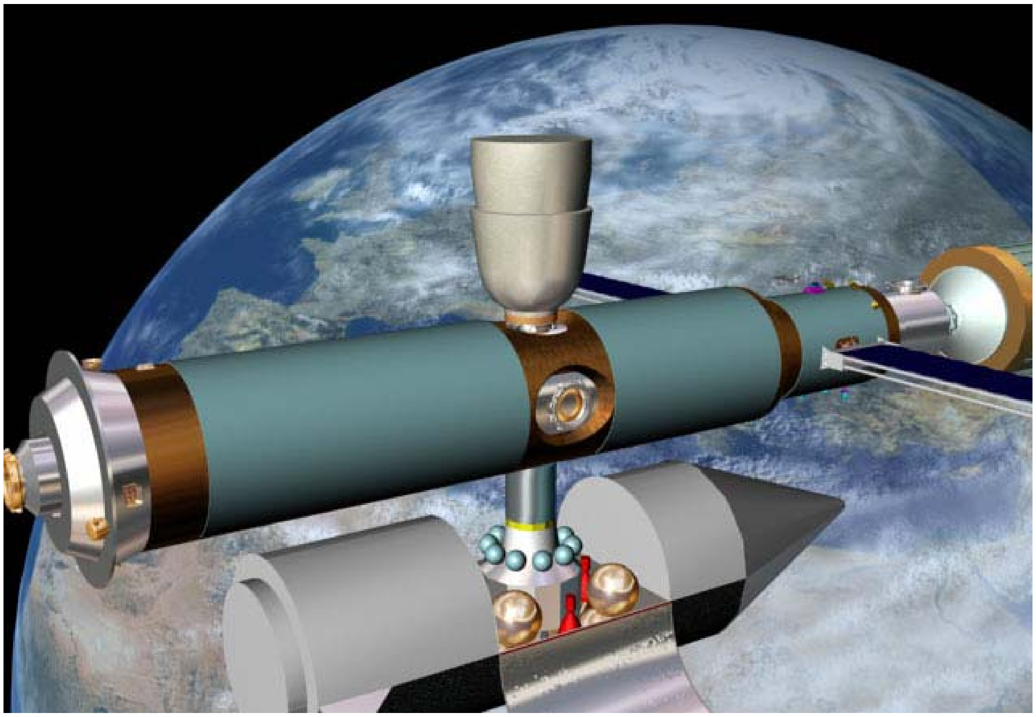
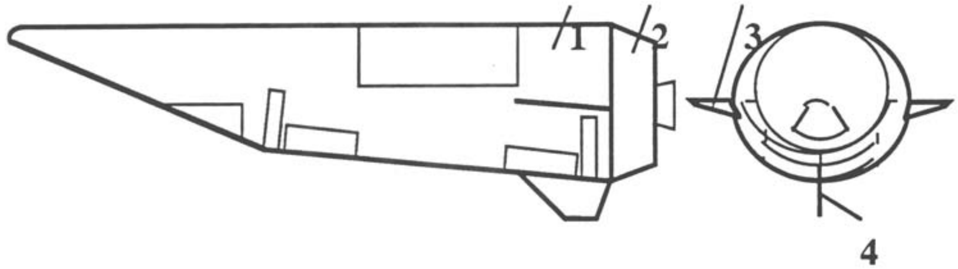


Figure 7 The Energia EA MPK design docked to the 1989 Mars spacecraft (reference 24)

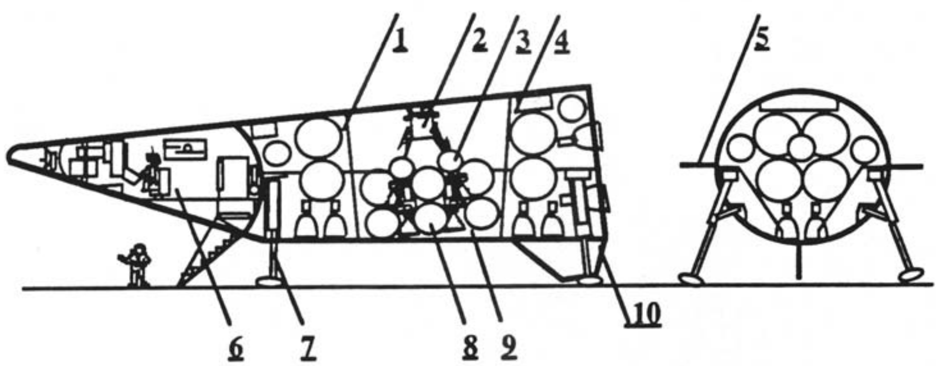
The ISU mission used three biconic lander designs, one being the crew lander and ascent craft, the second being the cargo vehicle, and the third the habitat lander. Each biconic was 23 m long and 5.5 m in diameter. The mass on landing was 70 tonnes. Each lander contained a standard crew compartment and a specialised component, either a habitat, ascent/abort stage, or cargo. The mission was designed around a crew of 4. The overall mission architecture was clearly influenced by the Energia nuclear electric mission (Energia staff provided part of the design team) and the use of a biconic lander with an ascent stage contained within the main structure. Many other aspects of the ISU mission study resembled the 1984 CfM study as well, in particular the use of multiple landers that were joined on the surface to form the Mars base.

The Grover *et al.* study closely resembles in overall philosophy that of the DRM scenarios, utilising three Energia launches and ISRU propellant manufacture. The biconics in this study were 22 m long and had a maximum diameter of 9.1 m. Lander mass was approximately 35 tonnes. They were similar in size and appearance to those of the 1984 CfM study. Two scenarios were proposed. In scenario I, a HLB containing the ISRU plant and cargo is launched from earth, accompanied by a tail-sitting biconic that contains the unfueled Mars Orbit Insertion and the Trans Earth Insertion stages. A tail sitting biconic vehicle is launched later and contains the crew habitat. At the end of the crew's stay on Mars, the Trans Earth Injection stage and the habitat are boosted into Mars orbit where they dock before leaving for Earth. On arrival at Earth, a small Earth Descent Vehicle



1. BICONICAL LANDING MODULE
2. ORBITAL TRANSFER STAGE
3. HORIZONTAL RUDDER
4. VERTICAL RUDDER

Figure 8 External features of HLB with crew quarters in ISU study (reference 31).



1. LANDING ENGINES BAY #1
2. ASCENT MODULE
3. SECOND STAGE ASCENT VEHICLE
4. LANDING ENGINES BAY #2
5. HORIZONTAL RUDDER
6. LIVING MODULE
7. LANDING GEAR
8. FIRST STAGE ASCENT VEHICLE
9. ASCENT MODULE BAY
10. VERTICAL RUDDER

Figure 9 Crew and ascent HLB in ISU study (reference 31).

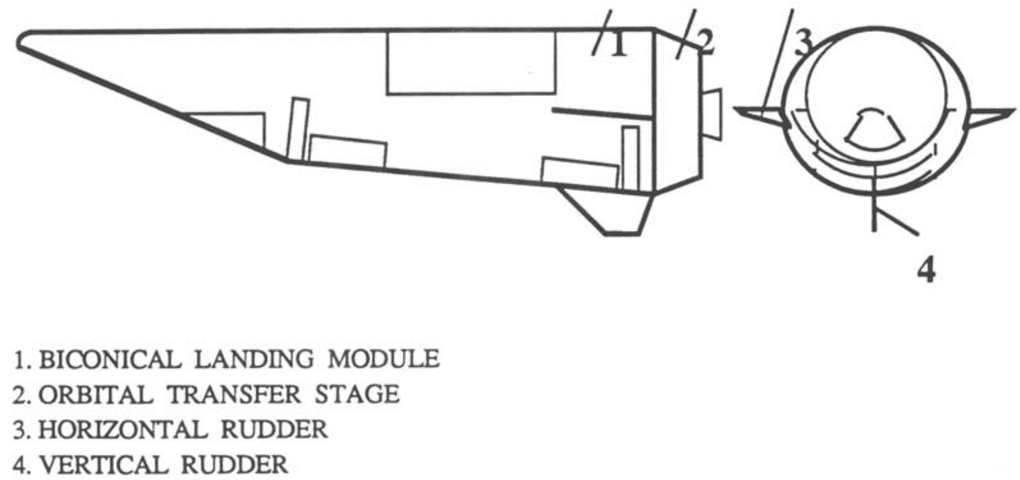


Figure 10 Cargo HLB in ISU study (reference 31).

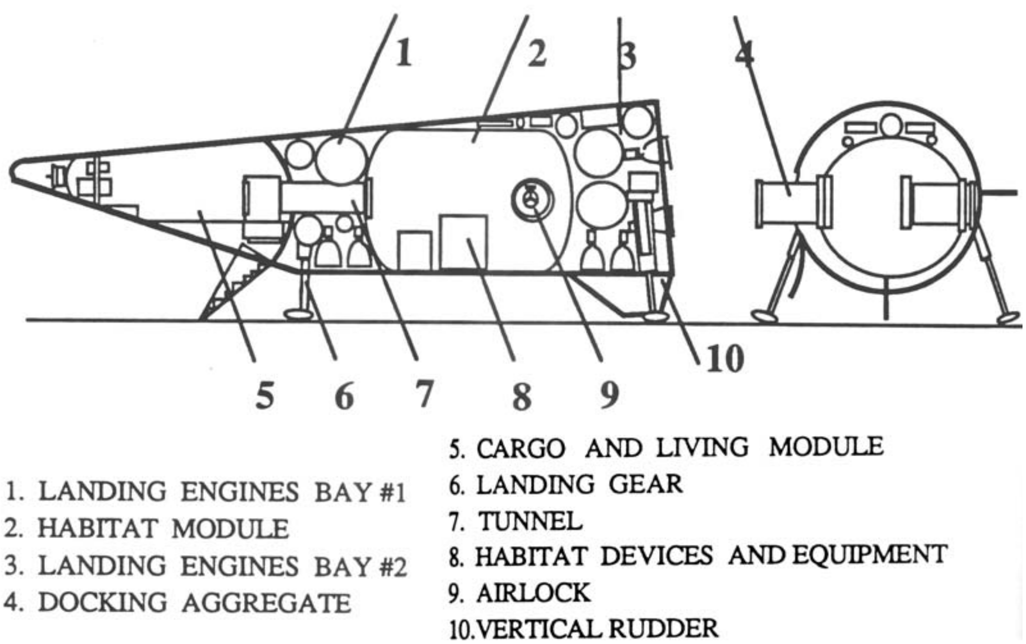


Figure 11 Habitat biconic in ISU study (reference 31).

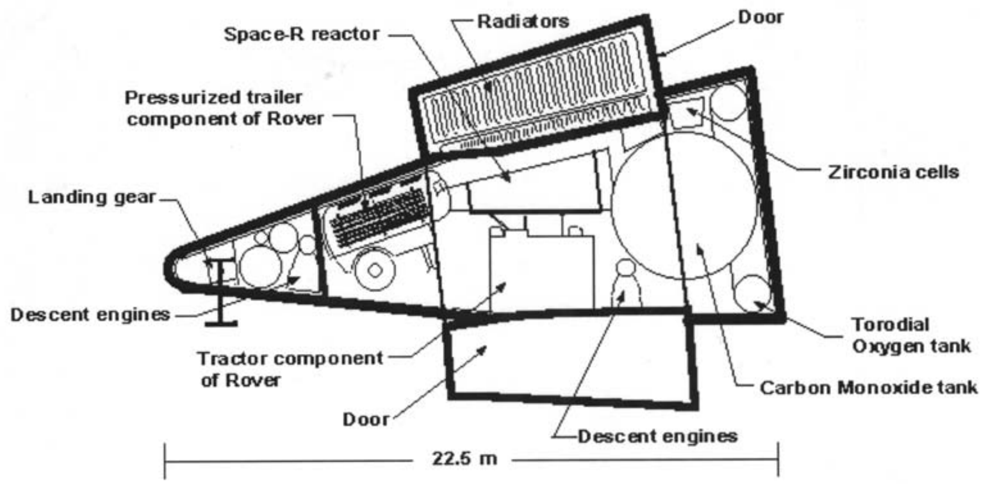


Figure 12 HLB from Scenario I of Grover *et al* (reference 30).

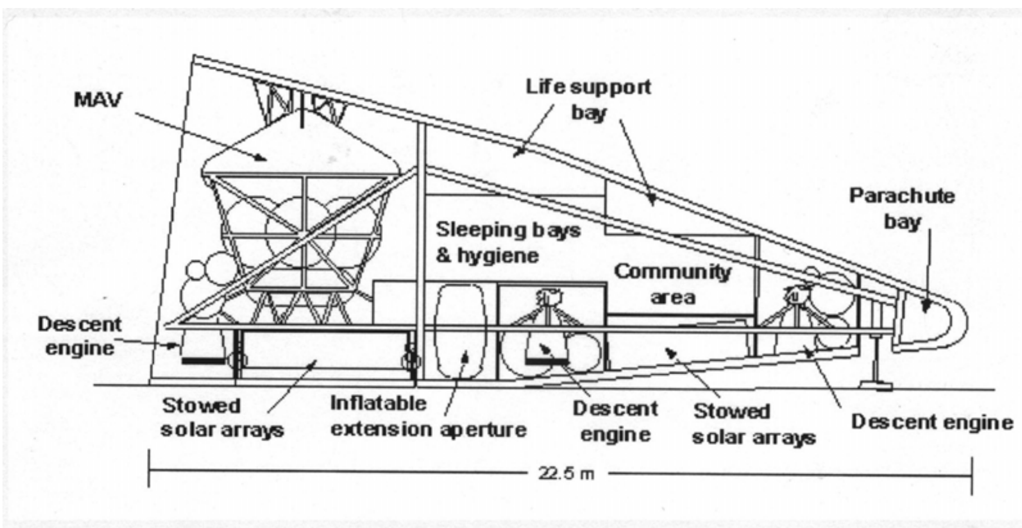


Figure 13 HLB from Scenario II of Grover *et al* (reference 30).

aerobrakes to the planet's surface. In Scenario II, the first two launchers consist of the surface habitat, once again a horizontally landed biconic and a Trans-Earth Injection stage that aerobrakes into Mars orbit. Unlike Scenario I, the surface habitat also contains the ascent stage. The third launch takes the crew to Mars and consists of the various stages and a habitat for use between planets. The Mars Ascent Stage docks with this vehicle for the return journey, and the crew compartment doubles as an Earth descent capsule. All bionics used in these scenarios have the same overall proportions and dimensions.

4.4 WHY A HLB FOR MARS-OZ?

We believe there are five reasons justifying selecting a HLB configuration for MARS-OZ. They are:

- Existing MARS (FMARS and MDRS) are tuna cans. The MS needs to explore different architectures within its program to ensure that the eventual configuration chosen for a crewed Mars mission is the best possible. A HLB is a very attractive alternative, given its advantages listed in this document and the fact that they, and similar craft, have featured in many mission architectures over the last 50 years. Use of a HLB is in no way to be construed as a criticism of the configuration used at the FMARS and MDRS.
- As already noted, tuna-can designed MARS pose logistic issues because of their shape. Coolie hat and headlamp shaped landers would pose similar problems. Both VLBs and HLBs could be transported as a unit, a very attractive feature from a logistical perspective. A VLB would have to be shifted from a horizontal to a vertical attitude once on site, whereas a HLB can be left on site in the same attitude it was transported in.
- The various logistic and operational advantages of this configuration arise from the fact that an analogue HLB can be built and checked out in a city location, transported as a single unit, and then set up on site with a minimum of further work. This not only reduces transport and assembly costs, but also saves time.
- These simple logistics have the additional value in that this mode of operation simulates more closely the setting up a base on Mars than does on site assembly.
- Because a HLB MARS is transported as a unit, it can be easily transported back to the city for refurbishment, taken to another site, or placed on tour for PR purposes, as desired, and at any stage during the program.

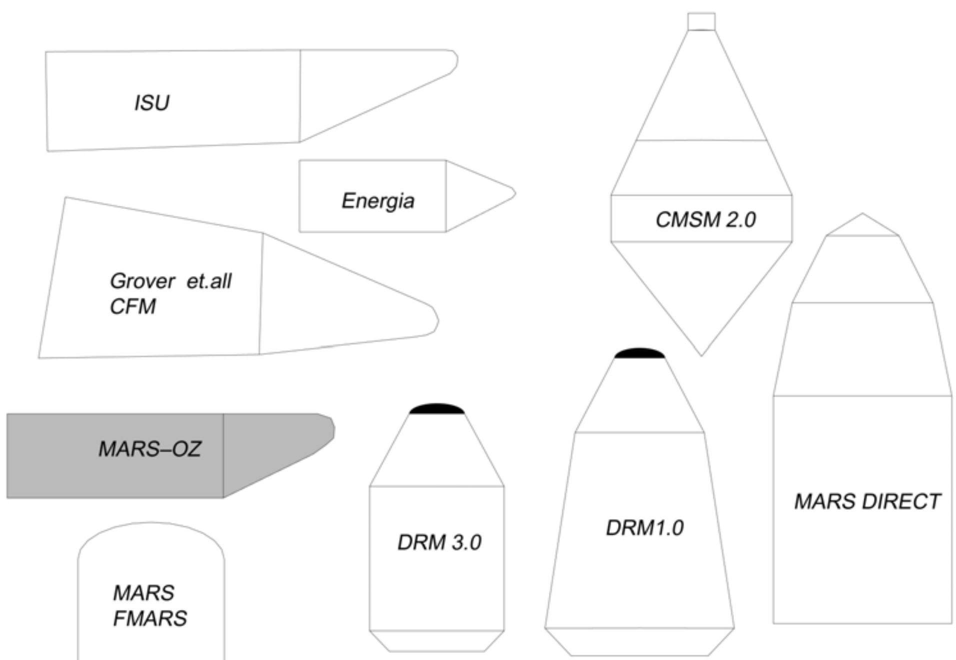


Figure 14 Comparison between the MARS-OZ lander units and other habs and Mars lander aeroshells. (See section 5.2.1) Drawing by Tristan Sterk.

5 MARS-OZ OVERALL CONFIGURATION

5.1 OVERALL ISSUES

The habitat unit's dimensions are set by legislated limits for loads on Australian roads. A length of 19 m is the maximum for unescorted loads and a width of 4.5 m is the maximum possible for self escorted loads without police. The maximum weight for an unescorted load is 22 tonnes. Height is another critical parameter, 3.1 m will pass under all bridges, but higher loads will need some careful route selection to avoid low overhead bridges and other impediments. As a rule of thumb, biconics are typically three or four times longer than wide. A MARS-OZ 4.5 m in diameter and 18 m long, weighing no more than 22 tonnes therefore should be transportable anywhere in Australia as a single unit with self-escort and some route selection.

For ease of manufacture and transport, a cylinder-cone (as in the Energia and Keldysh designs) is preferable to a strict biconic. The proposed habitat for MARS-OZ consists of a cylinder 12 m long and 4.5 m in diameter with a 6-m long upswept nose cone. The habitat stands on four adjustable legs (fitted with skids to allow limited repositioning) 0.5 m above the ground but will need additional tie down as a precaution against strong winds. The main entry and egress will be through an airlock on the flat rear bulkhead of the habitat.

The internal volume of MARS-OZ with these dimensions is 238 m^3. For a four-person crew this equates to 59 m^3 per crewmember, twice that onboard the Russians space station Mir. Allowing for volume loss from onboard equipment, a person-volume ratio similar to that for Mir is readily achievable. By using inflatable extensions, as proposed in the Grover *et al.* scenario II, CMSM, and DRM version 3.0, this volume can be expanded to whatever level is required. We propose that the habitat be transported on a boat trailer and then jacked up off it, allowing the trailer to be removed from underneath. Useable (as opposed to actual) floor space in the two-deck habitat module is ~122 m^2, about that of a small three bedroom house. This is greater than the North American 2-deck MARS (~100 m^2) but less than that of the three deck E-MARS (~150 m^2).

A bionic of these dimensions has approximately a third of the volume of the externally set dimensions in the Grover *et al.* or DRM studies and half that of the ISU study. However the external appearance and habitable volume of MARS-OZ and a HLB is approximately equivalent. Figure 14 shows a size comparison between different Mars aeroshells and analogue habitats.

To minimise logistic costs and local environmental impact, MARS-OZ should use local energy sources (preferably solar, see section 5.2.3), incinerate biological waste (common in US caravan designs), and recycle water as much as possible (I believe that 80% recycling is possible using commercial equipment, also from the US). Alternatively, biological recycling using the greenhouses would also be desirable.

5.2 PROPOSED MARS-OZ

Figure 15 View of the completed MARS-OZ facility. ("HOP" is the former name for the Marsupial Rover.) Artwork by Jozef Michalek.

The proposed MARS-OZ consists of five components: habitat, inflatables (greenhouses & garage), solar farm, support base and cargo module. The following descriptions and accompanying sketches are a conceptual proposal only; actual internal design and fitting out should done by people with specialist expertise in the design of living facilities in cramped spaces, such as boats and caravans.

5.2.1 Habitat

The proposed habitat (Figure 16 & Figure 17) consists of a cylinder 12 m long and 4.5 m in diameter with a 6-m long upswept nose cone. The habitat stands on four legs (fitted with skids to allow limited repositioning) 0.5 m above the ground but will need additional tie down as a precaution against strong winds. The main entry and egress will be through an airlock on the flat rear bulkhead of the habitat.

The habitat consists of two decks, each with 2.1 m headroom. The upper deck provides living and working space while the lower deck provides personal sleeping, washing, and toilet space. The interior should be robust enough to provide sound proofing and privacy but should not be load bearing, so that it can be moved if modifications are required.

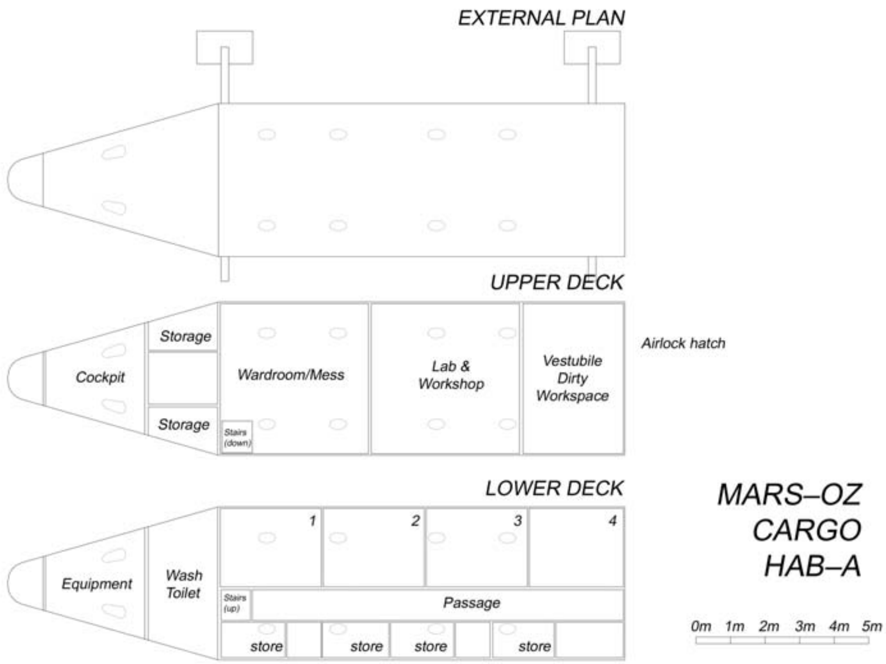


Figure 16 Plan views of MARS-OZ habitat. Drawing by Tristan Sterk.

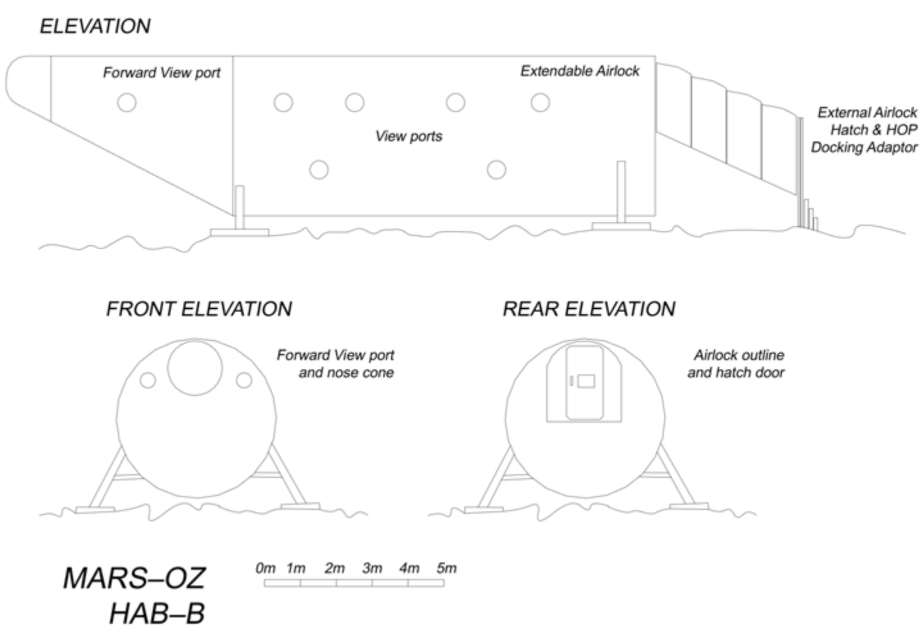


Figure 17 MARS-OZ habitat exterior elevations. Drawing by Tristan Sterk.

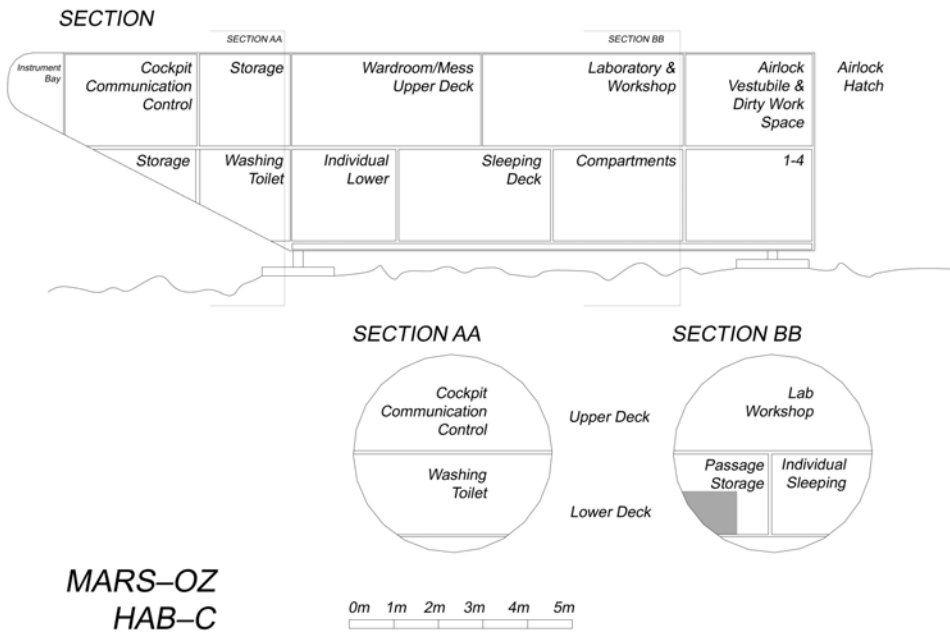


Figure 18 MARS-OZ habitat interior elevation. Drawing by Tristan Sterk.

The lower deck is divided length-wise into four individual sleeping cabins to the right and 1-m high stowage compartments to the left, accessed by a passageway 1 m wide to the left of the centreline. Each sleeping compartment is 3 m wide and 4 m long. Consideration should be given to the rearmost compartment having movable partitions so that it could be enlarged to a double berth. The forward end of the lower deck leads through a bulkhead into a washing and toilet compartment.

The upper deck is divided into four compartments by transverse bulkheads running the full width of the deck. The cockpit, communication, and control deck occupies the forwardmost compartment where the upper deck extends into the nose cone. All communications and control systems for MARS-OZ should be centralised in this area. Four aircraft type seats could be fitted in the area with folding tables, providing the main area for computer work. A sixth sleeping berth could be built into the side of this compartment, if required. The rear 2 m of this compartment is used for storage and equipment racks on both sides. Moving aft, the second compartment is 4.5 m long and contains a combined mess and wardroom, with stairs leading to the lower deck. The third compartment is also 4.5 m long and comprises the workshop and laboratory space. The aft 3 m long compartment provides an area for space suit stowage and dirty work, minimising dust spreading to the interior of the habitat.

A hatch in the centre of the rear bulkhead leads to a 4.5 m long folding ramp providing access on a 30 degree slope to the surface. The ramp is covered by an inflatable or accordion airlock that can be docked with the Rover. When the Rover is not docked to the airlock, a ramp extension with collapsible safety rails leads to the surface. A ramp rather than a ladder or stairs, should be used, to facilitate access by an injured crewmember. There should also be a small airlock in the main hatch to allow transfer of equipment and samples without using the main system.

Each living compartment should be provided with at least one viewing port. This will minimise the sense of enclosure in the habitat. The ports should be tinted to simulate Martian light conditions. Although not functionally necessary, thought should be given to external detailing to make it resemble an actual lander, e.g. thruster ports, thermal shielding, antennae, and winglets.

5.2.2 Cargo Module

Almost all recent Mars mission architectures (MD, ISU, Grover *et al.*, DRM and CMSM) involve the landing of two or more vehicles on the Martian surface. One is the habitat, the other is a combined ascent or earth return vehicle and cargo carrier. Existing MARS have concentrated only on the habitat. A second structure for MARS-OZ (Figure 19, Figure 20), to simulate this vehicle, has significant advantages.

The conceptual mission architecture has the rover, power source and ascent stage carried in a cargo module, along with the ISRU plant. Such a module would be a biconic of the same dimensions as the habitat, with an ascent stage in a rear compartment, as in the Grover *et al.* study. Hatches in the side would allow easy access to the rest of the interior.

As well as providing visual verisimilitude for MARS-OZ, the cargo module could be used to house the Rover vehicle while in transit, store fuel on site for the Rover, and provide a lockable storage space when the facility is not in use. If a solar power system is not available, then the cargo module could also house a diesel generator and fuel to supply power.

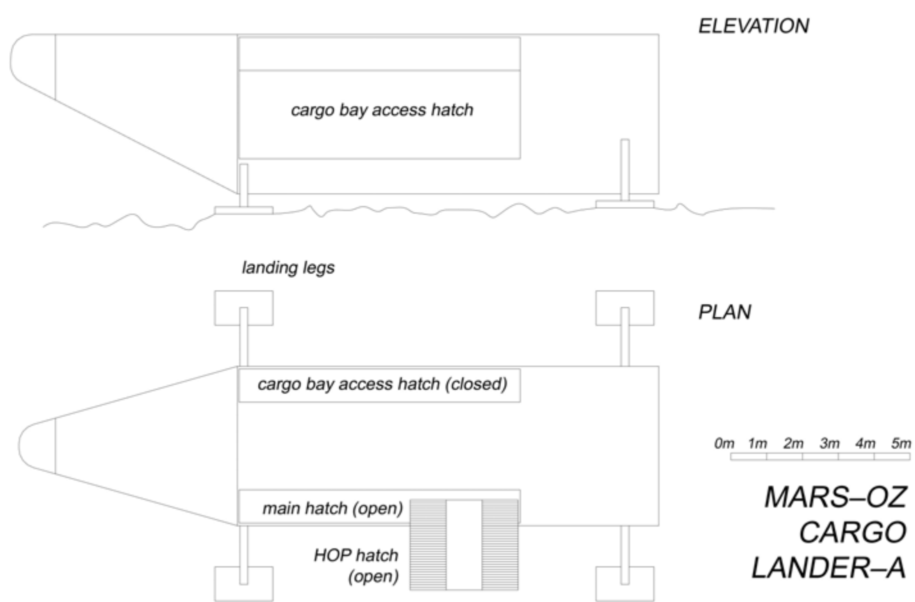


Figure 19 MARS-OZ Cargo Module external plan and elevation. Drawing by Tristan Sterk.

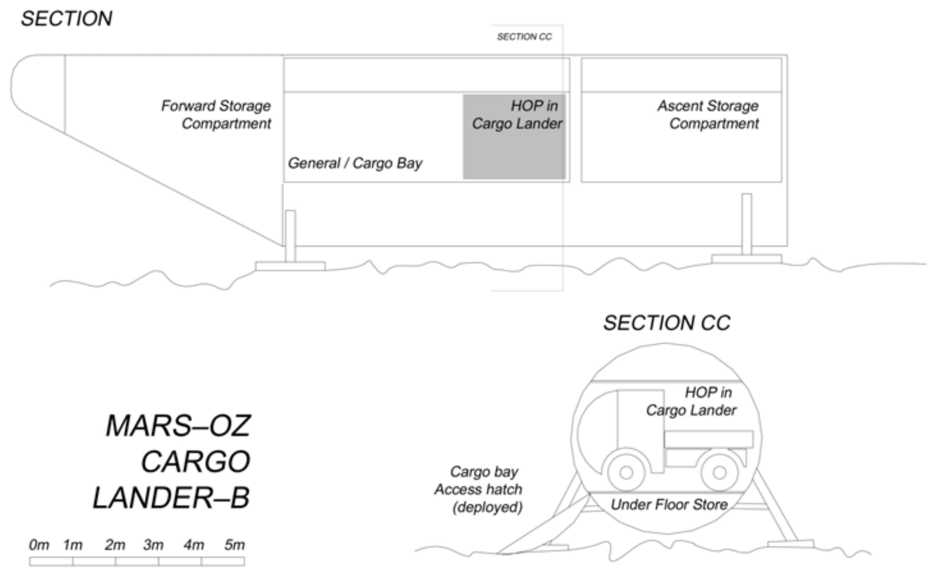


Figure 20 MARS-OZ cargo module interior elevations. Drawing by Tristan Sterk.

Construction of the module need not be sophisticated, although it should be robust, secure, and weatherproof. The module would require similar tie down points as the habitat, although more extensive, as it would be lighter.

5.2.3 Solar Farm

Previous MARS at Devon Island and Utah have relied on diesel power units. It would be desirable from many viewpoints if the power needs of MARS-OZ could be supplied entirely from local resources. These reasons include minimising logistic costs and environmental impact, imposing energy use discipline in habitat design, and providing a showcase for self sustained architecture. Solar energy is the most relevant for Mars analogue purposes, but wing generators could supplement this. For the initial concept, we envisage a concertina array, as it is the most easily deployable, with additional tie down against high winds.

5.2.4 Inflatables

Inflatable structures or their analogues can play a key role in MARS-OZ. Two roles are immediately evident. Firstly they can provide greenhouses for biological recycling of water and food production; secondly they can provide the equivalent of a pressurised garage for the Rover vehicle. The concept of the inflatables is based on those used to cover outdoor pools in winter, although other designs may prove more feasible, including conventional greenhouse frame and plastic covering, or balloon inflatables. In addition to the basic inflatables, transfer tunnels and an airlock will be necessary, as we envisage the inflatable complex being mated to the main airlock at the rear of the habitat. The airlocks should allow mating with the Rover and use by individuals. Adequate tie down against high winds of the transfer tunnels and inflatables will be necessary. Inflatable structures or their analogues could be added incrementally.

For greenhouses it would be desirable to have the transparent material transmit as much light as would be experienced on the surface of Mars, and of the same spectral characteristics. Given that a person on a 3,000 calorie per day diet can be supported on 60 m^2 of hydroponic agriculture[33], therefore 240 m^2 and 360 m^2 would provide enough space to grow food for a four and four person crew, respectively. Two or three inflatables 13 X 13 X 6 m would be sufficient to provide for this area and some additional work and storage space, each approximately the size of a back yard swimming pool inflatable cover.

A garage large enough to contain the Rover vehicle plus extra working and storage space is also desirable. It would allow servicing of the vehicle under cover equivalent to a pressurised environment on Mars, and space to sort and store samples and work on other equipment. Such an inflatable could be smaller than those used for greenhouses, say 8 X 6 X 3 m.

5.2.5 Support Facility

Although the MARS-OZ crew will be living entirely within the habitat complex, there may need to be accommodation for a support team to monitor and assess the work program. This should be located approximately 1 km away, out of line of sight. The facility would include accommodation (tents or transportables), washing, and toilet facilities, a power source, and a lockable storage facility. It would be desirable if the power, waste, and water management facilities were based on those used for the main habitat, allowing minimal environmental impact. The support facility could provide accommodation for a small security team during the period when MARS-OZ is not in use, or alternatively, they could live in the habitat itself. The support facility should be as small as possible to minimise cost and impact on simulation.

5.2.6 MARS-OZ Assembly

Construction of the entire MARS-OZ facility need not be carried out in one phase. The habitat will form the core of MARS-OZ and is therefore the essential first stage. Some form of support facility will also need to be present from the beginning. Further components can be added as funding allows, starting with the cargo module, and proceeding to the solar farm and inflatables. The inflatable structures can themselves be added in stages. A drawing of how the final MARS-OZ facility might look is shown in Figure 15.

5.3 OPERATING CYCLE

Fieldwork in the northern Flinders Ranges is most practical during April-October, because of the temperature. We envisage that initially MARS-OZ may be inhabited for four months of the year, and, as it matures, to 6 or even 8 months a year. As with MDRS and FMARS, crews would initially rotate through on a 2-6 week basis. Later in the program, longer duration missions can be contemplated.

6 RESEARCH

6.1 RESEARCH OBJECTIVES

Research carried out at MARS-OZ is envisaged to focus on, but will not be confined to, five main areas. These are engineering, science, environmental systems, data management, and human factors. At this stage the research projects are tentative only, indicating more the range of possibilities rather than the final detailed studies. Nor are these projects necessarily concurrent, as MARS-OZ has a provisional working life of at least 5 years.

6.2 ENGINEERING

- *The MARS-OZ habitat and associated structures.* The habitat configuration is itself a major engineering research project and evaluation of its function and practicality will form a key part of engineering research. Included in this work will be issues such as internal configuration of the habitat and the “urban architecture” of MARS-OZ, which will consist of the two modules, power facility, and various inflatables.
- *Communications.* There are three levels of communications necessary for MARS-OZ; short, medium, and long range. Short-range is between crewmembers on simulated extra vehicular activity (EVA), between them and the Rover and between them and the habitat. Medium range will be between the Rover and the habitat when the Rover is on traverse. Long-range will be between the Rover and habitat and a simulated mission control, either in the nearest capital city or possibly at the support base. It will also provide a link to the outside world. SAFMARS is the chosen system for long range communications, medium range will be some form of off-the shelf HF system and short range an off the shelf UHF system. Experimentation will be needed to develop the best protocols for the different levels of the communications systems.
- *Dust management.* Mars and Arkaroola are dusty environments. MARS-OZ will allow documentation of the effect of dust on mechanical and electronic equipment and testing of dust management strategies.
- *Rover.* The Marsupial Analogue Rover will play a key role in MARS-OZ. Unlike other analogue rovers, the MSA Rover features a utility layout that greatly increases its flexibility for operations (Figure 21). Important questions that need to be addressed are how to best dock the Rover to the habitat for crew and sample transfer, effective range and endurance, and emergency procedures. The Rover will also be trialed on a range of terrains, including rocky, sandy, and firm (Figure 23), to study mobility and recovery procedures.
- *MarsSkin.* The analogue MCP suit is another key feature of the MARS-OZ program and a point of difference between MARS-OZ and other MARS (Figure 22). Evaluation of the utility of such suits, possibly in contrast with analogue pressurised suits, should be part of the research program.
- *Robotics.* There are two obvious possibilities in this field. The first is the design and use of remote manipulators on Marsupial and possibly on the habitat. The second is the use of remotely controlled or autonomous vehicles, whether surface or airborne, in exploration. They could be evaluated in a range of roles, including as an adjunct to, in support of, or independent to crewed exploration.

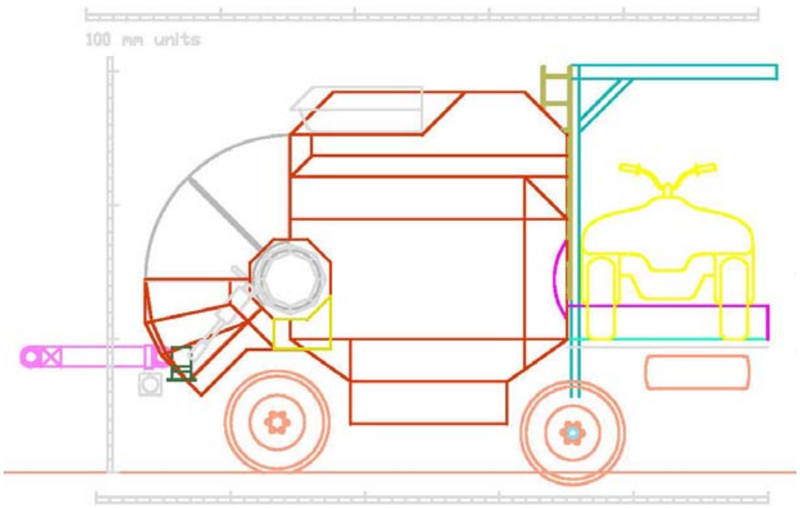


Figure 21 HOP: An early concept of a MSA rover. Drawing by Jason Hoogland.

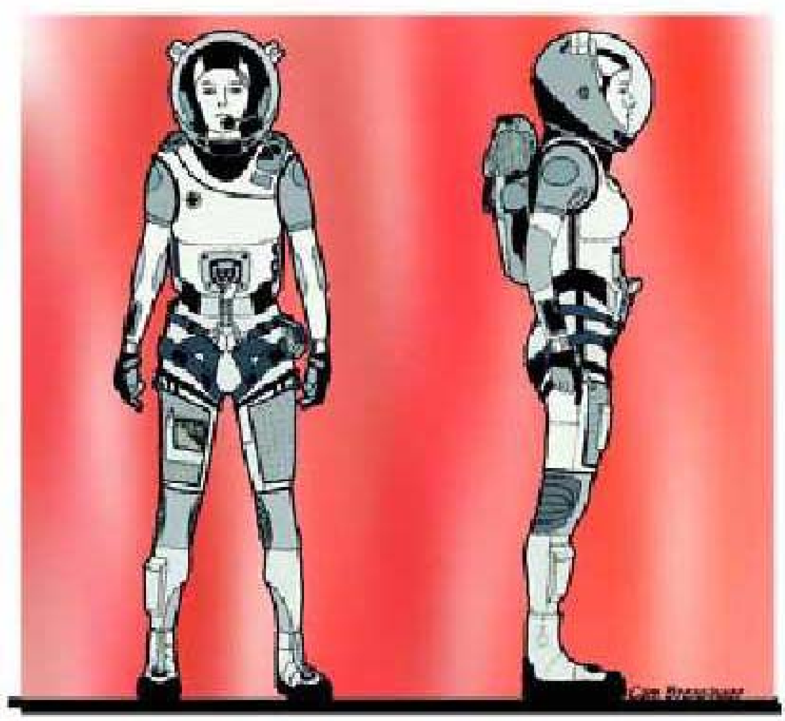


Figure 22 Mechanical counter pressure space suit concept. Drawing by Dava Newman.

6.3 SCIENCE

- *Geology*. The Arkaroola area is a region of considerable geological interest[34] [35]. Geological research in the Arkaroola area could focus on no fewer than five main areas. These are the fossil hydrothermal systems of the Mt. Painter complex (Figure 24), the history of evolution recorded in the Neoproterozoic sediments of the Adelaide Geosycline (especially testing the "Snowball Earth" hypothesis), the geomorphological evolution of the Northern Flinders Ranges, and the Cainozoic history of the Lake Frome Plain. Some of these deposits, such as the mobile sand dunes at Gurra Gurra Waterhole, have already been used as Mars analogues.

- *Palaeontology.* The Neoproterozoic sediments in the region contain many stromatolitic horizons and cherts that may contain microfossils. The younger Neoproterozoic successions host the world famous Ediacara fauna, the controversial assemblage that is believed to represent the first assemblage of large animals on earth. Finally, although not of great relevance to Mars, the Cainozoic sediments host several important sites for Cainozoic vertebrates.

- *Meteorology*. Studies into the climate of the site would be critical for obtaining baseline data for the ecological, environmental monitoring and dust management research projects.

- *Hydrology.* There are a number of hydrological issues that could be studied. These include the hydrology of the Paralana Hot Spring, the hydrology and hydrochemistry of uranium bearing waters of the Lake Frome Plain, and the mound springs along the eastern margin of Lake Frome. The Honeymoon uranium mine lies within the selected area and there may be corporate sponsorship available to study the geochemistry of some of these waters.

- *Biology.* Numerous opportunities exist for the study of dry land ecology, endolithic and cryptoendolithic organisms.

- *Microbiology.* The Paralana Hot Spring (Figure 25) contains a population of extremophiles that are only just beginning to be studied. The extremophile populations of the various salt lakes in the study area are largely unknown. Yet another aspect of research is the microbiology of the internal habitat environment.

- *Geophysics.* Many of the faults in the Arkaroola area are seismically active. One potential research topic would be to establish a local seismometer net to pinpoint the zones of greatest activity. Another project would be the monitoring of radon emissions along faults and fracture systems.

- *Remote sensing*. Potential projects include evaluation and comparison of various remote sensing systems for mineral mapping including Aster, HYMAP, and LANDSAT. Ground truthing of remotely sensed data is also important, using instruments such as PIMA and especially actual XRD analyses of surface mineralogy.

Figure 23 Rocky alluvial outwash from the Flinders Ranges (background), east of Arkaroola.

Figure 24 Haematitic hydrothermal silica deposits at Mount Gee

6.4 ENVIRONMENTAL SYSTEMS

- *Life support*. While MARS-OZ is not a totally enclosed system, the aim is to recycle water and waste as much as possible. Various mechanical, chemical, and biological systems can be trialed as a series of research programs.
- *Waste management.* Refuse and solid human waste management will be a key issue on Mars and is also important in any remote installation on earth, including Arkaroola. Various strategies for minimising waste production should be tested. One attractive option for disposal of solid human waste is high temperature incineration, which would produce a low volume residue potentially useful in horticulture.
- *Horticulture.* The use of greenhouses for horticulture is predicted for Mars. Research at MARS-OZ can examine plants grown in soil and hydroponically under simulated Martian light conditions. Related research can focus on conditioning simulated Martian regolith to a level where it can support plant growth. The level of experiments could vary from test scale plots to fully self sufficient gardens. The greenhouses could also be used to dispose of solid human waste and form part of the recycling system. Finally, the psychological impact of even small horticultural impacts on a small enclosed group of people can be evaluated.

Figure 25 The radioactive Paralana hot spring, an extremophile habitat.

6.5 INFORMATION SYSTEMS

- Data acquisition. As on Mars, MARS-OZ will acquire large volumes of data in terms of images, measurements, and observations. Questions such as: how best to acquire this data (by video, digital camera, note-pad, or voice recognition) need to be investigated.

- Data management. Management of the data is another issue. How much processing should be carried out on site before transmitting it on?

- Data transmission. How is the data best transmitted? By SAFMARS, or will other technology (such as polar orbiting mobile phone network or MARISAT) be required? How might the lessons obtained from these studies be best applied to Mars?

6.6 HUMAN FACTORS

- *Human-machine interfaces.* Some of the questions that arise here include the user friendliness of the habitat, comparative studies of tuna can and HLB habitats, and when to chose between human and robot operations for a particular task.
- *Psychology.* This is a key area of research, although the duration spent by any team in MARS-OZ is unlikely to match those of any Mars mission. Questions suitable for study might include how mental states and perceptions change over a period, and how these reflect the interaction with the physical, technological, and social environment.
- *Group dynamics.* As with psychology, the duration of the missions planned for MARS-OZ is not likely to be equivalent to those on Mars, at least not initially. But issues of crew size, age structure, gender balance, special relationships with crews, rituals (meals, entertainment sessions), relaxation and workload can all be studied. As the MARS-OZ program matures, it may be worth considering longer term stays in the habitat to more validly research these questions.

6.7 PERSONNEL

A useful method of carrying out research in MARS-OZ is by using honours students. Most honours projects in the biological sciences can be completed in a 2-6 week field period, which fits in well with the 1-2 month crew rotation of FMARS and MDRS. Furthermore, honours theses are completed within 12 months, which opens the way for rapid publication of results. Supervisors of honours students can carry out longer-term research projects associated with MARS-OZ, and it is recommended that individual projects be components of larger research programs coordinated by senior researchers. Visiting researchers from overseas should also be welcome participants.

7 BUDGET

7.1 PRELIMINARY COSTING

Accurate costs cannot be determined until we have a detailed design. At present the only guide for costs are those calculated for the MARS used in other parts of the world. Costings from the Mars Society in the United States and the UK have been normalised to the Australian dollar using the following conservative currency conversions:

1 US$ = 2 A$ 1 pound = 3 A$

All figures include a 15% contingency factor. Transport costs have been excluded as this is a site-specific variable.

7.2 CONSTRUCTION COSTS

The results for construction costs were:

- **FMARS $641K**
- **MDRS $596K**
- **MS-US costs construction of MARS for Europe and Australia at $570K.**

The progressive decrease in costs represents experience gained on each successive MARS and economies of scale though production of multiple units. In each case the construction costs were spread over two years[36].

The Mars Society in the UK independently calculated the cost of the European Mars Analogue Research Station (E-MARS) [37].

- **E-MARS $529**

All include a 15% contingency factor. Details of these four construction costs, excluding the most extreme variables of transport and travel, are contained in Table 3. This data shows that, at a minimum, we will need over A$500K to build the habitat and possibly as high as A$700K. There are a number of uncertainties due to the unique features of MARS-OZ, including the biconic design, the intention to use higher levels of recycling of water and waste, and the cargo module, so therefore we should, at this stage, use the higher figure. Transport and travel costs will be over and above this figure.

	FMARS	**MDRS**	**HAB-3 & 4**	**E-MARS**
Fabrication	306000	300000	300000	319962
Construction	80000	60000	60000	63993
Interior fittings	40000	60000	70000	53328
Equipment	34000	0	6000	6399
Labour	24000	28000	40000	42663
Management	108000	50000	40000	21330
Subtotal	592000	498000	516000	507675
15% contingency	88800	74700	77400	76151
Total	**680800**	**572700**	**593400**	**583826**

Table 3 Costing of various MARS in Australian dollars.

7.3 Operating costs

The only operating costs known at present are those for FMARS and MDRS. That for FMARS is not applicable for MARS-OZ as the logistic costs of operating in the Canadian Arctic are much higher than those relevant to Arkaroola. The annual operating cost for MDRS in Australian dollars, excluding travel and transport, with a 15% contingency, was estimated as:

- $115K per annum once it is up and running. The MS-US estimated similar costs for Europe and Australia.

Operating costs should be budgeted at $120K. If half of this consists of overhead and half of research costs, and the average honours student project costs $10,000, then 6 honours students could be cycled through MARS-OZ each year. MARS-OZ should provisionally operate at Arkaroola for 5 years.

7.4 Potential Funding Sources

7.4.1 Sponsorship

Target A$1,000,000+

Enough money to design, build, ship the habitat unit, install it and run the analogue research station for 2 years.

It should be noted that an Australian MARS would receive broad and sustained media exposure, both nationally and internationally.

Benefits to sponsors would be open for negotiation with interested parties and could include:

- Naming rights – "…Mars Australian Research Station".
- MarsOz always being referred to using Sponsor's name – whether in print or verbal communication (Much like the Flashline Station).
- Large prominent name / logo decals on the station.
- Company name / logo on MarsOz shirts / caps, etc.
- All public documentation to have sponsor name / logo where appropriate.

7.4.2 Income Generation

One way of offsetting these costs is by seeking to use MARS-OZ to generate income. Several possibilities other than sponsorship have been suggested and should be pursued. They include:

- Hiring the facility out for advertising.
- Tourist excursions to the facility from Arkaroola.
- Selling a modified MARS-OZ shell design as novelty holiday homes for the rental market.
- Renting the facility out for adventure tourism when not in use.
- Hire as a film or TV set.
- Sale of the integrated habitat concept for use in remote or environmentally sensitive localities.

8 PROGRAM WAY POINTS

8.1 PROGRAM STATUS

A series of program way points provide a guide to significant landmarks in the achievement of the goal of an operating MARS-OZ. The major ones are:

1. Decision to commit to MARS-OZ
2. Region selection
3. *Preliminary design*
4. Formal design
5. Site selection
6. Construction
7. Deployment
8. Operation

8.2 THE NEXT STEP

MSA is currently at point 3 (in italics). The MARS-OZ project is at a critical definition stage as it moves to point 4. The formal design process will allow firm costing, an appreciation of the environmental impact, safety and emergency guidelines, legal implications and a detailed operational plan. These will allow the MSA to set about raising the funds for the project and approaching the landholders in the selection area for permission to establish MARS-OZ, as well as seek local government planning approval.

8.3 ACKNOWLEDGEMENTS

I would like to thank Marshall Hughes, Jason Hoogland, James Waldie, Frank Schubert, Dr Larry Lemke and Dr Carol Stoker who provided much useful background discussion. Michael West supplied useful critique of the designs. Jennifer Laing, Guy Murphy, and Dr Graham Mann made many comments on the manuscript. Finally, Jozef Michalek and Tristan Sterk prepared the drawings of the modules and the artwork for MARS-OZ, without which the proposal would have been a much duller document.

Dr Jonathan Clarke

9 ENDNOTES

The contents of web sites are subject to change without notice. Earlier versions of most internet sites created from 1996 onwards can be found at www.archive.org

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