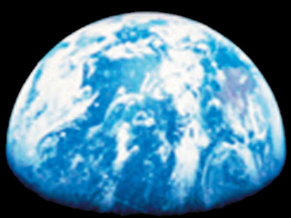
LunAres

International Lunar Exploration in Preparation for Mars

Mission

Select, among the identified key concepts, technologies, and systems that will enable human Mars exploration, those that can best be tested on the Moon, and suggest a framework for international lunar missions that can be carried out to validate them by 2020. Include the enabling policy, legal, societal, and economic aspects.by 2020. Include the enabling policy, legal, societal, and economic aspects.



Scope

- Summarize, review, and assess current plans for exploration of the Moon and Mars.
- Identify critical scientific and technological elements that will enable Mars exploration.
- Among the identified enabling elements, select those that can best be tested/ rehearsed through a set of lunar missions.
- Define a legal, policy, and social framework to sustain a program of exploration of the Moon in preparation for Mars.
- Describe a set of international missions to the Moon in which to test the identified enabling elements.
- Define a legal, financial, and policy framework to enable international cooperation.
- Draw conclusions and make recommendations to the space community and to policy-makers.

Team LunAres would like to acknowledge the generous support of our sponsors:

The authors would like to express their sincere gratitude and appreciation to the individuals who contributed their time, energy and passion to assist in making this project possible.

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Some day people will travel to Mars. It will be a long trip, but fun. This will be a big step for mankind. We would be able to find out if there was life on this planet. It probably will look like a red desert.
J. Stephen Hartsfield, Seventh Grader, 1984

A vision

Space agencies worldwide are moving toward an orientation of lunar exploration. The Vision for Space Exploration in the United States and the Aurora program in Europe include an international effort of preparation for human missions to Mars as an important component of their lunar plans.

This report identifies the enabling elements for an initial human mission to Mars and selects those that can best be rehearsed in the context of near-term international human and robotic lunar missions. The report uses this list of enabling elements to suggest a set of lunar missions leading to an eventual human mission to Mars. The analysis includes a recommended policy, legal, and social framework in which to implement the missions.

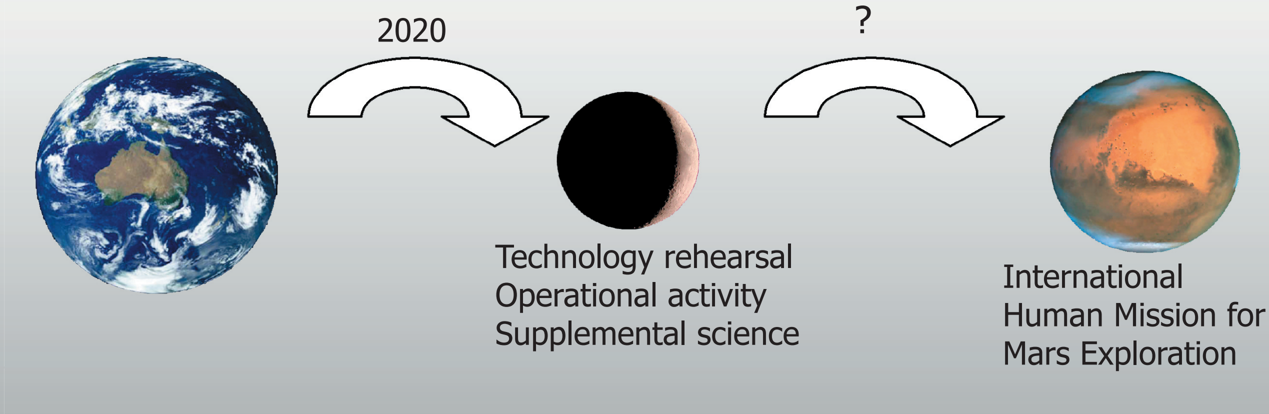


Figure 1 Proposed approach for exploration of Mars

Current Plans

Some space agencies have already sent probes, satellites, or human missions to one or both of these bodies. NASA and ESA have proposed programs culminating in a human mission to Mars that call for or require international cooperation.

For NASA, and more recently for ESA, the Moon is the preferred location for a rehearsal mission program to support human exploration of Mars. ESA plans to send an astronaut to Mars as part of an international crew and wishes to use the Aurora program to strengthen links to European and Canadian industries, universities, and other international partners. CSA (Canada) and RSA (Russia) intend to provide technology demonstrators for these efforts. The lunar robotic missions of JAXA (Japan), CNSA (China), and ISRO (India) can also contribute with valuable scientific data, technology validation, and operating experience.

Current Plans

The past is but the beginning of a beginning, and all that is and has been is but the twilight of the dawn.

H.G. Wells, "The Discovery of the Future," 1901

The implementation of a lunar program in preparation for a human mission to Mars that uses and supplements current plans requires an assessment of the policy, budget, outreach, science, and technology objectives of those plans. Looking also at the gaps and overlaps of these plans provides a basis to make the necessary assumptions for an international framework and to define the possible enabling elements to be selected. The different Mars and Moon related programs of the space agencies are shown in Figure 2.

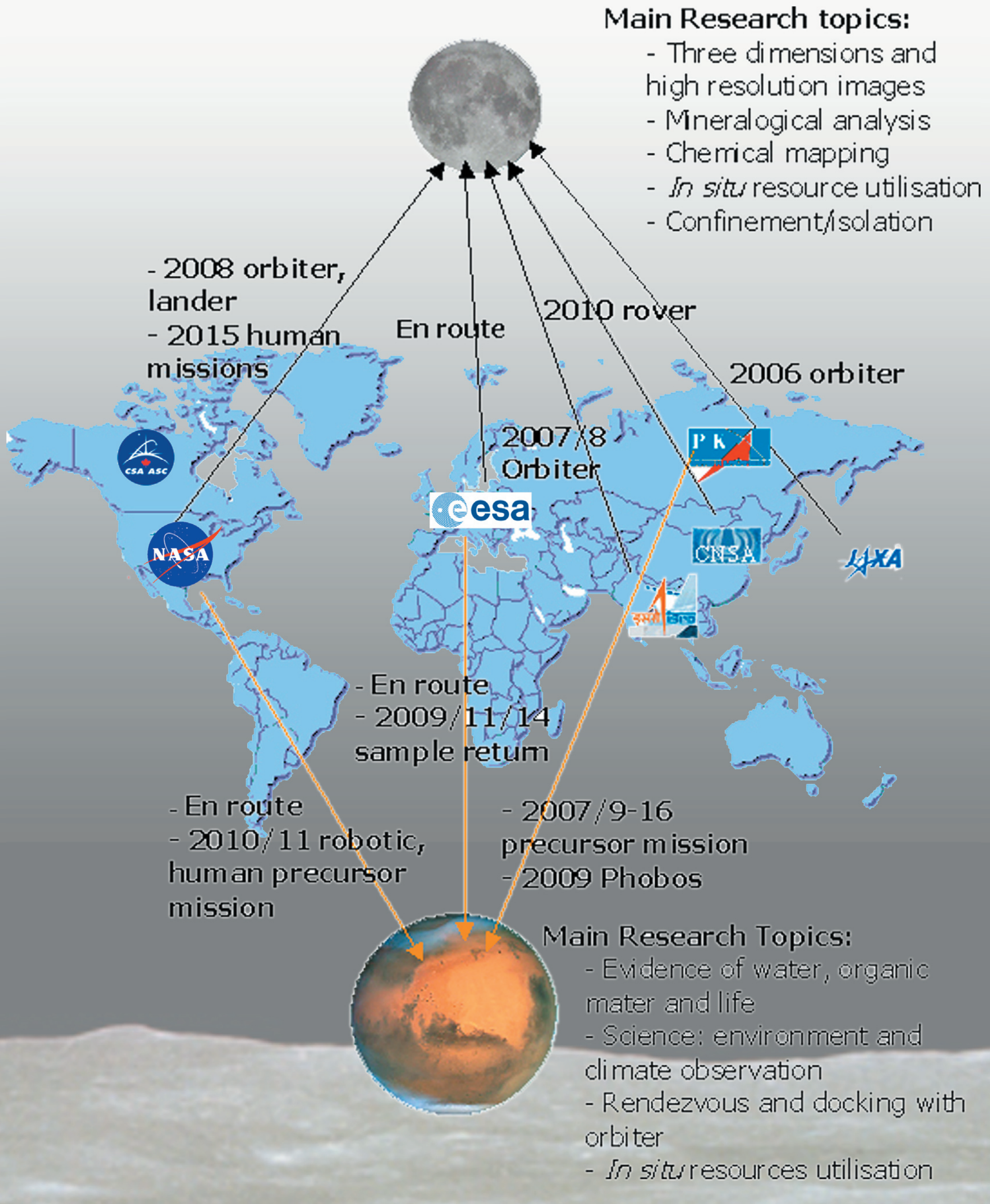


Figure 2 Programs of space agencies to the Moon and Mars

The future cannot be predicted, but futures can be invented.

Dennis Gabor, 1963

Moon versus Mars

Figure 3 presents an integrated timeline for these plans.

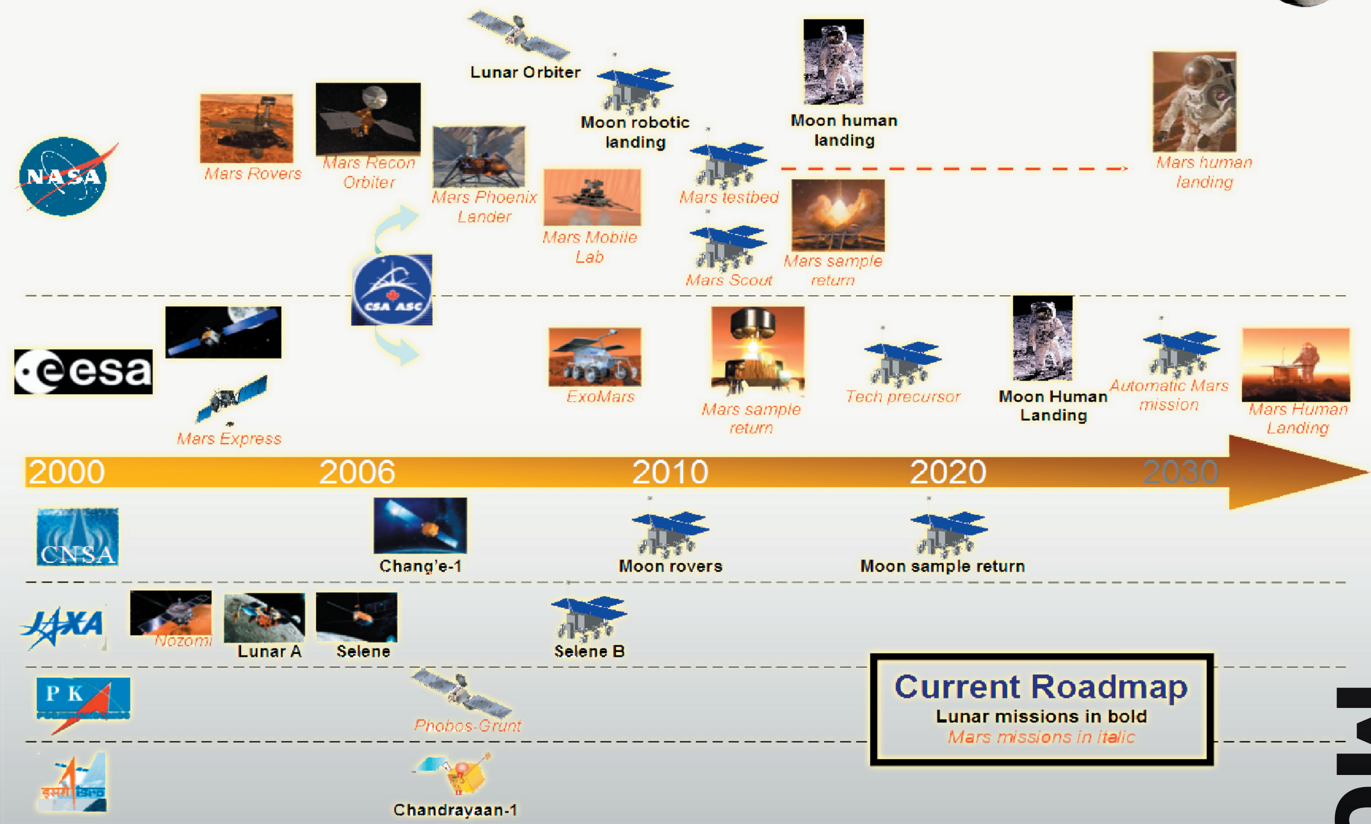


Figure 3: Roadmap of existing programs to the Moon and Mars

A lunar mission can take advantage of the similar features of the Moon and Mars, providing experience and knowledge for future human Mars missions. However, the two planets also have some fundamental differences regarding atmospheric, environmental, and astrodynamic properties. Therefore, this report distinguishes between those elements suitable for lunar testing and select out those which are not. Figure 4 below gives a few examples of the similarities and differences between the two environments:

Features of the Moon
- 1/6g
- No atmosphere
- A lunar day = 27.3 Earth days

Features of Mars
- 3/8g
- Presence of an atmosphere
- Lower surface temperature than the Moon
- Sandstorms
- A martian day = 24.66 Earth days

Similarities
- Composition of the soil
- Landscape
- Reduced gravity
- Possibility of frozen water
- Need for environment shielding

Figure 4 Similarities and differences between the Moon and Mars

I had the ambition to not only go farther than man had gone before, but to go as far as it was possible to go.
Captain James R. Cook

Moon versus Mars

The similarities make the lunar environment a good location to serve as a test bed for enabling technologies to be used for future human missions to Mars. Table 1 below describes the differences in mission design for a human mission to the Moon or Mars.

Areas	Elements	Effect on mission to	
		Moon	Mars
Crew training	Flight and mission duration Distance from Earth	Short transfer No special training	Long transfer More psychological tests and training required
Rendezvous & Docking	Total mass in LEO at departure	Up to 550 tonnes	Up to 750 tonnes
Assembly in space	Total mass in LEO at departure and need of integrated transfer vehicle	Can split up in several single transfers	Need more mass to sustain long duration transfer
Orbit maneuvers	Gravitation	Less	More
Trans- Lunar/ Mars Injection	Needed ΔV	3050 m/s (Apollo type)	5600 m/s (for minimal energy Hohmann)
Trajectory	Orbit mechanics	Free return possible	Trade off between transfer duration and propellant mass
Transfer duration	Distance	3 – 5 days	150 – 300 days
Life support	Mission duration Possibility to resupply	Same Is possible (fast response)	Same No
Communication	Distance	Low gain, ~2.5 sec. round trip time	High gain, power, accuracy, ~20 up to 50 min. round trip time
Orbit insertion	Needed ΔV for impulsive maneuver Other possibilites	920 m/s (Larson 1999)	2000 – 2800 m/s (Larson 1999) Aerocapture
Entry/Descent vehicle	Atmosphere	No atmosphere -> impulsive maneuvers	Entry capsule, parachute
Habitat	Stay duration Radiation environment	Same Sometimes shielded from Earth´s magnetosphere	Same Interplanetary space, some shieling from atmosphere
Mobility	Soil properties Pressure Gravity	Same Same 1/6 g	Same Same 3/8 g
Power generation	Solar Flux Day/Night cycle	1368 W/m² 27,3 days (except at poles)	589 W/m² 24.66 hours
In-situ resource utilisation	Soil composition Atmosphere Water	Yes No atmosphere Maybe	Yes Yes Maybe
Quarantine	Alien lifeforms	Not necessary	Maybe yes

Table 1: Comparison between Human Missions to the Moon and Mars

The greatest gain from space travel consists in the extension of our knowledge. In a hundred years this newly won knowledge will pay huge and unexpected dividends.
Professor Wernher von Braun

A human Mars mission involves no emergency return or abort options. Hence, crew selection, training, psychological support, and reliability of all subsystems will need to be emphasized.

Enabling Elements

Technical and scientific enabling elements for human Mars exploration are identified in the following areas:

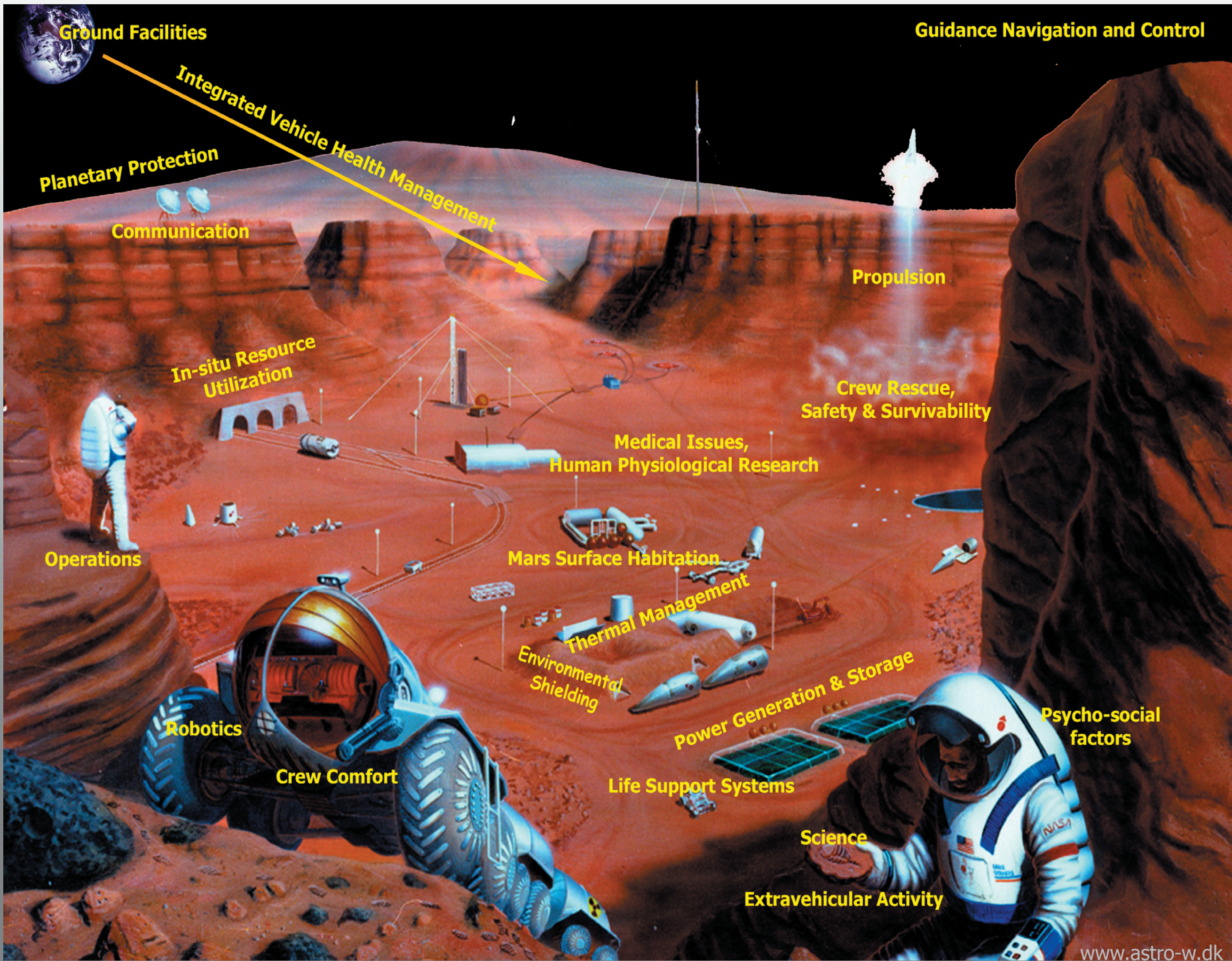
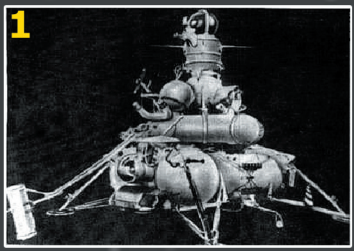


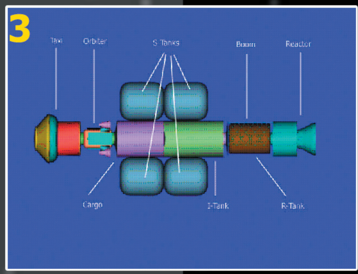
Figure 5: Areas of selected enabling elements for a human Mars mission

The enabling elements that can best be rehearsed on the Moon are selected and rated by performance, relevance to safety, technology readiness level, cost, political acceptability, sustainability, and scientific value.



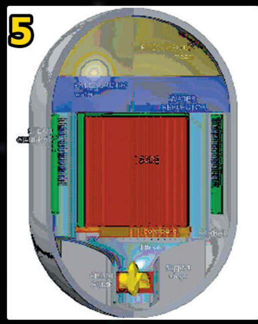
Lunar Sample Return

Demonstrates a soft and precision landing and sample return mission



Lunargo

Support spacecraft for all preparation missions in a permanent Earth-Moon orbit.



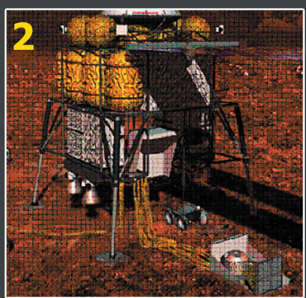
Nucargo

This mission will have the nuclear reactor as main payload

Type I - Robotic missions:
Remote sensing and resource mapping, technology testing, automated science experiments.

Type II - Preparation mis
Essential technology demonstrations to prepare spe cargo missions for the pre-deployment of infrastr

2009



Lunar Precursor Family

A family of robotic missions willl be developed to allow for consistency among robotic precursor missions that carry payloads for technology demonstrations

Heavycargo

Heavy landing missions will include robotic units and inflatable structures.

IS

Mission ISRU sy

LunAre

Habcargo

The main paiload of this mission will be the Habitation Module

Short Human Mission

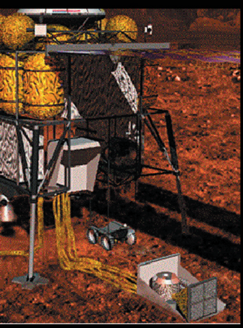
14 days near the lunar south pole.

ssions:
ecifically for a human mission;
ructure for human missions.

Type III - Human short-stay missions: Human expeditions of a few days duration.

Type IV - Human long-stay missions: Human missions where up to three years are spent on the Lunar surface

2020



SRUcargo

n 6 will have the
ystem as a main
payload

Ecocargo

The last preparation mission will have an inflatable low-pressure greenhouse as the main payload

Long Human Mission

- Land a human crew on the Moon around 2020, for a mission duration typical to long stay Mars mission scenario (450 days)
- Demonstrate enabling elements needed to support a human presence on Mars.

s Missions

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Rehearsal Missions to the Moon

The goal of the lunar rehearsal missions will be a long-term in a lunar surface base, comparable to the Mars mission profile and operations.

The missions

The rehearsal missions for the enabling elements are classified into four categories in order of complexity:

Type I - Robotic missions: Remote sensing and resource mapping, technology testing, automated science experiments, operations, simulations

Type II - Preparation missions: Essential technology demonstrations to prepare for a human mission; cargo missions for pre-deployment of infrastructure for humans

Type III - Human short-stay missions: Human expeditions of up to 14 days duration

Type IV - Human long-stay missions: Human missions of up to three years on the lunar surface

I Robotic missions

1 - Lunar Sample Return Mission (LSR):

Demonstrate soft and precision landing, surface Guidance, Navigation, and Control (GNC) capabilities, automatic sample return, technologies for probe sterilization, power transmission, and radiation measurement.

2 - Lunar Precursor Family (LPF):

Lunar Soft-Lander Demonstrator (LSLD): It demonstrates precision and soft landing capability and identifies water if present in lunar South Pole craters

ISRU demonstrators I-IV (IDEM): It demonstrates the practicality of different ISRU processes

Inflatable Structure Experiment (ISE): It demonstrates the usability of inflatable structures on the lunar surface and demonstrates precision landing

Automated Plant Growth Experiment (APEX): It demonstrates automated plant growth in the lunar polar environment

Construction Rover: It investigates the use of unprocessed lunar regolith

II Cargo preparation missions

Test all the capabilities and the technologies needed for heavy landing and simulate a possible Mars sequence of cargo missions

A first assembly of a cycler occurs, called Lunargo, from five main taxi missions:

3 - Heavy robotic and structures landing- **Heavycargo**
4 - Nuclear Reactor - **Nucargo**
5 - ISRU Unit - **ISRUcargo**
6 - Habitation modules - **Habcargo**

III First Human Moon Mission (Short Stay)

Send a human for a 14 days stay near the lunar south pole and intendes to test all space elements to gain experience and reduce risk for a long stay human mission to the Moon.

Figure 7: Sequence of events for a short stay mission

And now 'tis man who dares assault the sky...And as we come to claim our promised place, aim only to repay the good you gave, And warm with human love the chill of space.
Prof. Thomas G. Bergin, Yale University

IV Long-duration Human Mission to the Moon

Demonstrate technologies and reproduces a Mars mission with the assumptions that necessary equipment will have been transferred using cargo missions, a basic lunar base will have been built during the short-stay missions, and low-gravity and radiation shielding will have been developed. The objectives are:

Land a human crew on the Moon around 2020, for a mission duration typical of a long stay Mars mission scenario (450 days) and return them safely afterwards, ensuring planetary protection for both Earth and Moon

Demonstrate enabling elements needed to support a human presence on Mars

Continue of the construction of a lunar base

Test the vehicle building-blocks that will be used in a Mars mission

Develop surface stay protection, medical procedures, crew selection and interaction, inflatable structures, building construction using regolith, and food production and storage using the green house

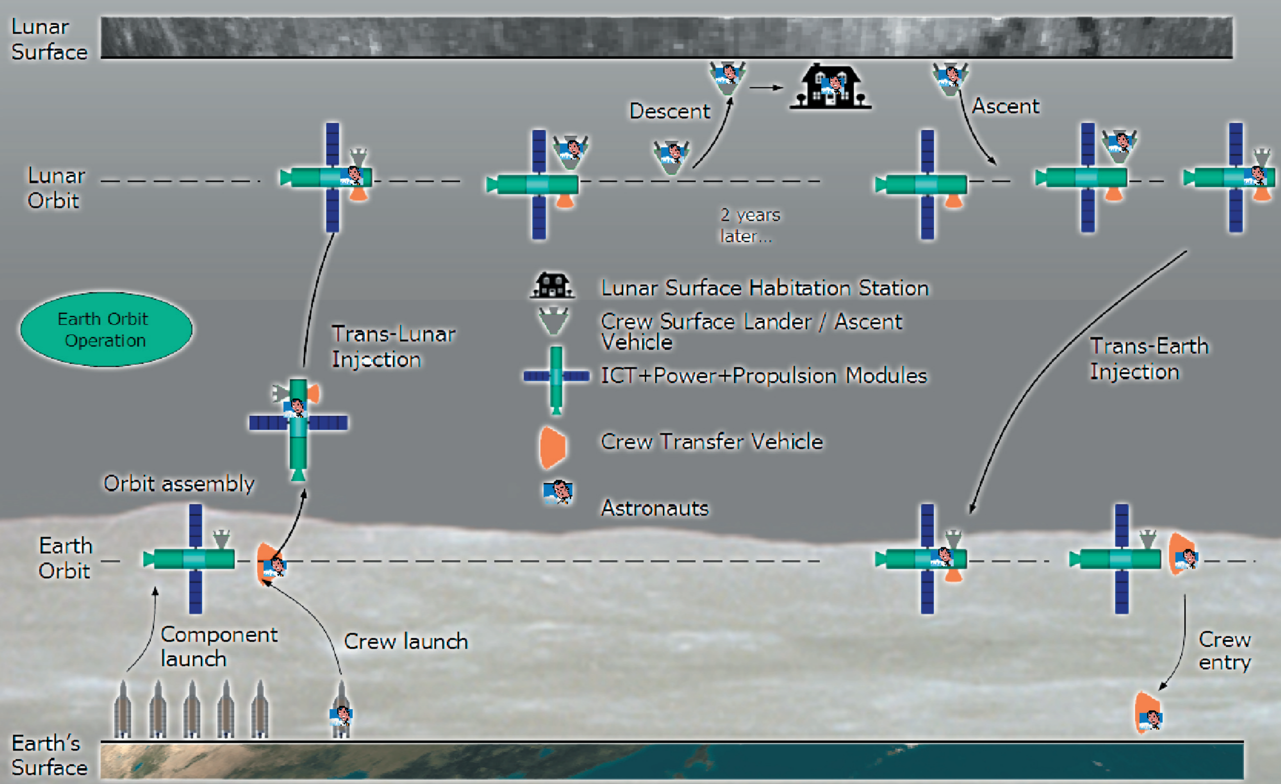


Figure 8: Mission phases for long-stay duration missions

The highest and best form of efficiency is the spontaneous cooperation of a free people.
Woodrow Wilson

Policy, Legal, and Social Framework

Any political framework that will successfully implement international cooperation among space exploration programs must acknowledge the individual motives and needs of the nations involved. It must ensure that, to the extent practical, agencies minimize duplication of effort while accomplishing their space exploration activities.

Exploration Program Management Structure – The Space Exploration Forum

LunAres recommends a loose coordinating body called the Space Exploration Forum. Its primary role will be to maintain a database in which participating nations will register their lunar and martian exploration activities, to limit duplication of effort and to allow for synergies among them. Such a structure will allow nations to coordinate their space exploration activities while still maintaining several national space identities.

Management of individual missions is accomplished by the agency or partnership and is facilitated by the Forum. The Forum does not have the authority to manage missions, but individual mission managers are encouraged to follow its recommendations as they are key elements for the overall success.

Forum Substructure

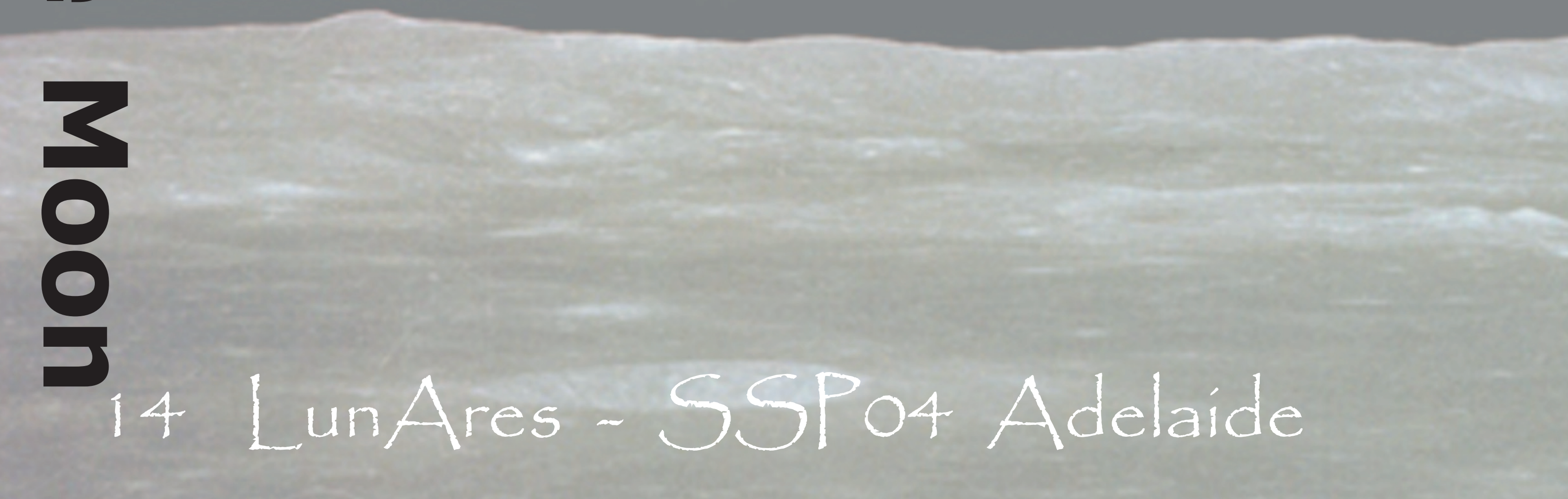
Three Advisory Boards are recommended:

> The Technical Advisory Board will make recommendations to the Forum on standardization, technology harmonization, and overall mission operations coordination.
>
> The Social Outreach Advisory Board will inspire the public and enable their sustained participation in, and support for, Moon and Mars exploration missions.
>
> The Legal Advisory Board will define recommendations for the individual missions' legal documents and their basic legal structure.

Implementation

Membership in the Forum will be voluntary. Member states, agencies, or other organizations that express an interest in participation in the Forum will define its rules. Representatives from industry and social organizations (e.g., space advocacy groups such as the Planetary Society) will be welcome as observers.

Given the current political scene, establishment of a commitment by most space-faring nations to the Space Exploration Forum is premature. In the near-term it is recommended that regular meetings should occur between space agencies at the Administrator level to encourage future coordination. These meetings should become progressively more formal, culminating in the eventual formation of the Space Exploration Forum. The Forum, together with its technical, legal and societal advisory boards, should be established prior to the first human lunar mission period.. The first highly-publicized act involving the Forum should therefore be the first international human mission to the Moon.



The moon is the first milestone on the road to the stars.

Arthur C. Clarke

Recommendations

Test on the Moon those elements of a human Mars mission identified as best suited to lunar rehearsal.

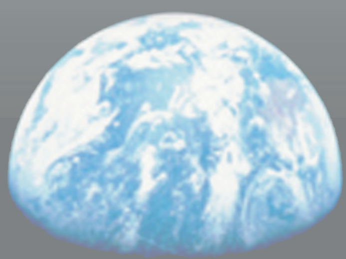
Emphasize human-driven mission elements, including psycho-social issues, medical factors, and operations.

Conduct lunar science that yields knowledge useful to preparation for a human Mars mission, contributes to sustainability by attracting public support, or promises significant scientific return at a relatively small additional cost.

Demonstrate both operational and technical implementation of in situ resource utilization (ISRU) on the Moon while paying special attention to the aspects that are transferable to Mars and favoring approaches that support a sustained presence on the Moon.

Choose one or more potential transition or exit strategies to be implemented upon completion of the lunar rehearsal program. These strategies should be designed to ensure availability of resources for Mars exploration while supporting, to the greatest extent practical, a sustained presence on the Moon.

Establish an international coordinating body, the Space Exploration Forum (SEF), composed of a Legal, a Technical, and a Social Outreach Advisory Board.



This Executive Summary was written by the students in the 2004 Summer Session Program at the International Space University. Published: August, 2004

Images courtesy of :
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