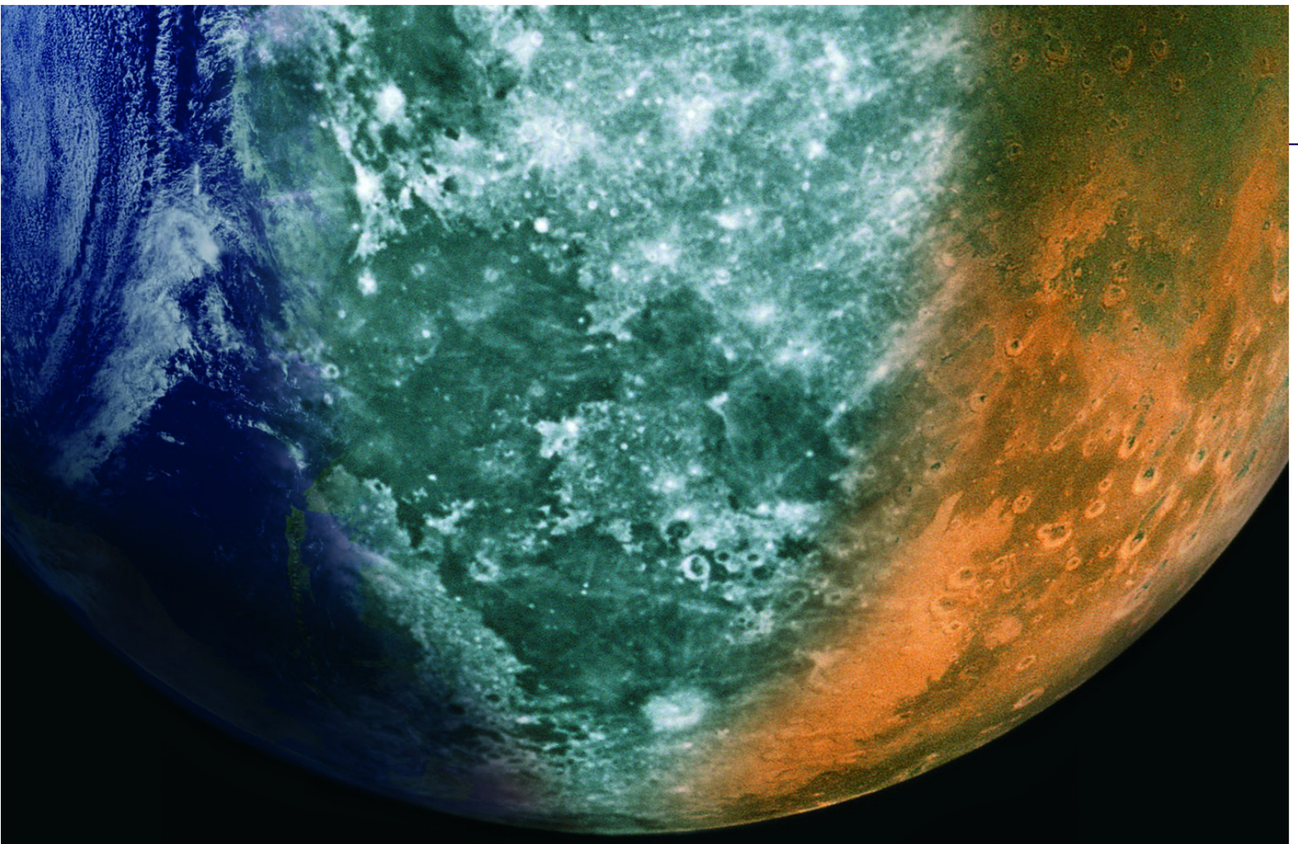
*The Future of European Space Exploration*

# TOWARDS A EUROPEAN LONG-TERM STRATEGY

EXECUTIVE SUMMARY

DECEMBER 2005



# The Future of European Space Exploration
## TOWARDS A EUROPEAN LONG-TERM STRATEGY

December 2005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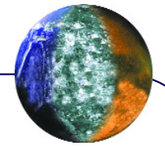


## Contents



This document is the result of stakeholder consultation and studies performed by ESA in co-operation with several third parties throughout the year 2005. It does not represent an official view or statement of ESA, but will serve as a reference for further deliberations leading to the definition of a European long-term strategy for space exploration.

# 1 Foreword

For many years, Europe has been playing a leading role in the utilisation of near-Earth space and the exploration of the universe. Spacecraft built by European companies and launched by European rockets, as well as European contributions to cooperative projects, have provided major benefits for the citizens of Europe and beyond, paving the way for major advances in areas such as weather forecasting, land use monitoring, telecommunications, and, in the near future, global navigation with the Galileo constellation of spacecraft. Beyond the development of new technologies and commercial applications, space also offers new opportunities in almost every field of scientific endeavour.

Exploration and human spaceflight are the most emblematic aspects of the space endeavour. They respond to the deeply rooted desire of humankind to answer compelling questions about the origins of life on Earth and its possible presence on other planets, to go beyond the limits of today's knowledge, to extend known boundaries and eventually expand human presence in the Solar System. Great civilisations have been characterised by their will to explore the unknown, and Europe has a fundamental heritage of exploration since it has always played a leading role in its quest for the new world.

Some 40 years of investment and innovation have provided firm foundations for European space activities as we enter the 21st century, but we cannot sit back and dwell on past successes. Instead, we must adapt and evolve as challenges and opportunities for collaboration or competition arise, whether from the ambitious space-faring nations of Asia or new space initiatives in the United States and Russia.

European leaders and citizens, quite rightly, expect the space sector to sustain its record of technological innovation, industrial leadership and scientific excellence, while providing a positive vision of the future. Space exploration should be a showcase for Europe, not only of its ability to master the required technologies and create new ones, but also of its ambition to transmit a message of cultural and human values. Indeed, by targeting the search for life and the extension of human presence into the Solar System, and by making new territories accessible to humankind, space exploration represents a tremendous endeavour and a unique tool to encourage and maintain public interest in investing in technology and to inspire new generations and attract them to scientific and technology-related studies. The younger generation will shape the society of tomorrow on the basis of what they learn to value today.

In order to achieve these goals, the European Space Agency has recognised the importance of developing a strategy for space exploration that will enable Europe to play a recognised role in the context of a global space exploration effort in a fast-changing and challenging environment. During the past year, ESA has consulted a wide range of stakeholders in order to build the basis for the development of a comprehensive, inspirational long-term strategy that offers numerous benefits for European and global society. This document explains how ESA envisages achieving these ambitious goals through the pursuance of four Cornerstones - themes that reflect the key societal principles that are the drivers behind the strategy. Much work has still to be done to arrive at a consolidated long-term strategy and this document will necessarily need to be modified and updated in the years to come. However, I am sure that it will prove to be a valuable reference source during forthcoming deliberations on the future evolution of European space activities.

Daniel Sacotte,
Director of Human Spaceflight, Microgravity and Exploration

# 2 Introduction

In 2001, space exploration was identified by the ESA Member States as one of Europe's key priorities for the future. As a result, it was decided to initiate a preparatory space exploration programme, Aurora, with the aim of developing a coherent roadmap that would lead to the in situ exploration of Mars. A European Space Exploration Programme defining the initial steps of a long-term programme has been tabled for the ESA Council Meeting at Ministerial Level in December 2005.

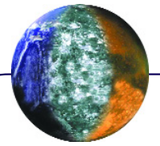
Meanwhile, NASA has announced its intention to concentrate its efforts on a U.S.-led international programme that will see humans returning to the Moon before 2020. China, India, Russia and Japan have also indicated their interest in lunar exploration and exploitation.

Against this background, it is essential that Europe continues planning for the future, developing a consistent reference framework which provides perspective and orientation for future European investments in space exploration. This will make it possible to align European stakeholders behind common goals, thus ensuring the stability of the programme. It will also enable Europe to prioritise its investments in line with the long-term strategic objectives and maximise the overall societal return. Such a strategy would increase the visibility of Europe's role in space exploration and make it easier to communicate this to the general public, decision makers and international partners.

Therefore, in parallel to the implementation of activities that will prepare for near-term exploration projects, ESA has initiated a process for the development of a long-term strategy for space exploration to serve as a framework for the future. In 2005, as a first step in this process, ESA set up a multidisciplinary scenario team to conduct broad stakeholder consultations and invite various leading space and non-space organisations to perform related studies. The results of this work are summarised in this document, which will serve as a reference for further reflections and open discussions. It will form the basis for the development of a consolidated long-term strategy within the next two years, taking due account of the actions identified in this document and the overall evolving context for the implementation of the European space exploration programme.

The document addresses in particular the:

- **Preliminary recommended European vision and high-level requirements** for space exploration;
- **International context,** summarising what is known about international space exploration plans;
- **European achievements and near-term activities;**
- **European approach to space exploration,** defining key societal principles and analysing European drivers;
- **European strategic cornerstones,** defining the goals, objectives, activity elements and recommended near-term actions;
- **Implementation aspects,** highlighting key elements to be considered for the implementation of the strategy in relation to affordability, innovation, science coordination, ethics and legal issues;
- **Next steps,** proposing specific actions to support the consolidation and formal endorsement of the European long-term strategy.



# 3 European Vision and High-Level Requirements

AS A RESULT OF THE BROAD STAKEHOLDER CONSULTATIONS, THE FOLLOWING EUROPEAN VISION STATEMENT AND HIGH-LEVEL REQUIREMENTS HAVE BEEN RECOMMENDED:

EUROPE WILL IMPLEMENT A VISIBLE, AFFORDABLE AND ROBUST SPACE EXPLORATION PROGRAMME, DRIVEN BY THE LONG-TERM GOAL OF IN SITU EXPLORATION OF MARS BY HUMANS, WHICH CREATES BENEFITS FOR SOCIETY, ENGAGES OTHER SPACE-FARING NATIONS THROUGH COLLABORATIVE ACTIVITIES AND, THEREBY, CONTRIBUTES SIGNIFICANTLY TO SOCIETAL DEVELOPMENT.

## European High-level Requirements

The long-term programme will be organised around four strategic cornerstones:

- **Europeans in Space -** support European projects and policy objectives, and position Europe as a visible and strategic partner;
- **Habitability and Life Beyond Earth -** increase the knowledge of life, its evolution, and its environment;
- **Sustainable Human Life in Space -** create innovation to support and improve human living conditions;
- **Sharing the Space Adventure and Benefits -** fostering broad engagement and a robust support base, sharing benefits in the form of awareness, education, inspiration, security and commercialisation.

The European space exploration programme will have two components:

- Sustained implementation of European-led missions with limited dependence on possible international partners;
- Contributions in terms of capabilities and research to the international space exploration endeavour selected in accordance with the European heritage and core competences and under considerations of possible synergies with the European led-missions and other European space activities.

This combined approach will increase the overall programme robustness, strengthen Europe's leadership position in focused areas and exploit synergies with other space activities.

In the near term, European space exploration will contain the following elements:

- **Robotic exploration of Mars** to search for evidence of life, to understand the habitability of the planet and to prepare for future human exploration;
- **Optimum utilisation of the International Space Station** in preparation for the implementation of future exploration missions;
- Development and demonstration of **innovative technologies, capabilities, infrastructures and knowledge** to secure a visible and robust role for Europe in the robotic and human exploration of Moon and Mars, within the international context.

The long-term plan will be sufficiently **flexible and robust** to cope with variations in funding envelopes and in the international context.

In order to ensure **sustained societal relevance and support,** ESA will engage all relevant stakeholder groups in an open debate on the scope, content and implementation aspects of the European space exploration strategy. The consultation of stakeholders should address issues as European scientific and technology priorities as well as implementation aspects related to ethical issues, public inspiration and scientific and technological innovation.

ESA's contributions to an international space exploration programme will be clearly visible and recognised as European in origin. ESA will strive to achieve **maximum cost effectiveness** through the synergy between its investments in space exploration and other space activities. However, **international cooperation** will be an essential element of the exploration strategy. ESA will promote cooperation with all space-faring nations, but define its space exploration strategy so that total dependence on other nations for particular aspects of the programme is minimised.

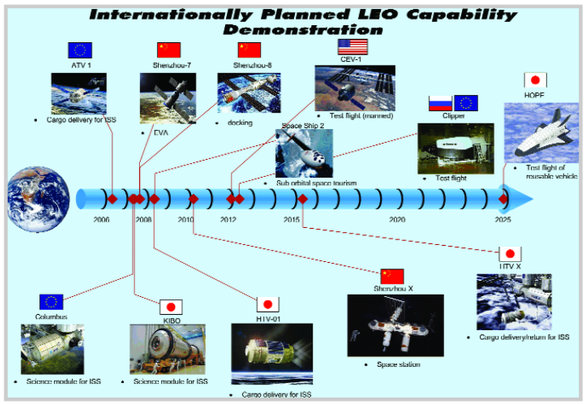
# 4 International Context

All of the major space-faring nations (US, Russia, Europe, China, Japan) have shown different degrees of interest in long-term Solar System exploration.

| Major Cooperation Opportunities | Major Cooperation Threats |
|---|---|
| Robotic lunar exploration with US, Russia, China, India and Japan | Transfer of technology and knowledge |
| Lunar surface systems with US and possibly Russia | Dependency on international partner |
| Robotic exploration of Mars with US | Possible schedule delays |
| Human access to space with Russia and Japan | |

| Major Strength of Potential Partners | | Major Cooperation Uncertainties |
|---|---|---|
| US: | Clearly defined and communicated long-term strategy and cooperation areas | Commitment to long-term plan and budget requirements |
| Russia: | Attractive cooperation opportunities with very experienced partner | Reliability of partner |
| China: | Emerging economic power with increasing investments in space exploration and strong ambition | Limited transparency and insight on future plans |
| Japan: | Capabilities and strategic objectives similar to Europe | Restriction of cooperation areas for strategic reasons |
| Canada: | Associated member of ESA | Mode of cooperation |
| India: | Emerging economic power with increasing investments in space exploration | Compatibility with current and evolving geopolitical context |

Analysis of Potential Partners




Planned International LEO Demonstrations



### *United States*

Following the January 2004 Presidential Vision, NASA has been asked to focus mainly on space exploration. The agency is to define and implement a programme to return Americans to the Moon by 2020 "as a first step to Mars and beyond".

One major implication of this directive is that, if space exploration costs overrun the agency's dedicated budget, NASA must fill the gap by reducing the financial resources dedicated to its other programmes. Another implication is that the exploration programme should confirm US independent human access to space.

Exploration Systems Architecture Studies issued by NASA in September 2005, while assuring a credible programme for the US to be back on the Moon by 2020, leave little room for international cooperation in the initial stages, when US efforts will be largely devoted to a lunar transportation system. Only after 2013 will surface systems development be open to other countries. The US approach to international cooperation also takes into consideration political concerns about the transfer of advanced technologies to other nations, particularly China and India.

### *Russia*

The Russian space agency (Roscosmos), Russian industry and the Academy of Sciences are currently elaborating a Moon exploration plan which includes a Moon base. Various projects, at different degrees of definition, are considering robotic exploration of the Moon and Mars. The most advanced of these are Phobos-Grunt and Luna-Glob, an orbiter for accurate mapping of the Moon and monitoring of a number of static surface penetrators.

Russia's most important project is Clipper, a transportation system conceived to serve the International Space Station and to be used as a crew exploration vehicle. Funding for the project remains open, though partnership with Europe is the preferred solution. The opinion of Roscosmos is that other countries could join Russia and Europe, e.g. Japan.

### *Japan*

The Japanese and European space programmes are very similar in their approach and development, although Japanese investment is only half that of Europe's. A new 20-year strategic plan is now under preparation. However, the JAXA 2025 document refers to the growth of autonomous space activities in Japan and a self-sustainable space industry with world-class technological capability. It also envisages development of technologies for the establishment and utilisation of a lunar base.

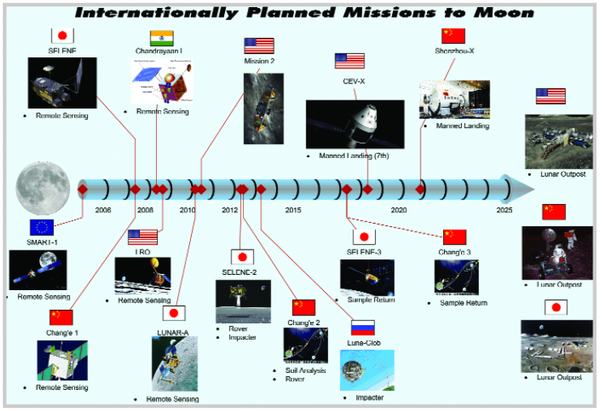
Plans for exploration of the Solar System focus on robotic exploration, while Japanese manned spaceflight will continue to receive adequate funding. JAXA recognises that the space exploration programmes of the US and Europe will greatly influence its future strategy.

The Japanese vision addresses the Moon more than Mars, but their approach and ongoing programmes will confirm existing strong links with the US and make Japan an excellent partner for Europe in robotic and human space exploration.

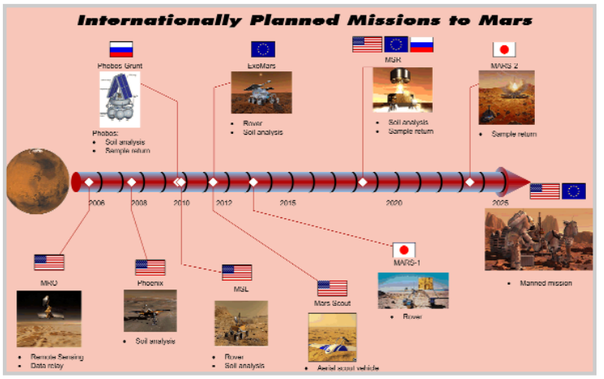
### *China*

Space activities are an important element of a comprehensive State strategy, which encompasses technological, scientific, industrial, geopolitical and security goals. China has accomplished major achievements in the fields of launchers and manned spaceflight, and is eager to aquire further advanced technology.

However, China also has a strong programme in the field of science and applications and is currently planning more satellite missions than any other nation. Preliminary plans foresee a national lunar programme based on a lunar reconnaissance orbiter, a soft lunar lander and a sample return mission. A new White Paper on China's space activities is now in preparation, with possible adoption in 2006.



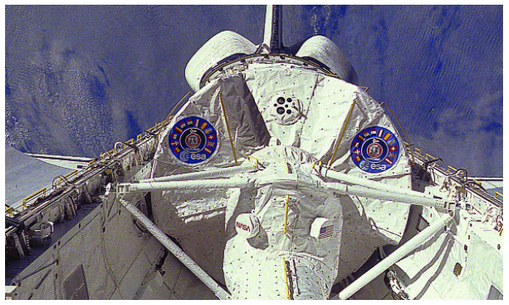

Planned International Missions to the Moon




Planned International Missions to Mars

# 5 European Achievements and Near-Term Activities

## 5.1 European Space Exploration Activities: The Story So Far

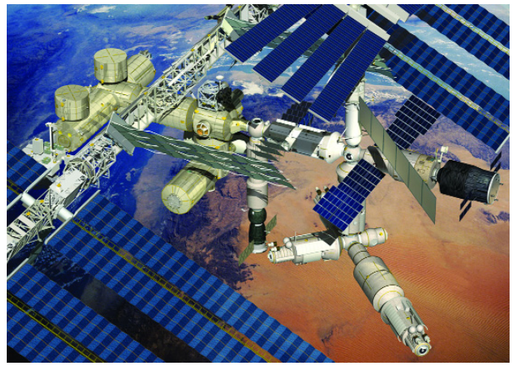


Spacelab

Europe first became involved in human space exploration in the early 1970s, when it opted to develop the Spacelab modular laboratory. In 1983, during the maiden flight of Spacelab, Ulf Merbold made history by becoming the first ESA astronaut to fly in space and the first non-American to be launched on a US space vehicle (two manned national missions had previously taken place: the flight of German cosmonaut Sigmund Jähn to the Salyut-6 space station in 1978, and of French astronaut Jean-Loup Chrétien to Salyut-7 in 1982). With 22 flights in various configurations between 1983 and 1998, Spacelab enabled scientists to conduct microgravity research in many different disciplines. European astronauts also participated in various groundbreaking Shuttle missions involving the Hubble Space Telescope, the Tethered Satellite, the Eureca retrievable satellite and the Shuttle Radar Topography Mission.

At the same time, cooperation with the former Soviet Union enabled European astronauts to experience long-term spaceflight on board the Salyut and Mir space stations. These included the 179-day Euromir-95 mission in which Thomas Reiter became the first ESA astronaut to walk in space.

More recently, Europe has become a major partner in the International Space Station (ISS) programme. The ISS offers unprecedented access for research and applications in space conditions, and represents an initial step towards extended human space exploration. The European scientific community participating in microgravity research is now about 1900 members. 192 European companies are involved, of which 125 are from non-space sectors.



Artist's view of the completed ISS

Since April 2001 ESA astronauts have made 8 visits to the ISS. European contributions include the Columbus laboratory, the European Robotic Arm, three Multipurpose Logistics Modules, two ISS Nodes, a number of Automated Transfer Vehicles (ATV), the Data Management System for the Russian segment and a European-built observation module or "cupola". In addition, Europe is providing specialist scientific facilities including a microgravity glove box and various refrigerators and freezers.

Europe has also developed the Ariane family of rockets, which for many years has dominated the world's commercial launch market. The latest version is the Ariane 5, which was introduced in 1997. Future additions to Europe's launcher fleet will include the Vega vehicle.


Ariane 5

Meanwhile, the European space science programme has played an increasingly important role in the exploration of the Solar System and beyond. Most recently, Smart-1 has used a revolutionary ion engine to reach the Moon, the Mars Express orbiter has returned spectacular 3-D images of the Red Planet, and the Huygens probe has touched down on the surface of Titan. European capabilities in robotic exploration will be further enhanced by missions to Mercury and Venus, with the possibility of a robotic mission to the surface of Mars in 2011.

Space science has also provided opportunities to cooperate with emerging space powers. Europe has recently collaborated with China on the Double Star mission and offered experiments to fly on an Indian robotic mission to the Moon. All of this experience and development of advanced capabilities places Europe in an ideal position to participate in even more ambitious international programmes of exploration in the decades to come.

## 5.2 The European Aurora Programme and Its Near-term Activities

The European ***Aurora*** programme began in 2001, when ESA Member States (with particularly strong support from Italy) agreed that space exploration should be one of their future priorities. The continuation of the ***Aurora*** programme, which has been decided at the ESA Council Meeting at Ministerial Level in December 2005, contains two major elements:

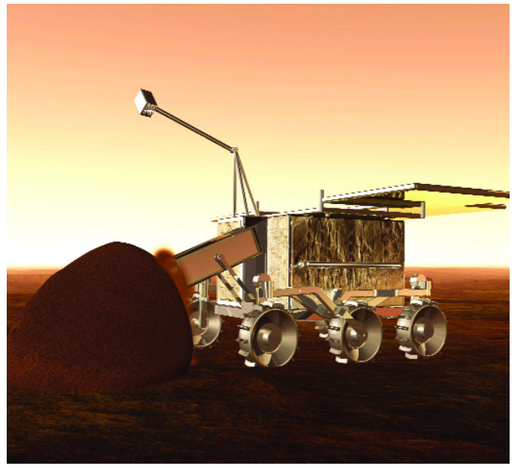
***The Core Programme***

This component includes activities aimed at enabling Europe to participate meaningfully in a future global exploration programme. Based on a building block approach, the activities to be performed will assure the robustness of the European contribution. They include:

- Exploration roadmaps, scenarios and associated architecture studies, based on a continuous interaction with the stakeholders. These activities will enable European governments to determine their objectives, interests and priorities through the identification of further missions or elements that need to be realised;
- Technology developments related to a Mars Sample Return mission;
- Technology developments related to exploration in general, flight demonstrations of selected enabling capabilities and the preparation of potential European contributions to the exploration of the Moon;
- Awareness activities dedicated to the engagement of European citizens in exploration.

***Exploration Missions***

ExoMars is proposed as the first European-led robotic exploration mission to Mars, with launch planned for 2011. ExoMars will provide valuable experience in the design and operation of new enabling technologies and capabilities, namely the entry, descent and landing system, and the rover, drill and sample acquisition systems. In addition to opening the way to future robotic and human exploration missions,



Artist's view of the ExoMars rover while drilling a rock on Mars

ExoMars will conduct groundbreaking scientific research by searching for traces of past and present life, characterising the Mars biological environment and improving the knowledge of the Mars environment and geophysics, while identifying possible hazards for future landings. It will also qualify Europe to conduct future, independent Mars missions.

Mars Sample Return is the most likely successor to ExoMars. It includes many of the elements representative of a human mission to Mars and provides the opportunity for Europe to advance in the development of key enabling technologies.

Artist's impression of the Mars Sample Return orbiter

## 5.3 The Clipper Programme

The Russian Federal Space Agency (Roscosmos) and Russian industry have initiated work on Clipper, a partially reusable transportation system to serve exploration purposes following initial missions to the ISS. Roscosmos has proposed to ESA a participation in the development and operations of the system. ESA is investigating the overall technical and programmatic feasibility and the modalities of cooperation with a view to preparing a decision on a joint preparatory programme.

Such collaboration would ensure access to space for European astronauts, strengthen strategic cooperation between Europe and Russia, and further extend European space transportation expertise, while making the associated investment affordable.

Clipper

# 6 European Drivers for Space Exploration

On a global scale, space exploration provides a visible and unifying challenge to humanity and offers opportunities for broad international engagement and participation. It can contribute to global societal security through sharing of knowledge, international cooperation and economic development.

The European approach is driven by the following **key societal principles**:

- European investments in exploration shall create inspiration, knowledge, innovation, competitiveness and cultural development, while addressing fundamental questions of humankind;
- European contributions to an international explorationprogramme will support the European project and overall European policy goals, enhancing the role andimpact of European values;
- The European space exploration priorities shall be defined through engagement of a diverse group of stakeholders, meeting defined stakeholder interests and requirements;
- Benefits resulting from exploration will be shared widely among all stakeholders.

A European long-term strategy should not be based on a single motivation, but offer scope to respond to a combination of drivers. Potentially the most important of these is the will to maintain a strong industrial base, followed by the desires to advance scientific knowledge about the Universe and to provide a source of inspiration for European citizens.

***Innovation and Development.***

Future exploration missions will require major innovations that can help to strengthen the technological and industrial base for non-space applications. Practical benefits from space exploration include innovating technologies, development of the industrial base, resources from other bodies, and unique research and products that can be developed in microgravity.

The jobs, skills, technologies, manufacturing facilities and equipment required to explore space are significant. With unemployment at the core of economic and social difficulties in most European countries, maintaining and developing a strong European industrial base is one of the real levers for space exploration today. A well-funded, properly directed space programme can enhance industrial competitiveness and contribute to economic growth.

***Scientific Knowledge.***

Europe has historically been the source of major findings about the structure of the solar system and the Universe. The European desire for scientific discovery will continue into the future, with space exploration regarded as a major tool to further increase scientific excellence. However, although science will be a major beneficiary of a strong European space exploration programme, science alone is not a sufficiently strong imperative to justify the level of investments required for a long-term, sustainable space exploration programme.

***European Identity and Cultural Development.***

Space exploration is a challenging, cooperative endeavour that offers opportunities to further strengthen European ties, foster European identity and define European values and priorities. Europe's identity is partly defined by how it compares, relates and interacts with nations around the world. In a future exploration programme, Europe must decide how autonomous and independent it wishes to be. At the same time, European interaction with other space-faring nations will encourage decision makers to take ethical and environmental issues into consideration when setting up an international exploration programme.

Exploration could also contribute to ongoing European construction, since the size and cost of space activities means that they cannot be conducted solely on a national level. Indeed, 70% of European space budgets are spent at the European level.

***Inspiration and Education.***

The exploration of unknown places can be inspirational for many people. The combination of courage, determination and hard work in pursuing the unknown reminds people of the strength of the human spirit and the great things it can accomplish. Exploration can capture interest, resolve human curiosities, and stimulate minds with new ideas.

The inspiration provided by space exploration is, perhaps, the most important motivation for young students to pursue careers in science, technology, engineering and mathematics, but it also increases public awareness of space activities, their benefits and importance.

***European and Global Societal Security.***

Civil space exploration can benefit both European and global security interests. Exploration has led to the globalisation of environmental concerns and some technologies required for future human exploration may contribute to the implementation of sustainable development policies (e.g. management of resources, waste and energy).

The key drivers for European space exploration are closely linked to the four cornerstones of ESA's long-term strategy, as shown in the diagram below.

| Key Driver / European Drivers | European Project | Knowledge | Innovation and Development | Inspiration and Education | Global Societal Security | Cultural Development |
|---|---|---|---|---|---|---|
| Europeans in Space | ● | | | | | |
| Habitability and Life Beyond Earth | | ● | | | | |
| Sustainable Human Life in Space | | | ● | | ● | |
| Sharing the Space Adventures and Benefits | | | | ● | ● | ● |

European Drivers versus Cornerstones

# 7 Europeans in Space

Since the late 1950s and 1960s, human space exploration has always been politically driven. Political considerations can also be found in Europe, as an important element underlying the European choices with regard to human spaceflight. Since space exploration is a global undertaking that will receive increased visibility in the decades to come, political motivations will certainly play a key role in the development of the European long-term exploration strategy.

## 7.1 Objectives

The major goal of this strategic cornerstone is to enable Europe to be a visible and significant partner for space exploration. Key elements regarding the presence of Europeans in space are related to the manifestation of European values and capabilities, the role of Europe in a collaborative exploration endeavour, and Europe's competitiveness and security.

The major objectives of this cornerstone are to:

- Ensure European participation to international space exploration endeavour;
- Assure European access to space exploration enabling capabilities including in particular mobility in space and on planetary surfaces;
- Ensure the presence of Europeans, their culture and values, in future space settlements (e.g. a lunar base);
- Support the European project through a visible role in the international space exploration undertaking;
- Support the implementation of broader European policy objectives (e.g. in fields as education, health and resource management);
- Protect the interests and security of European citizens;
- Strengthen the strategic partnership with emerging space powers.

## 7.2 Elements

***Support for the European Project.*** Space exploration offers an opportunity to support the building of Europe in the 21st century. This may be achieved through the development of a common vision and long-term strategy, respecting European culture and values and securing a visible European role. The implementation of a visible, ambitious European project will contribute to improving the image of European organisations, while providing an inspiring example of the benefits of a common European Approach in addressing global challenges. The implementation of a multinational programme involving ESA member states will enhance the European integration process, increasing the efficiency and effectiveness of research and development activities.

***Securing European Access to Strategic Space Exploration Capabilities.*** If Europe is to play a significant role in the global space exploration undertaking, it must invest in key capabilities that secure the competitiveness of European industry, acquire and maintain technological competences, and protect the interests of European citizens. One key question to be addressed in Europe in the near-term concerns the requirement for secure, autonomous access of humans to space. Europe currently relies on cooperation with the US and Russia, but it is likely that other secure means of access to space for Europeans will be required in future.

In the near-term, other strategic space exploration capabilities encompass capabilities for entry / descent and landing on planetary surfaces. In the longer term they include in situ resource utilisation, human and cargo transportation, and advanced propulsion and power systems, such as those based on nuclear technology.

***A Tool to Implement European Policy Objectives***. Space exploration should be positioned as a visible tool for contributing to the implementation of a number of high-level European policy objectives. The current ESA - EU strategy, which is based on the ESA Director General's Agenda 2007, the EC Green and White Papers and the EC - ESA Framework Agreement, aims to elaborate the European space programme as the tool to implement European space policy, and to support the EU for preparing the 7th Framework Programme and the 2007-2013 financial perspectives. Space exploration has the potential to support EU policy priorities and objectives, including:

- Development of a knowledge-based society, with the acquisition of new knowledge and data through scientific discoveries;
- Competitiveness for growth and employment through the promotion of innovation and technological developments;
- Sustainable development.

***Enhancing Global Security.*** Space exploration offers various opportunities to respond to global security challenges. The technical and financial challenges associated with sustainable human exploration will ultimately lead to increased international cooperation at government-to-government and industry-to-industry levels. This will offer opportunities for improving multicultural understanding and supporting global economic development.

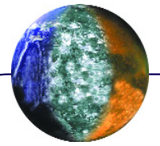
Space exploration addresses fundamental questions related to the origin of life, its evolution and existence beyond Earth. A debate on these issues contributes to an enhanced dialogue between different cultures and offers opportunities for identifying common interests.

Innovations required for space exploration, especially in the areas of waste management, advanced energy systems and sustainable life support systems (e.g. water and air recycling and processing, telemedicine and food production) have potential applications in the fields of sustainable development, health and environmental protection. These address the basic needs of European citizens and can offer potential solutions for developing countries.

## 7.3 Recommended Actions

Further actions are required to explore and consolidate the political motivations for space exploration and support the formal political endorsement of a European long-term exploration strategy. The following activities are recommended in the near-term:

- ***Engage in a systematic, institutionalised dialogue*** at political level so that awareness and con sciousness of the strategic and societal relevance of space exploration may be increased and a common European vision for space exploration may be accepted. Special attention should be given to the increased role of the European Parliament in European decision-making and the development of relations with the relevant inter-parliamentary groups.Interactions with organisations interested in space-related topics are envisaged (e.g. the Space Project of the Organisation for Economic Cooperation and Development).
- ***Identify exploration capabilities*** that will be strategic for Europe in the coming decades and develop a strategy that will ensure access to such capabilities, either through autonomous developments or long-term cooperation with strategic partners.
- ***Review the European policy framework,*** identify the contributions space exploration can make to the implementation of European policy objectives and take measures to ensure that space exploration is recognised as a tool for implementing these objectives.



# 8 Habitability and Life Beyond Earth

This cornerstone is about increasing our knowledge of life, its evolution, and its environment. It addresses the question of how to define "habitability" as far as the Solar System is concerned, and includes the new research field of exobiology, an interdisciplinary field that touches upon issues not normally considered to be part of natural science, e.g. philosophy and theology. In particular, the discovery or absence of a second, independent genesis will drastically change our world view by indicating that life is either a natural consequence of physical and chemical laws or very unique.

## 8.1 Objectives

The major goal of this strategic cornerstone is to understand the history and fate of life on Earth and the distribution of life in the Universe in general. Key aspects include:

- Studying the origin and evolution of life on Earth;
- Understanding the relationship between life and its environment;
- Studying how terrestrial life can adapt and survive beyond our home planet;
- Searching for extraterrestrial life on Mars;
- Defining planetary protection guidelines;
- Promoting scientific progress for the natural and social sciences through the field of exobiology.

## 8.2 Elements

***Habitability and the Origin of Life.*** What makes a planet habitable? Is habitability restricted to planetary environments? Although we do not understand how life originated, we know that basic requirements for the formation of living cells can be summarised as:

- Liquid water as a universal and versatile solvent;
- A number of critical elements, including carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur, that are used to build the molecules that form living structures and act as nutrients for their living processes;
- Sources of energy, including heat, sunlight and energy-releasing chemical reactions.

One estimate for the time necessary for life to arise from inanimate building blocks is about 10 million years. If this estimate is correct, then conditions on a potentially habitable body such as a planet need to be stable for at least this period of time.

***Habitability and Evolution.*** Habitable conditions evolve naturally alongside the evolution of a planet. These, in turn, are closely linked to the evolution of conditions within the planet's star system. At each stage, the conditions change so that the environment becomes uninhabitable for certain life forms whilst opening up new possibilities for others. The majority of the astounding diversity of life forms that inhabit the Earth today could not have survived on the primitive Earth, and yet the organisms that inhabited the primitive Earth still exist, often in extreme environments.

In the case of our planet, a combination of early photo-synthesisers that pumped oxygen into the atmosphere, geological processes that buried vast amounts of organic carbon and sedimentary carbonate deposits led to increased levels of oxygen in the atmosphere. In this case, the biological and geological mechanisms that changed conditions on the planet were also critical to further evolution of life on the Earth.

***Space Exploration and Habitability.*** The geological record relating to the first one billion years of the Earth's history has largely been erased. However, there are other planets, notably Mars, that could potentially still have a record of this critical time period.

Although Mars apparently lost its surface water very early in its history, there seems to have been a period that lasted some 300-500 million years when conditions were potentially favourable for primitive life to appear and evolve. Given the rapid degradation in environmental conditions on the planet's surface, Mars may also provide an opportunity to study the rate of evolution from fossil remains as well as the potential for life to survive in the Martian subsurface to the present day.

Space exploration is also crucial in order to learn whether there has been a second genesis of life on another planet. Current hypotheses suppose that life appears relatively easily, given the basic ingredients and sufficient time. Even if

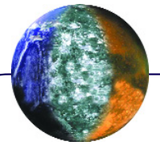
life has not survived on Mars to the present day, the discovery of fossilised traces will support the hypothesis that the appearance of life is relatively straightforward. This finding will have an enormous impact on society.

## 8.3 Recommended Actions

The definition of scientific themes to be addressed within this strategic cornerstone requires wide consultation of the European scientific community. Particular attention should be paid to existing synergies with ESA's Cosmic Vision 2025 space science programme, as well as the European Programme for Life and Physical Sciences in Space (ELIPS). Typical themes to be addressed in the near term may include:

- Habitability of terrestrial planets;
- Hazards to humans on Mars;
- Weather forecasting for Mars;
- Research on biomarkers for current life forms and signatures of life on the early Earth.

ESA should ***initiate an ad hoc survey committee*** through the Exploration Programme Advisory Committee. The survey committee should include members of the agency's Life Science and Solar System working groups. It should initiate, oversee, and evaluate a consultation of the scientific community regarding the long-term plan of the exploration programme and any synergy with the Cosmic Vision plan.



# 9 Sustainable Human Life in Space

Moving humans away from their home planet and establishing a new habitable environment on the Moon or Mars will require the development of new, advanced technologies with a broad range of terrestrial applications, e.g. environmental risk management, recycling of resources (water, oxygen), energy management and exploitation of new resources, control of autonomous ecosystems and sustainable agriculture. Integrated advanced sensing systems will be developed for biodiagnostics, medical treatment, environmental monitoring and control.

## 9.1 Objectives

The major goal of this strategic cornerstone is to enable sustainable life in space during human exploratory missions. The major objectives are to:

- Promote research and technology development and foster integrated innovation processes, engaging the space and non-space industrial sectors;
- Promote sustainable development;
- Strengthen European industrial capabilities and competitiveness;
- Enhance economic security of European and world citizens through social and technological innovtion;
- Increase Europe's strategic independence;
- Raise the European standard of living and quality of life.

This cornerstone opens new opportunities for ESA to collaborate with industrial players that are not usually engaged in space activities. Building up a strategic partnership with relevant organisations will make optimum use of existing European competences and limited resources, enabling identification of synergies for research and development activities so that Europe can achieve a leadership position in these key areas.

## 9.2 Elements

Human exploratory missions, such as the establishment of a permanently inhabited lunar base or human visits to Mars, will add a new dimension to human spaceflight as far as distance of travel, radiation environment, gravity levels, mission duration, level of crew confinement and isolation are concerned. In addition to these significance health issues, resource management and advanced life support systems will require innovative solutions, such as ESA's MELISSA (Micro-Ecological Life Support Alternative), which is intended to produce food, water and oxygen from organic waste.

Key issues of life sciences that must be addressed prior to the design of lunar and Mars exploration missions include:

***Gravity Effects.*** Little is known about the adaptation of the human body to a prolonged stay in a low-gravity environment, e.g. on the Moon. Appropriate counter-measures must be developed to control the physical deconditioning effects.

***Radiation Issues.*** Enhanced levels of radiation from many sources can threaten crew health, especially during extravehicular activities. In order to provide effective protection, estimates of expected radiation doses and their radio-biological effects must be developed, and counter-measures investigated. Major strategies include:

- careful planning of mission duration, timing and operations;
- surround crew habitats with sufficient absorbing matter; and
- increase initial resistance of exposed personnel against exposure.

***Psychological Issues.*** Current countermeasures may be adopted for a lunar mission. However, missions to Mars will involve an unprecedented degree of isolation and confinement. Before human expeditions to Mars become a reality, efficient countermeasures must be developed to cope with the different stress factors.

***Living and Working Environment.*** This includes:

- the architecture and functioning of the spacecraft and lunar / Martian habitat;
- the quantity and quality of consumables (e.g. oxygen, food, potable water); and
- the quantity and quality of waste produced. Existing techniques will be used, but substantial mass savings can be achieved by recycling of oxygen, carbon dioxide and water, cleaning of towels and cloths,recycling packaging, on-site food production by bio-regenerative systems and in situ resource utilisation.

## 9.3 Recommended Actions

In order to ensure a high degree of flexibility and reduce vulnerability to changing international plans, the following steps are recommended for implementation:

- Identify key elements required for sustaining human health, well-being and performance efficiency during human exploratory missions;
- Identify the key exploration elements that are important for sustaining life on Earth;
- Identify the key elements that are important for solving problems that affect both space and Earth, particularly those where Europe can have a competitive and leading role;
- Set up a research and development strategy that is based on European core competences;
- Reach a competitive position for the selected key elements that will be Europe's contribution to sustainable human life in space and in hostile environments on Earth.

ESA is encouraged to issue an announcement of opportunity for multidisciplinary / topical teams for such key elements, which may serve as networks that bring together representatives from industry and academia in order to coordinate the preparation of core elements of the European research plan and specific related activity or project proposals.

# 10 Sharing the Space Adventures and Benefits

It is vital that Europe's space exploration endeavour includes a renewed effort to engage the wider public. This cornerstone explores ways of increasing support and enthusiasm for space exploration amongst Europe's citizens. Such engagement will be critical to building the public and political support that is necessary to sustain long-term investment in space.

## 10.1 Objectives

The goal of this cornerstone is to foster broad societal engagement in space exploration activities and share benefits of the programme implementation with the overall stakeholder community within and outside Europe.

The objectives of this cornerstone are to:

- Share the space experience;
- Create new perspectives for cultural and educational development;
- Promote global participation for addressing global challenges;
- Establish an adequate legal and ethical frame work for space exploration and utilisation.

## 10.2 Elements

In the development of the long-term strategy for space exploration, ESA has attempted to engage a wider group of stakeholders, including scientists, industrialists, NGOs, artists, ethicists, theologians and journalists. A number of key observations have emerged.

***Clarity and Focus.*** Europe must have a clear, highly-focused strategy that will generate long-term interest in space exploration. This should include some highly visible European symbols, such as major stand-alone missions under European leadership.

***Public Involvement.*** Increasing public involvement and awareness should be an intrinsic part of the exploration programme in order to build a sense of public ownership across Europe. Artistic and cultural activities relating to space are an important way of strengthening public engagement.

***Educational Outreach.*** Innovative communication methods and clear language should be used to help inspire and enthuse young people about space.

***Space as a Global Project.*** Europe can provide a distinctive path for space exploration, grounded in the European values of peace, prosperity and freedom. This approach should have a strong commitment to international development and environmental protection, while avoiding military applications.

***Commercialisation.*** Commercial opportunities should be built into the exploration programme from the earliest stage. This will require the creation of an adequate legal frame-work, the reduction of bureaucratic obstacles, and improvements in the commissioning processes used by space agencies in relation to industry. New fiscal incentives may also be required to encourage private sector investment in space.

The stakeholders also proposed a number of ***pilot projects*** that could be developed to strengthen this cornerstone. They ranged from a video diary based on an astronaut's working life to artists in residence with ESA, a Martian habitat simulator in Iceland and public proposals for non-scientific work on the ExoMars rover. It is proposed to take forward four activities that emerged from the stakeholder discussions.

## 10.3 Recommended Actions

It is recommended that ESA will initiate a European Space Exploration Challenge that will include two elements.

***The Societal Recognition Challenge*** will recognise outstanding efforts that have helped to:

- Raise public interest and knowledge of space exploration;
- Develop commercial activities related to space exploration;
- Exploit new avenues offered by exploration activities for cultural and educational development;
- Engage new partners and organisations in the conduct of space exploration activities;
- Support the establishment of a legal and ethical framework for space exploration.

***The Industrial Inducement Challenge*** will aim to:

- Foster innovation in areas relevant to the European exploration programme;
- Engage new industrial players to pursue exploration-related research and development;
- Stimulate organisations to apply their competences to exploration-related purposes;
- Facilitate an exchange between organisations from different industrial sectors;
- Inform and inspire the general public.

ESA should also engage in a dialogue with European media in order to create awareness of the scope and benefits of the European long-term exploration strategy. This may be achieved through bilateral meetings, workshops or an internet-based discussion forum. Public opinion and concerns must also be continually monitored through polls and other research techniques.

A first Citizen's Jury, to be held in the UK, is proposed for Spring 2006. This experiment will offer a new way of gaining social feedback, giving insights that can provide a template for future public engagement activities by ESA. Such an event could also spark a wider debate amongst the media and opinion formers about public attitudes, values and priorities in relation to space exploration. If successful, it could be repeated in other ESA member states later in the year.

Finally, for engaging non-traditional players in space exploration and strengthen the societal relevance, a European network for space exploration should be created through development of strategic partnerships with key stakeholder organisations (e.g. NGO's, international organisations).

# 11 Implementation Aspects

## 11.1 Managing Affordability

The amount of funding for the time period 2006 to 2035 will ultimately determine the content of the European exploration strategy and the pace of its implementation. This amount of funding may vary significantly, depending on the assumptions taken and on the success and attractiveness of the European and global space exploration programmes.

Various funding scenarios have been developed, based upon the current funding plans and taking into account economic growth in Europe, the relative importance of R&D investments, the status and further development of the International Space Station programme, and the relative importance of exploration within the European programme.

In the **reference scenario for European space exploration,** the total amount of funding available for the period 2006 - 2035 amounts to 30.3 B€. This comprises 4.7 B€ for 2006 - 2015, 11.4 B€ for 2016 - 2025 and 14.2 B€ for 2026 - 2035. The actual funding may very well vary between 20 B€ and 50 B€ depending on the assumption used for in particular economic growth, growth in European R&D investments and the importance of space exploration within the overall European space policy.

The different funding scenarios will be used as a reference for the development and analysis of an implementation strategy that will be sufficiently flexible and robust to cope with large variations in funding over a 30-year time period.

## 11.2 Fostering Innovation

Raising the level of innovation is one of the major objectives of the Lisbon Strategy. Hence, one of the key objectives of the long-term exploration strategy is to maximise the innovation potential that results from investments in space exploration, not only for the space sector but also for other industrial sectors and markets, European citizens and society at large.

In summer 2005, the Fraunhofer Institute for Industrial Engineering conducted an industrial stakeholder consultation on behalf of ESA. The prime objectives of the consultation were the identification of ways to support economic growth through innovations resulting from investments in space exploration and the creation of supporting information for strategic investment decisions based on prospects for industrial multiplication.

It became clear that many synergies exist between the innovation needs of space exploration and other industrial sectors. These include industries that supply technology for space exploration as a minor part of their business, as well as sectors such as railway technologies and chemicals that do not normally operate in the space sector. Clearly, the space exploration programme must make every attempt to involve European industry - in particular the non-space sectors - in the process of technology development.

In order to ensure that the innovation potential is properly directed and exploited the Fraunhofer Institute for Industrial Engineering also suggested an end-to-end management framework, defining the overall process from technology foresight and study to exploitation of technologies. It is recommended that ESA thoroughly reviews the proposed framework with the objectives of improving and adapting procedures already in place within the agency's environment for innovation management.



## 11.3 Considering Ethics

An ethical approach implies a questioning of the values, principles, concepts and purposes of space activities as well as their foreseeable consequences and implications. Salient ethical issues can be divided into:

- General ethical demands which the European strategy should meet;
- Awareness of issues specific to the conduct of the European exploration strategy.

Decisions should not depend solely on space expertise. Instead, the debate should include the general public and experts such as ethicists and social scientists. Decision makers need to be as well informed as possible, and their awareness of ethical issues needs to be maintained and encouraged. For example, the question of whether the exploitation of celestial bodies should be free and open to all is an issue of values. It requires an open debate on the purpose of such activities as well as the status of these bodies.

Planetary protection is another example. In particular, should the extraterrestrial environment be preserved and protected for itself, or should human interest be the sole criterion? If extraterrestrial life is detected, then various ethical issues would arise in relation to its status and the extent to which protection from and for the life form would be needed.

Prolonged human missions raise concerns about the well-being, dignity and fundamental rights of the crew. The possibility of physical or mental disease, death or criminal behaviour should also be foreseen and discussed.

## 11.4 Coordinating Science

The European Space Science Committee of the European Science Foundation has produced a number of recommendations for future coordination of science activities involving the exploration programme. These address, in particular, the need to integrate exploration science opportunities in a broader science agenda that includes space as well as life and physical sciences.

## 11.5 Addressing Legal Issues

The current legal framework provides broad principles, but certain concepts laid down in the legal corpus of space activities are too vague and should be further developed. Major definitions of certain terms are lacking, e.g. space object, space debris, delimitation of outer space. Well-established themes, such as liability, registration, settlement of disputes, are being affected by new forms of space activity and will have to be adapted to new circumstances.

There is also a need for a legal framework that covers dispute resolution and commercial space activities. Specific issues regarding the protection of intellectual property rights and property rights on other worlds need to be addressed.

Europe needs to take a proactive role in the review and possible adaptations of the existing legal framework in order to ensure that European interests are properly respected.

# 12 Next Steps

Further work is required to arrive at a consolidated European long-term strategy for space exploration. This work should ultimately lead to the definition of future proposals for near-term exploration capability developments, research and missions, as well as associated roadmaps.

Stakeholders must be encouraged to participate in consultations that help to identify and consolidate European interests in space exploration, strengthening the support base and ultimately obtaining endorsement of the strategy.

Continuous assessment of international space exploration plans will make it possible to identify opportunities for cooperation. An open dialogue with representatives of other space- and non-space-faring nations will prepare the ground for future cooperative activities.

The long-term space exploration strategy should be integrated into the broader, emerging European space policy, addressing, in particular, interrelations with science, European launcher policy, research and technology development policies, and the international framework.

The following key supporting actions have been identified as part of the stakeholder consultation effort:

- Issue an **open call for ideas** organised around the four strategic European corner stones and related activity themes, in order to foster continuous interest and engagement of stakeholders, further consolidate the content of the cornerstones and solicit inputs on research, development and mission proposals. In particular, this open call will contain an announcement of opportunity for the creation of multidisciplinary teams to support the development of research plans and prepare future project proposals.

- Establish a **multidisciplinary, long-term strategy advisory body** that includes representatives of all stakeholder groups, with the mandate to advise ESA on all elements of the European long-term strategy, including technology and innovation, science, inspiration, political and cultural aspects.

- Initiate a **political awareness campaign** to inform political decision-makers at national and European level about the strategic relevance of European investments in space exploration, leading to the identification and implementation of a process for the formal endorsement of the long-term strategy at the appropriate political level. During this campaign, particular attention should be paid to addressing the strategic issues concerning the European requirements and approach for securing access to human transportation, nuclear power and propulsion.

- Set up an ***ad hoc*** **survey committee** through the Exploration Programme Advisory Committee (EPAC). This ***ad hoc*** committee should include members of the relevant working groups of ESA's Human Spaceflight and Science Directorates - the Life Science Working Group and the Solar System Working Group. The committee should, if necessary, also include engineering expertise in addition to that of the EPAC. The committee should initiate, oversee, and evaluate a consultation of the scientific community regarding the scientific content of the long-term plan for the exploration programme and any synergy with the relevant part of the Cosmic Vision plan.

- Create a **European network for space exploration** through development of strategic partnerships with key stakeholder organisations (e.g. NGO's, international organisations).

- Coordinate and support **multidisciplinary ad-hoc teams** created on the basis of the open call for ideas, with the objective of preparing elements of the research roadmap and specific project proposals.

- Implement **citizens' juries** in ESA Member States to foster an open dialogue with randomly selected representatives of the general public concerning the rationale, content and implementation aspects of the European long-term space exploration strategy.

- Initiate a systematic dialogue with **media representatives** in order to increase awareness of the European space exploration strategy and optimise its inspiration elements.

- Define and implement a **space exploration prize contest** for inspiration and innovation, following the model of the European Space Exploration Challenge outlined in section 10.3.

Furthermore, it is recommended that a thorough review of the ESA approach to innovation management should be initiated. One objective will be to improve and complement existing structures in order to facilitate the engagement of non-traditional industrial players. Such a review would also maximise the creation and exploitation of innovation potential resulting from European investments in space exploration. Specific attention should be paid to development and validation of adequate procedures for technology foresight, monitoring and scouting, synergy evaluation, spin-in and preparation of collaborative research and development.

Alongside this action plan it will be necessary to activate a partner network, e.g. starting with the European Commission. This will involve identifying key players, selecting key accounts, beginning an information exchange and preparing a structured collaboration. At the same time, it will be necessary to start planning an image building and communication campaign for the establishment of a "prime technology partner" in Europe.

# 13 Acknowledgements

The ideas and concepts developed in this report are the result of broad stakeholder consultations during 2005. A high level of interest of the approached stakeholders in engaging into an open dialogue on the rationale, merits and content of a European space exploration long-term strategy can be noted.

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