IAA STUDY GROUP ON GLOBAL HUMAN MARS SYSTEM MISSIONS EXPLORATION

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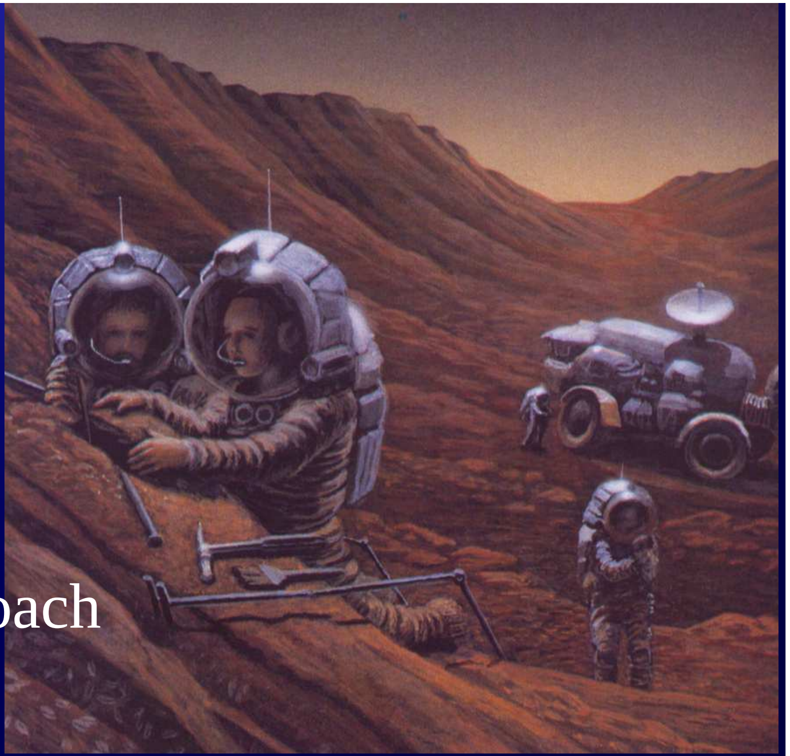

IAA study group SG 3.16

A cooperative Human Mars mission framework including, but not limited to, requirements and technologies, is still missing.

In August 2012 the IAA has set up a study group to deal with this subject with the goal of identifying, assessing and synthesizing a global set of goals with its related criteria and requirements for future human exploration of the Mars system and establishing technology opportunities and roadmaps.

The Cosmic Study has been completed and approved by the IAA

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The IAA Cosmic Studies

The goal of the study is:

The report will carry out the first worldwide assessment of a human mission to Mars with the required technologies and roadmap. Special emphasis will be put on engaging new and emerging spacefaring nations.

Space for Humanity

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The IAA is aware of the remarkable work conducted for many years by national and regional space agencies in the framework of the International Space Exploration Coordination Group (ISECG), which has established, and is regularly updating, the Global Exploration Roadmap.

While agreeing with the content of this roadmap, and associatively providing an exhaustive and progressive list of objectives that includes missions to the Moon, asteroids and Mars, the preliminary conclusions of SG 3.16 stress the importance of Human Mars Exploration as a global international enterprise.

IAA study group SG 3.16

The starting point of this study is that the very ambitious goal of bringing humans to the Red Planet must be pursued as a truly international enterprise, in which all countries contribute toward the final achievement.

This goal can be pursued in a spirit similar to that which animated the ISS program, as a large-scale international effort.

Intermediate destinations – the Moon, the Lagrange points in the Earth-Moon system, the asteroids – can be seen as intermediate steps toward Mars.

IAA study group SG 3.16

In this light it is possible to outline an international program, involving not only the countries that now participate to the ISS program plus the other spacefaring countries, but also a number of other countries, and in particular of developing countries, that can find a role in this global enterprise.

This global enterprise can follow the existing dynamic of international human spaceflight, giving human exploration its real meaning. The long term perspective is establishing permanent bases on other celestial bodies and moving towards the creation of human settlements away from the Earth.

A mission to Mars

The GER by the ISECG mentions three destinations for human exploration, namely the Moon, the Asteroids and Mars. A Human Mars mission may be:

- A flyby mission
- A mission to one of the satellites of Mars (from where astronauts may tele-operate devices on the planet)
- A short stay mission (a flag-and-footprint mission)
- A long stay mission, with limited scientific operability
- A long stay mission, with full scientific and exploration capabilities
- A long stay mission, the first step toward colonization.

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Motivations

- Notwithstanding the innate drive to explore, justifying a human mission to Mars in the near future is a tricky business
- A recent study of the National Research Council of the National Academies of the USA identified two 'enduring questions' motivating human spaceflight:

How far from Earth can humans go?

What can humans discover and achieve when we get there?

- Most of us are sure that humans can go to Mars (and well beyond), but the second question has still fuzzy answers

Motivations

- Pragmatic rationales:
  - Economic benefits
  - Contributions to national security
  - Contributions to national stature and international relations
  - Inspiration for students and citizens to further their science and engineering education
  - Contributions to science

- Aspirational rationales:
  - Eventual survival of human species
  - Shared human destiny
  - Aspiration to explore

Motivations

The intent of this IAA study group is not to produce yet another project design, but rather to help future projects build-up in:

– surveying the spectrum of criteria, which such a project should satisfy in order to be approved, to remain supported and, finally, to be successful

– analyzing the objectives of each mission phase and their requirements

– examining the available options and establishing the rationales of choices, taking into account their influence on the objectives

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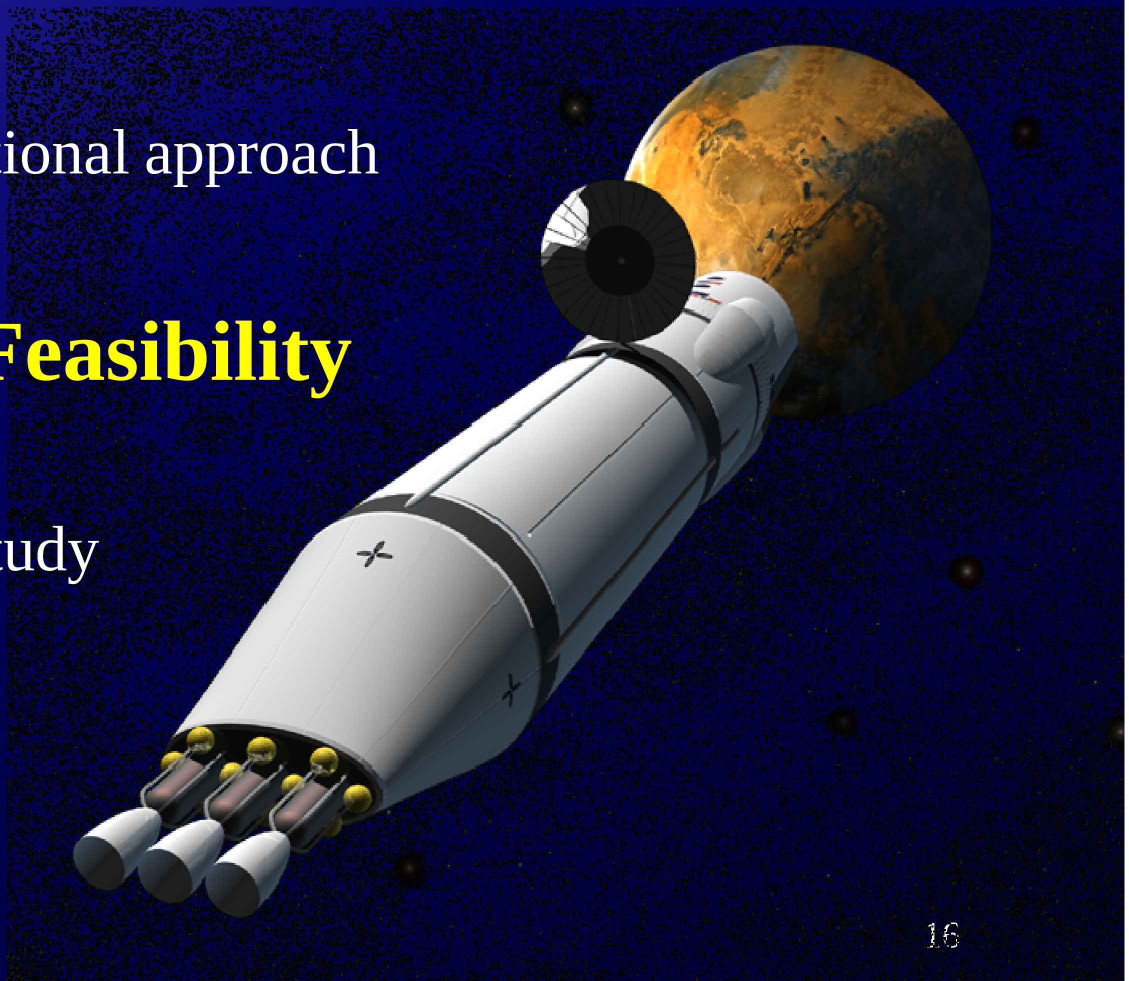

Sustainability

- Economic sustainability
- Integration between Mars exploration and economic exploitation of space resources
- The development of a lunar market is an important condition for sustainability of Mars exploration
- Introduction of a

Human Mars Mission Feasibility Index

Human Mars Mission Feasibility index

- The Human Mars Mission Feasibility Index (HMMFI) should include technical, human, programmatic, political, sustainability parameters.
- Each year it may be updated to take the evolution of the different parameters into account.
- Different types of approaches can be suggested. Two possible alternatives are described in some detail in the study, but this topics has just been touched and more work is required
- The HMMFI is one of the points which require to be dealt with in a continuation of the study

Feasibility

- In designing such an overarching project, one must be very attentive in meeting the criteria required for securing the decision to start the project and the continuous commitment of the partners. Before feasibility, *attractiveness* needs to be properly established, balancing ***Foreseen returns*** with ***Known risks***.

- These aspects relating to the appeal of the Human Mars System Exploration project, not sufficiently covered in most of past project studies, have been given special attention in this report; in fact the same attention of technical (and human) feasibility aspects

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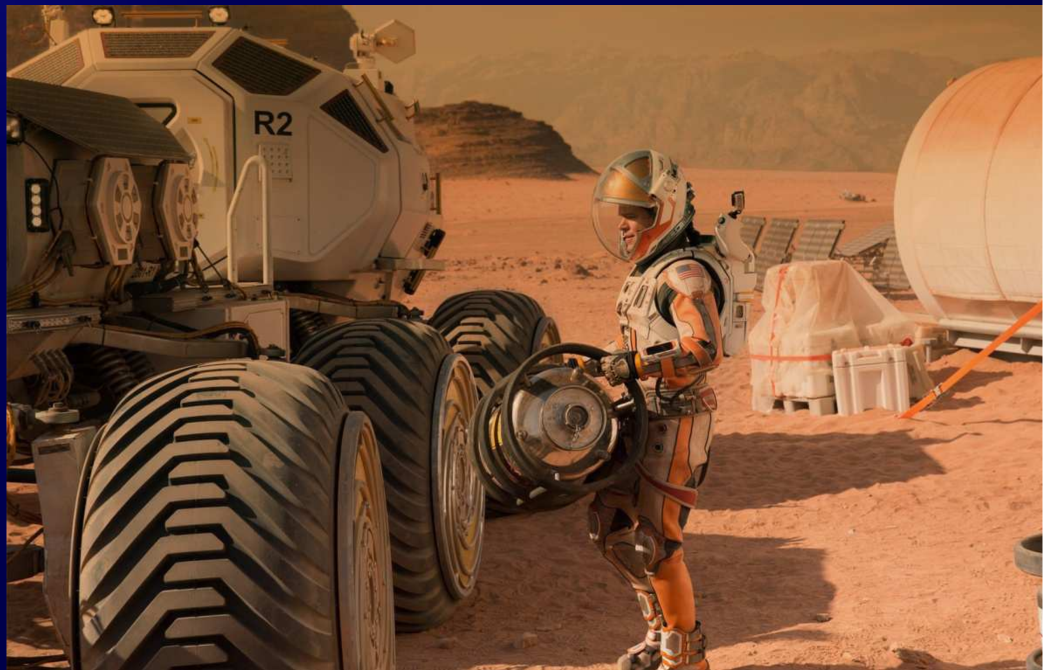

Risks

- Never exploration could be performed without risks and the evaluation of risks is a cultural and political issue. Our culture, particularly in the case of western society, is increasingly risk averse
- Apart from major risks, loss of crew and loss of mission, many other risks, of economical or political nature, must be faced: program overcost, delays, oversold scientific returns, dead-end endeavor, discontinued support from partners, etc.
- These risks must be balanced against the returns of the mission, and plans to keep them at bay must be done

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Lessons learned from the past

- A brief overview of the basic ideas underlying the various missions concepts is presented
- Since the very beginning (i.e. the 1950s) the two alternatives of chemical and nuclear propulsion (NTP and NEP) were both pursued
- Only later, in the effort to reduce costs, plans for the use of chemical propulsion in human Mars missions were considered again
- Also solar electric propulsion was considered in more recent times

Mars

- The surface of the planet may be divided into two zones, an area in which human presence is allowed and one in which only robotic exploration can be performed
- Since the tendency is to plan more than a single mission, there are two alternatives as discussed in NASA DRA5 :
  - each mission should land in a different place;
  - all missions should land in the same place.
- In a few years a true outpost may be built, and colonization may start earlier.

The human issues

- Reduced gravity: almost zero gravity in space and 0.38 g on the planet
- We have a long experience on the effects of microgravity, but what is the effect of the reduced gravity of Mars is completely unknown
- Opinions span from it being only marginally better than microgravity, to a substantial improvement of the situation with respect to the latter
- The best solution to microgravity problem is providing an artificial gravity by rotating the spacecraft. How much gravity is enough?

Radiation

- Radiation in deep space originates from
  - Galactic Cosmic Radiation (GCR)
  - Solar Energetic Particles (SEPs)
  - Occasional occurrence of a hard spectrum SEP
- A human crew exploring Mars is subjected to a high radiation environment both during space travel and the stay on the planet
- During a 400-day mission the cumulative effect GCR could pose a significant radiation hazard
- The effect of GCR at the Martian surface during a 30-day (short) stay was estimated to be acceptable

Radiation

- A further difficulty is that the knowledge acquired on medical effects of radiation, obtained from studying subjects in Earth gravity, cannot be applied fully to subjects in microgravity
- A spacecraft bound to Mars and the habitat on the planet need to have some type of screening, either passive (quite heavy) or active (still requires much study)
- On the planet there is the possibility of either covering the habitat with regolith or using lava tubes
- The choice of a location at a low altitude can reduce the problem

Radiation

- The most straightforward way to reduce radiation exposure is reducing the time spent in space, by using advanced propulsion systems
- A protective chemical therapy is also a possibility
- Finally, studies regarding human hibernation did show that this practice may be possible and could be an alternative to decreasing the time spent in space
- All these solutions, namely active shielding, advanced propulsion, drug therapy and hibernation, require technologies which need to be developed

Space transportation system

One of the main issues related to a Human Mars Mission is how to get there and how to get back

- Consensus on long stay, ISRU for part of the propellant to get back to orbit and the pre-positioning of assets on Mars
- Different opinions about the transportation systems:
  - Simple mission to make it affordable and achievable in the near future: 3 or 4 astronauts, all chemical, aerocapture, assembly in Mars orbit rather than in LEO and no more than 4 heavy launchers
  - Development of nuclear based propulsion systems to reduce the amount of propellant and pave the way for game changing technologies

Space transportation system

A synthesis of the most critical options is

- Crew size
- Launcher and LEO strategy
- Spacecraft configuration
- Interplanetary trajectory
- Interplanetary propulsion system
- Mars orbit insertion
- Descent vehicles and Entry Descent and Landing (EDL) strategy
- Mars orbit to Earth orbit strategy
- In Situ Propellant Production (ISPP)
- Overall redundancy and multiple missions strategy

Space transportation system

- At 7 to 20 k$/kg, transportation to LEO is the recurring cost (the total launch cost is about 20 billion $)
- Only short- and long-stay missions aimed to the surface of the planet are considered (no flyby or ‘indefinite stay’ considered)
- A long discussion is made about the relative merits of solutions based on chemical and on nuclear (both thermal and electric) propulsion. Also solutions based on solar electric propulsion are discussed

Planetary infrastructure

- Habitat (with life support system)
- Power system (quite large quantity of energy)
- Rover(s)
- In-Situ Resources Utilization (ISRU) plant
- Workshop(s)
- Greenhouse(s)
- Auxiliary equipment

- Exploiting existing lava tubes may be highly beneficial to increase the habitable space in a radiation-safe condition

The outpost on Mars

- Regolith can be used for building the outpost
- A greenhouse can be used to grow food
- Astronauts must have the possibility of fixing their equipment
- Additive Manufacturing is an important asset for the possibility for the astronauts to build their own spares. It would greatly enhance safety and at the same time reduce the need for a large stock of spare parts

The planetary infrastructure

- One large pressurized rover is needed, or one or two small unpressurized vehicles similar to quads
- Batteries or hydrogen-oxygen fuel cells
- It is possible to use a conventional internal combustion engine, fueled by a methane-oxygen combination produced on site
- Some robotic, or teleoperated, rovers
- The outpost requires many consumables, which may be either carried from Earth or produced on site

The ground sector

- Although apparently a less important issue, a number of infrastructures on Earth are instrumental to mount a Human Mars Mission
- They include the communication network, the ground control centers, the astronaut training facilities and all the labs for performing ground simulations of the various devices
- Since the mission will be performed by a number of nations, the centers shall be distributed among the various participants, and this may cause political problems

Mission architecture options

The road leading to a human Mars mission is made of a number of preparatory missions

- Two specific missions are highlighted:
  - a heavy robotic Mars sample return mission
  - the second is not exactly defined but would have as primary objective to test and qualify the manned habitat for a 3 years journey without resupply

- Even if no reasonable goal about the date for a first manned mission to Mars can be stated, it is possible to state that it could be undertaken earlier if chemical propulsion is chosen for interplanetary transportation.

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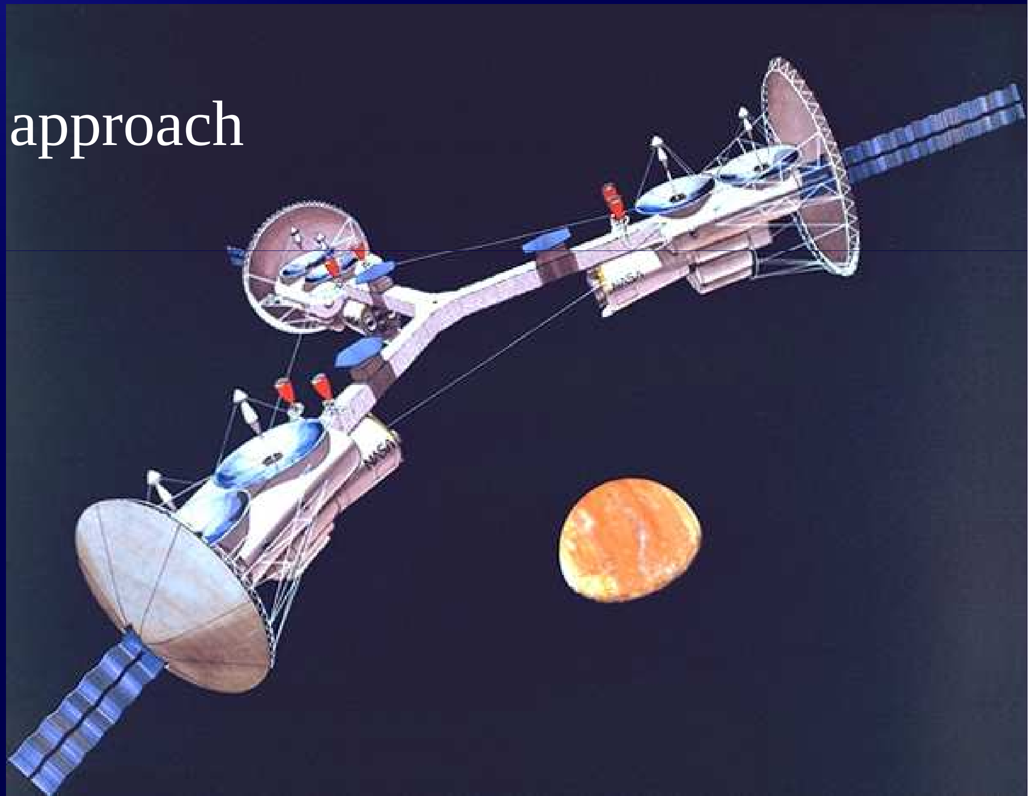

Recommendations

Define an International Mars reference mission scenario, with the involvement of Space Agencies/Industries, to agree on a preliminary technical baseline and the required technological decision milestones, for instance:

1. Nuclear thermal and nuclear electric propulsion
2. Zero-boil off technology for cryogenic propellant storage
3. Nuclear power generator for in-space and on-planet usage
4. Passive or active radiation shielding technology
5. Artificial gravity in space
6. Study of the effects of Mars gravity
7. Aerocapture technologies for large payloads
8. Life support systems, in particular regenerative ones
9. In Situ Resources Utilization (ISRU) systems
10. Exploration technologies, robotics, rovers, drillers, etc.

Reccommendations

- Improve the common knowledge of the human factors, as the most critical issue for the Mars mission
- Foster the global involvement of countries, in particular of the emerging and developing countries, through the existing subjects like ISECG, UNOOSA-HSTI, IAA, etc.
- Study the development of a **Human Mars Mission Feasibility Index**
- Clarify the interdependence between a human Mars exploration mission and the development of a viable cislunar industry

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Follow-up

Starting a new IAA study on human Mars missions aimed to deepen the following points:

- Economical aspects and interaction between private business and exploration
- Study the related business cases
- Delve in greater detail on the affordability of human Mars missions
- Define the stepping stones and discuss how the validation of the relevant technologies can be performed
- Develop the **Human Mars Mission Feasibility Index**

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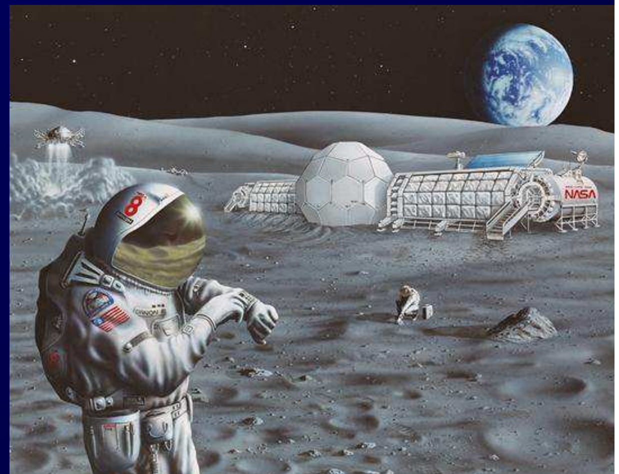

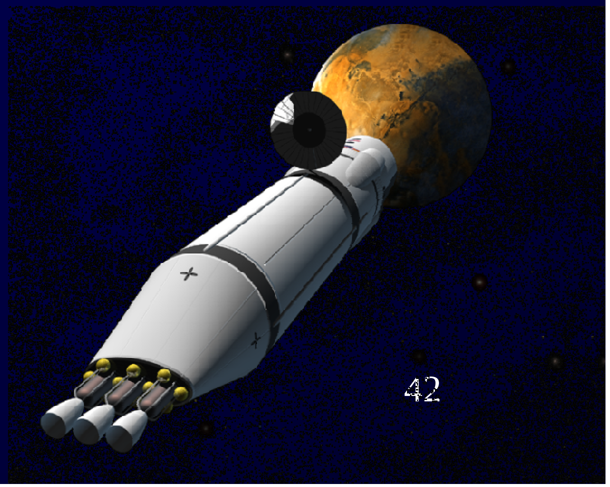

Conclusions

- The human Mars exploration is considered – for the time being – the final goal of human space exploration
- The robotic Mars exploration had outstanding successes
- Many other steps must follow to proceed along this path, as shown by the ISEGC exploration roadmap
- Sending humans to Mars and bringing them safely home is a formidable task, requiring a long-term engagement of a number of countries, working together in the most complex and daring collective effort ever performed by an international group in times of peace

Conclusions

- The first critical step is reaching Earth orbit. Any decrease of cost in this phase may make the large IMLEO involved in Mars missions more acceptable
- Human factors are critical to mission success, most certainly those linked to microgravity and radiations
- Psychological factors are critical
- Among the most critical technical factors are those related to deep space propulsion, either conventional, with high TRL and lower cost, or more advanced, requiring more R&D investments but allowing faster transit and opening the way to future developments

Conclusions

- Sustainability is a critical point, and to improve it the development of a cislunar industry is essential
- Humankind cannot afford a false start on its way to Mars, and affordability and safety must be taken into consideration since the beginning
- A single accident, in particular if leading to the loss of the mission or, even worse, to the loss of the crew, or even minor setbacks may cause the discontinuing of the program with a setback which may last decades
- As a conclusion of the study, a number of recommendations regarding all the aspects of the mission are forwarded

Conclusions

The first mission to Mars must not be just a flag and footprint mission and the final point of an ancient dream, but a mission which will open a new era of exploration, aimed at transforming humankind into a spacefaring species