SAFMARS

Operational Concept Description

Project Phase 0 – Mission Development

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AMENDMENT LOG

Ver.	Release Date	Description of Change (Including Sections Affected)	Author	Reviewer / Approver
0A	2001-02-8	Draft document raised for restricted distribution to MSA and ASRI for discussion.	J Hoogland	MSA exec, ASRI exec
0B	2001-02-9	Corrected grammatical and typo errors. Update on private web.	J Hoogland	S Wilson, G Murphy
0C	2001-02-18	Incorporated reviewer changes, returned for final review.	J Hoogland	S Wilson, G Murphy
1A	2001-03-26	Changed name from MARSNET to SAFMARS, all sections, public release of document	J Hoogland	

TABLE OF CONTENTS

1 DOCUMENT OVERVIEW

This document describes a proposed system:

- allowing dedicated, year-round, low cost email messaging between Mars Society personnel and members anywhere in the world, and
- providing autonomous or manual remote monitoring, data acquisition and control of Mars Society assets worldwide,
- creating greater public and private interest in the Mars Society and its goals,
- extending and enhancing Mars analogue research capabilities for the international research community.

It includes a description of this system, its objectives and benefits. It attempts to present high level concepts for design, implementation, operation and maintenance, and to assess some of the major impacts and risks.

1.1 DOCUMENT PURPOSE

The purpose of this Operational Concept Description is to:

- describe the objectives and scope of SAFMARS, or Store And Forward for Mars Analogue Research System,
- elicit requirements from potential system users,
- seek support for the project,
- assemble an advisory committee and project team, and
- initiate phase 0 of the project.

1.2 DOCUMENT HANDLING AND CONTROL

This Operational Concept Description document for the SAFMARS is to be handled in accordance with the Document Control requirements in the forematter.

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1.3 Source DID

This Operational Concept Description for the SAFMARS was created from the formatted Operational Concept Description Data Item Description (DID) available from the *ASRI Project Resources Library* at www.asri.org.au.

1.4 DID Derivation

The Operational Concept Description DID was created by ASRI from the OCD DID published with MIL-STD-498.

1.5 Document Structure

This Operational Concept Description is structured as follows:

Document overview	Contains a Glossary and References.
Current system	Introduces the Mars Society and the current focus of its private research activity, as well as the nature of communications systems in use.
Nature of changes	Explains why SAFMARS is being proposed, and what role it would fulfil.
New system concept	Details the SAFMARS concept with diagrams and preliminary analyses. Jump here for technical details of the proposal.
Operational scenarios	Briefly outlines how SAFMARS would be used.
Summary of impacts	Describes some potential impacts of the new system.
Analysis of proposal	Identifies some potential advantages and perceived disadvantages.
Appendices	Provide more detailed information on certain subjects.

1.6 Definitions

1.6.1 Internal Definitions

Terms and abbreviations used in this document are defined below:

Analogue research	Work that furthers our understanding of a planet (e.g. Mars), or of missions to it, by employing

	analogous environments, systems or conditions at another location (e.g. earth)
Aphelion	Furthest orbital point from sun
ARC	NASA Ames Research Centre
Bus	The basic frame and structural elements of a satellite
C3	Command, Control and Communications
COTS	Commercial-Off-The-Shelf
CRC	Communications Research Centre, Canada
CRCSS	Cooperative Research Centre for Satellite Systems
DID	Data Item Description
DRM	NASA Design Reference Mission
EDL	Entry, Descent and Landing. Describes the phases for entry of a planetary landing vehicle.
Feature set	That set of features which closely resemble Mars or Mars missions in analogue research activities
GEO	Geostationary Orbit
Ground station	A ground terminal with a permanent high bandwidth internet connection
Ground terminal	An integrated radio transmitter/receiver and computer allow communications between the ground and a satellite
GTO	Geostationary Transfer Orbit, an elliptic orbit with apogee at the GEO orbit
HF	High Frequency radio
ICBM	Intercontinental Ballistic Missile
ISRU	In Situ Resource Utilisation
ISS	International Space Station
IT	Information Technology

JAESAT	Joint Australian Engineering Satellite
kbps	Kilobits Per Second
km	Kilometers
LAN	Local Area Network
LEO	Low Earth Orbit
LMO	Low Mars Orbit
Mars Direct	A mission concept for sending human explorers to Mars, proposed by a team led by Dr Robert Zubrin in 1991.
Mars-x	Generic designation for both a single fixed Mars Analogue Research Station of the Mars Society, and for the entire programme.
Microsatellite	A small satellite in the < 100 kg class
MS	The Mars Society
MSA	Mars Society Australia
MSMC	Mars Society Mission Control
Nanosatellite	A small satellite in the < 10 kg class
NASA	National Aeronautics and Space Administration of the US
NSF	National Science Foundation, US
Perihelion	Closest orbital point to sun
PM	Project Management
Programme	An enduring management structure encompassing an ongoing series of time-limited activities, usually projects, conducted around a common theme. MSA has one Technical Programme consisting of a range of Projects.
Project	A time-limited activity with a defined purpose
QUT	Queensland University of Technology
SAFC	Store and Forward Communications

SAFMARS	Store And Forward Mars Analogue Research System
SEI	Space Exploration Initiative, a proposal by President George Bush, Snr., for human exploration of the Solar System. The administration lacked the will to pursue the initiative and it languished in the late 1980's.
SFU	Simon Fraser University, Vancouver, Canada
SSTL	Surrey Satellite Technology Ltd.
START-II	Strategic Arms Reduction Treaty 2
STK	Satellite Tool Kit®
TRL	Telematics Research Laboratory, SFU
US	The United States of America

1.6.2 External Definitions

Further definitions are contained in higher-level project documents (if any), the *MSA Glossary of Terms* and the *ECSS Glossary of Terms*.

1.6.3 Precedence of Definitions

Should there be a conflict in definitions, the following order of precedence applies:

- Section 1.6.1 of this document
- Higher-level SAFMARS documents
- *MSA Glossary of Terms*
- *ECSS Glossary of Terms*

1.7 References

Documents external to the SAFMARS documentation system, and referenced in this document are described below:

1. Alena, R., NASA Ames Research Centre, *private communication*, 2001-01-23
2. Allery, M.N. et al., *Low Earth Orbit Microsatellites for Data Communications using Small Terminals*,

www.ee.surrey.ac.uk/CSER/UOSAT/papers/papers.html, 1995, Last accessed: 2001-02-05

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8. *CraterNet website*, www.polylab.sfu.ca/spacesystems/HMP/, Last accessed: 2001-02-21.

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10. *Haughton Mars Project website*, www.arctic-mars.org/, Last accessed: 2001-02-04

11. Hoffman, S., et al., *The Reference Mission of the NASA Mars Exploration Study Team*, NASA Johnson Space Centre, Jul 1997, http://exploration.jsc.nasa.gov/PlanetaryMissions/EXLibrary/EXdocuments.htm#, Last accessed: 2000-07-01

12. *International Amateur Radio Union (IARU) website*, www.iaru.org, Last accessed: 2001-02-05

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18. *SatelLife website*, www.satellife.org, Last accessed: 2001-02-07

19. Satellite Tool Kit (STK) software, Analytical Graphics Inc., www.stk.com.

20. *SpaceRef.com Focus on Mars: Mars on Earth, Summer 2000 Field Season*, www.spaceref.com/focuson/marsonearth/, Last accessed: 2001-02-04

21. *SSTL Small Satellites Home Page*, www.ee.surrey.ac.uk/SSC/SSHP/, Last accessed: 2001-02-07

22. *The Mars Society website*, www.marssociety.org, Last accessed: 2001-02-08

23. *Volunteers in Technical Assistance (VITA) website*, www.vita.org, Last accessed: 2001-02-05

24. Walter, M., *The Search for Life on Mars*, Perseus, Cambridge, 1999

25. Wei, S., Sweeting, M., *Global email system and Internet access in remote regions via LEO microsatellites*, International Astronautical Federation Conference Paper, 1996, www.ee.surrey.ac.uk/EE/CSER/UOSAT/, Last accessed: 2001-02-07

26. Zubrin, R.M., Baker, D.A., Gwynne, O., *Mars Direct: A Simple, Robust, and Cost Effective Architecture for the Space Exploration*, AIAA Paper 91-0328, www.nw.net/mars/marsdirect.html, Last accessed: 2000-07-01

MSA reference documents are available in Adobe Portable Document Format (PDF) from the MSA Library at www.marssociety.org.au/library. ASRI reference documents are available in Adobe Portable Document Format (PDF) from the ASRI Project Resources Library at www.asri.org.au. ECSS documents are available from www.estec.esa.nl/ecss.

2 CURRENT SYSTEM OR SITUATION

2.1 CONTEXT

This subsection, together with the Appendices, places this proposal in the context of current Mars Society activities.

The next great step taken by humans will be upon the planet Mars. During Soviet and American preparations for the journey to the Moon, extensive use was made of earth “analogue environments”, places on our home planet where we could better understand the challenges that awaited us on another world. Space flight remains a difficult business and the attention of Mars mission researchers is increasingly turning to areas on earth that individually and collectively replicate features of the Martian environment or Mars missions. These can be reached for a tiny fraction of the cost and risk, and vital lessons can be learned.

See Appendix – Haughton Mars Project, Appendix – Mars Society Project Work [14] [22] for more information regarding current and past Mars analogue research.

The Mars Society has initiated a major project to establish a string of Mars Analogue Research Stations (herein referred to as the Mars-x Project) around the world. The first Mars-x was established in 2000, and these stations are expected to make significant contributions to planning and facilitating future human missions by providing unique research platforms and raising public awareness of the opportunity that lies before us.

The four stations expected to make up the worldwide network will be located in remote areas where communications and infrastructure are marginal at best. It is unlikely all stations will be occupied for field operations throughout the year. Without a system of year round communications, autonomous scientific field instruments (common tools in analogue field research) may have very limited usability, and the physical condition of each Mars-x will be unknown.

2.2 BACKGROUND, OBJECTIVES, AND SCOPE

Human missions to Mars were a driving vision from the earliest days of the space age. Plans were put forward during the Apollo programme and beyond for sending humans to Mars, yet each has faltered at one or more of the many hurdles. The great Werner Von-Braun advocated a plan for massive spacecraft to Mars carrying dozens of people and all their return fuel. Concepts like this called for astronomical expenditures, misinterpreting the political commitment to Apollo. The challenge set by Mars led to a mindset amongst planners that was unfortunately not conducive to the kind of disciplined, innovative mission design that would make Mars feasible.

In 1991, Dr Robert Zubrin, leading a team of engineers at Martin Marietta Astronautics in Denver, Colorado, proposed *Mars Direct*, a mission concept that brought human missions to Mars within reach [26]. Using a common-sense approach detached from the Von-Braun Mars heritage and from bureaucratic machinations within NASA, Mars Direct placed far greater emphasis on In Situ Resource Utilisation (ISRU), leading to smaller spacecraft that could use existing technology.

The *Mars Direct* proposal was a milestone in the race to Mars. Risks could be readily managed and total mission start up cost amounted to US$25 billion and around US$2 billion for each expedition (around one third of the total equivalent cost of the Apollo programme).

At the same time, NASA, prompted by the Bush Administration and its advocacy for the Space Exploration Initiative (SEI), had done its own sums. Employing the same approaches to mission design that had hampered previous efforts, including Low Earth Orbit (LEO) assembly and dispatch of gigantic space ships, a US$400 billion mission was proposed, immediately scuttling any prospects of political support for humans to Mars.

Subsequently, NASA recognised the value of Mars Direct and fashioned its own ISRU-based concept, the *Design Reference Mission* (DRM), now at version 3.0 [11]. In spite of support professed by NASA Administrator Daniel Goldin for any Mars proposals costing less than US$20 billion, the agency has been engrossed in an expensive and drawn-out commitment to the International Space Station (ISS). Ironically, a driving imperative of the ISS (which began life as Space Station Alpha within the now defunct SEI) was for LEO assembly and deployment of human missions to Mars.

Many are frustrated with political reluctance to outline a vision for the expansion of humanity beyond earth. Recognising the challenges posed by

- a lack of public understanding of the value of Mars and the benefits to be gained by sending humans to explore and perhaps even colonise the Red Planet,
- the inability of planners to convince public leaders of the affordability of human missions,
- competition from the scientific community for funding to support robotic exploration, and
- a growing aversion to risk by politicians and large space agencies such as NASA following the end of the Cold War,

private activity has seized the initiative. The Mars Society (MS) was formed in 1997 to further the goal of increased exploration of Mars and future human settlement, and from its beginnings in the US has developed into an international organisation.

The Mars Society plans a progression from Earth-bound Mars analogue research, to Mars micromissions and payloads, and eventually to more ambitious privately funded robotic and human missions. The first phase of this progression, analogue research stations, is now well underway. This document describes how the Mars Society can enhance this first phase and embark at once on the second by gaining experience in space mission design and operations.

The Society believes that by promoting the opportunities to send people to Mars now within our grasp, and by undertaking research facilitating such missions, the tide of public and political opinion can be turned. While Mars-x will make significant contributions to mission planning and design, it is a vital tool in *making Mars more real for more people* here on Earth. SAFMARS would add to this realism in several ways (see section 3.2).

2.3 OPERATIONAL POLICIES AND CONSTRAINTS

This subsection provides a perspective of organisational aspects of the Mars Society of relevance for the SAFMARS proposal.

In a wider sense, there is currently no representative group within the Mars Society co-ordinating the establishment and operation of the international Mars-x series of facilities. There is a lack of wider ownership of Mars Society research priorities and lack of a formal process for co-ordinating international research activities. There is no formal documentation system, nor a process for initiating and managing projects.

The Mars Society remains under the auspices of a Steering Committee, with largely US membership and management. International chapters lack coherent frameworks and standard processes. Yet there is substantial potential in these international groups in terms of membership growth and research contributions.

The developmental and operational requirements of SAFMARS, international in scope, would help drive improved processes for distributed project management and international decision-making within the Society. SAFMARS would help cement cooperation amongst chapters. It would help make members feel they are part of a truly international movement.

It would be based on a lightweight project management system developed by the Australian Space Research Institute Ltd. (ASRI) in cooperation with Mars Society Australia (MSA) and based on the most recent international aerospace standards. This approach would minimise schedule and budget risks and provide a coherent framework that could be applied to other Mars Society projects[1].

[1] The ASRI Project System attempts to balance proper documentation of project decision making and standardised processes with the need for light, nimble procedures for volunteer based technical

The Mars Society is evolving. Its growth has been remarkable and SAFMARS would help consolidate these gains, crystallising member enthusiasm, talent and capability around a system that would serve to unify Mars-x, the flagship Mars Society project.

2.4 DESCRIPTION OF CURRENT SYSTEM OR SITUATION

This subsection describes communications systems currently in use by the Mars Society for analogue activities.

Figure 1 Conventional 56 kbps C-band data dish used by HMP [10] [5]

Mars-1 has to date depended on local HF voice communications and a packet radio Local Area Network (LAN) feeding data through broadband geostationary (GEO) satellite gateways used as part of the HMP [10].

A joint team from NASA Ames Research Centre (ARC) and Simon Fraser University (SFU) in Vancouver have deployed four space-based communication systems for HMP [1] [5] [8] during the 1999 and 2000 field seasons:

- Two sets of satellite telephones supplied by Canadian companies; two MSAT units provided by TMI Ltd, and an Iridium unit provided by InfoSat Ltd., both donating time and equipment.
- Twenty-four hour network communications provided by a 1.8 m dish, 56 kbps C-band terminal linking the Canadian Anik E1 GEO satellite to a 9 m dish terminal located in Ottawa, both provided by the Canadian Communications Research Centre (CRC).
- An experimental high speed link using a 50 cm dish Ka-band ultra-small aperture terminal (USAT), suitcase portable, for the NASA Advanced Communications Technology Satellite (ACTS), providing 512 kbps wideband internet communications via a 1.8 m dish terminal at the Air Force Research Laboratory in Rome, New York (ACTS was

operations. This document is based on one of the first Document Item Descriptions (DIDs) for the new system.

a former GEO satellite that underwent scheduled decommissioning during the 2000 field season).

The ACTS gateway was integrated to a range of radio networking solutions, including an SFU-provided medium-range packet networking system, using hardware provided by WiLan Ltd. of Calgary. All of these systems have been explored for use in disaster communications and TeleLearning applications.

The availability of such infrastructure for Mars-x and other Mars Society projects greatly boosts research and outreach activities. However, piggybacking will not always be an option and the costs of remote broadband communications are likely to remain a significant proportion of total field operations costs. In the context of limited private budgets, reliance on donated, hired or purchased systems for all communications needs will tend to limit the quantity and quality of research work. This could limit the public impact of the Society.

2.5 USERS OR INVOLVED PERSONNEL

This subsection describes personnel arrangements for current Mars Society analogue research activities and those of the HMP communications team.

A committee of nine people currently manages Mars-1. Mars-2 is a new project being led by this same committee. Both Mars-Oz and Mars-Euro are being planned independently by international branches of the Mars Society. The Flashline Committee consists [22] of:

- Dr. Robert Zubrin - Mars Society President
- Dr. Pascal Lee - SETI Institute/NASA ARC and Mars Society Project Scientist
- Marc Boucher - aTerra Technologies Corporation, Mars Society Board Member
- Richard Wagner - Author/Editor, Mars Society Board Member
- Dr. Chris McKay - NASA ARC, Mars Society Steering Committee Member
- Dr. Carol Stocker - NASA ARC, Mars Society Steering Committee Member
- Dr. Charles Cockell - British Antarctic Survey
- Maggie Zubrin - Mars Society Executive Director and Board Member
- Frank Schubert - FMARS Project Manager

A group of around one dozen was involved in the construction and commissioning of Mars-1 in 2000, which needed to work closely with HMP personnel. In 2001, Mars Society members from all over the world have been invited to apply for a limited number of bursaries to undertake a research programme of their choice at Mars-1 during the northern summer field season.

Mars-1 has not been constructed to satisfy a specific user demand, rather it is intended to demonstrate leadership, generate public support for Mars missions and answer important operations planning questions. It is expected to support a flow of research papers for journals and conferences. Field campaigns will be outlined and scrutinised at the annual international Mars Society Convention.

European members, led by the German chapter of the Mars Society, are planning Mars-Euro. Mars-Oz is being planned by MSA as part of its Technical Programme to maximise opportunities Australia can provide for valuable Mars analogue research.

The HMP NASA-SFU communications team has included [5]:

- Stephen Braham, head of the SFU PolyLab, a Sun Microsystems Technology Research Excellence Centre specializing in advanced applications of network computing,
- Peter Anderson, head of the Telematics Research Laboratory (TRL), established to perform research into all aspects of Telematics, ranging from networking infrastructure for TeleLearning through to TeleMedicine, but with a focus on the needs of disaster communication and emergency preparedness. TRL is co-operator of the PolyLab and has close links with the Canadian CRC,
- Richard Alena and Brian Glass, NASA ARC.

The ACTS project team included Robert Bauer, Michael Zernic and Louis Ignaczak, from NASA Glenn Research Centre [4].

2.6 SUPPORT CONCEPT

This subsection outlines support arrangements for the current system. As nothing resembling SAFMARS is in place at present, attention will focus on Mars-x communications support.

Mars-1 deployment and construction was made possible by HMP support, and operation will continue to rely on this co-operative relationship to a large extent.

The nature of planned communications support for Mars-2 is currently unknown. Mars-Euro and Mars-Oz planners are investigating the use of low cost HF digital packet radio, and MSA hope to implement SAFMARS and will carry satellite phones (possibly Globalstar) for safety backup.

3 JUSTIFICATION FOR, AND NATURE OF, CHANGES

3.1 JUSTIFICATION FOR CHANGE

The Mars Society needs:

1. to offer members opportunities to be involved in exciting projects and demonstrate success on a number of fronts,

2. to generate even greater public and corporate awareness and interest in the organisation and its goals,

3. to strengthen links with national space agencies and universities around the world (potential customers) and to position the Society at the centre of international Mars research and mission preparation activities,

4. some means of monitoring and controlling Mars-x assets for security purposes,

5. some means of remote automated data acquisition, reducing demands on high bandwidth communications systems and supporting Mars-x and mobile field research activities,

6. to strengthen co-operation, purpose and contact amongst international members of the Society,

7. to minimise costs associated with analogue research and assets where appropriate, and

8. to seek ways to continually improve the fidelity of Mars analogue research activities.

Not only would SAFMARS become a useful support service, it would also become a valuable research tool in its own right.

Firstly, the finite speed of light results in a delay of between 3 and 22 minutes for communication transmissions between earth and Mars over the course of an earth year[2]. Responses to questions between flight and ground crews during human Mars missions could take at least 45 minutes. Normally a routine inconvenience, this is an extremely long time in any emergency situation. Crews will need to be far more autonomous than was the case with

[2] The elliptic orbit of Mars has an aphelion (furthest point from the sun) of 2.49×10^{11} m and perihelion (closest approach to the sun) of 2.07×10^{11} m, while earth's more circular orbit has a radius of 1.49×10^{11} m. The speed of light is $c = 2.99 \times 10^{8}$ m/s, and so to first order transmissions between earth and Mars require between 3 minutes at closest approach and 22 minutes when they are farthest apart ($t = x/c$).

the lunar landings. Thus one feature of the SAFMARS system (uncontrollable but predictable message delays) that might be considered a disadvantage could in fact be turned into an added benefit. It would help us better understand crew productivity and autonomy issues for Mars mission command and control scenarios.

Secondly, it is highly likely human Mars missions will be preceded and supported by a powerful communications relay satellite system, probably in Mars geostationary orbit. However, there will be a role for Low Mars Orbiting (LMO) microsatellites for precisely the same reasons that LEO microsatellites are useful on earth – they provide cost effective low-power communications requiring only small, mobile, non-tracking ground terminals for low-level needs. They're more appropriate for certain tasks, such as automated data acquisition and control of remote science stations or exploration robots. They'd also provide a cheap and robust backup system for surface-surface crew messaging.

During Mars-x operational campaigns, communications will be essential for:

a) transmitting data and observations to "backroom" researchers,

b) enhancing Mars mission simulations through the interactions between crew and "Mission Control", and for

c) outreach purposes, creating interest amongst the general public (e.g. by allowing messaging between the public and crews and field diary entries on Mars Society websites)

Mars Society field operations are unlikely to be confined to permanent Mars-x stations. Expeditions into remote areas serviced by existing research infrastructure (e.g. Canadian Polar Islands or Antarctic Bases) are a first step, but the programme must look also to areas of scientific value that have fewer support facilities. These mobile field expeditions will be highly dependent on communications services.

3.2 DESCRIPTION OF NEEDED CHANGES

A year-round communications system assuring low-level services such as telemetry and packet messaging to and from anywhere in the world is necessary. The digital Store and Forward Communications (SAFC) class of low earth orbiting microsatellites ideally suits this duty. These have evolved since the launch of UoSat-2 in 1984 into a relatively standard and highly cost-effective remote data system.

This document therefore proposes establishment and operation of SAFMARS – the Store And Forward Mars Analogue Research System. This would be the first microsatellite communications system devoted to analogue research activities for human Mars missions. It would be the first space-based project of the recently formed international Mars Society. It is a system designed to increase Mars Society capabilities, reduce communications costs and add a new and valuable dimension to human Mars mission analogue research.

SAFMARS would consist of one to three dedicated SAFC microsatellites in different high inclination orbits (preferably sun-synchronous, see section 4.3), together with 3-9 digital packet radio ground terminals for distribution around the world, with 1-3 of these acting as semi-permanent ground station gateways connected to a broadband internet link.

SAFMARS would allow emails to be sent between Mars Society research stations, mobile units (e.g. rovers), field expeditions, Mission Controllers and the internet. SAFMARS orbital components (e.g. JAESAT) would cover the entire surface of the earth each day, relaying messages between ground stations and allowing communication amongst operations and expedition crews and automated monitoring and control of analogue systems.

It would consist of three segments; space, ground and software, which could be developed by three Mars Society teams on three continents. The space segment would consist of the JAESAT orbital component and others secured by Mars Society members. The ground segment would consist of mobile terminals for communicating with these orbital components, integrated with site Local Area Networks (LANs) and the internet.

The software segment would consist primarily of a highly functional Mars Society Mission Control (MSMC) website, terminal software as well as various autonomous system communications protocols. The scope of the software segment would extent beyond SAFC to the integration of Command, Control and Communications (C3) for *all* analogue activities into a single, user friendly interface accessible from anywhere in the world via the internet.

Working closely with the Mars-x project, SAFMARS would add impetus and strengthen the international nature of Mars Society activities. The project would be overseen by an international committee and, according to this proposal, would raise 50% of its own funding requirements.

The SAFC payloads would be secured on existing or proposed satellites for minimal cost. The acquisition or development of two types of ground terminals would be required, one for fixed Mars-x class stations connected to a LAN, and one for man-portable small field expeditions. The system would be particularly sensitive to the cost of these terminals. Various groups have made progress in recent years toward effective lower cost units [23] [25].

SAFMARS would provide the ability for Mars Society personnel and members to deliver useful email messages to each other regardless of where they are, year-round, in a predictable manner. These would include text, digital multimedia (or other binary) files, data and remote station control instructions. This would not replace other broadband and real-time services, but would reduce dependence on third party providers and enhance analogue research capabilities.

3.3 PRIORITIES AMONG THE CHANGES

The project should commence immediately and take advantage of a unique opportunity to acquire the Store and Forward Communications (SAFC) payload on the Joint Australian Engineering Satellite (JAESAT). JAESAT is planned for launch from Ukraine in late 2002.

A commitment to SAFMARS should be made for a period not less than three years, during which time its life cycle plan would evolve based upon operational experience. Three years is a typical lifetime specification for a microsatellite (most operate well beyond this), and a period over which some of the SAFMARS equipment will have fully depreciated (e.g. computers).

The highest priority is at least one orbiting SAFC payload (i.e. a dedicated facility) in polar and preferably sun-synchronous orbit.

There is a need for cost effective ground terminals. These stations are now being produced at a cost of the order of US$2,500-$15,000 for a suitcase-sized system that interfaces with a laptop computer. The growth of the microsatellite market has led to increasing interest in the use of inexpensive ground terminals for communications in developing nations [18]. Ground terminals come in two main forms, tracking and non-tracking. Recent work has focussed on refining non-tracking systems.

Some options for acquiring ground terminals include:

1. **Commercial Off The Shelf (COTS).** There is clearly scope for a supplier of digital packet radio and satellite equipment (e.g. Codan www.codan.com.au) to become a major naming sponsor of SAFMARS. A long-term relationship would help ensure the use of state of the art equipment. Alternatively, funding might be raised to purchase COTS ground terminals through a tendering process.

2. **Co-operation with other Volunteer Organisations.** Volunteers in Technical Assistance (VITA) and SatelLife, amongst others [18] [23], have become world leaders in microsatellite SAFC for developing nations. Mars Society members could work with such organisations, and raise funds to compensate for materials, fabrication and testing expenses to build ground terminals.

3. **In-house Development.** This would be most feasible if development facilities and costs could be shared, say, with one or more universities. The motivation could be two-fold: provision of motivating educational opportunities for a real “customer” (The Mars Society) and positioning

the respective universities[3] for a role in a growth area (microsatellite SAFC, or space generally). Where possible, however COTS components would be used.

The priority for SAFMARS would remain on provision of a vitally useful service, and for this reason risky Research and Development (R&D) is to be avoided. R&D should be pursued only once the basic system is operational and serving its user community. Any such R&D would first seek to further the research priorities of the Mars Society, yet any spin-offs (such as a very-low cost ground terminals) could be valuable as a source of revenue.

Nonetheless, COTS is a preferred concept. The project will presumably operate on a stringent budget and total system cost will be sensitive to ground terminal cost. With a satisfactory supply of terminals identified, computer hardware and software will form the next critical element, and again, where possible an off the shelf solution meeting user requirements would be preferred.

With all these baseline system elements in place, further efforts would focus on securing one or two additional polar orbiting SAFC payloads.

3.4 CHANGES CONSIDERED BUT NOT INCLUDED

SAFMARS would not supplant the need for high bandwidth communications for remote Mars Society activities. It would supplement these and add new dimensions to analogue research.

While the benefits of this proposal are clearly outlined in section 7.1, SAFMARS has been motivated partly by the unique opportunity described in section 4.1.

The total cost of purchasing or developing an AMSAT-class microsatellite for SAFC duty is estimated at US$80,000 - $100,000 while the purchase of an appropriate launch on a commercial basis can cost around US$30,000 - $60,000. It might be difficult to justify this against other funding priorities (Mars-x facilities). However, the JAESAT opportunity (described in section 4.1) is expected to cost the Mars Society substantially less, given the funding and in-kind support already provided to the project. So while the pseudo-commercial purchase of three orbital components has been considered, this proposal focuses on the immediate use of JAESAT.

3.5 ASSUMPTIONS AND CONSTRAINTS

We assume that commercial satellite services will remain expensive and that communications will form a significant component of set up and ongoing costs of Mars Society analogue research activities (see APPENDIX –

[3] These would be approached early in the process, should such an option be considered desirable.

Satellite Communications). Determining exact costs would require assumptions regarding the future usage profiles of commercial communications services.

It is assumed that marketing of the project will generate enough interest from members and sponsors to assist with its completion. Technically SAFMARS is a relatively standard exercise for personnel with professional management and engineering experience, indeed the basic system is currently in use by other organisations. Managing the international co-operation (internal and external) will be a challenge and the project should budget for some limited international travel. Support from Mars Society leadership it is expected to facilitate assembly of an excellent project team.

Two satellites placed in appropriate orbits (sun-synchronous and displaced 180° to each other), could halve the message delivery time and double the network capacity compared to use of just a single satellite. Additional spacecraft would improve performance and also provide redundancy. There is a risk (as with any aerospace system) that satellites carrying SAFMARS SAFC payloads will fail. In the proposed arrangement with JAESAT, the vital interests of the Mars Society would see MSA working as closely as possible with ASRI to undertake comprehensive risk analyses and implement mitigation strategies.

ASRI currently requests a Statement of Intent from Mars Society Australia demonstrating a commitment to the JAESAT SAFC payload. This is necessary to finalise the Ukrainian launch opportunity. ASRI wishes to build a long-term relationship with Ukraine, and seeks to respond to the generous launch offer with minimum delay. MSA requests a Statement of Intent from the Mars Society Steering Committee or the President supporting SAFMARS, as well as expressions of support from international chapters recognising the collective benefits.

If this broad agreement cannot be achieved and JAESAT is lost, but sufficient interest remains in SAFMARS, attention will focus on securing another SAFC payload in the appropriate orbit.

4 CONCEPT FOR A NEW OR MODIFIED SYSTEM

4.1 BACKGROUND, OBJECTIVES, AND SCOPE

The Steering Committee has allocated a substantial portion of the Society budget to establishing Mars-1 and Mars-2, together with some smaller works such as the rover project. The philosophy is to capitalise on smaller successes, demonstrating the capabilities, credibility and commitment of the organisation, in order to attract increasing support.

Presumably communications between Mars-x facilities during field operations were to depend on the use of donated, hired or purchased equipment using donated or commercial satellite services to provide real time voice and data. Software buffers have been proposed to simulate the earth-Mars relay delay. During Mars-x “off seasons”, apparently no remote monitoring or control has been planned with the security of assets dependent on difficult accessibility.

However a window of opportunity has emerged for a low cost Mars Society SAFC satellite payload. JAESAT, the Joint Australian Engineering Satellite has been a joint venture between funding partner Cooperative Research Centre for Satellite Systems (CRCSS), educational partner QUT and manager, the Australian Space Research Institute Ltd (ASRI) since 1998. CRCSS have provided AU$60,000 over three years from an educational fund (US$1 = AU$0.55, Feb 2001). The objective has been to provide Australians with experience in the full cycle of microsatellite development and deployment, and to foster greater national participation in space activity.

At the time of writing many of the subsystems, materials and structures for JAESAT have been acquired or are nearing completion. The project recently reached a critical milestone with the Ukrainian Yuzhnoye space agency formally proposing a launch for late 2002 aboard a Dnepr. This has forced a final commitment to fabrication, integration and testing of the satellite. Unfortunately CRCSS have reallocated funding to another project and QUT have been unable to provide support needed to assure completion of the spacecraft by the launch delivery deadline. Thus a satellite for which much work has already been done faces losing a launch and even cancellation.

This has presented an economically attractive opportunity for the Mars Society to acquire the first and most important element of SAFMARS. ASRI and MSA propose to commit to the launch of JAESAT and mobilise support and personnel necessary to complete the remaining work on time and to a tight budget.

4.2 OPERATIONAL POLICIES AND CONSTRAINTS

According to international rules relating to amateur radio [12], amateur satellite facilities cannot be used for profitable purposes. Even if SAFMARS were to use amateur digital SAFC services freely available on several orbiting microsatellites, the system would be competing for bandwidth with no control over service availability or quality. SAFMARS must have dedicated orbital components.

Operating frequencies and modes will need to be selected on the basis of constraints imposed by international and local regulations, and the global radio environment.

System usage will depend on resource contributions made to establish and operate SAFMARS by various organisations and individuals. The advisory committee will consider the various interests of users, sponsors, the Mars Society and Mars analogue research, to determine usage policy and system development priorities.

4.3 DESCRIPTION OF THE NEW OR MODIFIED SYSTEM

The SAFMARS concept is illustrated in Figure 3. The following components form the basic system:

- Space segment – One to three SAFC microsatellites. Additional facilities and services augmenting communications are to be considered as separate systems. The orbits must be polar to ensure 100% global surface coverage, and should be sun-synchronous to ensure 24-hour global coverage with similar pass times each day (allowing crews to better plan their activities).

- Ground segment – A minimum of two types of ground terminals are needed – those for Mars-x facilities for integration into a LAN and man-portable units for mobile field expeditions. A third desirable type, a modified Mars-x class terminal, or *ground station* would incorporate enhanced radio equipment for improved performance. It would act as a semi-permanent or permanent ground station with a hardwired internet connection (Figure 3 shows such a ground station with a tower). However, both the Mars-x and portable units could be used for this purpose and towers or larger antennas would not be essential. The ground segment would include the ground station internet connections, computers and networking hardware (e.g. a dedicated SAFMARS server).

- Software segment – The software necessary to control, monitor, format, archive and distribute incoming and outgoing messages via ground stations, and to interface with, monitor and control Mars-x subsystems. This segment will include a virtual Mission Control (MC), with private access to high value services for registered Investigators (such as priority messaging) and access to general information and low priority services for the general public (such as crew messaging associated with outreach activities).

In line with the current state of microsatellite SAFC, SAFMARS should employ data speeds of at least 9,600 kbps. Given that the number of eventual orbital elements is presently uncertain, the delivery time for messages will be one of the least flexible parameters in the system. For this reason, and because research stations will become increasingly data-rich, the network should be optimised for maximum data throughput. All four Mars-x should be able to transfer at least 4 Mb of email messages per day year-round. This could be achieved either by:

1. **More SAFC microsatellites.** As the number of orbital elements increases the net data transfer capacity grows. However, with a fixed set of ground stations the average message delivery time remains the same unless intersatellite communications are implemented. This is the “little LEO constellation” concept (yet to be attempted), which is beyond the current scope of this proposal.

2. **Enhancing data rates.** At each satellite pass, stations will have only a brief period (of the order of ten minutes) to send and receive messages, and the higher this rate, the greater the potential storage capacity. The data rate will be subject to a range of factors, including chosen protocols and interference.

3. **Increased on-board SAFC memory.** If data rates are high enough, on-board memory can become a limiting factor in data transfer capacity.

4. **Data compression.** This is hardware-independent and state of the art data compression techniques should be used to maximise transfer capacity.

5. **Improved protocols and scheduling.** Although some basic transmission protocols must be standardised, scope may exist for improvements in communications techniques (e.g. scheduling) that maximise daily data transfer through the network.

Data rates and thus transfer capacity are strongly affected by interference. Surrey Satellite Technology Ltd. (SSTL), world leaders in microsatellite SAFC, has produced a global map of interference experienced in SAFC modes. Multiple frequency combinations (modes) are used on the uplink and downlink for typical SAFC payloads. The satellite selects the best mode available based upon factors such as signal strength. The difficulty experienced by a satellite in finding suitable modes can be plotted along its orbit and this information, gathered for many vehicles, leads to Figure 2. The location of Mars-1 and approximate locations of the proposed Mars-2/3/4 stations has been marked.

Some of the highest interference levels are found over the Australian continent. In addition polar ground locations have the most persistent access to LEO satellites in sun-synchronous orbits. For these reasons we can expect that Mars-1 at approximately 75°N (and Mars-Euro if Iceland, 65°N is chosen) will be serviced best by SAFMARS. Mars-2 (~35°N) and Mars-Oz (~30°S) will see SAFMARS microsatellites for similar periods, although Figure 2 suggests reception for Mars-2 may be superior (note only detailed analysis with global interference models will provide reliable estimates of system performance).

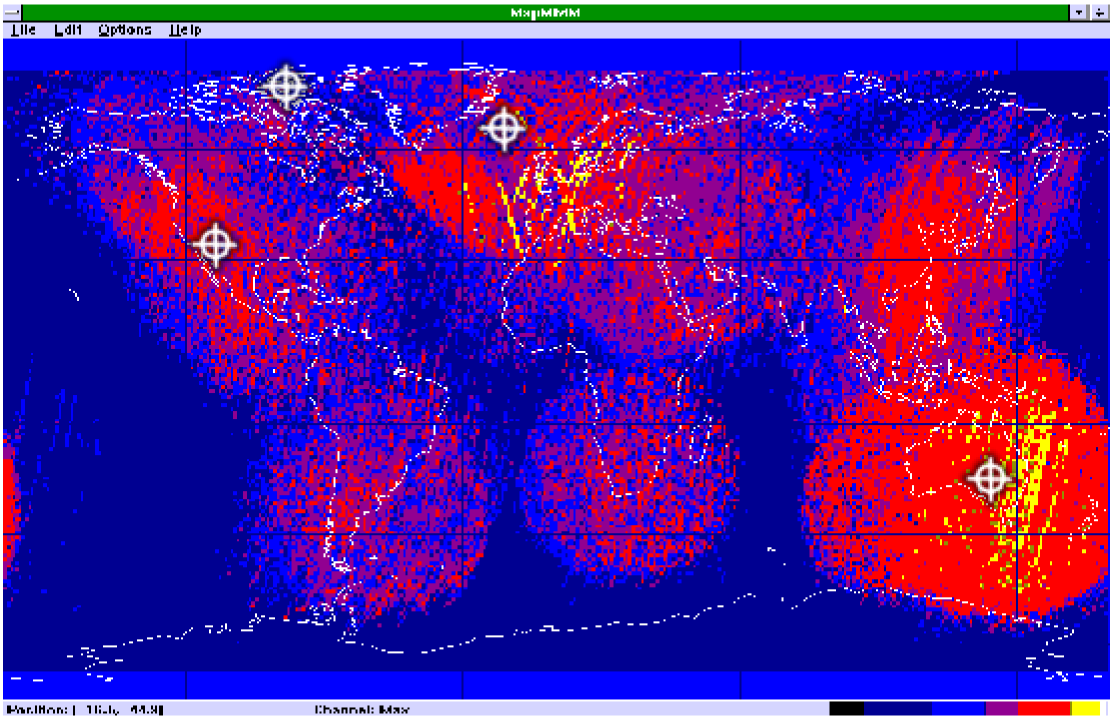


Figure 2 Global uplink interference data survey by SSTL[1]

SAFMARS must be a minimal maintenance system. This demands high reliability of SAFC payloads and ground stations. Portable terminals must be light (<20 kg) yet robust for at least 3 years of mobile field expeditions, while Mars-x terminals should be able to operate continuously for a period of one calendar year between routine maintenance activities, with a design life also of 3 years. All terminals should auto-acquire and seek to maximise data transfer in the limited satellite pass windows, and should allow multiple ground terminal access.

A reliable remote power system and scheduler is required for ground terminals. Standard solar panel installations should be adequate for Mars-2 and Mars-Oz, but a special system may be required for Mars-1 and Mars-Euro. Mars-x terminals must be fully integrated into station power and data networks. Portable units would most likely employ batteries and/or be powered by field vehicles.

Mars-x terminals, in addition to linking with passing satellites must also integrate into a LAN. A standard specification for this network must be determined, and is expected to evolve with operational experience.

SAFMARS itself will not consist of ancillary equipment such as sensors and instrumentation for station keeping and experiments, but must be capable of collecting information and issuing controls remotely via automated and manual commands in a safe manner, via the SAFMARS server and/or the Mission Control web interface. The types of information that will require year-round monitoring for each Mars-x include (but shall not be limited to):

1. Internal environmental conditions (temperature, humidity), at least once per hour,

2. External weather station (rain level, wind speed and direction, temperature, humidity, irradiance (direct and indirect)), at least once per 5 minutes,

3. Power levels for all subsystems,

4. Door sensors for security purposes, at least once per hour,

5. A high resolution still digital colour image, at least twice per day,

6. Scientific station data, with specifications on the frequency of collection and bandwidth of data transfer to be determined based on typical experimental requirements (standard specifications should be developed/adapted).

The types of command and control functionality desired includes (but need not be limited to) the ability to:

1. Activate and control power sources and distribute power,

2. Turn various subsystems on or off (repeatedly),

3. Re-programme any on board computer systems, and

4. Operate any roving equipment.

The software segment must ensure that safety of crew and assets is safeguarded through various checks, fail-safes and access privileges.

Ground stations are needed to interface the network with the internet. They could employ either Mars-x or portable terminals, however increased performance might be achievable with enhancements. They could be located anywhere in the world subject to the following requirements:

1. The ground station computer must be connected via a high bandwidth link to the internet at low cost,

2. A System Administrator must be readily available to ensure maximum availability of the station (including computer, software and radio equipment), and ideally would be co-located with the system,
3. Minimum radio interference,
4. Maximum altitude,
5. Maximum latitude.

A high altitude ground station offers the greatest opportunity for LEO SAFC satellites to be acquired sooner and to communicate for longer during each pass window. Ideally ground stations would be located near the poles, where radio interference is low and access is high. However in polar regions the first two requirements cannot generally be satisfied. Location of ground stations in universities with Mars Society student groups is desirable.

Hardware has been acquired for a ground station at the Queensland University of Technology (QUT) in Brisbane Australia, where the JAESAT project has been based. However, the nature of the proposed JAESAT ground station arrangements is presently uncertain.

Given that SAFMARS would not be fully operational until the launch of its first orbital component, there is sufficient opportunity for further negotiations and research into ground station locations amongst international project partners.

Some preliminary analysis of SAFMARS has been undertaken. Satellite Tool Kit (STK) [19] was used to determine representative access times for Mars-x facilities, and potential ground station and expedition sites. Ground terminals have been constrained to acquire only when the satellite elevation exceeds 10°. This is a conservative estimate, leading to pass duration windows of around 8 minutes in the case below (10-13 minutes is achieved in practice).

Figure 4 shows the northern hemisphere Mars-1/2/Euro, potential ground station locations in Oslo and Germany and a potential expedition site in Tunisia. Estimates have been made for the locations of Mars-2 (Mojave Desert) and Mars-Euro (Eastern Iceland).

Figure 5 shows ground tracks during ground terminal acquisition of the UoSat-3 spacecraft (HealthSat-1, see APPENDIX – Satellite Communications) for these locations. In this view earth rotates as the satellite orbits along a near constant path in space (the terminator also remains “fixed”). When during each orbit the satellite is acquired by a station, the ground tracks have been marked. Stations at higher latitudes have the most frequent access to the satellite. These also have the poorest access to GEO satellites.

UoSat-3 was the world’s second digital SAFC microsatellite, and occupies the desired orbital inclination for SAFMARS space segment components. It was launched from Kourou in 1990, weighs 45 kg with a near circular orbit of average altitude 790 km and is still functional. Initial inclination was 98.4° however this ranges within ~1° over time due to the oblateness of earth. This simulation is based on Keplerian elements from 21 January 2001, and the orbit propagation has been calculated for a 24 hour period from 21 January to 22 January 2001.

We see in Figure 5 that UoSat-3 is approaching Mars-1 and its ground track will fall slightly to the west of Devon Island. STK simulation shows that UoSat-3 will soon be acquired by both Mars-1 and Mars-Euro simultaneously, allowing real time data transfer between these stations.

Site	Passes	Duration	Pattern
Mars-1	11	8.95	[4,7]
Mars-2	4	8.55	[2,2]
Mars-Euro	9	8.36	[9]
Mars-Oz	4	8.75	[2,2]
Birdsville	4	8.16	[2,2]
Cooper Pedy	5	7.93	[3,2]
McMurdo	15	8.95	[15]
Sandy Desert	4	7.62	[2,2]
Tunisia	4	8.05	[2,2]
Brisbane	5	7.83	[2,2]
Germany	5	8.68	[3,2]
Oslo	7	8.27	[4,3]
Perth	3	8.90	[1,2]

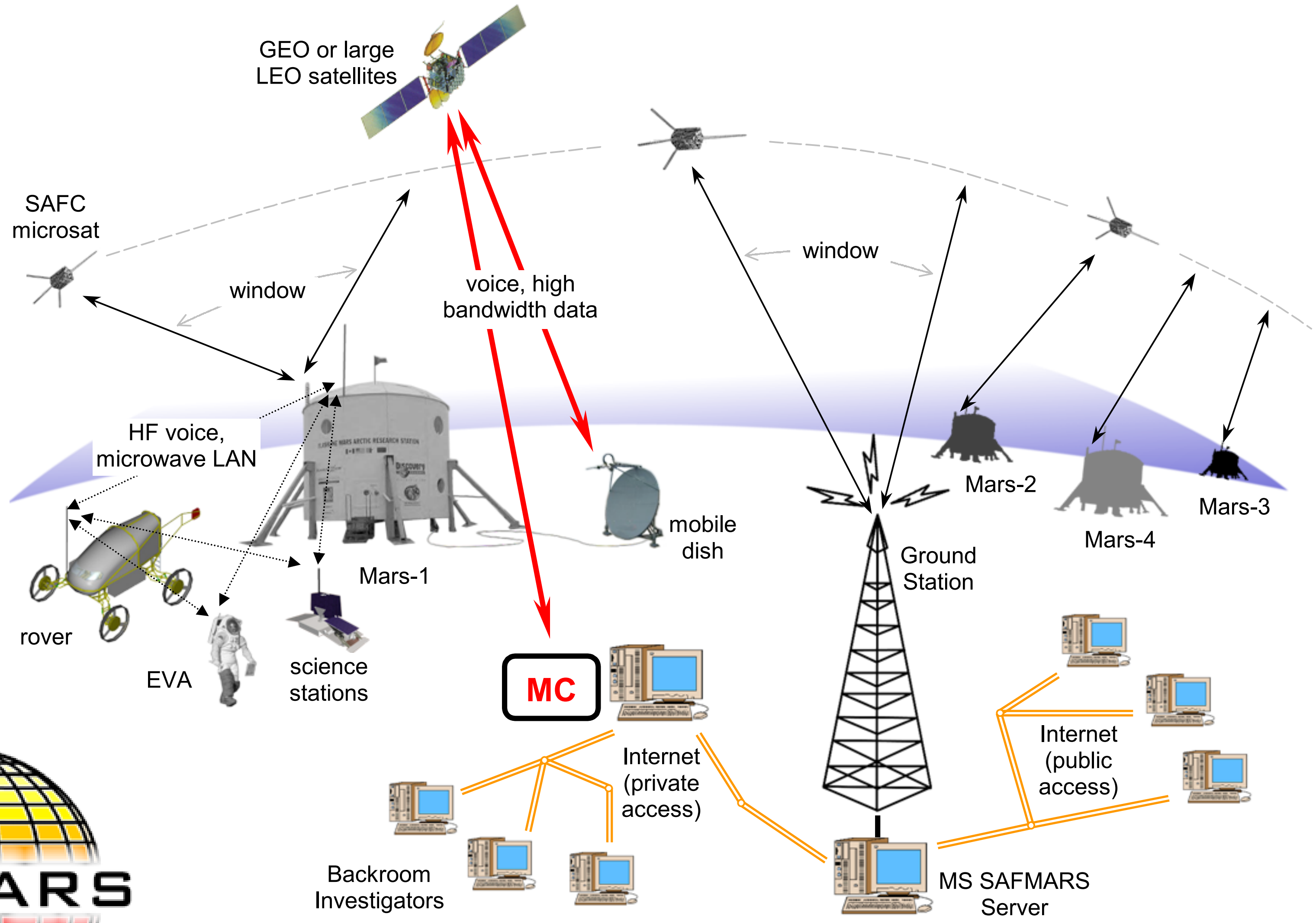
Table 1 Summary of data appearing in APPENDIX – STK SAFMARS Simulation.

Figure 6 shows UoSat-3 over the Southern Ocean travelling south, with communications in progress between the satellite and a potential ground station in Perth and potential expedition sites near Birdsville in Queensland and Cooper Pedy in South Australia. We also see how the satellite provides frequent service to McMurdo in Antarctica.

Finally, Figure 7 and Table 1 summarise access for each ground terminal for each satellite pass. In Figure 7 the bars represent the start and finish of each pass for each ground terminal (y axis). In Table 1 pass duration is in minutes, and passes occur in patterns consisting of a string of acquisitions in either one or two groups. McMurdo (82°S) sees the spacecraft 15 times each day, while Mars-1 sees it 11 times - both have the best pass window duration average of 8.95 minutes. Regular passes are spaced at around 1.7

hours (close to the orbital period), and occur in strings of one or two groups. Thus Mars-Euro sees UoSat-3 repeatedly nine times in a row, but Mars-1 sees it four times then seven times, around seven hours later. Because the orbit is sun-synchronous, these patterns repeat daily.

It is interesting to note access achieved by various potential ground stations. In the southern hemisphere, all other things being equal, Brisbane would appear a better choice over Perth (for this particular orbit) with five daily passes. Oslo sees the satellite more often than central Germany. However, there are many factors of importance in ground station selection and this is simply a preliminary analysis intended to illustrate the nature of the system.



SAFMARS

Figure 3 SAFMARS Concept

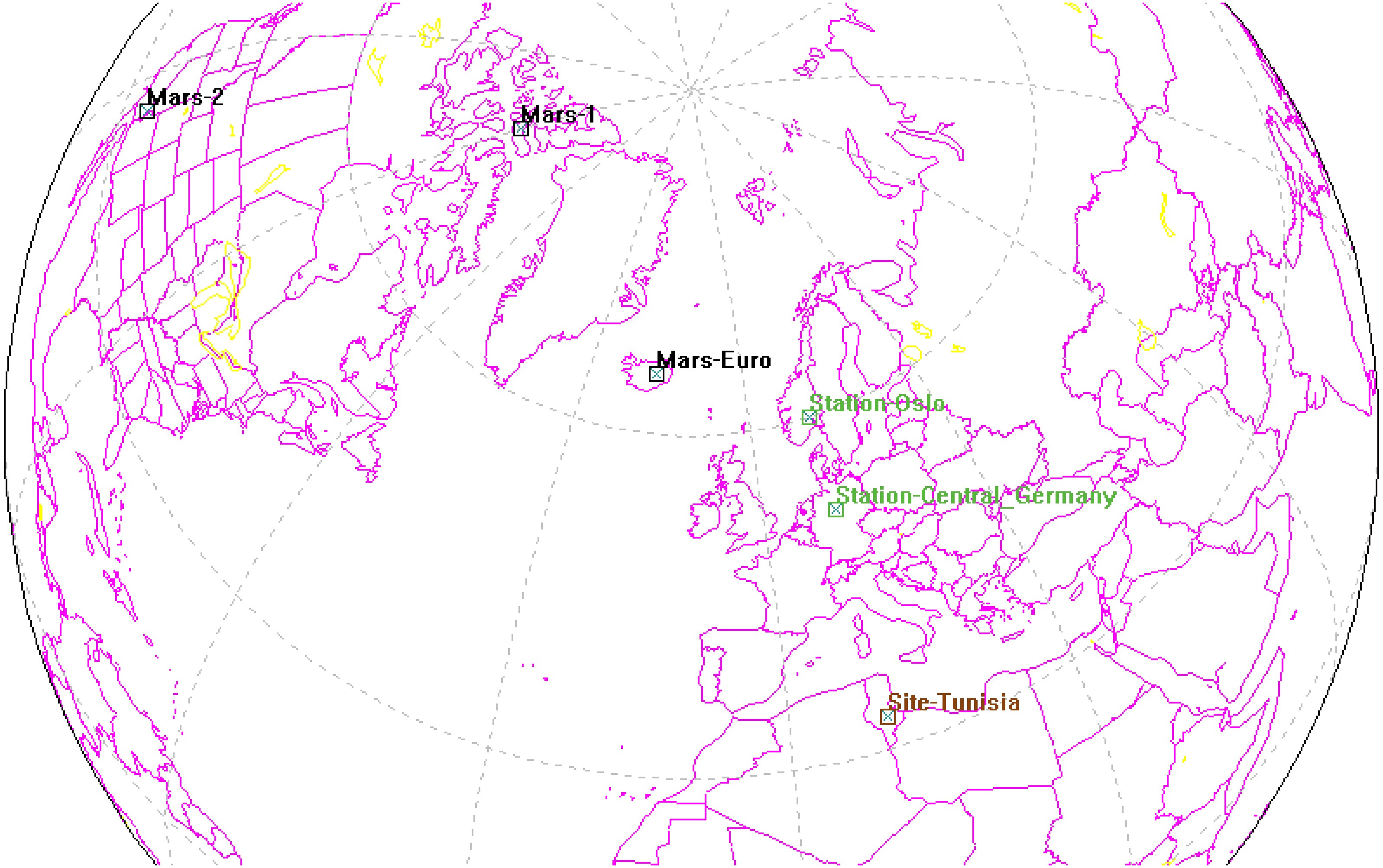


Figure 4 Northern hemisphere Mars-x facilities.

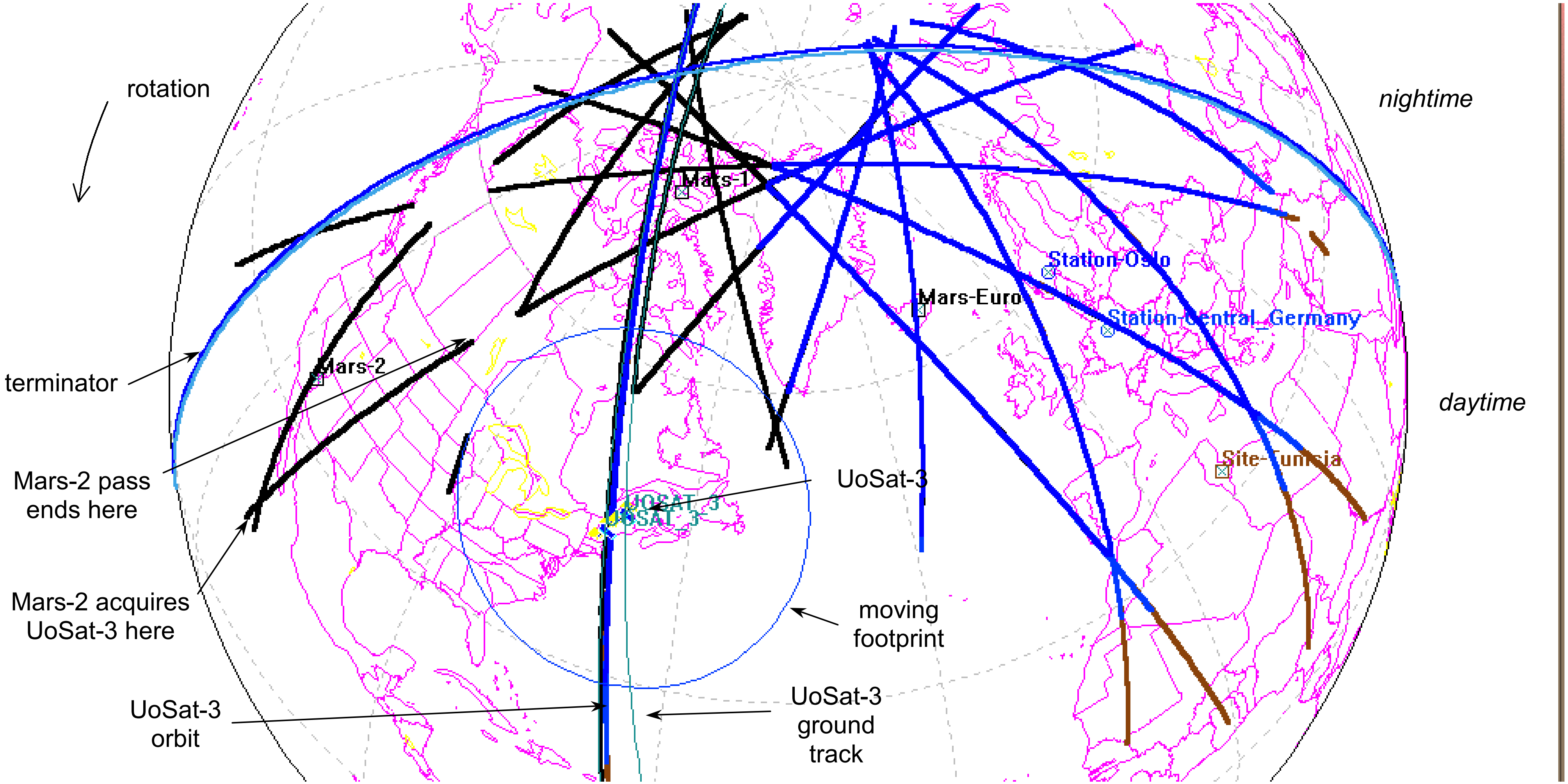


Figure 5 Ground tracks of UoSat-3 in northern hemisphere.

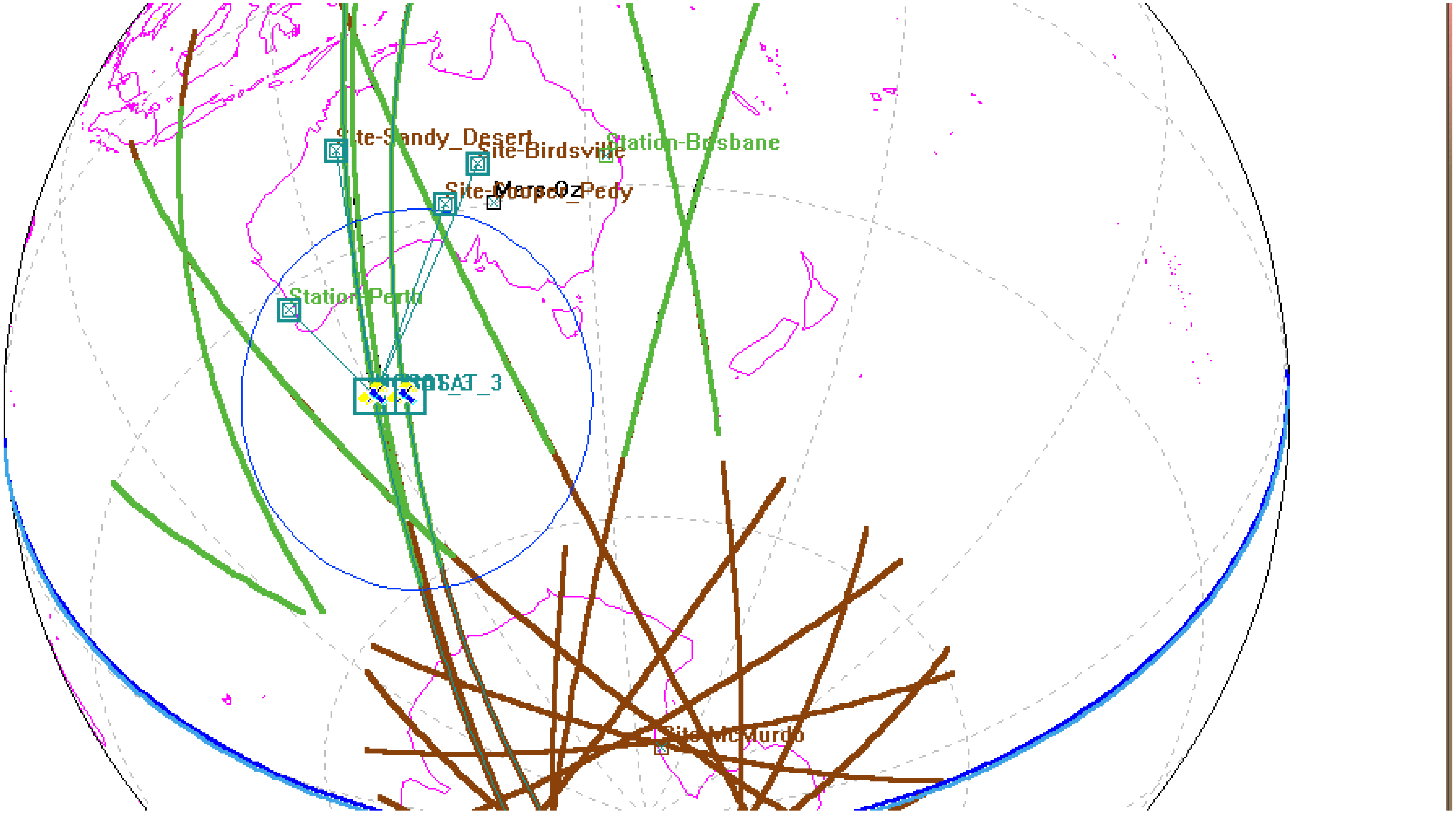


Figure 6 Ground tracks of UoSat-3 in southern hemisphere.

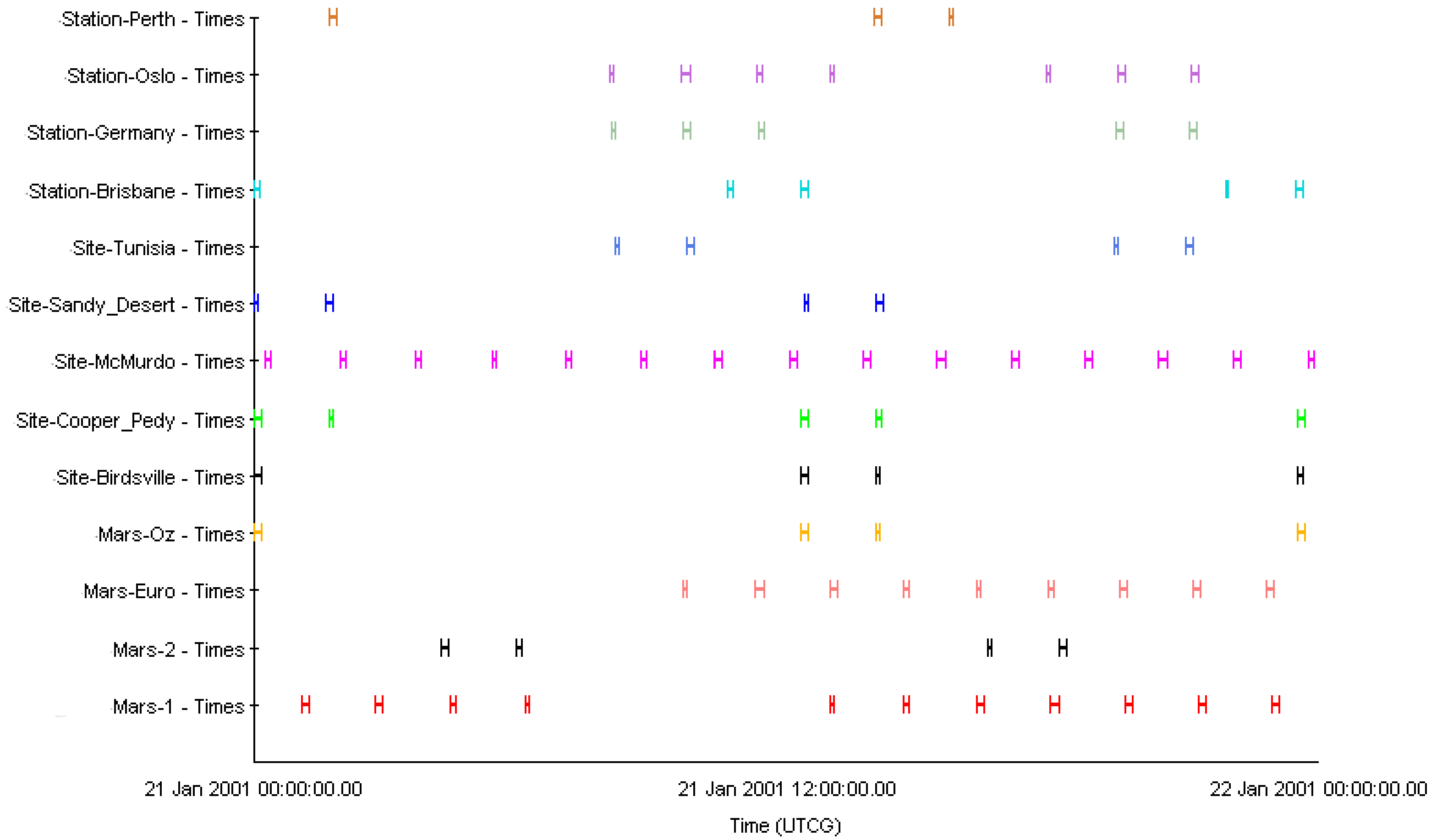


Figure 7 Access graph for UoSat-3 during a single 24 hour period in late January 2001.

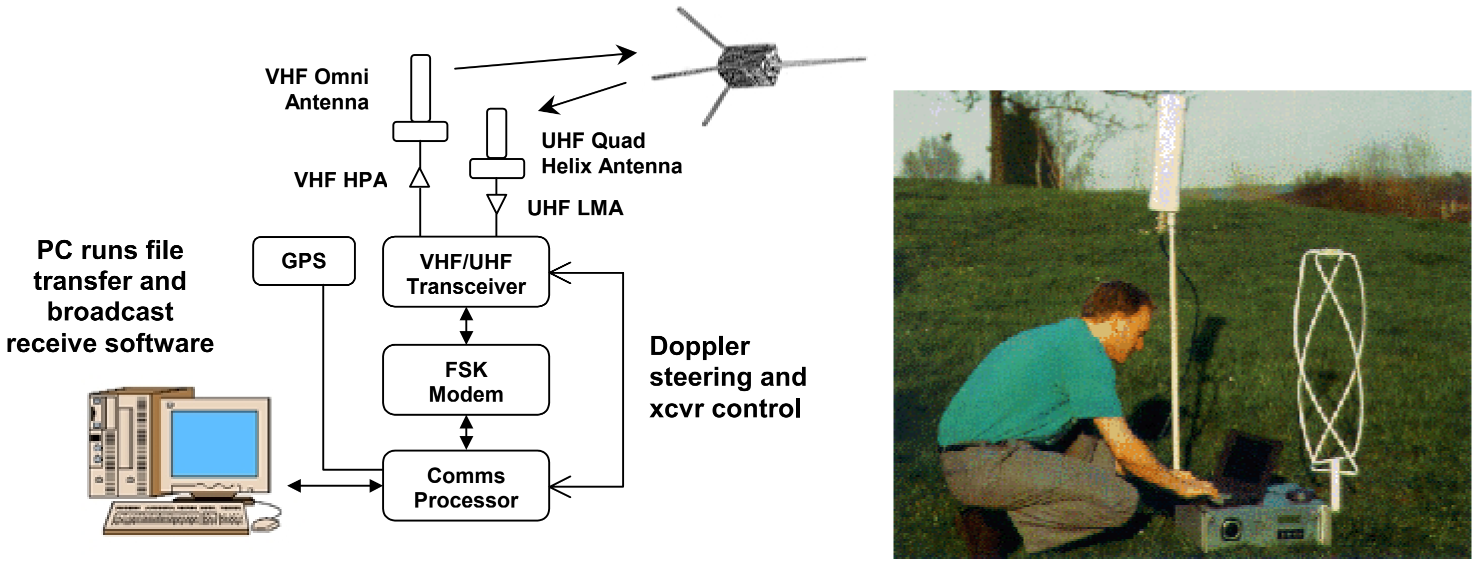


Figure 8 Small, non-tracking SAFC Integrated Ground Station (IGS) of SSTL [1] [25]

4.4 USERS/AFFECTED PERSONNEL

The SAFMARS project would be owned by the Mars Society and managed by MSA, which will seek international co-operation to develop and implement the concept. JAESAT would become the first (essential) orbital element of SAFMARS. As ASRI would retain ownership of the satellite, within this framework MSA would own and operate the JAESAT SAFC service and possibly supply spacecraft communications services to ASRI.

Under the proposed agreement, all satellite hardware would be supplied by ASRI to satisfy MSA requirements. ASRI would determine the payloads that fly on JAESAT. MSA would develop hardware specifications for ASRI for the SAFC payload, undertake payload software development, integration and testing, all subject to ASRI JAESAT project management.

Whilst amateur access to SAFMARS orbital SAFC payloads would be possible (and desirable as a backup to help rectify problems or during commissioning), Mars Society traffic would always take precedence. The project team would work in co-operation with the ham satellite radio community during system design and implementation.

It is proposed an international SAFMARS advisory committee be formed to own the project. The committee would review this OCD, identify the functional elements of the project, task the development of a project management system to an ex-officio Project Manager, mobilise key personnel, be responsible for fund raising and sponsorship, review design, oversee implementation and develop usage policy. MSA would be assigned overall management duties, taking direction and advice from the advisory committee and appointing Australian and international Mars Society members in a project team under the auspices of the Project Manager.

A Project Handbook will be drafted in line with the ASRI Project System. MSA will be the first Licensee of this new system, which provides a set of project management and system engineering documentation and processes based upon the most recent international aerospace standards.

SAFMARS committee meetings, seminars and workshops would be held at least once a year at the international Mars Society convention. Where possible, subsystems would be sub-contracted to internal Mars Society units or individuals during the design, development and operational phases.

Preference would be given to three distributed teams assigned responsibility for the space segment (MSA), the ground segment and the software segment. A management committee would be formed, answering to the advisory committee, with representatives from these project teams led by the Project Manager. Project email lists would be established and use made of internet chatroom facilities for regular management team meetings. At least one 3 day meeting of a representative from each of these teams should be held during 2001 outside the international Convention, to facilitate co-ordinated planning and monitoring of technical, sponsorship, budgetary, personnel and scheduling issues.

The advisory committee should consist of Mars Society representatives, those who have led Mars-1 and Mars-2 development, and international Mars research scientists. The project team should include at least three experienced project managers and systems engineers (who need not have had experience in communications systems), and at least two radio amateurs familiar with the design and operation of satellite digital SAFC systems. These team members should make a 3-year commitment to the project to provide continuity.

University students would be engaged to undertake detailed analysis work on the system, costing, detailed design, fabrication and testing as part of coursework. The teams would plan around various semester dates in their locations to ensure a pool of available students (e.g. student recruitment in Australia would focus on Feb-Mar). The project should ramp up to at least a dozen university students during 2001 (primarily undertaking detailed work on the project as part of courses in electrical and electronic engineering, software, telecommunications and networking). Some will need to liase closely with the JAESAT team to ensure final fabrication, integration and testing of the space segment by the end of 2001. Given the importance of these students, the involvement of local academic staff members in each team is considered *highly desirable*.

Mars Society volunteers, including university students complementing those undertaking coursework, will supplement the project team. Personnel will be needed for administrative support (e.g. Document Control) and fundraising, among other things.

In the absence of significant support, SAFMARS will become a project of MSA, who will own and operate the network at its sole discretion subject to any agreements negotiated with third party providers (e.g. such as ASRI) or customers (e.g. Mars Society).

4.5 SUPPORT CONCEPT

Mars-x terminal assets would remain fixed at each facility, with maintenance undertaken during operational campaigns. Portable terminals would be stored at a convenient and secure location and members would apply to the advisory committee or its representative for use. Freight would be at the expense of the user, and as part of usage policy the advisory committee would need to anticipate the potential for equipment damage (beyond simple wear and tear). To the maximum extent possible the system would be “plug and play”, and highly user friendly.

5 OPERATIONAL SCENARIOS

The system should allow:

1. station data and telemetry (e.g. for Mars-x and its associated peripherals such as rovers, science instruments etc.) to be monitored year round,

2. station control instructions (e.g. for non-occupied remote control) to be sent year-round, and

3. email messages to be transferred between field operations crews and the internet, with control subject to settings specified within the MC website.

It is envisaged that all communications on SAFMARS would be encapsulated in standard email messages, unless alternative schemes lead to essential memory or bandwidth savings. Email messages could include any of the standard binary file compression types, including (but not limited to) MPEG, JPG, and MP3.

The AX.25 and PACSAT digital packet protocols shall be employed in SAFMARS. These have proved their robustness in other SAFC microsatellites. Security coding would be required to control access to SAFC services, although the scheme used and other protocol issues (such as querying and allocation) will largely reflect specifications for the first orbital component (i.e. JAESAT).

By providing a reliable, base level of communications with field crews, SAFMARS would establish a framework for Command and Control of analogue field operations. This would be achieved via a Mars Society Mission Control (MSMC) website to which one or more Mission Control personnel, anywhere in the world, are given password access.

When field operations are not in progress at any of the Mars-x stations or elsewhere on the network, the SAFMARS server would undertake automated station monitoring and control (perhaps within certain limits) and message control. A designated SAFMARS Administrator would receive system alert messages from time to time and undertake regular server and system maintenance. They would liase via email with System Administrators of SAFMARS ground stations.

When field operations are in progress, the MSMC interface would be used by designated Mission Controllers via the internet to control and monitor station systems and send/receive priority messages to/from field crews. The SAFMARS Administrator would determine the level of privilege for each Mission Controller with super user capabilities.

Usually, SAFMARS would be augmented by high bandwidth data and voice communications during campaigns - SAFC will usually supplement real time facilities. The MSMC website must be more than a SAFC control interface – it would also assist in the management of these augmented communications. It would provide archiving of augmented communications for later analysis. The website would in fact become a fully integrated tool for all Mars Society analogue research activities, providing access to data and messaging and a suite of utilities allowing Controllers to ensure safe and effective field operations, and Investigators to work most efficiently with field crews.

The MC website would be based around selectable modes, including (but not limited to):

- **Automated Mars-x facility mode**. This is where a Mars-x facility is shut down between operational campaigns, full security measures are invoked, data acquisition and facility telemetry is automated.

- **Manual Mars-x mode**. This is where personnel are on site and special care must be taken to ensure automated controls do not endanger safety, data is routed automatically to registered Investigators etc., but no formal mission simulation is taking place on site (even though it could be occurring at other sites).

- **Mission simulation mode.** This is where precise delay buffering could be used for messages and data, and tools and information permitting high fidelity simulations are readily available, including integration with other Mars-x facilities for joint simulations.

- **Field expedition mode.** This is where communications are less intense but field personnel may be exposed to a higher degree of personal risk and need special attention.

Update messages or diary entries could be automatically sent and formatted directly onto Mars Society websites, at the discretion of Mission Controllers. A facility allowing emails to be sent by members through an online form could be activated for automated, direct routing, again subject to Mission Controller discretion.

The most important aspect of the Mission Control interface is that it would not require users to be located in a large Houston-type control room, but anywhere in the world with an internet connection. This description is preliminary and would require consultation with Mars Society members and aerospace professionals to determine full functional specifications.

6 SUMMARY OF IMPACTS

6.1 OPERATIONAL IMPACTS

In the form described, SAFMARS would provide a significant capability for the Mars Society and this would impact on operations. Field campaigns could be more co-ordinated, and there would be rapid dissemination of outcomes. It would provide a robust safety net. Costs of campaigns are likely to be lower, although only further analysis will yield reliable figures. More fieldwork will be possible, it will become more flexible and safety and security will be improved.

6.2 ORGANISATIONAL IMPACTS

In reference to section 2.3, it is neither practical nor wise to postpone the progression of projects that enjoy broad support until effective management systems and representative processes are in place. Often we cannot afford to wait for these things. Projects such as SAFMARS will help to evolve these systems and processes, however this does not negate their critical importance to ultimate success.

The space segment, at this time JAESAT, requires mobilisation of students to complete the spacecraft. This is in progress in Brisbane, Australia. The spacecraft must be completed by the end of 2001 for testing and delivery to Ukraine in early 2002. The mid-late 2002 launch gives around 18-22 months to complete the ground and software segments. SAFMARS would pioneer a framework for future international Mars Society projects during the first 6 months.

SAFMARS will be the first Mars Society project to be designed, managed, implemented and operated as a truly international joint venture. It relies on global reach. Most importantly, SAFMARS would be the first step in co-ordinating the Mars-x project and exploiting synergies amongst members and organisations around the world.

SAFMARS would launch the first Mars Society space borne payload, and promises high promotional value. This will help motivate more volunteers, secure more corporate support and gives us experience necessary to move to the next phase – payloads to Mars.

6.3 IMPACTS DURING DEVELOPMENT

SAFMARS depends on dedicated microsatellites. There has been steady growth in the number of educational, research and amateur groups seeking to build and operate microsatellites. Often, however, these projects lack customers. This tends to increase the chance of project failure. Customers, paying or otherwise are usually critical to properly defining the system, establishing and monitoring a schedule and motivating the project team. The Mars Society, for example will provide a major impetus for JAESAT, which has languished without a customer.

The Mars Society would use its extensive network of members and associates to seek extra orbital components for SAFMARS. New microsatellite projects are emerging every month, and there is even the possibility of negotiating with owners of existing SAFC microsatellites to secure services. The availability of launch opportunities is likely to increase in the next few years, particularly in view of the looming 2007 START-II deadline for ex-Cold War ICBM's. JAESAT is poised for just such an opportunity.

To ensure a proper and fair balance of incentives and galvanise international groups, it is proposed that the Mars Society Steering Committee commits to dollar for dollar funding to the project. With three project teams (space, ground, software) spread over, say, three continents (e.g. Australia, Europe, North America), each would seek sponsorship and donations in its local area (in a co-ordinated fashion), and funds raised by each would be matched, dollar for dollar (based on exchange rates at the time) by Mars Society funds from the US. Thus the Steering Committee would effectively acquire SAFMARS for "half the price" (only half the cost would be covered using existing funds), and the current strength of the US dollar would improve cost effectiveness still further.

7 ANALYSIS OF THE PROPOSED SYSTEM

7.1 SUMMARY OF ADVANTAGES

SAFMARS would provide the ability for Mars Society personnel and members to deliver useful email messages to each other regardless of where they are, year-round, in a predictable manner. These could include text, digital multimedia (or other binary) files, data and remote station control instructions. This would not replace other broadband and real-time services, but it would reduce dependence on third party providers.

SAFMARS would:

1. give Mars Society members experience in space operations contributing to the next phase – interplanetary Mars missions,

2. create added public and private interest in the organisation and its goals,

3. be made available for the use of field scientists in national space agencies and universities, perhaps in return for rapid access to research data and information, helping strengthen relationships between the Mars Society and the research community,

4. allow improved monitoring, control and security of Mars-x assets,

5. enhance the quantity and quality of research activities of the Mars Society by allowing automated data acquisition, enhancing Mars-x communications and supporting mobile field expeditions to anywhere on earth,

6. provide an immediate opportunity for closer international co-operation amongst Mars Society members, providing an additional impetus toward establishment of Mars-x facilities and strengthening the global nature of the movement,

7. include a realistic intrinsic delay in messaging, not dissimilar to that faced in actual Mars missions, that would provide another valuable analogue research dimension,

8. provide valuable experience in the implementation and operation of a global communications network that could directly assist in designing communications systems for Mars.

7.2 SUMMARY OF DISADVANTAGES/LIMITATIONS

Some perceived disadvantages might include:

1. The need for a rapid commitment from the Mars Society if the JAESAT opportunity is to be seized,

2. The need for a commitment of no less than 3 years to SAFMARS from the Mars Society, the advisory committee and project team members,

3. The diversion of resources away from Mars-x and other tasks (such as the rover project).

All of these can be countered. Firstly, rapid progress of projects is ultimately the best approach for success. Secondly, the need for a 3-year commitment is not onerous and allows costs to be spread over the 2-year development period, providing an opportunity to thoroughly pursue cost reductions. Finally, SAFMARS should not be seen as competing for resources (people and money) but will ultimately grow the available pool.

7.3 ALTERNATIVES AND TRADE-OFFS CONSIDERED

Only the simplest, most achievable and least expensive alternative is being proposed to meet the requirement. Inherent in this is the trade-off between capability and cost. SAFC does not provide a real-time, on demand service. SAFMARS does not seek to provide these capabilities, but will complement and enhance the use of augmented communications. It provides a system that is appropriate for the needs of the Mars Society.

8 APPENDIX – HAUGHTON MARS PROJECT

Much of the following has been extracted from [10].

8.1 THE PROJECT

Haughton crater is a relatively uneroded 23.4 million year old impact structure, located near the western end of Devon Island in the Canadian Arctic Archipelago; it is the highest-latitude terrestrial impact crater known (75°22' N, 89°41' W). The crater is approximately 800 kilometres north of the Arctic Circle and over 100 miles from the northernmost commercial airport on Earth, in Resolute.

In June 1997, the first field expedition of the Haughton Mars Project was undertaken. A brief chronology of the HMP follows:

1996. The National Research Council (NRC) of the US National Academy of Sciences and NASA Ames Research Center (ARC) approve a postdoctoral research proposal by Pascal Lee, a graduate student at Cornell University, to study the Haughton Crater site as a potential Mars analogue.

1997. Pascal Lee joins NASA ARC as an NRC Research Associate with Chris. P. McKay and A. Zent as advisers. An initial Haughton-Mars Project research team, HM-97, is formed. It includes researchers from NASA ARC and the Geological Survey of Canada. Four team members (Lee, Rice, Schutt, Zent) visit Haughton in August, 1997 and confirm the good potential of the site for Mars analogue studies.

1998. The scientific field work at Haughton is viewed as an opportunity to carry out additional research exploration technologies and strategies for future robotic and human missions to Mars. On HM-98, twenty-four team members from NASA ARC, JSC, KSC and several research institutions and universities in the US and Canada visit Haughton to do Science (geology, biology, remote-sensing) and Exploration Research (ground-penetrating radar surveys, field spectrometry, stereo camera tests, permafrost drilling, robotic helicopter tests, human exploration metrics). The National Geographic Society contributes a first grant to the program.

1999. The Haughton-Mars research program expands. On HM-99, forty team members from NASA, the Canadian Space Agency (CSA), the Russian Institute for Space Research (IKI), several other research institutions and universities in the US, Canada and the UK, the US Marine Corps, and the Mars Society join for research at Haughton Crater. After HM-99, NASA ARC formally establishes the NASA Haughton-Mars Project (HMP). Dr. Pascal Lee is Principal Investigator (P.I.). Dr. Kelly Snook (NASA ARC) is appointed HMP Project Manager.

The HMP Science programme seeks to:

1. Compare the Earth and Mars, in particular the many apparent similarities in geology between Devon Island and Mars, in order to understand better the geologic and environmental evolution of Mars, the history of water on Mars, the role of impacts on Mars, and the possible contexts for life on that planet.

2. Study the effects of meteorite impacts on the Earth, in particular their geological, environmental and biological effects, and how our planet recovers from such events.

3. Study life on Earth in the extreme polar environment of the high Arctic, in particular in the context of an impact crater, in order to understand better the adaptations and limits of life, its possibilities on other planets, the preservation and mode of exposure of biosignatures, and practical issues of planetary protection.

During the field season science reports will be available at times. Please check the individual disciplines for these reports.

The science area includes the following disciplines:

- Geology
- Biology
- Environmental Sciences

The HMP Exploration Research programme is currently divided into three main areas of research:

1. Information Systems (IS), in which studies are conducted to define, develop and test communications architectures and information systems that will enable humans and robots to explore Mars safely and effectively. Research in IS on the HMP includes studies in Human-Centered Computing (HCC) and the development of Mobile Exploration Technologies.

2. Robotics, in which robotic exploration technologies and strategies are investigated to support future robotic and human missions to Mars. Research in Robotics on the HMP includes field tests of robotic vehicles and components in anticipation of upcoming Mars exploration missions, the definition of the requirements of robotic systems for human Mars exploration support, and the deployment and evaluation of operational robotic systems in response to the exploration and survey needs of the HMP Science program.

3. Human Exploration, in which other aspects of field studies relevant to the human exploration of Mars are investigated. Research in Human Exploration includes the study of exploration logistics and operations

requirements, the planning and execution of field sorties and traverses, the definition of science protocols and instrumentation, the development and use of field gear (e.g., gloves, suits, tools, roving vehicles), the testing of field medical equipment and telemedicine experiments, the evaluation of exploration diets, the monitoring of human psychological factors, the simulation of exchanges with "Mission Control" incorporating time delays, etc.

8.2 FIELD REPORTS

Below are two HMP field reports, providing insight into the nature of the environment and operations:

Field Report, Thursday, July 6, 2000.

This is the first field report of the season. The first field members arrived at base camp Friday, June 30th. There were 11 of us to start. Our camp has since grown to 30 including five Marines. Due to poor weather conditions - including a windstorm with gusts up to 100kph - deployment was slower than expected. In addition, some of our supplies have had routing problems on their way to Haughton Crater. Our satellite communications links were established on Tuesday, July 4 at 23:24 PM CDT. The quality and bandwidth are exceptional considering where we are.

Yesterday was an extremely busy day as the United States Marine Corps paradroped supplies and gear in an operation that lasted much of the day. There was a lot of excitement as we watched the Marines fly two C-130 Hercules in formation and drop our supplies. (Video footage and pictures will be available tomorrow.)

During the course of the field season I'll be posting these daily reports along with as much video and pictures as I have time for. Of course, science is the primary reason we are here. As such, I will be posting reports from all the disciplines being studied. New sections to the site will be added as the season progresses.

Marc Boucher
HMP 2000 Webmaster

Field Report, Thursday, July 13, 2000.

HMP-2000 DAILY SUMMARY REPORT
Thursday, 13 July, 2000
by Pascal Lee, HMP PI.

Weather

The weather today was touch and go, with ceillings at or below 1000 ft, visibility between 0.5 and 10 miles, temperatures in the low 30s (+1°C) and winds in the 5-15 kts range, with snow flurries and occasional sleet showers.

Science and Exploration Research

Pascal, Charlie, Dr. Jeff and Terry left on a mid-morning traverse to collect soil core samples of the ancient lakebeds inside Haughton Crater and of the impact breccia rubble deposits on Wyle Hill, above Trinity Lake. They used spare soil coring augers from the Apollo program provided to the HMP c/o Dr. Jeff by co-Investigator Dr. David McKay of NASA JSC. Pascal, Charlie and Patrick later returned to Trinity Lake and to Wyle Hill to carry out additional surveys and sampling of the exposed breccia and to install a UV flux measurement package on the lake shore. Oz and Colleen continued their geologic surveys in the valley maze in the western part of the crater. They are finding very interesting fault features created when the crater itself was formed approximately 23 million years ago. Darlene, Marianne,Patrick and Margarita went to Cornell Lake and nearby Laval Lake and Astrobiology Funding Pond to sample their potential diatom records. Margarita ran the second webchat session of the HMP Education Program, starring Tony Griffith a.k.a. "Devon Ops" today. Steve put together new audio and video technology for the connection to Mission Control. Rick and Bruce set up their antenna array and checked out their newly-arrived NASA communications ATV. Tony coordinated the HMP field science team "replanning meeting" this evening and conducted a very succesful webchat simultaneously. Dr. Jeff and Terry programmed and delivered electronic Personal Information Carriers (PICs) to core field team members.

Life on Devon

John and Samson installed the camp water pump along the Lowell Canal, and also the water piping and hot water heater system. This now allows hot and cold running water to be available on demand in the kitchen in the SE end of St John's Cathedral. AC and Samson did carpentry and began putting together a washroom that will be adjacent to the kitchen. Marc C. found a website providing telephonic communications worldwide for free, which will make our lives a lot easier (and cheaper!) from now on. The Mars Society hab assembly team finished diassembling the aluminum platforms used in the paradrops. They were helped by Joannie and Joe. The pallet parts are being flown out to Resolute Bay and will eventually be recovered by the Marines. Two First Air Twin Otters brought in cargo and new visitors this evening. Our camp incinerator has now arrived, along with other anticipated payloads delivered by the Marines yesterday. Dr Kelly Snook, HMP Project Manager, visited the camp and Ozzie Courage from Resolute Bay examined the damaged equipment of the Mars Society Flashline Station project before they both returned to Resolute Bay. Dr. Jeff Jones, John Kunz and Dale Cameron also departed for Resolute. Newly arrived team members this evening include Lt. Col. George Martin, M.D., USAF (joining the HMP for the second year), Dr Rainer Effenhauser, M.D., flight surgeon at NASA JSC, Doug Butler, Biomedical Engineer at Wyle Labs, Sean Glenn, cameraman for the Discovery Channel USA team (and yes, he IS related to John!), and Ole Gjerstad and David de Yolpi from Discovery Channel Canada. Mark Webb cooked another great dinner: White Bean Tomato Soup, Tropical Chicken Teriyaki with white rice and peas, and Apricots in their syrup. Late this evening, celebrations were improvised to welcome our new visitors.

We are 31 people at camp tonight, including 27 HMP field team members: Rick Alena, Joe Amarualik, Marc Boucher, Doug Butler, Steve Braham, Charlie Cockell, Mark Connolly, Marianne Douglass, Rainer Effenhauser, Bruce Gilbaugh, Ole Gjerstad, Tony Griffith, Terry Guess, AC Hitch, Pascal Lee, Colleen Lenehan, Darlene Lim,, Margarita Marinova, George Martin, Samson Ootoovak, Gordon "Oz" Osinski, Joannie Pudluk, Sandy Salluviniq, John Schutt, Patrick Van Hove, Mark Webb, David de Yolpi.

4 Discovery Channel TV crew members: Tom Eichler, Sean Glenn, Andy Liebman, Karin Mainville.

8.3 EXPLORATION, INFORMATION SYSTEMS - HMP 2000

Human-Centered Computing Studies

To understand human life and work in extreme environments, ultimately in space, by ethnographic studies of field science and exploration at Haughton; to investigate collaboration and learning in the field, particularly through computer media, with special interest in improvisation, replanning, and repairs.

Tasks on HMP-2000: The HCC scientist will systematically investigate individual experiences by shadowing particular scientists in the field (in the work tent, on EVAs); observe and model field trials of human-robotic systems (e.g., tests of the robotic imaging hopper) ; continue to acquire a scientific video record of HMP activities. All data gathered will be exploited in the NASA JSC MOD Questlab study with emphasis on time-delayed monitoring and communication with other communities using the full resources of the internet and multimedia. Information to be collected will include field notes, photos, and short videos, likely organized into conceptual maps (Cmaps.)

The information will be sorted into raw (unreleasable) data, information sharable with colleagues of the expedition, information sharable with official scientific "back rooms", and information sharable with the public. Determining the categories and their definition is a central purpose of this study. The value of Cmaps for collecting and disseminating multimedia will also be assessed based on data collected over three field seasons of HMP activities. An effort will be made to evaluate the gap in mental maps between before field deployment and after.

Figure 9 Dr Bill Clancy lectures on Human Centred Computing at HMP, 1999

Mobile Exploration Technologies Studies

To systematically evaluate a variety of wireless field communications hardware and software architectures and systems, and their associated technologies, in support of science and exploration activities at Haughton; to define the requirements of similar operational systems in support of the human exploration of Mars.

Tasks on HMP-2000: Among a variety of tasks, the MEX scientists will deploy and test a variety of radio communications systems with a range of power, bandwidth and network configuration to support communications across Haughton Crater. A dedicated instrumented NASA ATV will serve as the primary mobile platform for the proposed field trials.

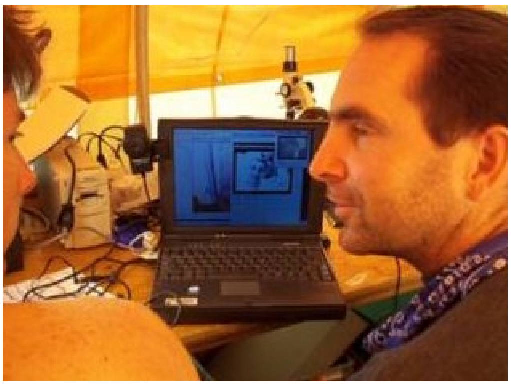


Figure 10 Telemedicine using the Mobile Exploration System, 1999

8.4 PARTICIPANT ORGANISATIONS

A list of HMP-2000 Supporting, Consulting, Collaborating, Licensing, or Participant Home Institutions follows:

Government Agencies

- NASA
- British Antarctic Survey (BAS)
- Canadian Space Agency (CSA)
- Communications Research Centre (CRC)
- Geological Survey of Canada (GSC)
- Indian and Northern Affairs Canada (DIAND)
- National Research Council (NRC)
- Nunavut Impact Review Board (NIRB)
- Nunavut Research Institute (NRI)
- Nunavut Water Board (NWB)
- Polar Continental Shelf Project (PCSP)
- Qikiqtani Inuit Association (QIA)
- United States Marine Corps

Research Institutions

- SETI Institute
- Carnegie Mellon University (CMU)
- Université Laval
- Massachusetts Institute of Technology (MIT)
- McGill University
- Simon Fraser University (SFU)
- Scripps Institution of Oceanography
- Stanford Genome Technology Center

- University of New Brunswick
- University of Toronto
- Yale University

Societies

- Mars Society
- National Geographic Society (NGS)

Corporations

- Apple
- Adobe Systems, Inc.
- aTerra Technologies, Inc.
- Campbell Scientific, Inc.
- Canon Canada, Inc.
- Floatograph, Inc.
- Kawasaki Motors, Inc.
- Komatik Designs
- Mountain Hard Wear, Inc.
- Pacific Storage Center, Inc.
- Salisbury & Assoc., Inc.
- Transplanetary Corporation
- Wi-Lan Ltd.

9 APPENDIX – MARS SOCIETY PROJECT WORK [14] [22]

The world's leading space agencies have been undertaking Mars analogue research in various locations and disciplines for several decades [24]. These efforts have often been motivated by the search for possible life in the Solar System, or by a desire to better understand the geophysical processes of our Blue Planet. Comparison often highlights unforeseen possibilities for geological, atmospheric and biological evolution, and our improved understanding of earth offers fresh insights into the planets.

Polar environments have proven of great interest, for example the McMurdo Dry Valleys in Antarctica and certain arctic islands in Canada. The Haughton-Mars Project (HMP) is a multidisciplinary investigation to study the Haughton crater on Devon Island, Territory of Nunavut, in the Canadian high arctic. HMP began in 1997 and has now become a collection of multidisciplinary research projects sponsored by NASA, NSF, and a number of research organisations (see Appendix – Haughton Mars Project).

Still, much remains to be learned of the challenges facing human missions to Mars. These will be the most remote expeditions ever undertaken, calling for significant crew autonomy. How will they cope? How can we best prepare them? For the foreseeable future, Earth-Mars transits will be voyages of opportunity. Chemically-propelled trips will last around 7 months each way, while crews will remain on the Martian surface for around 18 months. It is wise to make our mistakes here, before we leave, for there will be no turning back. Analogue research will only grow in importance as those first missions approach.

Negotiations between inaugural Mars Society President, Dr Robert Zubrin, and HMP culminated in 2000 with the commissioning of a fixed, flight-like human habitation module, F-MARS (Flashline Mars Analog Research Station, after the primary sponsor) within Haughton Crater. F-MARS was designed, deployed and is operated in close co-operation with HMP. It is made available for groups to undertake Mars analogue research.

In form, F-MARS is intended to represent the first kind of combined Entry, Descent and Landing (EDL) vehicle and habitat that might touch down on the surface of the Red Planet and shelter its human occupants. Two leading proposals for sending humans to Mars have employed a similar design [11] [26].

Figure 11 Mars-1 as-built during the 2000 campaign.

Shown above is the exterior layout of the Flashline Mars Arctic Research Station. The Station is 8.3 m in diameter and 8.45 m tall. The primary components of the station are twelve wall panels, each 6.1 m long and 2.17 m wide, and 12 dome sections converging on a 1 m diameter central node at the top. The Walls and domes are made of a unique weatherproof and superstrong fibreglass honeycomb that is 15 cm thick, but only weighs as much as 2.5 cm thick pine.

The structure is supported by 6 vertical steel legs, augmented against horizontal loads by 6 oblique steel legs. The structure has two decks, separated by 2.7 meters. The lower deck features two airlock ports, two windows, and a sample hatch. The upper deck features 4 windows. The living quarters and cooking area are upstairs, the laboratory, workshop, storages areas, EVA prep areas, bathroom, and airlocks are downstairs.

Note that an air drop failed during deployment and some of the structure (e.g. floors) have been improvised. The facility will be enhanced during the 2001 field season.

F-MARS also contributes to the broad public awareness objectives of the Mars Society. It helps make Mars more real for more people everywhere, via the Mars Society website (www.marssociety.org) and the media (e.g. Discovery Channel).

The facility is limited by accessibility. A brief two-month window in the northern summer is the only opportunity for air access, demanding rigorous and expensive planning and logistics. Therefore to take advantage of the special feature sets of other analogue environments, the Mars Society plans establishment of a worldwide network of Mars Analogue Research Stations, designated[4] throughout this document as:

- Mars-1 (F-MARS), Haughton crater, Devon Island, approximately 75°22' N, 89°41' W,
- Mars-2, a Mars-1 replica station to be sited in the South Western United States, possibly in 2001,
- Mars-Oz, a station to be located in the Australian outback as part of MSA Operation Red Centre, and
- Mars-Euro, a station to be located in Europe, possibly in Iceland.

[4] When all stations are complete, they would be numbered according commissioning order, i.e. Mars-1, Mars-2, Mars-3 and Mars-4.

10 APPENDIX – SATELLITE COMMUNICATIONS

Satellite communications have been a part of our lives since 1958 when US President Dwight Eisenhower delivered a Christmas greeting via the SCORE satellite. Geostationary satellites, first proposed by British science fiction writer Arthur C. Clarke in 1945, have provided the bulk of commercial and military orbital communications services. Geopolitical conditions during the Cold War, together with physical limits on space available for geostationary satellites, led to an overwhelming focus on larger, more powerful and more expensive communications systems.

Two broad counter-trends have emerged since the early 1980’s. First, electronic miniaturisation and digital communications research has paved the way for smaller subsystems, demonstrated the feasibility of more cost effective components and increased digital data rates. Second, educational institutions, small national space agencies, humanitarian organisations, amateur groups and start up companies are increasingly seeking to play a role in space by building and deploying small “micro” satellites using launch payload space that could otherwise be wasted.

GEO orbits have the benefit of a perpetual ground footprint. Portable, fixed-pointing ground dishes within the footprint can provide high bandwidth duplex connections for users. However, high-energy Geostationary Transfer Orbit (GTO) launches are expensive, and the infrastructure required for economic viability is extensive (large satellites, continual station keeping etc.). GEO systems are not the most effective or efficient way of providing communications to users with lower level needs.

GEO and Low Earth Orbiting (LEO) constellations are gradually providing more accessible private global voice and data communications (Table 2). Nevertheless, capital investments are significant and must compete with increasingly more attractive surface and submarine systems. The growth of such satellite services is good news for remote communications. Yet while many users could potentially benefit, the value of the remote market is small (mostly poor developing nations, exploration companies and scientific fieldworkers) and cost reductions are likely to be slow.

Service	Area of Service	Service Cost	Data Speed	Hardware Cost	Hardware Type	Time Line	Satellite
Currently available services:							
Globalstar **www.globalstar.com**	N. America, Australia, Europe, parts of L. America, Carrib. N. Africa, China	About $2 /minute (US to US) . $2.50 + all other countries	None at this time. Up to 9600 bps planned by the end of 2000.	Starting at about $1,200.	Small handheld and fixed units multi-mode cellular and Satellite -	Launched early 2000, Plan to extend coverage extensively by the end of 2000. See map.	48 LEO satellites
Inmarsat Mini-m **www.Inmarsat.org**	Global	From $2.15 / min	2400 bps	$2,600 - $3,000	Notebook size terminal with flat, directional ant. Voice/fax/data	No changes in service foreseen	4 GEO Satellites
Inmarsat - M4 **www.Inmarsat.org**	Global	From $7.00 / min	64,000 bps	$9,000 -$11,000	Notebook size terminal with larger flat, directional ant. Voice/fax/data	Launched early 2000, growing market for service.	4 GEO Satellites
Motient (Skycell) **www.motient.com**	North America, Caribbean, Central America	$2 – $2.50 /min plus long distance fees.	1200 bps – 4800 bps	$1,800 to $4,000	Notebook size terminals (mobile, marine, fixed site)	No Changes in service foreseen	2 GEO Satellites
Services, not yet available							
AceS **www. acesinternational .com/**	Asia	About $1/ Min	2400 bps	$1,300 - $1,500	Small hand held dual gms/satellite	Commercial Launch Fall 2000. Beta units tested and functional.	1 GEO Satellite.
Ellipso **www.ellipso.com**	Global	Less than $1 / minute.	300 to 9600 bps	$1,000 -$2000 depending on type of terminal	Hand held, mobile, and fixed terminals.	Operation is scheduled for early 2002	17 MEO satellites
ICO **www.ico.com**	Global	Less than $1 / min.	?	?	Small hand held dual gms/satellite	Recently bailed out of bankruptcy and merged with Teledesic. Service launch planned for 2003	10 MEO satellites
Thuraya **www.thuraya.com**	India, Central Asia, Middle East, Europe, North and Central Africa	Less than $1 / minute.	2400 bps – 9600 bps	?	Hand held Dual-mode satellite and GSM mobile phone	Planned launch of first Satellite in May 2000. Service beginning September 2000.	2 GEO satellites.

Table 2 Comparison of commercial global communications services (all US$) [15].

LEO “store and forward” communications (SAFC), whereby users within a small, moving satellite footprint can transmit and receive messages and data via onboard satellite handling and storage, provides an alternative to these systems. According to Table 2, the cost of uploading a 500 Kb email message via a laptop modem and a Globalstar phone to anywhere in the world, at US$2.50 per minute, is around US$17 [5]. A SAFC satellite in polar orbit could upload the same message (although with an assured delay until receipt of at least 2 – 6 hours) for a total system unit cost of less than US$0.14 [25] [6]. Thus a low-level service satisfying the needs of many, and particularly the special requirements of the Mars Society, can be provided for less than 1/100th the cost.

This concept was first proposed in 1957 [21], and implemented on the COURIER satellite in 1960 using on board tape recorders. It has evolved over three decades by the merging of microsatellite and digital packet radio technology.

Microsatellites were pioneered by the Amateur Satellite (AMSAT) organisation using donated ancillary payload opportunities. The first Orbiting Satellite Carrying Amateur Radio, OSCAR-1, was launched on December 12th 1961 and operated for 20 days (non-rechargeable batteries supplied power). It's 100 mW transmitter sent "HI" in Morse Code at 144 MHz, as well as information on the internal temperature of the satellite.

Surrey University in the United Kingdom has become a well-known centre of microsatellite development. Building on the advocacy of an academic staff member who recognised the educational value of microsatellite design, construction and operation, the Surrey Satellite Technology Limited (SSTL) spin-off now exports microsatellites around the world.

A typical microsatellite (AMSAT-NA) is cubic, consists of a stack of payload trays and weighs around 15 kg. Solar panels are used to recharge a battery, and attitude control is generally passive via alignment with earth’s magnetic field for maximum simplicity. With impetus provided by organisations such as NASA embracing a “faster, better, cheaper,” philosophy, development in this class of satellites is likely to progress more rapidly. We are already seeing microsatellite and nanosatellites of increasing sophistication, with three axis stabilisation, integral propulsion and more capable on board processing and data handling.

A digital SAFC transponder was first flown on the UoSAT-2 microsatellite in 1984 sponsored by VITA (Volunteers in Technical Assistance) and AMSAT, soon followed by a similar US military experiment on GLOMR in 1985. This led to subsequent SAFC satellites in the same SSTL series [21]. UoSAT-3 was launched in 1990, and became HealthSat-1 in 1991, followed by

[5] 500 kilobytes $\approx 500 \times 8$ kilobits, and @ 9.6 kbps, the message upload takes around 7 minutes. Delay between upload and receipt of the message is unknown and is not included here.

[6] Based on a SSTL unit total cost estimate of US$0.02 per minute, at the same baud rate. Note also that the pass window duration (10-13 minutes) limits message sizes.

procurement of HealthSat-2 from SSTL by the US medical aid organisation SatelLife in 1992.

The SatelLife SAFC satellite and ground stations, based initially on Healthsat-1 and now on the successor Healthsat-2, forms part of its HealthNet low cost global communications network. This illustrates the kind of system available for the Mars Society to support and extend Mars analogue research activities.

HealthSat-2 is capable of full-duplex SAFC communication at 9.6 kbps (a typical domestic PC modem currently operates up to 56 kbps). Its polar orbit allows communication with ground stations several times a day anywhere in the world. Stations near the equator acquire the satellite four times a day. Each acquisition or "pass window" lasts for about 13 minutes. At any given time, the satellite is visible to ground stations within a footprint of 6,000 km diameter. The analysis of section 4.3 uses the orbit of Healthsat-1.

HealthSat-2 has one downlink and two uplink communication channels. Several users can request messages from the satellite at any given time, and isolated users co-located within the footprint can relay messages in real-time during the pass window.

Two types of ground stations are employed for remote locations. The first is a terminal capable of serving several users via a single computer, and runs WiSP (Windows Satellite Program) software developed by SSTL. The second type is a network ground station capable of serving several users on a Local Area Network (LAN). SatelLife developed all the software for its satellite gateway operations and network ground stations using the Linux operating system. Ground equipment consists of an IBM-PC compatible computer, a Terminal Node Controller (TNC), a satellite radio, and antennas.

For the user, the HealthNet software is similar to any offline email read/write package. It permits messages to be addressed to internet destinations, or to any other HealthNet user. Binary files may be attached to messages or transferred by separate file request. All routing and delivering is transparent to the user.

11 APPENDIX – STK SAFMARS SIMULATION

08 Feb 2001 12:49:48
Access Summary Report

UOSAT_3-To-Mars-1

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
	1	21 Jan 2001 01:03:12.39	21 Jan 2001 01:13:46.05	633.653
	2	21 Jan 2001 02:43:12.60	21 Jan 2001 02:53:31.85	619.253
	3	21 Jan 2001 04:24:33.05	21 Jan 2001 04:33:21.58	528.536
	4	21 Jan 2001 06:07:47.50	21 Jan 2001 06:12:51.55	304.049
	5	21 Jan 2001 12:57:55.69	21 Jan 2001 13:02:03.69	248.008
	6	21 Jan 2001 14:37:15.69	21 Jan 2001 14:45:42.49	506.797
	7	21 Jan 2001 16:17:04.81	21 Jan 2001 16:27:17.31	612.501
	8	21 Jan 2001 17:56:52.06	21 Jan 2001 18:07:27.70	635.639
	9	21 Jan 2001 19:36:25.96	21 Jan 2001 19:46:42.71	616.753
	10	21 Jan 2001 21:15:38.77	21 Jan 2001 21:25:36.58	597.809
	11	21 Jan 2001 22:54:34.10	21 Jan 2001 23:04:39.80	605.699
Global Statistics				
Min Duration	5	21 Jan 2001 12:57:55.69	21 Jan 2001 13:02:03.69	248.008
Max Duration	8	21 Jan 2001 17:56:52.06	21 Jan 2001 18:07:27.70	635.639
Mean Duration				537.154
Total Duration				5908.696

UOSAT_3-To-Mars-2

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
	1	21 Jan 2001 04:13:49.97	21 Jan 2001 04:23:10.36	560.390
	2	21 Jan 2001 05:53:50.48	21 Jan 2001 06:02:09.00	498.525
	3	21 Jan 2001 16:30:44.17	21 Jan 2001 16:37:15.89	391.718
	4	21 Jan 2001 18:08:40.35	21 Jan 2001 18:18:44.33	603.981
Global Statistics				
Min Duration	3	21 Jan 2001 16:30:44.17	21 Jan 2001 16:37:15.89	391.718
Max Duration	4	21 Jan 2001 18:08:40.35	21 Jan 2001 18:18:44.33	603.981
Mean Duration				513.653
Total Duration				2054.614

UOSAT_3-To-Mars-Euro

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
	1	21 Jan 2001 09:38:53.61	21 Jan 2001 09:45:40.24	406.629
	2	21 Jan 2001 11:17:46.47	21 Jan 2001 11:28:08.02	621.552
	3	21 Jan 2001 12:57:27.36	21 Jan 2001 13:07:33.69	606.329
	4	21 Jan 2001 14:37:12.55	21 Jan 2001 14:45:02.59	470.035
	5	21 Jan 2001 16:16:24.45	21 Jan 2001 16:21:46.60	322.146
	6	21 Jan 2001 17:53:52.80	21 Jan 2001 17:59:52.09	359.294
	7	21 Jan 2001 19:30:39.77	21 Jan 2001 19:39:21.45	521.675
	8	21 Jan 2001 21:08:41.19	21 Jan 2001 21:19:08.05	626.865
	9	21 Jan 2001 22:48:56.23	21 Jan 2001 22:58:41.01	584.780
Global Statistics				
Min Duration	5	21 Jan 2001 16:16:24.45	21 Jan 2001 16:21:46.60	322.146
Max Duration	8	21 Jan 2001 21:08:41.19	21 Jan 2001 21:19:08.05	626.865
Mean Duration				502.145
Total Duration				4519.305

UOSAT_3-To-Mars-Oz

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
	1	21 Jan 2001 00:00:00.00	21 Jan 2001 00:09:52.44	592.440
	2	21 Jan 2001 12:18:11.25	21 Jan 2001 12:28:22.61	611.361
	3	21 Jan 2001 13:59:41.66	21 Jan 2001 14:04:48.20	306.539
	4	21 Jan 2001 23:30:07.97	21 Jan 2001 23:40:00.69	592.718
Global Statistics				
Min Duration	3	21 Jan 2001 13:59:41.66	21 Jan 2001 14:04:48.20	306.539
Max Duration	2	21 Jan 2001 12:18:11.25	21 Jan 2001 12:28:22.61	611.361
Mean Duration				525.765
Total Duration				2103.059

UOSAT_3-To-Site-Birdsville

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
	1	21 Jan 2001 00:00:00.00	21 Jan 2001 00:08:49.37	529.373
	2	21 Jan 2001 12:19:20.54	21 Jan 2001 12:29:29.94	609.401
	3	21 Jan 2001 14:01:14.75	21 Jan 2001 14:05:31.40	256.652
	4	21 Jan 2001 23:29:22.79	21 Jan 2001 23:38:47.54	564.753

Global Statistics

Min Duration	3	21 Jan 2001 14:01:14.75	21 Jan 2001 14:05:31.40	256.652
Max Duration	2	21 Jan 2001 12:19:20.54	21 Jan 2001 12:29:29.94	609.401
Mean Duration				490.045
Total Duration				1960.179

UOSAT_3-To-Site-Cooper_Pedy

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
1	21 Jan 2001 00:00:00.00	21 Jan 2001 00:09:44.65	584.645
2	21 Jan 2001 01:42:05.49	21 Jan 2001 01:46:35.32	269.832
3	21 Jan 2001 12:19:03.56	21 Jan 2001 12:28:27.43	563.864
4	21 Jan 2001 13:59:08.22	21 Jan 2001 14:06:47.80	459.578
5	21 Jan 2001 23:30:51.66	21 Jan 2001 23:39:30.07	518.411

Global Statistics

Min Duration	2	21 Jan 2001 01:42:05.49	21 Jan 2001 01:46:35.32	269.832
Max Duration	1	21 Jan 2001 00:00:00.00	21 Jan 2001 00:09:44.65	584.645
Mean Duration				479.266
Total Duration				2396.330

UOSAT_3-To-Site-McMurdo

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
1	21 Jan 2001 00:14:53.29	21 Jan 2001 00:23:32.42	519.126
2	21 Jan 2001 01:56:54.64	21 Jan 2001 02:04:06.64	431.994
3	21 Jan 2001 03:39:09.68	21 Jan 2001 03:45:05.98	356.301
4	21 Jan 2001 05:20:59.99	21 Jan 2001 05:26:46.71	346.726
5	21 Jan 2001 07:02:07.30	21 Jan 2001 07:08:59.58	412.280
6	21 Jan 2001 08:42:45.79	21 Jan 2001 08:51:06.47	500.680
7	21 Jan 2001 10:23:08.25	21 Jan 2001 10:32:40.61	572.365
8	21 Jan 2001 12:03:19.22	21 Jan 2001 12:13:34.36	615.137
9	21 Jan 2001 13:43:19.72	21 Jan 2001 13:53:52.61	632.897
10	21 Jan 2001 15:23:10.61	21 Jan 2001 15:33:47.32	636.712
11	21 Jan 2001 17:02:55.65	21 Jan 2001 17:13:32.56	636.914
12	21 Jan 2001 18:42:43.69	21 Jan 2001 18:53:19.77	636.084
13	21 Jan 2001 20:22:47.98	21 Jan 2001 20:33:15.17	627.184
14	21 Jan 2001 22:03:22.23	21 Jan 2001 22:13:20.74	598.508
15	21 Jan 2001 23:44:35.58	21 Jan 2001 23:53:37.04	541.467

Global Statistics

Min Duration	4	21 Jan 2001 05:20:59.99	21 Jan 2001 05:26:46.71	346.726
Max Duration	11	21 Jan 2001 17:02:55.65	21 Jan 2001 17:13:32.56	636.914
Mean Duration				537.625
Total Duration				8064.374

UOSAT_3-To-Site-Sandy_Desert

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
1	21 Jan 2001 00:00:09.20	21 Jan 2001 00:05:54.57	345.375
2	21 Jan 2001 01:37:14.42	21 Jan 2001 01:46:59.93	585.510
3	21 Jan 2001 12:23:59.89	21 Jan 2001 12:29:18.22	318.324
4	21 Jan 2001 14:01:16.09	21 Jan 2001 14:10:56.77	580.683

Global Statistics

Min Duration	3	21 Jan 2001 12:23:59.89	21 Jan 2001 12:29:18.22	318.324
Max Duration	2	21 Jan 2001 01:37:14.42	21 Jan 2001 01:46:59.93	585.510
Mean Duration				457.473
Total Duration				1829.892

UOSAT_3-To-Site-Tunisia

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
1	21 Jan 2001 08:08:00.81	21 Jan 2001 08:14:02.84	362.035
2	21 Jan 2001 09:45:41.03	21 Jan 2001 09:55:46.06	605.034
3	21 Jan 2001 19:22:10.16	21 Jan 2001 19:28:05.36	355.201
4	21 Jan 2001 20:59:02.58	21 Jan 2001 21:09:12.69	610.109

Global Statistics

Min Duration	3	21 Jan 2001 19:22:10.16	21 Jan 2001 19:28:05.36	355.201
Max Duration	4	21 Jan 2001 20:59:02.58	21 Jan 2001 21:09:12.69	610.109
Mean Duration				483.095
Total Duration				1932.378

UOSAT_3-To-Station-Brisbane

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
1	21 Jan 2001 00:00:00.00	21 Jan 2001 00:07:52.43	472.435
2	21 Jan 2001 10:40:11.38	21 Jan 2001 10:46:54.34	402.959
3	21 Jan 2001 12:18:15.57	21 Jan 2001 12:27:53.56	577.985
4	21 Jan 2001 21:52:30.04	21 Jan 2001 21:57:11.29	281.254

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
	5	21 Jan 2001 23:28:40.80	21 Jan 2001 23:38:55.16	614.354

Global Statistics

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
Min Duration	4	21 Jan 2001 21:52:30.04	21 Jan 2001 21:57:11.29	281.254
Max Duration	5	21 Jan 2001 23:28:40.80	21 Jan 2001 23:38:55.16	614.354
Mean Duration				469.797
Total Duration				2348.987

UOSAT_3-To-Station-Germany

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
1	21 Jan 2001 08:02:20.02	21 Jan 2001 08:08:31.62	371.601
2	21 Jan 2001 09:40:25.13	21 Jan 2001 09:50:57.96	632.832
3	21 Jan 2001 11:20:54.90	21 Jan 2001 11:28:13.64	438.737
4	21 Jan 2001 19:25:03.76	21 Jan 2001 19:34:42.00	578.236
5	21 Jan 2001 21:04:30.97	21 Jan 2001 21:14:17.04	586.071

Global Statistics

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
Min Duration	1	21 Jan 2001 08:02:20.02	21 Jan 2001 08:08:31.62	371.601
Max Duration	2	21 Jan 2001 09:40:25.13	21 Jan 2001 09:50:57.96	632.832
Mean Duration				521.495
Total Duration				2607.477

UOSAT_3-To-Station-Oslo

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
1	21 Jan 2001 07:59:40.28	21 Jan 2001 08:06:28.24	407.958
2	21 Jan 2001 09:38:17.37	21 Jan 2001 09:48:48.22	630.848
3	21 Jan 2001 11:18:08.70	21 Jan 2001 11:27:25.32	556.615
4	21 Jan 2001 12:58:48.43	21 Jan 2001 13:03:04.54	256.109
5	21 Jan 2001 17:49:38.13	21 Jan 2001 17:56:47.92	429.786
6	21 Jan 2001 19:26:43.11	21 Jan 2001 19:37:00.12	617.008
7	21 Jan 2001 21:06:50.91	21 Jan 2001 21:16:28.23	577.318

Global Statistics

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
Min Duration	4	21 Jan 2001 12:58:48.43	21 Jan 2001 13:03:04.54	256.109
Max Duration	2	21 Jan 2001 09:38:17.37	21 Jan 2001 09:48:48.22	630.848
Mean Duration				496.520
Total Duration				3475.642

UOSAT_3-To-Station-Perth

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
1	21 Jan 2001 01:40:53.64	21 Jan 2001 01:51:23.34	629.696
2	21 Jan 2001 13:58:05.37	21 Jan 2001 14:08:14.55	609.185
3	21 Jan 2001 15:39:08.82	21 Jan 2001 15:45:12.19	363.371

Global Statistics

	Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)
Min Duration	3	21 Jan 2001 15:39:08.82	21 Jan 2001 15:45:12.19	363.371
Max Duration	1	21 Jan 2001 01:40:53.64	21 Jan 2001 01:51:23.34	629.696
Mean Duration				534.084
Total Duration				1602.252