

# IAA Mars Cosmic Study Report

## Executive Summary

### Chapter 1 – Introduction

The journey to Mars is discussed in this IAA Mars Cosmic Study. The time has now come to lay plans for an intensified international robotic exploration of Mars, leading to an International Human Mars Exploration Project. It is the purpose of this Mars Cosmic Study to review the background for such an international robotic/human Mars program and to press for action. The advancement of knowledge, including the further unraveling of the mysteries of the cosmos, is a human endeavor, yielding to those willing to invest appropriate intellectual and physical resources. Resultant discoveries enter the repository of human understanding, benefiting all inhabitants of the planet. As space exploration has matured, the scientific community has become more international in its collaborations, and political constraints are viewed more and more as impediments to progress. The explosive growth of space activities, previously driven by political competition, is now beginning to react to economics.

The IAA position is that an international project of expanded robotic and human space exploration of Mars can provide a vision of new beginnings with fresh perspectives. Robotic spacecraft generally have acquired data according to the preprogrammed expectations of their creators. This limitation will change with future automated spacecraft, but currently only a human space explorer can acquire knowledge through creative, real-time organization of information, while also learning to live and work in space. The cost of human exploration of Mars raises questions of cost/benefit. Mars offers a rich menu of scientific exploration opportunities, but the potential cost of human Mars exploration demands more than just science return. Human Mars exploration would teach us how to create small, self-sufficient, closed-cycle biospheres. The resulting knowledge and technology will help us protect Earth's natural biosphere.

The benefits, especially the cultural ones, are best realized by an international program. It is up to us to find a mission architecture and pace of development for a feasible international program that does not too strongly compete with Earthly needs for scarce resources. If the program uses existing aerospace facilities and personnel resources, e.g., surplus resources from declining military programs, and spreads the costs internationally, then additional resource costs may be affordable. Participation in such a program at an appropriate level will also help developing countries create technological and industrial infrastructures capable of enhancing worldwide sustainable economic growth.

We are confident that we can extend our capabilities to human interplanetary journeys. Such voyages of discovery can be undertaken before we fully understand the long-term response of a human being to the environment present in the crew quarters of the space habitat, but at some risk to the crew. We shall gain a significant amount of data regarding human adaptation to microgravity and isolation on long space missions such as a human mission to Mars. We shall also learn to design and build-in true long-term reliability of our mechanical and electronic systems.

## Chapter 2 - Why Mars?

Mars, the next planet out from the Sun beyond the Earth, although cold and wind-swept, is still the most Earth-like of all the other Solar System planets. On its surface are huge volcanoes, deep canyons, vast flood channels, and extensive sand seas. The diameter of Mars is a little over half that of the Earth and gravity at the surface of Mars is .38 that of the Earth. The atmosphere is thin and consists mostly of carbon dioxide. The pressure at the surface is about 1/100 that at the Earth's surface, and it changes with the Martian season as part of the carbon dioxide in the atmosphere freezes out on the pole to form a polar ice cap during winter. At the equator, surface temperatures range from about  $-90^{\circ}\text{C}$  at night to  $+20^{\circ}\text{C}$  at noon, overlapping temperature conditions found on Earth. On the carbon dioxide polar caps, temperatures can drop to  $-120^{\circ}\text{C}$ . It is of great scientific importance to explore, document, and analyze the processes that have turned Mars into a barren, inhospitable domain.

Some space scientists believe that all Mars resource expenditures should be confined to robotic exploration of Mars, at least through the first half of the 21st Century, and that to implement a human expedition to Mars would be too costly. They believe that a human expedition would severely drain funds and "starve" research efforts in robotic space exploration, aeronautics, basic science research, and industrial research. Others feel that space exploration for science alone is too narrow a goal. They believe that human progress overall would be stimulated and even scientific and basic research objectives would be attained faster if a mix of robotic and human space exploration is performed in parallel. Humanity reveres and supports science, but society also values exploratory journeys of the human spirit. The point of view of this Mars Cosmic Study Report is that an international program of automated Mars probes and precursors in parallel with human missions to Mars will best serve humanity.

Mars has special significance for what it may reveal about the origin and evolution of Earth-like planets and the origin of life. Although Mars is compositionally similar to the Earth, it has evolved quite differently. While the Earth is a fertile, tectonically and volcanically active planet, Mars evolved into a frigid, relatively inactive and sterile body. Why did the two planets evolve so differently? Part of the answer will come from further intense studies of the Earth. But such studies should be accompanied by complementary intense studies of Mars.

Because of the implications for life and global change on the Earth, the climatic history of Mars is of particular interest. Liquid water cannot exist on the surface of the present-day Mars. Surface conditions are such that it will freeze or sublime. Yet ancient surface features show abundant evidence of water erosion. Orbiter pictures of the surface show numerous ancient, branching dry river valleys, seemingly cut by running water. The valleys attest to both the abundance of water during those former times, and to climatic conditions that permitted liquid water to flow across the surface. What were the climatic conditions during those times and why did the climate change? If conditions on Mars were similar to the early Earth, did life arise on Mars as well?

Few scientific questions, such as whether life ever existed on Mars, will be answered by one simple experiment. Only by addressing a range of interrelated geological,

atmospheric and biological issues will the major questions ultimately be resolved. Some of the principal research areas are the following:

#### Composition and internal structure

The level of our current knowledge of Mars is quite primitive. For example, we do not know the mineralogy or chemical composition of its principal rock types, and thus we do not know the planet's bulk composition.

#### Geological evolution and ages

The relative chronology of Mars' major surface features is known in a general way; however, absolute ages can only be gained through the analysis of samples.

#### External processes

The Mars system (including Phobos and Deimos) was bombarded throughout geological time by the same population of meteoroids and the same radiation environment encountered by the Moon and Earth. What were the specific effects for Mars?

#### Composition and dynamics of the atmosphere

The Mars atmosphere, although much thinner than the Earth's, is a natural planetary laboratory in which to test models of atmospheric processes that are applicable to Earth.

#### Water in Martian history

Mars is of great interest because it exhibits evidence of past surface water and this hints at Mars having had different atmospheric conditions in the past than today. We have much speculation, but little hard evidence, pertaining to questions such as the relative roles of water erosion, mass wasting (landslides), wind erosion and wind deposition.

#### Existence of past or present life on Mars

Perhaps the most important single question that can be asked about Mars is, "Did life ever exist there?" The past existence of life on Mars is made plausible by the evidence of water in early epochs. And, if life got a foothold on Mars in its early history, there is a possibility that life exists now, perhaps in some energy-rich environment, protected from the oxidizing effect of the current surface environment. Volcanic fumaroles or warm brines that may exist below permafrost zones are commonly cited as potential life-supporting habitats. The success of strategies for discovering evidence for past or present life on Mars depends significantly on our ability to control the contamination of Mars by terrestrial biological materials, which could confuse the interpretation of sample analyses. The fate of terrestrial organic material introduced into the Mars environment must be understood early in the exploration program.

Mars is the only planet beyond the Earth-Moon system where permanent settlement seems remotely feasible. One of the primary objectives of early Mars exploration should be to determine how practical human settlement really is. Although Mars is more hospitable than any planetary body other than the Earth, it is still very inhospitable. The atmosphere is too thin and of the wrong composition to sustain humans, radiation levels are high, temperatures are low, and the availability of water and other resources are unknown. Early expeditions to the planet should, therefore, include among their goals an assessment of usable resources such as water, oxygen, building materials and thermal energy. A Mars base (or long-term outpost) may

require growing food on Mars. Various means of growing food on Mars must therefore be assessed.

It is not possible to foresee in advance exactly what the scientific return from Mars exploration will be. It is because we know so little about Mars that its scientific exploration is so interesting. Each successive automated Mars mission has shown new surprises. Challenging projects, such as a Mars exploration mission, also become vehicles for technology development and demonstration. Robotic missions to Mars must develop greater autonomous capability. Human missions must perform well for time durations that are significantly longer and more demanding than any previous human space flights. Accomplishing these missions can be the focus of sustained interest and investment in technological advancement, thereby providing motivation for humans to excel in technical fields.

Among the more important challenges that will drive technological advancement and that can produce benefits on Earth are: propulsion and power; human health and adaptation; life support system development, resource utilization, and ecological technologies; increased reliability and lifetime of hardware and systems; automation and robotics; and improvements in new sensors.

Historically, the lack of perspective and challenge in societies often resulted in their stagnation and dissolution. An important characteristic of healthy societies has been the stimulation of innovative ideas to fulfill a challenging vision. Education should involve not merely the acquisition of skills, but an increase in perspective and the elevation of the human spirit. The prospect of the spreading of civilization into the cosmos offers humanity the superb opportunity to achieve continuance, expansion, prosperity and knowledge. Large national challenges such as undertaking space programs and increasing educational opportunities are positively linked historically.

### **Chapter 3 - Why International?**

An International Mars Exploration Program, including human missions, is the next step in a series of what has been mostly nationalistic explorations that began in low Earth orbit, sent humans to the Moon, and sent robotic probes to the farthest reaches of the Solar System. An ambitious robotic Mars program is already underway, based on national programs, but with international contributions. Europe, Russia, Japan, and the United States all have, or intend to have, robotic Mars exploration programs. Most will feature a degree of international cooperation.

This document urges the extension of this cooperative international robotics program into a formal International Mars Exploration Program which includes human missions. Past and current studies show that human missions will involve major technological and life support problems, and will require significantly increased resources. Because of the magnitude of this undertaking, coupled with the current geopolitical world situation, humanity should seriously consider making such an extension in a primarily international, rather than primarily national, context.

The rationale for an international context for a Mars Exploration Program is based on philosophical, technological, financial, scientific, and educational factors. All nations stand to gain from participation in the development of fundamentally new technologies. A Mars Program can be so designed that access to knowledge and technology spin-offs is readily available for those nations currently possessing lesser technological capability. Also, when the funds come from several countries, the

multiplicity of supporters can sustain the program cash flows through a difficult economic or political period experienced by one individual supporter. Global markets historically emerge for the aerospace products of each participating country.

The Mars Program can have a major impact on education. The training of additional professors, scientists, engineers, and technologists is both necessary to provide the technical depth for a Mars Program, and will be the byproduct of its undertaking. Since education is fundamental to the rise of civilizations and the increase of standards of living, the contributions of the Mars Program to education are among the primary reasons why it should be undertaken.

There are a number of significant challenges that must be overcome if the vision is to be accomplished. The Mars Program may be the most ambitious single peacetime technical project ever undertaken by humanity. Quite apart from the technical challenges that must be solved, a Mars Exploration Program with many nations as participants must nonetheless be managed as an integrated whole. There are a number of models that could be candidates for setting up the required management structure, including some adaptation of the management functional structure of the U.N., ESA, Intelsat, NATO, International Space Station (ISS), Antarctic Base, and others.

The financing of the Mars exploration program will be the next greatest challenge to be faced. To a great extent, the mechanism for obtaining the funds will depend on the management structure chosen. Consideration will also have to be given to the developing nations. The intent of making the Mars program truly global will have to be balanced against each country's ability to fund its share of the enterprise. Thus the question of some developing nations providing funds versus providing contributed value (such as headquarters sites, launch sites, tracking/communications sites, materials, or human resources) could become important.

Sharing control is a sensitive issue that cuts to the heart of the viability of any international venture. To participate in any international program, each participant must give up some of the management control it normally exercises over its national programs.

A number of benefits would be expected to accrue from an international Mars exploration program. History teaches that the cost of the program's share to any one nation can be smaller, particularly if the program has strong management lines of control. One of the chief benefits of its existence would be the effect on world stability. Historically, programs which involve major international commitments have proved more resistant to adverse political pressures within the undertaking nations. A case can usually be made that space programs brought more long-term return to their nation's economy in the form of goods and services in all industries and sectors than was actually expended on them, with return-on-investment ratios near 7:1, or higher.

There are several reasons why the exploration of Mars is important at this point in the history of the world. These include our perception of the need of the world to have positive beneficial goals that bind nations together, thus creating capabilities to address global technological, economic and environmental problems. Many nations must deal with the problems of converting armament industries to peaceful uses, while retaining technical expertise both for future commercial benefit and for maintaining national defense capability. The wide range of systems and technologies

required for Mars exploration, including electronics, power, automation, robotics, materials, propulsion, life support, and others, are among the most productive for national technological advancement.

#### **Chapter 4 - Mars Automated Missions And Precursors**

A great deal of information has already been obtained from the Mariner, Mars, Viking and Phobos spacecraft, but it is necessary to extend those findings to answer new questions in planetary science, comparative planetology and cosmology, and to allow the formulation of a detailed scientific basis for future human flights.

Robotic missions should continue to improve our scientific understanding of Mars and to demonstrate new robotic technology. Scientific robotic missions should be continued even after human landing on Mars. However, robotics can also be used for testing and verification of the human spacecraft systems and other relevant hardware, for development of the strategy and scenario of the initial human mission phase, and for preliminary logistics of cargo delivery. From this point of view, they can be considered as precursors for future human flights to Mars.

The automated missions should collect the basic information in the disciplines of Martian geology, geochemistry, atmospheric sciences, climatology, and exobiology, etc., but also data on the performance of the engineering subsystems. The precursor missions can be the backbone of a Mars scientific program, and in their development of robotic technologies, can complement future human exploration. The automated missions can help in landing site selection and site preparation for human exploration and can be an important part of the human Mars mission development program. Their dual role is not only desirable, but essential to ensure that the effort and expense of getting to Mars yields valuable scientific results and reduces the risk and cost of human exploration. Robotic precursor missions can also establish the degree to which human presence is a requirement for a more efficient and elaborate study of Mars, and what role automation might be called upon to play in assisting human exploration.

#### **Chapter 5 - Options for Human Expeditions to Mars**

Once a crew-carrying Mars ship is in Earth orbit and ready to be launched towards Mars, the sequence is straightforward: interplanetary transfer to Mars, capture in Mars orbit; direct descent to the surface using a lander; surface mission operations; ascent to Mars orbit; possible rendezvous with an orbiting ship; interplanetary transfer back to Earth; capture in Earth orbit; and finally, Earth landing. An automated mission, if it returns a sample to Earth, generally follows the same sequence. If an automated Mars surface mission does not return to Earth, then the sequence ends with the Mars surface mission, just as it did for the Viking spacecraft.

While the basic mission sequence is simple enough, the complexity arises from the choice of mission profile and the choice of interplanetary propulsion system(s). There are two basic mission profiles - a slow, minimum energy transfer; and a much more costly (in terms of propellant required) high energy "fast" transfer, each of which again has several variations. The selection of a mission profile hinges on the selection of a propulsion system or systems. There are currently three propulsion options potentially available to the designer: chemical rockets, nuclear thermal rockets, and electric engines using nuclear or solar power. Of these, only chemical rockets have been safely demonstrated for human missions. Aerobraking and aerocapture into

planetary orbit, after an interplanetary trip, can be used with any of these options, adding further choices.

Selection of technical alternatives for missions to Mars must respond to a set of constraints and objectives collectively called "mission drivers." Deciding on the mission and system design is a compromise among conflicting requirements and desires. Engineers must make trade-offs between competing performance requirements. Failure to carefully define priorities between these requirements only leads to potentially harmful compromises and needlessly drives up costs.

Mission objectives affect mission design and system selection through requirements such as crew size, scientific vs. operations cargo characteristics, stay time at Mars, surface site access, and the potential desire for building towards a continuous presence at Mars (e.g., a permanent Mars base). Analysis of skill mix needs indicates a minimum crew number of five to eight for a Mars mission. Greater demands for primary science skills as well as needs for international representation could lead to a larger rather than smaller number of crew. The size and cost of a mission are directly driven by crew size. In recent studies, cost considerations have tended to drive the number of crew to the lower limits of what is believed by the study authors to be a safe and reasonable crew complement.

For an international project, it is essential that the space systems development, production, operations and associated ground and support systems be internationally shared. A Mars mission lends itself well to this end, since there are many major components and a large number of minor ones to be assigned or subcontracted to the international partners.

## **Chapter 6 - Mars Surface Systems and Operations**

The role of the Mars Surface System is ultimately to provide (with a modest start) a complete spectrum of capability for realization of the international exploration community's goals for robotic and human exploration and possible future settlement of Mars. This robotics/human exploration capability may include pre-programmed and autonomous robotic systems, teleoperated rovers, stationary geophysical stations, initial Mars human expeditionary outposts, self-supporting human bases, and Mars-based space transportation systems. To plan the Mars Surface System, it is necessary to examine fundamental top level goals, to derive the next level of requirements, and then to conceptualize a set of temporal relationships, interactions, and phase transitions that best describe a strategic approach which ensures accomplishment of those goals.

Goals of Mars exploration require the Mars Surface System to support the collecting of scientific data that increases our understanding of Mars on a global scale and supports the development and verification of Mars as a future abode for humans. Upon examining those two primary goals, the subsidiary goals were categorized under "Exploration", and "Human Expansion". These categories require different implementation schemes. Exploration generally emphasizes "global" Mars coverage with temporary human presence at any single site, and Human Expansion emphasizes growth and evolution outward from a single site with permanent human presence.

A characteristic of the planetary Exploration goal is that it is ultimately desirable to visit a multiplicity of sites. This implies either the capability to travel great distances across the surface of Mars using a mobile "base" concept, or that many sites can be

visited from an orbital base or through several separate expeditions to Mars. Elements that provide temporary support associated with limited means and short durations are most appropriate. On the other hand, the Human Expansion goal requires a different approach in that a human settlement begins with a unique landing site from which a surface base infrastructure may grow outward. Within the framework of the Human Expansion goal, it is expected that increasing capability may be provided by utilization of local resources that will enable much longer surface stays, support other goals, and open the way to long-range surface exploration capabilities.

The implementation and operations concepts must not preclude either approach, but rather must provide for the simultaneous implementation of both through the utilization and exploitation of common assets. Indeed, the Human Expansion implementation must evolve through a growth approach that utilizes the Exploration assets. From the other viewpoint, the Exploration assets must not preclude, and wherever possible, must facilitate future growth.

An analysis of the mission-level requirements in Chapter 2, "Why Mars?", has yielded the following basic requirements for the Mars Surface System:

#### Mars Scientific Goals

- Understand the composition and internal structure of the planet Mars;
- Determine the geological evolution and ages of Martian surface features;
- Determine the composition and dynamics of the Martian atmosphere;
- Determine the origin and history of water on the surface of Mars;
- Determine the existence and evolution of life on Mars, extinct and extant.

#### Mars Habitation Goals

- Determine the practicality of permanent human settlements on Mars;
- Determine and evaluate methods to make the human settlements self-sufficient and less dependent on Earth resupply.

The next step in the requirements analysis process is to assign the above mission level goals to potential functional hardware categories so that the surface system assets can be further defined in subsequent studies. This is done in the Mars Cosmic Study Report through an iterative process and those goals are allocated to major Mars Surface System functional categories that may contain a number of hardware assets.

The basic strategic approach is to design each phase and sub-phase to be interdependent and supportive of each subsequent phase and sub-phase. This approach results in no "dead-ended" hardware, and, in the long run, should reduce costs in that fewer original development programs will be needed. Although each sub-phase depends on the others, the decision to implement any phase is an independent activity. The sub-phase to sub-phase dependency is implemented through the design process by ensuring the availability of the additional performance capability required to support the subsequent phases when, or if, the decision to advance is made based on international resource availability and priorities. The potential implementation concepts can vary widely depending on the detailed analyses of the requirements and the special interests of the international partners involved. The implementation concepts presented in the IAA Mars Cosmic Study Report are only to demonstrate that there exists at least one solution to the problem.

## **Chapter 7 - Human Factors and Physiological Aspects**

An interplanetary space flight or inhabiting a foreign planet for long durations can subject the crew to debilitating, injurious and possibly fatal stresses. Some of these stresses are radiation, hypogravity, isolation/confinement, toxicity, and mission specific environmental conditions. To be sure that the mission has a high probability of succeeding, it will be necessary to expand human knowledge of these stresses and their human effects over time before undertaking such a flight. Much can be learned by inhabiting and working aboard the International Space Station (ISS).

The planning for the mission should also include consideration of crew selection and performance, habitability of the environments, sociological issues, life support, environmental health, and management of crises and illnesses. The accepted level of risk needs to be decided. We must realize that, inherently, risk cannot be totally eliminated and should not be denied; missions should be designed with prudent levels of risk (possibly a 3% risk of catastrophe). The best way to manage the levels of risk for a mission is to understand the environment and the conditions of that mission, including how a human will be affected and will perform in that environment, and the mitigating benefits of possible control measures.

Human factors and physiological problems will probably not delay the human exploration of Mars, provided the quest for problem solutions begins now. The selection of the crew will be based on physiological, psychological, sociological, and task considerations, and cross training for stable relationships. A significant amount of preliminary work still needs to be performed in the areas of radiation, hypogravity, and isolation/confinement to understand the effects of these stresses. The biological effects of the radiation anticipated en route, on Mars surface, and in case of an abort flight, should be precisely determined. The timing, shielding, and countermeasures should be such that the hazard is acceptable and the effects should be mitigated as much as reasonably possible. For long duration missions, a 1-g environment for the astronauts (preferably using a long tether and low rate of rotation) would eliminate the potentially mission-defeating effects of hypogravity. Sufficient knowledge of the effects of prolonged hypogravity and zero-g should be acquired and separately addressed to ensure crew survival in case of failure of the 1-g system and to deal with the reduced gravity on Mars. The psychological effects of isolation and confinement should be reduced by the careful selection and training of crew members. The environments provided should be carefully designed for habitability, and crew activities should be carefully planned and provisioned.

## **Chapter 8 - Mars Program Organization and Legal Aspects**

The International Exploration of Mars Program should reflect the premise that the Project will be an adventure benefiting all of humanity, and should welcome the participation of all nations and cultures. Strategies for designing the organization and its leadership body, task forces, committees, staff selection, funding, headquarters location, operations, standards, language protocol, and venues should reflect this premise.

However, it should be recognized that, while the International Exploration of Mars Program is an inspirational and a logical objective for many space professionals, it may not have high priority for other global citizens. In these times of deep economic, environmental and social concerns, some may consider such a Mars program an unwise use of technical talent and money. Therefore, a primary task, especially

during the organizational phase, should be the education of the public through the world media (print, radio, television, film, Internet) and through lectures to schools, civic groups, professional organizations, etc., on the economic, environmental, motivational, scientific, political and technological justification for exploring Mars.

The Mars Cosmic Study suggests that a mixed public/private International Mars Exploration Forum (IMEF) be initially established to provide the focus for the organizational phase. Coordinated scientific and operations planning have enabled the participants in previous international efforts to optimize the scientific return from each spacecraft and to share in the resulting measurements from all spacecraft. As an open forum, the IMEF by itself would probably not be effective in coordinating or melding national plans or developing regulatory, technology-transfer, or trade policies. While general space policies have been negotiated in the United Nations Committee on the Peaceful Uses of Outer Space, these have been slowed by national political agendas and hence those policies specific to the Mars activities might be negotiated only between the countries involved.

The IMEF's purposes would be to:

- promote the concept of internationally cooperative space exploration;
- motivate governments to participate in international Mars missions;
- identify humanitarian, economic and technical benefits of Mars exploration which will motivate governments to participate in international Mars missions;
- educate professional groups, the public and the media on space exploration benefits;
- identify opportunities to coordinate and, where feasible, to combine existing national Mars exploration plans;
- gather technical and scientific data relevant to international Mars missions;
- make recommendations for further investigations;
- propose technical plans which will provide a foundation for international Mars missions.

The IMEF would provide:

- a clearinghouse of historically relevant information, data and reports on Mars exploration;
- access to a Mars database and reports on the results of the investigations and recommendations;
- a report recommending the structure of a more permanent IMEF administrative organization and the regulations and policies governing the venture;
- a report recommending a program designed to stimulate international public support.

The robotic space exploration community has successfully shown the way by forming the International Mars Exploration Working Group (IMEWG), which is an organization containing representatives from the space agencies of the various spacefaring nations.

There are no legal or treaty barriers to international Mars exploration.

Multidisciplinary problems that can be expected to develop when exploring Mars will be subject to legal provisions of treaties formulated by nations since 1967 to ensure that outer space and celestial bodies are used for peaceful purposes for the benefit of all humanity. International cooperation and national responsibility are expected to maintain conditions essential for preventing harmful influences, and for the conduct of safe, orderly operations (including the prevention of planetary contamination).

The sources of space law which are relevant to Mars exploration are:

- international law in general, including international customary law;
- treaties, conventions and agreements formulated within and outside the UN;
- statutes of international space organizations outside the UN, e.g., Intelsat, Inmarsat, ESA, etc.;
- space-related regulations of the UN specialized agencies, e.g., the International Telecommunication Union, the World Meteorological Organization, etc.;
- interpretations of UN resolutions, negotiating histories, expert analyses and the Vienna Convention on the Law of Treaties; and
- national space laws and their implementing regulations.

All space activities must comply with a set of basic policies adopted by many nations. Fundamental concepts ratified by 93 nations are in the 1967 "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies." Explorations and usage are to be performed for the benefit of all countries without discrimination; states are required to encourage and facilitate international cooperation. Whenever advances in space science and technology create new situations, provisions of the 1967 Outer Space Treaty have been expanded into new treaties providing for assistance and return of astronauts and space objects, liability for damage, and registration of objects launched into outer space.

As of Oct. 20, 1995, the so-called Moon Treaty, "The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies," offered by the United Nations to States for consideration in 1979 and entered into force on July 11, 1984, has been ratified by only nine nations (Australia, Austria, Chile, Mexico, Morocco, Netherlands, Pakistan, Philippines, and Uruguay). France, Guatemala, India, Peru, and Romania have signed the Agreement but have not ratified it as of that time.

Some attention should be given to treaty provisions governing the relation between the Moon and Mars because legal provisions for the Moon have been drawn in such a manner that they also apply to Mars. In addition, a study should be initiated as to whether international agreements need to be made specifically for Mars because it differs so much from the Moon.

## **Chapter 9 - Economic and Resource Considerations**

This Mars Cosmic Study is not directed mainly at the aerospace engineer or the space scientist who may already be committed to space exploration. Rather it is intended for the informed citizen and the members of governing bodies of societal institutions who collectively decide on the expenditure and application of global resources. While perhaps intrigued and favorably disposed towards the advancement of knowledge about our Solar System and our galactic home, these readers will ask to know the costs and the benefits of Mars exploration. They must compare and justify the applications of resources to space exploration versus applying those same resources to the many problems of the planet - hunger, education, disease, pollution, etc. In the end, it is an informed and objective cost/benefit study that they desire.

Foremost, it must be recognized that all space funds are spent on Earth; spent on the development and application of advanced technology. Much progress has been made in modern engineering and manufacturing in estimating the cost of products to be competitive in their respective market niches. The major problem in applying costing

techniques to the estimating of Mars exploration costs is that a large part of the project remains in the R&D and "unknown" input realm. One of the main cost uncertainties has been the availability of low-cost launch vehicles to deliver the Mars vehicle (possibly in segments) to Earth orbit and to provide Mars mission logistic support.

Various human Mars mission designs have been postulated and rough, order-of-magnitude costs have been estimated. One postulated "off-the-shelf" technology plan lands a crew on Mars 19 years after the initial start, and includes a backup second mission landing, for a 30 year program. The cost in 1992 U.S. dollars was estimated at \$170 billion, with an average annual cost burden of \$6 billion and annual costs that vary between a minimum of \$1 billion to a maximum of \$13 billion. Another recent study estimates that a Mars Exploration Program consisting of three missions has a 90% probability of costing less than \$110 billion. An international Mars Exploration Program can spread the costs so that no participating country need spend more than a small fraction of 1% of its GNP to participate.

## **Chapter 10 - Conclusions and Recommendations**

The IAA Mars Exploration Subcommittee concluded that international space exploration uniquely offers humanity access to an exciting frontier of new knowledge. Discoveries on new worlds in new environments by robotic explorers add to our knowledge of the Solar System, but they also explore the possibilities for extension of human life beyond our fragile Earth. We believe that demonstration of the reality or, conversely, of the impossibility of human habitation of other planets will have a profound influence on the ability to establish international controls for safeguarding our own planet in the 21st Century.

The planet Mars is the most natural objective for this grand exploration. Its geologic evolution has been similar to that of Earth in many ways. In its atmosphere and on its surface, we find water, carbon, and nitrogen - all required for the existence of life. Martian landforms include volcanoes and extensive channels, apparently formed by large amounts of flowing water. Today, the atmospheric pressure on Mars is only one percent that of Earth, and temperatures are seldom higher than zero degrees Celsius. It is important to discover what events led to these bleak conditions, because the answer may have implications for changes on our own planet.

Travel to Mars is technically challenging, and operations on its surface are difficult. Therefore, a comprehensive program of Martian exploration should include both robotic and human missions. A principal issue of programmatic strategy is the proper balance between automated and crewed missions. The IAA International Mars Exploration Subcommittee recommends a focused robotic precursor effort with an ongoing effort of robotic missions to assist the emplacement of the human Mars outposts and to continue human scientific exploration.

In this Mars Cosmic Study Report we present a variety of alternative approaches to mission architectures but do not recommend any particular choice. The form of the Mars exploration program will be influenced by the nature of the organization created to implement it. In this work, we have argued strongly for an international effort. We favor an approach that begins with informal, non-official consultations and conferences under the auspices of an International Mars Exploration Forum (IMEF) to establish the technical and political issues for an international cooperative exploration program. As consensus is achieved, at first informally, the Forum evolves in stages to

a formal activity, the International Commission for the Exploration of Mars (ICEM), for achieving human presence on Mars. Financially, the sharing of costs among the nations of the world in a truly global effort will make the percentage of GNP required from each country affordable.

#### Additional Sections in the IAA Mars Cosmic Study Report

##### Addendum I : Update of Mars Exploration Programs - c1995

An update of Mars robotic/automated probe missions from several countries.

##### Addendum II : Mars Direct: A Practical Low-Cost Approach to Near-Term Piloted Mars Missions

A study investigating human expeditions to Mars by utilizing existing or near-term technology.

##### Addendum III : Mission Planning and Mars Architecture Trade-Offs

This review addresses the evaluation of Mars exploration architectures and discusses appropriate steps for IAA to develop a "preferred" International Mars Program.

##### Appendix A : A Short Guide to Mars

Physical descriptions of Mars.

##### Appendix B : International Exploration of Mars Survey - c1992

Results of a questionnaire circulated to members of the IAA in 1992 to determine the membership's views on a proposed international mission for Mars exploration.

##### Appendix C : International Space Exploration Institute

Description of a postulated space exploration organization.

##### Appendix D : Additional Bibliography on Exploration of Mars