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NASA
INTERNATIONAL SPACE UNIVERSITY

# HUMAN MISSIONS TO EUROPA AND TITAN – WHY NOT?

INTERNATIONAL SPACE UNIVERSITY

EXECUTIVE SUMMARY

# Executive Summary

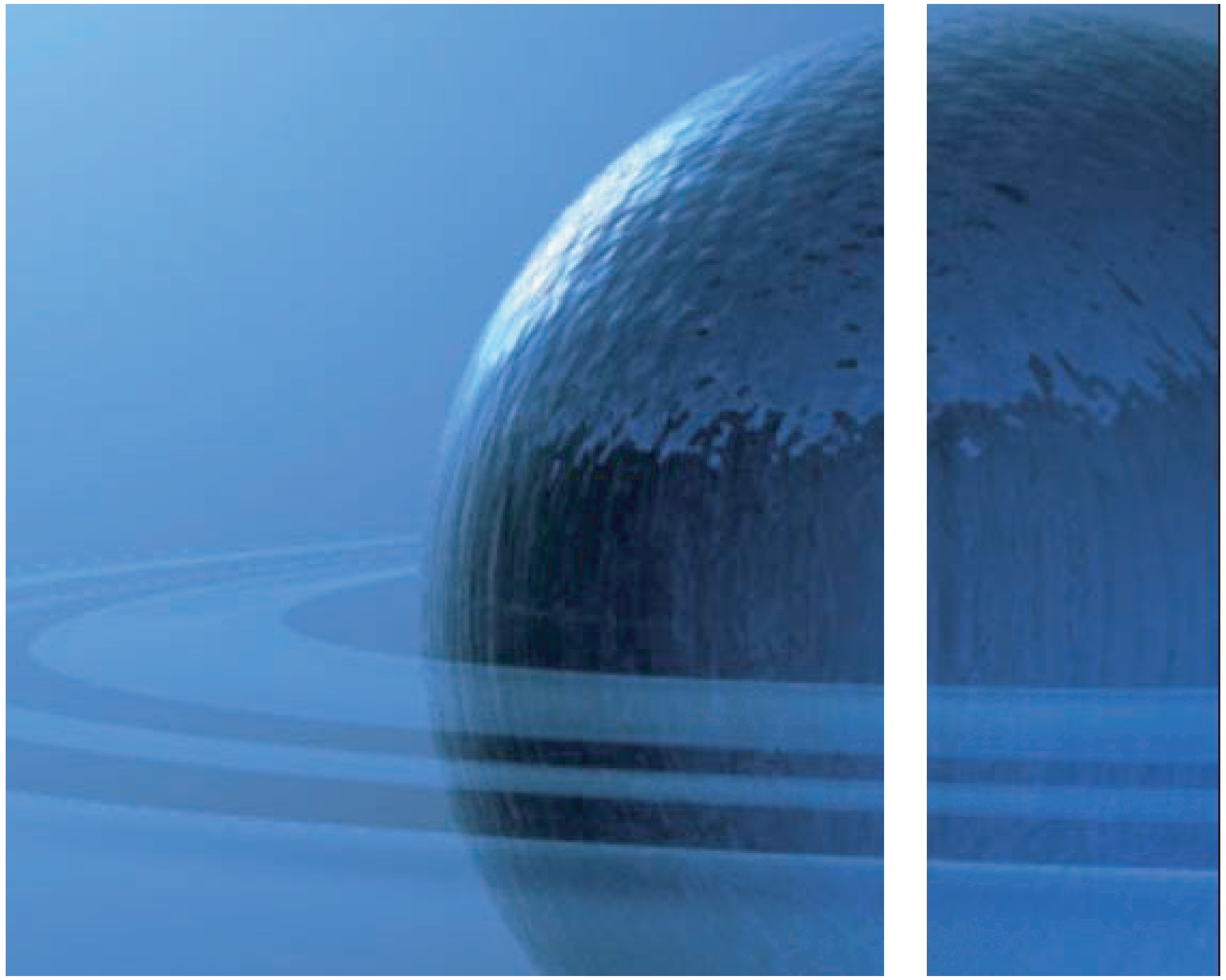
This Executive Summary and its related report are the result of twenty-nine students from eleven different countries working together on the team project at the International Space University Master of Space Studies course 2003/2004.

## Mission Statement

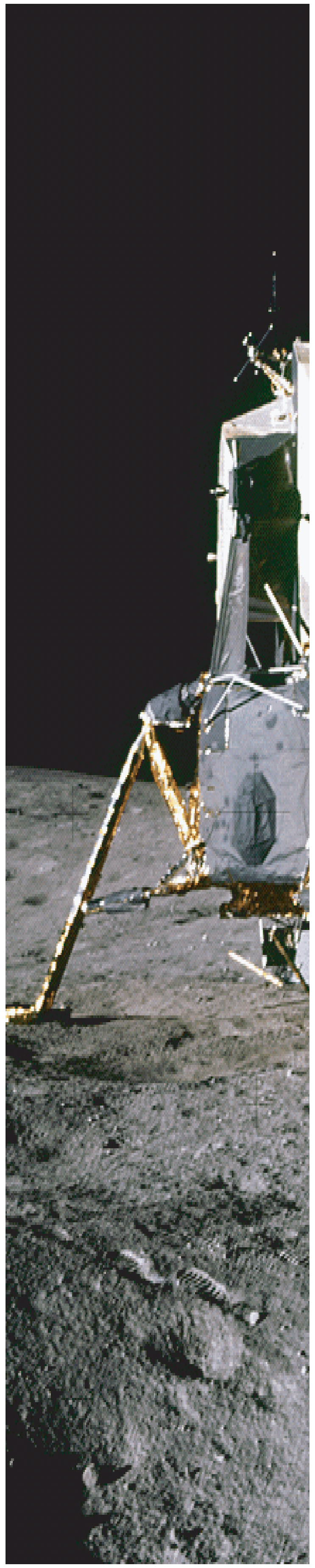
To enable human exploration beyond Mars with a primary focus on Europa and Titan.

Overall Strategy

Primary: Outline a step-by-step Development Plan of the key barriers and their solutions to enable human exploration of the outer solar system.
Secondary: Perform a case study which supports and emphasizes the key elements of the Development Plan.



# Human Exploration...



*"We did it, because we didn't know it was impossible".*

Unknown

*"As for the future, your task is not to foresee it, but to enable it."*

Antoine de Saint-Exupery

When? - "A human mission to Europa/Titan could be possible by 2070."

**What is our Current Status?**

For the first time since the Moon Race, international governments and space agencies have set bold new goals of placing humans onto other planetary bodies. With the recently announced US initiative, a return to the Moon is planned within the next fifteen years. China is also aiming high and plans to put taikonauts on the Moon. ESA's Aurora Programme and the new vision for NASA both plan to send humans to Mars before 2030. These new initiatives will help to end the impasse of past decades by establishing new objectives and inspiring the next generation to pioneer our future in space.

**Looking Beyond!**

This mission builds upon current plans within the US and Europe to send a human mission to Mars. It is imperative that the momentum of the human spaceflight program is not lost. Therefore, plans must be made to ensure that human exploration of the solar system continues beyond Mars.

**A Human Mission to Europa and Titan - Why Not?**

In order to achieve human exploration of the outer solar system, a clearly defined plan must be developed and executed, as well as a comprehensive strategy detailing all of the major milestones and barriers, across all disciplines, which must be overcome.

**Theseus - The Development Plan**

In Greek mythology, Theseus was a hero who found his way out of King Minos' labyrinth with help from Ariadne's ball of thread. Our Development Plan is the "ball of thread" which will lead to the successful exploration of the outer solar system by humans. The plan focuses on several key points that presently make it unfeasible for humans to go on such a mission and defines the necessary steps for technological research and testing. In addition, it provides for major robotic missions to the Jovian and Saturnian systems, to improve our scientific knowledge to the point where a human mission is feasible.

This summary also contains an analysis of the Program Management aspects that must be carefully considered so that the Development Plan and resulting mission can be achieved. It will take into account several possible scenarios with respect to the world's socio-political and economic development. Each scenario details the policy, motivation, organization and management, economic considerations, and legal issues with which it is associated.

**Why Send Humans to Europa and Titan?**

The benefits of such a mission are immeasurable and fall into three basic categories: technological, scientific, and social. Every nation will benefit from developing advanced technology which will revolutionize our daily lives in ways that we cannot begin to imagine. Scientific exploration may lead to the discovery of life in the outer solar system as well as help us to understand the physical processes that are occurring on these distant bodies. In addition, the social impacts are just as important as they promote further interest and commitment to science and research. By enabling a mission that is international in scope, the peoples of the world will be united in a common goal that spans languages, religions, and cultures.

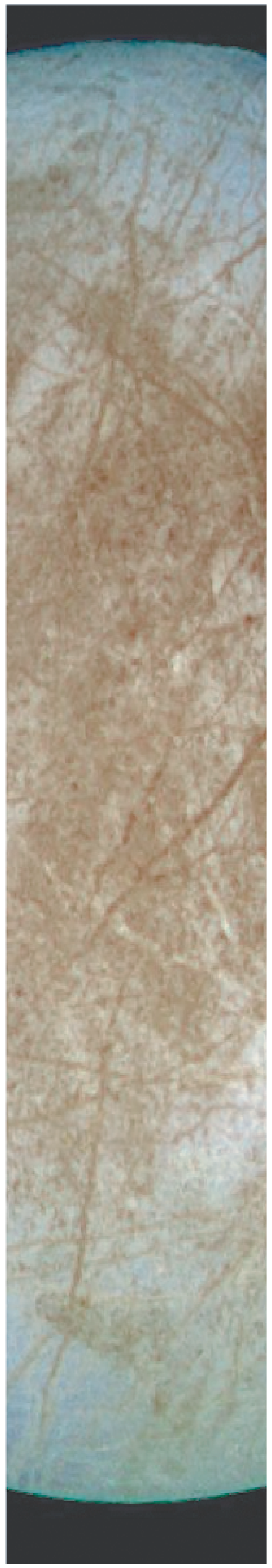
**Human Risk versus Exploration?**

Everything has its costs, everything has its risks; it is vital that we understand that space exploration is dangerous and that the risk of human loss is always a possibility. Both manned and unmanned space exploration is important to the future survival of the human species. It is possible that the Earth will become uninhabitable for humans someday, thus the ability of humans to venture to the outer planets will be the mark of a significant stage in human history, where groups of humans are able to live away from Earth for sustained periods of time.



...it is a desire inherent in our blood





## Jovian System / Europan Science

The Jupiter Icy Moons Orbiter (JIMO) will be launched around 2010 and will orbit the three icy Galilean moons - Callisto, Ganymede and Europa to fulfill four mission goals: To explore the potential for sustaining life on these moons, to investigate their origin and evolution, to determine the radiation environment around them, and, finally, to determine the rates at which they are weathered by material impacting their surfaces.

### The Europa and Callisto Explorer Mission

This mission will consist of one orbiter and two small landers. Scientific experiments include investigation of the radiation levels on Europa and Callisto, performance of astrobiology studies, and determination of the properties of ice on the surface of the two moons from orbit. This will give far more accurate ocean depth estimations for Europa and Callisto (if one exists) and for sub-surface feature detection.

### The Io Radiation Explorer Mission

The activities of the mission will be to observe the volcanic activity on Io, measure the radiation extremes, how they relate to the volcanic activity and make simultaneous radiation measurements with the Europa and Callisto orbiter.

### The Europa Surface Mission

This mission will involve an Europan orbiter and a large lander that will deploy a melting probe at the surface of Europa, at a landing site carefully selected according to data from previous missions. The probe will melt through the icy crust and enter the ocean. This mission will help to define more precisely the ocean composition, map the ocean floor, and conduct more detailed astrobiology experiments.

### The Europa Sample Return Mission

The purpose of this mission will be to collect samples using a lander and an ocean probe, for return to Earth for detailed analysis. The mission will also demonstrate In-Situ Resource Utilzation (ISRU) technologies in the Europan environment.

## Saturnian System / Titan Science

The Cassini and Huygens mission will start orbiting the Saturnian system in July 2004 and will greatly aid our understanding of Saturn and its moons (especially Titan). The following missions are concepts, unique to our plan. As in the case of the Jovian -proposed missions, they are expected to take advantage of the technologies enabled with the JIMO mission.

### Titan Orbiter and Balloon Mission

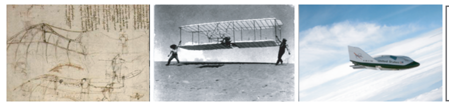
The follow-up mission to Cassini/Huygens will consist of an orbiter and an atmospheric balloon that will be dedicated to exploring Titan. Their objectives will be high-resolution mapping of the surface, analysis of the surface composition with an imaging spectrometer, atmospheric studies, and mapping of the plasma environment and radiation profiles in the atmosphere.

### Titan Balloon and Helicopter Mission

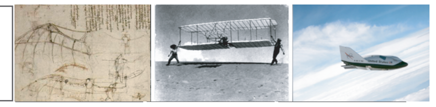
This mission will provide a more detailed knowledge of Titan using an orbiter, an atmospheric balloon, and several small helicopters. It will focus on astrobiology and atmosphere/surface interactions, while also identifying the most promising sites for geological studies and ISRU.

### Titan Sample Return Mission

The main goal of this mission is to characterize precisely what astronauts will encounter during a future mission to Titan and to make comprehensive astrobiological studies. It is a critical step for ISRU, habitat and scientific instrumentation development, and for landing site selection.



# What are the Technical Challenges...



It is clear that the level of technology required for a human mission to the outer planets will be far in advance of what is presently available. There are three key areas which demand significant advances before such a mission can become feasible:

**Propulsion**
Human travel to the outer solar system requires innovative propulsion systems capable of delivering a $\Delta V$ in the vicinity of 60 - 80km/s, a variable specific impulse ($I_{sp}$), a long operational lifetime, and high efficiency. We suggest aiming directly for high-efficiency systems like the Magneto-Plasma Dynamic (MPD) or Variable-Specific Impulse Magnetoplasma Rocket (VASIMR) since they not only offer far better $I_{sp}$, but, in the case of VASIMR, also moderate thrust capability.

**Power**
Nuclear power, on the order of magnitude of tens of $MW_e$ will be necessary to sustain a human mission to the outer solar system. The system will have a high output, efficiency, operational lifetime (minimum five years), and reliability, which shall be achieved via the integration of results from ground based testing, simulations, and data from robotic and human missions.

**ISRU**
The surfaces of both Europa and Titan contain considerable amounts of water-ice that can be extracted and processed to generate liquid water, liquid oxygen (LOX), and liquid hydrogen (LH) for the mission. These compounds will be used to support life, shield from radiation, support base and field operations, propel ascent and descent vehicles, perform interlunar trips, and provide the necessary impulse for sample or even crew return. However, ice is not our only source of resources; telescopic observations reveal that Europa possesses a tenuous atmosphere of oxygen. In order to fully develop ISRU technologies and techniques, a number of missions will have to be performed.

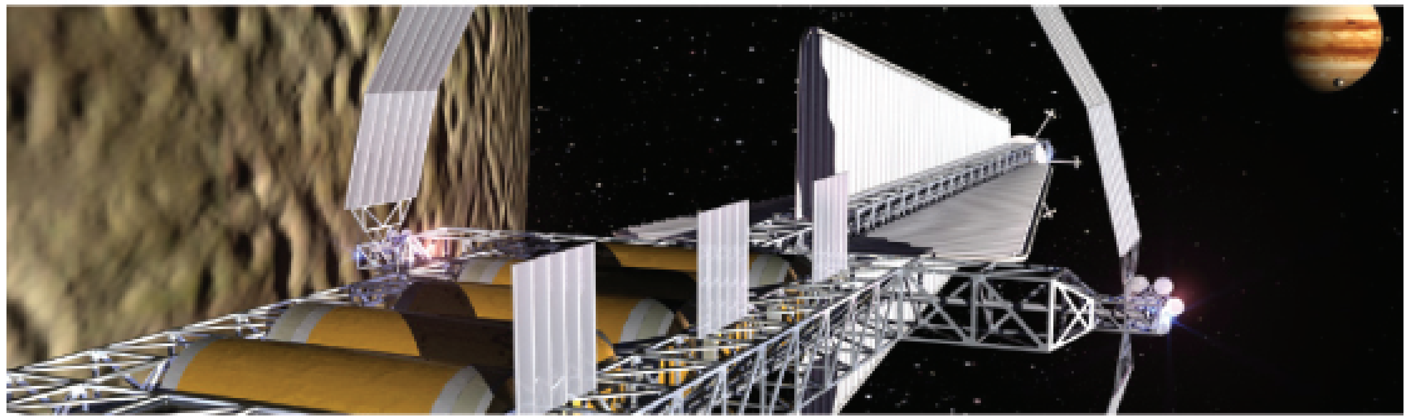
**What about Life Support?**
Four areas of space life science that must experience significant advancements are described below:

**Environmental Control and Life Support System (ECLSS)**
A closed ECLSS system is far superior for long-term missions than today's approach of completely stocking a spacecraft with the necessary supplies prior to launch or the continual re-supply of a spacecraft. Research on regenerative life support systems should be continued to increase the lifetime of a system beyond that which is necessary for a mission to Mars, and to ensure that it functions in variable radiation and gravity environments.

**Artificial Gravity**
Artificial gravity techniques are the most reasonable countermeasures to minimize the long-term effects of microgravity. There are many difficulties associated with this technology such as subsystem alteration, mass, power demand, spacecraft stability, and human tolerance to rotating environments. It is proposed that the first phase of investigation should be the production of a short-radius centrifuge. Follow-up phases should focus on the development of truss/tether techniques and torus structures.

**Habitation Module**
Habitat design plays a fundamental role within long-duration missions. Care must be taken to ensure that the module is "fit for extensive human habitation", as opposed to being merely "tolerable". All future human missions should incorporate habitat design that focuses on physical and mental health maintenance as opposed to simple functionality.

**Radiation Protection**
The radiation environment on Europa prohibits any mission, human or robotic, without adequate radiation protection. There are a number of solutions proposed to mitigate the effects of radiation: carbon or hydrogen nano-fibers, magnetospheric shielding, adaptation to high radiation levels, and pharmacological countermeasures. It is likely that the solution will involve a combination of pharmacology, passive and active shielding, diet, exercise, and possibly even genetic engineering in order to minimize the effects of long-term exposure of the human body to the radiation environment.





...to be overcome?



It is crucial that program management is properly organized, planned, and controlled to ensure its efficiency and sustainability over an extended period. The program management will encompass elements of national and international policy, motivation, organization and management, financial considerations, legal issues, outreach and education, ethics, and social implications. Since it is almost impossible to predict exactly the state of the world more than fifty years in the future when this mission takes place, the program management will be analyzed considering four different possible scenarios:

**1. International, Publicly Funded**

NASA assumes initial leadership, thus being responsible for outlining and managing the overall plan, with any other interested agencies participating on various levels. Once the Development Plan is progressing smoothly, NASA will be relieved of its overall management responsibilities by the creation of an international organization, the International Space Consortium (ISC). The ISC will promote international missions to the outer solar system and be responsible for establishing the governing body. This body of highly qualified individuals, representing all involved countries, will meet regularly to determine the various functions of the mission as a whole.

**2. International Public/Private Collaboration**

A single government agency is incapable of carrying out such a large project on its own, and a venture via international public collaboration is insufficient to raise adequate funds. This, along with other factors, ultimately results in the establishment of a non-profit foundation to coordinate joint public and private space exploration efforts. In order to build upon the support of governments, there should be collaboration with the private sector through the inclusion of both profit and non-profit companies and organizations. This cooperation in space will have several advantages, namely, the improvement of international relations and the stimulation of new ideas by sharing varied experiences and perspectives.

**3. Exclusively Privately Funded**

Space commercialization explodes, resulting in a major increase in launches, international capability, and technology. Flights to Low Earth Orbit (LEO), the Moon, and perhaps even Mars are almost routine events. Travellers have a choice of flying to exotic Earth locations as well as to extraterrestrial settings. In addition, permanent settlements and private enterprises have been established on the Moon and all technological developments that will enable human missions to the outer solar system will be carried out by the private sector. Businesses such as tourism, transportation, mining, energy, material manufacturers, and pharmaceutical companies will be among some of the key developers of space technology.

**4. Major Societal Shifts**

The final program management scenario proposed for our Development Plan involves three major societal shifts:

A. New Space Race
China (or another nation) has become a major space power and has successfully reached the Moon and Mars without international cooperation. This has heightened tension between the US and China (and their respective partners) in the intervening years.

B. Discovery of Life on Europa and/or Titan
Evidence of past or present life is discovered on Europa, Titan or elsewhere. Depending on what is discovered (i.e. intelligent life, microbes, fossils, etc.), people from all over the world want to be a part of this mission in order to study this new life.

C. Potential Destruction of the Human Race
The human race faces the possibility of imminent extinction originated by a world war, asteroid threat or extreme environmental problems. Only in the face of these types of global threats do different cultures, ideologies, and countries of the world have the potential to move beyond their differences to work together for a common cause: the survival of the human race.

### Legal Issues

It is believed that the existing legal framework is largely acceptable for a human mission to Europa and/or Titan. The relevant treaties are as follows:

- Outer Space Treaty, 1967
- Rescue Agreement, 1968
- Liability Convention, 1972
- Registration Convention, 1975
- Moon Agreement, 1984

However, modifications to these treaties would be needed to allow such a mission to take place, especially if it is to be pursued via international cooperation. Examples of such adjustments are given below:

Criminal jurisdiction - it is suggested to create one consistent set of rules regarding the jurisdiction of the entire craft and of all the crewmembers, regardless of nationality.

The Planetary Protection Clause - conscientious effort should be made to avoid contamination, both of celestial bodies by Earth sources and of Earth by extra-terrestrial sources.

Nuclear power sources - any use of nuclear power must comply with the "Principles Relevant to the Use of Nuclear Power Sources in Outer Space".

### Outreach and Education

Outreach and education efforts should be directed at people from every age group, culture, and discipline. Such measures are imperative as global awareness of the project will promote overall education and inspire the general public, as well as provide vital public support for this high-profile, expensive, and complex mission.

In order to reach the whole population, many entities should be involved, including developing nations, non-profit agencies, museums, and schools. One idea is to create an "Outer Space Analogous Environment" on Earth by designating cities around the world as space entities, which would serve as centers to inspire and educate the poulation on space, science and technology. For example, Stockholm could be Saturn, with a large-scale physical model of Saturn built in the city. Stockholm would then also house a museum of information and artifacts associated with Saturn specifically and with outer space in general. Another city would then be designated as Mars, and so on.

Tutorials, activities, and lessons about the mission and other space related areas would be posted on the Internet, in a variety of languages, for easy access by educators world wide. In addition, reality TV shows may be possible, so as to capture the public's interest and hence chart the progress of the mission.

### Ethics and Social Implications

One must ask whether this mission is important enough to incur such a high risk to human life. It is obvious that a huge amount of political will and public support would have to be generated in order to fund the mission. The general public would have to be well-informed of the dangers of spaceflight and of the risk of human loss. Eventually, an acceptable risk value will have to be determined for the mission. It is suggested that a Code of Ethical Principles be drafted by the governing international organization. This document would act as a set of major guidelines for all decisions to be made, including the following topics:

- Radiation limits
- Risks to the Earth (e.g. nuclear technologies)
- Planetary Protection
- Code of Conduct for the crew onboard the spacecraft
- One-way ticket issues
- Conflicts of interest
- Crew composition
- Genetic alteration/modification

### Cost of the Development Plan

Unfortunately, an accurate estimation of the cost of the entire Development Plan is not feasible for many reasons, including the long time-scales associated with the Development Plan, the high level of novel development required and the overall complexity of the proposed steps. Two methods of cost estimation were used in order to approximate the overall cost of the Development Plan. The first method uses a combination of analogy and parametric costing methods and the second uses the Apollo Program as an analogy.

Therefore, depending on the future scenario, the total cost for scientific missions and the development of technologies could range between 220-470B USD. However, due to the high level of uncertainty, the 220B USD estimation probably sets the lower limit and represents the best-case scenario.

In order to provide a vision of the requirements presented in Theseus, a case study was carried out with the purpose of illustrating the outcome of Theseus on a human mission to Europa.

Rationale and Assumptions

| | |
|---|---|
| **Mission:**□ □ □ | METTLE |
| **Purpose of Human Mission:**□ | Search for the existence of past or present life on Europa |
| **Destination:**□ | Jovian System |
| **Timeframe:** | year 2070 |
| **Mission Duration:** | 4 years |
| **Assumptions within Case Study:** | All major financial, scientific, technological and managerial issues to enable such a mission are solved, thus focusing purely on the mission development. |

## Spacecraft Design

The spacecraft will be 200m long and include a toroidal habitat with a radius of 45m that will rotate at 3 rpm providing a 0.45g artificial gravity environment, thus mitigating the long-term effects of microgravity on the crew. The harsh environment of free space and Jupiter's high radiation will be the main driving factor for spacecraft design. The crew will be shielded from cosmic rays and Jovian radiation by the combination of passive shielding and super conductive magnets, which will produce a magnetosphere around the spacecraft. Eight 2.5 MW VASIMR engines, mounted at the rear of the spacecraft, in four pairs, will provide the necessary propulsive force. The spacecraft's energy will be supplied by six nuclear reactors mounted on booms, with large radiators to dissipate excess heat. Miniature autonomous robot assistants, that will visually inspect the surface of the spacecraft to detect anomalies, will perform maintenance and inspection of the structure and systems and, if necessary, repair damaged areas.

## Main Habitat Ring

The interior of the torus will provide a habitat with a diameter of 4.5m and will consist of all necessary facilities to allow a successful long duration space mission. Modules for sleeping, living, working, exercising, and recreation make for a total of twenty-four (modules), providing a habitable surface of approximately 1000 $m^2$. This area will allow the crew of six to carry out their daily tasks efficiently.

Large flat screen monitors shall be installed on the walls, allowing the crew to display pictures of friends, family, and animated 3D simulations of the astronaut's favorite environments on Earth. Personal rooms have been designed for privacy and others to be used for communal gatherings, such as dinner. These are seen as essential, as they will ensure healthier crew dynamics during the long duration mission.

Hydroponically grown fresh fruit and vegetables stimulate the senses via the creation of a natural environment, thus helping the psychological well-being of the crew during flight.

The Health Maintenance System (HMS) has been designed so as to guarantee the success of the mission. The system provides two main functions:

1. In-flight preventive, diagnostic and therapeutic medical care.
2. Patient stabilization and transport for serious medical situations.

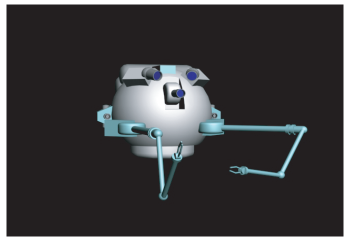
## Mission to Europa To Trace Life's Existence (METTLE)

Spacecraft assembly will be *carried* out in a LEO spaceport with the aid of advanced launch systems. The mission will begin with the ignition of the VASIMR engines, causing the spacecraft to spiral away from the Earth and onto its trajectory towards Jupiter. This propulsion system gives a flight time of 1.5 to 2 years, and will also be used for deceleration upon approach to Europa.

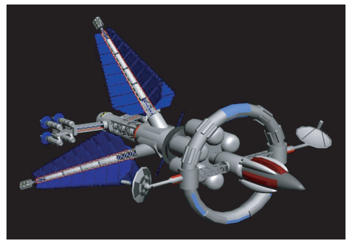
After orbital insertion around Europa, the Descent Vehicle with a crew of three shall descend to the surface in order to perform its primary research. The tip of the submarine, equipped with a nuclear core, will melt through the ice and venture to the most interesting part of the moon - its subsurface ocean. After melting through the ice crust, the submarine will enter the ocean of Europa, and conduct astro-biological experiments for a total of sixty days.

Upon completion of the experiments, the submarine will return to the surface of the ocean with the use of a rotating screw-like structure. This will provide traction when moving upwards. The propellant for the ascent will mainly consist of $H_2$, which will have been produced by ISRU. As soon as the surface is reached, the Ascent Vehicle will launch and rendezvous with the orbiting spacecraft. Meanwhile, the crew onboard the orbiter, will have been performing scientific observations and experiments at Callisto. Finally, the engines will be ignited to propel the spacecraft for its voyage back to Earth.

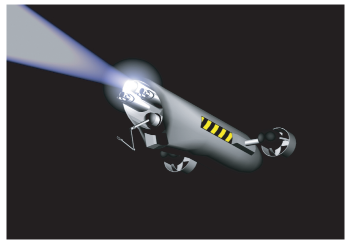
*Maintenance Robot Assistant (MRA)*



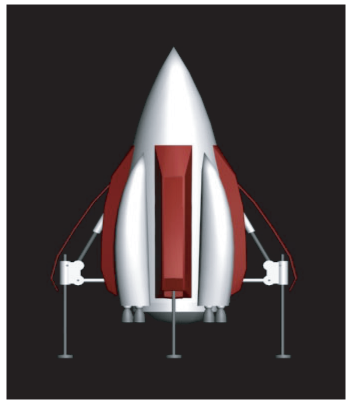
*METTLE'S spacecraft design for interplanetary flight*



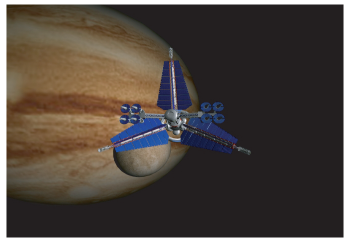
*Hydrobot design for Europan sub-surface activities*



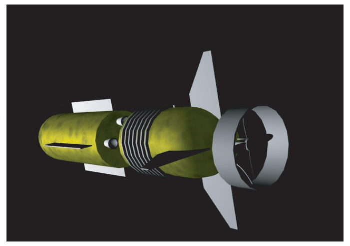
*Descent vehicle with submarine/ ascent vehicle inside*



*METTLE'S spacecraft design*

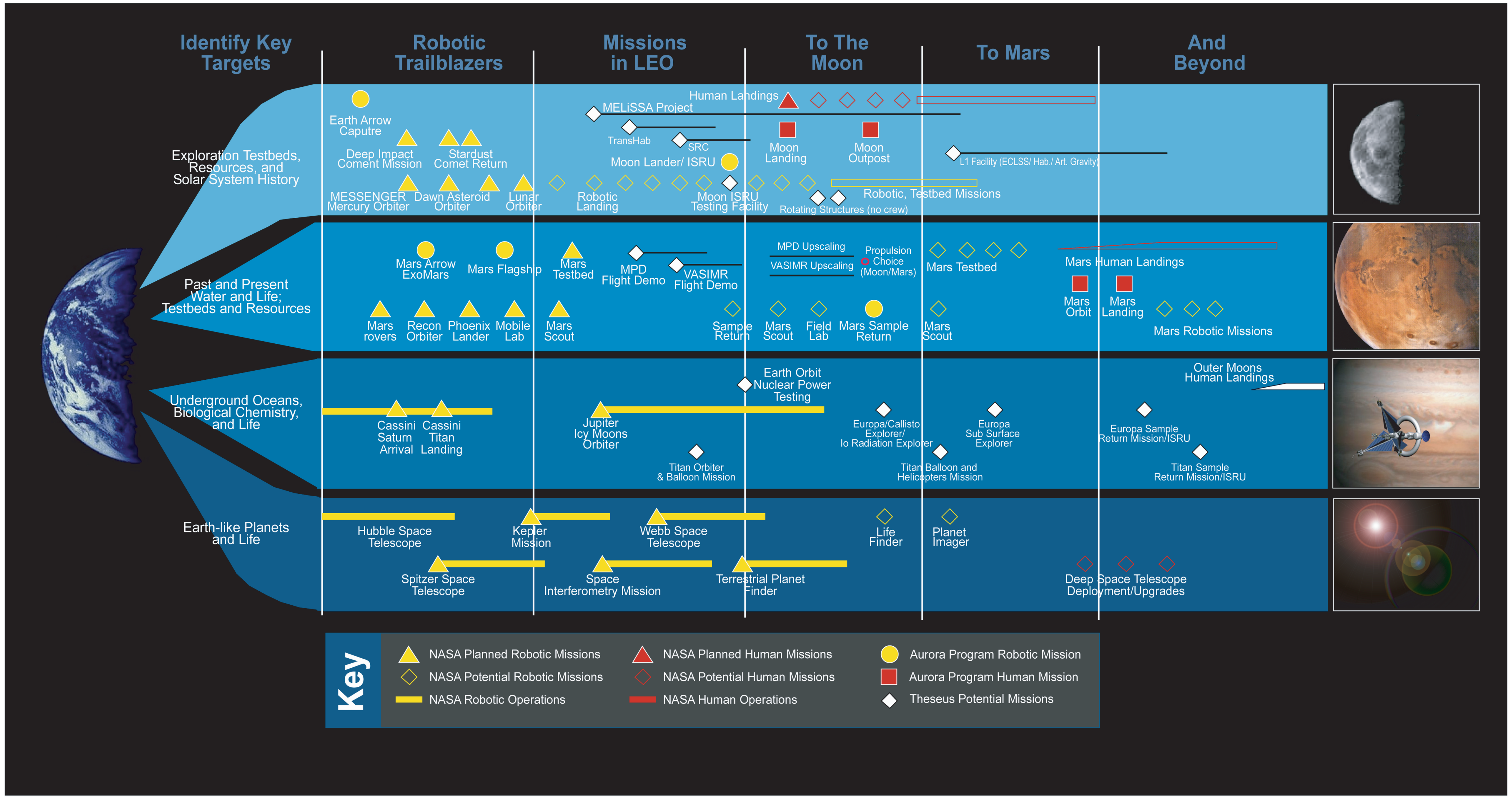


*Submarine for sub-surface activities*



### To Europa, Titan, and Beyond

The Theseus Development Plan is formulated to enable human exploration of the outer planets with the main emphasis on Europa and Titan. However, these two worlds are not the only places that ought to be explored should the Theseus plan be realized. As of April 2004, Jupiter and Saturn were known to have more than a combined total of ninety moons; many representing unique worlds. For example, the Saturnian moons Enceladus and Iapetus both exhibit unknown physical properties and processes. The former displays many similarities to Europa while Iapetus is one of the most puzzling moons in our solar system with its contrasting very dark and very bright hemispheres. Beyond Jupiter and Saturn, Uranus and Neptune have their own distinct worlds: after outgassing events on Triton were observed in 1989 by the Voyager 2 spacecraft, it is theorized that this moon of Neptune has an active interior. The METTLE mission, therefore, is just one of the numerous options enabled by the Theseus Development Plan.




*Theseus' Potential Missions Incorporated into NASA's Space Initiative and ESA's Aurora Program*

Exploration of the outer solar system is only one of the options initiated by the Theseus plan. The ability to transport large and advanced payloads in space can also pave the way for the construction of bases on the Moon and Mars, as well as for the establishment of permanent human settlements in space. The asteroid belt also provides an area available for exploitation and colonization. A number of small posts, spread throughout the asteroid belt, could function as supply and servicing stations for human missions to the outer planets or for resource utilization on either the Earth or potential planetary bases.

The future remains unpredictable as do any of these possibilities. Projects like this should remind us that the final frontier for humans is outer space, not just Mars. The human imagination will determine where the frontier stops and given the scope of our known universe, Europa and Titan are very close indeed.

This Executive Summary and associated report were written by students in the 2004 Master of Space Studies program at the International Space University, Strasbourg, France.

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