

ESA/AURORA-BP(2002)5
Paris, 2 April 2002
Att.: Annexes a + b
(Original: English)

EUROPEAN SPACE AGENCY

Aurora Board of Participants

Input on Aurora Strategy for the Exploration Programme Advisory Committee (EPAC)

Summary

The document presents the Aurora strategy as formulated by the Executive and the Potential Participants to the programme, including the evolution since the Programme's approval.

It has been prepared in response to the request formulated by Delegations at the first ABP, and given to the EPAC as an input to its work in consolidating a long-term plan for Aurora.

Required decision

Aurora Participating States are invited to take note of this document.

Contents

- 1. Introduction**
- 2. The context**
- 3. The philosophy**
- 4. The future of human exploration**
- 5. The technology drive**
- 6. The robotic missions**
- 7. The scientific aspects**

Annexes

- a. Mission proposals from the call for ideas**
- b. Executive Summary of the Primes work in support of Aurora**

1. Introduction

This document is meant as an input to the Exploration Programme Advisory Committee (EPAC).

One of the main tasks of the EPAC will be to support the executive in the definition of a long-term strategy for the Aurora programme and in the identification of the main missions and technologies to be proposed for its implementation.

This document constitutes therefore a summary of the thinking and learning on the part of the executive during the preparation of the Programme Proposal and since the start of the programme in January.

Even if the work on the Programme Proposal ended only in October 2001, some relevant strategic evolutions should be added:

For the first time, the ESA Member States and Canada agreed to a programmatic framework and nominated a Delegate Board to prepare future exploration. This is a significant step and difference with respect to previous efforts in this sense, and it signals a new climate in Europe concerning exploration.

The embryonic strategy for the programme, outlined in the Aurora Programme Proposal, has been approved by Member States and constitutes the basis of this document. The strategy is to prepare the future of human exploration through robotic means and as an incremental process, which looks at closer targets first, such as the Moon, the Asteroids/NEO's and sees in Mars the most attractive final target. Recent papers from the IMEWG and the Planetary Society support such an approach. This gives additional confidence that Aurora is moving in the good direction and points to future possible cooperation venues.

The interest raised by the Aurora initiative, even if a relatively low profile was adopted during the preparation phase, is further proof that this is the right moment to build such a programme in Europe.

2. The context

2.1 Political ambitions

Europe, as made up by ESA and the EU Member States, has the highest GNP in the world, 380 Million people and a long history of cultural & scientific leadership, expressed through great exploration and discovery achievements. EU wants Europe to be the most dynamic knowledge driven society by the end of this decade. ESA and the EU research ministers agreed on a joint European Space Strategy calling for ESA to prepare the next step of human exploration, i.e. the human exploration of the planets. The Search for Life is emerging as one of the strongest motivators of public interest in space activities.

2.2 Programmatic realities

Europe spends about 1/6th of the US in space activities, and has not made independent human access to space a strong priority. France and Italy are basing their Mars exploration programmes on NASA cooperation. Current NASA plans seem however less clear on the long-term opportunities.

In ESA the science programme is the leading programme for planetary exploration. However, it does not foresee another Mars or Moon (after Mars Express and SMART-1) mission before its Bepi Colombo mission to Mercury. Proposals for missions to asteroids (Master) or Moon (Moro) have not received high priority in the past and a recent call for a re-flight of the Mars Express platform selected Venus as the target. Clearly, the need for a balance among different scientific disciplines and budgetary constraints, make it difficult for the ESA Science programme to support a regular series of missions to the same planetary targets, as required by the preparation for human exploration of the planets.

In situ Exobiology activities in ESA are included in the Microgravity programme (naturally evolving from the life sciences work), in itself part of the Manned Spaceflight programme. Although a significant amount of work has been invested in the definition of scientific objectives for exobiology and a preliminary design for a scientific multi-user facility, no missions are foreseen to actually carry such a facility to its target planet (Mars).

As part of the same life sciences programme, a number of activities, including simulation, have been carried out on the medical aspects of long human flights.

A number of studies have been carried out to define scenarios & technologies for human exploration of Mars and Moon. Because such missions were never firmly anchored in the ESA long-term plan, associated work and technologies did never progress beyond the preliminary study phase.

These elements from other programmes shall be taken into account in the definition of the Aurora Programme. For this reason, the Aurora Programme is multidisciplinary and interactive with other programmes and it constitutes an opportunity for cooperation with all exploration related programmes within and outside ESA.

2.3 The Aurora Programme

As approved by the Ministers at the Edinburgh Council, the European Space Exploration Programme Aurora is an optional programme of the envelope type. This means that the funding is allocated by participants to fulfil the objectives of the programme through a consistent set of spacecraft missions and technology developments over an extended period of time, as opposed to single mission or development programmes. The funding for an envelope programme is released to cover consecutive 5 year periods of the programme at a time, which allows for continuity of activities, re-planning when necessary and overall optimal usage of resources. This form of programme ideally combines the planning flexibility of the mandatory programme with the financial flexibility of the optional ones.

The programme has two components: a Definition component, to support planning, feasibility, scientific and outreach activities, and a Development component, in charge of missions and technologies development. At present the funding for the programme is limited to the 3-year preparatory period, which has only the Definition component. The Aurora programme as approved goes, however, beyond the preparatory period and covers as well the following periods. On the year preceding each new period, participants shall decide the funding for the following period on the basis of a proposal by the Executive. The main objective for the next two years is therefore to define the detailed strategy and the proposal for the developments needed for its implementation.

In deciding the programme, the ESA Council also adopted the specific implementing rules, which lay down the interactions between the Executive and the Member State representatives through the Aurora Board of Participants (ABP) and the role of the EPAC.

The preparatory period was subscribed in November by: A, B, CAN, CH, F, I, NL, P, E and UK for a total of 14.1 MEURO.

3. The philosophy

The Aurora Programme philosophy is based on the following considerations:

Experts agree that a human mission to Mars cannot be launched before 15 to 20 years. This is not only based on sheer programmatic considerations (it took 20 years to get the ISS on orbit) but also on technical and the human physiology aspects.

The technical readiness aspects, in particular need careful consideration: for example, to date the success rate of the US and Russian robotic missions to Mars has been very modest.

System studies are useful, especially in terms of mission analysis and architectures but technologies also need to be developed and tested, not only studied. Robotic missions will not only serve to develop technologies but they will also provide training for the engineers who will put humans on the planets while providing valuable scientific opportunities for exploration. This also applies to the medical scientists and biological community.

Because the decision to send a human mission to Mars or the Moon is a major one and it will probably not be borne out of a political race like in the Moon case, the priority for Europe is in preparing the conditions for that decision to be taken with the best possible knowledge, resolve and position as an international player.

Some of the influence of this philosophy on the Aurora programme strategy can already be identified:

1. Robotic missions driven by the need to demonstrate technologies for human exploration will preferably target planets where humans can go first, i.e.: Moon, Mars, or asteroids due to simpler and less energetic scenarios;
2. Among the typology of missions, landers & sample return are more closely related to the end goal than remote sensing missions;
3. Among the scientific disciplines, exobiology presents 3 main characteristics with respect to Aurora:
 - Humans should not be sent to Mars before an as accurate as possible investigation of the presence of any life form on the surface has been conducted. Once on site, humans can further the search through better identification and analysis of research sites and more complex operational skills.
 - Both the Search for Life and Human exploration are looking for water as a fundamental resource.
 - Technologically speaking, with the exception of the search for extrasolar planets and of organic molecules in space, the search for life equates with in situ sampling or sample return. This in turn reflects the technological similarity with the human mission requirements.

4. The future of human exploration

The European Space Strategy (ESS) which was endorsed by the EU Research Council and the ESA Council calls Europe to prepare “... *for the ‘next step’ in human space exploration: the exploration of the Solar System*” and to take action for: “...*stimulating new technological advances and inspiring our youth towards scientific interest...*”. No credible scenario exists today for this next step, which must be initiated now as the International Space Station ISS nears completion. Given the time-span of such a human mission, Europe also faces the issue of how to exploit the industrial know-how developed in the ISS framework and to orient it toward the new mission. Such future endeavour, all agree, will be an international one, and the role which each participant will be able to play, will inevitably depend on the technological and scientific progress achieved by the potential participants and their political resolve. An independent European strategic view of the future of human exploration will provide the framework for its own exploration activities. Furthermore, such an effort will bring a fresh contribution to the US and CIS reflections on the subject.

4.1 Planning for human exploration

In the past, human exploration studies beyond the Moon have mainly concentrated on Mars, being relatively close and the most Earth-like planet in the Solar System. The first serious plans to send humans to Mars were published in 1951 by Wernher von Braun. These plans were up-dated and enlarged during the Apollo era with the intention to use the Saturn V launch vehicle once the Apollo Programme would be completed. With the cancellation of the Saturn V after the end of the Apollo Programme the immediate possibility to send humans to Mars ended.

Only a few further studies were done until the US Congress mandated an activity that eventually led to the SPACE EXPLORATION INITIATIVE, which was endorsed by President Bush in 1989. This initial plan was followed by a series of studies by industry.

In the early Nineties a NASA Team compiled the “NASA Reference Mission” which was derived from a split mission concept (Zubrin). In such a scenario, the return vehicle is sent ahead of the human mission, and refuelled using ISRU. This reference mission was used as a basis for a continuing series of studies, amongst others also by ESA's “Groupe de reflexion”, which looked at the European interest in the reference mission.

The 4th Cosmic Study of the International Academy of Astronautics, published in November 1997 (tbc), proposed an effort to establish the technical and political issues for an international co-operative exploration programme. In view of the high cost of human Mars exploration and in an effort to share the development cost of the needed heavy launch vehicle, the following 5th Cosmic Study (2001) proposed an integrated lunar and Martian exploration and development programme.

In the meantime the NASA Exploration Team has further enlarged the range of studies in an effort to widen the support for the creation of the necessary infrastructure and it

proposes a “stepping stone approach”. The stepping stone approach defines core capabilities and enabling technologies for a wide range of applications, including commercial use of space, and suggests developing these capabilities and technologies successively to enable humans to live and work longer and further away from Earth. It is expected that this approach will enable a new or re-elected US President one day to take a decision on a new Exploration Initiative, a decision, which can then be based on demonstrated capabilities and available technologies. In view of the recent events the timing of such an initiative is wide open. The key elements of such a decision are funding and the level of risk which is considered acceptable.

ESA has at various times in the past initiated studies on possible scenarios for human exploration of the planets. The MARSEMSI (1992), SISTEMSI (1993), ADAM & EVE (1997) studies looked at a direct evolution toward planetary exploration of the elements being developed in the frame of the Columbus programme. More specifically oriented toward Moon exploration, the Mission to the Moon study (ESA-SP1150, 1992) and the Beateberg Workshop (ESA SP 1170, 1994) scenario for Moon exploration, laid down an European strategy which was a precursor to the Aurora one, by starting with robotic landers and evolving toward robotic first and later human outposts. This generated studies on lunar resources (1994), robotics (ROLEX 1996) and the LEDA and EuroMoon studies. Finally, recent studies (2000-2001) looked at possible European visible, self-standing contributions to the NASA reference Mars human mission scenario. This were the “European Mission Architectures and Technologies in the Mars Exploration Scenario”, the “Future Power System for Space Exploration” and the “Automation and Robotics for human Mars exploration” studies. Also the impact on humans of long duration flights has been analysed at a preliminary level in the Humex study.

In parallel to these scenario studies a number of technology studies and bread boarding related to exploration technologies has been sponsored by ESA. For example in the rover, energy production (fuel cells, electrolyzers, etc.) and life support systems (MELISSA) areas.

4.2 ESA's approach to human exploration

ESA's approach to human exploration is determined, on the one hand, by the desire to play a significant role in an international endeavour, and, on the other hand, by the necessity to focus the effort and to take advantage of synergies in order to keep the expenditure at an affordable level. It is therefore proposed to elaborate a framework for human exploration, which has Mars as its main objective, because this planet is the most likely target for human exploration. It is the most Earth-like planet of the Solar System and recent indications of the presence of water raise the likelihood of being able to find traces of life on its surface. Clearly, the Moon and the Asteroids/NEO's are considered important intermediate steps.

Consequently ESA suggests for the Aurora Programme to define a sequence of robotic missions, which will successively develop the capabilities and enabling technologies necessary for a human mission to Mars. These robotic missions shall (also) collect the

information necessary to prepare the landing of humans and provide opportunities for scientific research in exobiology and life sciences whenever possible. This dual role of robotic missions will ensure that the effort and expense of getting to Mars provides valuable scientific results and reduces the risk and cost of human exploration.

Robotic precursor missions will also establish under which conditions human presence is possible and what role automation and robotics is able to play in assisting human exploration.

4.3 Phases of exploration

Human Exploration of the Solar System, and especially the exploration of Mars, will most probably proceed in the following sequence:

- Remote sensing from the planetary orbit,
- Surface analysis and exploration,
- Return of a sample from the surface of the planet,
- In-situ resource utilisation (ISRU)
- Robotic outpost,
- Human exploration phase

These phases will certainly overlap to a certain degree but they will all provide necessary information and technology demonstration for subsequent phases. Not all the necessary steps will be part of the Aurora programme, indeed all Agencies are increasingly coordinating the efforts in exploration thereby contributing missions which respond best to each Agency's requirements and constraints (for instance in most cases Aurora is expected to benefit from the results of remote sensing data from other programme's missions). In order to better approach the definition of a framework for the Aurora Programme an attempt must be made to define for each of these phases technology readiness requirements, intermediate exploration tasks and opportunities for scientific research. In doing so it must be made sure that technology readiness is progressively elevated to the level necessary for a human mission. In parallel the knowledge of the target planet must be improved in order to be in a position to decide whether or not to send humans and where to send them.

Preparation for human exploration of the Solar System has also to take human factors and physiological aspects into account, because long interplanetary missions can subject the crew to significant stresses, like radiation, hypogravity, isolation/confinement etc. It will be necessary to improve our knowledge of these stresses and their effects on humans before deciding such a mission. Research and simulation on ground but also inhabiting and working on the International Space Station ISS will help significantly in this respect.

4.4 Elaboration of the Framework for Exploration

An independent European strategic view of the future of human exploration shall provide the framework for the exploration activities within the Aurora Programme. The

elaboration of this framework will have to be organised on two levels. On the higher, strategic level, the EPAC, perhaps with support from hearings of key personalities, will have to define the goals and interests.

On a more technical level, a technical working group will have to define a European view of how to reach that goal. This effort will require significant technical expertise of the members of the group, which can be complemented by support from industrial and academic contractors. An important input for the group will be information on present activities in international technical forums, like ISTC, IAA, NASA HEDS, etc. Also studies performed in Europe in the early '90s should be revisited for the validity of some of the analysis work (trajectory, etc). However it is very likely that the overall scenario must be revisited in the light of the lessons learned from the ISS or the new knowledge relative to the environment of Mars.

5. The technology drive

For each of the phases of exploration introduced in the previous chapter, technology availability and readiness requirements can be defined to enable the tasks to be accomplished in that phase. In a number of areas (soft & precision landing, alternative power generation, aerocapture, etc.) the technologies to fulfil these requirements do not exist yet, or not at European level. The Aurora technology drive is geared to allow Europe to acquire sufficient knowledge of the necessary technologies to be able to decide which should be given priority for development at European level, and to have sufficient competence to judge the necessity/value of those offered by partners. This status can be compared with the inventory of technology studies from TRP, GSTP and similar activities by the Science Directorate and at national level. The difference of the two defines the areas in which the Aurora Programme will have to invest mostly in this preparatory phase.

Taking into account the Phases of Exploration as defined in Section 4.3, the technology steps to be taken are as follows:

5.1 Remote sensing

The techniques used for this phase are basically a derivative of Earth Observation Instruments. Presently a number of missions are under way from US, Japan and European Agencies, dedicated to this type of observations. The main scope of these missions is to provide a better understanding and modelling of the Mars environment including Mars atmosphere composition and Mars surface properties. The basic capabilities for this type of mission already exists, the challenge is to integrate all the data in a consistent model. In some cases the remote measurements will have to be integrated by local measurements in real time. Typically this may concern the need for weather stations at the surface of Mars, to take into account the variability of the Mars atmospheric conditions.

5.2 Surface analysis and exploration

The technologies needed for this phase of exploration encompass a large number of disciplines, which need to be mastered to a different degree, depending on the complexity of the landers and ground operations foreseen. The main technological steps needed in this exploration phase concern:

- Entry, descent and semi-hard & soft landing
- Precision navigation and landing
- Aero capture / aero braking
- Advanced electric propulsion
- Landers
- Surface Power generation & storage
- Surface mobility / Rovers
- Provision of a reliable source of energy for Rovers
- Exobiology instrumentation
- Drilling and in situ sample analysis
- Weather stations
- Radiation monitoring
- Mars environment, weather and dust models validation
- Planetary protection technologies

As a correlated activity the provision of a telecommunication infrastructure in Mars orbit may be very beneficial. Ultimately, for a more complex mission scenario this may become a necessity. For the first missions, however, the Orbiters themselves should provide sufficient capability to ensure the autonomy of the mission.

5.3 Return of a sample from the surface of the planet.

For missions in this phase it is expected that the provision of a reliable source of energy at the surface of the planet may become more stringent than for missions in the previous phase.

The additional technologies related to this phase of exploration mainly concern:

- Precision & Soft landing
- Drilling and sample handling
- Ascent vehicle
- Rendezvous and Docking (RVD) in Mars orbit
- Sample return vehicle
- Earth re-entry capsule
- Aero capture in Earth atmosphere / ballistic capsule
- Planetary protection technologies and facilities

Precision landing may be critical to this mission, concerning the landing site selection and the possible utilisation of existing infrastructures (landers, rovers) from previous missions.

The development of the technologies listed above should be carried out in steps to avoid cumulating too many risks on a single mission. Some of the technology development can also be combined with missions of scientific interest to other bodies than Mars, namely Moon and Asteroid with the aim to optimise the available resources in the frame of Exploration.

5.4 In-situ resource utilisation (ISRU)

The main areas of interest, on the side of robotic exploration, concern:

- On site fuel production using CO₂ from the Mars atmosphere and H₂ carried from Earth or derived from water ice, if available on the Mars surface,
- Generation of energy using locally produced fuel by chemical or mechanical processes.

5.5 Robotic outpost

A robotic outpost is expected to be the final step before a human mission to Mars will get underway. The main task is therefore to validate all the necessary technologies including:

- Man rated transportation system,
- Provision of a reliable and powerful source of energy on the surface of the planet,
- Radiation protection facility,
- Man rated return vehicle,
- Validation of the Environmental Control and Life Support (ECLS) systems

5.6 Human exploration phase

The technologies needed in this phase are essentially the ones developed in earlier phases scaled up to the requests of a human mission. The presence of humans on the missions increases the safety requirements significantly and makes extensive medical and biomedical preparations necessary. Technologies are specific to a human mission alone, such as life support, waste recycling, medical support, etc. must be developed mainly through ground research/development in parallel to the robotic missions (see ch.7). Missions in this phase will be done in co-operation with International partners due to the complexity and cost of the enterprise. This needs a rather long term planning and a definition of priorities at European level to identify the main areas of interest and of strategic value.

6. The robotic missions

6.1 Selection Criteria

Robotic missions, together with technology development and scientific preparation constitute the starting point for Aurora. The approach to their selection is of course different according to the timeframe considered. Missions for which the development phase should start in the 2005/2009 period, should ideally be selected for feasibility assessment this year, in order to go into ph. A next year (2003) and be submitted for decision at the programme review in early 2004.

Thus, **the foreseen/likely launch date becomes a first discriminator** between missions that should be assessed in priority and missions that can be considered as part of the long term plan reflection. Once the first set of missions is decided, the launch date will become simply one mission requirement to be fulfilled.

The **second criterion is tied to the technological step** that can be achieved in a given mission. While for the long term this criterion may lead to identification of broad mission classes, in the near term the choice is limited by the development time of the technologies.

Finally, **the scientific objectives are the third criterion**. In keeping with the ESA tradition, once a mission is selected, the Agency would issue a call for ideas for the scientific experiments. Here as well, the criterion should be tied to the end objectives of the programme, that is the need to verify the existence of extant or extinct life forms, the characterization of the environment that may support further mission planning (water, In-Situ Resource Utilisation likelihood, radiation environment, atmosphere characteristics, etc.)

Cost should clearly be an important consideration, but it should be given as a target during the feasibility analysis of the missions. The current lack of definition makes it impossible to use cost as a discriminator at this stage.

6.2 Missions proposed

The missions listed in Annex a. and b. are a grouping of mission ideas coming essentially from 3 sources:

- The Call for Ideas issued in Feb. 2001 (Annex a.)
- Existing ESA studies relevant for the Aurora programme (annex b.);
- Missions planned by other Agencies which may offer an opportunity for cooperation (annex b);

As such they are described in very different levels of detail and in some cases represent little more than a scientific requirement. They give however an overview and feeling for

the European community's wishes for exploration missions (it must be noted that the call for ideas was less focused than the programme is now). Existing ESA studies started from specific missions requirements, which may need to be modified in view of the Aurora objectives. Finally opportunities for cooperation carry their own technical and political constraints and need agreements to be in place before real analysis work can start.

In the end it may be necessary to identify a mission, which can satisfy a subset of the technological steps outlined in the previous chapter, and then issue a call for scientific opportunity instruments.

7. Scientific Aspects

The response to the Aurora Call for Ideas clearly shows the scientific interest associated with human and robotic exploration missions. An analysis is shown in Annex a., and it should be added that a number of the proposals came from laboratories and scientists new to space research.

In this chapter the emphasis is placed on the specific scientific preparation work that should be associated from the start to the Aurora programme, to support the requirements definition of both robotic and human missions.

It should be highlighted how this area of work may be the most promising for short term technological spin-offs in areas related to:

- human physiology diagnostic and health care equipment,
- planetary protection and relative sterilisation and life forms detection techniques
- closed environment & life support systems, which can be already tested in arctic missions;
- etc.

7.1 Plan of ground activities

In this plan for ground based activities in preparation of future planetary exploration missions we will focus on mainly three topics:

- Planetary Protection,
- Sample curation facility and
- Human related issues

In the following paragraphs general strategies/approaches for each of these topics will be described.

7.2 Planetary Protection (PP)

Planetary Protection (PP) is a topic of extreme importance for any mission (orbiting or landing) which targets another planet that is of interest in the search for life. PP encompasses avoiding contamination of:

- The target planet by Earth micro organisms and organics
- Earth by potential organisms from other planets (e.g. through returned samples)
- Samples that are to be examined for traces of life either in situ or for a returned sample

Clearly, from the Aurora Programme standpoint, active involvement in this issue will follow the Space Science Programme's one from Beagle-2 and that acquired from the Netlander experience.

7.3 Sample Curation Facility

Connected to the topic of PP is the issue of a sample curation facility. As Sample Return Missions (especially from Mars) are envisioned as a complementary step to in situ exploration missions there will be a need to have a structure in place for the curation of those samples, which should be safe with regard to PP and at the same time ensure the maximum of scientific research productivity. This is a very complex issue, which needs a lot of preparation and expertise.

One of the recommendations for actions in the next 2-3 years from the April workshop following the Call for Ideas described the need to start larger meteorite collection activities in Europe. This would be a starting point to develop at first a curation facility for meteorites. This experience could then be extended to the kind of facility needed for returned samples from other planets, while the (then) ongoing meteorite curation activities would develop operational experience.

A possible way to proceed could be envisioned as follows:

- Assembly of a science team to meet 3-4 times over a period of 9 months to define the requirements and a concept for a meteorite collection programme and a sample curation facility. This science team should include people involved in Arctic/Antarctic programmes, scientists, and people with experience in the curation of specimens (e.g. natural history museums).
- According to the output of the science team a call for proposals from universities and museums for co-funding and realisation plans can be initiated.

7.4 Human Related Issues

Much of the research that is currently conducted in the frame of the life and physical sciences programme of ESA is relevant to future human exploration missions. Nevertheless long-term human planetary exploration missions pose some challenges that are beyond the scope of current activities.

One major field that will need extensive new research lines is the issue of psychological reactions to confinement and isolation, as well as aspects of medical support during long duration missions and operational aspects. This complex theme is best tackled through analogue environment studies and dedicated simulation studies. Thus four major activities are foreseen:

- Use of the Concordia Antarctic Station as analogue environment in preparation of exploration missions. A letter of intent for cooperation on this topic has been signed by the directors of IFRTP and ENEA (PNRI), the organisations building Concordia and the Director General of ESA, CNES and the President of ASI. The creation of a working group with representatives of these organisations is foreseen. This group will be responsible for the implementation of this cooperation, which will not only encompass science, but also specific technology tests in a harsh environment or, for example the routine use of technologies developed for space. In the last sense a framework agreement for the co-funding of the implementation of a grey water recycling system (technology developed for ESA) in Concordia is currently in preparation.
- Use of a dedicated simulator at the Institute for Biomedical Problems (IBMP) in Russia. This activity would be a cooperative study or sequence of studies to examine especially psychological aspects of long-term confinement and isolation, in combination with a high degree of crew autonomy. Here a letter of intent for this kind of cooperation and a small study to assess possible scenarios and technological issues are currently in preparation.
- Organisation of a workshop (planned for June/July 2002) to develop the research priorities for planetary exploration simulations in general as well as specific priorities for the different facilities.
- Development of a concept for a new European Mars (Mission and/or Habitat) simulator. This simulator should provide the capability to perform research on those aspects that cannot be studied with the other available facilities. A multidisciplinary team including for example an architect, a psychologist, an MD, will work on a pre-Phase A level design, taking into account the conclusions of the abovementioned workshop, the REGLISSE study, which is currently running, and other sources. This activity is foreseen to start in the first half of 2002.

7.5 Other ground-based activities

In addition to the three major activities, examples of other lines of research should be mentioned.

Research in advanced countermeasures, for example the use of small radius centrifuges in bed rest studies must be conducted. This will probably be included in the ongoing activities of the Life and Physical Sciences Programme, where similar studies are routinely performed.

ANNEX a

Proposed Missions for the Aurora Exploration Program

The following three chapters describe mission scenarios for Mars, the asteroids and for the Moon based on the results from the *Aurora* “Call for Ideas”. The timeframes for the respective missions are best estimates based on information available.

Technical support for all three mission targets, Mars, the asteroids and the Moon, is required. A common theme amongst all three is the need for an advanced power source. The specific technological support is described at the end of each chapter together with the proposed missions.

The need to reduce launch costs might require the use of new opportunities for small payloads (e.g. network landers), like the *Ariane 5 ASAP*.

The original text of the Call for Ideas is included at the end of this annex.

Mission relevant aspects for the Aurora Mars exploration program

We, certainly, cannot say how life originated and developed on other celestial bodies under the conditions peculiar to them. But it stands to reasons that the organisms forming in the process of biological evolution must differ essentially from terrestrial animals and plants since it is the environment that forms life.

Aleksandr Ivanovich Oparin (1894-1980)

About 50 proposals are specific enough to categorize them in mission scenarios for a future Mars exploration program. The numbers at the end of each paragraph represent the number of proposals that are relevant for the specific section (Table 1, 2, 3).

The search for extraterrestrial life in the Universe will dramatically affect our view of the world and our place within. In our solar system, Mars has the highest probability of harboring extinct or extant life. A comprehensive approach to the search for life on Mars requires a long-term exploration program including a mix of many different components: remote sensing, independent landers, network landers, sample return and human missions. Each technique is suitable to address different science objectives. A well-defined strategy for the use of the individual components makes a successful exploration program.

The scientific goals of future Mars exploration are to determine the present state and the evolutionary history of Mars in order to prepare for a manned Mars mission.

There are two interconnected themes that can describe this goal: to determine the planetary thermal evolution, and to determine the atmospheric evolution. Knowledge on both themes is essential not only for the aspect of space science and comparative planetology but even more so for exobiology, in-situ resource utilization and human missions to Mars.

Exobiology

The search for life is almost equivalent to the search for liquid water. The inventory and evolution of volatiles in the solid body as well as the evolution and stability of the atmosphere are the determining conditions for any occurrence and evolution of pre-biotic relevant compounds to the origin of life. If it were found that the conditions for life to start had been present in the history of Mars, the objective would be to locate environments that might still harbor the remnants of extinct life or the presence of extant life. Detailed knowledge of the Martian surface is required for this task.

In-situ resource utilization (ISRU)

Physical limitations are the most stringent constraint of any space mission. Using resources on Mars to produce fuel and water would dramatically reduce the cost of future robotic and especially manned Mars missions. Knowledge about the atmospheric composition as well as potential subsurface water reservoirs is key to develop and use ISRU systems for future Mars missions.

Manned Mars Mission

All aspects of robotic exploration missions to Mars (remote sensing, lander, sample return) are essential precursor missions to deliver people to Mars and return them safely to Earth. They can provide three key information's: (1) detailed knowledge of the engineering aspects, (2) scientific potential of prospective landing sites and (3) discriminate between those tasks that are best done by humans and those that are best done by robots.

- (1) Engineering aspects include: knowledge about the atmospheric conditions in the upper (wind shear) and lower (landing system depended) atmosphere (by a global meteorological network, high flying remote sensing and in-situ).

Knowledge about surface elevation, block and slope frequencies (by global geodesy of low flying remote sensing spacecraft).

Knowledge about the surface chemistry and physics related to ionizing radiation, UV radiation, aggressive chemicals in the soil, electrostatic charging and abrasive character of dust particles (in-situ landers).

- (2) High scientific potential of prospective landing sites are of great importance considering the considerable resources that will go into a manned Mars mission. Robotic precursor missions must provide the necessary information to identify these landing sites.
- (3) Scientific questions will be re-defined continuously as robotic missions provide more and more information about Mars. This will influence the tasks (selection, training and mission profile) for human missions.

Implantation of exploration objectives – Mission outlines

Global remote sensing has priority before any complex lander missions in order to locate sites that are worth the effort to put a lander on the surface. The best instrument suit will be useless if used in the wrong environment. Two exceptions are geophysical and meteorological networks. Both can, and should be part of an early exploration phase because of their inherently long operational lifetime.

The scientific instruments required to investigate the geophysics, geochemistry, geology and atmospheric science are available today. Some adaptations, however, are required and should be addresses in an appropriate technical support program.

Remote Sensing (16)

What is required for remote sensing on Mars is a monitoring mission scenario and not a survey mission scenario. That means dedicated orbiters for one purpose, except for the additional use as relay satellite. Two categories of orbiter missions are evident (1) short lifetime, low flying orbiters and (2) long lifetime high flying orbiters.

- (1) The operational lifetime of a low flying orbiter is determined by the specific time required to accomplish its scientific objective. This time might be shorter than one Martian year. Low flying orbiters are required to provide high resolution imaging, VIS-IR and γ -ray spectroscopy, sounding radar and altimetry to determine the chemical and mineralogical composition of the Martian surface, to determine near surface water and ice, to construct a detailed global geodesic model (important for engineering aspects for lander missions, including manned Mars missions) and to correlate the individual features with optical features for landing site selection and autonomous navigation of robotic rovers. Imaging missions are characterized by high pointing accuracy and high data rates. **(9)**
- (2) Long lifetime, high flying orbiters are meteorological satellites that monitor the whole planet for at least one Martian year on the kilometer scale to determine the present Martian circulation pattern. They are characterized by high data rates and power consumption. Their operation has to be coordinated with simple meteorological ground stations. Together that will provide a global, spatially (vertical and horizontal) resolved weather pattern. **(4)**

Navigation and communication networks in support for future surface missions would also fall in the category of long lifetime, high flying orbiters. **(3)**

Surface lander (26)

Surface lander can be categorized according to their life time in two categories: (1) long lifetime lander and (2) short lifetime lander.

- (1) Long lifetime landers are meteorological and seismic networks. Meteorological stations are distributed at different latitudes and longitudes that measure standard meteorological data (barothropic component). Their operation should be coordinated with high flying meteorological satellites (for the baroclinic component). They are characterized by low data rates. Seismic networks record Mars quakes to determine the internal structure of the planet. They are characterized by high data rates. Both, meteorological stations and seismic networks should operate for at least one Martian year. **(8)**
- (2) Short lifetime lander are more or less complex packages to characterize the lander environment (geochemistry, lithology, aspects of exobiology, ...). There is no need for coordinated operation with orbiters, long lifetime or high data rates. Lander missions with rovers are part of this group as well. **(18)**

Sample Return Mission (4)

Sample return missions are important components of a Mars exploration program. Some scientific investigations that are essential to determine the evolution of the planet Mars, like age dating and trace element analysis, are best done in sophisticated Earth based laboratories. In-situ instruments to accomplish this effort are not envisioned at this time. Correlated micro imaging with micro elemental analysis, relevant for biomarker identification, is another area that cannot be carried out in-situ for the foreseeable future. Sample return missions are the one part of a multi-component exploration strategy that is very relevant for human Mars exploration, due to landing, take off, in orbit docking and Earth re-entry technologies and end-to-end mission operations to be implemented.

Manned Mars Mission (8, very specific)

All previous mission components can be considered as precursor mission for a manned Mars mission. Three aspects, however, specifically relevant for the manned Mars mission have to be included in robotic precursor missions: (1) radiation monitoring, (2) electrostatic charging and (3) abrasive character of the dust.

- (1) Radiation monitoring can be included in long lifetime, simple surface units like meteorological or seismic networks. Measurements required are directional and total dose of ionizing radiation and UV radiation. **(6)**
- (2) Electrostatic charging of surface components and dust might be dangerous for sensitive instrumentation. More so is it a problem for manned missions. Charged dust particles that adhere electrostatically on surfaces (space suit) might be transported into the living area with probably harmful consequences (skin irritations, eye irritations and inhalation). Apollo astronauts on the moon had a serious problem with dust in the interior of their spacecraft. However, they were only exposed for a relatively short time to the lunar dust (which might even be less chemical aggressive than Martian dust). This kind of measurement can be included in long lifetime, simple surface units like meteorological or seismic networks. **(1)**
- (3) Physical abrasion of hardware (space suit, helmet) by Martian dust might limit the useful lifetime of equipment with low fault tolerance. This kind of measurement can be included in more complex lander platforms. **(1)**

Conclusions

In order to increase our understanding of life on Mars and to prepare for a manned Mars mission, we need to understand Mars in its origin, evolution and present state. A sequence of missions will be able to achieve this goal.

- There are missions that are independent of other exploration elements: seismic networks and meteorological ground stations can be put in place immediately or later in the program. Both would be relatively cheap and require no further remote sensing information than what we have today.
- Meteorological orbiters are also independent from other elements (except from small meteorological network stations) but are inherently more expensive because of their new characteristic for planetary missions and because of their long operational lifetime.
- Apart from these missions, all surface missions, including landers, sample return and manned missions should only be employed if sufficient remote sensing data for the specific mission is available. The logical consequence is that the first missions to Mars should be low flying orbiters to complete the orbital reconnaissance of Mars (optical imaging, spectroscopic measurements, radar and altimetry with global high resolution coverage).
- After completion of the orbital phase, dedicated lander platforms (including sub-surface drills and long distant rovers) can address specific scientific objectives at well-defined locations on Mars (planetology, exobiology and human safety issues).
- Sample return missions are the next step, although there are voices that want to skip this step and directly go to the manned Mars mission to return samples back to Earth. There are pros and cons for this opinion. Sample return might not be required for a successful manned Mars mission but has high scientific value on its own.
- Manned Mars missions will provide us with the finest instrument available to gain new knowledge about the world around us – humans.

Ground based research has to complement missions. Specific instrument proposals have not been discussed because they do not influence the program architecture.

Remote Sensing	Meteorology	4
	Comm/Nav	3
	Geochemistry	9
Lander	Exobiology	7
	Geochemistry	6
	Geophysics/Meteorology	4
Sample Return		4
ISRU		5
Manned Mars mission		8

Table 1: Number of proposals dealing with specific mission scenarios. Most geochemical lander and orbiter missions are also relevant for exobiology.

Scientific objective	Technique	Type of mission	Timeframe
Understand the history of water on Mars and identify former bodies of liquid water (target selection for exobiology lander)	Imaging VIS-IR spectroscopy γ -ray spectroscopy n-spectrometry	Remote sensing (will be accomplished with ESA Mars Express, NASA '05 Orbiter and CNES '07 orbiter)	< 2010
Understand depositional conditions (sediments) and identify organics. (Biogenic) fractionation and relative ages.	EMF payload (ESA SP 1231)	Lander (e.g. Babakin type of lander, Mars-Exo-BSC-TN 0001, 2001)	2007-2009
Absolute ages, fractionation processes, biomarkers.	On Earth	Sample return (ESA & CNES proposals)	> 2011

Table 2: Mission sequence for Exobiology.

Scientific objective	Technique	Type of mission	Timeframe
Identify locations for landing. Collect engineering data required for a safe manned mission. Provide safe and efficient operation of manned mission.	Imaging Meteorological monitoring Altimetry Navigation/communication	Remote sensing	2010-2020
Human safety	Meteorological monitoring Radiation monitoring Fieldmeter Short term weathering	Network-Lander (starting with CNES Netlander) & airborne monitoring (e.g. balloons)	2007-2020
In-situ resource utilization (ISRU)	Tbd	Lander (payload might be attached to other robotic landers)	Tbd

Table 3: Mission sequence for manned Mars mission. All orbiter and lander missions prior to a manned mission are required to characterize potential high value landing sites. Mentioned here are only aspects that apply directly to the manned Mars mission.

Required technical support:

- Advanced power source (e.g. nuclear) for longer mission duration and for missions to higher latitudes.
- Autonomous rover capability.
- Drill system.
- Aerocapture/braking.
- Precision landing.

Mission relevant aspects for the Aurora asteroid exploration program

The principal conclusion is that impacts of the magnitude proposed by Alvarez and others to explain phenomena observed at the Cretaceous/Tertiary boundary (extinction) are inevitable natural phenomena occurring at a rate of about once per 50 million years.

G. W. Wetherill, E. M. Shoemaker, 1982

About 22 proposals are specific enough to categorize them in mission scenarios for a future asteroid exploration program (Table 1, 2).

Asteroids, like comets, are the remnant population of planetesimals from which the planets accumulated 4.6 billion years ago. The scientific rationale to investigate asteroids is threefold:

1. To increase our insight into the mechanisms and processes involved in the formation and evolution of planets, including the asteroid/meteorite link and the delivery of organic material to the early Earth (Main Belt Asteroids, Trojan Asteroids, Kuiper Belt Objects and Near Earth Objects – NEO's).
2. Using asteroids as a resource in the future (especially NEO's).
3. Identify the hazard that asteroids pose to life on Earth (especially NEO's).

To accomplish this goal we have to:

- Search, identify and determine asteroids and their orbital parameters from ground based and orbital observatories.
- Characterize the diverse population of asteroids with fly-by and landing missions.

There are three aspects that must be stressed specifically for asteroid exploration:

1. Space mission to NEO's are the cheapest interplanetary missions.
2. Studying asteroids will give us a better understanding of the available inventory of extraterrestrial organic matter delivered to the early Earth, and other planets, by asteroid, meteorite and cometary impacts, relevant to the origin of life.
3. Although major impacts of asteroids on the Earth are rare events, their consequences are catastrophic. We are the first generation that can study ways to avoid the single most dangerous threat to mankind's long-term survival.

In a way we can study the origin of life as well as the termination of species with the cheapest interplanetary missions.

Goal	Technique	Type of mission	Timeframe
Identify parent bodies (asteroids) of meteorite falls.	Fireball cameras (support program in progress)	Ground	In progress
Discovery and tracking of NEO's and Interior to Earth asteroids (IEO's)	Near Earth Space Surveillance Mission (NESS) (support program in progress)	Earth orbit	In progress

Table 1: Ground and Earth orbit component of an asteroid exploration program.

Goal	Type of mission	Timeframe
Characterize asteroids (geochemistry, geophysics)	Fly-by on <u>multiple</u> asteroids of different classes	2008
Characterize asteroids (geochemistry, geophysics)	Landing and in-situ exploration on <u>multiple</u> asteroids of different asteroid classes	2010-2020
Characterize most primitive cometary material	Mission to a long period comet	2010-2020

Table 2: Flight component of an asteroid exploration program.

Search, identification and characterization of asteroids (either in the main belt or NEO's) are essential before committing to a fly-by or lander mission. The emphasis on fly-by missions is on visiting multiple targets (different asteroid classes).

A fly-by and/or landing on asteroids are essential to characterize the internal structure of these objects. Based on observational evidence, a great number of NEO's are believed to be gravitational bound rubble piles. If this is the case, any method to deflect or destroy an Earth approaching asteroid must reflect this circumstance.

Required technical support:

- Advanced power source (e.g. nuclear).
- Advanced propulsion system (e.g. nuclear, solar sail).

Mission relevant aspects for the Aurora lunar exploration program

Who can say that it is not extremely probable, nay beyond doubt, that there must be inhabitants on the Moon of some kind or another?

Sir William Herschel, 1780

About 4 proposals are specific enough to categorize them in mission scenarios for future lunar exploration (Table 1).

Our Moon has inspired human imagination since the early times. After several robotic missions, including the only robotic sample return from a solar system body so far, the Apollo program and a recent set of remote sensing missions (Lunar Prospector and Clementine), there are still scientific questions that remain to be answered.

Some of these questions are fuelled by the recent discovery of hydrogen on the lunar South Pole. With the prospect for using this potential reservoir for in-situ resource utilization, renewed interest has surfaced for a new lunar exploration initiative. There is also some scientific interest in characterizing the polar hydrogen deposits – to investigate the potential cometary source of the deposits.

At the same time, the Aitkin basin might offer an important glimpse into the composition of the lunar mantle if the impact penetrated the lunar crust.

Goal	Type of mission	Timeframe
Detailed mapping of lunar pole	Orbiter (e.g. ESA LunarSat)	2006
Characterize the hydrogen deposits at the lunar poles; determine and investigate lunar mantle material at Aitkin basin.	Lander with rover (e.g. ESA EuroMoon)	2008

Table 1: Mission scenario for a future lunar exploration.

Required technical support:

- Advanced power source for rover (in permanent dark areas during operation).
- Autonomous rover capability (mostly not in line of sight with lander).
- Cold resistant components (coldest location in our solar system).

Call for Ideas

Planetary Exploration

To Define the Scientific Objectives for

An Exploration Programme