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Space-Based Technologies and Commercialized Development

Economic Implications and Benefits

Stella Tkatchova

Space-Based Technologies and Commercialized Development:

Economic Implications and Benefits

Stella Tkatchova, RHEA System S.A., Belgium

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Dedication

To my Mum

Table of Contents

Chapter 4

Chapter 5

Chapter 6

Foreword

I would like to congratulate Dr. Stella A. Tkatchova on her monumental study, 'Space-Based Technology and Commercialized Development: Economic Implication and Benefits'

During the Cold War era not only human space exploration but also military-oriented space technologies evolved rapidly as tools to achieve domination in a military power and as sources of national pride. This technological competition also generated numerous benefits to society.

In the areas of satellite telecommunication systems and navigation systems, we see clear benefits from space technologies. The existence of a wide variety of stakeholders throughout the world indicates that investments in high technological space areas should be continued for the improvement of life and a better future for all humanity.

Although the current economic crisis is causing a pause in new human space exploration initiatives, especially in the leading space-faring countries, new players such as China and India are accelerating their efforts to join the group of leading countries.

Through the twenty-five years international partnership in the ISS program, it can be seen that it has served to ease world tensions; and such programs will continue to be effective in an era of civilized conflict too.

In this study, Dr. Tkatchova thoroughly analyzes the space economy and its benefits for nations, space agencies, space and non-space companies, and society by using actual historical experiences, especially human space exploration. This is the time I have seen such a book which so clearly sets out the direct and indirect benefits from space activities. She also looks to the future and identifies the expected benefits from space tourism and a manned Mars mission.

I hope this book will provide all of us with a reconfirmation of the benefits from space activities and contribute to our decision-making for new space programs, especially new international human exploration programs.

Todome Kazuhide
President of JAMSS
Japan Manned Space Systems
12 April 2010, Tokyo

***Todome Kazuhide** is the President, Japan Manned Space Systems Corp.(JAMSS), a leading Japanese aerospace operations company. He started his career in 1972 as a mechanical engineer at the Space Development Division, of the NEC Corporation working on the design of structures for scientific satellites. He holds a Degree in Mechanical Engineering from the Hokkaido University. In 1993 he became the Manager of the Satellite Development Department at NEC Corporation. Later on in 2000 he joined NT Space working as a Space Director and later on as a General Manager and Vice President. However, his passion for further encouraging the development Japans' human space flight, such as the International Space Station (ISS) KIBO Module and the HTV transfer Vehicle and for supporting Japanese research on board the ISS, led his career to Japan Manned Space Systems Corp.(JAMSS). In 2005 he became the Managing Director of JAMSS in 2008 the Executive Director and in 2009 the President.*

Preface

The objective of this book is to identify, describe and analyse the benefits to national space agencies, space companies, non-space companies and private investors, from the commercial use of space-based technology and services from human spaceflight and interplanetary space missions[1].

In this book the different aspects of commercialisation of space technology and the new markets and space applications in the context of today's society needs are analysed. Furthermore, in it there is an analysis of the market trends taking place in today's' space industry and its competitiveness, the changes taking place within the industry and the changing space agencies industrialisation policies

The development of commercial crew and cargo services, the development of new low cost launchers and sub-orbital vehicles, the emergence of a space tourism market, the construction of solar power satellites and space ports, are recent trends taking place in the space industry. These new developments are only possible because of the capital invested by private investors and entrepreneurs, who understand the importance of space technology in our day to day lives. However, in order to be able to achieve technology innovation and in parallel sustain private funding, companies will have to have to consider the benefits from commercialisation of space technology so that they can develop viable business cases. Measuring the economic impact from the use of space-based technology and learning lessons from MIR and ISS commercialisation and the aviation industry, will support identifying direct and indirect benefits from space technology commercialisation. The direct benefits will be employment, revenues from sales, new markets, cost savings, employment and technology reliability/interoperability, while the indirect benefits will be free publicity, technology innovation, international cooperation/partnerships and environment protection. The above benefits definition will support companies in projects assessment through performing cost benefit analyses.

Finally in this book there is an analysis of the space tourism market and two business cases one on mitigation and removal of space debris and the second one on solar power satellites use for energy provision.

Commercialisation of space-based technology from future interplanetary missions can contribute with new ideas, cost-effective solution and the development of key - enabling technologies, that will result in space applications that will improve our day to day lives and bring economic benefits to national economies.

ROLE OF SPACE TECHNOLOGY AND INFRASTRUCTURE

Space technology and infrastructure, such as telecommunications, navigation and earth observation space systems have become essential in our daily lives. In the 70s the Apollo missions contributed to more than 1,500 spin-offs to our lives with the development of kidney dialysis machines, freeze dried foods, scratch resistant lenses and flame resistant textiles. Today navigation systems contribute to air and road traffic safety, precision agriculture, oil and rack positioning and earth observation systems support environment monitoring, disaster and natural resources management. In addition, research on-board the ISS is contributes with the development of new medicines, osteoporosis therapies, cell and tissue growth studies, development of medical instrument scanning equipment, new light materials and new methods for water purification and processing.

Nevertheless many citizens and companies do not fully appreciate or understand the benefits of space technology and R&D to our daily lives. Therefore, decision makers, space agencies leaders, space companies, university researchers and space visionaries are burdened with the challenging day to day task to continuously justify the benefits and role of space technology and explorations to our daily lives. Rather than concentrating their efforts and resources in developing key - enabling technologies and solutions using space-based technologies and solutions for environment protection and monitoring and for solar power energy generation.

CHAPTER 1: COMMERCIAL TRANSPORTATION SERVICES

Chapter 1 analyses NASA 2011 budget and strategy for encouraging the development of key enabling technologies, extension of ISS commercialisation and the development of commercial crew and cargo vehicles and services. The development of low cost launchers, private sub-orbital transportation vehicles and space ports and US commercial space flight capabilities hold a promise for a new space exploration vision and industry.

Therefore, in this chapter there will be an overview of NASA Funding for 2011 and NASA Commercial Orbital Transportation Services (COTS) program. Furthermore, in it there will be a discussion on the indicators for measuring the impact of different projects under NASA COTS program. In addition, this chapter will provide an overview of SpaceX, Orbital, Virgin Galactic, Ansari X-prize and Google Lunar X-prize and Caribbean space port activities. Finally, in it will be discussed the importance of integrating non-space companies mission requirements for future space missions.

CHAPTER 2: MOON AND MARS SPACE EXPLORATION CONCEPTS

The Apollo 11 landing on the Moon on July 24th 1969 marked a new era of human space exploration, due to which a new generation of space scientists, visionaries and dreamers was born. A generation for which Lunar habitats, Mars missions and interplanetary colonization are were only but a natural step to interplanetary space exploration.

Today, almost 40 years after the last Moon landing in 1972, we are starting to understand the benefits from space exploration to humankind. Therefore, this chapter will provide an overview of the Apollo mission benefits, NASA 1969 space exploration strategy, Russian, European, Japanese, other countries Moon and Mars programs.

In his "Plan of Space Exploration", the father of space rocketry, Konstantin Tsiolkovsky, already in 1926 defined at least sixteen steps[2] for human space exploration, such as using solar radiation to grow food, transport throughout the Solar System, colonization of the entire Solar System and the Milky Way. His vision not only became the road map of modern rocketry, but described some of the benefits from space exploration, such as using solar radiation for food growth and transportation.

His vision was carried out by Korolev and Wernher von Braun, who were the fathers of modern rocketry. Korolev launched the first artificial satellite „Sputnik" in 1957 and the first man in space Yuri Gagarin in 1961, while Wernher von Braun launched the first humans on the Moon in 1969. Nevertheless of the success of human space flight missions the challenges in justifying human space flight still remain. Therefore, in this chapter there is an analysis of the expected benefits from space agencies Moon and Mars space exploration visions and description of the reasons behind benefits definition.

CHAPTER 3: SPACE STATIONS COMMERCIALISATION

The objective of Chapter 3 is to introduce space agencies' commercialisation strategies and also to analyses the lessons learned, the reasons and the benefits behind space station commercialisation. The lessons learned from the space station commercialisation will illuminate the hidden hurdles of commercialisation of space stations and interplanetary missions. Furthermore, this chapter will provide an analysis of the challenges facing the commercialisation of space stations and space-based technology for interplanetary missions.

CHAPTER 4: SPACE INDUSTRY MARKET TRENDS

Space industry provides navigation, telecommunications and earth observation services essential for our day-to-day lives. The analysis of the market trends in the space industry will provide a better understanding of the industry and the trends taking place.

Market trends analysis in the space industry will provide an understanding of the challenges facing the global space industry. The industry encompasses several market segments, such as Telecommunications, Earth Observation, Navigation, Human Space-Flight and Interplanetary Exploration segments.

Chapter 4 will present an overview of the space industry stakeholders, market trends in the telecommunications, navigation and launcher segments and in general national space industries (i.e. Europe, Russia, Japan, etc.). In addition, it will discuss the benefits of interplanetary human and robotic exploration for national space industries.

CHAPTER 5: EMERGING MARKETS AND SPACE APPLICATIONS

Telecommunications, navigation and earth observation space systems have become essential for the safety in our daily lives. Research on-board space stations has contributed to the development of new drugs, osteoporosis treatments, development of new materials, medical equipment and development of new methods for water purification and processing.

In recent years, space agencies have started encouraging the development of new markets and new industrial applications for the wider use of navigation (i.e. Galileo, GPS) and earth observation space systems (i.e. GMES). Space agencies and private comapnies involved in the development of space applications will face numerous challenges in market segmentation definition, however the space applications with their technology and process solutions may contribute to energy production, environment and disaster management processes and protection.

Only a few years ago, the idea of private citizens paying for trips to the ISS was in the realms of science fiction. Today in 2011 it has become a reality and entrepreneurs are investing in the development of sub-orbital transportation vehicles and construction of space ports. Space agencies have started recognizing the importance of commercial crew and cargo transportation services and NASA has even allocated a budget for encouraging the development of these services. Nevertheless, investing in commercial space projects is still considered to be challenging and risky, as funding is limited and is primarily available through prize competitions or partial project funding from agencies.

Today space exploration is considered by many visionaries and scientists, as a future source of energy through the use of solar power satellites and the construction of lunar solar power stations.

CHAPTER 6: COMPETITIVENESS OF SPACE INDUSTRY

Space industry is dominated by the rules and regulations of its institutional customers. High market-entry barriers, complex procurement rules, technology-driven competition and buying rules define the space market segmentation. High interdependence between players, high market-entry barriers, mergers and acquisitions, and the small number of players indicate the existence of an oligopoly market structure.

Export regulations, licensing, International Traffic in Arms Regulations (ITAR) and European Authorized Representative (EAR) regulations are some of the market-entry barriers which space companies have to face. These barriers will not only result in revenues losses from sales for space manufacturing companies, but they will also influence the direct and indirect benefits from commercial utilisation of space-based technology from interplanetary missions and future commercial and crew and cargo transportation services. This chapter will analyse the competitiveness of the space industry, discuss the market structure in the space industry, the market-entry barriers, and the space-related patents and partnerships.

CHAPTER 7: SPACE TOURISM

NASA astronaut Roberta Bondar said: “To fly in space is to see the reality of Earth, alone. The experience changed my life and my attitude towards life itself. I am one of the lucky ones.”. Space tourism offers the possibility for more and more people to enjoy something that up till now less than 500 professional astronauts and “flight participants” have been able to experience: the excitement of a launch, microgravity and the stunning view of Earth from space.

Market surveys indicate that the number of people willing to spend serious money on a ticket to space is huge, but of course a strong function of the price. At the moment, the only possibility to pay your way into orbit is buying a $30 million ticket for a flight with a Russian Soyuz spacecraft to the International Space Station. However, more affordable albeit much shorter trips into space will soon become available via Virgin Galactic, which is offering flights onboard its suborbital rocket plane for about $200,000. Early 2008 Virgin Galactic had about 200 assured passengers, $30 million in deposits and about 85,000 registrations from interested potential customers.

CHAPTER 8: SPACE ECONOMICS AND BENEFITS

In Chapter 8 there will be a short introduction to space economics, assessment of direct and indirect economic impacts and benefits from the use of space based technology. Furthermore, in it there is an overview of space budgets, space employment and products. For the identification of direct and indirect benefits examples from the aviation industry will be used and based on them a proposal for measuring the economic benefits and impacts to national economies from interplanetary space-based technologies will be made. The direct benefits will be employment, revenues from sales, new markets, cost savings, employment and technology reliability, while the indirect ones will be promotion, technology innovation, international cooperation and environment protection.

The expected result of this chapter is to show the economic impact space based technologies that they can have on non-space industries and propose approaches for assessing the benefits for space agencies, industries and societies from commercialization of space-based technologies.

CHAPTER 9: AN ANALYSIS OF TWO SPACE BUSINESS OPPORTUNITIES

Chapter 9 analyses two commercial applications and develops the business case for each of them. The first application is the mitigation and removal of space debris. This application is immediately economically viable and feasible to implement with current technology or relatively minor technological advances. Space debris is defined as any man-made object in earth orbit that is not deployed by any working systems. The large number of space debris creates significant hazards for existing satellites and would generate even bigger risks for any future expansion of human presence in earth orbit. The market for space debris mitigation and removal is large.

The profit opportunities are relatively easily defined, yet only a handful of private companies currently provide products and services to this market.

The second application we evaluate is Space Solar Power (SSP). SSP involves the conversion of solar energy into electromagnetic waves by satellites in orbit, beaming these waves to rectifying antennas (rectennas) on the ground and converting them into electricity. Space Solar Power is considered currently unviable either for technological or economic reasons. Nevertheless, with certain technological advances and/or the engagement of high-value clients it could offer tremendous opportunities for profit. Space solar power is a source of energy that does not generate greenhouse gases, has a much smaller heat rate than any conventional power generation method, and can provide enough energy to meet the needs of the entire Earth's population for a practically unlimited time horizon. Consequently, successful implementation of large scale SSP systems could in the long run solve at least two existential problems facing humanity – energy generation and climate control. We develop our business case around two hypothetical SSP systems.

After analyzing the technological challenges and developing the business cases, we turn to the major issues of financing any commercial ventures that wish to operate in each of our two chosen space industries. Space debris mitigation and removal and especially Space Solar Power have several features that make them unattractive for private capital providers. First, there is a significant upfront investment in research, development and testing before any product becomes operational. Due to the uncertain outcomes and long payback periods, investments in R&D in general attract only a small number of specialized private investors like venture capitalists or large companies operating in oligopolistic industries. Investments in SSP-related R&D are expected to be extraordinarily risky with paybacks exceeding 25 years.

OBSERVATIONS

The new developments taking place in the global space arena will impact not only national space industries, but will also bring benefits to national economies. In 10 years space agencies would have changed their industrial policies and some agencies would have implemented programs for encouraging space applications and commercial crew and cargo markets development.

Furthermore, it is possible that the high expectations from the space tourism market to have soured down and companies, such as Virgin Galactic, Bigelow and Space Adventures to have already diversified their services and entered traditional space industry markets (i.e. launching micro-satellites).

In addition, the impact of the US President decision to cancel the US Constellation program in 2010 would have been already felt with reduced institutional human space flight activities by space agencies.

However, commercial crew and cargo services markets, would have developed but the lack of a space station after 2021 would have impacted private investment in commercial projects. The lack of a clear deadline from NASA for human spaceflight missions to Mars or to asteroid missions will drag and delay the development of these planned human spaceflight missions. Therefore, resulting in delays in the development of human rated heavy launchers and the implementation of new propulsion systems. Most of the planned human space missions to asteroid or Mars may transform into robotic ones rather than human space flight ones.

Companies and space agencies involved in developing low cost launchers will learn several lessons from MIR and ISS commercialisation. One of them will be that non-space companies are not ready to provide funds for helping agencies achieve their cost-recovery objectives. As for private space companies, space agencies are usually the end-customer. The second lesson will be that top-down market analysis, unknown customers and markets, the length of time required to market a product developed in space, the complexity of the relationship with space agencies, and the lack of a long term vision, may confuse commercial companies. Finally, competition from terrestrial technologies may discourage customers to launch commercial projects using space-based technologies.

Space agencies will allocate their budgets primarily in the development of earth observation and navigation systems and in the implementation of programs for encouraging the development of space applications. Decisions makers in space agencies and public bodies may face difficulties justifying human space flight exploration and be constrained in attracting long term funding for human space flight missions.

Space industry would have transformed and become much more competitive and traditional space companies would have started partnering with new players, such as Space Adventures, Bigelow, Space-X and Virgin Galactic.

These companies will have attract long term funding and develop *conservative business cases* in order to overcome mission delays and secure the integration of their user requirements in the early phases of space missions. The companies involved in commercial projects will have to develop business cases for which investors will be willing to invest. Therefore, they will need to *qualify* the benefits for space agencies and non-space companies from future commercialization of space technology for future interplanetary missions will contribute to defining a commercialization strategy for future missions. The space tourism market would have developed, in parallel the market for space debris mitigation and possibly the one for generation of solar power through satellites would have also developed.

Commercialisation of space technology and solutions can be primarily achieved through the development of space applications for self-sustainable energy solutions or for understanding climate change and reduction of human made pollution.

ENDNOTES

[1] The analyses, statements and conclusions in this book are the authors' personal ones and not of the organisations for which they work

[2] Konstantin Tsiolkovsky Plan for Space Exploration included the following steps for space exploration :(I)creation of rocket airplanes with wings, (II)progressively increasing the speed and altitude of these airplanes, (III)production of real rockets-without wings, (IV)ability to land on the surface of the sea, (V) reaching escape velocity (about 8 Km/second), and the first flight into Earth orbit, (VI)lengthening rocket flight times in space, (VII)experimental use of plants to make an artificial atmosphere in spaceships, (VIII)using pressurized space suits for activity outside of spaceships, (IX)making orbiting greenhouses for plants, (X)constructing large orbital habitats around the Earth, (XI) using solar radiation to grow food, to heat space quarters, and for transport throughout the Solar System, (XII)colonization of the asteroid belt, (XIII)colonization of the entire Solar System and beyond, (XIV)achievement of individual and social perfection, (XV)overcrowding of the Solar System and the colonization of the Milky Way (the Galaxy), (XVI)the Sun begins to die and the people remaining in the Solar System's population go to other planets (Lytkin, 2008).

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Finally, I would like to thank my Mum, the of my family, friends and boyfriend Adrien for their great support and patience during all these years.

Stella Tkatchova
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Chapter 1

Commercial Transportation Services

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"In my own view, the important achievement of Apollo was a demonstration that humanity is not forever chained to this planet, and our visions go rather further than that, and our opportunities are unlimited."

Neil Armstrong

1. INTRODUCTION

In 2010 the Obama administration proposed a new NASA budget and strategy for encouraging the development of key enabling technologies, extension of ISS commercialisation and the development of commercial crew and cargo vehicles and services. In order to pursue the new strategy for space industry development the new Obama administration cancelled the US Constellation program that envisioned returning to the Moon and a human space mission to Mars. The development of low cost launchers, private sub-orbital transportation vehicles and space ports and

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US commercial space flight capabilities holds a promise for growth in the space industry and development of new markets.

Therefore, in this chapter there will be an overview of NASA Funding for 2011 and NASA Commercial Orbital Transportation Services (COTS) program. Furthermore, in it there will be a discussion on the indicators for measuring the impact of different projects under NASA COTS program. Finally, this chapter will provide an overview of SpaceX, Orbital, Virgin Galactic, Ansari X-prize and Google Lunar X-prize and Caribbean space port activities and discuss the importance of integrating non-space companies mission requirements for future space missions.

2. NASA FUNDING FOR 2011

In 2010 the Obama administration completely changed the direction of the American space exploration program and proposed the extension of ISS utilisation, encouragement of the development of commercial crew and cargo transportation services and human space flight mission to Mars after 2035. The new NASA budget for 2011 will invest in the following areas (NASA, 2010):

1. Transformative technology developments and development of technology demonstrations to pursue new approaches to space exploration - NASA is planning to invest $7.8 billion over five years to develop cost effective technologies and develop technologies, such as in-orbit refuelling and storage.
2. Robotic precursor missions to multiple destinations in the solar system - NASA is planning to invest $3 billion for five years in the development of robotic missions that identify hazards and planetary resources for human visitation and habitation.
3. Research and development on heavy-lift and propulsion technologies - NASA is planning to invest $3.1 billion over five years for R&D in the area of development of new launch systems, propellants, materials and combustion processes.
4. Development of US *commercial* space-flight capabilities
5. Extension of future launch capabilities, including modernizing the Kennedy Space Centre after the Space Shuttle retirement
6. Extension and increased *utilization* of the ISS until 2020 - NASA has allocated $2 billion for over 4 years (see Figure 1) to support the extension of International Space Station (ISS) until 2020, increase space station capabilities, and support scientific research.
7. Development of cross-cutting technology aimed at improving NASA, other government and *commercial* space capabilities in new key areas, such as communications, sensors, robotics, materials and propulsions

8. Accelerating the next wave of Climate change research and observations and next generation of green aviation
9. Planetary science - NASA proposes an increased budget for the identification of Near Earth Objects (NEO), a Mars Science Laboratory, a Europa Jupiter System Mission and many others.
10. Education including focus on Science Technology Education and Mathematics (STEM)

The objective of NASA is to direct its R&D budget and technology development for achieving sustainable and affordable space-flight technology.. The *first objective* will encourage innovation and the development of new technologies such as, in-orbit refuelling, storage, affordable long-lived power in space, reusable high energy in-space propulsion or development of high-strength and low-mass modular structure solutions (Mankins, 2010). However, these technologies will have to be *affordable* and *safe* therefore, technology innovation will be a strong driver. NASA will also have to develop technologies such as intelligent modular space systems and re-usable low cost systems.

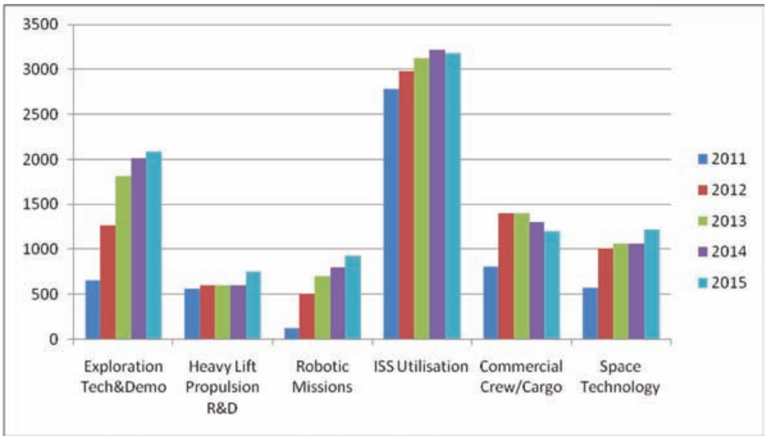
Investing in the development of robotic precursor missions will contribute to the development of autonomous space operations, lunar and planetary resource utilisation[1], reconfigurable high bandwidth communications[2], and development of intelligent self-sufficient robotic systems[3] (Mankins, 2010).

NASA's investment in the development of heavy-lift and propulsion technologies will aim at encouraging the development of a new generation of space propulsion technologies that will aim at reducing launch costs. One of the *short-term issues* that arises is whether NASA will continue funding of Ares-V under the new budget. The *second* issue that arises is whether NASA *needs* to develop a heavy-lift launcher and new propulsion technologies, bearing in mind that the Obama administration cancelled the program for the Moon return. The *third issue* is whether there will be market demand from the space industry for the use of a heavy-lift launcher.

NASA may develop a heavy-lift launcher and in 10 years realize that there is no market demand for this type of technology, in a similar way as the European Ariane 5 was developed several years ago due to the expected market demand for heavy-lift launchers. Once it became operational, the expected demand was not as strong as predicted and Arianespace had to use the launcher for launching 2 spacecraft[4] at the same time in order to fulfil its capacity. Nevertheless, the development of heavy-lift launcher capabilities will enhance US space-flight capabilities for future Lunar or Mars missions.

Figure 1, shows an overview of NASA's budget for 2011 until 2015. Clearly, the budget shows that NASA will increase its ISS budget with around $2 billion for over a four-year period (NASA, 2010).

Figure 1. NASA 2011 proposed budget (NASA, 2010)



NASA's budget is *highest* for ISS utilisation, commercial crew and cargo development, and technology exploration and demo. However, the new budget *does not show* a clear vision for human exploration nor does it present a space exploration scenario or scenarios (exploration of Mars Moons, such as Phobos or Langradian points, etc.) as proposed by the Augustine committee. Furthermore it does not *set* a clear timeline for transformative technology development and demonstrations, R&D for heavy-lift and propulsion technologies nor the development of commercial crew cargo capabilities.

NASA's new budget for ISS utilisation will extend the *station's lifetime* until 2020 and beyond. As well as upgrading ground and on-board systems, the budget will allow the use of the station's scientific capabilities such as support research in human physiology, inflatable space habitats, and a program to continuously upgrade Space Station capabilities (NASA, NASA Funding Highlights, pp 129-132, 2010). The new direction which NASA undertakes raises an issue whether NASA will once again implement a program for encouraging *ISS commercial utilisation* with the hope of reducing the costs of ISS exploitation or will *just continue* to *rely on scientific utilisation.* Resorting to *ISS commercialisation* for attracting commercial customers and increasing utilisation of the ISS on board resources may open new markets, encourage the development of new applications, and become a test bed for commercial projects which can later be flown for interplanetary missions. However, NASA will once again face the problems with low market demand for ISS on-board services, unknown customers, high market-entry barriers, business risks, and ISS partner's political and strategic interdependence (Tkatchova, 2006), due to the nascent stage of ISS markets evolution.

The new aspect introduced by the Obama administration is NASA allocating around $6 billion for a five-year period, to encourage the development of commercial crew and cargo capabilities. The budget will be allocated through competitive solicitations under the NASA COTS program and its sub-program for Commercial Crew Development (CCDev). The budget for developing commercial cargo and crew capabilities will come from the retired space shuttle in 2011. Basically in 2012, NASA will allocate a budget of $1.4 billion which corresponds to around 3 Space Shuttle Missions per year, as the cost of one shuttle mission is approximately $450 million (NASA, Frequently Asked Questions, 2008).

For example, on the same day NASA announced its 2011 budget, NASA awarded $50 million in contracts under the CCDev program for technology development of the commercial crew program. Some of the selected companies were Paragon, Boeing, and United Launch Alliance (ULA), who competed among the 36 proposals received (Foust, 2010). This strong *interest from industry* probably triggered NASA to encourage the development of commercial space transportation services and aim at introducing competition, as a catalyst for the development of new businesses capitalising on affordable access to space (NASA, NASA Funding Highlights, pp 129-132, 2010). This would thereby encourage the creation of a *competitive environment* and influence the market structure of the launch industry. Encourage the creation of self-sustainable and competitive markets segments use space-based technology and space stations (i.e. MIR, ISS)commercialisation, has already been an objective of many space agencies in the late 1990s.

Nevertheless, the sub-orbital space tourism market is still in its very *nascent* stages of market development (see Chapter 5). It has unknown customers and benefits, high launch service prices, the market is strongly regulated and high market risks. Therefore, private investors may be *reluctant* to invest in the development of technology for commercial human space-flight because of the expected end of the ISS in 2020. The expected new business development of commercial space transportation services *may fail* to bring economies of scale and thus reduce the cost of human access to LEO.

NASA will have to set up a *flexible commercialisation strategy* that will not be focused on cost recovery or revenue generation, but on encouraging the development of new markets and applications, cost-effective technology innovation, technology diffusion and interoperability. One, that will be in the frame of a clear timeline and concrete exploration destinations for the future US space exploration strategy.

2.1 US Human Space Exploration Strategy

The US is the global leader and pioneer in human interplanetary space exploration. However the US Constellation program was cancelled under the Obama administration, as a result of budget constraints as recommended by the Aldridge committee. The Aldridge committee was responsible for analysing the future of US human spaceflight and address the following questions (Review of Human Spaceflight Plans Committee, 2009)

- What will be the future of the Space Shuttle?
- What will be the future of the International Space Station?
- On what should the next heavy-lift launch vehicle be based?
- How should crews be carried to low-Earth orbit?
- What is the most practicable strategy for exploration beyond low-Earth orbit?

The questions above were quite generic and short-term as they address the *questions* related to space transportation and utilisation of the ISS, but *do not address* the establishment of sustainable long term vision of interplanetary space exploration to Mars or other destination. Nor did they address the aspect of sustainability in balance with affordability of the future US vision for future human spaceflight or the expected benefits from human space-flight activities. Nor do they consider the strategic and economic impact that any change of the US Constellation may have on the future space industry and the US national economy, such as loss of skilled labour. Neither of the questions address the expected *scientific, technology* or *economic* or *spin-off benefits* that will bring the future exploration program. None of the above questions address the aspects related to the development of *new space markets, space applications, technology spin-off, commercialization, technology innovation, technology diffusion and reduction of the program costs*. Nor do they address the aspects related *to* the creation of self-sustainable markets in which companies have developed applications from the use of space-based technology from the US Constellation vision.

The above objectives are quite diverse and they are not concentrated on one aspect of space exploration, such as the utilisation of the ISS or future Lunar exploration and can be considered, short-term in the context of long term interplanetary human exploration.

The final results of the committee are not very optimistic and the study starts with the opening "*The US human space-flight program appears to be on an unsustainable trajectory*" (Review of Human spaceflight Plans Committee, 2009). The following recommendations were made:

- NASA budget to match its exploration objectives
- NASA to lead a new international effort in human exploration
- Space Shuttle life extension until 2011
- Development of heavy launcher capabilities

- US life extension support to the International Space Station (ISS) until at least 2020
- Further development of LEO commercial launch services
- Encourage the development of US commercial space industry
- Before visiting Mars, the US space exploration effort to concentrate on visiting the Moon or the second option of exploring the Flexible path that proposes after 2020, the start of the lunar fly-bys, visits to Lagrange points and near-Earth objects, and Mars fly-bys.

From the above recommendations the Obama administration took the ones, such as encouraging the development of LEO commercial services, US commercial space industry, development of heavy launcher capabilities and extension of the ISS utilisation,

The above recommendations were based on an analysis using several criteria, such as benefits[5] to stakeholders (i.e. capability for exploration, opportunity for technology innovation, etc.), risk and budget realities (i.e. identification of options matching NASA budget).

The Aldrige committee selected twelve evaluation criteria for comparing the five exploration scenarios and provided final recommendations. Some of the criteria were the following*; exploration preparation, technology innovation, scientific knowledge, expanding human civilization, economic expansion, global partnerships, public engagement, schedule, program risk and mission safety challenges, workforce impact, program sustainability and life-cycle costs.*

Some of the above criteria are quite *generic* and *not easily quantifiable*, such as the *criteria* of expanding human civilization. Furthermore, their cost engineering approach as they have undertaken a contradictory approach for building the cost estimates for Ares V design and development.

Certain of the above criteria overlap with the expected direct and indirect benefits, such as employment, technology innovation, international partnerships and public awareness. Therefore, the proposed scenario options should be used only as a general reference.

The estimated cost for a future lunar mission is around 129USD Billion[6]. In 2007 NASA requested a budget of $16.3 billion and for 2008 of $17.3 for the Orion Vehicle. The vehicle is planned to be a six person spacecraft developed by Lockheed Martin (ASD-Eurospace, 2008). Lockheed Martin was to develop the Orion for a period of 7 years and the initial (2006-2013), 'Phase A' of the contract corresponded to around $3.9 Billion and the second phase (Phase B) corresponds (2009-2019) to around $3.5 Billion (Integrum, 2008). The Obama administration may support the construction of an Orion light vehicle.

The retirement of the Space Shuttle after 2011 will constrain the US space industry growth, as there will be a *gap* of at least several years until the Ares I and Ares V vehicles are operational, thereby making the US *totally dependent* on Soyuz launchers for manned access to the ISS. This dependency could result in *irreversible consequences* to NASA and the US space industry as they will lose competent and skilled employees. Thus, *slowing down* technology innovation in the US space industry and reducing its space industry competitiveness.

However, the expected $6 billion for encouraging the development of commercial crew and cargo transportation services will *reduce* the US dependency on the Russians and created competition for traditional launch service providers. As a result of this competition it is possible that traditional launch service providers increase their R&D investment in *reliable* and *low-cost launchers.*

During *this gap of several years*, the US may not only lose its world-wide market positioning, but could be overtaken by new space powers (i.e. China) that already has human-rated launchers. In addition, the US will also experience negative publicity[7] and may lose its world-wide image as a *global space leader*.

After the selection of Obama as a President of the US, the US space policy focused on re-assessing the importance of the US Constellation program. Nevertheless, the committee provided valuable recommendations which resulted in extended utilisation of the ISS until 2020, increased funding for commercial crew and cargo transportation services and in heavy-launcher capabilities. These new trends may encourage the creation of competition between traditional launch service providers and encourage the development of low cost launchers.

3. NASA COTS PROGRAM

NASA's Commercial Orbital Transportation Services (COTS) program was initiated in 2006. NASA allocated around $500 million to companies competing for the development of cargo transportation services to the ISS and another $50 million for the development of Commercial Crew Development (CCDev) transportation services.

The *objective* of the program is that private companies design, develop and test their own transportation services and develop vehicles and services which NASA and other customers can buy after the Space Shuttle's retirement in 2010. Thus, NASA will aim at encouraging the creation of a market for commercial space transportation services.

The objectives of the program are the following (NASA, NASA Commercial Crew&Cargo Program Office, 2009):

- To implement US Space exploration policy with investments to encourage the development of commercial space industry
- To develop cargo and crew space transportation capabilities to achieve safe, reliable and cost-effective access to Low Earth Orbit (LEO)
- To create a market environment in which commercial space transportation services are available to government and customers

The companies that win a contract under NASA's COTS program are expected to be responsible for the overall *design, development, manufacturing, testing and operations* of their own technology and perform a technology demonstration. Their technologies should meet NASA requirements, which are defined under COTS ISS Service Requirements Document (ISRD), the COTS Human Rating Plan and the ISS to COTS Interface Requirements Document (IRD).

NASA has a limited role in NASA's COTS program so that it can encourage private companies to develop their own commercial projects. The *role of the space agency* is to *monitor* the program of the *selected private companies* and *assess* whether they have successfully completed the milestones and allocate funding. If requested, NASA provides technical assistance through review and consultations with the private partners. NASA private partners pay for NASA technical assistance or facilities via the Reimbursable Space Act Agreements (NASA Commercial Crew&Cargo Program Office, 2009). Demonstration flights to the ISS are permitted to be made only by private companies that are funded under NASA's COTS program and also have private funding

Figure 2 shows an overview of the type of commercial services that are expected to be developed under NASA's COTS program.

After the retirement of the Space Shuttle in 2011, NASA will rely on the commercial transportation services companies for transportation services to the ISS.

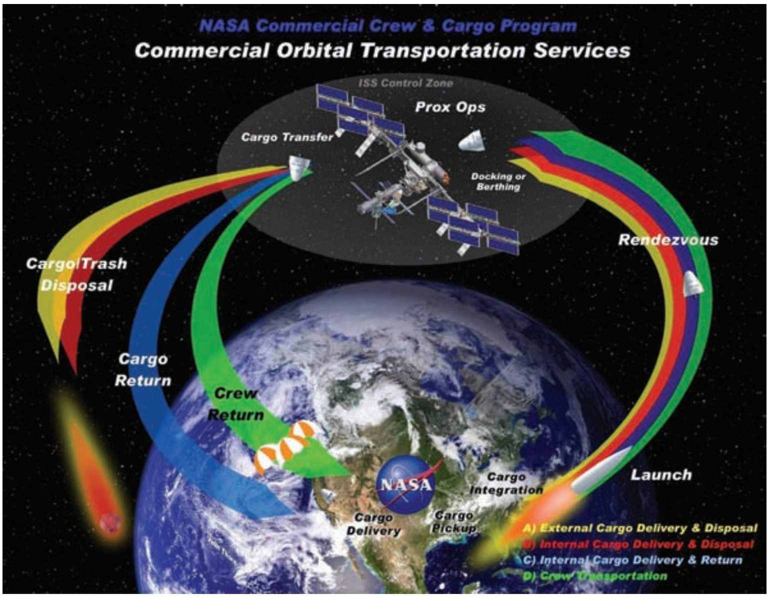
NASA will be the "end – customer" for the services provided by Orbital and SpaceX. So in a away, the ISS will be like a "test-bed" for testing their services these companies and also the market for developing commercial transportation launch services. This is probably one of the reasons for NASA's extension of ISS utilisation until 2020.

3.1 NASA's COTS Program Phases

NASA's COTS program is divided into two phases. Phase I includes the development and demonstration phase while Phase II is the actual provision of ISS commercial resupply services to NASA (NASA Commercial Crew&Cargo Program Office, 2009).

Phase I started in 2006 and will continue until the end of 2010. In this phase NASA encourages industry to develop and demonstrate their cargo transportation

Figure 2. NASA COTS program (NASA, NASA Commercial Crew &Cargo Program Office, 2009)



capabilities. **Phase II** will fund the development of cargo transportation capabilities for resupply services to the ISS (NASA Commercial Crew&Cargo Program Office, 2009).

After the retirement of the Space Shuttle, NASA will be able to access the ISS only through NASA's agreement with RSA for Soyuz flights in 2011 (Dinerman, 2008). Extension of the Space Shuttle lifetime is not expected due the costly launch of each space shuttle. For example, a single Shuttle launch costs approximately $450 million (NASA Frequently Asked Questions, 2008). This cost per Space Shuttle mission corresponds to almost $500 million which NASA has invested from 2006 until 2010 in its COTS program. With the new budget of 2011, it is very possible the budget for its COTS program will increase. Furthermore, the initial interest from private investors may be strong when dealing with a guaranteed institutional customer (e.g. NASA) but may be short-lived due to the end of the ISS in 2020.

NASA initially signed initially signed an agreement with SpaceX and Rocketplane Kistler and allocated $278 million to SpaceX and $207 million to Rocketplane Kistler. However, Rocketplane was not able to *raise private funding* for the project and NASA cancelled its agreement with them and then signed $178 million agreement with Orbital.

Similar problems as the ones experienced by Rocketplane may be experienced by future companies wishing to become involved in NASA's COTS program. The problems may come due to high market expectations, unknown customers and markets, top-down market analysis, only one guaranteed customer, and long periods of space technology development and market reach. Future private companies involved in NASA's COTS program may be requested by NASA not only to present clear business cases and attract private funding, but also to identify *direct* and *indirect benefits* from their projects. Furthermore, NASA may require a cost-benefit analysis as part of its requirements from private companies. However, the *issue is whether* the companies under the NASA COTS program will be motivated enough to continue to develop cargo and crew vehicles, which will have no platform to go to due to the end of the ISS's lifetime in 2021.

Nevertheless, NASA's COTS program may encourage the creation of a competitive environment for the commercial space transportation services and possibility for NASA to choose its suppliers.

3.2 NASA Commercial Crew Development (CCDev) Program

NASA's Commercial Crew Development (CCDev) program aims at encouraging the development of technologies and competencies that will encourage the development n the commercial human space-flight services. This program is like a precursor of a future commercial crew program (Foust, 2010). NASA awarded $50 million to five companies for developing competencies in technologies in the area of orbital and sub-orbital commercial services, as presented in Table 1.

The above five companies were chosen from 36 proposals and demonstrate that traditional players like Boeing and ULA have seriously undertaken the challenge of developing commercial crew services. The entrance of traditional players in the commercial transportation services market provides an indication of the possible market potential of commercial transportation services market.

Table 1. NASA CCDev contracts in 2010

Company	Contract Size
Blue Origin	$3.7 Million
Boeing	$18 Million
Paragon Space Development Corporation	$1.4 Million
Sierra Nevada Corporation	$20 Million
United Launch Alliance (ULA)	$6.7 Million

3.3 NASA COTS Program Impacts

NASA COTS strategy will encourage the development of commercial cargo and crew services and the development of sustainable and affordable key enabling technologies. Therefore, for NASA, it will be important to set up *key performance indicators (KPI)* for *assessing* and *comparing* the success of the results from the different commercial projects during the different phases of NASA's COTS program.

The KPI can be divided in *quantitative* and *qualitative indicators* and can be applied during the different phases of project development (Alexandrova, 2009).

Table 2 shows an overview of quantitative and qualitative indicators that can be used for assessing NASA's COTS program project evolution at different stages of the project's development.

For example, NASA can use certain criteria only when assessing progress of projects whether the private companies are meeting the requirements under the COTS ISS Service Requirements Document (ISRD), the COTS Human Rating Plan, and the ISS to COTS InterfaceRequirements Document (IRD). NASA can use them during the different phases of its COTS program development, thus clearly contributing to measuring the benefits from its COTS program, but also helping private companies define their own benefits from NASA's COTS program and encouraging long-term funding for the program.

3.4 SpaceX

SpaceX is one of the companies that won a contract under NASA's COTS program to demonstrate the delivery and return of cargo to the International Space Station. The company was created in 2002 and its main objective is to develop and provide reliable low-cost launchers (SpaceX, 2010). SpaceX have developed two types of

Table 2. Key performance indicators

Quantitative Indicators	Qualitative Indicators
Employment	International Cooperation
New Contracts	Environment Protection
Revenues from Sales	Energy Saving
Market Penetration Rate	Technology Diversification
Cost Savings	
Number of patents	
Technology Reliability	
Technology Interoperability	

Figure 3. Falcon 1 liftoff of the Falcon 1 RazakSAT mission (SpaceX, 2010)

launch vehicles Falcon 1e and Falcon 9. Falcon 1e can deliver 1,010 kg to Low Earth Orbit (LEO) at astandard launch price starts at $10.9 million to LEO. While, Falcon 9 can deliver 10,450 kg to LEO, and 4,540 kg to Geostationary (GTO) and has a standard launch price starts at $45.8 million to LEO or GTO.

Falcon 1 (Figure 3) will be in competition with the European launcher Ariane 44L and will offer launch services in the same range as US launchers Atlas 2AS and Delta 2. Falcon 9 (Figure 4) will be in competition with the Russian Proton launcher, the European Ariane 5G and the Chinese Long March 3B (see Chapter 4). SpaceX's price is the lowest from all the three launchers as the company's price ranges between $45.8 million up to $51.5 million for LEO launches. However, before Falcon 9 becomes a true competitor to the above three launchers Falcon 9 launch reliability will have to be proven.

In parallel to the launch vehicles development, SpaceX won a contract under NASA's COTS program for using their Dragon transfer vehicle for ISS re-supply after the Space Shuttle retirement. The Dragon capsule is designed for both logistics

Figure 4. Falcon 9 (SpaceX, 2010)

and crew transportation. The contract value from NASA's COTS is of around $1.6 billion and with approximately 12 flights (SpaceX, Dragon Overview, 2010). However, this contract is probably for the design and construction but does not include the launch costs which will be the ones attributed to Falcon 9.

Figure 5, shows an overview of the Dragon Crew Capsule, which will be also used as a crew return capsule.

The new Dragon vehicle may become a *potential competitor* to ESA's Automated Transfer Vehicle (ATV) and JAXA's H-II Transfer Vehicle (HTV). Figure 6, shows an initial comparison of cost estimates for transfer vehicle construction which exclude the launch costs.

One of the *prime issues* that will arise for SpaceX will be linked to its future markets for the Dragon capsule after the retirement of the ISS in 2020. SpaceX will have to be able to get a return on their investment for a *very short time* of around 5 years as their capsule is not yet operational. Another option for SpaceX, in addition to its 12 mission contract with NASA's COTS program as to win an additional one of 12 missions until the end of the ISS lifetime and beyond, thereby totalling it to 24 missions and therefore being able *to raise additional private funding* due to the existence of a guaranteed customer, like NASA. Furthermore, in case the space tourism market further develops and exits the nascent stage at which it is, the Dragon capsule may be able to provide services to companies such as Bigelow inflatable space station.

From Falcon 1 and Falcon 9, SpaceX will gain direct benefits from revenues from sales, new markets, technology reliability and interoperability. SpaceX may even be able to generate cost benefits and actually make a clever investment in the launcher development based on NASA's COTS budget. Furthermore, SpaceX will enter a *new market* in which there will be no Space Shuttle and in a way will have the opportunity to have *dominant price position* and service positions, which will permit them to request higher prices from NASA for future launch services, at least until 2020. After the end of the ISS in 2020, they will have to find another market and re-orient their activities towards the launch of telecommunication satellites in

Figure 5. Profiles of Dragon Crew Capsule (SpaceX, 2010)

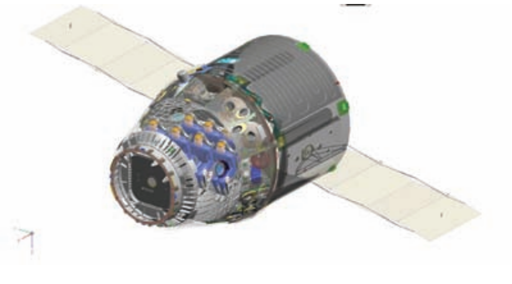
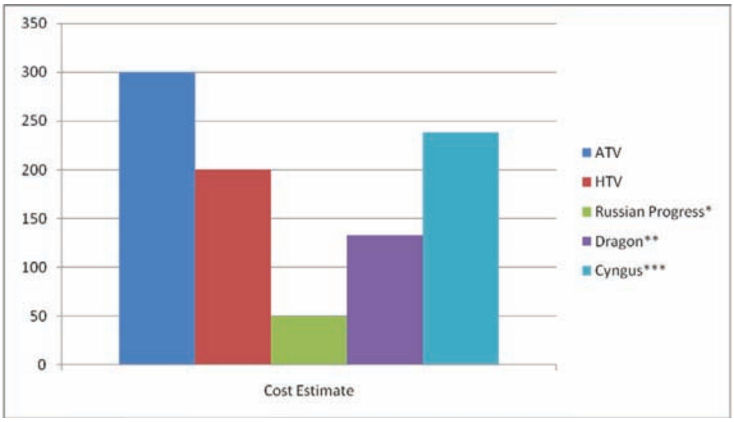


Figure 6. Comparison of cost estimates for ISS re-supply vehicles (Clark, 2009), (Zak, 2002), (SpaceX, Dragon Overview, 2010), (Klamper, 2009). The cost per transfer vehicle excludes the launch costs. Russia's cost for Progress vehicles has probably changed. Under NASA's COTS program, SpaceX will provide 12 complete missions for the $1.6 billion price, and that price includes the Falcon 9 launches. Similar cost estimates have been derived for the Cygnus capsule where NASA's COTS contract sum to Orbital has been divided by 8 which is the number of expected missions to the ISS



GTO. However, their direct benefits from the Dragon vehicle will be in the area of technology reliability and interoperability. Since the successful flights of Falcon 1 and NASA's COTS program, SpaceX has generated enormous indirect benefits from worldwide free publicity and technology innovation.

3.5 Orbital

Orbital is a traditional US space system company and provides satellite integration for civil, commercial, and military satellites in the US space industry. Orbital is also responsible for the launch of the abort system and abort test booster for the Orion vehicle for the future Moon and Mars missions. At present, Orbital is developing the Taurus II low-cost launcher under the NASA COTS program to launch around 5,750 kg to the ISS. In 2008, Orbital was awarded the $1.9 billion contract for re-supplying the ISS and having 8 Cygnus space flights (Tarig Malik, 2008).

The Cygnus vehicle (Figure 7) will be in competition with ATV, HTV and the Dragon transfer vehicle. Once the Taurus-II launcher reliability is proven, the launcher may become a future competitor to the Russian Dnepr (Figure 8), Long March 2C, and Soyuz launch vehicles. Nevertheless, the launcher and the transfer

Figure 7. Orbital Cygnus Transfer Vehicle (Orbital, 2010)

Figure 8. Taurus-II medium sized launcher (Orbital, 2010)

vehicle are in the early phases of development. Orbital will face similar issues for the future Cygnus capsule utilisation after the end of ISS in 2020 as SpaceX will face for their Dragon capsule.

However, Orbital will probably successfully market Taurus-II due to its launch experience with its other vehicles (i.e. Taurus, Pegasus, Minotaur) and its civil and military customers that may use the Taurus-II later on for heavy payload launches. Due to its participation under NASA's COTS program, Orbital will generate direct benefits from achieving technology reliability for its Taurus-II launcher and interoperability of the Cygnes transfer vehicle. Furthermore, it will generate revenues from sales for both civil and military customers and gain indirect benefits from technology innovation, free publicity, and international cooperation.

3.6 Virgin Galactic

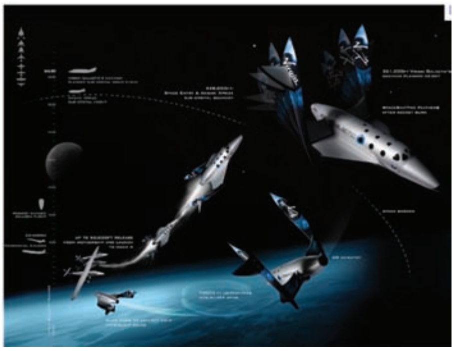
Virgin Galactic was created around 2004, with the objective to provide sub-orbital space travel and once SpaceShip One of Burt Rutan won the Ansari X- prize, the Virgin Group made a huge investment in the design and development of a new generation of sub-orbital vehicles, such as SpaceShipTwo. Today, in 2010, a future space tourist can book a ticket for $200,000 per seat in SpaceShipTwo (Figure 9) (Galactic, Space Tickets, 2009).

SpaceShipTwo is designed for sub-orbital space tourist flights and will carry 8 people of which six will be space tourists and two pilots. The sub-orbital vehicles are beeing designed and constructed by a joint venture company which is formed between Burt Rutan and Richard Branson (SpaceShipTwo, 2010). The company called Space Ship Two is planning on building at least 5 most spacecrafts.

Virgin Galactic has managed to generate enormous publicity due to its clever and exciting promotion campaign that is driven by the creator of Virgin Galactic Richard Branson. An excellent example of his promotional ingenuity is his advert with Volvo for the promotion of the Volvo XC90 V8Space thus successfully promoting space travel.

Since its creation, Virgin Galactic has already managed to attract around 340 passengers (Virgin Galactic, 2010) and collect $25 million from future passengers from the sales of sub-orbital flights (Galactic, News, 2009). In addition, the company is looking at *diversifying* its markets in order to generate "economies of scale" and enter new ones, which are reserved for traditional space companies. For example, in 2008, NOAA and Virgin Galactic set-up a collaboration use of SpaceShipTwo for earth observation of climate changes. On board SS2 during test flights there were NOAA sensors to measure the atmospheric composition for CO2 (Marks, 2008). This new initiative will bring indirect benefits to NOAA and to Virgin Galactic

Figure 9. Virgin Galactic SpaceShipTwo (SpaceShipTwo, 2010)



and will also increase the company social responsibility and public image as an environmentally-friendly company.

In addition, the company is looking at using SS2 (Carberry, Winter 2010) for micro-satellites for up to 200 kilos (Carberry, Winter 2010). The development of a micro-sat launcher, demonstrates VG knowledge of the launch market. The company will thus become a direct competitor to the small launchers, such as Taurus, Rockot and Athena. *VG diversification* of its services and competencies shows a clear understanding of the *nascent stage* of the space tourism market. The successful development of VG activities will have a direct impact and encourage the construction of space ports, such as the one in Mojave one or the construction of new ones.

The company has already generated direct benefits from revenues from space tickets sales, entrance of new markets like ones with NOAA and indirect ones include huge free publicity, international cooperation and partnerships, environment protection, and technology innovation.

3.7 Ansari X-Prizeand Google Lunar X-prize

International competitions for encouraging the development of innovative space technologies and concepts have become a popular vehicle for new R&D technologies. One of the most popular competitions is that initiated by the X-Prize foundation the Ansari X-prize.

The successful design, development and launch of SpaceShipOne on the 4th of October 2004 demonstrated the future of commercial orbital flight. The first flight of SpaceShipOne had to demonstrate that it could carry three passengers 100 km above of Earth's surface for two weeks. Scale Composites won the Ansari X-Prize of $10 Million. During the actual flight, a "product placement" advertisement for chocolates was filmed. Scale Composites that won the prize, generated *direct benefits* from new markets and revenues from sales as they won new orders from VG for building new spacecrafts. In addition, they gained *indirect benefits* from the international partnerships, free world-wide publicity and technology innovation.

For example, companies like Google gained huge worldwide publicity, as a result of the setting-up of the Google Lunar X-prize.

The objective of the Google Lunar X PRIZE is to land a lunar rover on the lunar surface. This rover has to be capable of travelling 500 meters and to send images from the Moon (X-Prize, 2010). The teams that compete have to be 90% privately funded. The prize is of $30 million and there are already many international teams competing. Companies involved in the Google Lunar Prize gain primarily indirect benefits, such as free publicity, technology innovation, and international partnerships.

3.8 Caribbean Spaceport

The successful development of sub-orbital space tourism will encourage the development of spaceports. For example the space tourism market is expected to grow up to $1 billion by 2021. With numbers of sub-orbital space tourists possibly reaching up to 15,000 for 2021 and orbital ones of 60 for 2021 (Futron, 2002). Already the development of the sub-orbital market encouraged the creation of new market segments, such as spaceports creation. For example in Europe a group of Dutch entrepreneurs combined in Spaceport Partners has initiated the development of a spaceport called the Caribbean Spaceport to be based on the Southern Caribbean islands Aruba and Curacao both belonging to the Kingdom of the Netherlands. The concept behind the spaceport development is to attract not only the space tourists for sub-orbital flights but also their families, friends and other visitors for a week of leisure activities at its Space Experience Park facilities on the Caribbean islands.

From 2014, Caribbean Spaceport aims to serve the promising suborbital science and education and the small satellite markets (Wielders & Wouters, 2009). The regional economy therefore is expected to benefit from a multitude of direct, derived and indirect economic effects.

Figure 10 shows an overview of the Caribbean Spaceport (Caribbean Spaceport, 2010).

Spaceport Partners already conducted an additional spaceport feasibility study on assignment of an airport in the Netherlands proper.

Caribbean Space port will gain direct benefits from new markets development and employment and indirect ones of free publicity and international cooperation.

Figure 10. Caribbean Spaceport (Caribbean Spaceport, 2010)

4. SPACE MISSION REQUIREMENTS AND CONCEPT DEFINITION

The creation of a space mission always starts with the definition of the *primary* and *secondary* space mission objectives. These objectives are usually integrated in mission requirements and concepts.

The early *integration* of non-space companies' mission requirements will permit *cost savings* and technology innovative solutions that will encourage the development of technologies and processes that can benefit Earth-based applications. As for example, a water purification process developed by ESA for future closed life-support missions and tested under ESA MeLISSA project for water management, was recently used by a private company for water purification and resulted in the industrial involvement of the project. The early integration of private companies will permit the research and technology on board the space missions not only to be "technology push" but also to be influenced by industry research and technology needs.

Once non-space companies understand space mission architecture, they may even be able to *identify areas* in which they could contribute to the mission or identify technology they can benefit from. They may even be able to participate in collaborations and share R&D research and thus achieve, at the same time, cost savings and technology innovation.

Space missions pass through different phases of definition, design and development, as described below. Commercialisation of space technology usually occurs after launch in the late Phase E of space mission. For example for commercialisation of the MIR station occurred in Phase E and for the ISS in Phase C and D (Figure 11).

- Phase 0 – mission objectives definition
- Phase A – feasibility studies, mission analysis, planning and pre-design
- Phase B – spacecraft design and payload, hardware procurement and developmen
- Phase C – H/W building/testing
- Phase D – launch campaign
- Phase E – launch
- Phase E1 – LEOP and commissioning, routine operations

For example, in ESA, there is the Concurrent Design Facility (CDF) in which experts from different departments, such as orbital mechanics, thermal, quality, simulations and cost engineering departments perform real time mission studies. The engineers perform feasibility studies in each of their designated areas and provide final recommendations on the feasibility of the space mission.

To prevent designing and building facilities that are of no commercial potential to non-space companies, it is possible that, at the Concurrent Design Facility (CDF) level there could be experts from different departments who analyse not only the "spin-off" potential of a certain payload on board the mission, but also assess the potential for setting up future business cases or future applications.

The early integration of private companies industrial or research needs will permit the R&D and technology on board the space missions not only to be "technology push", but also to be influenced by industry research and technology needs. They could even apply financial modelling, performing cost benefit analyses or project option trade-offs for assessing the technologies' potential and projects.

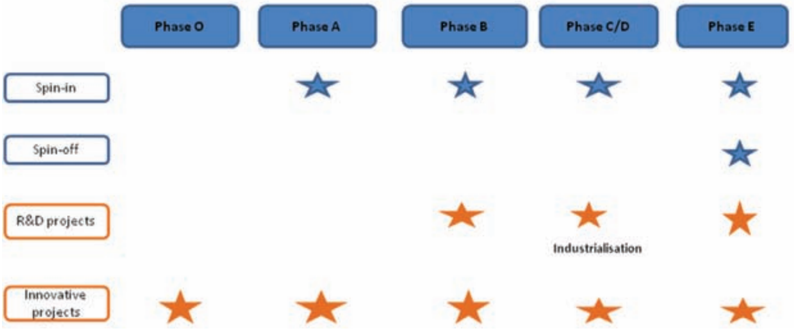
Early integration of 'non-space users' requirements will contribute to more *cost-effective missions* and prevent building technologies that could be of little use to non-space companies. Furthermore, the early integration of private companies' requirements will permit the early identification of the direct and indirect benefits and the early utilisation plan from the use of the space-based technology in a similar way as VG is developing their SpaceShip 2 based on the end-customers' needs.

Private companies involved in commercial space projects may even interconnect space mission phases to market evolution phases and thus, be able to identify, not only the early benefits from the concept, but also achieve early project industrialisation starting in Phase C.

5. BRIGHTER SPACE EXPLORATION TRENDS

In the nearby future around 2011 up to 2021, Virgin Galactic will be expected to be having regular flights of SpaceShip Two. SpaceX, would have launched the Falcon 1 and Falcon 9 and their reliability would have increased. In addition, they would

Figure 11. Space Mission Phases



have also successfully launched the Dragon transfer vehicle to the ISS. SpaceX would have become a successful low-cost launcher provider, thus competing with other traditional launchers service providers (see Chapter 4).

NASA's COTS program would have increased its budgets, due to Obama's new policy for encouraging the development of commercial crew and cargo transportation vehicles. After the Space Shuttle's retirement in 2010, all US payloads will be transported to the space station either by the Russian Soyuz vehicle or by the newly developed commercial cargo transportation vehicles. Therefore, the development of commercial cargo transportation services may become the engine behind the development of new markets, ideas and cost-effective solutions for US space industry. Furthermore, NASA's new budget for commercial crew transportation services will encourage the companies under NASA's COTS program such that SpaceX may start performing test flights to the ISS in 2012, in order to reduce NASA's reliance on Russian Soyuz vehicles.

Virgin Galactic will have signed several agreements also with NASA, CSA, ESA and JAXA or with meteorological agencies, such as Eumetsat to carry scientific instruments on board SpaceShipTwo (SS2). Furthermore, by 2021 the company would have invested in the development of unmanned satellite launchers to micro satellites.

By 2012, Space Adventures would have already launched several space tourists on-board a Soyuz-TM for a trip to the ISS and will be preparing new space tourists for 2015. Probably Space Adventures will partner with other companies and may be even looking at using the Russian ISS modules for future tourist activities, or even lobby for keeping the Russian ISS modules in orbit beyond the station's lifetime so that they could be visited by space tourists or would have started already partnering with companies providing access to commercial capsule for crew and cargo transportation to the ISS.

The US would have happily retired the Space Shuttle and most of the engineers working for the STS would have started working either for SpaceX, Orbital or Space Adventures. The expected growth of the space tourism industry and the construction of sub-orbital transportation vehicles would have encouraged the construction of new space ports or adaptation of old airports.

The fashion industry will start the design and development of "space garments," cosmetics and games for future space tourists. Customers of space tourist companies may not only be private individuals but also national space agencies which may be willing to fly their payloads to the ISS at lower prices. They can even start acquiring Foton capsules and drop towers for performing short-term microgravity experiments. Of course, all these futuristic activities will only develop if there is a true market for them.

By 2015, NASA would have increased its funding of up to $100 million USD for the Commercial Crew Development program and in this way encourage the development of commercial human space-flight activities. Furthermore, NASA's COTS program will be considered by politicians as a NASA tool which encourages the competitiveness of the US space industry.

In 2018, we may even witness solar power satellites providing electricity to cities. After 2040, we may witness the creation of Lunar Solar Power Stations. Lunar mining and solar power generation could become the areas of interest to governments, venture capitalists and energy companies due to the ongoing energy crises.

In 2020, most probably there could even be a Google Mars X-prize for landing a rover on the surface of Mars and transmitting images of the Martian surface.

After 2021 the ISS lifetime space enthusiasts will be *fighting* with space agencies to keep the ISS operational in a similar way as they fought for keeping MIR operational. In 2022, the ISS may transform into a kind of orbital space museum and be visited only by space tourists.

Meanwhile traditional space companies and new companies would have started to partner with each other. US space industry lobbyists will be lobbying for increased regulation while private companies will be lobbying for de-regulation of the industry and reduced space agency interferences. Due to economic downturn and reduced budgets, space agencies will start choosing the cost-effective launchers thereby encouraging competition for receiving high quality services at an acceptable price.

6. GLOOMIER SPACE EXPLORATION TRENDS

In the late 1990s, everyone was expecting a boom of commercial satellite communication. However, the bankruptcy of the Iridium telecommunications system and their incapability to attract enough subscribers became a stigma for the whole space industry, thus demonstrating the difficulty of developing commercial space systems and managing competition from terrestrial systems.

Companies involved in the development of sub-orbital transportation vehicles for space tourism and design and development of private space ports, may become exposed to strong *market risks* due to their assumption of an *existing market*. The nascent stage of the space tourism market, the complexity of space systems, and the optimistic expectation that the market has reached the edge of commercial human spaceflight and regular sub-orbital tourism, may mislead decision-makers and politicians.

Historically, space agencies became the prime customers in the industry. They are the prime engines behind space missions and space technology developments. The space industry that provides services to space agencies has an oligopoly market structure with few dominant players (i.e. system integrators such as Boeing, EADS Astrium, Thales Alenia Space etc.) and high market entry barriers.

Nevertheless, since several years, space agencies have started to *recognize* the importance of the development of space applications and therefore, started encouraging space and non-space companies to develop applications. For example, navigation systems can be used for disaster management, precision agriculture or oil and rack positioning applications. Research performed on board the ISS can contribute to drug development which allows pharmaceutical companies to have space patents and have osteoporosis medicines. Thus, these companies involved in the development of application- based technologies can attract private funding.

NASA will start encouraging technology innovation through fostering competition between companies either through national prizes or programs such as its COTS program. Thus, in a way NASA will encourage change in the market structure of the space industry and push space companies to reduce their reliance on space agencies as the sole customer for their services. Competition between different suppliers will give NASA the freedom to choose suppliers and technologies for future space missions and thus, break up the oligopoly market structure in the space industry.

Nevertheless, private companies may be reluctant to invest capital in the development of launchers that will provide commercial cargo services due to the end of the International Space Station's in 2021. The new Obama strategy for development of commercial cargo services should have been introduced in 1998 years ago when the first ISS module was launched.

NASA new space vision will change the ways by which NASA and space companies are doing business. Thus, the agency will attempt to introduce the market forces into the space industry and encourage the competition between the new and the old players. Traditional space companies may even increase the market-entry barriers and encourage space agencies to increase regulations in order to protect themselves. New players will face difficulties in entering the traditional space markets.

The *lack of clear benefit definitions* may reduce sufficient political, strategic and financial support for the US Constellation program and may even be one of the reasons for cancelling the program.

If the US Government wants to attract long-term funding for the development of commercial cargo transportation vehicles, however, their approach may result in attracting the Defence and Security Department and the space technology development for the mission may have *dual use* of the future technologies.

7. DISCUSSION

The new players in the space arena will re-vamp the market structure of the space industry and NASA may change the industrial policies and relationships with the US space industry.

Companies, such as SpaceX, Orbital and Bigelow will gain new NASA contracts for developing commercial transportation vehicles and transfer capsules (i.e. Dragon) while others, such as Space Adventures and Virgin Galactic, will become service providers.

NASA's enthusiasm for technology innovation and the development of commercial crew and cargo services may diminish as a result of facing a completely *nascent market* with unknown stakeholders and the need of a large governmental investment to encourage its development.

Furthermore, NASA may end up being the *sole customer* and *service guarantee* for these commercial players, as a result of which these companies may attract additional private funding and increase their debts. Therefore, NASA will need to be very careful to not become a subsidizer of a market of which it will be its own customer, which in the long-term future may push the agency to implement and develop only LEO space missions in order to sustain these commercial companies. The issue is whether NASA's COTS program will stimulate the development of launchers and vehicles for interplanetary missions or not. In order to continue with the development of interplanetary launchers and vehicles, NASA will need to implement a different program and allocate an additional budget for their development.

The high expectations from the space tourism market may turn into only empty expectations and companies, such as Virgin Galactic, Bigelow and Space Adventures, will start diversifying their services in order to enter traditional space markets (ones in the area of launch services for micro-satellites of between 50 to 200 kilos or even bigger ones of more than 200 kilos). The new companies involved in the development of low cost launch vehicles or sub-orbital ones, may *aim* at segmenting the market between each other and competing with *traditional players*, thus failing to overcome the traditional market-entry barriers in the space industry and generate benefits from their price leadership. The new players in the industry will need to *perform cost-benefit* analyses on the services and solutions they will be offering in the traditional space markets (i.e. launch of micro-satellites) and the *trade-off* to the resources they will need to invest in order to overcome the market entry barriers.

In 2016, NASA may be exposed to political forces and the next US President may cancel Obama's proposal for NASA's investment in the development of commercial crew and cargo services. In a similar way as Obama cancelled the US Constellation program of which already $9 billion USD dollars were invested. The future US President may cancel Obama's proposed investment in the development of commercial crew and cargo services. This potential threat to Obama's new approach to developing key enabling technologies may *discourage* private investors to provide funding due to the lack of long-term self-sustainable vision.

In the worst case scenario in 2016, the US space companies will be crippled due to the continuous NASA changes to the Human Space Flight program. There will be no Space Shuttle and no alternative launch vehicle because of the private investors' reluctance to invest in their development, the ISS retirement in 2020, and the additional political threats.

8. CONCLUSION

The new NASA budget will re-vamp the US space industry and encourage the development of new technologies and new markets in the area of commercial crew and cargo space transportation and break the *oligopoly of traditional space companies*. However, the unclear NASA objectives for future interplanetary travel and the lack of exploration deadlines may lead to the end of human space flight for the US.

Furthermore, NASA may be too optimistic on its hopes for the sub-orbital space tourism market which, still in its very early stages of development faces unknown customers and benefits, high launch and service prices, a strongly regulated market and high market risks due to the lack of historic experience. Private investors may be *reluctant* to invest in the development of technology for commercial human spaceflight due to the expected end of the ISS in 2020. NASA will have to set up a flexible commercialisation strategy that will not be focused on cost-recovery or revenue generation, but on encouraging the development of new markets and applications, cost-effective *technology innovation, technology diffusion* and *interoperability*. That will be in the frame of a clear timeline and concrete exploration destinations.

NASA's COTS program is a great platform which will increase the choice of suppliers for NASA and access to new technologies at the price of a single space shuttle launch (around $500 million). Due to the commercial nature of the program and the expected benefits from it for both private and government investors, benefits definition and measurement of project performance through the use of KPI under NASA's COTS program will be important. The KPI can be divided into quantitative ones such as employment, new contracts, market penetration rate as well as qualitative ones such as international cooperation, environment protection, technology diversification and others.

Early integration of 'non-space user' requirements into the early phases of space missions will contribute to more *cost-effective missions* and prevent building technologies that could be of little use to non-space companies. Furthermore, the early integration of private company requirements will permit the early identification of the direct and indirect benefits and early utilisation plan development for the use of the space-based technology, in a similar way as VG is developing their spacecrafts based on the end customers' needs. Private companies involved in commercial space projects may even interconnect space mission phases will be able to identify not only the early benefits from the concept but also achieve early commercialisation.

Companies such as Virgin Galactic, SpaceX and Orbital have started to diversify their markets, thus showing their realistic expectations of the market. They will develop sub-orbital flight capabilities and launch capabilities for micro satellites, small and big ones for over 200kilos. Once their launchers prove their reliability, they may become competitors to traditional launch service providers. However, they may not have the same success with their transfer vehicles which may retire together with the ISS retirement in 2020. Companies involved in the Google Lunar Prize will gain primarily indirect benefits, such as free publicity, technology innovation and international partnerships. While, others such as Caribbean Space port will gain direct benefits from new markets development and employment and indirect ones of free publicity and international cooperation.

NASA can start encouraging technology innovation, through fostering commercialisation and competition between companies either through national prizes or programs, such as NASA's COTS program. Fostering competition among US space companies (see Chapter 6) may even result in the creation of a robust and sustainable US space industry thereby changing the market structure of the space industry and pushing space companies to reduce their reliance on space agencies as the sole customer for their services. In addition, *competition* between different suppliers will give the freedom to space agencies of *choosing* suppliers and technologies for future space missions. Increased cooperation between traditional space companies and new commercial ones will be observed as the space tourism and sub-orbital tourism markets develop.

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ENDNOTES

[1] Lunar and planetary resource utilisation, such as extraction, processing, and manufacturing of useful materials (e.g. propellants) and system elements, as for example Helium-3 for fusion fuel, ferrous materials for construction or platinum group materials (Lewis, 2009).

[2] Reconfigurable High Bandwidth Communications and Networks, such as long-range high-rate communications(e.g., optical communications), reconfigurable local wireless networks (Mankins, 2010)

[3] Intelligent Self-Sufficient Robotic Systems, such as high mobile, dexterous and autonomous robotics (i.e. advanced versions of conventional "rovers") as well as UAV-like vehicles, system, etc. (Mankins, 2010)

[4] For example, in 2009, Ariane 5 launched in a dual configuration Herschel and Planck telescopes

[5] The Augustine Committee had identified the following benefits as an evaluation criteria – capability for exploration, opportunity for technology innovation, opportunity for increased scientific knowledge, expansion of U.S. prosperity and economic competitiveness, enhancement of global partnerships and potential engagement of the public in human space-flight (Review of Human Spaceflight Plans Committee (2009)).

[6] The Appollo program was estimated to cost around $ 129.5 Billion in today's money (Review of Human Spaceflight Plans Committee (2009)).

[7] NASA's budget corresponds to around $57.10 per taxpayer per year, which is almost symbolic bearing in mind the remarkable science and technology achievements from the Phoenix mission and the Spirit and Opportunity missions. Through these missions NASA demonstrated its capability to develop, build, and operate robotic Mars missions.

Moon and Mars Space Exploration Concepts

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> *"Many say exploration is part of our destiny, but it's actually our duty to future generations and their quest to ensure the survival of the human species."*
>
> *Buzz Aldrin*

1. INTRODUCTION

The Apollo 11 landing on the Moon on July 24th 1969 marked a new era of human space exploration, due to which a new generation of space scientists, visionaries and dreamers was born; a generation for which Lunar habitats, Mars missions and interplanetary colonization are were only but a natural step to interplanetary space exploration.

Today, almost 40 years after the last Moon landing in 1972, we are starting to understand the benefits from space exploration to humankind. Therefore, this chapter will provide an overview of the Apollo mission benefits, NASA 1969 space exploration strategy, Russian, European, Japanese, other countries Moon and Mars programs.

In his “Plan of Space Exploration”, the father of space rocketry, Konstantin Tsiolkovsky, already in 1926 defined at least sixteen steps[1] for human space exploration, such as using solar radiation to grow food, transport throughout the Solar System, colonization of the entire Solar System and the Milky Way. His vision not only became the road map of modern rocketry, but described some of the benefits from space exploration, such as using solar radiation for food growth and transportation.

His vision was carried out by Korolev and Wernher von Braun, who were the fathers of modern rocketry. Korolev launched the first artificial satellite “Sputnik” in 1957 and the first man in space Yuri Gagarin in 1961, while Wernher von Braun launched the first humans on the Moon in 1969. Regardless of the success of human space flight missions, the challenges in justifying human space flight still remain. Therefore, in this chapter there is an analysis of the expected benefits from space agencies Moon and Mars space exploration visions and description of the reasons behind benefits definition.

2. APOLLO MISSION BENEFITS

The Apollo program started in 1963 and finished in 1972. During this period six successful Moon landings (i.e. Apollo 11, Apollo 12, Apollo 14, Apollo 15, Apollo 16 and Apollo 17) were performed. These missions brought back lunar samples and resulted in scientific and technology benefits. For example, as a result of the Apollo missions more than 1,500 spin-offs were developed from the space technology developed (Greene, 2008). Many of these spin-offs became important to our day-to-day lives, such as scratch resistant lenses, lunar boots, kidney dialysis machines, water purification technology, dry lubricant and fire resistant materials as presented in Table 1.

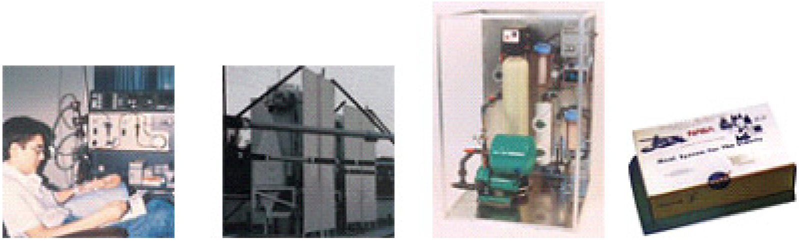
For example the Apollo computer system led to the automation of retail checkout systems, as software programs allowed faster and safer credit authorization. Other examples are the development of freeze dry foods processes for preserving food nutrients and the use of the Apollo space suits fabric for environmentally friendly building material, such as the Teflon-coated fiberglass use. Or the use of the metal-bonded polyurethane foam insulation for protecting the Apollo spacecraft has been widely used for insulation of the Alaskan pipeline (NASA, 2009) (Figure 1).

The Apollo missions brought not only scientific benefits, but also political and national ones to American people. Funding the Apollo program was not an issue as it was initiated in the peak of the Cold War when the US and the Soviet Union were engaged in fierce political, strategic and technological competition. In 1966, NASA informed the US Congress that the estimated cost for the Apollo Program corre-

Table 1. Spin-offs products from the Apollo missions (Stenger, 2003; NASA, 2008; Greene, 2008)

Day-to- day applications	**Healthcare**	**Industrial Processes**
Scratch-resistant lenses for sun-glasses	Kidney Dialysis Machines	Cordless tools- drills, dust vacuums
Lunar boots	Hospital monitoring equipment	Water purification technology
Freeze-dried food	Cool suits	Insulation barriers
Athletic Shoe Design		Process for bonding dry lubricant to space metals
Thin, light, flexible, yet durable and non-combustible fabric		Digital signal-processing techniques part of CAR and MRI
		Vacuum metallizing techniques
		Flame-Resistant Textiles

Figure 1. Apollo spin-offs (NASA, 2008)



sponded to around $24.8 Billion in 1969 or in the currency of today corresponding to around $129.5 Billion (Committee, October 2009). The benefits brought to humankind from the Apollo missions far outweigh their cost (see Table 1).

For NASA, the direct benefits were increased employment and the development of reliable and interoperable technology solutions, such as the Saturn V launch vehicle (i.e. the super booster that propelled the Apollo spacecraft to the Moon). The Apollo missions brought unprecedented indirect benefits such as worldwide awareness and recognition for the achievement of NASA and Americans as well as technology innovation and international cooperation. In addition, the US space industry enjoyed tremendous growth and developed unique competencies in constructing the Apollo Command Service Module (CSM), the Lunar Module (LM) and the Lunar Rover.

The Apollo era was the golden space era for NASA, the US space industry and the American people. It influenced the future development of science and national space industries, as well as triggering technology competition and innovation.

2.1. NASA Global Exploration Strategy of 1969

In 1969, then US President Nixon set up a Space Task Group (STG) to study and define the future US space exploration goals. Their recommendations were for the creation of a Low Earth Orbit (LEO) space station that would host around 6-12 astronauts and later on expand to become a habitat for between 50 and 100 astronauts. The STG proposed the expansion of human space exploration to Mars before the end of the 20th century. Mars was chosen as a future destination due to its earth-like features, its proximity to Earth and the probability that it could support extraterrestrial life[2] (NASA, 1969).

The STG recommended the development of a transportation system that will provide cost and operational capability through the construction of the following new systems:

- Reusable Space Shuttle
- Reusable Space Tug - the idea was to develop a reusable space tug for moving men and equipment between different Earth orbits (NASA, 1969)
- Nuclear Transportation System
- Human spaceflight mission to Mars

STG recommended the launch of a *manned Mars mission* as a long-term goal of the US space program and a NASA manned mission to Mars in 1981[3].

This objective was truly ambitious considering that for the last 40 years, from the 38 spacecraft launched to Mars, only 19 have been successful. Therefore, for many scientists Mars is considered to be a planet of mystery and of unexpected dangers for human space-flight missions.

The expected *direct* and *indirect benefits* as defined by the STG from future space exploration activities are as presented in Table 2.

Table 2. STG 1969 benefits (NASA, 1969)

Economic benefits from the use of space systems: technology advancements, improvements of reliability, quality control, solid state electronics, computer technologies, new materials development and system engineering.	**Exploration benefits** opening new opportunities to explore and investigate the human environment.
National security benefits that can encourage the national spirit of the US as the leader of advanced technologies.	**Social benefits** providing educational services, international relations, and the creation of opportunities for cooperation.
Scientific benefits through the support of ground and space research programs, and benefits such as observation of the electromagnetic spectrum, search for life on other planets, the use of Zero-G for life sciences, physical sciences and engineering.	

The STG committee clearly understood the importance of defining the benefits from the utilization of space-based technology. However, due to the difficult economic times in the 1970s and need for the development of a *less costly* transportation system, the Space Shuttle was chosen as the prime program (NASA History Division, 1972).

The main arguments for choosing the Space Shuttle over future interplanetary space programs were that the Space Shuttle could be "accomplished on a modest budget" making space operations less complex and less costly and encouraging international cooperation (NASA History Division, 1972). However, historically the Space Shuttle turned to be one of the most costly space transportation systems. The total cost of the Space Shuttle program since its launch in the late 1970s until around 2005 has been estimated at $145 Billion (Pielke, 2005), as each shuttle launch is considered to cost of approximately $300 Million per launch. Nevertheless, without the Space Shuttle, the International Space Station (ISS) may not have become a reality.

Today in 2011, the Obama administration is exposed to similar economic challenges as of the US economy being in recession and worldwide financial crisis. However, in contrast to Nixon Obama decided to follow-up up more the STG 1969 recommendations on human Mars mission and feasibility studies in nuclear transportation systems.

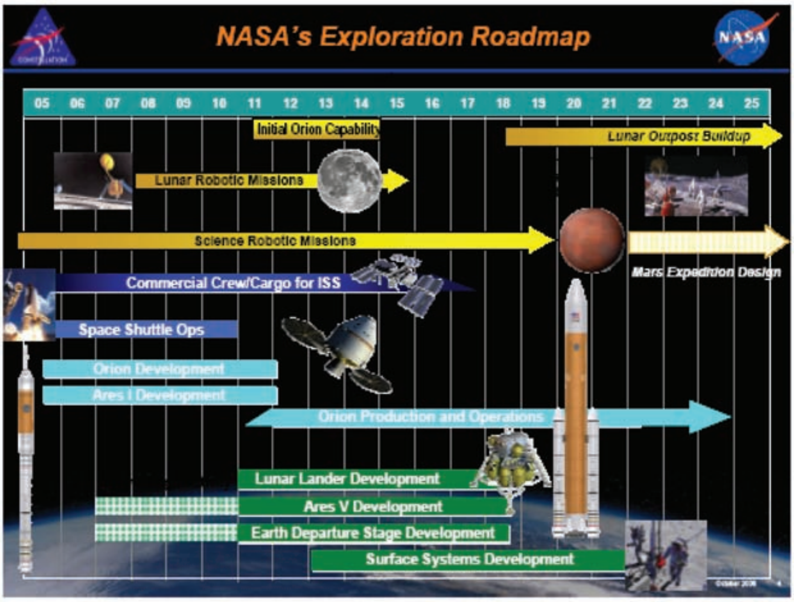
The STG 1969 provided visionary recommendations for human space exploration, but the economic reality did not permit their implementation. Furthermore, Nixon's historic choice to invest in the development of the Space Shuttle demonstrated that choosing the less expensive option may be most costly for launch operations.

2.2. NASA Moon and Mars Exploration Visions of 2004

Until the beginning of the 2010, the US Constellation program was NASA leading human space exploration program and it incorporated Lunar and Mars human space flight missions. However, when the Obama administration came in 2010 the program was reviewed and cancelled. Nevertheless there were certain aspects of the program that are re-used in the new Vision, such as keeping the Orion vehicle and the Ares V heavy launch vehicle. Therefore, in this section there will be a short overview of the US Constellation program.

In 2004, the US Constellation was introduced with the objectives of human return to the Moon by 2025 and human missions to Mars after 2030 (Connolly, October 2006). The US Constellation *vision* for space exploration *proposed* the retirement of the Space Shuttle in 2010, the start of robotic Moon exploration and the human exploration activities for 2020 (see Figure 2). Thus, using Lunar exploration as a

Figure 2. The US vision for future space exploration (Connolly, October 2006)



basis for the development of new technologies and competencies to be used for Mars exploration.

The space exploration themes were *concentrated* on the use of the *Moon for future human and robotic missions to Mars, pursuit of scientific research for addressing questions related to the solar system and the universe and for the extension of sustained human presence to the Moon for eventual settlement.*

The themes were proposed in the *context* of expanding Earth's *economic sphere to encompass the Moon and pursue lunar activities with direct benefits to life on Earth, developing global partnerships and engaging the public* (Connolly, October 2006). According to the Exploration Vision, human visits to Mars will begin only after there is "adequate knowledge about the planets" (NASA, February 2004) and successful demonstration of sustainable human exploration missions on the Moon. This means that NASA was planning undertake a future human spaceflight Mars mission, only after it has *generated* sufficient planetary knowledge and once technologies are developed for Lunar and Mars missions.

However, once the Space Shuttle retires in 2010, NASA was planning to launch the Ares I crew transportation vehicle and the Orion capsule was planned to host 6 astronauts, as presented in Figure 2.

Human return to the Moon was expected to be initiated by 2020, however, due to the cancellation of the US Visions the development of the Ares V launch vehicles and the Orion capsule, their development and launches may be delayed.

In the initial US vision the gap between the retirement of the shuttle and the expected Ares I launch, was at least 7 years. Alternatively, in the best case scenario, NASA may buy LEO launch services from the companies involved in the NASA COTS program, such as Space-X and Orbital (see Chapter 1) in 2015. Still leaving NASA fully dependant on Russia for astronaut transportation to the ISS. This *gap* gives to Roscosmos the supplier power to increase prices for launch services to the ISS.

As the program was expected to bring direct benefits to humanity, it is important that the direct and indirect benefits are defined.

The prime objective of the US Constellation vision was to develop and test new technologies for power generation, propulsion and long term life support systems, which will be beneficial for a future human space exploration on Mars.

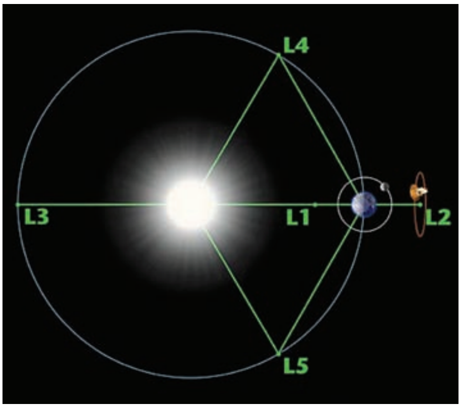
For implementing the objectives of space missions of such as scale, there will be a need for new transportation capabilities, international cooperation with other countries, sustainable technology innovation, interoperable cost-effective technologies and solutions, and industrial utilisation. However, for implementing the new Obama concept for increased ISS utilisation, the development of heavy launch vehicles and future Mars missions after 2035 will require *securing long-term funding* in order to be able to protect the *program from political and strategic games.*

The recommendations of the Augustine committee is that *'The U.S. Human Spaceflight program appears to be on an unsustainable trajectory'* because the program's objectives do not match the allocated financial resources. The Committee proposed the extension of the Space Shuttle's life to 2011, and the International Space Station (ISS) to 2020, as well as the development of Low Earth Orbit (LEO) commercial launch services and encouragement of the development of the US commercial transportation industry (see Chapter 1). However, the reliability of cost estimates of the Augustine committee for Ares I, Ares V and Orion are considered by certain authors as quite contradictory and unrealistic (Mars Society, 2010).

Finally, the Committee recommended that before visiting Mars, the US space exploration effort should concentrate on visiting the Moon or as a second option, exploring the Flexible path which, after 2020, translates into the start of the lunar fly-bys, visits to Langrange points, Near-Earth Objects (NEO) and Mars fly-bys (Committee, 2009) (Figure 3).

The release of the Augustine Committee report triggered numerous ***discussions*** about the future of human space exploration and interplanetary space travel as the expected re-shaping of the US Constellation program during economic crises may result into short-term budget cuts and/or the end of the program. NASA has already

Figure 3. (NASA, 2011)



spent around 9 Billion USD on the US Constellation program of which 3.5 Billion USD for Ares 1 and 3.7 Billion USD for the Orion development (News, Obama trims US space ambitions, 2010). So the Obama administration will need to *investigate* the direct and indirect benefits for the US economy, the space industry and society before considering cancelling or re-structuring the US Constellation program, as its cancellation may result in dramatic technological, scientific and international re-structuring of the space industry and potential loss of scientific and technological benefits.

2.3 NASA post-US Constellation Vision

In the dawn of the Space Shuttle Retirement in 2010 and the reality of the economic crisis that hit the US in 2009, the elected US President Obama decided to re-vamp the US human space-flight program. His administration proposed that *the utilization of the ISS is to be extended until 2020* NASA to encourage the development of *commercial space transportation services*, *development of new technologies* (i.e. in-orbit fueling and deposits) and development of *robotic interplanetary exploration* (NASA, 2010), thus cancelling the US Constellation program and the idea of returning astronauts back to the Moon.

The new Obama plan *encourages* the lowering of costs involved in the development of space technology, the creation of a *competitive environment* and the development of new markets. Although these objectives are quite innovative, it will be difficult since the space industry has operated in a very closed and almost oligopolistic environment. Therefore, the environment in which space industry has operated may change and may result in market forces entering the environment.

Obama's plan for future exploration will impact the structure of the US space industry, NASA and its international space agencies.

This new plan will create a *domino effect* upon its ISS partners, such as ESA, CSA, RSA and JAXA and encourage them to change their industrialisation strategies towards commercial space flight. Certain ISS partners may also have safety *objections* to the use of new space transportation technologies or transfer vehicles (i.e. Space-X Dragon Capsule) that are not initially planned to be assembled with the ISS.

This new plan *will require* that NASA restructures its *contractual relationship* with space companies and defines the route by which to encourage the development of commercial transportation services. NASA will have to decide whether to apply commercialisation or privatisation processes or further expand its COTS program to encourage the development of these services (see Chapter 1).

Thus, NASA may be *pressured to subsidize* commercial space flight activities and launch new commercialization programs. However, the agency will need to be very careful not to *repeat* the mistakes of the failed ISS commercialization.

However, President Obama is planning to add another 6 Billion USD dollars (NASA, 2010) to encourage the development of commercial flights to the ISS by 2015 (SpaceDaily, 2010). Furthermore, the new NASA budget proposes an increase for the ISS utilization, development of earth observation missions for monitoring climate changes and for the development of green technologies for aviation.

The above are *short-term objectives* and after the end of the ISS in 2020 there may be no space station and therefore, the commercial launch companies may end up developing launchers that will have no market after 2020. In a way, Obama's proposal may *resemble* Nixon's decision in developing only the Space Shuttle and therefore, reducing human spaceflight exploration.

NASA will need to *define* the expected direct and indirect benefits under commercialisation or its COTS program in order to assess which process will best encourage the development of commercial transportation services. In order to encourage the creation of self-sustainable markets, the development of new services and the attraction of private funding, cost benefit analyses (CBA) and case studies of the different services and applications will become a necessity.

3. ESA STRATEGIC EXPLORATION PLAN

European Space Agency (ESA) is one of the prime partners in the International Space Station (ISS) and since 2008 has launched the ISS Columbus module and the Automated Transfer Vehicle (ATV). Europe set up a strategic plan for long-term exploration starting from 2009 until 2020 with the following objectives (ESA, 2008):

- The development of European autonomous transporation capabilities to LEO and the ISS[4]
- The extension of the ISS program utilisation and preparation for the development of human operations in LEO until 2020 and beyond
- The development of a lunar landing system, enabling implementation of autonomous, automatic European lunar exploration and participation in international human lunar surface missions by 2020
- Creating partnerships with NASA for the implementation of a Mars Sample Return programme, with the first mission being implemented in the 2020-2022 timeframe
- The development and demonstration of strategic competencies for long-term human space exploration, especially in the following areas: habitation (advanced structures, life support and mobility concepts), energy management (including fuel cells, nuclear and solar), servicing (including advanced robotics, rendezvous and docking, cryo-management, refuelling), advanced interplanetary communication, navigation, and advanced propulsion (including nuclear propulsion and soft precision landing).

ESA will have to *define* a strategy for pursuing or reducing its human space-flight activities after 2020. In the last 15 years ESA has gained an *intermediary position* between NASA and Roscosmos and has managed to work successfully both with the Americans and the Russians. Hence, ESA will have to perform a post-2020 strategic analysis to determine whether to partner with NASA for future Mars missions or for the development of commercial crew and cargo services or to partner with Russia. Therefore, it is relevant that future ESA technologies for interplanetary missions be interoperable with the US and the Russian technology concepts.

ESA is investigating the development of an autonomous lunar Lander that will be delivery cargo and logistics to the lunar surface.

Figure 4 shows an overview of the European Lunar Logistics Lander which will be a logistics and cargo Lander.

Europe is also aiming at developing *robotic competencies* for future Mars exploration. For example, ESA recently announced the construction of the ExoMars rover, which is going to search for past and present signs of life as well as biological life on Mars. The ExoMars rover is going to have a 2 meter drill and collect surface samples for analysing the planet's surface and subsurface. ExoMars will carry instruments dedicated to exobiology and geology research and will investigate the existence of methane on the surface of Mars, which may indicate for past or present life on the red planet. Furthermore, will also analyse the water and geochemical distribution of the subsurface and study the surface environment for future human Mars missions. In addition the mission has also technological objectives are

Figure 4. European lunar logistics lander (ESA, 2008)

the use of solar electric power on Mars and access of the subsurface with a drill that collects sales up to 2m.

ExoMars will be launched on board an US Atlas-V launcher and in addition the probe will use the NASA landing system called Sky Crane (Figure 5).

ESA will have to clearly identify direct and indirect benefits from the ExoMars mission, such as generating indirect benefits from *international cooperation* with NASA under the Mars Joint Exploration Initiative. In additionally, ESA will be able to share with NASA technology solutions and achieve technology *interoperability* and *reliability.*

Figure 5. ESA ExoMars mission (ESA, ExoMars, 2008)

4. RUSSIA'S HISTORIC CONCEPTS FOR MARS EXPLORATION

In the early 1960s, Korolev, the father of Russian rocketry, outlined the direction of the Soviet program which included the creation of an interplanetary spacecraft capable of flying and landing on the surface of Mars with a crew of two to three cosmonauts (Energia, 2008). Korolev's idea was to assemble 3 or 4 spacecraft in a flying formation that would later be used to fly back to Earth (see Table 3).

In the 1960s, the Russians studied the use of a spacecraft powered by electrical jet engines or a nuclear generator. They even developed an idea to deliver a "train" to the Martian surface with five movable platforms for collecting Mars samples. One of the platforms was planned to transport the crew, the second was to be a launch pad for an aircraft to fly in the Martian atmosphere, the third and the fourth were to carry the main and backup return rockets for the crew to return to Earth, while the fifth one was planned to be equipped with a nuclear power generator to supply the crew with power (Energia, 2008).

The most recent Russian Martian Concept will include the launch and assembly of the Martian vehicle elements in LEO. Then, the spacecraft will enter the interplanetary trajectory and head off to Mars. The initial vehicle mass is planned to be around 600 tons, with a total mission time-life of 2 years and the ability to carry up to 6 cosmonauts on board.

Energia the Russian institute responsible for the concept, believes that the vehicle configuration will be fully influenced (Energia, Features 2008) by key performance requirements, such as a *cost-effective* and *safety critical* propulsion system (i.e. electrical propulsion system) for interplanetary travel to Mars. Ac-

Table 3. A summary of the Russian concept studies from 1960 until 1999 (Energia, 2008)

Year of Design	Design Features
1960	Use of electric propulsion for interplanetary transit powered by a 7 MW nuclear reactor Crew of six cosmonauts Delivery to Martian surface of a group of vehicles to make up a self-propelled train
1969	Reactor power increased to 15MW Crew cut down to four cosmonauts Switch to a stationary 'headlight' shaped lander with frontal heat shield
1987	Switch to the use of two independent nuclear reactors to increase flight reliability Change shape of the lander
1988	Replacement of nuclear power plant with a solar power plant based on a firm type photoelectric converter
1990	Modular design for the solar arrays Switch from one lander to two (a manned and a logistics lander)

cording to Energia, the *advantages* of such a concept are the *safe crew return, low mission costs* and the use of a *reusable vehicle* that will allow the expansion of the in-flight developmental testing program and reduce the costs of the future Mars exploration program. Furthermore, the concept will allow the implementation of a comprehensive Martian surface research program and it will support the creation of an *environmentally safe interplanetary* vehicle (i.e. similar to the Viking vehicle designed for landing on the Martian surface).

The long-term Russian vision is to create a permanent Moon habitat as a mid-term perspective (Gingichashvili, 2009) from 2025 until 2035 and later on after 2035 perform human space-flights to Mars. In addition, Russia is planning to modernize the Soyuz vehicle, design a new space transportation vehicle for interplanetary missions and by 2035 have a human exploration mission to Mars.

To be able to investigate a future Mars mission the Russians have launched the MARS 500 experiment. In the MARS500 experiment Russia and ESA partner and together astronauts and cosmonauts will live and perform experiments in a simulated ground-based facility for 520 days and simulate a human flight to Mars. In this experiment, ESA has several crew members who will participate in the project by performing experiments for a period of 105 days. Thus, demonstrating the direct benefits for Roscosmos and ESA, for Roscosmos will be *cost savings* and technology *interoperability* while to ESA the benefits will be also technology interoperability and *innovation.*

Under a common program between China and Russia called CAST, Russia will be providing the launch capabilities, while China will be responsible for building the scientific instruments on board the mission. Both Russia and China will generate indirect benefits from international cooperation and technology innovation.

The international cooperation between Russia, ESA and China will bring direct benefits to their national agencies in technology interoperability and indirect ones from free publicity and technology innovation.

5. JAPANESE MOON AND MARS PROGRAMS

Japan is a space-faring nation with a long history in international space exploration and active participation in the ISS program with the Japanese "KIBO" module and HTV transfer vehicle.

On January 24th, 1990, the Japanese Institute of Space and Astronautical Sciences (ISAS), launched the lunar mission MUSES-A/Hiten with the mission objective to make a technology demonstration of a Moon swing-by orbit and separate a sub-satellite Hagoromo on the surface of the Moon on April 11th, 1993 (Kazuhide, 2009). Furthermore, Japan launched its first Mars mission Nozomi/Planet-B on July 4th 1998 with the objective of investigating the Martian upper atmosphere by focusing on the interaction with the solar wind (ISAS, 2008). Unfortunately, although the probe was nearby Mars, it was decided not enter Martian orbit because of technical difficulties.

Nevertheless, one of the most fascinating sample return missions is the MUSES-C/Hayabusa which landed on the asteroid Itokawa[5] and was launched on May 9th, 2003. Once the probe landed on the Itokawa asteroid and it collected a sample that returned to Earth in 2010 (ISAS, Hayabusa, 2008), thus demonstrating the future technical viability of asteroid missions.

In the next 10 years JAXA is planning to launch a probe with robot and is performing early concept studies for possible Lunar visits by 2030. It launched the lunar mission Muses-A/Hiten (JAXA, 2008) and as well, on September 14th, 2007 (JAXA, Kaguya Mission, 2007) it launched the Selen-1[6] and the "Kaguya" mother ship that launched two sub-satellites Rstar and Vrad.

On-board the SELENE was a High Definition Television Camera (HDTV) which was built and provided by NHK broadcasting company. JAXA and NHK had set a collaboration, by which NHK provides the images to JAXA at no charge, but sells the images to broadcasting companies or other entities interested in using them (Sakamoto, 2008).

From the Selene-1 mission, the *direct benefits* for NHK are revenues from the *image sales, cost savings from R&D collaboration with JAXA* and *technology reliability* and *interoperability* and has gained free publicity. As on each photo of the SELENE probe there appears the name of the company, so they have gained *indirect ones* consisting in free publicity, technology innovation and international partnerships.

JAXA has also gained *direct benefits* in cost savings, technology interoperability and *indirect* ones of free publicity and technology innovation, as they did not need to invest in the HDTV camera development. JAXA is also gaining *indirect benefits* from free publicity and international partnerships[7] due to NHK sales of their images including JAXA's name on them.

6. CHINESE LUNAR PROGRAMS

In October 2003, China became the third space power to launch its own "taykonuat"[8] in space and in September 2007, performed their first EVA. China is even considering launching its own space station and is planning on setting up a Moon Program which is comprised of three development phases. The *first* of which is the launch of a space probe to the Moon (i.e. the lunar probe Chang'e-1), the *second* one is to have a rover on the Moon by 2010, and the third one is to bring Lunar soil samples by 2017. China has also announced plans to send "taykonauts" to the Moon and set up a permanent Lunar base after 2025 (Coue, 2009). Certain authors even speculate with the statement that China may even reach the Moon before the US and thus, trigger a new Moon Race (Goddard, 2010).

In addition China is looking at improving the scientific management of space activities in order to increase the quality, reduce technical risks and increase the benefits from space technologies. However, the most interesting aspect of their approach is to aim at achieving long-term funding for their space activities through the Chinese government funding and the creation of diverse, multi-channel space funding systems, to guarantee the development of a Chinese space industry.

The development of the Chinese space program is still in its early days. However, their decision to invest in the development of a sustainable space industry and their policies to industrialize their space industry will require a *clear definition* of the direct and indirect benefits *to their* economy from the various space applications.

7. INDIAN LUNAR SPACE MISSIONS

On October 22, 2008, India launched its first Lunar mission Chandrayaan-1. On board the mission there were a number of international experiments from ESA, NASA and the Bulgarian Academy of Science (BAS).

Indian Space Research Organization (ISRO) is planning on launching Chandrayaan-2 to the Moon (SpaceDaily, 2010) and land a rover with two rovers, one Russian-built and the second one Indian-built. The Russian-built model will be a solar powered rover which together with the Indian rover, will collect lunar soil or rock samples and analyze them.

The Chandrayaan-1 mission is an excellent example of international cooperation. As a result, ISRO and its partners generated *direct benefits* from cost savings and technology interoperability and *indirect ones* from world-wide publicity, technology innovation and international partnerships.

8. GLOBAL SPACE EXPLORATION STRATEGY

In 2007 fourteen space agencies signed a common space exploration strategy for pursuing long-term interplanetary exploration.

“To present a vision for robotic and human space exploration, focusing on destinations within the solar system where we may one day live and work. It elaborates an action plan to share the strategies and efforts of individual nations so that all can achieve their exploration goals more effectively and safely”

The space agencies[9] expect that, through space exploration, significant "social, intellectual and economic benefits" will be brought to humankind. The following benefits are identified in the global exploration strategy (Coordination, April 2007):

- Securing knowledge and solving global challenges in space and on Earth through the use of innovative technology
- Permanently extending human presence into space
- Enabling economic expansion and new business opportunities
- Creating global partnerships by sharing peaceful goals

The above benefits are quite general, except for the ones related to economic expansion and considerations for commercial exploration. In addition, in the strategy are considered the future development of applications, such as commercial space tourism either virtual or real (Coordination, April 2007).

The Framework provides a "sneak preview" of the expected potential *direct benefits*, such as the development of *new markets* from commercial services and *indirect ones* from international cooperation.

9. CHALLENGES IN FRONT OF LONG-TERM HUMAN SPACE-FLIGHT ACTIVITIES

The *lack of a clear definition* of the expected benefits from the future use of the new technologies developed from interplanetary human space flight missions will lead to difficulties in justifying space exploration to tax payers and politicians, thus resulting in budget *re-allocation* to earth observation and navigation programs (see Chapter 4). A clear vision of the expected benefits will provide NASA with the necessary arguments not only to attract funding for the Vision for its long-term continuation, but also to mitigate the possible political and budgetary forces that could adversely affect the new Obama Vision.

Only by *clearly defining the expected benefits from commercial crew and cargo transportation missions and future Mars/asteroid missions.* NASA and its future partners will be able to gain the necessary *political, social* and *financial support* for implementing their national sustainable space exploration Programs.

The *direct* and *indirect benefits* from the future interplanetary missions will attract space and non-space companies and private funding for the development of commercial cargo transportation services. Companies will be able to develop new applications and markets based on the space technologies developed under the NASA COTS program. That will result in potential generation of revenues from the acquired IPR and R&D space patents from biotechnology projects for new drug developments, or new space-based materials, or new types of robotics. These patents can later be used by other sectors (i.e. health, nuclear, etc.), in a similar way as the kidney dialysis machine was created that widely used Apollo space -based technology.

Today, companies involved in space robotics may adapt their robotics for neuroscience operations or be used in the nuclear industry for accessing safety critical nuclear zones (see Chapter 5).

Integrating market needs and ''end-users needs" forces will encourage industrial projects to take part of the future Moon and Mars or other interplanetary space exploration missions, reducing the space interplanetary programs' dependence on political decisions. One such example of political decision dependency is the 2010 Obama administration cancellation of the US Constellation which *was launched* by the Bush administration in 2004.

The successful implementation of the Vision posed numerous challenges to NASA and, since these challenges were of a *budgetary, technical, political and strategic nature*, the Obama administration decided to cancel the program. The cost for the development of the US Constellation Vision was going to cost Billions of taxpayers' money.

NASA will have to identify other sources of funding and attract business angels, venture capitalists and others. Early cost estimates from 1989 for human space missions to Mars had a cost estimate of around $600Billion (Kluger, 2004). *As these initial cost estimates were too high* for the US Congress, the plan was never approved and due to the financial crisis of 2009, the Obama administration cancelled the US Constellation program.

Nevertheless, the new NASA budget for 2011 to 2015 (see Chapter 1) allocates funding of around $6 Billion for the development of commercial transportation services, encouraging the development of heavy lift propulsion systems that will reduce costs and will involve partnerships with commercial, academia and industry stakeholders and will encourage the development of new technologies. In the context of the new direction of NASA is undertaking the following issues may arise.

1. Increased dependence on the Russians for flights to the ISS at least until 2015
2. The retirement of the Space Shuttle will mark the reduction of the US human space-flight activities
3. After the retirement of the ISS in 2020, there will be no destination for the provision of commercial crew and cargo transportation services
4. ESA, JAXA and CSA long term human space flight activities are threatened as their humans spaceflight programs are tightly linked to NASA ones.
5. The global space industry will be influenced by the new direction which NASA is undertaking in working with space industry

6. NASA will be the prime customer for the services of commercial launch service providers
7. The commercial crew and cargo transportation market is emerging and therefore, customers are few, risks are high, costs for research and development are high and the environment is highly regulated
8. The space industry is not at present adapted for supporting the development of these types of services as it will be concluded in Chapter 4
9. The space industry is a closed industry with technology forces being primarily dominant
10. NASA will need to undertake a different approach for encouraging commercial services and partnership creations in order to prevent repeating the mistakes made in the failed ISS commercialisation

Finally, if NASA decides to pursue this new path for encouraging the development of commercial launch services, it will have to require cost benefit analyses (CBA) which will be a challenging task due to the lack of historic cost and revenue data and to the emerging and nascent stage of market evolution.

ESA, JAXA and CSA human space flight programs may be influenced by the new directions of NASA new direction of space flight activities.

From the above objectives it becomes clear that, for the successful implementation of the Vision, it was important to attract enough non-space and space companies to contribute ideas, technologies and funding. The Vision had to encourage *economic growth, contribute to the development of new markets and applications of use on Earth* in order to attract the necessary investment capital and new stakeholders. The space agency will also have to encourage the *commercial use*[10] of these technologies from non-space companies and promote these benefits to non-space industries. Nevertheless, the commercial exploitation of new technologies and resources for Moon and Mars exploration is not a prime objective of the plan for future exploration (Tkatchova, 2008).

Commercialisation of space technology will encourage the development of new markets and applications, technology innovation and may lead to a partial cost relief for space agencies. In a similar way as MIR and ISS commercialisation encouraged the creation of space tourism (see Chapter 3). While the Apollo missions encouraged the *spin-off* of technologies that resulted in the creation of scratch resistant sunglasses.

For successfully attracting private and international partners to the visions, there will be a need for a clear definition of direct benefits, such as new market applications, revenues and indirect benefits, such as technology innovation, space brands and others (Tkatchova,S.&Van Pelt, M.(2007)).

Identifying, defining, and *analysing* the direct and indirect benefits of commercialisation for the future stakeholders in Moon and Mars missions will contribute to public and political support and their successful implementation (Tkatchova, & Van Pelt, 2007). Similar support can be gained by the Obama administration for the new NASA 2011 budget and concept for encouraging the development of commercial crew and cargo services.

NASA recommendations for the US Constellation Vision (NASA, 2004) report also recommends three criteria for success of space missions to be: *sustainability*(i.e. long-term approach), *affordability* (i.e. the use of 'go as you can pat') and *credibility*.

The above factors could also be used for identification of the direct and indirect benefits from future interplanetary missions. However, in order to be consistent in our analysis, it is important to take also the criteria from STG 1969, of *commonality*, *re-usability* and *economy.* As already proposed in the earlier section the STG 1969 criteria of commonality (i.e. interoperability), re-usability and economy can be combined with the ones from today's concept for affordability and through the identification of cost-effective technology solutions, especially in the context of the new NASA budget of 2011 and the financial crisis of 2010. The new strategic vision is to develop new technologies for achieving cost-effective, sustainable, and affordable solutions.

These new technologies will be directly *linked* to *cost-saving technology* solutions and technology reliability/interoperability as *direct benefits*. The criteria for *sustainability* and *credibility* can be directly linked to the *indirect benefits* of free publicity and international cooperation.

The identification of the *direct benefits* for NASA will provide the opportunity for the agency to have a choice of technologies for space transportation and suppliers from which to choose for cargo and crew commercial transportation services to the ISS. Furthermore, it may encourage further the development of the commercial launch services, space tourism market, and the construction of space ports.

Commercialisation of space-based technologies for future interplanetary missions could also contribute to national economic growth and contribute to the development of new markets and applications.

10. EXPECTED BENEFITS FROM THE STG 1969 AND THE US VISION FOR SPACE EXPLORATION

STG 1969 vision and the US Constellation Vision for space exploration were linked in their attempt to define and crystallize the benefits for interplanetary space exploration. The STG defined a set of program objectives and potential benefits from future US space activities.

The identified benefits can be from the *application of space technology* for the direct benefit of mankind, *operations of military* space systems for national defense purposes, exploration of the solar system and beyond and the *development* of new capabilities for operating in space.

The first aspect suggests that space technology and exploration should be pursued only if it brings direct and indirect benefits to society, while the second one is focused on bringing defence benefits which is understandable when considering that this strategy was identified in the early days of the Cold War.

The third aspect is related to Moon and Mars exploration, the discovery of the solar system and fly-by missions to the asteroid belt, similar to what Obama's Augustine committee proposal in 2009 for revamping of the US Constellation program.

The fourth objective proposed the development of new competencies and technologies for space exploration. To achieve this fourth objective the STG proposed the implementation of three critical factors of *commonality*[11], *reusability*[12]*and economy* for the development of more cost-effective space technology. The above factors will be of critical importance for lowering the cost for future commercial crew and cargo service companies.

The use of the *three critical factors of commonality (i.e. interoparability*[13]*), reusability and simplification of* space-based hardware should be considered for the successful implementation of long-term self-sustainable interplanetary missions and in the definition of the direct benefits from the use of space-based technologies for the future interplanetary missions. Direct benefits, such as easy interoperability of various technology solutions (i.e. S/W solutions), entry in new markets (i.e. direct benefits), and in identifying indirect ones such as safety, due to the use of already tested and space qualified technologies. Therefore, technology reliability and interoperability will be considered as a direct benefit in for the direct benefits definition in Chapter 8.

11. MISSION BENEFITS FROM THE EUROPEAN SPACE EXPLORATION VISION

The European Strategic Plan for exploration is built upon the principles of aiming at technological advancements, generating scientific knowledge, and setting up global partnerships. In the context of human interplanetary space exploration Europe's objectives are more modest than the US ones.

Europe's space policy is built upon the fundamentals of *mutual agreement* between all the ESA member states. Therefore, Europe is widely influenced by national space objectives and the space budget is spread among earth observation, space sciences, and navigation sectors (see Chapter 4).

The ExoMars mission is an excellent example of how ESA can generate direct benefits from *technology innovation and interoperability* as a result from cooperating with NASA. In addition, ESA can gain indirect benefits from the free publicity of NASA for its participation in the ExoMars mission. Technologies, such as advanced propulsion systems, space servicing, in-situ resource utilization and communication, navigation and logistics services, may start to play an important role in increasing European space industry competitiveness (see Chapter 6).

12. MISSION BENEFITS FROM THE RUSSIAN SPACE EXPLORATION VISION

The Russian Mars exploration mission is built upon concepts in which there are various trade-offs between: *1) crew and spacecraft safety* and *2) cost-effective technical solutions*.

The above *two aspects* will be the prime requirements behind the Russian Space missions design and will result in direct benefits from a future Moon and Mars mission for Energia.

The *direct benefit* of crew and spacecraft safety is directly linked to *technology reliability* and the provision of *cost-effective* technical solutions to cost-saving benefits. Due to the Russian space agency cooperation with China, it can generate additional benefits, such as potential cost savings from cheaper construction of the on-board instruments as in the case for the Phobos-Gunt mission (i.e *direct benefit*). *Indirect benefits* will be in technology innovation and international partnerships.

While, from its partnership with ESA on MARS 500, the Russians can generate *direct benefits*, such as *technology interoperability* and *cost savings*, as the maintenance costs for the MARS 500 facility may be partially shared between ESA and the Russians. In addition ESA will generate indirect benefits in technology innovation and free publicity.

Roscosmos, ESA and the Chinese Space Academy as partners will be gaining competencies in *technology reliability* and interoperability. All partners in these missions will profit from technology innovation and international partnerships, as *indirect benefits.*

13. REASONS BEHIND BENEFITS DEFINITION

The *reasons* why space agencies, private companies and investors' need to define direct and indirect benefits are directly linked to the importance to assess the projects investment decision.

- define business case from industrial projects using space-based technology
- secure funding for the development of new markets and applications (private companies)
- attract the necessary funding for their industrial projects
- perform cost-benefit analysis for technologies that will bring benefits
- attract political and investor support for their interplanetary space programs build awareness for the existing opportunities
- attract first-time customers and develop new markets
- reduce the time to market of the technologies developed or the space patents generated from the use of space-based technology
- increase employment in the space industry
- achieve cost-saving solutions for their technology solutions
- achieve technology interoperability and innovation that can be potentially spun-off
- overcome political and strategic complexity typical for the space industry
- attract new technology solutions and easier exchange information

The above reasons will vary for the different stakeholders however, in the case of the launch of commercial projects that use space-based technology for improving their products and services, the above benefits will support private companies to *define their business case and develop their business model.*

14. DISCUSSION

Historically, space agencies have been the masterminds behind space exploration and they have encouraged the development of their national space industries.

In the last 20 years, space technology has transformed our daily lives, starting from telecommunications, climate change monitoring through earth observation satellites and navigation systems in our cars. Space technology has offered space and non-space companies the unique opportunity to develop new applications, markets and technologies.

Human space-flight was always a symbol of the scientific and technical excellence of the US and the Soviets during the Cold War. For politicians it was a symbol of ultimate *political success*, for engineers and scientists it was a symbol of their ability to break the boundaries of science and technology and for visionaries it was the only way for human evolution.

During the Cold War, space agencies *didn't need* to define the benefits derived from human space exploration nor did they need to justify their spending or to initiate the commercialization of space technology. As political, strategic, and technology forces were the dominant ones. As a result today space agencies and space companies have *no historic experience* at defining the direct and indirect benefits from long-term space exploration for non-space companies and national economies.

Justification of public investment in interplanetary and human space-flight activities became relevant in the last 10 years due the drying up of space public budgets, financial crises and increased military spending.

Furthermore, national governments will increase their deficits due to providing financial aid to save their national banks and automobile industries and to reduce unemployment. National economic recovery is slow and therefore, governments feel *under pressure* to justify their R&D investments and define the short-term benefits derived from science and technology. Therefore, in case space agencies decide to increase their ISS R&D research they may need to justify their activities and therefore, will need to assess the economic benefits from increased R&D on board the ISS.

MIR and ISS commercialization development (see Chapter 3) opened new frontiers for entrepreneurs who were willing to fly on-board a space station or undergo astronaut training. New companies, such as Space Adventures that offer space tourist flights to the ISS or others, like Virgin Galactic, invested in the development of new space transportation vehicles the likes of SpaceShipTwo. While others, such as Space-X and Orbital, invested in the development of Falcone I, the Dragon Capsule and Taurus II vehicle. Their involvement demonstrates a promising future for space tourism, commercial cargo and crew transportation services.

Nevertheless, the Obama administration will need to *analyze* the expected direct and indirect benefits from the investment in future commercial transportation services as private companies may not be willing to invest in the development of LEO launchers and services due to the expected end of the International Space Station (ISS).

Obama's new approach for interplanetary space exploration and his expected investment in the development of commercial crew and cargo services will result in changing NASA's relationship towards US space industry. The *lack of benefit definitions and assessment from* utilisation of space-based technology may reduce sufficient political, strategic, and financial support for the US Constellation program. Therefore, companies involved in the development of commercial crew or cargo transportation services will have to perform benefits analyses and this will be a challenging task due to the lack of historic market data as a result of the emerging nature of the market.

To prevent this from happening, not only do the benefits need to be defined, but the *criteria of sustainability, affordability and credibility will need to be integrated in the future mission requirements*. These developments can be implemented with a *unified approach* for identifying the direct and indirect benefits derived from the future Moon and Mars missions or other interplanetary missions. Space agencies may start to consider integrating the *requirements of non-space companies when defining space mission requirements.*

Future space technology concepts and designs for Moon and Mars and interplanetary missions will be influenced by the need to have *cost-effective, reusable and safety critical vehicle solutions.*

Russia will increase its technology cooperation with China and India for future interplanetary missions. This is a *negative trend* as the US will reduce its cooperation with the Russians who have vast competencies in long-term human space-flight missions.

China will increase its role in human space-flight, promote its space technology and possibly offer commercial launch capabilities for human space-flight. Thus, they may even start *competing* with the US and send human missions to the Moon at the same time as NASA. Russia and China will be able to achieve these missions due to their combined capabilities; Russian space technology competencies and with the Chinese cheap labour costs for payload development.

The *Moon Race competition* could push for increased technology innovation, commercial use space-based technologies, and successful implementation of human space Moon and Mars missions.

15. CONCLUSION

The STG of 1969 identified three critical factors of c*ommonality (i.e. interoperability), re-usability and simplification (i.e. referred to economy)* that can be used in the development of interoperable solutions for future Mars, asteroid and interplanetary missions.

In 2010, NASA's Constellation program was cancelled not only because of budgetary reasons, but also because of unclear expected benefits from industrial utilisation of space technologies from the future US Vision. Therefore, the *lack of a clear definition* of the expected benefits from the future use of the new technologies developed for interplanetary missions will lead to difficulties in justifying space exploration to tax payers and politicians.

In the context of the new direction of space exploration, companies involved in the development of commercial crew or cargo transportation services, will have to perform benefit analyses in order to be able to attract private funding. This will be a challenging task due to the lack of historic market data as a result of the emerging nature of the market. NASA may be even accused of creating conditions for subsidizing commercial flights.

To prevent this, not only do the benefits need to be defined, but the *criteria of sustainability, affordability, and credibility need to be integrated in the future mission requirements*.

Some of the reasons behind the need for benefits definition are the importance to develop business cases and attract private funding, attract political support, secure funding for the development of new markets and applications, achieve cost-saving solutions for new technologies and overcome political and strategic complexity.

Cost-saving technology solutions and technology reliability/interoperability as direct benefits and the criteria of free publicity and international cooperation will be linked to indirect benefits. Only by clearly defining the benefits *for* space agencies, space and non-space companies will be *able to gain* the necessary political, social and financial support for implementing a sustainable space exploration programs.

Companies involved in the provision of commercial cargo services will face challenges in securing funding for the development of new markets and applications, attracting investor support, reducing the time to market of the technologies developed, achieving cost-saving solutions and generating space patents from the use of space-based technology.

Certain space agencies, such as Roscosmos and JAXA, have demonstrated how international partnerships can result in benefits definition; such as cost savings and technology interoperability, and indirect benefits, such as free publicity and technology innovation.

Commercialisation of space based technologies holds a promise for the development of future technologies that will be beneficial to industries and national economies.

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ENDNOTES

[1] Konstantin Tsiolkovsky Plan for Space Exploration included the following steps for space exploration:(I)creation of rocket airplanes with wings, (II)progressively increasing the speed and altitude of these airplanes, (III)production of real rockets-without wings, (IV)ability to land on the surface of the sea, (V) reaching escape velocity (about 8 Km/second), and the first flight into Earth orbit, (VI)lengthening rocket flight times in space, (VII)experimental use of plants to make an artificial atmosphere in spaceships, (VIII)using pressurized space suits for activity outside of spaceships, (IX)making orbiting greenhouses

for plants, (X)constructing large orbital habitats around the Earth, (XI) using solar radiation to grow food, to heat space quarters, and for transport throughout the Solar System, (XII)colonization of the asteroid belt, (XIII)colonization of the entire Solar System and beyond, (XIV)achievement of individual and social perfection, (XV)overcrowding of the Solar System and the colonization of the Milky Way (the Galaxy), (XVI)the Sun begins to die and the people remaining in the Solar System's population go to other planets (Lytkin, 2008).

[2] In 2008, NASA's Phoenix mission discovered iced frost on Mars indicating the existence of water on the planet (Pappalardo, 2008). These findings indicate the possibility of past life on Mars and the opportunity for terraforming Mars. Nevertheless, there are many other missions planned to investigate life on Mars. In 2016 ESA will be launching the ExoMars spacecraft which will have a driller to drill the surface of the planet and look for past and present signs of life.

[3] The STG considered that before any manned mission to Mars, there will need to be detailed studies of the biomedical aspects, physiological aspects of flights of at least 500-600 days, robotic reconnaissance of planets, life support systems, propulsion systems and power supplies.

[4] ESA's is totally dependant on the USA or Russia for human space flight transportation. For example, the landing of the shuttle for one year and half after the Columbia accident in 2003 resulted into Europe waiting for at leats 3 years for the Shuttle to become once again operational in order to launch the ESA ISS Columbus module.

[5] The asteroid Itokawa is one of the smallest ever celestial object of 540m. length and its surface is covered with boulders and very few craters.

[6] The Japanese Selene probe provided high quality photos with a 100km resolution of the Apollo landing site called "Hola"

[7] JAXA have also set up a Virtual lunar development project and is actively cooperating with ESA on other missions such as the BepiColombo mission which is planned to be launched in 2014 and is planned to reach Mercury, the nearest planet to the Sun.

[8] Taykonaut is a Chinese astronaut or cosmonaut

[9] The Global Exploration Strategy was signed by the following space agencies: ASI (Italy), BNSC (UK), CNES(France), CNSA (China), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA (Europe), ISRO (India), JAXA (Japan), KARI (South Korea), NASA (USA), NSAU (Ukraine), Roscosmos (Russia)

[10] The commercial use or commercialisation of space technology is the process by which space-based technologies result into products and services that are sold to companies, without the transfer of the technology ownership

[11] the use of few major space systems across a wide variety of space missions

[12] the use of the same system over a long period of time for a number of space missions

[13] Interoperability refers to systems, processes and technologies commonly interfacing between each other. Software solutions can contribute to increasing the interoperability between various spacecraft sub-systems.

Chapter 3

Space Station Commercialisation

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"The dinosaurs became extinct because they didn't have a space program. And if we become extinct because we don't have a space program, it'll serve us right!"

Larry Niven, quoted by Arthur Clarke in interview Space.com, 2001

1. INTRODUCTION

The objective of this chapter is to introduce space agencies' commercialisation strategies and to analyse the lessons learned and the reasons and the benefits behind space station commercialisation.

The lessons learned from the space station commercialisation will illuminate the hidden hurdles of commercialisation of space stations and interplanetary missions. Furthermore, this chapter will provide an analysis of the challenges facing the commercialisation of space stations and space-based technology for interplanetary missions.

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2. COMMERCIALISATION, TECHNOLOGY DIFFUSION AND DISRUPTIVE TECHNOLOGIES

Commercialisation of space *technology does not involve the transfer of technology ownership rights[1]to the user or a commercial operator*. The user pays a certain fee for *"renting"* the space- based infrastructure.

The early days of space station commercialisations started with the MIR station and continued with the International Space Station (ISS). First attempts at utilising MIR as a commercial platform were launched by MirCorp, a US based company created in 1999 by a team of enterpreneurs. MirCorp had signed an agreement for commercial utilization of MIR and actively pursued its successful commercialisation. Thus, in 2000 funded the first privately funded human space mission to MIR and attracted the first space tourist, Dennis Tito for a one week flight to MIR (see Chapter 7). Furthermore, the company had signed a deal for creating a reality TV show "Survivor" and sending the winner for a trip to MIR.

MirCorp managed to trigger huge public interest and successfully promote MIR. Sadly their pioneering initiatives and ideas were ended with the de-orbiting of MIR in 2001. Nevertheless, their pioneering activities opened new frontiers, promoted human space exploration and set-up the foundations for future space tourism activities.

Commercialisation of space-based technology can encourage space technology diffusion into non-space industries and result in its adaptation to non-space sectors. Technology diffusion often introduces disruptive technologies to a new market. These technologies have the disruptive impact of technology innovation. Examples of such technologies are semiconductors, mobile telephones, digitalization, airliners and high-speed trains. For example, companies, such as MDA that developed the Canadian Arm on the ISS, have spun off their autonomous robotics and system engineering competencies for the mining, nuclear, security and medical sectors (see Chapter 5).

Spin-off of space technology is different to commercialisation and may bring direct and indirect benefits to national economies and societies. For example, NASA developed a chemical process that removes toxic waste from used dialysis fluid for the Apollo missions. Due to this development special kidney dialysis machines that save electricity were developed.

The successful commercialisation of interplanetary technologies may encourage not only spin-off processes, but also technology diffusion in other non-space sectors, such as nuclear, mining or security industries.

3. US RUSSIAN COOPERATION AND PRE-HISTORIC DAYS OF SPACE STATION COMMERCIALISATION

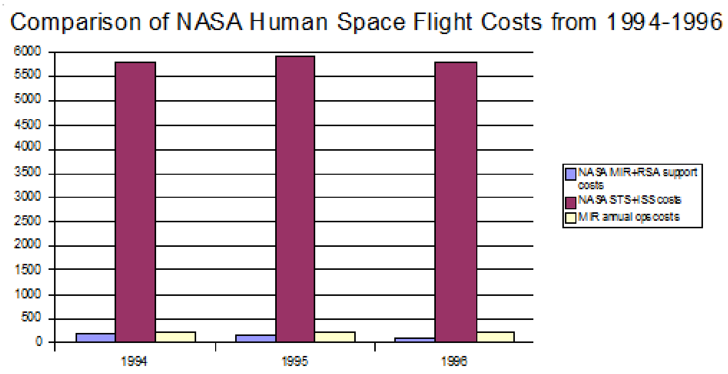
The US-Russian cooperation set up in the middle of the 1990s contributed to keeping MIR operational. Nevertheless, it was a fruitful cooperation which started with several Space Shuttle launches to the Mir in 1994 and continued until 1998 (Figure 1). Twelve cooperative space missions were performed with 12 Space Shuttle Flights[2].

NASA's achievement was impressive, as it has performed 3 Space Shuttle Flights per year under the US Russian Space Development program. For NASA, MIR became the only space laboratory in which US astronauts could learn to live for long-term periods[3] in Zero-Gravity[4] (NASA, 1996). The benefits the Americans identified from their cooperation with the Russians were the development and enhancement of the US capabilities in human space flight. Furthermore, the reduction of *development costs* for future U.S initiatives[5] through the use of Russian-developed technology. Through the cooperation with the Russians, the US for *Roscosmos* an opportunity to learn about long duration operations and generate benefits from life sciences and microgravity experiments. Nevertheless, for the US and for Russia, the direct benefits for future ISS assembly and operations were the development of common system operations (i.e.interoperability). Furthermore, for the US, the cooperation with Russia was foreseen as contributing to the advancement of the US national space program and the US aerospace industry.

The US and Russian cooperation brought MIR benefits in *operations cost sharing* for both space agencies. Figure 2 presents a comparison between NASA MIR and Roscosmos support costs, NASA Space Shuttle costs and MIR annual operation costs from 1994 until 1996.

Figure 1. MIR Space Station and Atlantis Space Shuttle (Images Courtesy of NASA)

Figure 2. NASA budget for the US-Russian Cooperation[6] *(NASA, 1996)*



The Space Shuttle mission costs in combination with the ISS escalating costs probably encouraged NASA to use initially MIR as a platform to gain humans space flight competencies, rather than re-invent the wheel.

Both space agencies generated direct and indirect benefits from this cooperation. While NASA gained *direct benefits* such as *cost-savings* and *technology reliability* and *interoperability* from the missions. As well as indirect benefits including *technology innovation*, *interoperability* and *cooperation* the Russians gained direct benefits from *revenues* from the NASA contract support.

The Roscosmos generated *direct benefits*, such as *revenues, employment and technology interoperability,* as the MIR station and STS rendezvousing required technology interoperability. In addition, they also gained *indirect ones* such as ones from *international cooperation*, *free publicity***and***technology innovation*.

4. EARLY DAYS OF COMMERCIALISATION

The MIR station (1986-2001) was a symbol of the Soviet space engineering and on its board more than 104 cosmonaut/astronauts from 15 countries lived and performed experiments (Hoffman, 1999), (Anfimov, 2001). The MIR station hosted experiments from the Intercosmos program[7] and offered the opportunity to smaller countries, such as Bulgaria, Hungary, Cuba, Poland to have their own cosmonauts and experiments on-board MIR.

The new democratization processes which started in the 1990s Central-Eastern Europe encouraged MIR commercialisation. Overnight, the Russian space industry faced symbolic space budgets, national currency inflation, industries restructuring and high levels of unemployment. That resulted in the inevitable economic transition to a free market economy. Funding the MIR annual operations costs in any an economy of transition was almost a "mission impossible." The MIR operations costs per year were between $220Million and $240Million (Astronautix, 1997) and for its 15 years of operation, the average total cost for the MIR station was between $3.3 Billion and $3.6 Billion.

So the Russian space officials decided to undertake the *unknown road* of commercialisation and thus attract funding to keep MIR alive.

Overnight, the Russians became the *pioneers in space stations commercialisation* and very quickly identified new markets and encouraged the setup of space entertainment projects.

In 1990, the Russians flew the Japanese journalist Toyohiro Akiyama to the MIR space station for a 6-day trip (Senger, 1990). This initiative encouraged the Russians and they continued with the advertising projects and in 1996, managed to attract Pepsi to invest in promotion campaigns related to space. In addition, in 1999 they also attracted Pizza Hut to pay around $1Million to have their logo on-board the Proton launcher. This initiative continued with Pizza Hut sending its pizzas to the ISS in 2001.Furthermore, in 2001 Segei Zaletin's and Alexander Kareli's space flight to the MIR station were sponsored by MirCorp (Zak, 2000).

In the late 1990s, there were discussions for setting up a reality show called "Destination MIR" and thus, flying the winner to the station. However, the show was never realised due to the unknown future of the MIR station.

Russian attempts to commercialise the MIR station were innovative and despite their chaotic nature and the lack of a clear commercialisation strategy, they encouraged the development of new markets (i.e. space tourism, branding, etc.) and space applications.

MIR commercialisation became the future platform for ISS commercialisation. As a result, the ISS partners started setting up commercialisation policies for attracting private companies to develop industrial projects on board the ISS.

4.1. ISS Commercialisation

The new market horizons that MIR commercialisation opened inspired the ISS partners[8] to initiate ISS commercialisation. Nevertheless, the escalating ISS costs[9] and the political pressure from national governments to initiate new ways to work with private companies also encouraged the ISS partners to initiate this process.

The ISS partners even set up commercialisation *objectives* that were to encourage the creation of new markets, achieve partial cost recovery, reduce ISS ground segment operations and enhance national space industry competitiveness.

The ISS partners clearly had high expectations on the *benefits* that ISS commercialisation will bring, such as new market development and cost savings.

Once the ISS partners decided to commercialise the ISS, they decided to allocate a percentage of their on-board ISS resources[10] for industry-based projects, they set up commercialisation policies and defined their ISS products and services. At the time, this approach seemed a reasonable one, however it was quite rigid as it imposed internal limitations on the ISS resources that could commercialise. However, future ISS commercialisation may be driven by customers needs for certain ISS facilities.

To achieve encourage ISS commercialisation, the ISS partners set up different initiatives (Table 1).

The ISS targeted customers were pharmaceutical companies, medical device developers or automotive companies. Some of the ISS partners encouraged the use of ISS facilities for experiments in the area of biotechnology, new materials, life sciences and fluid physics sciences. These types of customers were offered the opportunity of understanding Zero-G and test their technologies and processes in microgravity. For example, ESA gave companies who financed 100% of their commercial projects IPR rights for their research results and an ISS brand "space proven product". In addition, some of them could even buy marketing rights. Furthermore, with the IPR rights, companies could develop new products and improve their industrial processes.

The above activities encouraged the implementation of several commercial projects in the area of research, technology demonstration, and edutainment. For example, ESA flew a new generation of osteoporosis medical devices for scanning bone structure (i.e. OSTEO facility) and also another one of a small fish for investigating osteoprotegerin activity[12]. Osteoporosis is a disease with which astronauts

Table 1. ISS partners commercialisation initiatives

Commercialisation Policies and Strategies	Contract companies performance of market analyses of the targeted ISS R&D markets (for example, in the early days of commercialisation, ESA had requested research institutes and companies to perform market analyses for the biotechnology, nutrition and health sectors) Space agencies set policies for providing IPR and marketing rights for commercial projects.
ISS products and services definition	Commercial projects right to IPR and marketing rights
ISS prices proposal	ISS partners setting up of partnerships with non-space companies (i.e. such as ESA Commercial Agent) for identifying and implementing commercial projects
Creation of user-friendly conditions for encouraging commercialisation (for example, ESA reduced the internal process for selecting and qualifying[11] the commercial projects to 6 months)	ISS price promotions for ESA member states companies that are interested in implementing commercial projects.
Technical and proposal preparation support to commercial customers in the development and design of their commercial projects	

are familiar, as they experience accelerated bone loss in microgravity of between 1 up to 2% of bone density per month.

Therefore, research on board the ISS can contribute to finding new ways of preventing bone loss and therapies for increasing bone density and contribute to medical advances. Successful technology demonstration on board the ISS was performed with the launch of a new generation of energy saving lamps (i.e. High Intensity Discharge (HID) lamps). Another interesting project was the launch of the Mediet Food tray consisting of Italian cheese and dry tomatoes packaged using a new high pressure processing technology one that eliminates bacteria but keeps the properties of the fresh food.

The above commercial projects were just a few but they partially encouraged the development of new uses and adaptation of space-based technologies, processes and foods and contributed to *technology innovation, interoperability* and *free publicity* for the companies involved in them. Unfortunately due to the lack of sufficient information for the ISS on board research capabilities and the low interest from non-space companies very few commercial projects were flown on board the ISS.

4.2 ISS Facilities, Services and Prices

The ISS is a multi-disciplinary science laboratory and experiments to the space station are transported with the Space Shuttle, Souyz or Proton (Figure 3).

The ISS partners first defined the ISS on-board services for commercialisation and then set-up pricing policies. In 2001, NASA and Roscosmos were the first agencies to set up ISS prices and were immediately followed by ESA and CSA.

NASA, ESA and CSA set up the so called marginal cost pricing[13] approach, while the Russians set up their prices based on project demand. The prices shown in Figure 4 were set up in 2001 and most of them are no longer relevant as space agencies withdrew most of their prices. Nevertheless, the ISS prices depict an interesting *first attempt* by the ISS partners at defining their products and services and setting up new pricing approaches.

Initial marginal cost pricing was initiated by NASA and the logic behind it was to develop a clear picture of the costs that needed to be recovered, such as ISS variable ones. So NASA set up prices for using the International Standard Payload Rack (ISPR) facility and accommodates a few ISS Mid Deck Lockers (MDL). For example ESA European Drawer Rack (EDR) is an ISPR which accommodated 3 ISIS Drawers and 4 Mid Deck Lockers.

NASA bundled all its ISS services under one ISPR rack for a one year lease. While ESA undertook a *mixed pricing* approach of bundling the services for drawers (i.e. MDL) and lockers (i.e. ISIS Drawers) and at the same time offering to customers the flexibility of having prices for additional services.

Figure 3. International Space Station (ISS) (Images Courtesy of NASA)

The ISS on board facilities however, were designed and build for fundamental research rather than applied one.

The Russians had the most *customer-friendly and flexible prices* which was logical as they had the historic experience with the MIR commercialisation.

The prices in Figure 4 provided a clear message on the ISS partners' expectations and needs from ISS commercialisation. In a way the ISS partners were *sending a message* to the customers indicating the costs they wished to *recover* from their ISS contributions. This was probably *one* of the reasons that discouraged space companies to invest in the development of commercial projects. Furthermore, NASA's bundle pricing approach for a whole ISPR rack *did not offer* customers the flexibility of flying small payloads or choosing the services they wanted.

The ISS prices did not reflect prices for services such as ground test facilities, clean rooms, ground segment operations, payload qualification, integration or testing, or prices for the industrial use of drop towers, FOTON capsules or parabolic flights.

NASA's *inflexible prices* did provide an *indication* that for the agency, the process was not of a strategic priority. In contrast, Roscosmos was relying on the direct revenues from ISS commercialisation activities and therefore had set up user-friendly prices.

Setting up a pricing policy and defining prices for certain services using space-based technology from interplanetary missions will be a challenge due to the lack of relevant historic experience from space agencies.

Clearly, the ISS prices were particularly complex and did not offer *price promotions* and were *politically* driven rather than market driven.

For example, for future asteroid/Mars missions, space agencies can potentially apply differentiated pricing policies for the facilities and services and provide IPR or marketing rights they lease to private companies. However, the definition of the products and services and the selection of pricing approaches will be influenced by the expected benefits derived from the commercialisation of space-based technolo-

Figure 4. ISS product and service prices (Tkatchova, 2008)

ISS partners	Product/Service	Quantity	Price
ESA	EDR locker	1 locker for 3 months 3 crew hrs & 100 kWh	€830,000
	EDR drawer	1drawer for 3 months 4 crew hrs & 130 kWh	€1,050,000
	basic payload support	1 kg payload	€15,000
	data rate	1 min. TDRSS link	$100
	pressurised up/downmass	1 kg	$22,000
	upressurised up/down	1 kg	$26,500
	additional services	on demand	
	media & commercial	on demand	
NASA	ISPR rack (8 ISPR)	ISPR site per 1year 2880 kWh 86 crew hrs 2.0 terabits	$20,800,000
	external adapter (7 adapters)	1,800 kWh 32 crew hrs 2.6 terabits	$20,800,000
CSA	MDL locker	1 locker for 3 months 2.7 crew hrs. 90 kWh 30 gigabits space-to-ground	$650,000
	1 external pallet site (ExPA)	1 pallet site for 3 months 2.7 crew hrs 50 kWh 30 gigabits space-to-ground 1 min. TDRSS	$650,000
	data rate	1 min. TDRSS link	$100
	pressurised up/downmass	1 kg	$22,000
	upressurised up/down	1 kg	$26,500
	crew time	1 hrs	$15,000
	power	1 kWh	$2,000
RSA	up payload delivery	1 kg	$10,000-$20,000
	down payload	1 kg	$20,000-$30,000
	crew time	1 hrs.	$20,000-$40,000
	power	1 kWh	$1,300-$2,000
	pressurised volume	1 cub.m. per year	$800,000-$1,500,000
	EVA	1 exit	$2,000,000-$4,000,000
	space flight (guest mission)	1 person	over $10,000,000

gies for interplanetary missions. For example, space agencies may even introduce a *combination of different pricing models.* They could have cost-based pricing on the ground and test facilities, break-even pricing could be an option for certain projects, while for others applications, related value-based pricing might be applied.

Space agencies' choice to apply different pricing models will be influenced by the expected direct and indirect benefits from the commercial use of the space-based technology and the results from the cost benefit analyses (CBA).

4.3 JAXA ISS Commercialization Strategy

JAXA strategy for ISS commercialization was different they, JAXA set up an Industrial Collaboration Department with the objective to increase industrial competitiveness, expand space development and utilization, and promote the use JAXA's R&D results. In comparison with the rest of the ISS partners, JAXA started its commercialization activities later and, in 2004, set up the Open Space Lab program to create new business models and projects (Onada, 2008). For example such projects are the Panasonic LED lighting, ASICS space shoes and space yoghurt, that have used the space brand ‘Cosmode’ (Figure 5). This is a brand for product and service spin-offs that were developed under the JAXA Open Space Lab Program.

JAXA launched the “JAXA Cosmode Project” which provides and official brand mark for certified space related products and services. Since its launch there are around 20 certified Cosmode products and services. For example a company can apply for the “Cosmode” brand mark as long as it meets one of the three conditions (Nobuaki Minato, 2010) below:

- Space Certified - products or service which are able to be technically utilized in space with the authorization of JAXA
- Collaboration - products or service to be developed based on joint collaborative activities with JAXA
- Spin-off - products or services to be developed with a licensing contract for JAXA’s intellectual property

In the case a product or service is successfully certified with the “Cosmode” brand, the company offering the product or service with the “Cosmode” brand is required to pay 0.1% of the total sales from the certified product or service to JAXA. The principle used behind economic value creation was in investigating the impact of the “Cosmode” brand upon products prices and linking it with price sensitivity for consumers. Meaning that consumers rate the same product with the brand at a higher price than without the brand (Nobuaki Minato, 2010).

This approach for creating a space based brand *demonstrates* the impact of *branding* on price value of products and services and thus the *impact* on revenues from sales and the generation of direct benefits to companies using the brand.

Figure 5. Japanese space projects (Todome, 2008)

Examples of certified COSMODE products are space underwear (i.e. J-Space), satellite image travel guidance for Japanese tourists abroad and in Japan (i.e. JAL Map) and space tea.

In 2006, JAXA also developed a spin-off system where private companies can use JAXA's patents to develop their own products. Under its spin-off program, house insulation and vibration isolators were created. Furthermore, JAXA launched a Paid Utilization System for using KIBO under which different projects were launched, such as Olympus Camera Mission and the Lotte Xylitol projects and cultural utilization and of flying flower seeds to the ISS.

Companies that have used JAXA patents for developing new products can generate *direct benefits* from sale revenues and the development of new markets. The cooperation for developing new products (i.e. space yogurt, space shoes) brings the company's revenues from sales, new markets, technology innovation and free publicity. The *indirect benefits* are international partnerships and free publicity.

5. SPACE STATION COMMERCIALISATION PROBLEMS

The ISS partners involved in commercialisation quickly realized that offering non-space companies the opportunity to fly their experiments to the ISS required an in-depth understanding of the *targeted markets, segments* and *customers*. They faced the problems outlined in Table 2 that are linked to new market development.

The features described in Table 2 are typical in the development of nascent markets and of early commercialisation processes, as discussed in Chapter 6. The space station was *designed to be a multi-disciplinary laboratory* for scientific needs, not commercial ones. Therefore, clear market segmentation also posed a challenge will be further discussed in Chapter 5.

Table 2. Space Stations commercialisation issues

Unknown ISS markets and customers and benefits from using space-based technology High market risks Failure to understand the complexity of space technology	Commercialisation of a space station initially built for science and not for hosting commercial projects. Competition of terrestrial based technologies
Difficulties in defining the ISS on-board products and services Lack of sufficient funds for promoting space stations Long time for commercial project qualification Long time to market commercial projects	Lack of familiarity of non-space companies with space stations and microgravity environment Hosting ISS facilities built for fundamental research rather than applied one Lack of an global ISS image Complex environment and different ISS partners and ISS modules.

Nevertheless, the different stakeholders face different challenges. On *one side*, the customers are unfamiliar with space stations and microgravity environment facing the problems of an inherited complex environment in which their commercial payloads need a minimum of 6 months to be space qualified. On the *other side*, the space agencies are struggling to identify the markets and customers and to define space station on-board products and services and prices to support the commercialisation of a space station initially built for science and research, not for hosting commercial projects.

The above challenges and issues may be faced once again in case the ISS partners if they decide to launch once again ISS commercialisation in the context NASA new plan to prolong ISS utilisation until 2021.

The challenges that space agencies and end customers will face during the implementation of commercial projects will differ as the targeted markets for future interplanetary space missions may differ from the ISS ones (Tkatchova, Van Pelt, (2008)). As new technologies, processes and products will need to be developed for these programs. Early market segmentation of the targeted markets for the use of space-based technologies for future interplanetary missions will contribute to attracting non-space companies and therefore, non-space company requirements will need to be considered at an *earlier stage of mission phase development*.

6. SPACE STATION LESSONS LEARNED

MIR commercialisation formed the basis for future ISS commercialisation and created very high expectations for the ISS commercialisation success. However, these high expectations *fell apart* as the evolution of ISS commercialisation demonstrated the difficulties and complexity of this process. Describing the difficulties which space agencies, service providers and end customers faced during the early days of commercialisation will prevent similar mistakes in the use of space technology developed for interplanetary technologies (Table 3).

ISS commercialisation was considered as a way to achieve *partial cost recovery* and increase public awareness of the existing *microgravity research opportunities*.

Space agencies had the challenging task of creating a user-friendly environment and reducing regulation, in which non-space companies can develop commercial projects. For example, ESA offered to private companies with ISS commercial projects the opportunity to acquire IPR and marketing rights with which they can develop their own products and services. This approach to commercialisation was normal for the ISS partners as they are public bodies that have no business or commercial experience and therefore, the prime benefits they *foresaw* from commercialisation was ISS promotion and cost recovery.

Table 3. Space Stations lessons learnt

Assuming there is a market and its creation is easy	Space-based research versus terrestrial research (e.g. in the mid 1990s protein growth in microgravity was considered to contribute to the best protein crystal structure, however since several years, similar protein crystals have been grown in terrestrial laboratories)
Assuming technology features will be beneficial (K.Parker, 2008)	Space agencies assumed that ISS on board facilities and closed and controlled on board laboratory environment will be beneficial for research projects of private companies. Space agencies also assuemed that they understood commercialisation and tried to promote the ISS
Top-down market analysis, rather than a bottom-up market analysis	Cost estimates of today are doubled during missions and cost overruns can be expected for future interplanetary space missions
Transforming commercialisation into a political push, focusing on cost recovery and not defining the benefits of the technology	Awareness of space exploration increased as a result of the expected new markets and development of space applications.
Long “time-to market” period for commercial projects	Space stations unknown customers and markets, combined with a lack of historic reliable market data, marketing and sales strategy
Non-space companies misunderstanding the benefits of space-based technologies	Tragic accidents can create negative publicity for a mission and program, such as the Space Shuttle accident in 2003.
Long term planning for the development of commercial projects may be tricky as, as space missions take at least 10 years for success, therefore “time to market” of a product is rather long	Space agencies will have to trade off their monopoly position to a competitive environment

However, one of the most challenging lessons that space agencies learned was that it is very difficult to define a unique selling point (USP) the ISS that will encourage *non-space companies* to use space-based rather than terrestrial technologies.

Bottom-up market analysis combined with clear benefit definitions from the use of present and future space-based technology could bring not only space agencies clear benefits but also result in non-space companies investing in projects and developing new markets.

Companies involved in developing space-based commercial projects will have to develop conservative business cases in order to overcome mission delays and mitigate any potential risks coming from agency budget cuts. In addition, these companies will have to develop business cases in which investors will be willing to invest. Therefore, they will have to qualify the benefits derived from the future commercialisation of space technology for space agencies and non-space companies since future interplanetary missions will contribute to defining a commercialisation strategy for future interplanetray missions or ISS utilisation.

7. BENEFITS FROM SPACE STATION COMMERCIALISATION

7.1. US-Russian Cooperation Benefits

The US-Russian cooperation was considered to be the first step to peaceful space exploration and knowledge exchange after the end of the Cold War and both countries generated different benefits.

NASA's direct benefits were not only in acquiring new competencies, increasing technology reliability and interoperability, but also in achieving cost savings. NASA cost savings were achieved through setting up the foundation for a cooperative purchase of a Russian-built MIR2 module[14] for the ISS, as the labour costs of the Russian-built hardware were much lower than they would have been in the US. Probably NASA had performed a *cost analysis study* and had estimated that the cost for defining, designing and developing competencies and hardware for the future ISS would have been considerably higher. While, the indirect benefits for NASA were in the technology innovation due to learning about life on board space stations and also international partnerships.

For Russia the direct benefits from the cooperation with the US was keeping MIR alive, achieving cost sharing for MIR operations (i.e. covering around 60% of the MIR annual operations) and technology interoperability. Furthermore, this cooperation in a away created new markets for the Roscosmos and kept its aerospace engineers employed. Furthermore, it resulted in the same indirect benefits, as the ones generated from NASA in international cooperation and free publicity.

The final cost for the ISS could have even been doubled due to the US lack of early experience and competencies. The learning curve[15] could have been too long and the complexity effect[16] was going to be too high if the US had to develop the competencies and technologies from zero. Due to this cooperation, the Roscosmos management team became increasingly creative and started developing a new institutional market by offering the use of Russian-built launcher technology and services to NASA, ESA[17] (i.e. ESA taxi flights) and to other space agencies.

7.2. MIR Commercialisation Benefits

The end of the US Russian MIR cooperation in 1996 encouraged the Roscosmos to find commercial projects and set up partnerships with private companies to encourage commercialisation activities. For example initial activities were MirCorp securing private funding for the flights of two MIR cosmonauts.

In 2001, MirCorp was even considering to request the launch of private space stations just for space tourism activities. Nevertheless, the MirCorp vision for the future of space tourism came too early and the markets were yet *not ready* to embrace such innovative concepts for space exploration.

The Roscosmos, MirCorp and Pizza Hut were some of the *first stakeholders* in the MIR commercialisation, gained direct and indirect benefits, such as entering and developing the new markets of space tourism and advertising. The entrepreneurs who set up MirCorp in 1999 saw these benefits. For example for MirCorp the *direct benefits* were in new markets development and revenues from sales and the *indirect* ones were from worldwide free publicity and international cooperation. While, for the Roscosmos the *direct benefits* were sustained employment, cost sharing and revenues from sales of images and the *indirect ones* from free publicity and international cooperation. Pizza Hut also gained direct benefits from its promotion camapaign on board MIR, as it got promoted in Russia and entered new markets and generated revenues from sales and *indirect benefits* from free publicity and technology innovation[18].

MirCorp and PizzaHut gained extensive worldwide publicity due to their innovative approaches in advertising, while Roscosmos gained *direct benefits* from employment as there was sufficient cash to keep its aerospace engineers employed due to the revenues generated from the space adverts. In addition, Roscosmos was able to generate considerable overall cost savings due to private investments.

Russian commercialisation activities demonstrated the potential of space station commercialisation and formed the basis for ISS commercialisation.

7.3. ISS Commercialization Benefits

Inspired by the commercial projects that were successfully developed under MIR commercialization, the ISS partners actively started to support ISS commercialization.

Initially NASA set up the strategy followed by ESA, CSA and the Roscosmos, nevertheless ISS commercialization was a short-lived process of around 5 years.

The ISS markets *did not develop, due to the* unknown first customers, lack of understanding of the microgravity environment by non-space companies and the attempt to commercialize a station which is build for fundamental rather than applied research. Few first-time customers understood the benefits that the microgravity environment and space technology can bring, the long time to market it and the expected high market risks.

For the 5-year period, the ISS partners invested in ISS commercialization, and set up partnerships and commercialization offices that generated just a few commercial projects. ISS commercialization brought benefits to the ISS partners, intermediaries (i.e. partnerships), space companies and end customers. Unfortunately, the *economic impact* and *benefits* to different stakeholders was never identified.

For the *ISS partners* the *direct benefits* were employment and partial cost recovery of the ISS operation variable costs. The indirect ones are technology innovation from non-space sectors, free publicity and international cooperation.

For *intermediaries* the direct benefits were in employment and technology interoperability and indirect the ones were international cooperation and free publicity. While, for the *end-customers* the *direct benefits* were new market developments, revenues from sales and technology reliability and the indirect ones were from technology innovation, international partnerships and free publicity. Finally for the *space companies* the direct benefits were just in technology interoperability and service sales revenues and the indirect ones of free publicity.

End-customers and space agencies generated most of the benefits from ISS commercialization. However, the end-customers faced difficulties in understanding the complexity of the environment, the payload qualification process and finding the patience to launch commercial projects to the ISS.

Unfortunately, due to complex role which intermediaries (i.e. partnerships) played as service providers and the nascent stage of ISS markets development (S.Tkatchova, M. Pelt (2008)) they generated the least benefits and were the *least motivated* to encourage the development of ISS markets. Therefore, if space agencies want to further promote commercialization of space technology, they will need to encourage the *definition* and *measurement* of direct and indirect benefits from the use of space technologies for all stakeholders.

Therefore, if ISS commercial utilization is to be considered once again the direct and indirect benefits from commercialization of space technology has to be taken under account once again. As their definition will contribute to the space agencies' commercialization strategy definition and support companies to develop new market and attract of funding for their commercial projects.

7.4. Market Trends

In 2008 a financial crisis hit the world economy and most national economies entered a phase of economic downturn that continued through to 2010. The financial crisis hit the US first, followed by an economic stagnation in the EU-27 zone and Russia. In 2011, some of these countries were experiencing increased unemployment and inflation, similar to the processes taking place in the early 1990s with Central-Eastern European countries.

Economic slowdown will impact governments R&D investment in space programs and the future of global space industries, as *space budgets may be cut* at least by half and space missions with high long-term costs for design, development and operations may *be cancelled* (i.e. as the Obama administration did at the beginning of 2010 with the US Constellation program), thus limiting space exploration only to LEO and the development of navigation or earth observation systems.

Governments that have bailed their banks in financial difficulties will *reduce their investments* in national space programs, as they will not *foresee* direct benefits from human-spaceflight and interplanetary missions. Therefore, navigation and earth observation missions may be the only projects to see their budgets sustained, as these types of space missions bring immediate and measurable benefits for national economies and societies. *Reduction* of space budgets will encourage space agencies to attract research projects from non-space companies and aim at reducing their mission costs by a factor of 2 to 5 (Wertz, 2008, October 27) increase the benefits of their space-based research and implement commercialization strategies for increased space technology utilization.

The *lack of clear benefit definitions* may reduce sufficient political, strategic and financial support for the development of heavy launchers, future Mars and asteroids missions and may even be one of the *prime reasons* for cancelling the program. As decision makers will face difficulties in justifying human space flight activities.

For example, the US Government in its desire to attract long-term funding for the development of commercial cargo transportation vehicles may also attract the US defense and security department and future commercial launchers will serve the needs both of civil and military customers and have *dual use* of the future technologies.

8. DISCUSSION

MIR and ISS commercialization were processes innovative for the space industry and ones that created awareness of human space-flight. ISS commercialization encouraged the development of new markets, the launch of the first space tourists to the ISS and encouraged the development of new industrial applications. Space agencies involved in space stations commercialization quickly realized that offering non-space companies the opportunity to fly their experiments to the ISS required an in-depth understanding of the *targeted markets, segments and customers.*

Space station commercialization was a learning curve for the ISS partners and they learned numerous lessons. *One* of them was that non-space companies are not ready to provide funds for helping agencies achieve their cost-recovery objectives. As for private space companies, space agencies are usually the end-customer. *Second* is that top-down market analysis, unknown customers and markets, the complexity of the relationship with space agencies, and the lack of a long term vision, may be confusing for customers. *Third* that a space station build for fundamental research can hardly be commercialized as companies (i.e. pharmaceutical ones) are interested in performing applied research. *Finally,* competition from *terrestrial technologies* may discourage customers to launch commercial projects using space-based technologies.

Space agencies involved in the commercialization of space technology need to address the above challenges, encourage the creation of a competitive environment, and set up a user-friendly environment that encourages the entrance and dominance of market forces free of regulation, rather than political ones. Flexible pricing conditions, IPR rights, tax benefits bottom-up market analysis combined with *clear benefit* definitions from the use of present and future space based technology may encourage companies to become more involved in these processes.

Companies involved in developing space-based commercial projects may have to develop *conservative business cases* in order to overcome mission delays and secure the integration of their user requirements in the early phases of space missions. The companies involved in commercial projects will have to develop business cases for which investors will be willing to invest. Therefore, they will need to *qualify* the *benefits* for space agencies and non-space companies from future commercialization of space technology for future interplanetary missions and contribute to defining a commercialization strategy for future missions.

9. CONCLUSION

The economic transition of the Soviet Union led to symbolic space budgets and to putting a huge financial strain on Russia to keep the MIR station operational. A challenging task by itself as the annual operating costs for MIR corresponded to around 220 Million USD per year. So, initially, the US-Russian cooperation kept the MIR alive and both space agencies generated benefits from it. NASA developed unique competencies in human space-flight and Russia secured the funding to keep MIR operational. NASA's direct benefits were not only in acquiring new competencies, increasing technology reliability and interoperability, but also in achieving cost savings. While the Russians kept MIR alive, they achieved cost sharing for MIR operations, technology interoperability with the Shuttle and developed new markets and kept their aerospace engineers employed. In addition they gained indirect benefits including international cooperation and free publicity.

Pizza Hut advertisements on the Proton launcher and pizzas cooked on board the MIR, were some of the examples of how the Russians started their space stations commercialization. Unfortunately, MIR commercialization started too early for the market and the space agencies to grasp the concept of space technology commercialization and space tourism.

These pioneering attempts were quite chaotic, but became the basis for future ISS commercialization.

ISS commercialization was initiated by all the ISS partners and the commercial projects were few, but encouraged the development of new markets and space agencies to change their industrialization policies and strategies and develop the concept of space brands. Thus, not only demonstrating the potential of space technology, but also the impact space brands can have on the price of a product or service as in the case of the Japanese Cosmode brand.

The ISS partners faced unknown markets and customers, difficulties in defining the ISS on board products and services, lack of additional funds for space stations promotion and lack of end customers who understand the environment. Features are typical for nascent market and new commercialization processes. However, one of the most challenging lessons that space agencies learnt is that it was very difficult to define a *unique selling point (USP)* and *to* encourage non-space companies to use space-based *rather than terrestrial technologies.*

ISS partners had very high expectations from commercialization and these fell apart as the ISS commercialization evolution demonstrated how difficult and complex it is.

Unfortunately, the *economic impact* and *benefits* to different stakeholders from MIR and ISS commercialization was never measured. Nevertheless, the ISS commercialization brought *direct benefits* to the ISS partners including sustained employment (i.e. Russia) and partial cost recovery of the its operating variable costs and indirect ones, such as technology innovation from non-space sectors, free publicity, and international cooperation. For the end-customers, the *direct benefits* are new market development, revenues from sales and technology reliability, while the *indirect ones* are technology innovation, international partnerships and free publicity.

The global economic crisis that hit the worldwide economies may result in *space budget* and *space mission cancellations,* therefore identifying benefits from the use of space based technology may contribute to preserving the levels of space budgets.

Quantifying the benefits for space agencies and non-space companies from future commercialization of space technology for future interplanetary missions will contribute to defining a commercialization strategy for future missions, new market development and the attraction of funding for commercial projects.

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ENDNOTES

[1] Commercial companies can use space technology as an infrastructure utility. They can keep the IPR rights from their projects and also have the option to buy marketing rights. The rights can be different types, full rights for 100% investment or shared ones.

[2] Certain authors (Pike, 2008) discussed the initially planned three phases of the Russian-American cooperation in the context of the future International Space Station (ISS). In Phase One (1994-1997), the US was planning to pay around $400Million to Russia for the support of at least ten Space Shuttle missions. Phase Two was for the launch of the MIR Core module and Phase Three was the launch of the ESA Columbus Module and the Japanese KIBO module to the ISS.

[3] The Space Shuttle flights are of around two weeks and do not permit longer stays in microgravity.

[4] In 1993, NASA had unique and extensive experience with the Space Shuttle, but the only space station experience it had was the Skylab. Skylab was launched in 1973 with three astronauts visiting it for missions from 28 up to 56 days and a lifetime of 86 days (AIAA, 2008)

[5] By future US initiatives, NASA takes under consideration the International Space Station (ISS) which was the US idea for establishing a permanent habitat in space. The idea was that of the then US President Reagan in 1985 and it was conceived in response to the Russian MIR station. The construction of the ISS started in 1998 and the final assembly finished in 2010.

[6] The US budget for the cooperation with the Russians covered around 60% of the MIR operating costs per year and thus, contributed to keeping MIR operational.

[7] For example in 1988, as a result of the Intercosmos program Alexander Alexandrov the second Bulgarian cosmonaut performed 14 experiments on-board the Mir station.

[8] The ISS partners are NASA, FSA, JAXA, ESA and CSA.

[9] In 2000, NASA's ISS Exploitation budget resulted in 60% cost overruns as a result of which, in 2001, ESA froze a part of the ISS Exploitation budget (Tkatchova, (2006).In 2000, the initial costs for the design, development and operation of the ISS corresponded to around $40 Million. However by 2006 the ISS partners estimated that total ISS costs correspond to a magnitude of a $100Million.

[10] ISS resources include the facilities, such as the Fluid Science Laboratory (FSL), the Material Science Laboratory (MSL), Biolab or the European Drawer Rack (EDR).

[11] Commercial projects that are flown on board the ISS are payloads that need to be tested and qualified for payload safety to ensure that it can withstand the launch itself and that the payload is safe for the crew and systems on board.

[12] Osteoprotegerin activity on animals and humans is regulated by gravity.

[13] Marginal cost pricing is based on setting a price based on marginal costs which are the incurred costs by space agencies for flying a commercial payload.

[14] The ISS Zarya module was initially built for the MIR2 station and was launched in 1998 as the first module of the International Space Stationof (ISS).

[15] The learning curve theory is measured by the learning effect which is applied to the recurring costs in a project. The idea is that, as the quantity produced doubles, the cost is reduced by a percentage, referred to as learning factor.

[16] The complexity effect occurs usually when new technology is designed, developed and built. There are various levels of complexity factors - C where the cost=(1+C) times based on historical data. For example, off-the-shelf technology with minor modifications has a complexity factor of 0-0.2. While, the basic design exists and there are few technical issues, so there is 20% innovation and has a factor of 0.3-0.5. In the case of the ISS since it would have been new design development and qualification and achievement of major technological developments, the factor could have easily reached 1.6-1.9 (Ralf Huber, 1999).

[17] The US-Russian cooperation became the ancestor of the ESA "Tax-Flight" agreements the Soyuz flights to the ISS with European astronauts. ESA "Taxi-flights" increased after the Columbia accident in 2003. As when the Shuttle was grounded for more than a year ESA had to access the ISS through the so called one week Taxi Flights.

[18] At the time Pizza Hut had a pizza delivered on board the MIR station in microgravity and the crew cooked it in the microwave of the station.

Chapter 4

Space Industry Market Trends

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"Markets can be analysed, described and compared, but most of the time they remain unpredictable."

1. INTRODUCTION

Space industry provides navigation, telecommunications and earth observation services essential for our day-to-day lives. The analysis of the market trends in the space industry will provide a better understanding of the industry and the trends taking place.

Market trends analysis in the space industry will provide an understanding of the challenges facing the global space industry. The industry encompasses several market segments, such as Telecommunications, Earth Observation, Navigation, Human Space-Flight and Interplanetary Exploration segments.

This chapter will present an overview of the space industry stakeholders, market trends in the telecommunications, navigation and launcher segments and in general national space industries (i.e. Europe, Russia, Japan, etc.). In addition, it will discuss the benefits of interplanetary human and robotic exploration for national space industries.

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2. SPACE INDUSTRY STAKEHOLDERS

Space industry stakeholders are national space agencies, system integrators, subsystem suppliers, equipment suppliers, service and ground support companies. The customers in the space industry are classified into institutional and commercial ones.

The *institutional* ones are national and intergovernmental civil space (and defence), meteorological agencies (i.e. EUMETSAT, NOAA). Today, agencies such as NASA in the USA, Russian Federal Space Agency (i.e. Roscosmos) in Russia, ESA in Europe, JAXA in Japan, ISRO in India, are responsible for the majority of space programs.

The *commercial customers* in the space market are commercial satellite operators and launch service providers. Commercial satellite operators are often referred to as telecommunications operators and are specialised in satellite operations and the provision of communications, broadcast and mobile personal and professional communications. These are companies such as InmaRoscosmost, Eutelsat, SES Astra and Intelsat. There are also *launch service operators* that integrate and operate to provide commercial launch services to institutional and commercial customers. Launch service providers are companies such as United Launch Alliance (ULA), Arianespace, and International Launch Services or Sea Launch.

The *suppliers* in the space industry are system integrators, subsystem suppliers, equipment suppliers, as well as service and ground support companies.

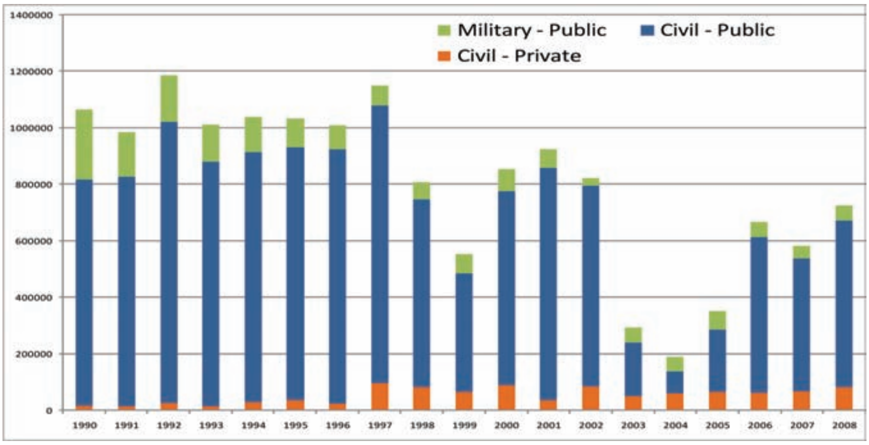
System integrators are the companies that have the competencies and knowledge to design, develop and integrate a complete space satellite. These are companies such as Lockheed Martin and Boeing in the USA, and EADS Astrium and Thales Alenia Space (TAS) in Europe.

Subsystem suppliers are companies that design, develop and produce space-based subsystems (i.e. solid booster, solar generator, engine, etc.). *Equipment suppliers* are companies that develop and produce equipment for the successful integration of space systems and subsystem levels (solar cells, EEE components, valves, mechanical parts, software suppliers). *Services and ground support companies* are companies that provide ground system design, development, manufacturing, operations of non-commercial systems (including raw data sales from EO satellites), and engineering services (ASD- Eurospace, 2008)

Figure 1 presents an overview of the spacecraft mass launched by civil, military and commercial customers from 1989 until 2008 (ASD-Eurospace, 2009, LEAT database).

Civil and military space agencies are the *biggest institutional market* for space companies. After a space agency procures a satellite, the system integrators, subsystem and equipment suppliers start the satellite manufacturing process. Once the satellite is ready to be launched, the launch service providers are responsible for

Figure 1. Civil and commercial customer launches (1989-2008) (Courtesy of ASD-Eurospace, 2009, LEAT database)



launching the satellite. Then, when the satellite is in orbit, the commercial satellite operators start selling telecommunications services to the end-users. Finally, their services result in downstream applications that could be in the provision of telecommunications or navigation services provision.

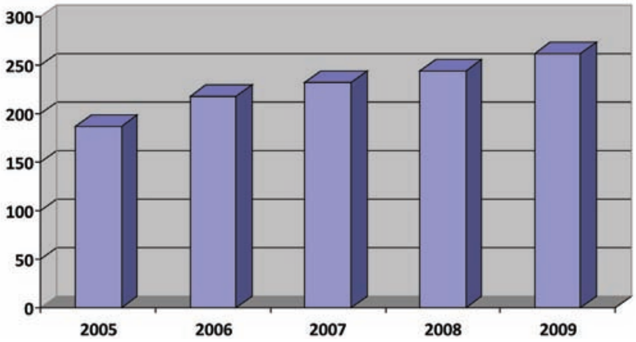
3. SPACE INDUSTRY ACTIVITIES

The space industry encompasses several market segments such as Telecommunications, Earth Observation, Navigation, Human Space-Flight, and Science Exploration missions However, measuring space industry revenues from the different sectors often poses a challenge to space analysts due to the lack of definitions of space activities, standards for defining the quality of data and consistent data availability[1].

For example certain reports (The Space Foundation, 2009) include international government space budgets, US government space budgets, space commercial transportation services, commercial satellite services, infrastructure support industries and commercial infrastructure services (see Figure 2). Commercial transportation services include revenues from the launch industry, while commercial satellite services include revenues from Fixed Satellite Services (FSS), Mobile Satellite Services (MSS) and Satellite Radio and Direct-to-Home Television (DHTV).

For 2009 the revenues from commercial satellite services represented 35% of the global space activities, followed by the ones from the commercial infrastructure that corresponded to around 32%. The revenues from the commercial satellite services (i.e. FSS, MSS, etc.) are of importance from the telecommunication services

Figure 2. Growth of global space industry activities 2005-2008 (The Space Foundation, 2010)



perspective for the space industry. Thus, demonstrating how beneficial would be the development of new space applications from other segments of space industry. That may result in similar developments and lead to increased *revenues from sales, new market developments (direct benefits)* and bring *technology innovation (indirect benefits)* to commercial satellite operators and end customers.

4. TELECOMMUNICATIONS

The satellite telecommunications market is the most commercial one and includes commercial and operational systems for video, data, and voice services provision. News and sports events on TV or radio are mainly transmitted via telecom satellites. Telecommunication services are widely used for tele-education, telemedicine, disaster management and security applications. The total revenue from commercial satellites has been estimated to be $91 billion (The Space Foundation, 2010).

Digital Broadcast Services (DBS) include direct-to-home television and satellite radio services, Fixed Satellite Services (FSS) include telephone, data, and video services and Mobile Satellite Services (MSS) provide telephone, voice and data services.

The telecommunications market is a growing market and new applications, such as High Definition Television (HDTV) and satellite radio are being developed. Communications market represents around 414 satellites with a turnover of around $ 72 Billion of which 234 communication satellites in GEO and HEO orbits and have a value of around $52.5 Billion and 134 satcoms in LEO and MEO orbits (ASD-Eurospace, 2010). This telecom growth has encouraged the development of new telecom satellites, such as the European Hylas-1, satellite that is going to carry an adaptable payload which will allocate bandwidth depending on the different geographical regions and in response to telecom traffic demand.

In 2010 some of the aged telecommunications satellites are planned to be replaced. In the beginning of 2010 Thales Alenia Space (TAS) won the contract for building and replacing the Iridium satellite constellation.

The growth of the satellite communications market has a strong impact on the launch industry, the launch technology evolution, and the market positioning of commercial satellite operators that offer services to end users.

Table 1 shows a comparison of commercial satellite operators and satellites in orbit.

In March 2010, SES had the highest number of satellites (i.e. 39 satellites in orbit) and is followed by Intelsat and Eutelsat, thus demonstrating that European companies are *leaders* in the telecommunications market. For example, in 2007 satcom TV reached 95 Million households worldwide and revenues reached up to $59 Million for 2007 (Ramos, E.(2008)) and subscribers for satellite TV are expected to reach up to 180 million by 2017. Furthermore, in Europe, the European Commission has launched a Space Call for encouraging the communication in S-band bandwidth. Furthermore, in the following years Globalstar is expected to launch a new generation of 48 mini satellites and Iridium to upgrade its satellites (ASD-Eurospace, 2009). By the end of 2010, a new constellation of 16 mini satellites referred to as O3b will be launched.

Table 1. Commercial satellite operator revenues and satellites in orbit (ESPI, 2008, ASD-Eurospace, 2010)

Company	Country	2007 revenues in US dollars	2008 revenues in Euros	Satellites in orbit	Satellites on order
SES	Luxembourg	2370	1610	37	9
Intelsat	Bermuda/USA	2200	1480	54	4
Eutelsat	France	1240	830	24	6
Telesat	Canada	684.7	464	12	3
Inmarsat	UK		390		
JSAT Corp.	Japan	347.4		8	3
Star One	Brazil	207.4		7	0
Hispasat	Spain	188.4		3	1
Singtel Optus	Australia	172.2		4	1
Russian Satellites Communications Co.	Russia	161		11	3
Space Communications Corp.	Japan	151.4		4	1

The *business model* used by the satellite communications companies is different from the one used by the system integrators or equipment manufacturers in the space industry.

In the telecommunications industry, the *wholesalers* provide the bandwidth capacity (also referred to as commercial satellite operators) while the *retailers* provide the services, such as Direct-To-Home TV or Digital mobile broadcasting of radio. The business logic behind the wholesale and the retailer activities is different. For example, the *wholesalers* maximize the price per transponder or per MHz or per Mbps, in contrast to the *retailers* that maximize the number of subscribers as presented in Table 2. In some cases wholesale and retail are performed by the same companies.

The business logic behind the wholesale and retail activities may also be applied for the services expected from the future navigation system Galileo or the expected GMES services[2], as this approach will bring direct and indirect benefits to the different stakeholders in the navigation market. Once the Sentinels satellites start to provide GMES services they can be used for geo-information data for land use, spatial planning or maritime security, oil spill prevention and disaster management. For example wholesalers using Galileo or GMES services may develop their business model through aiming at developing new markets and through generating revenues from sales (i.e. direct benefits), while, for the retailers, the direct benefits will be in cost savings and increased revenues from sales of their services. The wholesale companies indirect benefits are from technology innovation, while for

Table 2. Global satellite telecommunications stakeholders (Ramos, 2008)

	The Wholesalers (capacity providers)		**The Retailers (vertically-integrated service providers)**		
	Fixed Satellite Services (FSS)	**Mobile Satellite Services (MSS)**	**DTH TV broadcasting**	**Digital mobile broadcasting (DAB/DAM)**	**Broadband Access (BB)**
Number of companies	33 (SES, Intelsat, etc.)	6 of which (InmaRoscosmost, Thuraya, MSV with GEO sat.) And (Iridium, Globalstar, Orbcomm with LEO sat.)	2 US companies (Direct TV, Dish TV)	2 US Radio companies (XM Radio, Sirius)	2 US companies (Spaceway, WildBlue)
2007 Revenues	$8.5 billion	$1.18billion	$23 billion	$3 billion	$100 million
Newcomers	Around 5 (Protosat, Newsat, Vinasat, etc.)	2 (ICO & TerreStar)	none	At least 5 (CMB Sat, Ondas, S2M, Solaris, WorlsSpace Europe)	3 (Viasat, Eutelsat, Avanti)

retail they are on new markets and technology interoperability (direct benefits) and international partnerships (indirect benefits).

These are the positive developments in the telecommunications market, however there are also negative ones, such as space debris, signal jamming problems and signal pirating problems[3], or increased competition from terrestrial technologies as in the case of Iridium in the later 1990s[4], when satellite telephones were overtaken by the fast boom of mobile telephones.

Communications satellites are becoming exposed to the real threat of *space debris.* Issues with space debris are becoming quite concerning as already by 2007, it was estimated that there were 35,000 parts of space debris in LEO of at least one centimetre in diameter (ESPI, 2007), draft version).

The increase of space debris accidents, such as the collision of the US and Russian satellites on the 10th of February 2009 became an increasing concern for space agencies. Space debris is a major threat to LEO and GEO satellites, the Space Shuttle flights and the International Space Station (ISS). As Telecommunications, Earth Observation, Navigation satellites and the International Space Station, could be damaged, thus resulting in huge losses of hardware, public investment and even human lives. Therefore, one of the cases described in Chapter 9 will be about space debris monitoring and mitigation.

Thus, commercial satellite operators and retailers can generate *direct economic benefits* such as new market development, revenues from sales, technology interoperability and reliability and technology innovation and free publicity *(indirect benefits).*

5. NAVIGATION

Navigation satellite based services are a growing area of satellite services. Navigation systems provide for time, positioning and integrity information. The first navigation system, the GPS, was created in the early 1980s by the US military to meet the positioning needs of the military. However, in the 90s the later on they provided worldwide free access to the GPS signal.

Navigation systems are widely used for air traffic management, rail and maritime navigation, oil platform positioning, location-based services for disabled people, precision agriculture and leisure activities.

The navigation market is a fast growing market for both receivers and value added software and services. Navigation services have become so widely used that today certain mobile telephones have integrated GPS receivers. The products and services in the navigation markets have become quite complex and therefore, tracking direct benefits such as revenues from sales or new market developments is difficult.

The Galileo revenue estimates are very high with expectations in the order of 300 Billion Euros for worldwide markets by the year 2020 (L.E.K., 2009) (including services, receivers, satellite systems and value added downstream applications). Navigation stakeholders include national governments, navigation service providers, receiver manufacturers, software developers and value-added service providers. The operations for most of the navigation systems are planned to be managed by institutional organisations, except for the Japanese QZSS systems which is going to be managed by joint public private partnerships. The operations of the future Japanese QZSS may be exposed to similar problems which the failed Galileo PPP faced, such as private companies not willing to carry the market risks from operating a government built system.

Future stakeholders will need to investigate the market penetration rate of Galileo in comparison with GPS.

Today in 2011, only the US-based GPS and Russian GLONASS are fully operational. At present, there are only two test satellites Giove-A and Giove-B operational from the European Galileo system as presented in Table 3.

With the expected launch of the European Galileo system in 2013 and the Japanese QZSS in 2012, it is possible that the *technological* and *market competition* between different countries to increase. This competition will influence the navigation stakeholders and encourage the creation and growth of new navigation-based applications from which they will generate direct benefits.

Navigation stakeholders can also generate direct and indirect economic benefits from the typical features of navigation markets. These are features such as

Table 3. Global navigation systems (ESPI, 2008; Kazuhide, 2009)

Country	USA	Europe	Russia	Japan	India	China
System	GPS (military)	Galileo (civil)	GLONASS (military)	QZSS (civil)	IRNSS	Compass-M1 Beidou
Coverage	Global	Global	Global	Global 1 satellite near zenith over Japan to be used with US GPS	Global	Global
Operational	1995	2013	1982-2010	2010	2012	2007
Number of satellites	24+2	27+3	24	3/7	7	30 MEO 5 GEO
Operations managed	Department of Defence	Galileo Control Centre	Russian Forces	Joint Government Private Program	IRNSS Navigation and Space-craft Control Centres	China Satellite Navigation Project Centre

interoperability between different navigation systems (i.e. GPS, Galileo, QZSS), independant navigation systems[5], technology *interoperability*[6], common *standards* and *international cooperation*. Interoperability is of crucial importance due to needs for coordination of frequencies and services between different navigation systems, such as Galileo and the Chinese Compass-M1. Having an independant navigation system from the US is one of the prime reasons that Europe launched the Galileo program. Furthermore, the new 2010 national policy of the US recognizes the importance of cooperating with other GNSS providers in order to encourage *compatibility* and *interoperability* of civil service provision and enable market access for the US industry (National Space Policy, 2010). Thus, US companies will generate direct benefits from *entering new markets and generating revenues.*

These *direct benefits* can be experienced by navigation service providers when they enter new markets and develop navigation-based applications. Manufacturers of receivers and service providers will generate technology *interoperability* due to the existence of several navigation systems and the technological requirements for common software standards. Other *indirect benefits* for service providers, receiver producers and software developers will be *free publicity* and *international cooperation*.

Producers of navigation receivers and value added software could generate direct and indirect benefits and in the future they will be the ones developing new solutions for Lunar and Mars space missions. Thus, they will be able to generate *technology innovation (indirect benefits), reliability and interoperability (direct benefits),* developing *new markets, generating revenues (direct benefits)* whilst gaining *free publicity and international partnerships (indirect benefits)*.

6. LAUNCHERS

National launch capabilities have always been a luxurious commodity reserved for the richest and most technologically advanced nations. During the Cold War having launch capabilities was a *symbol* of technological, engineering, and *scientific superiority*. As a result of this political competition, two countries became the leaders in the construction of human-rated launchers and technologies.

The end of the Apollo era was marked with the retirement of Saturn V (see Figure 3) and the Apollo vehicle. Unfortunately for the Americans, the Nixon administration had decided to build the Space Shuttle, a reusable but costly vehicle that provides fourteen days of microgravity conditions for human space flight research in microgravity. However, this decision completely changed the direction in which the US was developing its competencies and forty years later resulted in loosing interplanetary exploration capabilities and competencies. If the US had continued Lunar exploration, maybe even at a more irregular rate, it is possible that by 2009

Figure 3. Saturn-V

they would have already built a Lunar base and solar energy generating lunar farms. However, launch costs seemed too high for the US administration to pursue it at the time (see Chapter 2).

Nearly fifty years after Gagarin's flight, new nations such as Europe, Japan and China have also developed human-flight competencies and capabilities for operating on board space stations, but have not developed their own human rated launcher, except for China.

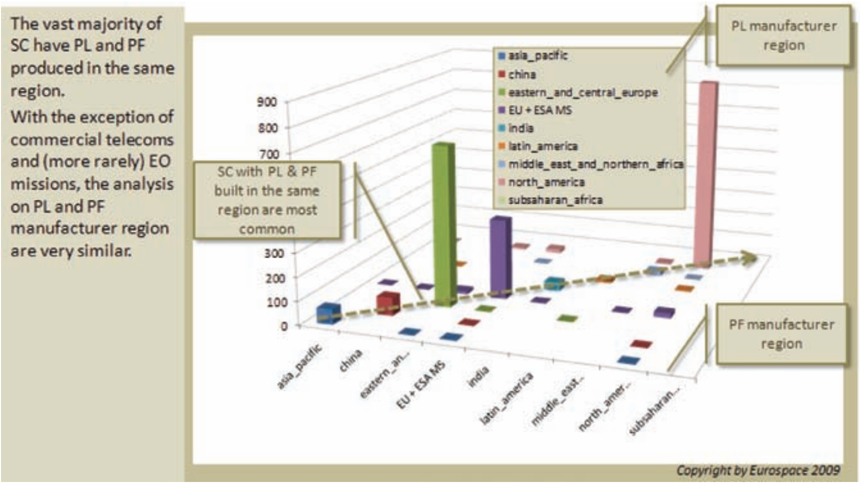
6.1. Public and Private Customer Launches

The customers in the launch industry define the market trends in the industry. In the last 10 years the evolutions of the telecommunications market resulted in an increase of commercial (i.e. private) customers for launch services. Public civil customers are civil space agencies (i.e. national, multi-national ones), such as NASA, ESA or universities, while public military customers are national ministries of defence or defence agencies.

Launchers are primarily adapted to the needs and requirements of the public customers rather than commercial ones since the institutional market for launch represents the majority of total launch activity (around 90%). Nevertheless the establishment of the NASA COTS program (see Chapter 1), the successful development of low-cost launchers, and the expected demand for telecom services, may result in the increase of commercial launches, and the adaptation of launch systems[7] to the needs of private customers.

US, Russian and European launchers are at the forefront of the launch market. In 2009 127 satellites were launched, from which Russia (50), US (34), Europe (14) and Japan (10) as presented in Figure 4 (Source: Eurospace LEAT 2010 ed.).

Figure 4. Spacecraft and payload manufacturers by region (ASD-Eurospace, 2009, LEAT Analysis, 2009)



The vast majority of SC have PL and PF produced in the same region.
With the exception of commercial telecoms and (more rarely) EO missions, the analysis on PL and PF manufacturer region are very similar.

SC with PL & PF built in the same region are most common

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Russia and Europe are the prime nations providing commercial launch services. The geostationary launches represent around 16 up to 22 satellites per year, small satellites in LEO around 2 up to 4 ones and micro-satellites around seven up to eight (Fillon Report, 2009).

Arianespace has captured in excess of 50% of the accessible commercial launch market (Fillon Report, 2009). Actually the Ariane launcher family began operations in 1979 as a solution to provide Europe with independent access to space. Eventually Ariane managed to capture a large share of commercial launch services to the Geostationary orbit (GEO), a market that US launchers failed to address after the US administration decided to focus all efforts on the Space Shuttle for all launch needs.

Russia became a leader in commercial satellite launches only as a strategy to compensate after the fall of the Soviet Union the lack of sufficient funds to support launch operations and maintenance. Today in 2010, Europe and Russia are not only leaders in commercial satellite launches, but have set up a strategy for *diversifying* the launch services provided from Europe's space port in French Guyana.

Arianespace has developed a "launch services supply" which includes the provision launch services with three launch vehicles; Ariane 5, Soyuz and Vega. Thus, offering the opportunity to its customers to have a choice of launchers. Nevertheless, European institutional customers (i.e. ESA, Eumetsat, CNES, DLR, etc.) are not obliged to use European launchers, differently to their US and Russian counterparts.

Clearly the Americans have missed the *opportunity* of commercial satellite launches and just recently started to explore these new areas with encouraging commercial launch services through the NASA COTS program. The US has finally realized the importance of developing of commercial launch services and therefore have actively started to support commercial launch services and companies like Space-X and Orbital. Commercial launches may increase only if the space tourism market develops and launch costs may come down, due to "economies of scale."

Companies like Virgin Galactic are aiming at developing sub-orbital vehicles as White Night Two that may potentially be used for the launch of micro-satellites in addition to space tourism, thus aiming at generating *economies of scale* from numerous subscriptions for sub-orbital flights.

The launch industry will directly benefit from increased revenues from sales and the *new launch market* from space tourism and also future Mars, asteroid missions will open up. In addition, launch service providers will gain direct benefits from *technology reliability* and *interoperability*. Free publicity, technology innovation, and international cooperation will be the *indirect benefits* generated in the industry.

6.2. Launchers Overview

Launchers can be grouped into two main groups, human-rated and automatic. The human-rated ones are the Space Shuttle, the Soyuz and the Long March ones (see Figure 6), while the others can be sub-grouped by orbit and the mass they provide, such as the European Ariane 5 for GTO (see Figure 7), the Russia Proton for LEO and the American Athena 2 for LEO (see Figure 6).

The overview of the average launch events, the human-rated and satellite-rated launches for the last 20 years is required for a better understanding of the market trends in the launchers market.

In the last 20 years, the average launch rate has been 78 launches per year (ASD-Eurospace, 2009).

There have been only 67 launch failures for the last 20 years on a total of 1,568 launches. For the last 20 years, on average, 810 tons of payload mass have been launched in orbit with around 65% of it returning to Earth with the space shuttle.

Human space-flight launches represent less than 10% of the total launches per year, but with the future development of future commercial crew transportation services the percentage of the total launchers may increase.

Unmanned launches represent around 90% of the total launches since 1990. Nevertheless, the human space flight contributes to the biggest mass of payloads launched to the ISS (International Space Station) corresponding to around 281 tons of hardware launched to MIR or the ISS for the last 20 years. However, with the finalisation of the ISS construction in 2010 the launched mass to the ISS will reduce, as already the US, Russian, European (i.e. ISS Columbus module) and Japanese (i.e. ISS KIBO module) modules of the space stations are launched and successfully assembled.

Figure 5. Launch events for the last 20 years (ASD-Eurospace, 2009; LEAT Analysis, 2009)

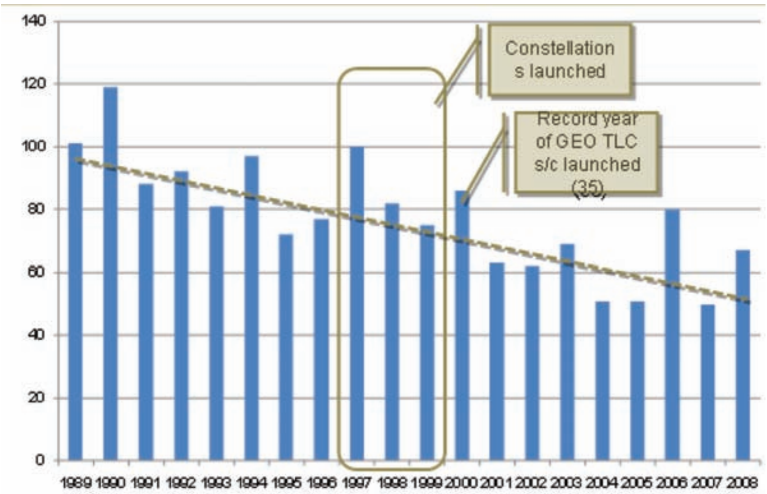
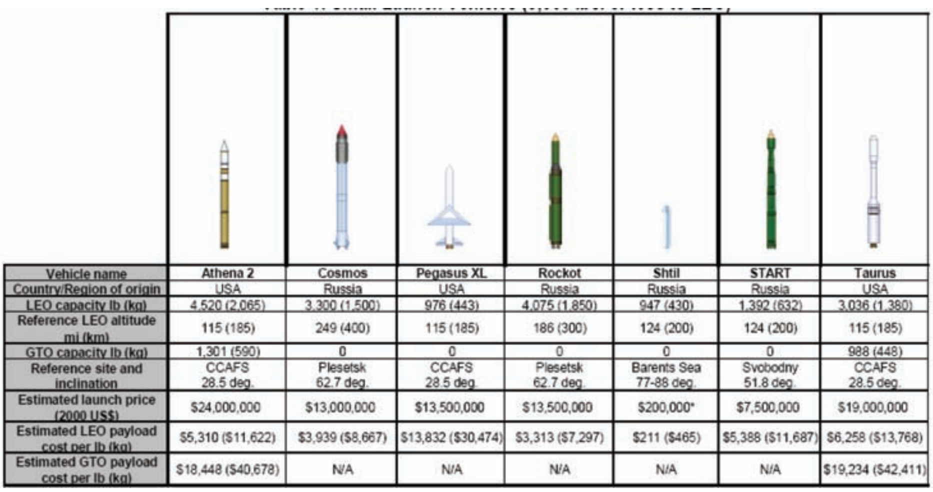


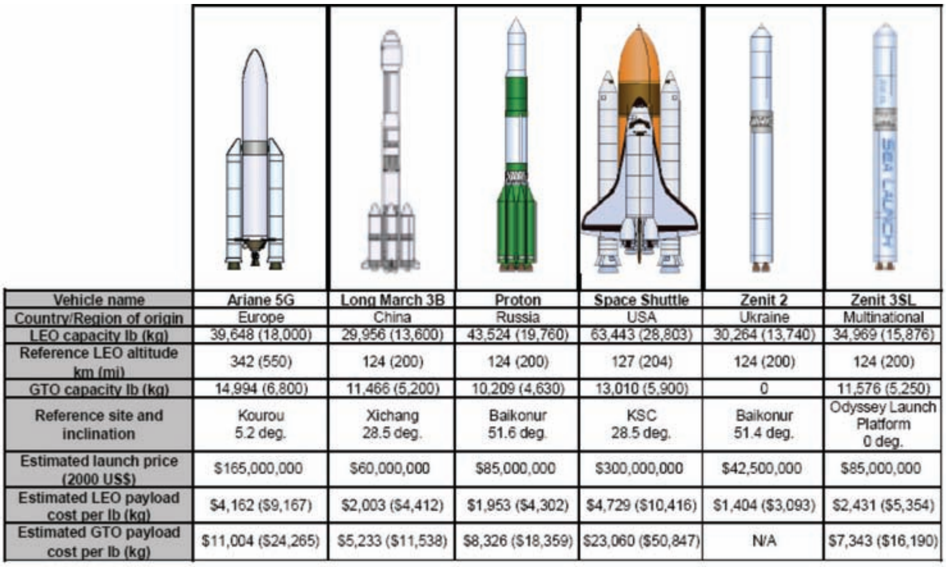
Figure 6. Launchers by LEO orbit, mass and price per kg of payload (Futron, 2002)



Vehicle name	Athena 2	Cosmos	Pegasus XL	Rockot	Shtil	START	Taurus
Country/Region of origin	USA	Russia	USA	Russia	Russia	Russia	USA
LEO capacity lb (kg)	4,520 (2,065)	3,300 (1,500)	976 (443)	4,075 (1,850)	947 (430)	1,392 (632)	3,036 (1,380)
Reference LEO altitude mi (km)	115 (185)	249 (400)	115 (185)	186 (300)	124 (200)	124 (200)	115 (185)
GTO capacity lb (kg)	1,301 (590)	0	0	0	0	0	988 (448)
Reference site and inclination	CCAFS 28.5 deg.	Plesetsk 62.7 deg.	CCAFS 28.5 deg.	Plesetsk 62.7 deg.	Barents Sea 77-88 deg.	Svobodny 51.8 deg.	CCAFS 28.5 deg.
Estimated launch price (2000 US$)	$24,000,000	$13,000,000	$13,500,000	$13,500,000	$200,000*	$7,500,000	$19,000,000
Estimated LEO payload cost per lb (kg)	$5,310 ($11,622)	$3,939 ($8,667)	$13,832 ($30,474)	$3,313 ($7,297)	$211 ($465)	$5,388 ($11,687)	$6,258 ($13,768)
Estimated GTO payload cost per lb (kg)	$18,448 ($40,678)	N/A	N/A	N/A	N/A	N/A	$19,234 ($42,411)

Europe's Ariane 5 is the only heavy launcher for commercial needs and it also has dual launch capabilities (AIAA, 2009). The US launchers Delta and Atlas 5 are allocated for institutional launches. The *prime competition* of Ariane comes from Russian launchers (AIAA, 2009). Ariane competitiveness is built up *reliability, competitive prices*, *respond to market needs* and *sustain engineering competencies*. However, with the expected future developments of US commercial transportation

Figure 7. Launchers by GTO orbit, mass and price per kg of payload (Futron, 2002)



Vehicle name	Ariane 5G	Long March 3B	Proton	Space Shuttle	Zenit 2	Zenit 3SL
Country/Region of origin	Europe	China	Russia	USA	Ukraine	Multinational
LEO capacity lb (kg)	39,648 (18,000)	29,956 (13,600)	43,524 (19,760)	63,443 (28,803)	30,264 (13,740)	34,969 (15,876)
Reference LEO altitude km (mi)	342 (550)	124 (200)	124 (200)	127 (204)	124 (200)	124 (200)
GTO capacity lb (kg)	14,994 (6,800)	11,466 (5,200)	10,209 (4,630)	13,010 (5,900)	0	11,576 (5,250)
Reference site and inclination	Kourou 5.2 deg.	Xichang 28.5 deg.	Baikonur 51.6 deg.	KSC 28.5 deg.	Baikonur 51.4 deg.	Odyssey Launch Platform 0 deg.
Estimated launch price (2000 US$)	$165,000,000	$60,000,000	$85,000,000	$300,000,000	$42,500,000	$85,000,000
Estimated LEO payload cost per lb (kg)	$4,162 ($9,167)	$2,003 ($4,412)	$1,953 ($4,302)	$4,729 ($10,416)	$1,404 ($3,093)	$2,431 ($5,354)
Estimated GTO payload cost per lb (kg)	$11,004 ($24,265)	$5,233 ($11,538)	$8,326 ($18,359)	$23,060 ($50,847)	N/A	$7,343 ($16,190)

vehicles (i.e., Falcon 9, Taurus-II) European and Russian launchers may be exposed to future competition from the USA commercial transportation service companies.

The high *launch cost per kilo* is a major constraint to intensive space exploration. Thus, each launch service has a separate contract with numerous external issues affecting the transaction. Furthermore the launch service itself is also affected by external issues, for example: the all launch sites (except Sea Launch) are owned and operated by governments and provided at no cost to satellite operators.

The cost of launching 1kg in space is quite significant and is dependent on whether the satellite is launched in LEO or GTO orbits. For the launch of 1kg of mass to low earth orbit (LEO), the reported prices can range from 8,000 to 22,000 US dollars. While, for geostationary launches prices can range from 10,000 to 30,000 US dollars per kilo. Therefore, *launch prices* must be seen as a *simple indication* and shall not be taken too strictly by analysts. Pricing launch services for future low cost launchers (such as Space-X) may be different, as pricing models may be more transparent and effected by less external issues. *High launch cost* is *the prime constraint* for reduced satellite launches, underdevelopment of commercialization of space technology and space tourism. Having a viable *business case* and *showing profitability for commercial projects* using space technology using the current launch prices is a true challenge.

Launcher reliability is a prime driver when choosing a launcher. The reasons behind the high launch price can be explained because launchers are designed according to *maximum performance*. In addition, they incorporate costly propulsion, the use of advanced materials and technologies (composites, Al-Li alloys, etc), *reliability* and *high development costs*. Other reasons for high launch costs are the *complexity* of the spacecraft integration and launch session and the small size of the market (Toylarenko & Jakhu, 1998). The *few launch rates* cannot generate economies of scale and therefore, prices cannot be reduced.

The prime reason behind high launch prices is that the *launchers are expendable* and are *designed for single-use. C*urrent technology still prevents the development of an inexpensive reusable launch system (i.e. the Space Shuttle is probably the most expensive launch system in the world with a launch cost ranging between $300 Million to up to $500 Million per launch, despite being partially reusable).

Launchers are produced in *batches (not in series)* and limited launch rates may also be a challenge to cost reduction because they limit the extent of *economies of scale* potentially applicable to the production facilities. The wide variety of launcher supply and different launcher versions and models do not support the rationalisation of production and the development of specific cost saving strategies based on volume. With less than 100 launch events in a year and more than 20 launchers in operations worldwide, no single launcher can reach production rates higher than 5 to 10 units a year (at the very best) and achieve significant economies of scale.

Today in 2010, companies such as Space-X are aiming at developing low-cost launchers, such as the Falcon 1 with a launch price of $8.9 Million, while others (i.e. Scale Composites) are designing sub-orbital launch vehicles, such as Space Ship Two. Furthermore, some of them are even diversifying their market and aiming at using their transportation vehicles (i.e. White Night Two) for micro-satellites launches.

Therefore, traditional launch service providers may *face strong competition* from these new players who will provide low cost launch services and at the same time launchers that meet NASA COTS requirements. Thus, NASA will start buying low-earth orbit launch services to the ISS under the NASA COTS program thus encouraging the development of commercial launch services to ISS, while NASA focuses on the asteroid and Mars space exploration. With the implementation of the future interplanetary program, there could be an increase in launches and launcher production while the ISS is operational, potentially resulting in price reductions due to increased launcher productions and *cost* savings from the launch of commercial payloads (direct benefits). However, with the end of the ISS around 2020 the companies offering launch services under the NASA COTS program will lose their main customer.

Therefore, *launcher interoperability* with other launch systems will need to become a *mission critical requirement to* mitigate the risk of not having reliable and constant launcher support for future Mars missions.

In the nearby future traditional launch service providers may become exposed to strong competition from new players that will provide commercial transportation services under NASA COTS program and will compete with European and Russian providers.

6.3. Human Rated Launchers

Human rated launchers have much higher safety requirements and therefore are more expensive. In 2009, only the Americans, the Russians and the Chinese have demonstrated the ability to launch humans in space with indigenous means: the Space Shuttle, Soyuz and the Long March 2F.

The *Space Shuttle* was designed to be a re-usable transportation low-cost vehicle and meant to be the main launch vehicle of the USA. However, Shuttle operations and refurbishing costs proved to exceed by far initial expectations and the US eventually decided to limit Shuttle usage to the needs of the ISS construction and Hubble repair, rather than making it the workhorse of US space launch capability as originally planned.

The Semyorka launcher family, from which the *Soyuz launcher* is derived, was developed in the late 1960s by the Russians. Two main versions of the launcher are available for operations, the Soyuz and the Soyuz-FG.

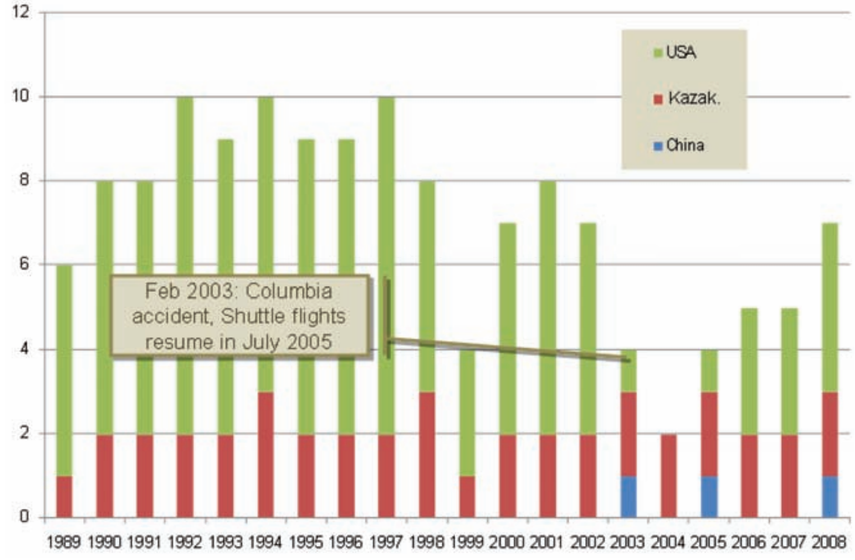
The Chinese developed the Long March 2F launcher as a modification of their heavy launcher CZ-2E for launching the Shenzhou spacecraft, so that 2003 China became the 3rd country world-wide with a human-rated launch vehicle. Figure 4 shows an overview of the worldwide human space flight launches.

This increase will encourage *technological growth* for the launch industry and launch service operators. The launch manufacturers and launch service operators will gain *direct benefits* from *increased revenues from the development of human space-flight programs (i.e. ISS utilisation), followed by development of new markets, technology reliability and interoperability.* The *indirect benefits* for them will be in *technology innovation* and *international cooperation,* as new launch vehicles and competencies will need to be developed by space agencies.

Technology reliability, crew safety and interoperability to other launch systems will be mission critical requirements (see Chapter 1).

The launch segment was going to benefit most from the US Constellation program and as launch part manufacturers and service providers were going to gain increased revenues from sales, new markets and technology reliability (*direct benefits*). In addition, they were going to gain benefits from *technology innovation, free publicity,* and *international cooperation.*

Figure 8. Manned launches worldwide 1989-2008 (ASD-Eurospace, 2009)



7. EARTH OBSERVATION

Climate change is becoming an increasing threat to national economies and societies. Industrialisation and urbanisation of countries, rise of temperature due to greenhouse emissions has lead to dramatic environmental changes (OECD, 2008). The major consequences are melting ice caps, changes of ocean levels and currents and flooding in certain regions. Climate change is feared to become a threat that will result in global tensions and instabilities (OECD, 2008), with fresh water resources getting scarce and the marine environment at risk.

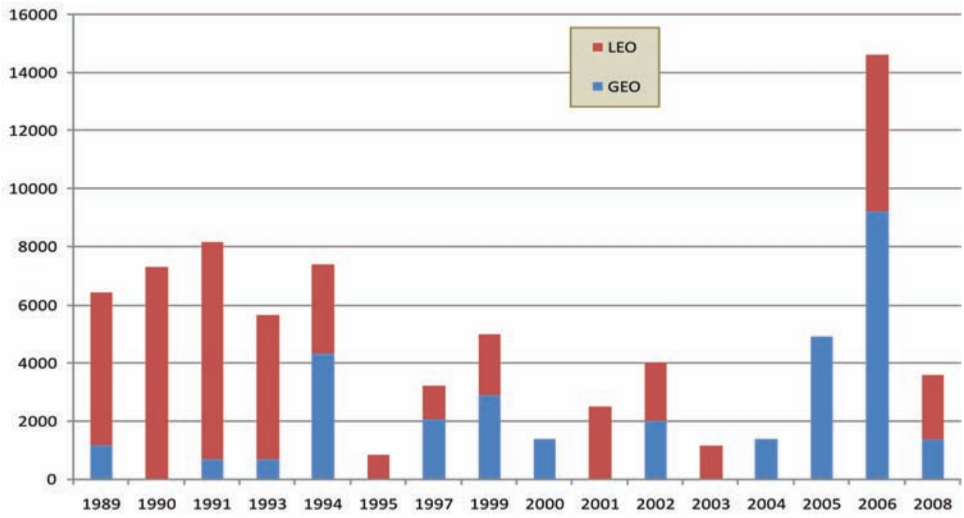
Earth observation satellites are starting to play a significant role in monitoring and assessing the damages of global warming on oceans, ice-caps, lakes and forests. The data from earth observation satellites supports the measurement of the impact of disasters (floods, landslides, etc.) or land erosion and pollution. In addition, the data from Earth observation (EO) satellites is used to predict weather changes and monitoring natural disasters through the use of optical or radar instruments.

EO applications were developed for two main end-users: the meteorological community (through the World Meteorological Organisation which is an UN agency) and the military and intelligence community. Earth observation applications have become so important that Europe is launching a Global Monitoring for Environment and Security (GMES) program under which it will develop and launch the Sentinels satellites that will monitor oceans, land and atmospheric composition. The Sentinel satellites will follow up on the services, which Envisat, Spot-5 and Landsat provide. Under the GMES program the satellites. Sentinel - 1 is a polar orbiting radar satellite for land and ocean imaging, Sentinel-2 is a multispectral satellite for monitoring vegetation, water and soil and Sentinel-3 is a satellite which will monitor the sea and land surface temperature changes, while Sentinel-4 and Sentinel -5 will be meteorological missions. The estimated worldwide investments in the development of earth observation systems is expected to reach up to 38-40 US Billion by 2020 (OECD (2008)). Figure 9 shows an overview of the Earth Observation satellites launched in LEO and GEO.

Expected trends are an increase in earth observation missions and the development of new missions for monitoring climate changes. This expected growth would result in the *re-shuffling* of national *space priorities* and *increased governmental investment in earth observation missions.* Therefore, this trend may lead to reduced budgets for human space flight and exploration and become a *potential threat* to space agencies budgets for human space flight and result in their reduction.

A budget reduction would place constraints on future investments in the development of human rated heavy lift launchers for exploration. Therefore, space agencies willing to justify human space exploration will have to give high priority to the development of technologies and solutions (i.e. closed life support systems) that could either *contribute* to the creation of self-sustainable energy solutions from space or to a better understanding of climate change processes and environment protection.

Figure 9. Earth Observation satellites launched in LEO and GEO (ASD-Eurospace, 2009)



Commercialization of space technology and the *true use of space-based resources* can be encouraged through the development *of self-sustainable energy solutions or understanding of climate* change for *pollution reduction.* Solar powered satellites and lunar solar power stations (LSPS) are some of the examples of the use of self sustainable solar energy solutions (see Chapter 9). The two business cases in Chapter 9 will discuss the use of space solar power satellites and the mitigation of space debris.

In order to attract additional investments in human space exploration activities, space agencies will have to aim at the development of interplanetary technologies and solutions that can *contribute* to self-sustainable energy solutions from space, such as lunar space solar power stations.

The development of earth observation services and products will bring benefits to space agencies, system integrators, manufacturers and service providers. For example, space industry stakeholders will generate increased revenues from sales of EO products, development of new markets, develop technology interoperability, generate increased investment in EO space systems due to climate change and achieve technology *innovation and international partnerships (indirect benefits)*, while companies providing services for human space flight programs may experience a loss of contracts due to reduced investment in human space flight programs.

8. LUNAR AND MARS SPACE EXPLORATION

Since 2004, NASA has been preparing for a Moon re-visit by 2020, the creation of a Lunar habitat by 2025 and for human exploration of Mars after 2030. However, the objectives of the US human space exploration program changed after the election of Obama as a US President. The Aldridge Committee had to re-assess the US human spaceflight program and thus match the exploration needs to program objectives, extend Space Shuttle life until 2011, extend the lifetime of the ISS until 2021 (see Chapter 1) and encourage the development of LEO commercial transportation services to the ISS (i.e. NASA COTS program).

Japan, Europe, Russia, China and India have also started actively developing their own robotic interplanetary missions.

In 2010, the Japanese probe Hayabusa made headlines by landing on the Itokawa asteroid for around 30 minutes and investigating the asteroid formation processes (Etienne, 2010). Asteroids contain raw materials and information on processes involved in the formation of the Solar System. The probe travelled around 7 years and during its stay on Itokawa brought back some samples from the asteroid surface. Inside the Hayabusa sample container were found traces from small particles that currently are being investigated whether they are from Earth or from the Itokawa asteroid. The Hayabusa probe was designed to land and take off the Itokawa asteroid and also test the ion engines, the optical navigation of the spacecraft and the deep space communication. After successfully landing back the mission generated huge *public interest* and due to its historic landing on an asteroid generated benefits from *technology innovation*.

Another European robotic mission is the Rosetta one, which is planned to land on Comet 67P/Churyumov-Gerasimenko in 2014. The 100 kilo spacecraft carries a small lander that will land on the icy nucleaus of the comet and investigate its chemical composition.

Europe is also developing interplanetary robotic competencies and is planning to launch the ExoMars mission in 2018. ExoMars will study the biological life on Mars and to search for past and present life. The ExoMars rover will have a drill that will gather samples from Mars' surface and search for traces of biological life. For the ExoMars mission, ESA and NASA are partnering together and therefore, both agencies will be able to generate indirect benefits from international cooperation.

Russia and China, on the other hand, are preparing to launch a robotic mission to Phobos, a moon of Mars with the objective to collect soil samples and monitor the Martian dust storms. The mission consists of a small orbiter and a lander that will perform an analysis of the comet's surface.

India also successfully launched the Chandrayaan-1 in 2008 with the mission objectives to conduct chemical and mineralogical mapping of the Moon. This mission is a result of a wide international cooperation *(indirect benefits*), which achieved technology interoperability *(direct benefits*) and free publicity *(indirect benefit)*.

The US is still the leader in robotic interplanetary missions starting with the successful launches of the Opportunity and Spirit rovers as well as with the Phoenix mission.

Phoenix was the mission that captured the imagination of the public worldwide, as it found water ice on the Martian surface. Its mission objectives were to investigate the geological history of water on Mars and its habitability. The design of the Phoenix mission used some *cost saving approaches*, such as the use of a fixed launcher rather than a rover, in order to *re-use parts* from other equipment from other space missions. This approach has brought direct benefits such as *cost savings, technology reliability and interoperability* to NASA. Indirect benefits generated by NASA were *technology innovation* and *publicity*.

Space agencies are developing and launching all these robotic missions, but if they want to achieve human space exploration to Mars, they will need to develop new technologies, such as heavy human-rated launchers, lunar orbiters, landers, habitats and transfer vehicles.

The US is the clear leader in robotic exploration followed by Japan, Europe and India. Some of the above robotic missions bring scientific and technology benefits to national agencies and research centres and they gather valuable information for the preparation of future long-term human exploration of Mars.

Robotic missions have already generated direct and indirect benefits for space agencies and private companies. The Phoenix mission brought *technology reliability, interoperability and technology innovation,* and *publicity* to NASA, while the Hayabusa mission generated technology innovation and free publicity *(indirect benefits)* for both JAXA. India's Moon mission generated indirect benefits from international cooperation as well as free publicity and direct benefits from technology interoperability. Space agencies and space companies can use present interplanetary robotic missions as a basis for defining the direct and indirect benefits from initial industrialisation projects from non-space companies.

9. RUSSIA SPACE STRATEGY

Since the first flight of Yuri Gagarin in 1961, Russia has maintained a leading position in LEO human space-flight. After the fall of the Soviet Union in the early 90s the country successfully commercialised its launchers and set up partnerships with private entities, Sea Launch, such as MirCorp and Space Adventures and started launching space tourists to the ISS (see Chapter 1).

The Russian space industry is experiencing a growth in the areas of launchers, navigation and development of new space applications (i.e. space tourism). Russia is a major partner in the ISS program and provides regular launch services to the space station through its Soyuz launcher.

The Russian federal program aims at serving the different needs of the Russian economy and society. Its objectives are to enhance people's lives, support the high rates of stable economic growth, create potential for further development and increase the level of national security (Russia Federal Space Program (2005).

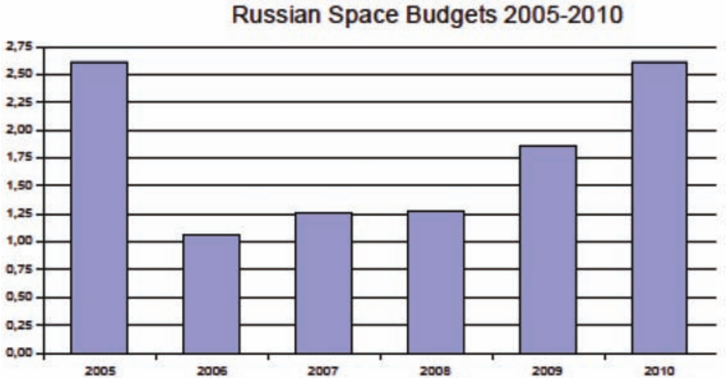
The Russian space industry plays an important role in the national economy, as Russian space activities play an important role and contribute to increasing *national external trade turnover* and influence Russia's export trade balance.

Figure 10, shows an overview of the Russian space budget from 2005 to 2010 in USD dollars. The exchange rate used is that of the 2/01/2009 and corresponds to 1USD=34 Rubbles. The budget data for 2009 and 2010 is an estimate (Integrum, 2008).

Clearly, the Russian Federation is increasing its investment in national space industry. However it is not clear whether the budget of 2010 will be sufficient to preserve the sector due to the world-wide financial crisis and the escalating inflation in Russia (14% in 2008, the Rubble also lost 23% of its exchange value against the

Figure 10. Phoenix Mission (Courtesy of NASA)

Figure 11. Russian space budgets 2005-2010 (Integrum, 2008)



Euro in the very last months of 2008). Nevertheless, Russia continues successfully to export its launch services and to market Russian space technology world-wide.

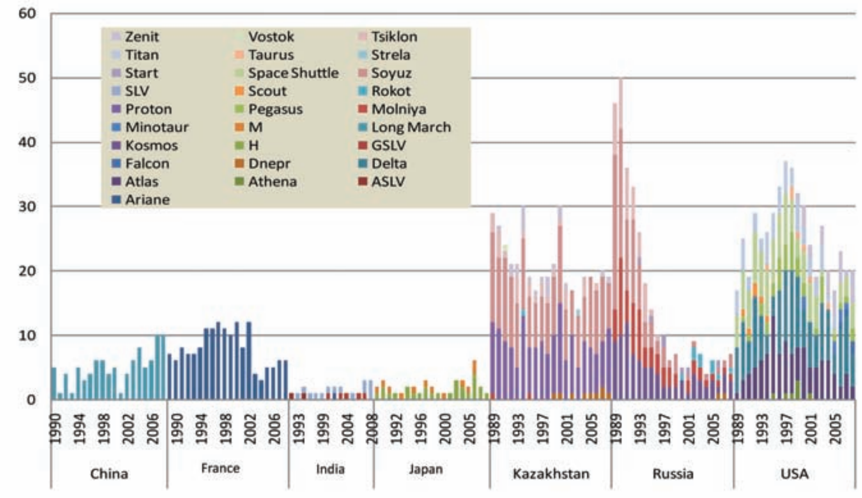
9.1 Russian Launch Capabilities

With the sharp reduction of governmental activity in space, the Russian launcher industry was on the brink of disappearing and only offering in the early 90s launch services to international customers could ensure the preservation of its industrial capabilities. As soon as 1995, Russian launchers started capturing international customers, primarily through joint venture agreements with US companies.

Globally, the Russian launcher production rate of the year 2000 was well below that of the Soviet era and was accompanied with all the problems associated to downsizing and restructuring a large scale highly technical industrial base.

The Proton and Zenit launcher families did particularly well, especially serving the geostationary market (see Figure 12). In contrast, the Soyuz still required

Figure 12. Russian launchers 1990-2005(ASD-Eurospace (2009))



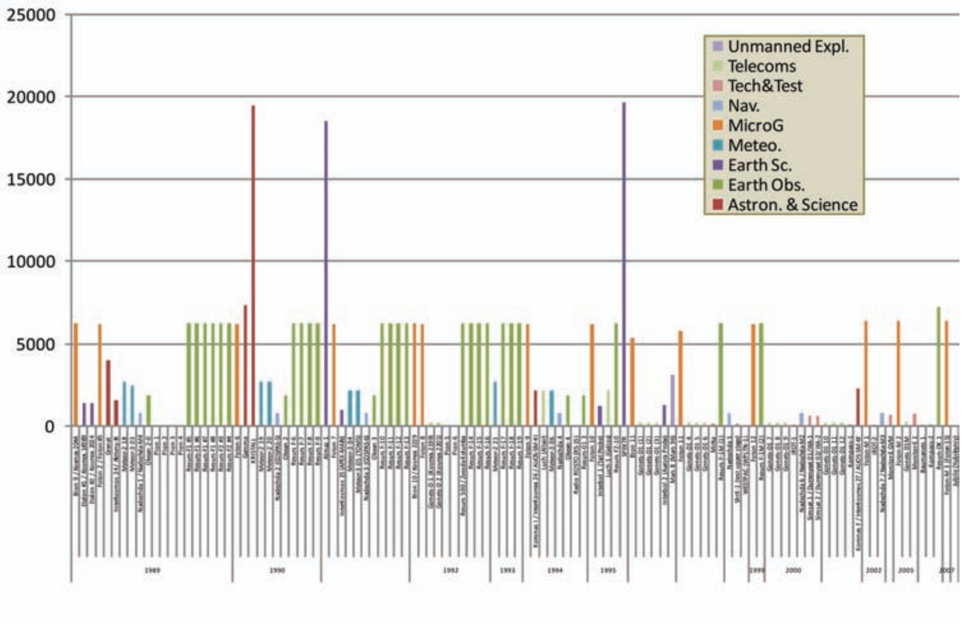
servicing the space station and was ill-adapted to serving the geostationary orbit, so after the end of the space station lifetime, the launcher will have to re-adapted to service the geostationary orbit.

With the end of the Soviet Union, Russia started phasing out several programmes, such as Resurs, Gonets and Strela, as there were reduced orders from their space agency for building and launching scientific and military payloads.

While not at the leading edge from a technical perspective, Russia has accumulated massive knowledge and experience over four decades of permanent human presence in Earth orbit. The Russian space sector is still maintaining impressive know-how and operational capabilities to support human presence in space. This sector is of course heavily involved in international scientific and technical partnerships (i.e. indirect benefits) as its activities revolve around the ISS program. However, the Russian space sector will have to diversify its activities, with the retirement of the ISS in 2020 and the lack of another space station. The companies providing human spaceflight services will have to *reduce* their activities.

Russia is already investigating ways to achieve long term space exploration and is also involved in an international study called MARS500. Its objective is to study the psychological and physiological effects on future astronauts for 500 days in a confined environment. This study is in collaboration with ESA and European candidates that take part in it. Furthermore, Russian space exploration enthusiasts have also set up an initiative to lobby for a human space flight Mars mission[8]. Thus, generating benefits from *international cooperation* and *free publicity*.

Figure 13. Roscosmos chronology of launches by program 1999-2007 (ASD-Eurospace, 2009)



Nevertheless, Russia continues in its plans to market Russian space technology world-wide, as clearly presented in Figure 13.

Earth Observation and microgravity payloads are the prime type of payloads launched. However, with the retirement of US Space Shuttle NASA and the rest of the ISS partners will rely on Russia for ISS launches. Thus, Roscosmos will have a *monopoly* position and thus, impose high launch prices to the ISS partners for astronaut launches. Furthermore, its human flight launches may drastically increase and they may be even capable of generating *economies of scale*.

The Russian program considers the *direct benefits* for the Russian economy from space industry activities as national employment of around 250,000 employees in the industry.

Another benefit is the impact of Russian space technology on the *international trade balance* of Russia. Although quite limited today (with regard to the whole Russian economy), it is interesting *to note* that Russian launcher technology is being marketed not only as a launch service, but also as *exported equipment*. A most notable case is the production of the US launcher Atlas first stage main engines by the Russian company Energomash.

The Russian space industry is a direct contributor to the national economy, as a result of its activities Russian companies and organisations generate direct and indirect benefits. Direct benefits include employment, revenues from sales and development of new markets and indirect ones, such as international cooperation and free publicity.

10. SPACE EXPLORATION EUROPE

Europe is a significant player in the global space industry and generates a consolidated turnover of around 6.7 Euros Billion for 2009 with around 30,300 people working for the industry. Europe has a long-standing history in human space-flight exploration driven by European Space Agency (ESA). ESA is an inter-governmental agency with 18 member states that *leads* Europe's space exploration in the areas of earth observation, navigation, telecommunications, launchers, science exploration, and human spaceflight programmes. ESA budget for 2010 is around 3.7 Billion Euros.

ESA is a significant player in human space-flight and contributes to the International Space Station with the Columbus module, Nodes 1 and Node 2 and the Automated Transfer Vehicle (ATV). In May 2009, for the first time in European space-flight history, the Belgium astronaut Frank de Winnie became the first European commander on-board the ISS.

Europe's space exploration strategy is primarily driven by the scientific and technological needs of its ESA member states. Each member state defines its national space priorities and communicates them to ESA. Thus, creating a very diverse funding methodology within ESA programs[9], as funding is based on a fair return and on meeting the needs of each of the members' states.

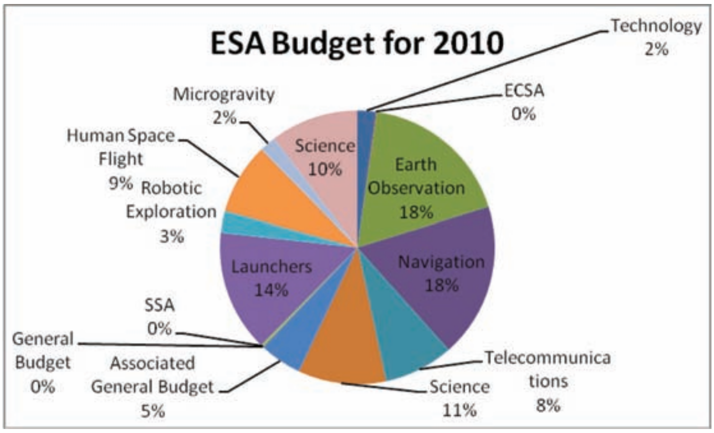
Figure 14, shows that ESA budgets are rather evenly distributed among launchers, earth observation, science, navigation and human spaceflight programs.

Since 2008, ESA budget has increased for navigation and earth observations programs. For example in 2008 ESA budget for navigation was around 10.73% of the overall ESA budget and for 2010 it is up to 19%. In contrast to ESA budget in 2010 for launchers, human spaceflight and science programs has reduced from the levels of 2008. This budget *trend* indicates that ESA will encourage primarily navigation and earth observation activities, rather than human space flight ones.

ESA together with the EC and all the EU member states have implemented the Global Monitoring for Environment and Security Sentinel (GMES) program that will provide data for climate monitoring, modelling and prediction.

Navigation is another strategic area in which Europe has invested and is aiming in developing an independent civil navigation system Galileo. Galileo is expected to be operational by 2013 and will bring value-added services to European industries such as aviation, rail and marine transport and so forth. According to the Nederland

Figure 14. ESA budget allocation for 2010 (ESA, 2010)



Economisch Institut, if the US GPS system fails to provide services for two days, Europe will suffer losses of $220 Million in the transport sector (AIAA (2009)).

Europe has also launched other exciting missions, such as the science mission Rosetta, that is expected in 2014 to reach the Comet 67P/Churyumov-Gerasimenko and orbit around it for around two years. Another interesting mission is the Gravity field steady state Ocean Circulation Explorer (GOCE), that will measure Earth's geoid g-force. Other exciting missions deal with the monitoring of Soil Moisture and Ocean Sanity (SMOS) or the Cryosat-2 space mission for monitoring Earth's ice thickness and cover.

After the successful launch of the ISS Columbus module and the ATV, ESA will have to define a new strategy for its human spaceflight and robotic missions, the current options include:

- Developing robotic competencies for the ExoMars mission
- End-to-end European Transportation Capability with an advanced re-entry vehicle
- Developing a Logistics Lunar Lander
- Developing Life Support and Environmental Control Systems
- Particpate in global for In Situ Resources (ISRU) lunar exploration space missions
- Participating in isolation and bed rest studies, such as MARS 500 study with Roscosmos

The above objectives show that Europe has not yet established a long-term human spaceflight exploration strategy after the end of the ISS in 2020.

ESA Member states have *not defined a unified approach* for further development of Europe's technology competencies for future interplanetary exploration. This is due to the diverse nature of the agency and of the importance given to meeting the space exploration needs of each of its member states. However, the lack of a human-rated launcher to the ISS may become quite costly for Europe. For example, the grounding of the US Space Shuttle for a year and half after the Columbia accident in 2003 resulted in huge financial losses for the European Space Industry. ESA had to keep its industrial teams operational for 3 more years in order to service the Columbus module, which was structurally built only to be accommodated in the Space Shuttle Cargo Bay. This delay in the Columbus launch *raised* the question whether Europe needs to invest in the development of human rated launchers or not.

The retirement of the Space Shuttle in 2010, and the cancellation of the Ares I, will provide a *unique opportunity* for ESA to develop a human-rated Ariane, thus commencing the servicing of the ISS after the retirement of the Space Shuttle. With the development of a human-rated launcher, Europe would have competencies in most of the human spaceflight aspects and would become the 4th space power covering the full range of human space-flight capabilities. Or ESA may encourage the launch of a program for the development of commercial transportation services similar to NASA COTS program.

For ESA, the direct benefits will include *technology reliability* and *interoperability* and the *indirect* ones will include *technology innovation, international cooperation* and *free publicity*.

Europe will not be able to exploit fully its research and technology capabilities and will not be able to remain a competitive player in human spaceflight exploration if it does not have a human-rated launcher. However, the development of a human rated launcher will require a massive investment and also a European human spaceflight vision. As the expected time life of the ISS will be until 2020, there will be case for encouraging the development of a European human rated launcher.

Nevertheless, there is a threat that ESA member states may withdraw their support to human spaceflight exploration and *invest primarily* into *earth observation* and *navigation* systems. The expected return of investment of these systems is higher, due to the ongoing space application development, such as location- based services, precision agriculture, GIS and oil and rack positioning.

Countries such as China and India may not only develop competitive low cost technologies and launchers for human spaceflight, but may even start offering their launch services to ESA and the European space industry.

ESA will have to *re-define* its human spaceflight strategy and even encourage the launch of a commercial transportation services program similar to the NASA COTS one. ESA member states may withdraw their support to human space flight exploration and invest primarily in earth observation and navigation systems and the development of space applications. Due to the new trend of ESA to encourage the development space applications development, due to the higher expected rate of return from these space applications.

11. SPACE EXPLORATION JAPAN

Japan is a space faring nation with an ongoing interest in human spaceflight. JAXA recently launched the KIBO module, which is the Japanese space laboratory on board the International Space Station (ISS). JAXA also successfully developed the HTV Transfer vehicle for the ISS and launched the SELENE mission to the Moon.

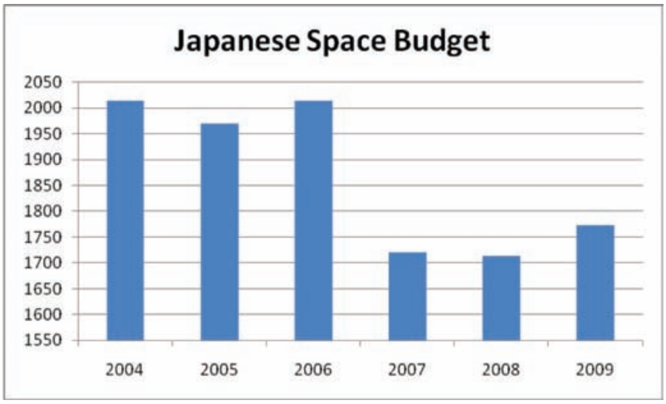
Japan has been very active in launcher development and has successfully developed a launcher family N1, N2, H1 and now H2. Just recently Japan upgraded its launch capabilities to the ISS with a new launcher H2B. Japan participates in various international partnerships not only related to the human space exploration, but also to interplanetary robotic missions, such as the BepiColombo an ESA mission to Mercury.

Japan has already successfully launched the SELENE mission to the Moon, on board of which is a High Definition TV Camera (HDTV) that provides outstanding images of the lunar surface and views of Earth over the Moon's horizon. JAXA also generated direct and indirect benefits from the mission, as it formed a partnership with a multimedia company that built the HDTV camera. JAXA generated cost savings, technology interoperability *(direct benefits),* and free publicity *(indirect benefits)* from the mission.

Figure 15 shows an initial overview of the Japanese space budget from 2004-2009. This budget will support Japan in the successful implementation of its national space policy, which is focused on the development of space applications, international partnerships and encouraging the competitiveness of Japanese space industry. The size of the Japanese space industry is of around 7 trillion yen and the space equipment industry is of around 230 billion yen its competitiveness is dependent on the institutional customers. Therefore, Japan will aim at encouraging the development of new markets, space applications, improve utilisation of space systems, develop autonomy in space and contribute to green innovation through earth observation satellites.

In 2008, Japan set-up a five-year old plan for space technology utilisation and promotion (Kwagaguchi, 2008). This plan states that Japan will actively pursue a space exploration program and a balance with international cooperation, thus focusing on robotic lunar exploration and examining the need for human exploration with international cooperation (Kwagaguchi, 2008). These new activities are a result of

Figure 15. Japanese space budget 2004-2009 (ASD – Eurospace, 2009)



a new Japanese space law which came into force on 27th of August 2008 (Kazuhide, 2009).

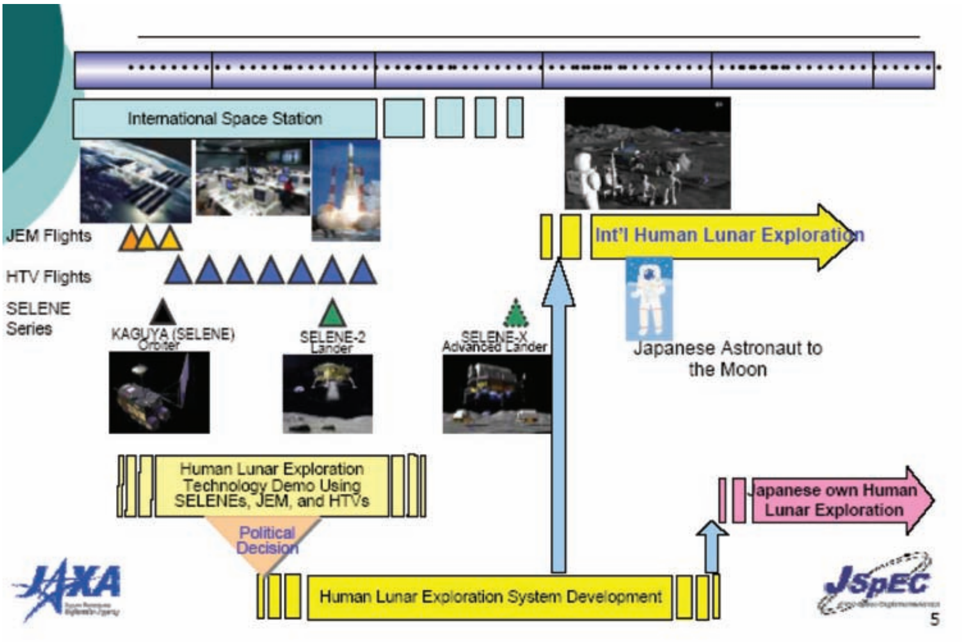
Japan's human space activities have been discussed in the Japanese Strategic Headquarters for Space Policy. Japan's government has decided that a manned Lunar exploration plan will be added to the Japan's Basic Space Plan that was published in May 2009.

In this plan, unmanned exploration was proposed to be done around 2020 initially to use space robots and later on Astronauts to the Moon. However, in the current environment of economic crisis, several discussions may occur before that happens.

ISAS launched their first Lunar mission MUSES-A/Hiten on January 24th 1990 and its prime objective was to confirm a moon swing-by technology and a sub-satellite of Hagoromo was landed on the Moon in 1993. Japan's first Mars mission Planet-B/Nozomi was launched on July 4th, 1998 and a more attractive mission of MUSES-C/Hayabusa was launched on May 9th, 2003. Hayabusa was touched down on the Itokawa of 500m length and a small sample of the soil was picked up and contained in the satellite (Kazuhide, T.(2009)).

The approach behind the Japanese space policy is to *encourage utilisation* and the advancement of technology in order to improve the *quality of life* and *security* of Japanese people (JAMSS (2009)). For example, after the launch of the Japanese ISS module KIBO, JAXA set-up a paid utilisation strategy that encouraged the launch of several projects such as the LOTTE Xylitol, Olimpus Camera and cultural utilisation to the ISS. Thus, encouraging international partnerships and encouraging *business forces to be driving* and also on promoting measures for meeting the utilisation needs of the Japanese government and private sector (JAMSS (2009)).

Figure 16. Japanese space exploration vision



JAXA has set a very clearly-defined strategy that has been proposed to the Strategic Headquarters for Space Policy. After the SELENE- 2 and the development of SELENE-X advanced Lander, there will be plans for Human Lunar exploration.

The objectives of the Japanese human space exploration plan are following: 1) JAXA is to study future human space exploration in order to prepare for manned space activity after the ISS, 2) JAXA to study international programs and interdependency[10] with the objective to participate in international studies and to develop technical competencies using the JEM/HTV approach and to decide with a decision on Japan's manned space activity.

In addition, Japan is planning to develop a human-rated launcher and develop a lunar lander and transform the HTV into a return capsule. Furthermore, Japan may be pressured to expand its human space flight activities due to the need to remain competitive in the space industry and the uprising competition in human space flight activates coming from China.

Japan is actively pursuing Lunar robotic exploration with the SELENE mission and investigate the Moon origin and evolution (JAXA (2009)). The SELENE mission is the forefather of the SELENE- X missions which are planned to be human exploration missions, as presented in Table 4.

Table 4. Japanese space exploration program

	Kaguya (SELENE)	**SELENE-2**	**SELENE-X**	**Human Exploration**
Technology Development	Lunar orbit insertion & observation from orbit	Landing Surface mobility Long-Term stay	Several mission candidates	In-situ activities performed by Japanese astronauts
Planetary science	Remote sensing of surface material gravity field	In-situ observation & geophysics	Development of a large scale lander	
Lunar utilization	Remote sensing of surface environment & material resources	In-situ investigation of surface environment & resource utilization	Construction demonstration on the Moon Lunar observatory	
International Collaboration	Data exchange for science and future exploration HDTV	International payload sharing HDTV, university small sat	Seismometer network	

Japan is looking not only at commercialization but also at privatization of JAXA assets and operations transfer to Japanese space industry. Thus, freeing budgetary resources for JAXA to develop and implement R&D missions.

The new Japanese future human space exploration strategy is very much focused on generating competencies and knowledge-base through international collaborations with the USA and Europe. Nevertheless, Japan has to set up a clear program for its future human space flight activities. As already discussed in Chapter 1, some of them are of *direct benefits*, such as *cost savings* for JAXA, new markets and revenues from direct sales as for example of images from the HDTV camera. The *indirect ones* include technology innovation, international free publicity and international collaborations.

12. DISCUSSION

The development of navigation and earth observation space applications and increased space agencies investment in these systems is a global trends taking place in space industry. Nevertheless, the lack of a long-term space exploration vision for human space flight and interplanetary space exploration will have a stagnating impact on the future the global space industry.

The expected reduction of funding for human-spaceflight activities is a global trend. After the end of the ISS in 2020, it is very possible that the US and the Russian space industries will experience a re-structuring of their national industries, as their industries will be most influenced by the end of the ISS and reduced human spaceflight activities, thus resulting in loss of employment and competencies.

Human space-flight requirements have lead to the production of the largest and heaviest pieces of hardware ever orbited and have increased the level of reliability expected from launch systems. Exploration requirements have contributed to the most advanced solutions for system longevity and autonomy, energy generation and preservation and last but not least propulsion. Therefore, these types of missions are very demanding on industry and it is expected that the space manufacturing industry will be drawing the largest share of the direct economic benefits of human exploration programs in the future. The situation needs to be analysed, since all segments of the space industry will not see the same benefits occurring.

The US Constellation Vision proved to be a ‘hot potato’ in NASA hands after the takeover of the Obama administration. Thus, actually potentially threatening the future of human spaceflight program and resulting in re-structuring, increased feasibility studies and administration. The successful development of commercial transportation services will have a global *impact* on the space industry structure as traditional space companies will exposed to strong *competition* from new players.

For instance, the Launcher industry should *benefit* from a growing demand for larger systems, and/or a growth of launch rates (and launcher production should follow). On the very long term, the growth and development of human space-flights could also help the development of a sustainable private market for space travel/experience, potentially supported by economies of scale at production level and product/service standardisation. Globally speaking, the launcher and launch service industries could experience increased *revenues from increased sales* as a result of the future interplanetary space missions.

It should be noted however, that in the past two decades, human and exploration missions have only represented a fraction of the total launch market. Human spaceflight needs have mainly been served by two launch systems, the Russian Soyuz and the US Space Shuttle, highlighting the very high specificity of this activity. As a whole, human space-related activity was responsible in recent decades for 20% of the expendable mass launched in orbit and of 90% of the retrievable mass. However, the launch mass for human space flight activities will most probably reduce with the finalisation of the ISS.

In contrast, the space exploration launcher needs are very different as far as robotic exploration is concerned which has been the case in recent decades. Exploration launches have only represented an extremely fragmented marginal market segment. There have been only 28 launches of exploration-related missions in the past 20 years, served by a wider range of launch systems (8 in total), but half of exploration missions were launched by NASA and made use of the Delta 2 launcher. In average, the mass at launch of an exploration mission is between 2 and 4 tons, comparable to the average GEO satellites. However, the limited frequency of this activity makes it less interesting for the launcher industry and can hardly represent, in the short to medium term, a dedicated market segment.

So market expectations, from the launcher segment perspective, cannot be overly optimistic with regards to human space-flight, especially since there is limited budget flexibility to expect in the short and medium term from civil space agencies budgets who single-handedly promote these types of programs. Commercial ventures are still embryonic and do not play a significant role in this market. If large investments are routed to these programs, they will be deviated from other types of programs (science, astronomy, and applications). Thus, there is a risk that the development of human space-flight and exploration programs is performed detrimentally to other types of programs and this may have negative consequences on the space industry as a whole.

Climate change and reduction of energy resources will become a prime reason for space agencies to re-locate its funding towards earth observation and navigation missions rather than human spaceflight one. As these missions contribute to the development of space applications and development of new markets and therefore, Europe and Japan are encouraging space systems utilization and space applications development. Therefore, human spaceflight programs will have to demonstrate projects that are applications-related and that encourage the development of applications linked to health, self-sustainable energy solutions, space debris and climate change.

13. CONCLUSION

From the late fifties until today, national space agencies have supported and encouraged the creation and development of their national space industries. Thus, ensuring some degree of independence in their strategic and programmatic ambitions in space. Human space-flight and interplanetary exploration of space have driven large developments and as a consequence, capabilities in design, development and production of space-qualified hardware have developed in the private (and public) industry. Furthermore, such programs have led to very significant achievements often associated with the most impressive space systems such as the Saturn launcher, the Shuttle orbiter, the Saluyt and Mir Space Stations, the Moon and Mars landers and orbiters, the Voyager probe.

The manufacturing space industry has been traditionally active on both public and commercial markets, with a strong degree of interdependence between those markets. Technology developed for *institutional needs* is occasionally used for space applications and systems where eventually, private operators develop a sustainable market and create an additional demand on top of the one originally supported by institutional programs only. This allows industry to expand and diversify its market base.

This has been typically the case for telecommunication applications where the customer base is now rather diversified, with commercial operators and the military representing the core markets. Other domains may witness similar evolutions are navigation and earth observation systems for climate change, ocean and marine monitoring. However, this is not the case for neither human space-flight (despite the over-optimistic claims of Virgin Galactic, we have yet to see commercial operations really starting in this domain, and it remains sub-orbital travel, not space travel), nor for exploration activities. The prospects for *diversification* are few in these areas and thus, the potential for market development outside the scope of civil institutional business remains very limited.

The spacecraft industry, focusing largely on building satellites for operational and emerging applications as well as scientific spacecraft, may not benefit significantly from more important efforts devoted to human space-flight and space exploration. Thus, for the simple reason that, without a clear trend towards growing civil institutional business for space, may translate into budget shifting from one area to another. If budget cuts in operation satellite applications are the consequence of sustained efforts in human space-flight and exploration, participating industries may lose their technology development streams that have supported the development of operational applications. This may cause competitiveness gaps between companies involved in human and exploration programs and the ones traditionally focusing on operational satellite applications, with the risk of competences lost and no added prospects for market and customer base diversification.

The *difficulties* associated with building an ambitious exploration program, within an international context, may further lead to inefficiencies associated with such a strategic direction. Indeed the current trend of main players in the area (USA, Europe, Russia, China and Japan to a lesser extent) is to *promote national endeavours* rather than seek efficiency of efforts through international cooperation. The willingness of potential partners to cooperate is also questionable, since the current split of capabilities and know-how within the existing space powers is uneven. Only Russia and the USA have significant and proven capabilities in the area of human space-flight, the capability to land and operate hardware on a celestial body is even more unevenly distributed.

Achieving a good level of international cooperation avoiding inefficient duplication of capabilities and pooling all available resources is an essential prerequisite for an ambitious space exploration program. However, the space powers have yet to define compatible policy boundaries for working together at achieving a common interplanetary space exploration strategy.

The Russian space federal program aims at a more pragmatic use of space technology for achieving economic growth, *increasing* the level of national security and increasing the national external trade turnover due to space products exports.

In Europe, ESA activities are more focused on Earth Observation and Navigation programs, than human space-flight ones. ESA Member states have not defined a unified approach for the further development of Europe's technology competencies for future Lunar and Mars exploration. The increased navigation and earth observation budget indicates that ESA is primarily going to focus its activities on encouraging the development of space applications. If ESA decides to develop a human rated launcher. With the development of a human-rated launcher, Europe would have competencies in most of the human space-flight aspects. However, due to the end of the ISS in 2020 most probably ESA will no invest in the development of a human rated launcher. ESA will probably invest it budget in encouraging the development of navigation and earth observation space applications. Thus, ESA may lose strategic positioning for the provisions of human space-flight services in case it does not develop a human-rated launcher.

Commercialization of space technology and the *use of space-based resources* can be achieved primarily through the development of applications for *self-sustainable energy solutions or understanding of climate* change for the *reduction of pollution.*

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ENDNOTES

[1] Employment and space budgets data is often imprecise and often space budget information duplicated. Due to the olgopoly market structure of space industry and the national protectionist policies (i.e.ESA geographical return rule) in space industry, revenues are often included in national agencies civil space budgets.

[2] GMES services will be provided by Europe's Sentinel satellites, which are a set of five Earth Observation satellites that will provide earth observation and meteorological data.

[3] Thuraya Satellite Telecommunications experienced jamming of their mobile satellite communication signal from three widely separated locations inside Libya. The Liberation Tigers of Tamil Eelam (LTTE) have also been using a vacant Ku-band transponder on an Intelsat satellite to broadcast its messages in Sri Lanka and the surrounding region. This shows the increasing threat of illegal misuse of space assets (ESPI (2007), draft version).

[4] In the later 1990s, the telecom industry experienced a downturn due to the bankruptcy of the Iridium system in 2000. Iridium failed to attract sufficient end users due to the wide competition of terrestrial mobile telephones.

[5] The first navigation system the US GPS was developed by the US military and fully owned by the US military. During the war in Kosovo in the late 1990s certain countries reported that the US military had blocked the use of the GPS signal in the region, thus resulting in economic losses to end-users. Therefore, European countries have decided to develop and launch an independent civil navigation system.

[6] For example, the Galileo receivers will be interoperable with the US-based GPS system or interoperable with GMES services signal.

[7] For example, a similar adaptation was made with the creation of the Sea Launch system that permits the launch of small satellites from a launch boat that is based in international waters, thus waving the liability/responsibility of launch states.

[8] The estimated cost of a Russian manned missions to Mars is considered to correspond to $20 Billion (Go2toMars(2008)), thus corresponding to around 2USD Billion per year. The initiative is quite interesting and deals with mission objectives, financing, biosphere, economy, technologies and culture on Mars.

[9] ESA funding is allocated into different programs such as launchers, exploration, navigation, human spaceflight, earth observation, and telecommunications.

[10] Japan, similar to Europe has been suffering from its dependancy on the US Space Shuttle for the human access to the ISS. Therefore, for Japan, it is of strategic importance to acquire and improve its autonomous human transportation capability, levering on international cooperation

Chapter 5

Emerging Markets and Space Applications

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"The Moon is the first milestone on the road of the Stars"

Arthur Clarke

1. INTRODUCTION

Telecommunications, navigation and earth observation space systems have become essential for the safety in our daily lives. Research on-board space stations has contributed to the development of new drugs, osteoporosis treatments, development of new materials, medical equipment and development of new methods for water purification and processing.

In recent years, space agencies have started encouraging the development of new markets and new industrial applications for the wider use of navigation (i.e. Galileo, GPS) and earth observation space systems (i.e. GMES). Space agencies and private comapnies involved in the development of space applications will face numerous challenges in market segmentation definition, however the space applications with their technology and process solutions may contribute to energy production, environment and disaster management processes and protection.

Only a few years ago, the idea of private citizens paying for trips to the ISS was in the realms of science fiction. Today in 2011 it has become a reality and entrepreneurs are investing in the development of sub-orbital transportation vehicles and construction of space ports. Space agencies have started recognizing the importance of commercial crew and cargo transportation services and NASA has even allocated a budget for encouraging the development of these services. Nevertheless, investing in commercial space projects is still considered to be challenging and risky, as funding is limited and is primarily available through prize competitions or partial project funding from agencies.

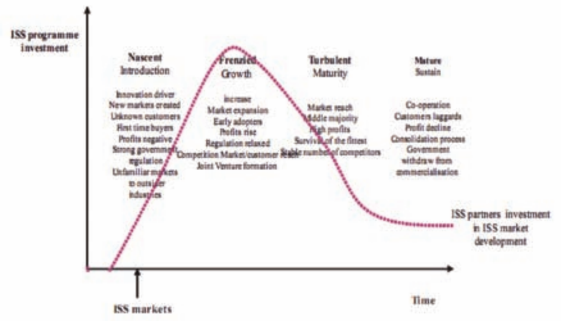
Today space exploration is considered by many visionaries and scientists, as a future source of energy through the use of solar power satellites and the construction of lunar solar power stations.

2. FUTURE MARKET EVOLUTION

Markets evolve through different phases of development; *nascent, frenzied, turbulent* and *moderate*. *Nascent* is when new markets are created, first-time buyers appear and markets are strongly regulated by governments. *Frenzied* is when markets start to expand and profits raise, while the *turbulent* phase is when profits of companies are high and there is a stable group of competitors. The final phase is the *mature one* where profits of companies start to reduce and government withdraw from the process and industry consolidation processes start taking place.

For example, in the early days of the ISS commercialisation, space agencies initiated commercialisation, new markets were created, profits were negative and customers were unknown. Thus, in the early days the ISS markets entered into the nascent stage of market development (S.Tkatchova, M.Pelt 2008) as presented in Figure 1. Due to the low market demand for ISS on-board facilities/services and because of the ISS partners' political and strategic decisions, ISS commercialisation was terminated for NASA and ESA. Nevertheless, the lessons learned from encourag-

Figure 1. ISS markets phases of development (Tkatchova, 2008)



ing the creation of ISS self-sustainable markets may be used for the future creation of self-sustainable markets for commercial crew and cargo transportation services.

One of the *prime lessons learned* is that technologies created for research objectives are a technology push and as in the case of the ISS is very difficult to commercialise. Nevertheless, space agencies may encourage private companies to become more actively involved in using space-based technologies by integrating non-space *user requirements*. Furthermore, they can set up industrialisation policies, offer IPR rights or marketing rights or space brand (i.e. as for example the Cosmode one) to companies involved in these processes, define space-based products and services classification and facilitate access to funding mechanisms for commercial projects.

The different space mission phases, as already discussed in Chapter 3, will bring different benefits to stakeholders in commercial projects. However, as proposed companies involved in a commercial project from the early phases of a space mission may be able to integrate their needs in the early space missions' facilities design, as discussed in Chapter 2. For example, Virgin Galactic integrated its customers' needs for the SpaceShipTwo design and as a result developed a modified design of SpaceShipOne for parabolic flights.

Furthermore, commercial crew and cargo transportation technologies will be designed integrating end-users requirements (i.e. NASA) and during the different phases of the NASA COTS program for crew and cargo development, companies such as Space-X or Orbital or others will experience different types of issues during *the different market phases* and *space mission phases*. For example, during the different phases of space technology development under the NASA COTS program, private companies initially will have to be able to attract funding for which they will need to contact investors and business angels. Nevertheless, investors may be reluctant to invest in markets with unknown customers, negative profits and strong regulation, unless they do not clearly understand the *expected direct* and *indirect benefits*.

Identifying the issues that companies will face in the early stage of the market evolution of their products and services will contribute to easier assessment (see Chapter 3) of the business potential and benefits of future commercial projects. Therefore, in order to be able to attract entrepreneurs and first-time customers for industrial projects, first space agencies and end-customers will need to understand clearly the direct and indirect benefits from the use of space-based technology. Certain benefits will be important in the earlier stages of market development, while others only in the later ones (i.e. turbulent, mature phases) of development. So they will not only be *different benefits*, but they will have a different *level of importance* during the different phases of market evolution.

For example, if company 'Y' is planning on developing a bone scanning device to be tested on-board the ISS, the prototype may be later offered to different hospitals. Therefore, the company will generate different types of benefits during the various market phases:

- **Nascent**: for example, company 'Y' will have to develop, test and qualify its device, with the intention of being flown to the ISS. For the company, of importance will be technology reliability, interoperability (direct benefits) and new market development. Company 'Y' will have to re-adapt its instrument and reduce its mass thus increase its products' technology innovation. Furthermore, in the early design stages of the instrument, it will work closely with the space agency and gain indirect benefits from the space agency free publicity (i.e. indirect benefits).
- **Frenzied**: once the markets start to develop, company 'Y' will start generating revenues from sales of its medical device, expand its markets and increase its employment (i.e. direct benefits). In addition it may even start participating in international partnerships in order to gain access to competencies it does not possess and gain indirect benefits from the creation of international partnerships and free publicity. Company 'Y' may increase its investment in the project and perform cost benefit analyses (CBA) that can be used for attracting funding from private investors and banks.
- **Turbulent**: during the turbulent stage if company 'Y' will increase its sales and achieve 'economies of scale' and will actually be able to achieve direct benefits from cost savings and revenues from sales. Indirect benefits may come from free publicity, as the company's medical scanning device will be well known and the company will continue to increase its technology innovation and exapdn its markets.
- **Mature**: in this stage, the direct benefits for company 'Y' will be found employment, technology reliability and interoperability, while the indirect ones would come from international cooperation.

During the nascent stage, the space agency will gain direct benefits from technology reliability and interoperability[1] and potential cost savings, because of technology adaptation to non-space users' commercial needs. The indirect benefits for the space agency will be technology innovation and also free publicity, as non-space companies will re-adapt their technologies for using space-based technologies from future interplanetary space missions.

The *nascent* and *frenzied* stages of market evolution will be most important for private companies, as they will be promotinng and launching their commercial space-based projects. Their capability to win first time customers in the nascent stage will be crucial for long term sustainable sales of their projects. The nascent and frenzied stages of development will *bring different benefits* to the institutional and commercial stakeholders. Understanding the benefits from industrial projects will permit the stakeholders to perform cost benefit analyses and attract private funding to implement their projects.

3. MARKET SEGMENTATION CHALLENGES

The identification of potential markets and industrial applications for the utilization of space-based technology from interplanetary missions is a challenging task, as commercialisation of interplanetary technology will be done for the first time.

Human space-flight is an extremely diverse sector of space industry that integrates most of the space market segments such as, launchers, navigation, telecommunications and earth observation space systems. In a way human space-flight is the "melting pot" of all space technologies. Therefore, market definition is more difficult in contrast to traditional segments, such as the ones that provide telecommunications, navigation and earth observation services.

In the early 1990s, the Roscosmos initiated early attempts to commercialise the MIR space station (see Chapter 2) and in these early days of space stations commercialisation market segmentation was *chaotic* and *unclear* as new markets were being created, customers were unknown, and market opportunities on-board MIR were unfamiliar to non-space companies.

Gradually as ISS commercialisation started space agencies applied a more unified approach to commercialisation and market classification.

The *ISS markets* were classified as research and development (R&D) and in emerging ones. The *R&D markets* were biotechnology, health, nutrition, new materials and environment, while the *emerging* ones were education, sponsorship, broadcasting, space-flight and infrastructure.

Some of the problems facing space agencies, private companies and intermediaries faced when they attempted defining the ISS markets were the following:

- Space technology commercialisation is a new pioneering processing
- Diversity of space applications and existence of different value chains in the different ISS markets
- Commercial crew and cargo services markets are in emerging stages of development
- Lack of benefit identification and classification
- Lack of historic experience and market information on first time customers
- Diversity of the scientific research on-board the ISS and MIR space stations
- Non-space companies not being aware of space-based research opportunities in microgravity on-board the space station

- Human space flight has historically been governmentally dominated and driven by the scientific and technological competition between the USA and Russia
- ISS markets will differ from the potential markets for future Moon and Mars missions (S.Tkatchova, M.Pelt, 2007). Spin-in and spin-off of space-based technology for future interplanetry space missions will play an important role.

The biggest problems are due to the *diversity* of the *targeted markets* as industry sectors have their own value chain and it is *difficult* to understand the benefits for companies from each sector. For example, in the case of the European navigation system Galileo, the Galileo navigation services will tap into numerous markets, such as aviation, location-based services (LBS), oil and rack position, precision agriculture and others.

The targeted markets will have *different value chains* and therefore market segmentation may be constrained and thus, the contribution of the use of space-based technology to end-customers' value chains.

Therefore, when segmenting the targeted markets for future Moon and Mars missions, it will be important to identify common relationships and patterns between different segments, such as health and nutrition. This segmentation approach will enable project stakeholders to create focused and easy segmentation. Therefore, it will be possible to establish interdependencies between different benefits, thus partially mitigating the risks from the diversity of the markets and the lack of existing market data.

3.1 Market Segmentation Methodology

NASA's new budget for 2011 will heavily invest in encouraging the development of new technology, commercial crew and cargo services and ISS utilisation until 2020. Encouraging the development of commercial crew and cargo services will require a much more *structured* market segmentation approach. One that will enable commercialisation stakeholders to identify common patterns and interdependent benefits from the use of interplanetary space-based technology. *Interdependencies* between *different benefits* is quite common and, for example,certain space tourist companies, such as Virgin Galactic has developed its SpaceShipTwo vehicle as a result of the demand for cost-effective sub-orbital flights and the global demand for environment protection. So, the cost-effectiveness (direct benefits) and environment (indirect benefits) became the drivers behind SS2's design and thus, resulted in technology innovation (indirect benefit).

Furthermore, space agencies will need to design and develop key enabling technologies and "spin-in" technology solutions and processes from non-space industries. Historically, ISS markets were technology-influenced, rather than market driven and, in order to encourage commercialisation, it is important that future markets be grouped based on *customers' needs* or *common features* (*i.e. price, promotion, product, place*), thus preventing technology driven market segmentation and encouraging the market driven one. There are different ways to achieve market segmentation in the space industry.

1. R&D and emerging ISS markets – this classification results in market segmentation, such as health, biotechnology and nutrition sectors.
2. Market classification by three groups life of citizens[2], environment[3] and risk management[4] (Doldirina, October 2007)
3. For classification of space industry applications using two-levels of segmentation: 1) macro-segmentation thus grouping the markets by *similar interests* and *issues*, 2) market segments classification by provision of services, addressing customers with specific global, regional and local trends, issues and potentially specialised suppliers (Lopriore, 2007). For example, for each of the value chains of telecommunications, navigation and earth observation, the market segmentation is classified under *customers*, *applications*, *products, geographical markets* and *others* (Lopriore, 2007).
4. Market classification can be done also by a *scenario-based* approach, by developing generic scenarios in which political, economic, social, energy, environmental and technology trends are identified (OECD, 2004).
5. Performing market segmentation by classification the markets using three different criteria; *safety, reliability* and *technology innovation* (Tkatchova& Pelt, 2007).

There is a lack of a *consistent* approach for market segmentation and as the above approaches are based on the end-user needs. For example, the *first (I) approach* is based on space agencies' need to understand the ISS markets and to have them classified according the technology resources aboard the ISS. The *second approach (II)* is to meet politicians' strategic and political needs and to promote space applications to citizens in their daily lives. The *third (III)* one is for space industry market segmentation and is targeted towards the space agencies' and space companies' needs.

This *third classification* considers the importance of the value-added services in a certain sector and measures it in two different ways (i.e. whether it is commercial[5] or non-commercial[6]). The non-commercial classification looks at benefits, such as employment and end users, which are similar to the direct benefits. The aspect of finding similar interests and patterns between different market segments is a *relevant* one to future market segmentation from the use of space-based technologies from interplanetary missions.

The *fourth (IV)* approach of 'scenario development' is linked to the needs of governmental bodies and politicians. This approach will not be used because it does not consider new market development for future space-based technologies from interplanetary missions.

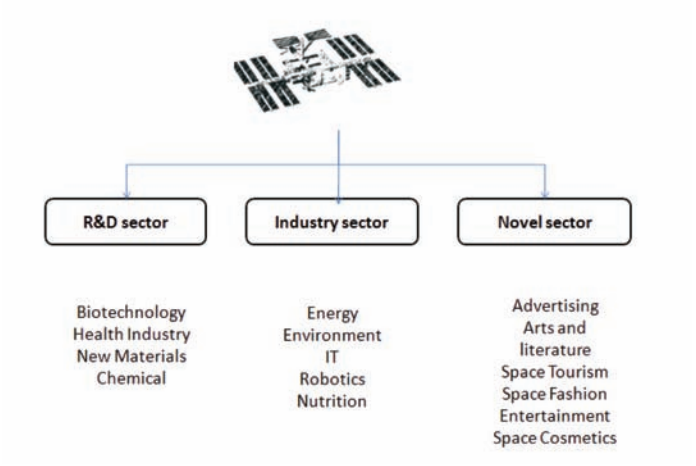
Finally, the *fifth (V)* approach is applying the criteria of *safety*, *reliability* and *technology innovation* which may be used as non-space companies could benefit from space product qualification and thus achieve reliability of their products or technology innovation. In this approach, it is important to look for *common relationships* between the non-space technologies and their customers and the space-based ones.

Institutional stakeholders might initiate a "top-down" market classification in order to be able to classify the prime industry and market sectors that will use space-based technology. However, non-space companies, on the other hand, may undertake a 'bottom-up' approach and develop industrial applications and projects. For example, companies investing in the development of sub-orbital transportation vehicles (i.e. Virgin Galactic), space tourism services (i.e. Space Adventures), low cost launchers (i.e. Space-X) and space tourism habitats (i.e. Bigelow hotel) need to have *strong business cases* in order to attract private funding. In order to sustain private investment and be able to generate 'economies of scale' these companies will need to perform *bottom-up market analysis* and *classification* and analyse the 'end-users' needs.

The different relationships and interdependencies between different market segments will have a *direct impact* on the development of *new industrial applications*, *technology innovation* and *future benefits*. Therefore,, market segmentation will be divided into three areas ***research*** and *development*, *industry* and *novel* sectors. Figure 2 shows an market segmentation between R&D, industry and novel sectors (i.e. encompasses also NewSpace activities).

Interdependencies between different market segments in the space tourism market can be observed. For example, the relationships between the different market segments lies in the fact that the idea for space tourism development was conceived in the *early days of MIR commercialisation* and was further developed by companies, such as MirCorp, Space Adventures and so forth. Later on, the launch of SpaceShipOne encouraged Virgin Galactic to commission the construction of SpaceShipTwo for sub-orbital flights. SS2 will be used not only for space tourist flights, parabolic flights and also for earth observation activities for NOAA (i.e. the US meteorological agency), will use it for targeting both the R&D and innovative markets and therefore, demonstrating the *relationships* between the R&D and the innovative segments. Another example is that the successful launch of SpaceShipOne and the future development of SpaceShipTwo by Virgin Galactic encouraged the

Figure 2. Market segmentation



development of tax preferences for developing new space ports (i.e the Spaceport America in New Mexico (FAA, 2008).

The state of New Mexico is building a spaceport and Virgin Galactic is expected to sign a 20-year lease agreement with annual payments of $1 million for the first 5 years. New Mexico state is expected to pay half of the construction costs. It will own and operate the spaceport and lease it to different users. The spaceport is planned to receive $140 million as direct financial support from the state and $58 million as support from the local government (FAA, 2008).

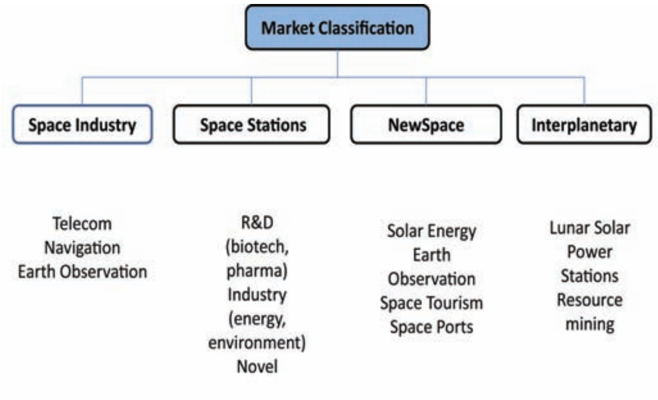
The *direct benefits* for the state of New Mexico will be in new market development, as well as employment and revenues from the leasing agreement. The indirect ones will be from *free publicity*, *technology innovation* and *international partnerships* with companies, such as Virgin Galactic.

The *relationships* between different market segments and the *interdependencies* of benefits will create a foundation for enabling commercialisation stakeholders, to create an easy and focused market segmentation and partially mitigate the risk of the lack of historic experience. Figure 3 shows an initial market segmentation is the initial segmentation into Space Industry Based markets, Low Earth Orbit (LEO) Space-Based markets, *New Space* and *interplanetary* space-based markets.

Bottom-up market classification, in *combination* with the criteria of safety, reliability and *technology innovation*, will ease not only the market segmentation but also the benefits identification for different stakeholders.

Early market classification will help the early identification of the benefits for future stakeholders in future industrial projects. As already discussed, the ISS markets are different from the future Moon and Mars ones, due to the different resources on-

Figure 3. Market segmentation classification



board space stations, Moon, Mars, Phobos and NEO natural resources. Thus, future companies involved in commercial projects using space-based technologies will be looking at exploiting different types of resources and developing new industrial applications, based on the use of these resources.

3.1.1. Space Industry

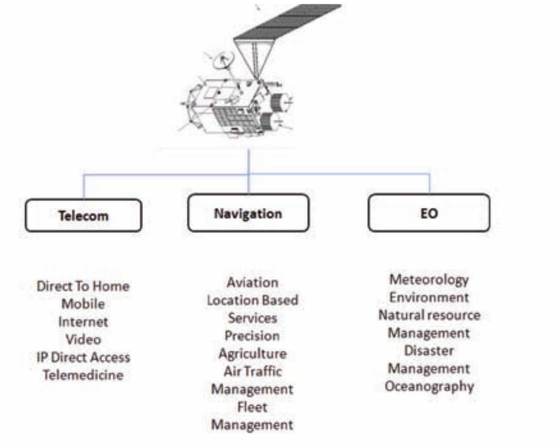
Telecommunications, navigation and earth observations systems are the prime market segments of the space industry. Navigation systems are essential for air traffic management, road transportation and shipping. Today air traffic control is much safer due to the wide use of GPS. Navigation systems are also used for location-based services of trucks, trains and tractors, precision agriculture and soil fertilisation, positioning of oil and rack platforms, GPS-controlled spreading of road-salt[7] and mapping of soil moisture[8].

Telecommunication applications are providing telephony, television and internet access packages to end customers. From 1000 satellites in space, one-third (i.e. 278 in 2008) are geostationary telecommunication ones and half the commercial satellites broadcast television. For example, 49% of French households receive their TV from aerial and 24% from satellite TV (CNES, 2010). In addition, telecommunication satellites are being widely used for the tele-medicine and education applications.

Figure 4 presents an overview of space market segments. The macro segments, such as telecommunications, navigation and earth observations are the primary ones and the micro ones are the secondary ones, such as environment monitoring, agriculture, energy and disaster management.

For examples, EO data can be integrated in Geographical Information Systems (GIS) or navigation services and thus, be used for disaster management applications.

Figure 4.Space industry market segmentation



In order to be able to identify and understand the direct and indirect benefits to space agencies and for aerospace companies and end-users of the services. The related market segment and industrial applications may be grouped together and the importance of a certain navigation, earth observation or telecommunication service could be marked with a *coefficient of importance*.

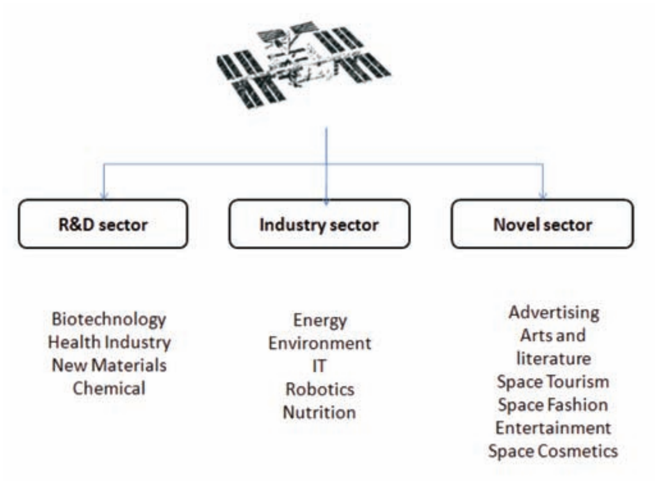
Certain space applications may develop faster than others for the future LEO or Lunar missions or be developed by space agencies spin-off technologies. Future applications related to energy resources, such as space-based weather forecasting and in-orbit advertising, may develop faster than others as they *may be* demand driven. Therefore, space applications linked to solar power generation and environment protection may develop faster than other applications.

3.1.2 Space Stations Markets

The space station LEO markets are linked to R&D experiments on board the ISS, such as drug development, micro-encapsulation, new materials development or development of TV shows and movies on board the space station (see Table 2), while the New-space LEO markets can be defined as sub-orbital flights (SS2), inflatable hotels (i.e. Bigelow[9]) or solar based satellites for solar energy generation.

In the early days space station commercialisation activities were chaotic and challenging, however with the ISS commercialisation. The ISS partners started to understand the importance of understanding customer needs and started to classify the markets according to ISS on-board facilities capabilities and new market opportunities. Figure 5, shows an overview of the industry sectors to which micrograv-

Figure 5 LEO space stations targeted industries



ity research on board the MIR or the ISS have brought benefits. *R&D sectors* deal primarily with research sectors (i.e. Biotechnology), the *industry sectors* include segments, such as nuclear or mining ones, that can benefit directly from space-based technology, while the *novel ones* encompasses segments, such as space tourism and space fashion.

Figure 5 shows a wide diversity of industry sectors that have different end user requirements, value chains and market applications.

Table 1 shows an overview of the space stations' targeted markets, particularly the industry sectors, the applications and the expected market size.

The direct and indirect benefits for companies involved in R&D and innovative markets will be different. For example, a robotics company involved in the development of robotics for a Lunar or Mars rover may partner with a medical equipment company for designing and developing *robotic tools* that will be used by astronauts on-board the space station or used for the construction of future Lunar habitats. The new space-qualified robotic tools can also be sold by medical equipment companies. Thus, both the robotics and the medical equipment companies will enter new markets, generate increased revenues from sales and achieve *technology interoperability* and *reliability* (i.e. direct benefits) as well as enjoy indirect benefits derived from *technology innovation*, *free publicity* and *international partnerships*.

3.1.3 New Space Markets

The New-Space targeted markets have historically developed from the MIR and ISS commercialisation (see Chapter 2). The relationships between the different

Table 1. Space station targeted markets

R&D Industry Sector	Industrial Applications	Market Size
Health Industry		
Drug Development Osteoporosis Medical Scanning equipment Sports equipment Cancer Research Physiological studies	New drug development, micro-encapsulation Bone microstructure measurement Preventive drugs /therapies, cartilage degeneration Hip, spine, ultrasound diagnostics equipment Radiation impacts on human health for nuclear energy Preventive drugs and therapies	In 2050, the total direct costs from osteoporosis is expected to reach 76.7 Billion Euros in the EU (I.O.F, 2005) Development of preventive cancer drugs and therapies for human space flight mission will need to be addressed for future Lunar, asteroid and Mars missions
Cell & tissue engineering Bone formation	Bioreactor development In-vivo diagnostics Effects of drugs on bone cell activity	ESA ERISTO project [10] Freqbone experiment on board the ISS
Lighter and stronger materials for aviation and automotive industries	Light weight materials Novel casting alloys Bio-materials High-temperature ceramics Self-healing materials Nano-materials	
Solar energy In-situ resource exploitation	LEO solar satellites LEO space solar stations	
Waste Management Closed Life-Cycle Systems	Water purification methods ESA Melissa project	ISS water recycling (astronauts drinking re-cycled water)
Software development	Requirements integration, operations and procedures management for TM/TC data management	Software solutions for SCADA systems management
Oil recovery	Monitoring oil recovery	Measuring thermo diffusion processes and the Soret effect=SCCO of crude oil
Tele-medicine Mining industry Nuclear industry Security industry	Neurosurgery Robotics for mining Nuclear industry Collision detection	MDA is working on spinning off its robotics experience for developing a robotic tool for neurosurgery (MDA, 2009)
Food industry	Food processing preservation and nutrition	
Novel sectors		
Advertising	Pepsi adverts Pizza Hut on Proton launcher Space Yoghurt Space Beer	Pizza hut advert on the Russian Proton launcher Richard Branson Volvo advert
	Space Art and Poetry	Culture
Gaming Movies TV shows	Virtual Lunar Gaming Board Games Space Wii	Open source software similar to Linux. Having open source results in reducing costs, sharing information, preventing duplication of data.

continued on following page

Table 1. continued

R&D Industry Sector	Industrial Applications	Market Size
ISS flights SpaceShipOne flights Lunar Hotels Space Ports Parabolic Flights Space fashion	Japanese company looking at using Lunar sand for building hotels Space Adventure offering as a future package Lunar trips.	The Russians plans to keep the Russian ISS modules after the end of the ISS and assemble them in LEO. This will be used as a basis for the Orbital Piloted Assembly Complex (OPSEK) that will be used as a basis for future Moon and Mars explorations. The Bigelow company may discuss with NASA to attach an inflatable module to the ISS for space tourism activities

segments, as discussed earlier can be observed in the space tourism area. Space tourism is expected to grow up to $1 billion by 2021, with around up to 15,000 sub-orbital tourists for 2021 and orbital ones of 60 for 2021 (Futron, 2002), this new trend has already encouraged the creation of new market segments, such as space ports creation.

In Europe, a group of Dutch entrepreneurs have initiated the construction of a space port called the Caribbean Space Port based in the Dutch Antilles island of Curacao. The idea behind the space port construction is to attract not only the space tourists for sub-orbital flights, but also their families for a week of leisure activities at the island (Wielders, 2009) thus, generating indirect economic benefits to the regional economy.

The increase of energy use in the last few years, as well as increased pollution and expected energy crises, have instigated the development of alternative energy concepts, such as Space-Based Solar Power (SBSP). The concept behind Space Based Solar Power (SBSP) can be generated when a satellite is launched in LEO and collects solar energy, that is converted into electricity by "photovoltaic" solar panels and then is transmitted the energy to ground based stations through microwaves or laser waves.

Each satellite is expected to deliver around one gigawatt of power (1GW) (Energy, Space Based Solar Power, 2009). The company "Space Energy", which is developing the project, has raised private funding to finance a satellite demonstrator that is expected to cost around 300 Million Euros (Sage, 2009). The success of a project such as this may result in a new technology trend in the use of space-based solar power and lead to the development of future solar power satellites funded by private investors and institutional users and therefore, is chosen as a case study in Chapter 9.

The possible targeted markets that can develop from commercialisation of ISS projects are the following.

Table 2. New-Space Markets

Industry Sector	Market	Industrial applications	Remarks
R&D sector			
Energy	Space Solar Power (SSP)	Clean energy provision	Energy Market Demand
Biotechnology	Pharmaceutical companies New drugs development	Pharmaceutical companies may be launching their own experiments to be tested during parabolic or sub-orbital flights	For example, space tourists may cooperate with pharmaceutical companies and perform some of their experiments on-board the ISS
	Laser Power Stations (LSP)		Japan is already developing LSP
Zero-G R&D	Foton Capsules		
	Parabolic Flights	Experiments Flight Tourists	
Earth Observation	Sub-orbital transportation vehicles	SSP2 for climate change monitoring	Virgin Galactic signed an agreement with NOAA for carrying their SS2 sensors for monitoring climate change
Nutrition	Space Food	Space Yogurt Space Beer	Space Food for space tourists
Innovative			
Tourism	Sub-orbital tourism	SpaceShip Two flights Armadillo Aerospace	VG will be using SS2 for its flights Space Adventures will be using the services from Armadillo Aerospace
	Launch of micro-satellites	Sub-orbital vehicles may also be used for launching micro-satellites with a mass of less than 200 kilos	
	Space Ports	Mojave space port is under construction	In Europe, the Caribbean Space Port, a project being driven by a group of Dutch entrepreneurs (Wielders, 2007)
	Space Hotels	Inflatable hotel in LEO Space stations for tourism	Bigelow inflatable hotel
	Space Fashion	Space clothes Space shoes	Japanese space designer for space tourists

Predicting which industry sectors will develop and grow will be a difficult task due to the lack of historic information and the unpredictable nature of emerging markets. Therefore, identifying the benefits from which different industry sectors (i.e. R&D) will benefit will be a challenge. Nevertheless, an initial expectation of the benefits in the different sectors can be made. For example, in the biotechnology sector, health industry *technology interoperability*, *reliability* (i.e. direct) and *innovation benefits* (i.e. indirect benefits) may be most important.

In contrast, the novel sector, for space brand advertising and fashion sectors in particular, new *market development* (i.e. direct benefits), *free publicity* and *international partnerships* (i.e. indirect benefits) will be more important than technology interoperability. Once commercialisation takes off, future benefits may be *grouped under* the R&D, industry and innovative markets, thus easing the understanding of future benefits for stakeholders from their participation in projects using space-based technology from future interplanetary missions.

3.1.4 Interplanetary Sectors

Interplanetary sectors encompass the use of space-based technology for the extraction of natural resources that are on the Mars, asteroids or Phobos and Deimos. Therefore, in this section, there will be a short description of the possible uses of space based technology and interplanetary resources from different missions.

The Moon being 380,000 kilometres away from Earth, has always captured the imagination of humankind. In 2004 the US presented their plan to return to the Moon and for the creation of a Lunar habitat. That was later cancelled in 2010 by the Obama administration. Nevertheless, one of the questions that arises is whether Lunar planetary resources, such as Helium -3 can be widely used for fusion fuel. Some of the following resources can be exploited from the Moon, asteroids and the Martian moons Phobos and Deimos (Lewis, 2009).

- Oxygen for propellants and local life support
- Ferrous metals for local construction
- Helium - 3 for fusion reactors
- Oxygen from ilmenite
- Solar wind gases from ilmenite
- Minerals, volatiles, platinum and cobalt mining
- Water on the Lunar poles that can be used for generating oxygen and supporting a lunar base (Ghose, 2010)

Planetary resources can be used for the construction of Lunar Solar Power Stations (LSPS) for power generation. For example, an asteroid of 1 mile in diameter may contain precious metals worth $20 trillion (Lewis, 1997) and may be of interest to mining companies. Exploiting the natural resources of Phobos and Deimos may become an attractive opportunity due to easier orbital access, resource processing opportunities and for frequent launch possibilities (O'Leary, 1985).

Finding water on the Moon may completely change the Lunar space exploration scenario and in the upcoming years construction for Lunar bases to become a reality due to the possibility to develop long term Lunar base.

Potential evidence of *interplanetary resources* will encourage non-space companies to develop new technologies, products and processes and these companies will develop industrial projects that will attract private investors. They will gain direct benefits from new market developments and technology innovation and cost savings from improving or developing new production processes.

One of the *new areas* in which new market applications can be developed is in commercial interplanetary robotic exploration and space tourism activities. Lunar space tourism may be of strong interest to companies involved in offering space tourism services. For example, Space Adventures is offering a Lunar trip around the Moon to its customers for a price of $100 million (Adventures, 2010). In addition, certain companies have even investigated the possibility of constructing lunar hotels for future lunar space tourists. These new market sectors may never even develop, but the fact that companies are already offering trips like this one *indicates* consumer interest.

The Google Lunar X-prize is an international competition for encouraging the construction and the launch of a lunar probe that will take images of the Lunar surface. The prize is of $30 million for the team that succeeds in constructing and landing a lunar probe that can travel 500 meters over the lunar surface and send back images of it to Earth (Foundation, 2010). There are already more than 18 teams competing worldwide until the deadline set of December 31st, 2014.

The teams competing for the Google Lunar X-prize will *generate benefits* from participating in this competition. For example ones such as *technology innovation*, *free publicity* and *international partnerships* (i.e. *indirect benefits*), will be the first benefits which the teams will gain, followed by new market development and increased sales and new space applications in the area of lunar gaming and entertainment may develop.

Private companies competing in the Google Lunar X-prize or being involved in lunar space tourism activities will gain *direct benefits* from new market development and *indirect ones* from free publicity, technology innovation and international partnerships.

4. FUTURE PRODUCTS AND SERVICES CLASSIFICATION

The future products and services definition from future commercial crew and cargo transportation services and from future interplanetary missions will have to be user-friendly and easier to understand by non-space companies.

Future interplanetary markets will be so diverse, that it will be difficult to classify the expected products and services and for each space mission (i.e for LEO, Lunar and Mars missions) they will be common and different. The *relationship* and the *interdependence* of the different market segments will *influence* the products and services classification.

Proposing a generic classification under space, launch, ground and applications segment will permit future stakeholders involved in the industrial utilisation of space-based technology to choose the relevant services to use for improving their products, services or processes.

- **Space segment**: products and services, such as the R&D payloads, on-board control software solutions, astronaut services and other services used on board space stations for operating commercial payloads. necessary for certain commercial projects
- **Launch segment**: includes the choice of launchers Soyuz or Ariane 5 launchers
- **Ground segment**: test laboratories, facilities, ground segment operations, software solutions for TM/TC data management
- **Space applications segment**: includes the development of applications as a result of being flown on board the ISS. for example water waste recycling process that was developed under ESA Melissa project at present has been successfully spin-off in a project for water waste process management

The above classification of future space-based products and services will permit the space agencies, service providers and end-users to identify benefits that they will gain from the commercial use of space technology. In addition, they will be able to identify the areas in which they can develop technology reliability and interoperability *(i.e direct benefits)* and technology innovation *(i.e. indirect benefits)*.

5. DISCUSSION

The development of new markets and space applications, will result in different benefits for national economies and for space agencies. Understanding the benefits from space applications will permit private companies to perform cost-benefit analyses, develop viable business cases and attract private funding.

There is a clear *lack of a consistent approach* for market segmentation, as new markets using space-based technology are in the nascent stage of market development where customers and profits are unknown. The identification of future markets and applications from the use of space-based interplanetary mission technology is a challenging task as human space-flight is a very diverse sector of the space industry and the commercial crew and cargo services market is at the emerging state of development. Commercialisation of space based technology is a pioneering process, as there is a lack of historic data, first time customers and benefits definition.

The biggest issues linked to targeting the different industry sectors is the *diversity* of the targeted markets and the difference in their value chains. Therefore, when segmenting the targeted markets for future interplanetary missions, it will be important to identify *common* relationships and patterns between different segments, such as health and nutrition. Thus, enabling project stakeholders to create focused and easy segmentation and identification of interdependencies between different benefits. The relationship between the different markets will have a direct impact on the development of *new space applications*, *technology innovation* and *future benefits.* Therefore, the market segmentation classification is based on space industry, space stations, New Space and interplanetary exploration.

The market segmentation will not be the only challenge in targeting future customers, but also the definition of future products and services will be a challenge. The relationship between the different market segments will *influence* the products and services classification. Therefore, in this chapter a generic classification was proposed for future products and services under space, launch, ground and applications segments. This type of classification will permit future stakeholders to identify benefits they will generate from the commercial use of interplanetary space technology.

For certain markets, the benefits such as R&D technology *interoperability*, *reliability* and *innovation* may be of bigger importance for others. Once commercialisation takes off, future benefits may be grouped under the R&D and innovative markets, easing an understanding of future benefits for stakeholders from their participation in projects using space-based technology for future interplanetary missions.

Forming a generic classification under space, launch, ground and applications segments will permit to future stakeholders to choose services to use for improving their products, services or processes. In addition, they will be able to identify the areas in which they can develop technology reliability and interoperability *(i.e direct benefits)* and technology innovation *(i.e indirect benefits)*.

For certain markets, the benefits will be R&D technology interoperability, reliability and technology innovation and will be of bigger importance than others.

Once commercialisation takes off, future benefits may be grouped under the R&D and innovative markets, easing an understanding of future benefits for stakeholders from their participation in projects using space-based technology for future interplanetary missions. That may even result in developing space applications, such as solar power generation and others.

Long-term financing is a *critical step* for funding a sustainable human space flight program. In order to attract industrial projects, space agencies will have to create a user-friendly environment, offer companies access to IPR rights and also give fast approval of industrial projects, thus encouraging non-space companies to launch industrial projects. Nevertheless, these companies will have to foresee the direct benefits from cost savings from using space-based technology and easier ways to "time-to-market". Initially, companies may be willing to make short-term investments in the projects and if there are sufficient bank guarantees, they may become interested in investing in longer-term projects.

6.CONCLUSION

There will be different benefits for the different stakeholders as new emerging markets such as space solar power generation, medical drugs development, new materials development and sub-orbital space tourism start to develop.

Nascent and *frenzied* stages of market evolution will be most important for private companies with commercial projects. The nascent and frenzied stages of development will bring different benefits to the institutional and commercial stakeholders. Understanding the benefits from industrial projects will permit the stakeholders to perform cost benefit analyses in order to assess different project options and attract private funding.

The direct and indirect benefits for companies involved in R&D and innovative markets will be different. For example, a robotics company involved in a project that is flown on board the ISS, may partner with a medical equipment company for designing and developing medical robotic tools that will be used by astronauts on board the space station or in future Lunar habitats. The new space qualified robotic tools can be also sold by medical equipment companies. Thus, both the robotics and the medical equipment companies will enter new markets, enjoy increased revenues from sales and achieve technology interoperability and reliability (direct benefits). In addition, they will gain indirect benefits, such as free publicity and partnerships.

The proposed primary market segmentation is the initial segmentation into Space Industry-Based markets, Low Earth Orbit (LEO) Space-Based markets, *New Space* and *Interplanetary* and NEO space-based markets. The *space industry markets* include primarily space applications from telecommunications, navigation and earth observation systems. For example space applications, such as location based services, precision agriculture, air traffic management (ATM), fleet management, oil and rack positioning use navigation systems, earth observation space applications, such as meteorology, environment and disaster management monitoring.

The *LEO markets* are linked to research performed on board the ISS, such as drug development, osteoporosis therapies, micro-encapsulation, development of light weight and nano-materials or applications linked to telemedicine. In addition under the LEO markets there are novel markets being developed such as the ones of space tourism, entertainment and edutainment.

Furthermore, the *New Space* markets were also developed from MIR and ISS commercialisation, but the projects in this market have been primarily funded by private capital. The *New Space* markets cover space tourism, solar power satellites, space ports construction and development of sub-orbital transportation vehicles.

Finally the *interplanetary* markets encompass the use of space-based technology for extraction of planetary natural resources from asteroids or use of Helium-3 for fusion fuel or exploitation of natural resources of Phobos and Deimos.

Forming a *generic classification* under space, launch, ground and applications segments will permit future stakeholders to choose the relevant services to use for improving their products, services or processes. In addition, companies involved in those types of projects will be able to identify the areas in which they can develop technology reliability and interoperability *(i.e. direct benefits)* and technology innovation *(i.e indirect benefits)*.

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ENDNOTES

[1] For commercial projects on board the ISS space agencies are responsible accommodating the experiments of private companies and therefore space agencies will generate technology interoperability.

[2] These are applications under which space technology serve citizens, such as food management, healthcare, urban planning and management (Doldirina, October 2007) etc.

[3] These are applications that deal with disaster management, assessing risks of natural disasters, air and traffic management (ATM), national security (Doldirina, October 2007)

[4] Technology resources refers to the ISS on-board facilities, such as Fluid Science Laboratory(FSL), Material Science Laboratory(MSL), Biolab, etc.

[5] Commercial benefits are measured by revenues generated by the service and the number of customers or subscribers.

[6] The value added for non-commercial ones is measured through the benefit for the final users and the volume of activity generated (i.e. employees, users, measurable output, etc.)

[7] In the French Alps was tested GPS-controlled spreading of road salt (CNES, 2010)

[8] The GPS signals were used for mapping soil moisture and snow thickness (CNES, 2010)

[9] For example, Bigelow generated revenues through flying business cards their inflatable hotel .

[10] The objectives of ERISTO are to develop innovative models of osteoporosis either through In-Vitro or In-Vivo diagnostics and using the unique benefit of space environment to provide “mechanical stress free” experimental conditions and to improve diagnosis, prevention and treatments of the osteporosis disease (ESA, 2010).

Chapter 6

Competitiveness of Space Industry

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"The intensity of the competition in an industry is neither a matter of coincidence nor bad luck. Rather, competition in an industry is rooted in its underlying economic structure and goes well beyond the behaviour of current competitors."

Michael E.Porter, Chapter 1: The Structural Analysis of Industries, Competitive Strategy

1. INTRODUCTION

Space industry is dominated by the rules and regulations of its institutional customers. High market-entry barriers, complex procurement rules, technology-driven competition and buying rules define the space market segmentation. High interdependence between players, high market-entry barriers, ongoing mergers and acquisitions and the small number of players indicate the existence of an oligopoly market structure.

Export regulations, licensing, ITAR and EAR regulations are some of the market-entry barriers which space companies have to face. These barriers will not only result in revenues losses from sales for space manufacturing companies, but they will also influence the direct and indirect benefits from commercial utilisation of space-based technology from interplanetary missions and future commercial and crew and cargo transportation services. This chapter will analyse the competitiveness of the space industry, discuss the market structure in the space industry, the market-entry barriers and the space-related patents and partnerships.

2. COMPETITIVENESS IN SPACE INDUSTRY

Competitiveness measures the ability of a firm to sell and supply goods and services in a market. For example, a country that has diverse launch capabilities and has foreign customers that use their launcher technology can have a high level of competitiveness in the launcher market.

There are various approaches for measuring foreign space industry competitiveness, either by measuring national exports/sales from space technology or national R&D or as a percentage of national GDP. Exports can have a direct influence on the export trade balance of a country as can be seen for Russia (see section in Chapter 4). On the other hand R&D investment measures whether a country aims at encouraging national competitiveness or economic growth through technology innovation.

The *interdependency* of the space industry stakeholders (see Chapter 4) in combination with the *high concentration ratio* in the European space industry and the *high market entry barriers, imply* the existence of an *oligopoly market structure* in the European space industry.

Oligopoly[1] is described as a market structure in which there are a *few players* (i.e. EADS Astrium, TAS) that *sell homogeneous products* and *services* and there *are high market-entry barriers.*

The oligopoly is referred to when there are very few dominant players on the market. For example, the European space manufacturing industry is very concentrated and 70% of the space industry employment is distributed in only four main groups (i.e. EADS, TAS, Safran and Finmeccanica). Market-entry barriers in the space industry are different for each country. For example, in the US market-entry barriers are considered to be ITAR regulations, while in Europe it is primarily ESA geographical return rule.

The competitive forces in a typical market are: *threat of new entrants, bargaining power of buyers, bargaining power of suppliers and threat of substitute products and services* (Porter, 1980). Companies developing commercial projects using space-based technology from future interplanetary missions may be driven by the forces above to find new ways to improve their products and processes. Therefore, these forces can have an indirect influence upon the direct and indirect benefits from the commercial use of space-based technologies for future Moon and Mars missions.

Space agencies are the prime initiators behind institutional programs, technology innovation and competition is limited (e.g. especially for launchers), there is mid-term stability and prices are negotiable. However, once the companies involved in the provision of commercial cargo transportation services become suppliers to NASA they may gain the *power of suppliers* and thus, in the future influence prices for launch services.

After the retirement of the Space Shuttle in 2010, Russia will be the only country providing astronaut transportation to the ISS. Therefore, they will be selling Soyuz seats to NASA and will have *the bargaining power of* suppliers for Soyuz seats to the ISS. Thus, they can influence *price*, *quality* and *terms* (Porter, 1980). The Russian space agency already used its *bargaining power* as a *supplier* and proposed a price of around $51 million per astronaut seat to NASA (Travel, 2009) which is higher than the price per space tourist which is around $29 million per tourist.

Therefore, the Russians may not only change the prices for NASA astronauts but also re-negotiate the *terms* of the ISS Memorandum of Understanding (MOU) and gain increased access to ISS on-board resources (i.e. US Destiny laboratory), such as power and communications links. NASA will need to be aware of the different possibilities of being charged higher prices and being exposed to potential changes to the terms of the ISS MOU.

Competitiveness of space-based systems can often be exposed to the technological competition from *terrestrial technologies*. Several examples of such competition can be found in the areas of telecommunications and protein crystallisation projects.

The Iridium satellite telecoms system was designed in the late 1980s when cellular telephones did not exist. Motorola was the prime investor in Iridium and for the first time in history, 66 satellites were built on a production line. However, by the time the system was built and operational in 2000, cell phones were everywhere and customers were paying symbolic prices per minute in comparison to Iridium's 3$ per minute. Due to the low subscription rates Iridium had to file for bankruptcy and the system was sold to the US Military. The Iridium case demonstrated that *technology innovation* by itself is not sufficient and that competitive technologies from *terrestrial suppliers should be considered* when launching a commercial project using space-based technologies.

In the mid 1990s', there were several studies demonstrating that protein growth in a zero-gravity environment is faster and more efficient due to the lack of gravitational forces. However, just a few years later, it was proven that protein crystal can be grown in ground-based laboratories. So, in a way, the competition from ground-based laboratories for protein crystallization growth destroyed the case of protein crystal growth on-board the ISS.

Competition in the space industry can be introduced *primarily from terrestrial technologies*. The long-time scale of space missions, the anticipated lengthy "time-to-market" and the high cost for the use of space-based technlogy, makes ground-based technologies more attractive. Therefore, for non-space companies considering investing in projects that will use space-based technology, it is important to understand the direct and indirect benefits for their project from the use of space-based technologies. Non-space companies will have to *understand* and *evaluate* the benefits of space-based technologies as opposed to ground-based ones.

The driving forces of competition will encourage companies to strive for technology innovation and cost savings and companies will aim at combining the use of space-based and terrestrial technologies for their commercial projects.

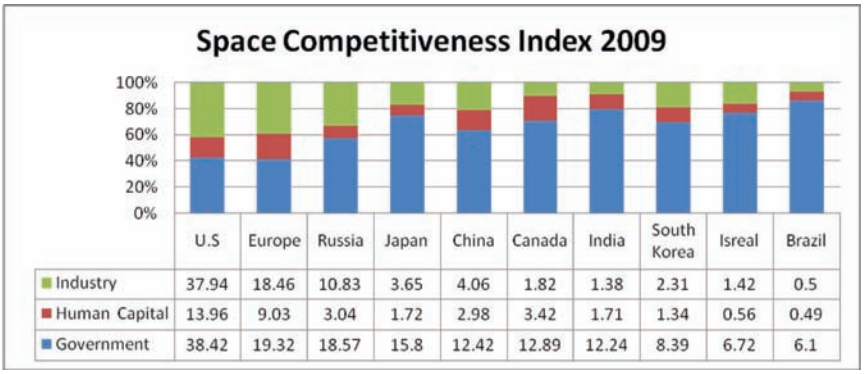
The competitiveness of national space industries is influenced by its institutional customers in the industry. Strong interdependencies between space industry stakeholders, high concentration ratios and market entry barriers demonstrate the existence of *oligopoly market structures*. Nevertheless, space markets are also exposed to the traditional market driving forces (i.e. threat of new entrants, bargaining power of buyers and suppliers, threat of substitute products and services, etc.). Russia is implementing its bargaining power as supplier to NASA and it will possibly re-negotiate the terms of the ISS MOU and gain access to additional US ISS on-board resources.

2.1 Space Industry Competitiveness Index

Certain companies have set up a space industry competitiveness index (SCI). This index measures three major dimensions in the space industry: government, human capital and industry, in several space countries (e.g. USA, Europe, Russia, Japan, Canada, India, China, South Korea, Israel, Brazil) (Futron, 2009). The aspects measured for *governments* is their ability to provide structure, guidance and funding in the space industry. The *human capital* aspect measures the national capability to develop relevant competencies and attract the people with the relevant competencies for these programs. Finally, the *industry* aspect measures the capability of the industry to finance and deliver space products and applications (Futron, 2009). Figure 1, shows an overview of the space industry competitiveness index for several countries.

The US has the highest SCI index, but it could be misleading. For example, the ESA budget corresponds to around $3.6 billion for 2009 while NASA's corresponds to around $14 billion (Eurospace, 2010) (see Chapter 4). So, in a way, ESA in the aspects of guidance and structure may be considered sufficiently competitive. A similar approach can be applied when comparing the Russian government's competitiveness with that of ESA or the US one. The difference between European and Russian competitiveness is less than 2 points, but Russia's 2009[2] budget is three times smaller than ESA's for 2009. The Russian space industry may be considered very competitive in comparison to the European one. This is due to the inherited launch infrastructure from Soviet times and to *unique engineering competencies* and *lower labor costs*. After the retirement of the Space Shuttle, Russia will be the

Figure 1. Space competitiveness index (Futron, 2009)



	U.S	Europe	Russia	Japan	China	Canada	India	South Korea	Isreal	Brazil
🟩 Industry	37.94	18.46	10.83	3.65	4.06	1.82	1.38	2.31	1.42	0.5
🟥 Human Capital	13.96	9.03	3.04	1.72	2.98	3.42	1.71	1.34	0.56	0.49
🟦 Government	38.42	19.32	18.57	15.8	12.42	12.89	12.24	8.39	6.72	6.1

only country providing human space-flight access to the ISS and therefore, will increase its competitiveness in the launch industry.

Figure 1, shows that the USA is the leader in Worldwide space industry competitiveness, followed by Europe and Russia. However, this index measures the general competitiveness of the space industry and not national competitiveness by market segments, such as telecommunications, launchers, navigation and earth observation.

For example, in the navigation sector as already discussed in Chapter 4, GPS is at present the most reliable service available for civil and military applications. Therefore, at present, and with the expected new updates with GSP-III, the US is the most competitive in a worldwide context, in contrast to Europe which is still designing its system and whose launch has already been delayed[3] to 2013. However, after 2013 Europe's competitiveness in the navigation market may increase once the system becomes operational as the Galileo system is expected to provide five different service signals (open services, safety of life, public regulated services, etc.) for various end user groups.

For example, in the launcher industry US competitiveness in institutional markets *will reduce* with the retirement of the Space Shuttle in 2010 but *may increase after 2011* with the new NASA investment in the development of key-enabling technologies and commercial crew and cargo transportation services. As a result of the new NASA COTS program (see Chapter 1).

National space industry *competitiveness* will change in the context of the NASA 2011 budget and the US space industry role in the development of *key-enabling technologies* and *commercial crew and cargo services development.*

Space industry competitiveness is an important macro-economic indicator that influences national export trade balance. Therefore, governments and national space agencies will have to clearly define ways to measure national competitiveness, as measuring it will also contribute to a better understanding, not only of the benefits that national space programs bring to national economies, but also of the influence they have upon space industry competitiveness.

3. SPACE INDUSTRY ORGANISATION

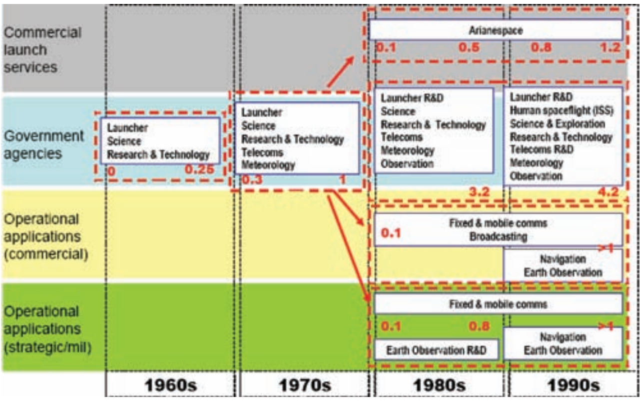
The space industry is organised to provide products and services to national space agencies and institutes. As already discussed in Chapter 4, it is an industry where there is political, strategic and technological interdependance between stakeholders. This *interdependance* is combined with high market-entry barriers and a few dominant players on the space industry arena. The dominant players tend to be the industry's system integrators that have developed unique competencies and thus, generating direct benefits from new market development and technology interoperability.

Figure 2, shows an overview of the European space industry interdependence.

The market segmentation in the space industry is defined by the end customers (i.e. institutional or commercial). Thus, often it is market segmentation driven and based on national interests and therefore, results in the duplication of competencies and technologies. This *duplication* is often encouraged by space agencies that strive to create a higher number of suppliers from which to choose when searching for certain competencies. Due to this duplication, space agencies will be able to generate technology reliability and interoperability (i.e. direct benefits) and technology innovation (i.e. indirect benefits).

For example, Europe developed its launch capabilities only after its decision to launch the Ariane program on July 31st1973 (Villan, 2007). This decision was a result of the US decision not to launch commercial satellites and the US resistance to Europe's need for independent launch services. The launch of the Ariane

Figure 2. European space industry stakeholders (Lionnet, 2008)



programme marked the beginning of Europe's *leadership* in offering commercial launch capabilities to commercial customers. Later, at the beginning of the 1980s, Arianespace was created, which became the commercial launch operator of Ariane (see Chapter 4).

At present in 2010, the Ariane launcher is the only heavy launcher (10 tonnes) that offers commercial launch services. Thus, the Ariane program demonstrated how space companies' early involvement in the development stage of a programme can result not only in the development of competencies, but also in guaranteed long-term business.

Clearly in the area of launchers a political decision encouraged Europe to tap into and develop a complete new market niche, resulting in direct benefits for the European economy of employment, development of new markets, technology reliability and interoperability. In addition it resulted in international cooperation between European nations who are stakeholders in Arianespace. The Ariane program provides not only strategic independence for Europe but also technology innovation benefits.

Arianespace operates in an *oligopoly market structure* and as market leader in the provision of launch services for heavy commercial payloads generates direct and indirect benefits.

Space industry market segmentation is driven by national interests and therefore there is often duplication of competencies and technologies. Nevertheless, for several years now, ESA has initiated a new activity linked to the harmonization of European competencies and technologies. However, it is possible that space companies oppose the harmonization process *in fear* of losing their positioning in their market and loosing benefits.

Space companies have an interest in being in a protected under an oligopoly market and therefore, they will not be strongly motivated to introduce competitiveness in their traditional markets. Therefore, they may even be able to identify the direct and indirect benefits from sustaining the oligopoly market structure.

4. GLOBAL SPACE MARKET COMPETITIVENESS

The institutional customers in the space industry define the market entry barriers in the industry. The market-entry barriers are the conditions under which new companies can enter a certain industry or market. These barriers can be regulative or legal or others, such as procurement rules for companies interested in supplying agencies with their products and services. Satellite manufacturing is the sector most influenced by ITAR regulations. Certain studies report a reduction in the US share of global satellite manufacturing, since the ITAR implementation. For example, for the period of the 1996-1998 the market share corresponded to 63%, for 1999-2001 to 52% and for 2002-2006 to 42%. This reduction has resulted into a loss of around $2.4 US Billion average revenues for the US satellite manufacturing industry since 1996 until 2006. (Industry, 2007).

However, ITAR regulations *created new markets* for non-US companies like the Thales Alenia Space (TAS), EADS Astrium and others. In order to mitigate the ITAR regulations, many non-US companies started developing their own capabilities and technologies and therefore, increased their *technology innovation* and *competitiveness*.

In some respects, the ITAR regulations increased security, but in others had a *knock-on effect* of reducing manufacturing revenues for US companies, and encouraging the *increase* of the non-US manufacturing revenues.

NASA's 2011 budget will encourage the development of key enabling technologies and commercial crew and cargo services. In the context of these new developments, the US will have to perform a feasibility analysis of the impact of ITAR regulations upon their development as there is potentially a *threat* for the US space industry that critical competencies and technologies (i.e. lunar orbiter, landers, lunar rovers, habitats, etc.) for these technologies be developed by non-US companies. Not only due to ITAR regulations, but also due to the interest of these companies to develop competencies and technologies independently from the US.

National and multi-national space agencies usually apply policies and rules that encourage European technology to be sold to European customers and US technology to be only sold to US customers. These policies and rules can also be described as market-entry conditions for entering the space industry.

ITAR regulations for US defence and aerospace technology

- **ESA geographical return rule:** related to the fair return of national investment in ESA, meaning the value of ESA contracts have to correspond to each ESA national member state's investment.
- **Standards:** national space agencies have certain software or manufacturing standards, that are required from suppliers. Often, national agencies have a list of suppliers who are the only ones with permission to provide products and services to the agencies (ECSS, military standards, etc.).
- Complex procurement rules which are familiar only to a few suppliers and result in the space market being closed.

US companies consider the ITAR regulations as a prime foreign market-entry barrier (58%) and they find entering the French (20%), German (15%) and Chinese markets (15%) as most difficult (Industry, 2007)

Due to strategic national interests and policies, many countries have developed competencies that are similar, but use different technological solutions. For example, three countries have developed human space-flight launch services, but have different launch systems; the US has the Space Shuttle, Russia has the Soyuz capsule and China has the Shenzhou capsule.

The high market-entry conditions are due to the high safety and quality standards required by space agencies. These conditions actually result in space industry stakeholders actively being exposed to technological competition, rather than a market-driven one.

4.1 Technology Innovation in the Context of ITAR Regulations

In the space industry, *technology innovation* is one of the prime prerequisites for the success of each space mission. ITAR regulations are relevant for non-US companies using ITAR-registered technology or US companies that export technology. As export licensing has a direct impact upon space companies' profitability, companies have lost revenues of around $2.35 Billion from 2003 until 2006 due to ITAR regulations (Industry, 2007). The export regulations primarily influence (7.7%) companies who are smaller and earn below $5 Million as space sales for 2006 (Industry, 2007). For example, Bigelow Aerospace suffered from the ITAR regulations. When they were launching their expandable Pathfinder spacecraft - Genesis I and Genesis II in Russia and the company had to pay $160,000 for Genesis I and $150,000 for Genesis II for ITAR monitoring and reviews (Communis, 2008).

Therefore, companies under ITAR regulations are *exposed* to the *risk* of *not having sufficient* funding for R&D projects or for *maintaining their competitiveness*. This risk may be of *significant importance* for US space companies involved in the development of key-enabling technologies and commercial crew and cargo services as they may experience ITAR-related costs and strong competition from European or Russian companies.

US companies have *already* lost potential benefits from revenues stemming from the sales of new satellite buses and indirect ones from technology innovation. Therefore, European manufacturers have developed new technologies and capabilities due to the ITAR regulations and European investment in new technologies (Industry, 2007).

The export ITAR regulations encouraged the creation of direct benefits for European, Russian and Chinese satellite manufacturers, ones such as new markets, revenues from sales. NASA's new strategy will encourage international cooperation with space agencies such as the Roscosmos, ESA, CSA and JAXA. The Obama administration may *re-assess* the US policy towards the ITAR regulations and consider issuance of licenses for space-related exports on a case-by-case basis (USA, June 28, 2010).

However, until the administration does not change its policy towards the ITAR regulations, other space agencies may start aiming at developing parallel programs for encouraging the development of key enabling technologies or commercial crew and cargo transportation services.

For future interplanetary mission, the ITAR regulations will prevent NASA from *gaining access* to the best worldwide technology solutions for future interplanetry missions. US space companies *may experience* a loss in technology innovation, international partnerships (i.e. indirect benefits) and access to new markets in Europe, Asia and others, thus experience a decrease in their sales revenues (i.e. direct benefits). While European or Russian companies will be *gaining benefits* from new market development, increased revenues, technology interoperability (direct benefits) and technology innovation and international partnerships (indirect benefits) due to new competencies and markets which have previously been US ones.

4.2 ESA Geographical Return Rule

Europe's space agency is managed by 18 ESA member states[4] and each member state funds the activities of the agency. Member states allocate funding to ESA programs based on their R&D needs and national competencies and later a part of this ESA budget is allocated back to the national space companies in the form of contracts. ESA national delegations make sure that the interests of their companies are protected and materialised in returned contracts from ESA to their national industries.

ESA's prime objective is to encourage European space industry competitiveness and at the same time, maintain the fair return of national investment in regional space companies.

ESA "geographical-return rule" is used when the value of contracts granted to national space companies corresponds to the percentage of ESA member states' investment in the space agency (ESA, 2009). The 'fair return' rule is calculated based on an 'industrial return coefficient' that calculates the ratio between the ESA share of a country in the weighted value of contracts (ESA, 2009)

Companies which come from non-ESA member states will have no opportunity of winning contracts with ESA. Therefore, for these companies, the rule represents *high market-entry barriers* and therefore, they could only win business if they partner with companies from ESA member states. Thus, companies from ESA member states will *gain direct benefits* from increased revenues and indirect ones from technology innovation and international partnerships.

Historically, the "geographical-return rule" was applied for ISS commercial projects. For example in 2001, companies from ESA member states contributing to the ISS exploitation program (i.e. Belgium, Denmark, France, Germany, etc.) had the right to apply for ESA promotional support for commercial projects that were to be flown on the ISS (Tkatchova, 2006). The promotional support meant that these companies could pay lower prices for flying their payloads to the on board ISS. So companies from ESA member states will gain direct benefits from cost savings.

For example ESA's geographical return rule is relevant to the companies involved in the future ExoMars mission and the future Lunar lander, as already initially presented in Chapter 1. For example, in the case of the ExoMars mission, whose objective is the search of life on Mars. TAS-Italy is the prime contractor, TAS- France is responsible for the carrier module, entry and descent system, EADS Astrium for the rover, EADS Astrium Germany for the lander platform, OHB for the mechanical and thermal subsystems and Kayser Threede for the payload integration (Williamson, 2009)

Italy is the ESA member state that has invested most in the ExoMars mission, therefore TAS-Italy will also aim at generating most direct benefits of technology reliability and interoperability, revenues from ESA contracts and indirect ones from technology innovation, free publicity and international partnerships. As a result of new capabilities that the companies will develop, the companies will achieve *technology reliability and interoperability* (direct benefits) and technology *innovation* and *international cooperation* (indirect benefit).

ESA's geographical return rule results in the *increase* of market entry barriers for non-ESA member state companies and the creation of *collusive oligopoly* in the European space industry. The questions that often arise among experts in the European space industry is whether the geographical return rule encourages European space industry competitiveness.

1. The geographical return rule *partially encourages* competitiveness of European space companies in their traditional areas of competencies.
2. The geographical return rule may also *limit* them in developing new competencies. To develop these new competencies they will need the support of their national delegations and to make sure that their country is well represented in the ESA program[5] under which they want to develop the competence.

ESA will have to define the role of the geographical return rule in case it gets involved in programs related to commercial crew and cargo transportation services. Furthermore, ESA may also consider measuring the *economic impact* from the geographical return rule on the *competitiveness* of European space industry.

ESA's geographical return rule for some companies was a *market entry barrier*, while for others it is a benefit as it was demonstrated in the case of commercial projects for the ISS, where certain companies had the right to ESA promotional prices, while others not. In the context of the ExoMars mission, the European space companies will generate technology reliability, interoperability (direct benefits),technology innovation and international cooperation (indirect benefit). The rule also encourages the creation of collusive oligopoly in the European space industry and also partially encourages competitiveness of space companies. Partially because it encourages competitiveness only for traditional competencies, and sometimes limits their capability to develop new competencies and technologies. ESA will have to define the future impact and role of the geographical return rule in the context of European space industry competitiveness.

4.3 Space Patents

Space patents are important results from the global space economy and certain space industry analysts use space patents as a measure of national space industry competitiveness.

Space patents are the product of inventions that companies make using space-based technologies for future interplanetary missions. The successful implementation of the interplanetary missions will require new technology solutions as NASA will demand technology spin-ins from non-space industries like aviation, pharmaceutics and others.

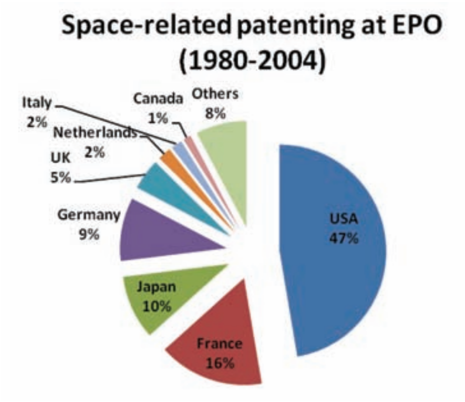
For example a pharmaceutical company developing medicines may identify faster "drug candidates" for drug development or discover a molecule that can be beneficial in the development of a medicine for slowing down osteoporosis. This company could invest in obtaining a patent and would be able to generate direct benefits from revenues from sales and entrance into new markets. Having the patent for a product or the research results will give the company a unique selling point and the opportunity to become a market leader in a certain market for drugs (i.e. osteoporosis, diabetes)

The definition used by the OECD for space patents is that *"space - related patents are ones from systems and applications, such as cosmonautics: vehicles or equipment"* (Jolly, 2007). Space patents can be issued under different patenting regimes depending on national legislation. Therefore, the data for Figure 3 is considered by the OECD to be incomplete.

The US is the country with the highest number of patents with around 47.3%, followed by France with around 16% and Japan with 10%.

The US space-related patents may increase with the new NASA 2011 budget which will aim at encouraging the development of transformative technology developments (i.e. in-orbit propellant transfer and storage, inflatable modules, etc.) and investing around $7.8 billion. Furthermore, NASA may grant IPR rights to non-space companies from innovations made using space-based technologies from the future Mars or asteroid missions. For non-space companies having space patents,

Figure 3. Space-based patents 1980-2004 (Jolly, 2007)



IPR and marketing rights may be an attractive business opportunity in a similar way as ESA granted to IPR the rights^6 to commercial projects flown on board the ISS.

Space patents are directly *linked* to the direct and indirect benefits that space and non-space companies can generate. The process of technology "spin-in" will encourage non-space companies to develop products and patent their innovations. Gaming companies for example, that make console games or PC games such as play stations or Wii consoles may develop games for astronauts.

These games may not only entertain the astronauts and cosmonauts, but can also help them keep physically and mentally remain fit during Mars human spaceflights. In this case, these gaming companies will develop space patents, keep the IPR rights and probably even issue marketing rights to advertise their products. Having a patent for a certain product, such as a game or software, gives the company a *unique selling point* within its market and allows the company to become the only supplier of this product. It enables the company to become a *market leader*, to possibly enter new markets and generating revenues (i.e. direct benefits) from the sales of this product. In addition, the companies will generate indirect benefits from technology innovation, free publicity and the creation of international partnerships.

Furthermore, US-based space patents may increase with the new NASA vision for developing transformative technologies, as NASA will invest around $7.8 billion for the development of these technologies. Thus, may consider granting IPR rights to private companies for their technologies. Space patents can be linked to the direct and indirect benefits companies can generate from the commercial use of space technology from interplanetary missions.

5. COLLABORATIONS

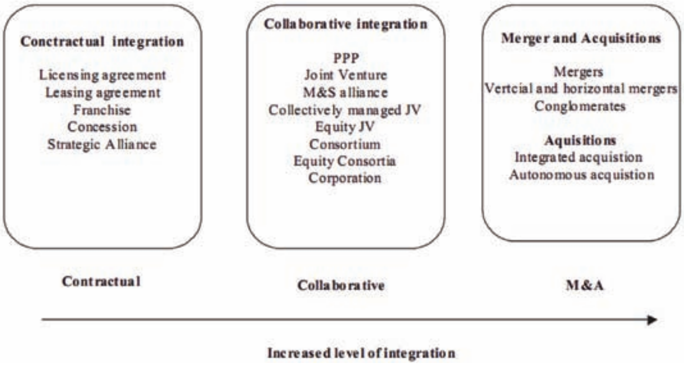
Technology innovation in space industry is one of the prime drivers behind space industry competitiveness. The future development of commercial crew and cargo transportation services, the expected development of critical technologies such as autonomous rendezvous and docking, closed-loop life support systems and commercial space activities, may encourage the creation of public private partnerships.

Certain partnerships will be only R&D while others will be public-private partnerships for developing new markets and sharing market risks.

Creating public-private partnerships is a challenging and often complex task, which requires a strong commitment from both the private and the institutional companies as well as common objectives. In addition, stakeholders will require a clear alignment of *objectives*, *activities, targeted markets, products* and *services, resources* and *competencies*. Partnerships can be grouped based on an increased level of integration between different companies and can be divided into loose and strong ones, as presented in Figure 4. The loose ones are more or less contractual ones when organisations partner together on certain projects or for proposal preparation.

For the different types of collaborations, stakeholders will identify different types of benefits. However, they will also have to assess the efforts and risks that accompany the creation of public-private partnerships and also understand who will be carrying the business and market development risks. Therefore, in the early stage of collaboration discussions, both private and institutional stakeholders will need to define the *expected benefits* clearly from the collaboration.

Figure 4. Partnerships grouped by increased level of integration (Tkatchova, 2008)



5.1 Public Finance Initiative (PFI) -Paradigm Case

The most recent example of a successful European public-private partnership is the Paradigm one and is responsible for the commercial operations of Skynet-5[7] a military satellite communications program. The program is procured as a Public Finance Initiative (PFI) and is considered to be worth £3.6 Billion UK pounds.

Paradigm, manages and operates Skynet 5 and will deliver telecommunication services (mobile voice communication, video, internet, broadcasting communications, etc.) to the UK military until 2020. The system is also expected to provide services to NATO, the armed forces of the Netherlands, Portugal, Canada, France and Germany.

The company is a subsidiary of the telecommunications department of EADS Astrium. The funding for the PFI is 40% government based and 60% is from private capital. The final 'end-user' is the UK Ministry of Defence and is given 80% of the service priority and the rest of telecommunications services availability of 20% is given to civil users.

EADS Astrium managed to attract private funding because it already had the end - user (MOD) in the value chain for the Padagrim project. Thus, demonstrating the importance of having a secure government long-term customer when attracting funding.

The above PFI case is an example of a successful public-private partnership, in which both end-customer and Paradigm can gain direct and indirect benefits. The end users in this case gain *cost savings, technology interoperability and reliability (direct benefits)* due to not being responsible for the operations and maintenance of the system. Furthermore, the end customer and the PFI also gain free publicity and technology innovation *(indirect benefits)*, as the PFI will also be responsible for the upgrade of the two ground-control stations.

Paradigm generates revenues from sales, increased employment and development of new markets *(direct benefits)*. Ones such as providing services to NATO and in the future potentially to the European Defence Agency (EDA). In addition, technology innovation and international partnerships are the indirect benefits.

Similar public-private partnerships may be set up for funding industrial projects, such as space-based internet or solar power satellites for power provision for governmental organisations. Furthermore, space agencies involved in programs for encouraging the development of commercial crew and cargo services or in the development of next generation of technologies may encourage the creation of public private partnerships for new technology development for low cost launchers and transfer vehicles.

6. DISCUSSION

Competition in the space industry can be introduced *primarily from terrestrial technologies*. Space-based technology has often been overshadowed by terrestrial-based ones, such as in the case of Iridium and the case of protein crystallisation growth on-board the space station. The long-time scale of space missions, the anticipated lenghty "time-to-market" and the high cost for the utilisation of space-based technology, makes ground-based technologies more attractive.

Therefore, non-space companies considering investing in projects that use space-based technology will have to understand the *direct* and *indirect benefits* for their project from space-based technologies.

The *oligopoly markets structure* of the space industry and the market segmentation that is developed and driven by national space agencies in Europe raises the issue of *competition* versus *duplication* of competencies. The *duplication* of competencies through Europe is often encouraged by national space agencies that are interested in having a higher number of suppliers in the industry, so that they could generate direct benefits from technology reliability and interoperability.

In this chapter, there is an analysis of the impact of ITAR regulations and ESA geographical return rules upon the competitiveness of national space industries. For example, the ITAR regulations *created new markets* for non-US companies like the European ones Thales Alenia Space (TAS) and EADS Astrium and others. In order to mitigate the ITAR regulations, many non-US companies started developing their own capabilities and technologies and therefore, increased their *technology innovation* and *competitiveness*. The ITAR regulations increased security, but had a knock-on effect of reducing manufacturing revenues for US companies and encouraging the *increase* of the non-US manufacturing revenues.

Europe has its own market-entry barriers, such as ESA's geographical return rule and it has a major impact on European space industry competitiveness. ESA's geographical return rule has a *dual role*. On one hand it *encourages competitiveness* in traditional areas of competencies and on the other it limits companies in developing new competencies. ESA will have to define the role of the geographical return rule in case it gets involved in programs related to commercial crew and cargo transportation services and the implementation of commercial projects on board the ISS.

The US companies under ITAR regulations are *exposed* to the *possibility* of *not having sufficient* funding for R&D projects or for maintaining their competitiveness, aspects which will be of *significant importance* for US space companies involved in developing key-enabling technologies and commercial crew and cargo transportation services. As US-based companies may *experience* ITAR related costs and strong R&D competition from European or Russian companies.

7. CONCLUSION

Competitiveness of national space industries is measured in different ways and is influenced by its institutional customers and their interdependence. The high concentration ratio and market-entry barriers demonstrate the existence of *oligopoly market structures*. However, space markets are also exposed to the traditional market driving forces (i.e. threat of new entrants, bargaining power of buyers and suppliers, threat of substitute products and services) as with the example of the ISS where Roscosmos is implementing an bargaining power as the only supplier for transportation services to the ISS.

Competition in the space industry can be introduced *primarily from terrestrial technologies* and non-space companies will have to understand and evaluate the benefits, that space-based technologies could bring to the opposed to ground-based ones.

Space industry competitiveness is an important macro-economic indicator that influences national *export trade balance*. The USA is the leader in Worldwide space industry competitiveness followed by Europe and Russia. Europe has a smaller budget and the competitiveness of its space industry is very high according to the space competitiveness index (SCI).

Defining and measuring *space industry competitiveness* will become an important indicator as the development of new technologies, infrastructures and research institutes will have a direct contribution to economic growth and positive export trade balance. Therefore, the lack of a well-defined measurement of national competitiveness may result in confusion among governments, national space agencies and research institutes.

Space companies have an interest to be in a *protected oligopoly market* and therefore, they will not be *motivated* to introduce competitiveness in their traditional markets. Therefore, they may even be able to identify the direct and indirect benefits from sustaining the oligopoly market structure.

Competitiveness of national industries is driven by political decisions. For example, a US political decision encouraged Europe to tap and develop a completely new launcher market niche, resulting in direct benefits for the European economy of employment, development of new markets, technology reliability and interoperability.

The ITAR regulations increased security, but it also had a *knock-on* effect of reducing manufacturing revenues for US companies and encouraging the *increase* of the non-US manufacturing revenues, thus, European companies developed *independently* from the US competencies and technologies. The export regulations encouraged the creation of direct benefits such as new markets, revenues from sales for European, Russian and Chinese satellite manufacturers. Due to the ITAR regulations, US space companies will experience a loss in technology innovation, international partnerships (i.e. indirect benefits) and access to new markets in Europe, Asia, etc.

In Europe, ESA's geographical return rule is a market barrier to new entrants, companies which come from non-ESA member states will have no opportunity to win contracts with ESA. Therefore, for these companies the rule represents a *high market-entry condition* and therefore, they could only win business if they partner with companies from ESA member states, while companies from ESA member states will gain direct benefits from increased revenues and indirect ones from technology innovation and international partnerships.

ESA may also consider measuring the economic impact from the geographical return rule on the competitiveness of European space industry.

ESA's geographical return rule also encourages the *creation* of a *collusive oligopoly,* partially encourages competitiveness of space companies, but also limits their capability to develop new competencies and technologies. ESA will have to define the future impact and role of the geographical return rule in the context of European space industry competitiveness.

Space patents can be linked to the direct and indirect benefits companies can generate from the commercial use of space technology from interplanetary missions. Furthermore, US-based space patents may increase with the new NASA vision for developing transformative technologies. NASA will invest around $7.8 billion for the development of these technologies and may also consider granting IPR rights to private companies for their technologies as private companies will be interested in keeping the patent rights and gaining unique selling points.

The *strong protectionist* approach of national space programs are favored by all space powers and is embedded in such regulations, such as 'buy American act' or European. Competitiveness of national space industries is influenced by high market entry barriers and the requirements of few dominant players. Nevertheless when private stakeholders enter the space market the situation will gradually change and result in increased competitiveness in the space industry.

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ENDNOTES

[1] The Oligopoly market structure includes the cartel, price leadership theory, the game theory, the prisoner's dilemma and the kinked demand theories.

[2] In 2009, the total ESAt is of around €3,75 billion while the Russian one is of around €3,000 Billion (Eurospace, 2010)

[3] The European Galileo will have 30 satellites in Medium Earth Orbit (MEO). At present, in 2009, there are only two test satellites in orbit- Giove-A and Giove-B. In the late 1990s, the launch of Galileo was planned for 2008 however, due to the problems with the creation of a public private partnership (PPP) the launch of the system was delayed.

[4] For example, Belgium is one of the countries which is the 6th member state contributing most to ESA of which 95% is national budget is allocated to ESA. The Belgium representatives at ESA carefully discuss and identify with the Belgium space industry, the national R&D needs for the different ESA programs.

[5] ESA member states allocate funding for ESA mandatory and optional programs. All ESA states are obliged to contribute to ESA mandatory programs, while for the optional ones ESA member states choose which program to contribute to depending on its national space industry competencies.

[6] For ISS commercialisation, ESA offered IPR rights to companies for their commercial projects. Companies had the opportunity also to buy the marketing rights from ESA from their commercial projects.

[7] Skynet 5 is planned to consist of three satellites and the ground control operations are expected to be integrated using two military stations as a basis.

Chapter 7

Space Tourism

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1. INTRODUCTION

NASA astronaut Roberta Bondar said: “To fly in space is to see the reality of Earth, alone. The experience changed my life and my attitude towards life itself. I am one of the lucky ones.”. Space tourism offers the possibility for more and more people to enjoy something that up till now less than 500 professional astronauts and “flight participants” have been able to experience: the excitement of a launch, microgravity and the stunning view of Earth from space.

Market surveys indicate that the number of people willing to spend serious money on a ticket to space is huge, but of course a strong function of the price. At the moment, the only possibility to pay your way into orbit is buying a $30 million ticket for a flight with a Russian Soyuz spacecraft to the International Space Station. However, more affordable albeit much shorter trips into space will soon become available via Virgin Galactic, which is offering flights onboard its suborbital rocket plane for about $200,000. Early 2008 Virgin Galactic had about 200 assured passengers, $30 million in deposits and about 85,000 registrations from interested potential customers.

2. HISTORY OF ORBITAL SPACE TOURISM

As early as 1988, famous singer John Denver expressed a serious interest in becoming the first space tourist. He was planning to buy a flight to the Soviet Mir space station, but ultimately declined because of the $10 million ticket price and the long training period required. In 1990 Japanese journalist Toyohiro Akiyama was send to Mir by his employer, the television station TBS, for $12 million. Technically not a space tourist, because he did not go just for recreation and did not pay for the trip himself, he nevertheless demonstrated that ordinary, relatively untrained people can go into space without too much trouble.

The first British citizen in space was Helen Sharman, who was launched into orbit as part of a Russian Soyuz crew. Sharman was a research technologist for a confectionery company when she was selected for cosmonaut training by a company called Antequera Ltd., a London-based company fully owned by a Moscow bank. Antequera organized the flight to strengthen the ties between the Soviet Union and the UK, but hoped to raise sufficient money from sponsors to cover the cost. However, interest in the flight from private sponsors and the British government was very low and even while Sharman was already in training, Antequera was formally dissolved. The Soviet bank that owned the company decided, however, to sponsor the mission itself in the interest of propaganda and in 1991 Sharman was send into orbit. Although Sharman's flight was not a fully private enterprise, it was not a normal government mission either.

The first person who can be regarded as a real space tourist was Dennis Tito, who was launched in 2001 onboard a Russian Soyuz capsule. Tito's flight, arranged by the private company Space Adventures, took him to the International Space Station (ISS), where he and his crew spend a week before returning to Earth. Self-made millionaire Tito paid some $20 million for his flight; only a small part of his estimated wealth of $200 million but still a lot of money for a holiday trip. The Russians could use the money well to finance their commitments to the Space Station, as their budget for the year was hardly seven times higher than the price Tito paid. However, ISS partners NASA, the European Space Agency ESA, the Japanese Space Agency and Canada where less thrilled with having a tourist onboard their costly outpost. But they could not stop the Russians from flying Tito to the station, as each partner is allowed to select its own crews. NASA could only insist on Tito agreeing not to sue the space agency or its partners in the event of personal injury. He also would have had to pay for any damage he would cause during the flight. Tito nevertheless enjoyed his eight day flight, listening to opera music, shooting video and stereographic pictures of the Earth and floating from one part of the station to another. His first words when he entered the Space Station were "I love space".

Figure 1. The International Space Station (ISS) (Courtesy of NASA)

A year later 28-year old South African Internet millionaire Marc Shuttleworth followed in his footsteps. By that time, an agreement had been reached between the Russians and the other ISS partners concerning space tourist trips to the station. There was no more open resistance to the flight. Mark's official designation became "Flight Participant", a name more fitting to the serious world of government space programs than the frivolous "space tourist". Mark liked the new name much better too; instead of being merely a passenger, he would be conducting a number of experiments for South African institutes and universities and also help his fellow crewmembers with some tasks. He would be more than a tourist. Ten days after blasting off the Baikonur launch pad, and after a thrilling period of Earth-gazing, weightlessness and experiments, Shuttleworth returned to Earth with a whole new view on the world. A view he wanted to share with the children of South Africa; together with a rapper, a DJ and a graffiti artist he toured around the country, visiting some 50 schools. By telling them about his experiences in orbit, he strove to excite the children and make them enthusiastic about space and a career in science.

At the time of writing, four more Flight Participants have been launched: American Gregory Olsen in 2005, Iranian/American Anousheh Ansari in 2006, Hungarian Charles Simonyi in 2007 and American Richard Garriott in 2008. Nevertheless, orbital space tourism has remained an exclusive experience and is likely to remain that for the near future. The Soyuz ticket price has actually gone up: while Dennis Tito paid some $ 20 million, it has been reported that Richard Garriott spent some $ 30 million for his flight.

There are plans for space stations dedicated to space tourism and other commercial endeavors. Once US company, MirCorp, was even owner of the Russian space station Mir for a short while. However, financing the rescue of the old station proved too difficult, and Mir re-entered the atmosphere in 2001 (the fascinating story behind this project is told in the documentary *Orphans of Apollo*).

The company Bigelow Aerospace, founded in 1999 by hotelier Robert Bigelow, has launched two prototype space stations up till now: Genesis I in July 2006 and Genesis II in July 2007. They are based on revolutionary inflatable technology, which makes it possible to launch spacecraft modules with larger on-orbit volumes than is possible with conventional rigid structures. However, without relatively low launch prices, access to such space stations will remain expensive and seriously hamper commercial exploitation.

3. THE PRICE OF ACCESS TO ORBIT

At the moment it is mainly the high price for a launch into orbit that prohibits a large orbital space tourism market. Flights costing tens of millions are only affordable for a very few multi-millionaires. To enable the average "man in the street" to take a holiday in Earth orbit, the space tourism ticket prices would have to come down dramatically.

The problem of high spaceflight costs lies mostly with the launch vehicle. The majority of today's launch vehicles are expendable, which are inherently expensive: a medium sized launcher can put a 10,000 kg satellite into a low orbit, but for that burns some 430 tons of propellant and throws away 40 tons of precious rocket hardware. Such a launch nowadays costs in the order of $130 million, i.e. $13,000 per kilogram of satellite.

The smaller the launcher, the worse the launch price per kilogram spacecraft gets due to the high "fixed" costs for launch control, launch pad security etc. that are not a direct function of the size of the launcher. A small satellite of a couple of hundred kilograms may cost some $20,000 per kilogram to put up. Larger rockets are relatively less expensive; an Ariane 5 launch costs "only" around $8,000 per kilogram low-orbiting satellite.

The Space Shuttle was the first attempt at a party reusable, operational launch system. The huge brown propellant tank is discarded, but since the most expensive parts of the system are reused, the Orbiter and the boosters, it was still expected that the Space Shuttle would dramatically lower the costs of getting into orbit. It was supposed to operate as a kind of space truck, delivering communication satellites, space station modules, space telescopes, onboard laboratories and astronauts into space at an unprecedented low price and on a weekly basis. Unfortunately the costs for getting the Shuttle ready for flight proved to far outweigh the benefit of reusing parts of the system. The checking and partial replacing of the 35,000 heat protective tiles on the Orbiter alone takes weeks and the complete post-landing overhaul of the

Orbiter costs over 100,000 man-hours, not including costs for mating the Orbiter with the External Tank and the two Solid Rocket Boosters and all the launch and mission operations. All this makes the Space Shuttle actually the most expensive launch vehicle in use this moment. The original Space Shuttle requirements had demanded a low-cost, easy to process cargo plane for space, but development budget restrictions and technology limitations resulted in a costly and labor intensive vehicle. The Challenger disaster and the recent tragedy with the Columbia prove that it is not as safe as expected either.

For a successful orbital space tourism business, the Space Shuttle would be far too expensive: Assuming a passenger module for 74 space tourists could be installed in the cargo bay of the Orbiter and 12 flights per year could be made, the ticket price would be around $3.6 million. While there are probably a number of people willing to pay such an amount for a space flight experience, flying 74 of them at a time would deplete the limited available market in short time. Moreover, the Shuttle turn-around time (the period between landing and re-launch) of around 3 months would be unacceptable for a large-scale space tourism operation.

The lesson learned from the Space Shuttle is that to really lower launch prices dramatically, a truly reusable launcher is required. Preferably, the system should involve only one single vehicle without expendable tanks or boosters that need to be retrieved and refurbished. It should land at the same place as it is launched, to avoid complicated and expensive transport. A limited number of easily replaceable metallic shingles should be employed, instead of thousands of fragile heat resistant tiles as used on the Space Shuttle. The propellants should be non-toxic, safe and relatively easy to handle to avoid complicated tanking and propulsion system maintenance procedures. The rocket engines should last longer than those on the Space Shuttle, should require less maintenance and should be easier to repair.

Ideally, the launcher would have some kind of combined rocket/jet engine that can use the oxygen in the atmosphere while flying at relatively low altitudes. This would mean less onboard propellant, smaller tanks and therefore a smaller, lighter vehicle. To make maintenance more efficient, these vehicles of the future may carry computers and sensors that constantly check the health of all subsystems and components during flight. A readout from this system would make it easy to determine where and what kind of maintenance is required. Routine manual checks of the entire machine after each flight would be unnecessary.

Unfortunately, developing launchers that fit all or at least many of these requirements and are also able to bring a significant payload into orbit has proven to be extremely difficult. With the current rocket engine and materials technology, even expendable launchers are heavy and hardly powerful enough to make it into space without discarding parts of themselves along the way. During this “staging”, rocket stages are jettisoned as their propellant tanks run empty. These stages fall in the ocean or crash on land and cannot be used again. A truly reusable launcher cannot benefit from such a simple staging system, but still has to be able to bring large satellites in orbit. Another problem is that today's rocket engines can only be operated for 10 minutes or so before major maintenance activities or new motors are required. Jet engines as used in modern airliners last for months without any trouble.

The problem is illustrated by the fact that nobody has even been able to make supersonic airplanes such as Concorde truly profitable, even though such aircraft are simpler to develop than spaceplanes (Concorde was operated commercially, but never earned enough to compensate for the $12 billion investment in today's dollars, excluding engine development).

Work on reusable rockets for launching satellites has been going on for about half a century now, without much success. The NASA/McDonnell Douglas DC-X Delta Clipper was a small vehicle to demonstrate that a reusable rocket can take off vertically, hover, then land vertically back at the launch pad. The project team also wanted to show that with only a small crew such a vehicle could be quickly readied for re-launch after landing. The project was quite successful: the unpiloted vehicle made twelve test flights from 1993 to 1996, of which two flights within 26 hours. Sadly, on the last flight a landing leg failed to deploy and the craft tumbled over. The crash made the oxygen tank explode and the vehicle was destroyed.

NASA's X-34 was an unpiloted, experimental rocketplane developed by Orbital Sciences. It was to test spaceplane technology and would have been dropped from a carrier airplane like X-15.

However, NASA cancelled the project in 2001. The most ambitious test project, NASA's and Lockheed Martin's X-33, involved a sub-orbital, single stage reusable test vehicle. It was to launch vertically like a rocket, fly 15 times the speed of sound, than land horizontally like an airplane. Sadly, the project was scrubbed in 2001 because of major problems with the development of the engine and the lightweight

Figure 2. NASA X-34 rocket plane (Courtesy of NASA)

hydrogen tanks. The cost of the project exceeded the $1.2 billion budget limit even before any test flights where made.

Both the DC-X and X-33 were regarded as models of larger reusable launch systems. Specifically, the X-33 was supposed to lead to the development of Lockheed Martin's "Venture Star" single stage reusable spaceplane. However, it would have been very difficult to scale the test vehicle designs up to full size, operational launchers without gaining too much mass.

In March 2004 NASA successfully tested the X-43A, an almost four meter long unmanned scramjet airplane. The X-43A is an airbreathing vehicle that uses oxygen from the atmosphere to achieve high speeds.

Flying seven times the speed of sound, the velocity is sufficient to compress the air in the engine without the need for compressors like in a regular jet engine. Spaceplanes with scramjets could use atmospheric oxygen during a large part of their flight to orbit, and thus would need to take less oxygen with them than normal rockets. The use of scramjets could thus result in smaller, more affordable spaceplanes. Unfortunately, scramjets only work at hypersonic velocities; at speeds lower than Mach 5 the air does not get compressed enough for efficient combustion and propulsion. Moreover, at low altitudes the air density is too high to fly Mach 5 or faster. The resulting pressures, forces and temperatures would destroy a spaceplane. The X-43A had to be launched to high altitude and velocity on top of a converted Pegasus rocket, and the whole combination was dropped from a B-52 bomber. At high altitudes scramjets don't work either, as there is not enough air for a scramjet to work effectively.

Scramjets are thus only part of the solution. Scramjet technology will probably be incorporated in so-called rocket-based combined cycle engines, operating as a

Figure 3. NASA X-43A (Courtesy of NASA)

rocket for take-off and to achieve hypersonic velocity, then switching to scramjet-mode to save the onboard oxygen. At high altitudes with insufficient oxygen levels, the engine would operate as a pure rocket again.

Another important issue is safety. Current crewed launch systems can still be considered immature, far from perfected prototypes when compared to commercial and military airplanes. The risks involved in human spaceflight are therefore still high, even after nearly 50 years of experience. When Lindbergh crossed the Atlantic, he was exposed to considerably danger in an experimental airplane that could not be guaranteed to stand up to the task. By now, intercontinental flights are safe and routine and hundreds of planes are crossing the oceans every day. In contrast, a crewed spaceflight is still something extraordinary that reaches the papers; with over 2% chance of a serious accident, astronauts and cosmonauts put their lives at risk each time they go up. For mass space tourism, spacecraft need to become more like aircraft in reliability, maintainability and safety, but this is difficult and in direct conflict with the economic requirements to keep the system as less complex and low-mass as possible.

The world's space agencies seem to be in no hurry to develop reusable launch systems for a limited satellite launch market that does not require regular launches. It may prove to be cheaper to launch an expensive, expendable rocket once in a while than to invest huge amounts of money in reusable launcher technology. The situation is a Catch-22: as long as launches are expensive, the number of satellites and people to be launched each year remains small. Reusable launchers only become economical at high launch rates, so their development and operation is not justified for such a limited market. Expendable launchers therefore remain in use, launch costs remain high and in turn the satellite market stays small. Space tourism may help out, as it appears to offer a large market worth billions of dollars per year, which success depends on efficient, reusable vehicles. Reusable launchers developed for space tourism could bring down launch costs dramatically, enabling not only regular tourist flights but also cheap satellite launches.

However, for a purely commercial enterprise the start-up costs for large scale orbital space tourism has proven to be a big problem. Cost estimates for the development of a fully operational reusable launcher with modern technology are in the order of $10 billion; relatively low in comparison with the historical development costs of the Saturn V moon rocket ($42 billion in today's dollars) or the Space Shuttle system (about $25 billion in today's dollars), but much too high for a starting commercial space tourism business. Furthermore, the certification process for an orbital space tourism launch vehicle (currently not existing) will be more elaborate and costly than for an uncrewed satellite launcher. Commercial airplanes are typically required to make a thousand test flights with the same aircraft before certification.

At the current state of technology, spaceplanes are expected to be replaced every hundred flights or so.

Even considering the most optimistic space tourism market predictions, it will take a too long time to recover such huge investments. Investors in the type of high-risk enterprises that the first space tourism companies will be, typically demand a high return on their investments within 5 years or so. If space tourism does not offer this, they rather invest their money in other businesses.

Government funding of the development of reusable space tourism launchers could be a solution to this problem. Funding by a government organization is common in the launcher industry; for instance, the development of the European Ariane launchers is funded by ESA, while the commercial operation and marketing is under the responsibility of a private enterprise named Arianespace.

However, the primary goals of government space agencies are scientific exploration and technology development, not the setting up of commercial businesses. The environment in which the space agencies have to work, with its entanglement of political, industrial and scientific demands and constraints, complicates space commercialization, and especially space tourism. Furthermore, America's and Europe's human spaceflight plans are currently aimed at the Moon and Mars, so the development of spacecraft and space stations for tourism is therefore not on their priority list.

An exception is the Russian space agency, which has embraced space tourism as a quick means of getting desperately needed additional funding. It is not surprising that western companies like Space Adventures are working with Russia rather than US, European or Japanese space agencies. In an optimistic scenario, the Russian space agency may decide that space tourism is their main space market of the future and the only sure way of supplementing its budgets. They may decide to further exploit their current leading position in the space tourism business, and focus their future developments on this new market.

Governments may support space tourism indirectly, by developing efficient reusable vehicles for launching satellites, which can then also be used by commercial space tourism enterprises. This is a likely scenario, as space agencies are very hesitant to endanger the lives of non-professional astronauts in any way. A single serious accident with a space tourist launch vehicle could endanger a whole government space program because of the political implications. Commercial companies like airlines are usually able to survive such problems since they are not directly related to politician's public images. Launching satellites can also be used as a way to make money in a development or certification phase, during which no space tourists can be allowed onboard.

4. SUBORBITAL

In 1996, the X-Prize Foundation announced a $10 million prize for the first non-government organization that would launch a 3-person rocket vehicle to an altitude of 100 km (62 miles), and that would repeat this feat within two weeks, using the same vehicle. The name of the prize was eventually changed into the Ansari X-prize, due to a large donation by the Ansari family (the same of which one member flew to the ISS in 2006 as a Flight Participant) The prize was won on October 4, 2004, the 47th anniversary of the Sputnik 1 launch, by a team lead by legendary Scaled Composites designer Burt Rutan and financed by Microsoft co-founder Paul Allen, using the experimental spaceplane SpaceShipOne that was dropped from its WhiteKnight motherplane (both planes developed by Scaled Composites).

On September 27, 2004, days before winning the Ansari X-prize, entrepreneur Richard Branson (best known for his Virgin brand of over 360 companies) announced that he was partnering with Scaled Composites and Mojave Aerospace Ventures (the joint venture of Scaled Composites and financier Paul Allen) to create a suborbital space tourism business, using a scaled-up version of SpaceShipOne. The flights will be sold by a new company called Virgin Galactic, for an initial price of about $200,000 (though Branson expects the price to drop after the first five years of operations). In a speech at the FAA Commercial Space Transportation Conference in Crystal City, Virginia early February 2009, Virgin Galactic CEO Whitehorn said that the company had nearly 300 customers and $39 million in customer deposits. He said that the system could potentially be profitable in its first year, and soon thereafter even become a publicly-traded company.

SpaceShipTwo is an air-launched vehicle designed to carry six passengers and two pilots to suborbital space and back. Each SpaceShipTwo passenger will be equipped with a pressure suit as a safety precaution, be free to move about a roomy cabin equivalent to a Gulfstream aircraft and peer at the Earth through wide, 18-inch (46-cm) windows during the several minutes of weightlessness offered on each spaceflight. “Because clearly, if you’re going to go into space, you’re going to want to see the view,” according to Whitehorn.

The new craft will be launched from a twin-cabin high-altitude jet that can double as a space tourist training craft. This WhiteKnightTwo airplane carries four engines and has a wingspan of about 42 meters. SpaceShipTwo’s cabin is much larger than the three-person capsule used on SpaceShipOne, and each of the two WhiteKnightTwo carrier craft cabins are identical to that of SpaceShipTwo to make it a useful training tool. Family members of passengers or other space tourists can also watch a SpaceShipTwo launch from inside a WhiteKnightTwo cabin.

Flights are planned to start at a dedicated suborbital airport called New Mexico’s Spaceport America. Initially, commercial flights were planned to start in 2008, but the development of SpaceShipTwo has been slowed by an accident with its rocket engine, which killed three workers. There are other companies working on competing vehicles, but Virgin Galactic and Scaled Composites appear to be far ahead of the competition (no other company even has a prototype like SpaceShipOne flying).

Interestingly, there are a number of other markets besides space tourism that suborbital vehicles such as SpaceShipTwo could serve, such as microgravity science, remote sensing and astronaut training. A market study performed for Virgin by an outside group found that NASA invests over $300 million a year in activities that could be addressed by SpaceShipTwo, including sounding rocket research, space life sciences work, education, and aeronautics research. A small step in the direction of using SpaceShipTwo for research is the plan to carry atmospheric sensors on SpaceShipTwo as well as the WhiteKnightTwo carrier aircraft. Some of the data from those sensors will be used to help calibrate NASA's Orbiting Carbon Observatory spacecraft. That agreement is under a no exchange of funds basis, but it should help to establish the Virgin Galactic's scientific credentials for other customers.

Another interesting NASA market is astronaut training. WhiteKnightTwo can provide brief periods of microgravity by flying parabolic arcs, but doing that it can also create acceleration forces up to 6 Gs to simulate the forces of launch and reentry.

The most ambitious plan is to launch small satellites, using the WhiteKnightTwo airplane carrying an expendable rocket instead of a SpaceShipTwo aircraft. According to Virgin Galactic, such a system could place up to 200 kilograms in a low Earth orbit. The target price for a launch is no more than $2 million, and the system would offer the flexibility to launch from almost any location, and to only weeks after signing a contract with a satellite customer. The company is working with Surrey Satellite Technology Limited (SSTL), to study the concept.

5. SPACEPORTS

Just like airlines need airports, so spaceports are required for large scale space tourism flights. Apart from providing the required passenger terminal, control center and runway/launch pads, such spaceports could house passenger training facilities, hotels, visitor centers and all kinds of other attractions. Spaceports can thus not only generate revenue through the actual flights, but also via many related activities (much like modern airports are also shopping and entertainment centers). A spaceport could generate many jobs in the area it is located.

The world's first private spaceport is being developed in New Mexico, under the name "Spaceport America". The $198 million project is designed to accommodate two of Virgin Galactic's WhiteKnightTwo airplanes and five SpaceShipTwo vehicles (but may also house other types of suborbital vehicles in the future). Apart from a runway, the facility will include training facilities, a mission control center, viewing galleries and passenger lounges. On December 15, 2008, the Federal Aviation Administration's associate administrator for Commercial Space Transportation issued an FAA Site Operators License for vertical and horizontal launches from the spaceport. Shortly after, Governor Bill Richardson announced that the State of New Mexico signed a 20-year lease agreement with Virgin Galactic, which will build its global headquarters at the spaceport. "The signing of this agreement is a momentous day for our state and has cemented New Mexico as the home of commercial space travel," he stated, adding that partnership would "create a whole new industry that is going to transform the economy of southern New Mexico—creating thousands of jobs, generating money for education, boosting tourism, and attracting other companies and economic opportunities to the area." The lease agreement with an anchor tenant released further New Mexico funding for the project and has cleared the way for construction to begin. The terminal and hangar are scheduled to be completed near the end of 2010.

In Europe, Spaceport Sweden is to be located in Kiruna, Sweden. Kiruna has been closely involved in space exploration through the Esrange Space Centre, which houses many sounding rocket launch pads and high-altitude research balloon facilities, as well as several satellite ground stations. The New Mexico Spaceport has entered into a Memorandum of Understanding with Spaceport Sweden to increase global cooperation in the commercial space industry, promote cultural understanding and stimulate local economic development, tourism and education. Both spaceports are working with Virgin Galactic, which is planning to launch some of its vehicles from Spaceport Sweden to allow passengers to fly through the Aurora Borealis.

6. GRADUAL DEVELOPMENT

Development of suborbital systems such the SpaceShipTwo WhiteKnigthTwo combination is much less expensive than the development of an orbital launch system able to launch several people into space: several hundred million dollars rather than $10 billion or more. The relatively low operational costs of a suborbital system make it possible to offer flights for about $200,000 rather than the tens of millions of dollars per ticket for an orbital flight.

A possible way to develop an orbital space tourism capability is the step-wise approach suggested by David Ashford of Bristol Spaceplanes Limited. Starting with a small suborbital vehicle, a company could make money that can be invested in the development of a larger two-stage spaceplane consisting of a large hypersonic carrier airplane with a smaller shuttle on top. At high altitude and velocity, the upper vehicle would be released from its mothership and launched into orbit. Systems consisting of two stages are less economical in operation than single stage spaceplanes, but less difficult and therefore less expensive to develop. From there on, larger two stage vehicles and eventually single stage spaceplanes could be developed. Just as normal airplanes, these advanced spaceplanes would use air for their engines while flying at low altitudes, to save on the amount of propellant that needs to be carried along. Following this approach, development costs and risks are spread while money can be earned long before the fully operational orbital vehicle is flying. It also allows the gradual build-up of a space tourism market.

However, the step in launch vehicle performance, complexity and size between suborbital X-prize type vehicles and real orbital space vehicles is huge: SpaceShipTwo flies up to a hundred kilometers altitude and achieves a maximum velocity of about 4,000 kilometers per hour, while to stay in orbit a velocity of about 28,000 kilometers per hour is required. That is a factor 50 difference in energy and corresponding propellant load; hence the huge disparity in size between the Space Shuttle system and the WhiteKnightTwo – SpaceShipTwo combination.

7. CONCLUSION

Historically, means of transportation such ships, trains and planes have been kick-started with government support, but made economical by private industries. We may need a similar evolution for making space tourism a profitable business. This process has now started, as private companies are working on advanced yet simple and low cost rocket aircraft for suborbital space tourism. Importantly, they do this without any direct government support or space agency involvement. Suborbital space tourism may open a sufficiently large market to enable the development of more advanced systems and ultimately fully commercial orbital spacecraft. This may be accelerated by rich investors, such as those that financed some of the X-prize competitors. These people may put some of their billions into the development of orbital space tourism vehicles without demanding huge profits in the short term. Nevertheless, the viability of suborbital space tourism is still to be proven, and the road from there to orbital space tourism for large numbers of people is likely to be long.

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Chapter 8

Space Economics and Benefits

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There are so many benefits to be derived from space exploration and exploitation; why not take what seems to me the only chance of escaping what is otherwise the sure destruction of all that humanity has struggled to achieve for 50,000 years?

Isaac Asimov

1. INTRODUCTION

In this chapter there will be a short introduction to space economics, assessment of direct and indirect economic impacts and benefits from the use of space based technology. Furthermore, in it there is an overview of space budgets, space employment and products. For the identification of direct and indirect benefits examples from the aviation industry will be used and based on them a proposal for measuring the economic benefits and impacts to national economies from interplanetary space-based technologies will be made. The direct benefits will be employment, revenues from sales, new markets, cost savings, employment and technology reliability, while the indirect ones will be promotion, technology innovation, international cooperation and environment protection.

The expected result of this chapter is to show the economic impact space based technologies that they can have on non-space industries and propose approaches for assessing the benefits for space agencies, industries and societies from commercialization of space-based technologies.

2. SPACE ECONOMICS

Climate change and environmental disasters will become the biggest threat to national economies. Monitoring environmental changes and analysing real time data for future climate change models is becoming of crucial importance in understanding climate change. Navigation and telecom satellites have become an inevitable part of our day to day lives. Today they are widely used navigation satellites for location based services, air traffic management, oil and rack positioning, Geographical Information Systems (GIS) and precision agriculture.

Earth Observation satellites role has also become important with climate changes and environment problems, as satellites provide real-time data for monitoring disaster management and climate change. Furthermore, research on board the ISS can also contribute to the development of closed life support systems, osteoporosis medicines and therapies prevention, and contribute to launching projects reducing water pollution through improved water purification processes.

Alternative energy sources are becoming important, as energy supplies are diminishing and countries are becoming reliant on a smaller number of energy providers. Therefore, technological solutions for solar satellite power generation (see Chapter 9) in LEO may become important to national economies.

Furthermore, with the development of telecommunications and navigation systems, market forces such as *demand* and *supply* became visible in an industry that is historically developed and dominated by governmental space agencies. For example the development of telecommunications has influenced the growth of other space segments, such as commercial launchers and commercial satellite operator services (see Chapter4) and making major contributions to national economies.

Economics is broadly divided into “macro-economics” and “micro-economics”. *Macroeconomics* deals with the human behaviour and choices related to the entire economy (Arnold, 1996, 3rd edition), such as measuring national Gross Domestic Product (GDP), unemployment and economic growth. While, microeconomics studies the individuals’ firms decisions and behaviour.

Furthermore, future development of industrial projects using space-based technology from the interplanetary programmes may even result in the successful development of a sub branch of economics, referred to as “space economics” which could even evolve into “interplanetary economics”.

At present, the only definition that could be easily found of "space economy" is one defined by the OECD (OECD, 2007) and it states:

All public and private actors involved in developing and providing space-enabled products and services. It comprises a long value-added chain, starting with research and development actors and manufacturers of space hardware (e.g. launch vehicles, satellites, ground stations) and ending with the providers of space-enabled products (e.g. navigation equipment, satellite phones) and services (e.g. Satellite-based meteorological services or direct-to-home video services) to final users.

The above definition is not linked to the national GDP or employment and is related only to the space market segments and applications typical for space industry (see Chapter 4). A definition must be generic and not related to particular market segments or applications, as they will change with time, driven by customer needs.

The definition does not deal with "space-based technologies and resources" as a scarce resources as "microgravity environment" and "space exploration" are not only expensive, but are also a scarce resource available only to the richest countries.

Economics is the science of scarcity[1] and how the market forces of demand and supply allocate these scarce resources (Dictionary, 2008):

"A social science concerned chiefly with description and analysis of the production, distribution, and consumption of goods and services"

Therefore, in this chapter is proposed the following definitions for "space economics" and "interplanetary economics":

"Space economics is a science concerned with the description and analysis of the design, development, production, distribution and use of products and services, derived by the use of space-based technologies and concepts"

The future creation of a Moon habitat and the development of various industrial projects for future interplanetary missions may even result in governments having departments dealing with interplanetary economics.

" Interplanetary economics is a sub category of space economics and is concerned with the description and analysis of the design, development, production, distribution and use of space-based products and services, used on Earth on celestial bodies (i.e. Moon, Mars, asteroids,etc.) and also human-made artificial spacecraft, stations and others. "

The above two definitions will be used for supporting the easier identification of direct and indirect economic benefits from space technology.

3. SPACE BUDGETS PER GDP

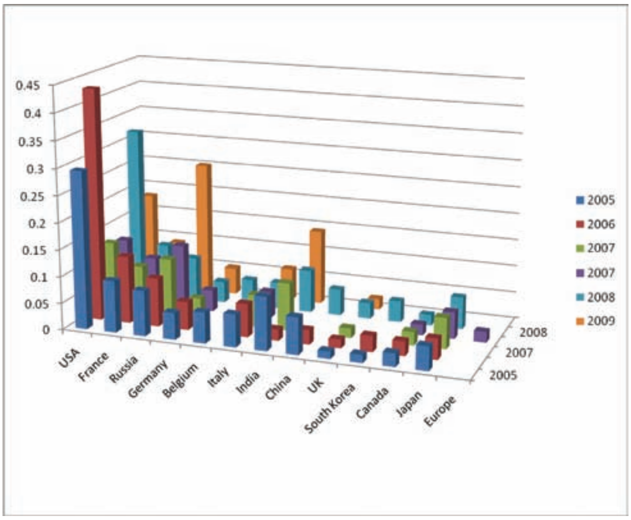
The overview of space budgets as percentage of countries' Gross Domestic Product (GDP) shows the percentage that national governments invest in space exploration programs. Gross Domestic Product measures the total market value of all final goods and services produced annually within a country (Dictionary, 2008). One of the methods used to measure GDP is the so-called expenditure approach, which totals the spending of the final users of goods and services. GDP is calculated by totalling consumption (C), investment (I), government purchases (G) and next exports (EX – IM) (Arnold, 1996, 3rd edition).

Space technology development is financed by national space budgets and countries that invest most in space missions are the USA, France, Russia, Germany and Belgium, as presented in Figure 1.

Figure 1, shows a comparison of space budgets as percentage of GDP for 2005 until 2009.

For 2009, Russia is the country with the highest space budget as percentage of its GDP, followed by the USA and India. Demonstrating that Russia will aim *to revive* its positions in the global space market and prepare its space national indus-

Figure 1. Space budgets as percentage of GDP (OECD, 2007), (ESPI, 2009), (ESPI, Russia's Space Cooperation with China and India, 2008), (Eurospace, 2010)



try to become the *sole* provider of launch services to the ISS. Furthermore, new players such as India will also re-position themselves on the global space arena. In contrast to European countries, such as France, Germany, Italy and Belgium that will maintain their traditional space budgets and positions. France has the highest annual space budget of around 2.4 Billion USD per year, followed by Germany with 1.3 Billion USD per year, Italy with 906 Million USD per year and Belgium with 237 Million USD (AIAA, 2010)

Often space budget allocation is difficult to be *justified* by politicians, as science and technology benefits from space missions become obvious only after several years. Space agency's activities are to *create* and *implement fundamental space based research.*

There is a lack of a *global definition on space budgets* and it is not clear whether they include civil or military budgets as the percentage of space budgets as part of GDP is calculated. The *lack of consistent* and qualified *economic data* on space budgets as a *percentage of GDP* imposes the need for data consolidation and limit policy makers in their decision making process.

The *decision makers* in space agencies often foresee the only benefits from space exploration in terms of expected revenue in space industry. For example ESA's geographical-return rule (see Chapter 6) ensures that the amount money countries invest in ESA is later transformed into contracts for their national space companies and thus, appears as revenues from sales for their space companies.

Commercialisation of space technology is not a prerogative and therefore, space agencies have *no mechanisms* and methods to analyse the direct and indirect benefits of their space missions.

Therefore, the *definition* of direct and indirect economic benefits from space exploration will aid decision makers and space lobbyists to justify budget allocation for space exploration.

3.1 World Space Budgets

Global space budgets often constitute both civil and military space expenditure, but information on civil space budgets can be found more easily than on the military space ones[2]. National space budgets are allocated by the space policy of the country, certain countries like Belgium allocate 95% of their space budget to ESA, while others such as the UK allocate only 65% of their annual national space budget to ESA.

The world space expenditures according optimistic assumptions reaches up to $86.17 billion for 2009 (Foundation, 2010), which is higher than the expected to annual growth of 4.5% per year until 2012, thus surpassing the estimates of $70 billion by 2012 (Space News, 2008).

Figure 2. World space budgets 2005-2010 (Eurospace, 2010)

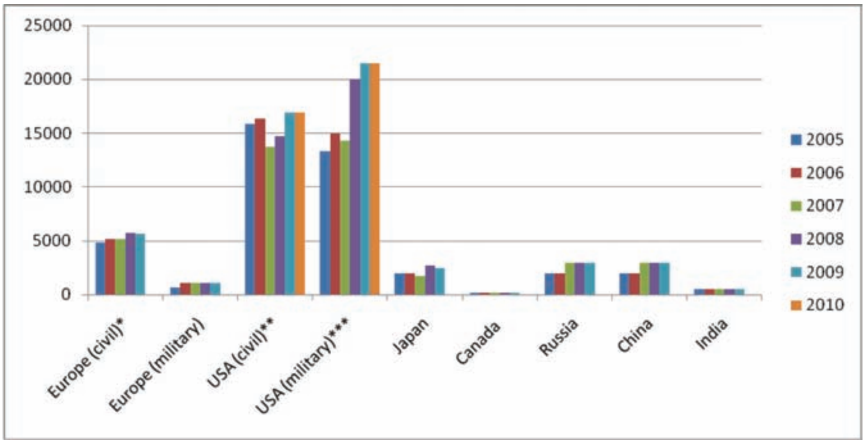


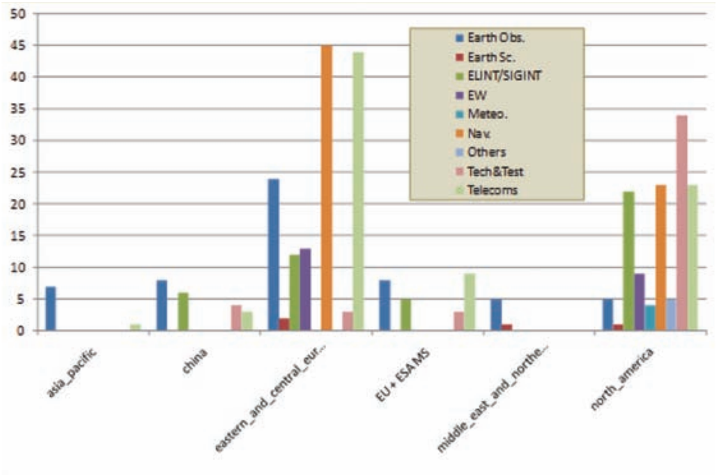
Figure 2 shows an overview of the national space budgets from 2005 until 2010. US space budget has the highest civil and military space budget. The US civil space budget in 2009 is of around $20 Billion USD and the range of the European one is of around 6.7 Euros Billion. European space programs are lead by European Space Agency (ESA) that has an annual budget of around 3.5 Billion USD for ESA programs, Eumetsat in addition European countries implement their own space programs.

Civil space budgets have more or less remained the same, in contrast to military space budgets that have increased. Military space budgets are primarily allocated for navigation and telecommunications applications, as presented in Figure 3.

In any case the US military space budget has been traditionally higher than the civil one. Nevertheless, the new NASA 2011 civil space budget (Chapter 11) may encourage the development of new key enabling technologies, heavy-lift and propulsion technologies and commercial crew and cargo vehicles that may have a *dual use* after the end of the ISS lifetime.

Countries aiming at performing interplanetary space exploration may face the *challenge* of exploring space with low space budgets and just concentrate primarily on implementing robotic missions. Furthermore, national space agencies may find mechanisms to encourage the creation of public private partnerships (PPP) that will be able to attract some private capital for their projects (see Chapter 6). For example countries that are just launching their navigation systems, such as Japan the Quasi-Zenith Satellite System (QZSS) may consider the implementation of a public private partnership for managing their system and for ecnouraging the development of space applications.

Figure 3. Military space missions by type of mission from 1996-2008 (Eurospace, 2009)



NASA is planning on introducing a completely *different approach* in doing business with space industry (see Chapter 3) through implementing programs, such as NASA COTS one. The most innovative aspect of the new budget is the budget allocation of $6 billion for commercial crew and cargo capabilities that will *encourage* the construction of commercial crew vehicles. NASA will introduce competitive bidding and based on it will allocate funding to companies willing to provide commercial cargo and crew launch services. Furthermore, the budget will allocate $7.8 billion for a five year period to programs linked to technology demonstrators, such as in - orbit refuelling and storage and will be cost effective.

The *opportunity* to develop US commercial crew and cargo transportation services industry will *attract* private investment in the development of low-cost launchers and sub-orbital vehicles that will require a *demonstration* of *viable business cases.* Future commercial cargo service providers will have to *assess* the market demand against *cost drivers* and assess profitability of the projects. Companies involved in industrial projects will even have to perform *cost benefit analyses* and define their *rate of return.* The NASA new objectives for 2011 for space exploration, such as prolongation of ISS utilisation, human Mars mission and future asteroid missions (Pasco, 2010). Future asteroid/Lagrangian points and Mars mission may spread over a period of a minimum of 25-30 years. One of the ideas is to have by 2025 asteroid space missions and Martian orbit and Phobos and Deimos landings by mid 2030 (Covault, June 2010). All these missions are long term ones and for the next 25-30 years these missions will be exposed to *strong political risks*, due to president changes and there may be inevitably changes in space agencies' budgets driven by political interests.

The Obama proposal in several years may also become a *victim* of political games that may even result in its cancellation in the long-term or change of space exploration objectives.

Therefore, space agencies will have to not only clearly to define the direct and indirect economic benefits, but also define an industrialisation strategy for attracting non-space commercial users and private funding for encouraging the development of commercial crew and cargo transportation services.

Space budgets *reduction* is usually the prime trigger behind space agency's decision to *commercialise* space technology. For example Russia's economic transition towards a market economy in the early 90's resulted in symbolic space budgets, space industry restructuring, high inflation and increased costs for materials. Commercialisation of Russian space technology was the only option for the survival of the Russian space industry (Tkatchova, 2006). During the period from 1990 until 2007 Russia launched around 922 satellites, with a much lower space budget than Europe. Russia's experience demonstrated the actual potential of commercialisation of space technology. Furthermore, they were the first space agency to initiate space station commercialisation (see Chapter 2) and demonstrate the potential of space tourism (see Chapter 7).

Space agencies will be able to better *assess* benefits from space technology utilisation and industrialisation. Furthermore, they will be able to *justify* their space budgets through directly communicating to national governments and taxpayers the direct and indirect economic benefits. In addition, space agencies will demonstrate how budget reductions can directly impact on the direct and indirect economic benefits. Private companies involved in commercial crew and cargo projects or industrialisation ones, will be able to perform cost benefit analyses, attract funding and assess their benefits from participating in them.

4. SPACE EMPLOYMENT

National employment is often considered by economists a macro-economic measurement for direct benefits. High levels of *national employment*, *capital* and *technology innovations* are the drivers behind economic growth.

Therefore, employment and technology innovation are benefits, that are considered when analysing the economic benefits from future industrial activities and interplanetary missions.

In the space industry there are a number of definitions used for quantifying national employment, however available data is not detailed enough.

The OECD uses the US Bureau of Census statistics includes in its space industry definition includes 'guided missiles and space vehicle manufacturing, space propulsion unit and parts manufacturing, other guided missiles, space vehicle parts and auxiliary equipment manufacturing' (OECD, 2007).

The Space Foundation uses the classification of the North American Industry Classification System (NAICS). Space employment includes statistics from companies that manufacture products, such as radar systems, guided missiles and space vehicles, propulsion units and also the business that provides telecommunication services (Foundation, The Space Report 2008). While, the report from the US Space Industry Defence counts employees from prime system integrator companies that sell satellites, launchers, satellite services, launch vehicles and services, and subcontractor companies and subs-systems companies that provide components to the prime companies, such as sensors, satellite antennas, solid rocket boosters and others. Finally, the NAICS classification also includes statistics on the companies that provide less complex components, sub-assemblers, structures, materials e.g. optics, propellant, coatings and services, such as information technology, research and custom fabrication services (Force, 2007).

Eurospace[3] defines space employment as direct employment of system integrators[4], subsystem suppliers, equipment suppliers and services suppliers. The employment is expressed in Full Time Equivalents (FTE) and the employees working on site at customers sites (i.e. NASA, etc.) are counted as separate categories (Eurospace, 2008).

In the US there is a lack of a clear definition of employment. The Space Foundation employment definition mixes manufacturing with services. The US space industry defence report also includes IT and research services. While, the OECD includes none of these services and only the manufacturing ones.

Employment is *defined* differently between various organizations, industrial associations and companies. Due to this difference, the comparison of employment statistics is like *comparing* apples with pears.

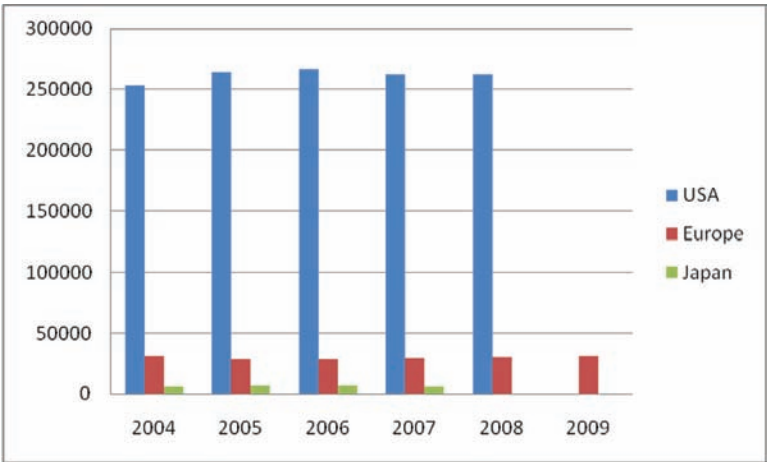
Therefore, the data on USA employment is inconsistent and incomparable, in contrast to the European one. For the purpose of analysis, the definition used by Eurospace on space industry employment will be used. Employment is a direct benefit that of the space industry and indirect one through other industries, such as Information Technologies (IT).

Figure 4 presents an overview of employment data from different sources and definitions.

The US has the highest employment worldwide, however with the retirement of the Space Shuttle in 2011 hundreds of people will loose their jobs and therefore, a reduction of empoyment in the US will be expected.

The *inconsistency* of employment data may be due to a number of reasons. First, that there are inter-dependencies between national space agencies, system integrators,

Figure 4. Worldwide space employment (Foundation, 2010)



sub-system integrators, equipment suppliers and ground segment service suppliers for a space mission (see Chapter 4). Second, there is interdependence between the various space missions. For example, a ground segment service company can provide engineering support for the ground segment design for example of the European earth observation Sentinels 1, 2 & 3 to support ESA (i.e. multi-national space agency) and a system integrator for these missions. So there are *two inter-dependencies*, one is the space missions as for example the GMES Sentinels consist of five space missions of Sentinel 1, 2, 3, 4 and 5. Due to these interdependencies employment data isn't always consistent.

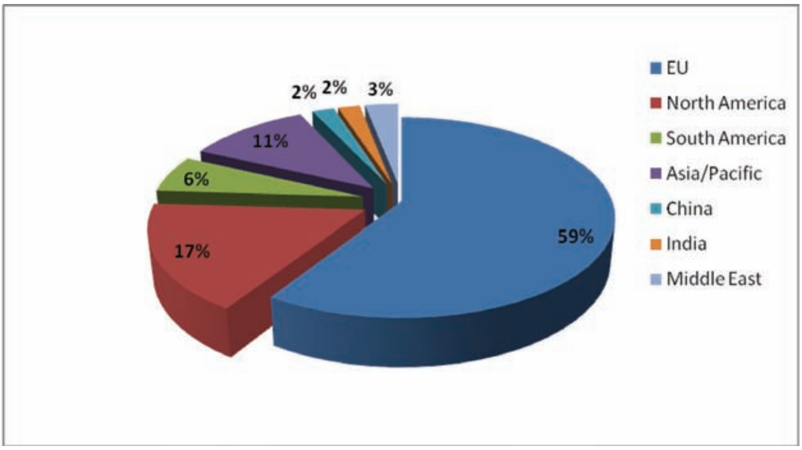
Employment is a direct *economic benefit* and national governments will have to provide consistent definition and measurement, in order to be able to measure the impact of the future interplanetary missions or commercial crew and cargo services to national economies.

5. SPACE PRODUCT EXPORTS AND EXCHANGE RATE FLUCTUATIONS

Space product exports influence the national trade export balance of a country and companies exporting their technologies are impacted by exchange rate fluctuations.

OECD defines space products as *spacecraft, including satellites, and suborbital and spacecraft launch vehicles* and *parts of balloons, dirigibles, and spacecraft not elsewhere specified (OECD, (2007).*

Figure 5. US Space products and services export (Force (2007)



USA is responsible for generating 32% of space exports followed by France with 23%, Germany with 16% and UK with 9%. Space product exports have been strongly influenced by the US ITAR (see Chapter 6).

Information on space product exports can be found in where the data is presented from the US point of view and covers the period from 2003 to 2006 (Force (2007)), as presented in Figure 5

The prime exports destinations of US space products and services are Europe with 59%, North America with 17% and the Asia/Pacific region with around 11%. However since 2002, the US exports are gaining from the significant US Dollar depreciation totalling at least 36% (Scott, 2007).

With space product exports of around 59% for the EU and with the decrease in value of the US dollar, US space companies *exporting* space products and services in the EU will have an interest to increase their exports and thus gain from the strong Euro currency.

On the other hand, European space companies exporting space products to the US will *incur losses* due to a stronger Euro and higher labour costs.

Companies such as EADS Astrium and Thales Alenia Space, therefore may reduce their exports to the US in order to mitigate potential revenue losses due to the USD dollar depreciation. For example, the European airplane maker Airbus incurred large losses because all its revenues are in US dollars and contracts, while the labour costs are in Euros (BBC, 2007).

Similarly to the US, due to a high rate of depreciation for the Russian rubble, Russia would benefit from increasing exports of its space products for the EU and USA. European companies, such as Thales Alenia Space (TAS) that export electronic parts for the Soyuz launcher may reduce their exports in Russia.

Space and non-space companies involved in projects linked to the use of interplanetary space based technologies, will need to take into *account* fluctuations in the national inflation rates. The successful implementation of future interplanetary missions and increased ISS utilisation and development of commercial launch services will result in the development of space products and services.

US companies (i.e. Space-X, Orbital) that provide commercial crew and cargo transportation services will have the incentive to increase exports of their commercial space products and service to Europe.

Thus, they will *gain direct benefits* from the revenues from sales and *indirect ones* through the establishment of international partnerships. In contrast, if the US dollar continues to depreciate, European companies exporting space products and services to the US, may incur losses due to the weak dollar and therefore have little interest to participate in US based programs. For European companies, the benefits will be only in indirect benefits, such as *technology interoperability, free publicity* and *international partnerships*.

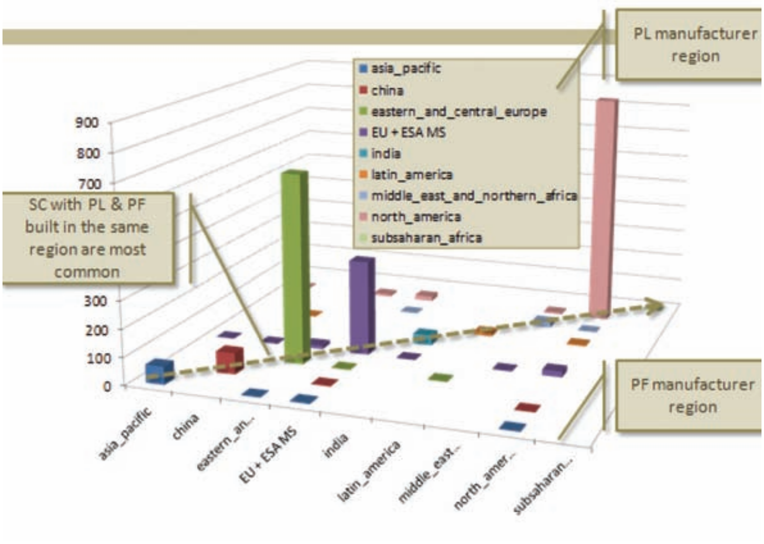
5.1 Impact of Exports/Imports on the Global Space Economy

Historically, space markets have always been strongly marked by strong protectionist policies where national customers are favoured for local supply. While export figures may concern important shares of subsystem, or basic equipment and components, they still represent a marginal fraction of the full system market as shown in Figure 6. The vast majority of spacecraft have payloads produced in the same region as presented in Figure 6.

The *strong protectionist* approach of national space programs are favoured by all space powers is embedded in such regulations, as the 'buy American act' (see Chapter 6). The graph above tells us that as a general rule customers *buy from local suppliers* and limit themselves in choosing primarily national suppliers. This situation is typical of government sponsored entities, such as the military and public space agencies. Competitiveness of national space industries is impacted as discussed in Chapter 6. As high market entry barriers are created and only few players are dominant, thus they encourage the creation of an *oligopoly* market structure.

When private actors enter the space market the situation gradually changes towards more opening of market and *diversification* of supply of products and services and increased competition. However, historic figures show that even with private entities the local preference remains strong in using the services of national suppliers.

Figure 6. Number of spacecraft by manufacturer region(x) and customer region (colors) 1989-2008 (Eurospace, 2009)



6. ECONOMIC IMPACT MEASUREMENT

Commercialisation of human space flight space technology is a relatively new process, but space technology has a major impact on our daily lives, such as the use of navigation, earth observation or telecommunications services. For example, a medical device developed especially specifically for the bone microstructure scanning for osteoporosis can have an impact for patients in remote areas who have no access to these devices. The benefits for the company that has developed the medical device will not only through technology innovation (indirect benefit), but also revenues from sales and new markets for the company that had developed it (direct benefit).

Commercialisation of space station's space-based technologies started in the mid 90s with commercial activities on board the MIR and ISS stations. Some of the early activities included Pepsi and Pizza Hut adverts on Proton launchers (see Chapter 2) and the launch of the first space tourists on board the ISS were some of the commercial activities that brought most publicity to the space agencies commercialisation initiatives and the birth of space tourism.

The above activities inspired entrepreneurs to invest in the development of suborbital space vehicles, construction of inflatable space stations and build space ports (see Chapter 7).

Due to the current nascent stage[5] for the commercialisation of space stations and space tourism segments, it is very early to discuss their economic impact. However, the development of commercial crew and cargo services and space tourism will influence not only the space industry, but will encourage the development in space ports development, space fashion, space cosmetics and even space nutrition and food services (see Chapter 6).

NASA COTS program, future Mars, asteroid and interplanetary missions, commercial transportation crew and cargo services and heavy launchers development and implementation may generate unexpected benefits, such as increased employment, technology innovation or international partnerships. The space industry will further *grow* and provide services to non-space companies willing to launch and develop commercial projects, related for example to osteoporosis drug and therapies development, health monitoring devices development and many other applications (see Chapter 5). Therefore, it is important to measure the economics benefits and impact from the use of space-based technology.

Today in 2010, the OECD and the FAA have defined and summarised economic impacts from space industry activities and in particular launch services. The FAA has investigated the economic impacts upon other non-space industries, as a result of the launch industry's influence on the US national economy (FAA, 2006).

The FAA definition of the economic impact is the following (FAA, 2006):

Economic impacts are quantifiable interactions between consumers and producers that result from a change in final demand for a product or service. These impacts track the financial transactions that occur throughout the production of a good or service, and they are measured in terms of increased economic activities, earnings, and jobs.

To calculate the economic impacts the FAA uses the so-called Regional Input-Output Modelling System (RIMS II) developed by the US Department of Commerce. The commercial launch transportation service, whose impact is investigated, includes the following space industry segments[6] (FAA, 2006)*: launch vehicles manufacturing* and *services, satellite manufacturing, ground equipment manufacturing, satellite service, remote sensing* and *distribution services.*

The above definition includes sectors of the whole space industry and includes telephony and Internet services. The latter can be classified under IT segments and therefore, the above FAA definition may be *misleading*.

Remote sensing is a separate space industry market segment, just like launch manufacturing and services (see Chapter 4). For example it will be like an aircraft producer calculating the economic impact, from the passengers using the bus from the aircraft to the airport terminal before take-off of the flight using this same aircraft. Clearly, the above definition of commercial space transportation services may *cause confusion* among non-space government organisations and companies, as it may place constraints on the future definition of economic data standards for commercial space transportation.

The FAA undertakes the following approach when defining the economic impacts (FAA, The Economic Impact of Commercial Space Transportation on the US economy, 2008).

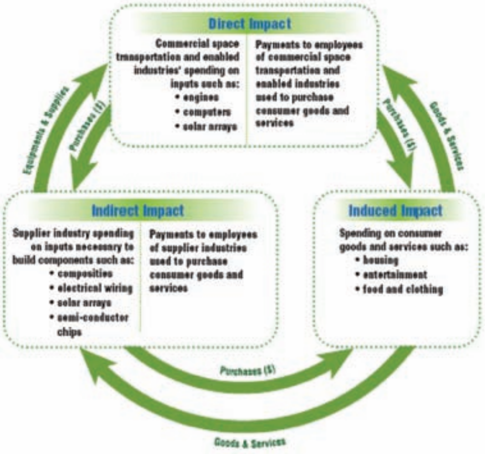
Direct impacts are the expenditures on the labour involved in providing the final goods or services. Indirect impacts involve purchases (i.e.metals, composite materials, processors) made by and supplied by the industries providing inputs to the launch and enabled industries.

Figure 7 shows the induced impacts from space transportation services and the successive rounds of increased household spending from the direct and indirect impacts (e.g. a spacecraft solar array design engineer's spending on food, clothes dry-cleaning, or any other household good or service).

The above approach *does not provide* a sound basis for the development of consistent data on space based economic and business activities, due to the *lack* of a set of clear definition of the industry segment and the elements that are measured. The approach above only partially contributes to identification of the benefits from the US commercial launch services or commercial crew and cargo services

Thus, the use of the above approach may result in the generation of numerous and *inconsistent* economic data sets. The creation of numerous data sets will inevitably

Figure 7. Direct and indirect economic impacts of commercial space transportation services (FAA, 2006)



result in data complexity and duplication and often into double counting. Thus, further expanding the problem with inconsistent economic data sets and false data.

At least the FAA provides a snapshot on the industries that are potentially impacted. The impacts are measured by economic activities, earning and jobs. For the FAA *economic activity* is the value of the goods and services produced in an economy, *earnings* is the sum of the employees' salaries and *jobs* are number of employees employed to produce goods and services in the economy (FAA, The Economic Impact of Commercial Space Transportation on the U.S. Economy:2004, 2008), Table 1 provides an initial overview of the industries in which potential impact from commercial launch services that is experienced.

Therefore, the development of transportation services industry, future interplanetary missions and heavy launchers development may experience similar impacts on non-space industries.

The successful implementation of the future commercial crew and cargo services development, interplanetary missions and development of key enabling technologies, will result in developing technologies, products and services that will have indirect impact on the sectors above. Therefore, it is important to *understand* and *measure* the impacts of commercial crew and cargo transportation services or of new key enabling technologies and also space ports construction on non-space industries.

6.1 Aviation Industry Benefits

The aviation industry has extensive experience in the provision of safe, profitable and reliable services and is an industry owned and operated by private and government owned companies. Future commercial crew and cargo services or sub-orbital services

Table 1. Economic impact on US industries from commercial launch services (FAA, The Economic Impact of Commercial Space Transportation on the U.S. Economy:2004, 2006)

Industry Group	Economic Activity ($000)	Earnings ($000)	Employment (Jobs)
Information Services	$45,341,392	$10,594,371	155,890
Manufacturing	$35,304,598	$ 6,628,829	94,890
Real Estate, Rental and Leasing	$9,416,563	$697,394	18,700
Finance and Insurance	$6,849,411	$ 1,900,361	29,200
Wholesale Trade	$6,217,235	$ 1,998,045	33,850
Professional, scientific and technical services	$6,047,037	$ 2,646,042	48,470
Health Care	$5,071,057	$2,468,565	61,460

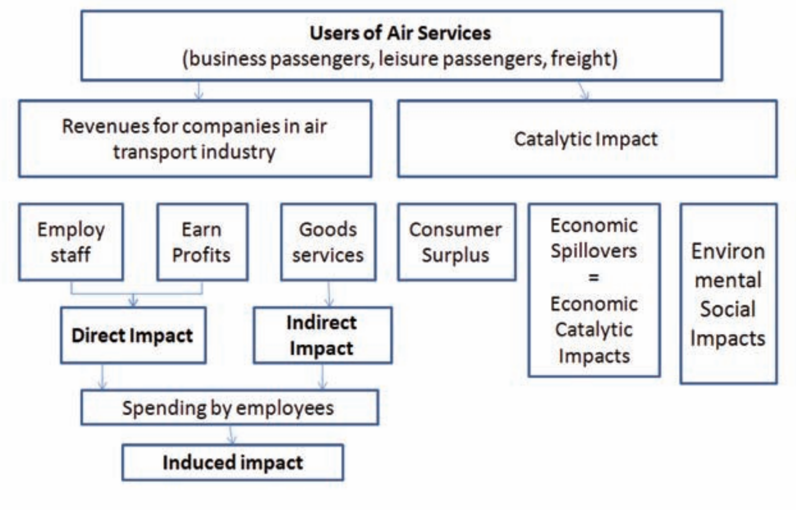
may build their business models based on the aviation industry ones (Tkatchova, 2010). As similar to the aviation industry, safety in space industry is of paramount importance. Also in human spaceflight, all on board systems are developed and designed with the safety of the crew in mind. For a future Mars or asteroid missions this is of critical importance as the crew will be exposed to numerous health risks (i.e. radiation, osteoporosis, etc). Contingency systems are back-up systems in case of failure or emergency and will be of crucial importance. From the qualitative benefits the relevant ones will be related to international commitments and environmental benefits are those dealing with noise and pollution. Therefore, it will be important to measure the benefits from these missions for national economies.

For performing economic assessment of projects, sustaining safety and reliability and securing services to manage the expected traffic growth is widely used cost benefit analysis[7](CBA) (Eurocontrol, 2000).

CBA contributes to the identification of a project's options, the investment required and the definition of expenditures groups and stakeholders. CBA is a widely used in the aviation industry and supports private investors, trans-national stakeholders, service providers and aircraft operators to understand the benefits and the resources they need to commit to a project (Eurocontrol, 2000).

Space tourism activities may develop in a similar way as in the aviation industry and direct and indirect economic impacts can be measured through measuring catalytic impact, direct and indirect impacts as presented in Figure 8. Catalytic impact measures environmental and social impacts, economic spill-overs and consumer surplus.

Figure 8. Economic impact (Cooper, 2005)



Cost savings for the aviation industry are defined as the ones that reduce the operating costs for the service providers and delays for the aircraft operators. *Capacity* is referred to as increased airspace capacity for a certain route, and reliability is related to the replacement of certain systems with new ones.

Once sub-orbital space tourism develops it is very possible that a similar approach for calculating of the impacts to be applied. However, at this *nascent stage* of space tourism services development the above approach can be taken under account for any long-term impacts calculation from space technology utilisation. As the nascent stage of market development will require from commercial crew or cargo services companies to secure *long term investments*, to face *high business risks* and *'long-time to market'*. Therefore, private investors, space companies, business angels, space agencies and regulatory bodies will be able to identify the direct and indirect economic impacts, quantify the benefits and prioritize projects. In the *aviation industry* the benefits are divided into *quantitative* and *qualitative* benefits[8].

- **Quantitative benefits:** cost savings, capacity, reliability, delays
- **Qualitative benefits:** safety, environmental, international commitments, contingency and upgradability

When defining the direct and indirect economic benefits from potential commercial projects for future interplanetry missions, some of the above benefits can be relevant. For example, from the *quantitative ones: cost saving* and *reliability*. Due to the historic existence of various space vehicles and launchers between the USA and the Russians, it is important to take into consideration the existence of *technology interoperability*, as it possible for the future Moon and Mars missions, Europe, Japan and Canada to also contribute with their technological solutions for which there will be a need for *interoperability.*

The *direct benefits* will be *cost savings, safety, reliability* and *interoperability*, while the indirect ones can be international partnerships and environmental protection.

The above benefits will permit to companies to perform market analyses, develop business cases, identify project trade-offs and prioritize their investment in new projects and markets. Therefore, the above benefits will be considered for identifying the future benefits definition from space technology utilisation.

6.2 OECD Benefits

OECD also undertakes an approach focused more classifying the various impacts, as a result of the investments in space industry. The impacts are categorised in *new jobs, new revenues, efficiencies, cost avoidance* and *social inclusion.*

Table 2. OECD categories of impact from space industry activities (OECD, 2007)

Category of Impact	Space Sector	In other sectors
New jobs	Workforce	Employment locally, regionally serving the space sector workforce. Employment in companies and organisations using space-related products and services to create new products or services.
New revenues	Revenues from new services	Revenues coming from new services, based on space-based elements (telecommunications, navigation, etc.)
Efficiency	Increased competitiveness	Productivity gains achieved by improving space assets user's production and distribution. Cost savings from ground segment operations.
Cost avoidance		Reduced damage to lives and properties
Social inclusion		Satellite communications infrastructure projects contribute to addressing the problem of social exclusion by improving accessibility

The above categorisation of impacts provides a better overview than that of the FAA. With the future implementation of the new commercial crew and cargo program, the expected development of heavy launchers capabilities and future utilisation of the ISS impact of space industry sector and non-space companies' commercial projects on the non-space sectors will *increase* and will need to be *measured.*

Therefore, it is *important* in the early days of the program to define a clear methodology for *economic impact analysis* not only of the space industry activities but also of those related particularly to human space flight, thus permitting a clear identification of the direct and indirect economic benefits. That later can be used for future Cost Benefit Analysis (CBA) for commercial projects under the future interplanetary missions.

Commercialisation of space-based technology for future *interplanetary* missions will be an innovative, challenging process that will bring to space and non-space companies *new business opportunities*, increased *revenues* from sales and *technology* innovation,. Furthermore, the definition of direct and indirect economic benefits from space exploration will aid decision makers and space lobbyists to justify budgets allocation for interplanetary space exploration.

6.3 Economic Measurement Issues

Commercial utilisation of space technology will permit companies to enter new markets, perform shared R&D or achieve cost savings and new commercial crew

Table 3. Economic measurement issues

Space Technology	New Markets	Standards
Failure to understand the complexity of space based technology from non-space companies.	Unknown customers, markets, high safety regulations and nascent stage of market development	Lack of a definition of direct and indirect economic benefits and of space activities
Space agency's new requirements, standards and processes for commercial crew and cargo services	Danger of creation of numerous data sets, that will inevitably result in data complexity and duplication and double counting	Lack of definitions of space budgets and standards on defining space economic data quality
Methodology for impacts definition has not been defined	Exchange Rate Fluctuations are not considered into space budgets[9]	Employment data is imprecise and definitions are diverse and not universal
Space budget duplication		Lack of a centralised non-commercial organization to consolidate data and provide quality data control and measurement (e.g. EU Space Economics Space Office)

and cargo transportation services. However, stakeholders involved in these projects such as private investors, space agencies, private companies and manufacturers will face *several issues* when defining the direct and indirect benefits from the use of space-based technology or the development of space applications for their projects.

The above issues will need to be investigated by national governments, organisations and associations in order to be able to measure the direct and indirect impacts from space technology utilisation. Furthermore, companies investing in the development of commercial crew and cargo vehicles will have to address some the market issues in order to be able to develop viable business cases using space-based technology.

6.4 Direct and Indirect Economic Benefits

Future interplanetary human space flights may bring direct and indirect benefits to national economies and societies in the areas of biotechnology, osteoporosis, nanotechnology, communications, robotics and others. Similar to the ones from the Apollo missions with around 1,500 spin-offs, such as kidney dialysis machines, water purification technology, dry lubricant and fire resistant materials. Space based technology utilisation brought technology innovation benefits in areas, such as quality control, computer technologies and new materials.

For the FAA economic benefits are defined as (FAA, 2006):

Economic benefits are wider in scope and generally include the intangible, positive effects that result from the availability of certain goods and services in the US economy.

Examples of economic benefits include decreased transaction time, cost savings, cost avoidance, improved productivity, increased efficiency, development of new technologies, technology diffusion, and attraction of new business to a region.

The FAA also descibes in its Quarterly launch report how certain US states encourage human space flight, in particular those related to space port construction for sub-orbital flights. In the US states Virginia and Florida, have both introduced a Zero G Zero Tax Act, the concept of which is to exempt companies from paying taxes on certain type of activities (FAA, Quarterely Launch Report, 1st Quarter 2009, 2008).

- In the US state of Virginia there is a tax exemption that will be applicable to income from launch services for trainings or gains resulting from ISS resupply contracts
- In the US state of Florida spacecraft contractors will be allowed to receive refunds by entering into specific agreements with the state (refunds based on new jobs and wages received by the employees)

Therefore, companies involved in the above activities will have strong incentives for becoming involved in space ports construction.

For the OECD some the *economic benefits* (OECD, 2007) from space industry activities are:

Financial benefits (sales & trade revenues) and indicators of present and future financial benefits (i.e. patents)

Some definitions define economic benefits as (Dictionary, 2008):

Economic benefits are quantifiable in terms of money, such as revenue, next cash flow and net income

For the purposes of this book, economic benefits will be referred to as:

Economic benefits from commercialisation of space-based technology can bring direct and indirect advantages. That could provide scientific, business and technological advantages that will improve daily lives of humans and protect Earth's and the outer space environment.

The *direct benefits* will be employment, revenues from sales, new markets, cost savings, employment and technology reliability, while the indirect benefits will be promotion, technology innovation, international cooperation and environment protection. For example Google gained *indirect benefits*, such as of free publicity, such as from the Google Lunar X prize competition.

The analysis performed in the earlier chapters 1, 2 and now this one provide recommendations on the type of the benefits that are the following.

- **Direct economic benefits** are increased employment, revenues from sales, new markets, increased cost savings and technology reliability and interoperability. Technology reliability also incorporates safety.
- **Indirect economic benefits** are going to be considered free publicity, technology innovation, international partnerships and environment protection.

The commercialisation of space-based products and services for future interplanetary missions can bring direct and indirect benefits for entrepreneurs, space and non-space companies, space agencies, national governments and non-governmental organizations.

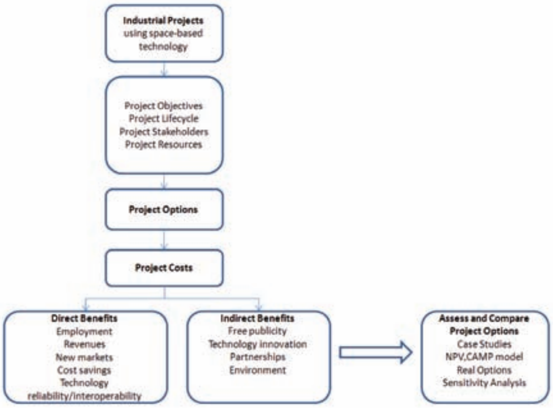
The *benefits* above will also support space agencies to measure and assess the direct and indirect benefits not only from commercial crew and cargo launch services, but also from the use of navigation systems. For example, the new US space guidelines of 2010, it is stated that department and agencies will "work jointly to acquire space launch services and hosted *payloads* that are *reliable,* responsive to United States needs, and *cost effective*" this statement show that NASA will be looking for finding cost-effective solutions for launching US payloads. Which will need to be measured and the above benefits can support the agency in measuring their cost-effectiveness. Furthermore, the US has recognized that other countries like Europe have their own navigation system like Galileo and *"enagage foreign GNSS providers to encourage compatibility and interoperability"* (National Space Policy, 2010). In this context the direct benefits of technology *reliability* and *interoperability* will be relevant for measuring this goal. Finally, the indirect benefit of international partnerships will be very relevant for the future US space policy, as stated " Promote appropriate *cost* and *risk-sharing* among participating nations in *international partnerships*".

Quantifying and qualifying the expected benefits will be important for to help end-users to define the expected benefits and convince private investors financially to contribute to industrial projects using space-based technologies. Non-space companies will be able to develop their business cases.

6.5 Economic Benefits and Project Options

In order to be able to attract private investment space companies involved in the construction of commercial transportation services, launchers, sub-orbital transportation vehicles, inflatable space stations or crew and cargo transportation vehicles, will have to assess *the need* for the private investment in their projects. Therefore,

Figure 9. Direct and indirect benefits for project options definition



they will have to define their project objectives and options, define their projects costs versus the direct and indirect benefits. When a company is assessing its participation in an R&D project it will have perform perform project trade-offs whether to use space-based or ground based technologies. Furthermore, the company will have to assess the project costs in the context of the different project trade-offs. Once the benefits are defined it will be possible to either use them for case studies development or Net Present Value (NPV) modelling, as presented in and further demonstrated in Chapter 10.

The definition of the direct and indirect benefits for private companies when entering new markets will help projects stakeholders to develop their *business cases, perform cost benefit analyses* and *prioritise their investment.* Furthermore, will permit to private investor not only to perform NPV but also to assess the potential of certain markets and calculate the expected projects potential rate of return that will bring them. Certain direct and indirect benefits will be directly linked, as for example increased revenues from sales and new markets will be linked. For example the Japanese brand COSMODE is directly linked to the additional value it brings and the price sensitivity of the product on which the brand is meaning that market studies indicate that customers price a product with a COSMODE brand higher than without it. In this case the publicity benefit is directly linked to revenues from sales and new markets.

In addition companies will be able to define their unique selling point and identify their industrial projects Strengths, Weaknesses, Opportunities and Threats (SWOT). Furthermore, the above benefits may be used by NASA or ESA or other space agencies which have programs similar NASA COTS program (see Chapter 3) or aiming at measuring economic benefits from commercial crew and cargo services.

7. DISCUSSION

From the analysis performed in this chapter it became apparent that there is a lack of clear definitions of space activities, budgets and economic data standards. There is a lack of a centralised non-profit organization to consolidate the data and provide quality data control and measurement. The inconsistency of the employment data may be due to several reasons. *First*, there is *inter-dependency between* national space agencies, system integrators, sub-system integrators, equipment suppliers and ground segment service suppliers for a space mission. *Second*, there is an interdependence of the various space programs.

The potential problems with the lack of a *good methodology* for impacts definition and the potential danger of the creation of numerous data sets will inevitably result in data complexity and *duplication* and into *double counting of space budgets.*

The example of the aviation industry is taken as it is an industry with extensive experience in provision of safe, profitable and reliable services and it is possible future sub-orbital commercial services to be a built in a similar way. Furthermore, the aviation industry benefits permit the easy assessment and trade-off of project options and the performance of cost benefit analyses. Therefore, the direct benefits of interoperability, cost savings, safety, reliability and interoperability will be derived from the aviation ones. As these are the benefits that will permit to companies to perform market analyses, develop business cases and prioritise their investment in commercial crew or cargo services. Measuring the direct and indirect benefits from different projects in the context of their early phase development will support companies to develop their business cases and perform cost benefit analyses for projects using space-based technology.

8. CONCLUSION

In this chapter we offered a definition of space economics, interplanetary economics and economic benefits. In addition we analysed space budgets, national employment and space products exports.

The definition of direct and indirect economic benefits from space exploration will aid decision makers and space lobbyists to justify budget allocation for space exploration.

Future interplanetary missions will spread over a period of a minimum of 20 years and is the most ambitious and complex program ever undertaken in the history of human space flight. During this period there will be changes in space agencies budgets, which will be driven by political interests.

Space agencies will have to not only clearly define the direct and indirect economic benefits, but also define an *industrialisation strategy* for attracting non-space commercial users and private funding for projects related to utilisation of space technology as for example for ISS utilisation.

The USD dollar depreciation may result into reduction of European companies exports to the US space products for the future US space programs, as labour costs are in Euros, but contracts in USD dollars. As they will incur losses due to the weak dollar and have a low interest to participate in the program. For them the benefits will be only in technology interoperability, free publicity and international partnerships. While, US companies will increase their exports and gain revenues from sales.

Once commercial crew and cargo services and sub-orbital space tourism develop it is possible to use the aviation industry examples to calculate the impacts to be applied, because the in the aviation industry crew safety is of crucial importance as in sub-orbital and human space flight. Companies investing in the development of commercial crew and cargo vehicles will have to address some the market issues in order to be able to develop viable business cases using space-based technology. Permitting the clear identification of benefits, ones that later can be used for future Cost Benefit Analysis(CBA), real options modelling for private companies and investors for commercial projects for commercial crew and cargo services or from the use of space based technologies from interplanetary missions.

Direct economic benefits are increased employment, revenues from sales, new markets, increased cost savings and technology reliability and interoperability. Technology reliability also incorporates safety. *Indirect economic benefits* are going to be considered free publicity, technology innovation, international partnerships and environment protection.

The above benefits will permit to companies to perform market analyses, develop business cases, identify project trade-offs and prioritize their investment in new market development. Therefore, the above benefits will be considered for identifying the future benefits definition from space technology utilisation.

For example in the context of NASA new space policy of 2010 the agency will can benefit from using the above benefits for measuring the cost -effectiveness, technology interoperability in the context of navigation systems and international partnerships for international cost and risk sharing for future space missions.

Commercialisation of space-based products and services for future interplanetary missions can bring direct and indirect benefits for entrepreneurs, space and non-space companies, space agencies, national governments and non-governmental organizations.

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ENDNOTES

[1] Scarcity is the situation in which human needs are greater than the resources available to satisfy them.

[2] Military space budgets are distributed on a national level and budget information is confidential.

[3] Since 1998 Eurospace has been gathering information on European employment. Eurospace is the biggest European space industry association, has created space industry definition and has created a consistent annual database. The information in this database is provided by the 150 members of the association.

[4] System integrators are companies that have the competencies to design and build a spacecraft and systems, from early design to launch, they are also referred to as manufacturers. These companies are also active on subsystem

and equipment level and in Europe these are EADS Astrium and Thales Alenia Space.

[5] Space Tourism has emerged as a promising market that is expected to reach up to $1 billion in 2020. However, the space tourist market is still in a nascent stage where technology innovation is the main driver, new markets are being created, first time buyers are joining in, customers are still unknown and there is still strong government regulation. Companies offering space tourist services are focused on creating new markets, targeting customers and diversifying their services (Stella Tkatchova, 2010).

[6] Launch vehicles manufacturing and services include US commercial launch vehicles and US commercial services, satellite manufacturing includes the sales of all commercial satellites constructed by US commercial manufacturers, ground equipment manufacturing includes satellite related hardware, gateways, satellite control stations, mobile uplink equipment, VSAT terminals and consumer electronics with satellite services, such as broadcast satellite dishes, phone booths, and handheld phones. While, satellite services include end-to end services and transponder leasing. The 'end-to end services' include satellite data and DTH, mobile data services and high-speed Internet services etc. While, remote sensing includes satellite data and imagery and distribution services includes the distribution services for truck, air and rail transportation that are required to move launchers parts from the manufacturing parts.

[7] Cost Benefit Analysis (CBA) does have its disadvantages, such as double counting of benefits and projects that are technology led and that offer an opportunity may not always overlap with the project requirement and also of consistency problems in relationship with benefits definition.

[8] Other benefits are the so called enabled/delivered benefits. The delivered benefit is the actual benefit to be realised from a project. For example, if new en-route radar equipment leads directly to more aircraft flying per hour, then an increased capacity benefit will have been delivered.. When a is carried out, that project is called an enabling project - the associated benefits are termed enabled benefits. Datalink is a good example of an enabling project. Datalink could be used for a number of applications, e.g. for controller - pilot dialogue, but it has no benefit without further projects to deliver these applications (Eurocontrol, 2000)

[9] For example the Space Foundation 2010 report presents all the national space budgets in national currencies

Chapter 9

An Analysis of Two Space Business Opportunities

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1. INTRODUCTION

There are many industries where space technologies can be applied commercially. As discussed in Chapter 5 Emerging Markets and Applications range from treating and diagnosing osteoporosis. In this chapter we choose two commercial applications and develop the business case for each of them.

The first application we analyze is the mitigation and removal of space debris. This application is immediately economically viable and feasible to implement with current technology or relatively minor technological advances. Space debris is defined as any man-made object in earth orbit that is not deployed by any working systems. The large number of space debris creates significant hazards for existing satellites and would generate even bigger risks for any future expansion of human presence in earth orbit. The market for space debris mitigation and removal is large. The profit opportunities are relatively easily defined, yet only a handful of private companies currently provide products and services to this market. We use one of these companies – Tethers Unlimited, Inc. (TUI) – as a focal point of our business case for space debris mitigation and removal.

The second application we evaluate is Space Solar Power (SSP). SSP involves the conversion of solar energy into electromagnetic waves by satellites in orbit, beaming these waves to rectifying antennas (rectennas) on the ground and converting them into electricity. Space Solar Power is considered currently unviable either for technological or economic reasons. Nevertheless, with certain technological advances and/or the engagement of high-value clients it could offer tremendous opportunities for profit. Space solar power is a source of energy that does not generate greenhouse gases, has a much smaller heat rate than any conventional power generation method, and can provide enough energy to meet the needs of the entire Earth's population for a practically unlimited time horizon. Consequently, successful implementation of large scale SSP systems could in the long run solve at least two existential problems facing humanity – energy generation and climate control. We develop our business case around two hypothetical SSP systems: 1) a 1 megawatt system intended to provide electrical energy in remote areas of interest to the military, which is based on designs developed by Heliosat, Inc.; and 2) a 1 gigawatt system, based on designs developed by Space Energy, Inc., that could, if replicated multiple times, provide base-load capacity for civilian electric power generation.

After analyzing the technological challenges and developing the business cases, we turn to the major issues of financing any commercial ventures that wish to operate in each of our two chosen space industries. Space debris mitigation and removal and especially Space Solar Power have several features that make them unattractive for private capital providers. First, there is a significant upfront investment in research, development and testing before any product becomes operational. Due to the uncertain outcomes and long payback periods, investments in R&D in general attract only a small number of specialized private investors like venture capitalists or large companies operating in oligopolistic industries. Investments in SSP-related R&D are expected to be extraordinarily risky with paybacks exceeding 25 years.

Second, the forecasting of revenues and costs in financial models necessary to determine the rate of return of investments is a lot more difficult in a space-related industry than in, say, a conventional electric utility. Higher modeling uncertainty forces investors to either require an exorbitant rate of return on capital, or just walk away from the deal. Last, commercial enterprise in space has to navigate an exceptionally complicated legal and political landscape. There are various security and property rights concerns that add even more uncertainty to an already highly risky enterprise.

Notwithstanding the risks associated with investments in space debris mitigation or SSP, we argue that these industries could offer attractive returns to venture capital funds, other private equity investors, or large corporations with a combination of dwindling investment opportunities significant free cash flows (e.g. power utilities and oil and natural gas companies). After the technological risks have been resolved, the scaling of each industry can be achieved with funding from public capital markets, which in addition can provide an exit channel for the venture capitalists and other private equity investors.

We discuss the role of government in participating side by side with potential private investors in hybrid financing vehicles for space debris mitigation or SSP. The importance of clean power generation and the higher risks in SSP make government involvement more pertinent, but space debris companies could also benefit from some specifically designed government policies to facilitate capital flow. Last, we discuss the impacts of the ongoing financial crisis and world-wide recession on the financing of hi-tech startups in general, and space debris mitigation and SSP companies in particular.

The remainder of the chapter in structures as follows. In Section 2 we develop the business case for Space Debris Mitigation. We analyze the technology and economics of Space Solar Power in Section 3. Section 4 discusses the challenges of and opportunities for financing startup companies in Space Debris Mitigation and Space Solar Power. Section 5 concludes.

2. ANALYSIS OF AN IMMEDIATE INVESTMENT OPPORTUNITY: SPACE DEBRIS MITIGATION AND REMOVAL

Space debris or orbital debris, also called space junk and space waste, are the objects in orbit around Earth created by humans that no longer serve any useful purpose (Wikipedia Space Debris). They consist of everything from entire spent rocket stages and defunct satellites to explosion fragments, paint flakes, dust, and slag from solid rocket motors, coolant released, deliberate insertion of small needles, and other small particles (Smith, 2007). (Figure 1, Figure 2)

Fortunately, at the most commonly used Low Earth Orbits, residual air drag helps keep the zones clear. Altitudes under 300 miles (480 km) will be swept clear from debris in a matter of months. At altitudes above this level, lifetimes are much greater, but drag gradually brings debris down to lower altitudes. At very high altitudes this can take millennia. (Figure 3)

At closing speeds reaching 50 thousand km per hour, even the smallest bits of space debris can cause serious harm to spacecraft; larger ones can have catastrophic outcomes. Near-Earth missions like the International Space Station, now carry ever-more sophisticated shielding. Not only is space debris a hot topic, it is also a fascinating and growing field of space science.

According to Dr. Walter Flury (ESA, 2007), ESA principal space debris expert, at the end of 2003, there were some 10 000 catalogued debris objects around Earth. Figure 4 shows the composition by source.

Figure 1. LEO space debris (source: ESA)

Figure 2. LEO space debris (source: ESA)

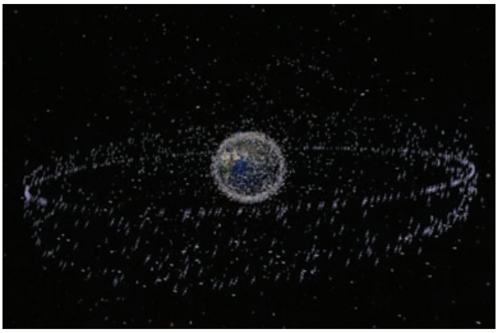


Figure 3. Spatial density of space debris by altitude according to ESA MASTER-2001 (source: ESA)

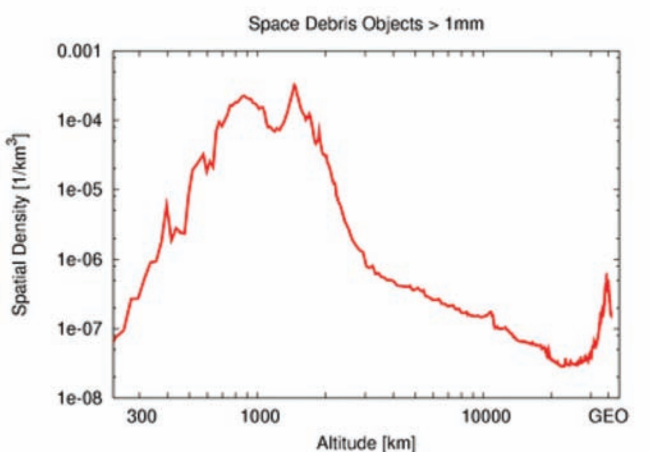
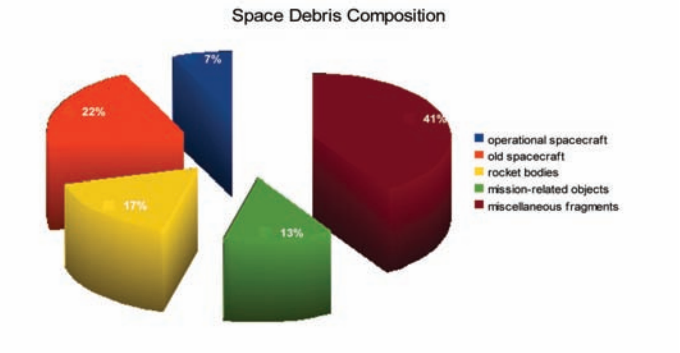


Figure 4. Space debris composition according to Dr. Walter Flury, ESA (source: ESA)



2.1. Significant Debris-Related Events

Debris Generating Events

In 1958, the United States launched a satellite named Vanguard I. It became one of the longest surviving pieces of space junk, and as of March 2008 remains the oldest piece still in orbit (Smith, 2007).

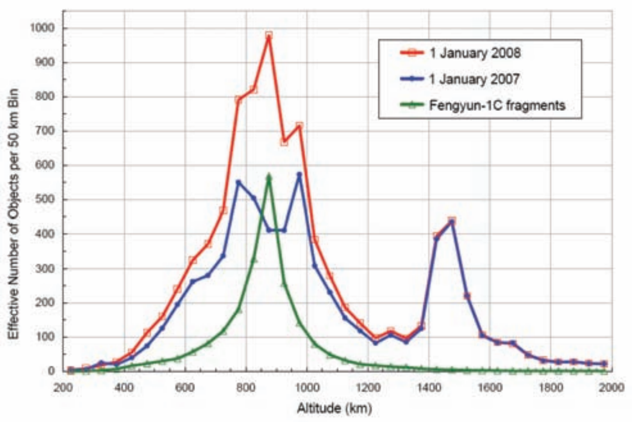
The worst uncontrolled reentry in history occurred in July 1979, when Skylab, America's abandoned, 78-ton space station – which had long since run out of maneuvering fuel – came down earlier than planned, raining debris across the Australian outback (Kluger, 2008).

In 2006, wreckage from a Russian spy satellite passed dangerously close to a Latin American Airbus carrying 270 passengers, reentering over the Pacific Ocean which is considered among the safest places in the world to bring down satellites due to its unpopulated vastness. 2006 as a whole had eight breakups – the most since 1993 (NewScientist.com, 2007).

The largest space debris incident in history was the Chinese anti-satellite weapon (ASAT) test on January 11, 2007 (CSSI, 2007). The event was estimated to have created more than 2300 pieces of traceable debris (approximately golf ball size or larger), over 35,000 pieces 1cm or larger, and 1 million pieces 1mm or larger. The debris event is more significant than previous ASAT tests in that the debris field has a higher orbit altitude, resulting in deorbit times of 35 years and greater. In June 2007, NASA's Terra environmental spacecraft was the first to be moved in order to prevent impacts from this debris (Burger, 2007). (Figure 5)

An event of similar magnitude occurred on February 19, 2007, when a Russian Briz-M booster stage exploded in orbit over Australia. The booster had been launched on February 28, 2006, carrying an Arabsat-4A communication satellite but mal-

Figure 5. Distributions of the catalog populations in the low Earth orbit region in January 2007 (blue), January 2008 (red), and the officially cataloged Fengyun-1C fragments. (source: NASA, 2008)



functioned before it could use all of its fuel. The explosion was captured on film by several astronomers, but due to the path of the orbit the debris cloud has been hard to quantify using radar. Although similar in magnitude, the debris field is at a lower altitude than the Chinese ASAT test and much debris will re-enter the atmosphere in a relatively short time. As of February 21, 2007, over 1,000 fragments had been identified (Spaceweather.com, 2007). A third breakup event also occurred on February 14, 2007 as recorded by CelesTrak (CelesTrak, 2007).

Additionally on February 20, 2008, the U.S. launched an SM-3 Missile from the USS Lake Erie specially designed to destroy a defective U.S. spy satellite feared to carry 1,000 pounds of toxic hydrazine fuel. This event occurred at about 250 km altitude and all created debris had a perigee of 250 km or lower. Although the apogee of some debris may be higher due to the explosion, the low perigee altitude will cause all debris to re-enter the atmosphere in a relatively short time period (NPR, 2008).

Debris Impact Events

In 1993, the first servicing mission found a hole over 1 cm in diameter in a high-gain antenna mounted on the Hubble Space Telescope. A debris object completely penetrated the antenna dish (but the unit continued working). In July 1996, France's Cerise military reconnaissance satellite was struck and severely damaged by, ironically, a catalogued Ariane upper-stage explosion fragment; a 4.2-metre portion of Cerise's gravity gradient stabilization boom was torn off (ESA, 2005). (Figure 6)

Figure 6. A debris cut off an antenna of satellite Cerise in 1996 (Credits: CNES/ ill.D.DUCROS,1998)

Only one person has ever been hit by manmade space debris – in 1997, an Oklahoma woman was hit in the shoulder by a 10 x 13 cm piece of blackened, woven metallic material that was later confirmed to be part of the fuel tank of a Delta II rocket which had launched a U.S. Air Force satellite in 1996. She was not injured (Today in Science History, 2009). (Figure 7)

On February 10, 2009, US commercial Iridium spacecraft (560 kg) hit a defunct Russian Kosmos satellite (900 kg) at an altitude of about 800 km (500 miles) over Siberia on Tuesday (BBC, 2009). Both vehicles were traveling at about 26,800 km/h. Since they were in different orbital planes, their relative closing speed must have been at least several hundred miles per hour. One of Iridium's mobile telephony nodes instantly became a cloud of space junk, as did the Russian spacecraft. It is hoped most of the debris will just burn up in the Earth's atmosphere, but there is a small chance some of it could hit the International Space Station. The Hubble

Figure 7. Impact on a solar panel (Credits: ESA)

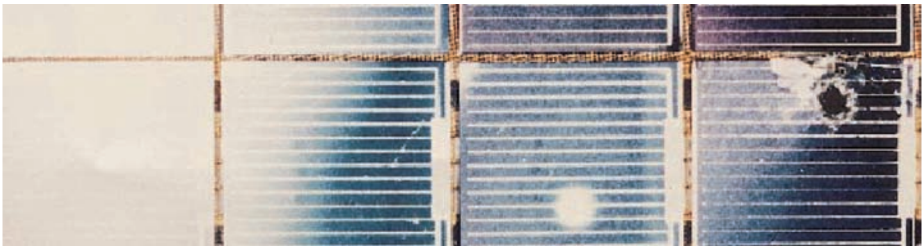
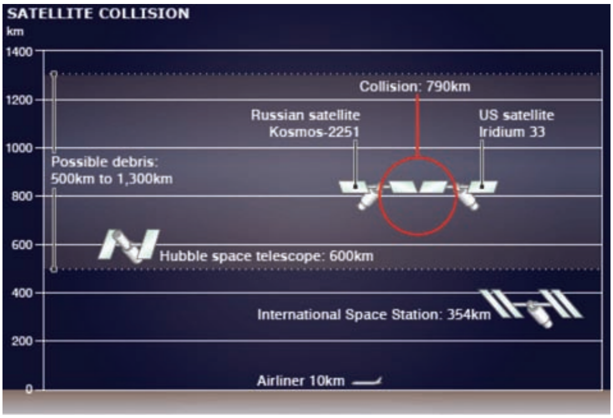


Figure 8. Iridium/Kosmos location at the time of collision (Courtesy BBC)



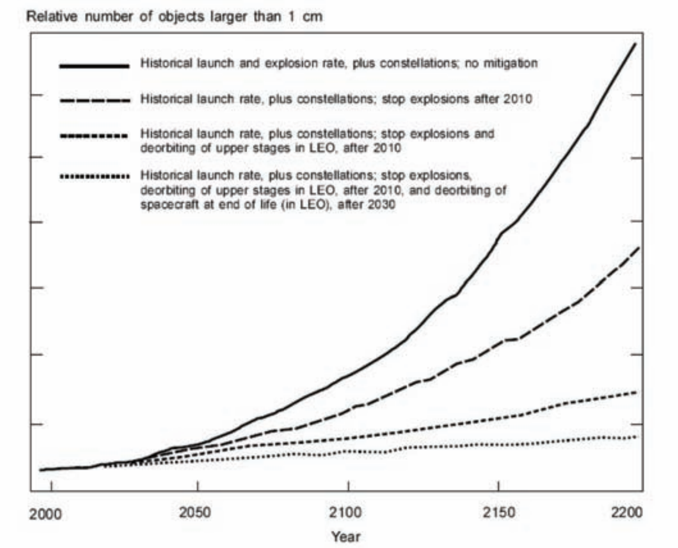
telescope and other observation satellites are also close to where the collision happened (see Figure 8).

2.2. Future Risk: Kessler Syndrome

Space debris has become a growing concern in recent years, since collisions at orbital velocities can be highly damaging to functioning satellites and can also produce even more space debris in a process called the Kessler Syndrome. The Kessler Syndrome is a scenario, proposed by NASA consultant Donald J. Kessler (Kessler, 1999), in which the volume of space debris in Low Earth Orbit is so high that objects in orbit are frequently struck by debris, creating even more debris and a greater risk of further impacts. The implication of this scenario is that the escalating amount of debris in orbit could eventually render space exploration, and even the use of satellites, too prone to loss to be feasible for many generations. With a large enough collision (such as one between a space station and a defunct satellite), the amount of cascading debris could be enough to render Low Earth Orbit essentially impassable.

The Kessler Syndrome presents a unique problem to human space travel. Space debris is very difficult to deal with directly, as the small size and high velocities of most debris would make retrieval and disposal impractically difficult. Given thousands of years, most debris in Low Earth Orbit would eventually succumb to air resistance in the rarefied atmosphere and fall down to Earth. If magnetically susceptible, the debris could fall in a few decades due to the drag of the Earth's magnetic field (Figure 9).

Figure 9. Trends in population of space debris particles larger than 1 cm low Earth orbit for different scenarios, 2000-2200



2.3. Possible Solutions

We must reduce the risks on the ground and the risks in orbit. To reduce these risks, the number of space objects in orbit around the Earth must be limited. To achieve this goal, there are four different options: avoidance, protection, prevention and removal.

Avoidance

This involves conducting maneuvers to avoid satellite collision with debris or to change the launch date if there is a risk of impact. This solution can be implemented to avoid the debris cataloged (i.e. those regularly monitored by a monitoring system for space), or debris larger than 10 cm. Par ailleurs, les données relatives à la trajectoire des objets spatiaux sont imprécises ce qui peut conduire à des fausses alertes. In addition, data on the trajectory of space objects are imprecise which can lead to false alarms. Avoidance maneuvers are expensive and are not always easy to achieve. As a result, this will be reserved for launch vehicles and for "fragile" satellites such as manned spaceship. Avoidance only covers part of the risk (less than 5%) and covers only items cataloged.

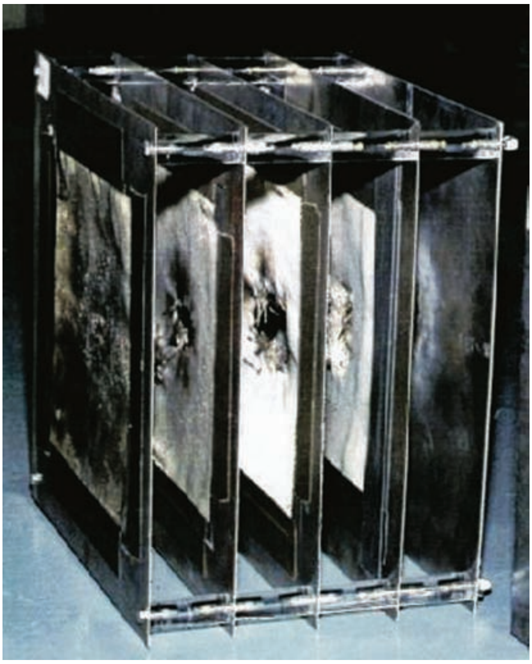
The first official Space Shuttle collision avoidance maneuver was during STS-48 in September 1991. A 7-second reaction control system burn was performed to avoid debris from the Cosmos satellite 955.

A hazard analysis conducted for a planned October 2008 mission of the NASA space shuttle Atlantis concluded that its greatest risk was from space debris, with a 1-in-185 chance of catastrophic impact. This level of risk will require a top-level launch decision. A typical space shuttle mission, to the International Space Station at 200 nautical mile altitude, involves a 1-in-300 risk, but the October 2008 mission is to the Hubble Space Telescope, which orbits at 300 km altitude, where there is more debris. If the mission proceeds, planned mitigating measures include flying the shuttle tail-first, placing the main engines as the first contact with debris.

Protection

Measures to protect satellites can be implemented to mitigate the effects of a collision with debris. Shielding specific multi-layer bumpers (Figure 10), this is to add protection to specific areas around the satellite. The main principle is to transform the kinetic energy into thermal one, which causes the melting of the impacting debris. These protections are mandatory for manned spacecraft, since they should not only protect the structural integrity, but also the pressure inside the vehicle. The multi-layer bumpers are designed to avoid the "unzipping" of the module – critical crack propagation in the module wall and depressurization-related phenomena, such

Figure 10. Multilayer protection shield debris (Credits: CNES)



as crew hypoxia and uncontrolled thrust due to air rushing out of the module wall hole. The bumpers are effective only with respect to the debris of a size up to 1 cm.

Table 1 lists debris by size category and the existing solutions to mitigate their impact. Avoidance works only for large sized debris, while protection covers only small-sized debris. There is no solution for debris of a size between 1 and 10 cm. The kinetic energy of the debris is too high, which makes shielding ineffective. Moreover, these objects are not classified. This means that we have no information on their position and it is impossible to avoid them!

To assess risk in the deadly 1- to 10-cm range, scientists at ESA and other space organizations use sophisticated probability models and software. Risk is predicted based on a spacecraft's cross-sectional area, its orbital altitude and flight path, the assumed size of debris objects, the geometry of a collision event and relative speed, among other factors. For example, for a satellite with a 100-m^2 cross-sectional area (including solar panels) orbiting at 400 km altitude, the mean time between impact with a debris object 10-cm in size has been calculated to be on the order of 15 000 years. While these figures may at first glance seem comfortably large for any particular satellite, there are many satellites in orbit around the Earth. "If you calculate the combined profile area of all satellites in orbit, you find that the average time between destructive collisions is about 10 years," says Klinkrad (Klingrad, 2006).

Considering that even a single 10-cm debris collision event could wipe out a multi-million-Euro spacecraft or hit the (manned) ISS, a risk of even one impact per decade suddenly becomes very serious.

Figure 11 shows the results of a lab test impact between a small sphere of aluminum travelling at approximately 6.8 km per sec and a block of aluminum 18 cm thick. This test simulates what can happen when a small space debris object hits a spacecraft.

Al sphere diameter: **1.2-cm**
Al sphere mass: about **1.7 g**
Impact crater diameter: **9.0 cm**
Impact crater depth: **5.3 cm**

Table 1. Protection solutions vs debris size

Debris size	Features	Solution
< 0.01cm	Erosion surfaces	No solution is needed
0.01 cm < & < 1 cm	Significant harm (perforations, different consequences)	Protection
1 cm < & < 10 cm	Significant damage	No solution
> 10 cm	Catastrophic consequences	Avoidance maneuver

Figure 11. High-velocity impact sample (Credits: ESA)

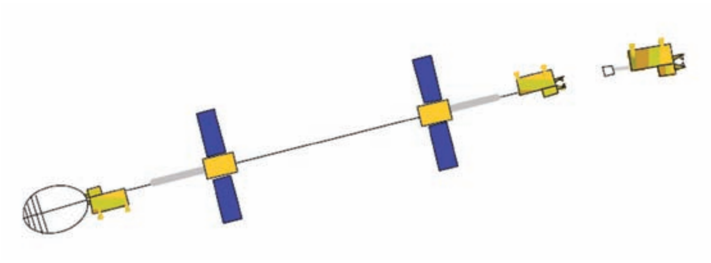
In such an impact, the pressure and temperature can exceed those found at the centre of the Earth e.g. greater than 365 GPa and more than 6,000 K (ESA, 2005).

Removal

Mitigating debris generation alone is insufficient for preserving the orbital environment because the chain reaction of collisions among existing debris has already been observed in specific orbital regions. The ultimate measure to improve the environment would be the removal of large objects from densely populated orbital regions. The removal missions should be conducted in a cost-effective manner, and a technical solution would be the electrodynamic tether system, which slows unused space objects and reduces their orbital lifetime. The feasibility of such concepts has been already demonstrated, although the costs would undoubtedly be extremely high:

- A novel approach is presented by Tether Application Inc. The ElectroDynamic Delivery Experiment (EDDE) consists of an autonomous space vehicle powered by lightweight solar arrays, a bi-directional electrodynamic tether, and batteries for power leveling. The EDDE vehicle can modify its orbit repeatedly without rocket fuel, and can change all six orbital parameters by modulating and reversing the current flow in the conducting tether. Tether Applications Inc. propose using a fleet of ~12 agile ElectroDynamic Delivery Express (EDDE) tethers to capture the large pieces of debris and drag them into short-lived orbits (Figure 12).

Figure 12. Concept of prototype EDDE flight experiment. (Courtesy Tether Applications, Inc.)



- JAXA is investigating a debris removal system and electrodynamic tethers (EDT) as promising technology for its orbital transfer system since they can generate sufficient thrust without requiring propellant (JAXA, 2008). The current efforts are directed to developing a small electrodynamic tether system aimed at on-orbit demonstration using a small satellite (Figure 13).

- Another interesting approach, called "Grapple, Retrieve, And Secure Payload" (GRASP), is proposed by Tether Unlimited Inc. GRASP (Figure 14) will enable small spacecraft to capture space debris objects in order to deorbit or otherwise dispose of them. As illustrated in Figure 6, the GRASP technology uses lightweight inflatable booms to deploy a large net structure, which can be maneuvered around a space debris object and then collapsed to securely capture the object. The GRASP system is lightweight and simple,

Figure 13. Conceptual image of electrodynamic tether demonstration Credits: ESA

enabling it to be carried on small spacecraft, even nanosatellites, and it can be used to capture objects that are tumbling or do not have the convenient grappling fixtures required by robotic arm based capture systems (see Figure 15).

- CNES is currently studying a promising orbital debris chaser concept capable of deorbiting a large number of spent upper stages (CNES, 2009). The concept is simple: the chaser satellite is equipped with a tether 30 to 50 km long that is used to capture debris. This tether is propelled towards the debris object and latched onto it. It is then cut, and the cleaner satellite and debris separate by reaction. The debris decays and eventually burns up in the atmosphere, while the chaser climbs toward the next debris item to be deorbited and repeats the same process. This original technique, using a chain reaction

Figure 14. Concept of TUI's GRASP (Courtesy Tether Unlimited, Inc.)

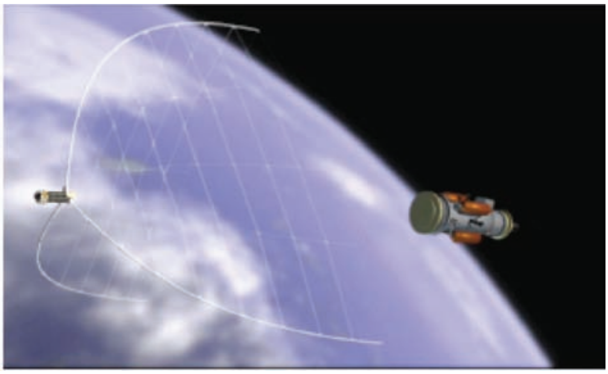
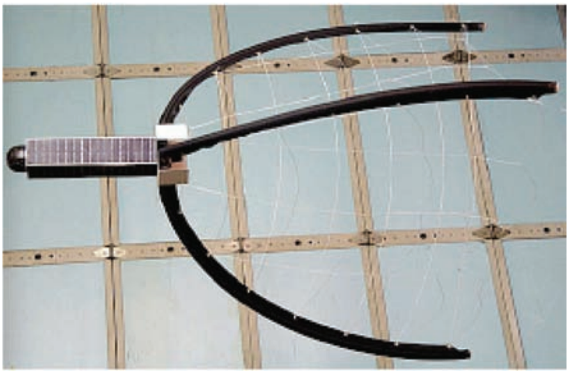


Figure 15. 1.5 m GRASP prototype (Courtesy Tether Unlimited, Inc.)



rather than propulsion, would be able to deorbit up to 50 items of space debris. (Figure 16)

- One plan involves floating a huge umbrella to catch the debris. This would require first of all, getting this thing into orbit and resolving the risks of creating even more debris. Second, how big could you make it? The debris is flinging around in every direction and it would be like trying to clean the ocean of salt with a paper cup.
- Another plan to solve the problem of space debris involves using some kind of laser blaster to pulverize any debris that is going to collide with a spaceship (Campbell, 2000).

Prevention

La solution la plus réaliste est d'éviter de générer de nouveaux débris et limiter ainsi la prolifération des debris. – The most realistic solution is to avoid generating new debris and thus limit the proliferation of debris. The United States and Russian space agencies had to address orbital debris issues from very early on, mainly for their human spaceflight programs. To ensure crew safety, all potential risks had to be evaluated, particularly space debris—a fact confirmed by the impacts regularly observed on reusable spacecraft on their return to Earth.

Awareness of the debris problem led to the formation of an interagency committee in 1993, called the IADC (Inter Agency Space Debris Coordination Committee). Its goals are to encourage cooperation and exchange between members, and above all to define common orbital debris mitigation measures. In 2002, the IADC released a

Figure 16. CNES orbital debris chaser concept (Credits: ESA)

document (IADC, 2002) and a later version in 2007 (IADC, 2007), expressing the consensus between its 11 member agencies, which now serves as the basis for all other regulatory documents concerning space debris. IADC is working to ensure that all space players apply the same regulations. Today, it has 11 member space agencies: ASI (Italy), BNSC (United Kingdom), CNES (France), CNSA (China), DLR (Germany), FSA (Russia), ISRO (India), JAXA (Japan), NASA (United States), NSAU (Ukraine) and ESA (European Space Agency).

According to IADC Mitigation Guidelines, in order to mitigate the generation of additional space debris, a number of measures have been proposed:

- **Passivation** of spent upper stages by the release of residual fuels is aimed at decreasing the risk of on-orbit explosions that could generate thousands of additional debris objects
- **Deorbiting** of a spacecraft in LEO within 25 years of mission end, while craft in GEO should be boosted to at least 300 km above the geosynchronous orbital ring and parked in a graveyard orbit. It is too expensive to bring a spacecraft all the way down from GEO to burn up, but graveyard parking is an adequate alternative.

However, implementing specific mitigation measures and codes of conduct remains at least somewhat controversial within the industry since their adoption as formal policy will invariably raise mission costs, but today almost everyone recognizes that there is a problem. In the future, there may be ways to cut the fuel requirements for deorbiting substantially (see Section 3.2 below).

Awareness of debris mitigation requirements leads to the establishment of guidelines and then regulations. But these must be translated into standards to be easily applicable by manufacturers and operators. This is the role of organizations like ECSS (European Cooperation on Space Standardization) in Europe and international bodies like ISO (International Organization for Standardization).

2.4. Costs for Space Industry

Existing studies have evaluated the mission costs due to space debris in a business as usual (no mitigation) scenario compared to the missions costs considering debris mitigation. Several studies have also estimated the time until the investment in debris mitigation will lead to an effective reduction of mission costs (Bendish and Wegener, 2001).

Wiedemann et al. (2004) present results from investigations of the key issues of cost estimation for spacecraft and the influence of debris mitigation and shielding on cost. Mitigation strategies like the reduction of orbital lifetime and de- or re-orbit of non-operational satellites are methods to control the space debris environment. These methods result in an increase of costs. Based on this analysis, a de-orbiting maneuver requires that the satellite has to be equipped with additional or enlarged propulsion system components like fuel tanks or engines. This approach represents a worst possible case scenario, since normally the satellite has already a propulsion system that may be able to perform the deorbit maneuver. An estimation of this penalty is expressed as function of the satellite mass at the beginning of life (m_{BOL}). The propulsion module mass is sized with Equation (1) for the dry mass of a satellite ($m_{dry,sat}$) and Equation (2) for the dry mass of a propulsion module, which Wiedemann et al. (2004) have derived from collected data on subsystem masses.

$$m_{dry,sat} = 0.843 m_{BOL} \tag{1}$$

$$m_{dry,pop} = 0.188 m_f \tag{2}$$

The fuel mass *mf* calculated as a function of the velocity requirement *Dv*, assuming that at end of life the dry mass of the satellite including the propulsion module have to be de-orbited:

$$\frac{m_f}{m_{dry,sat} + m_{dry,pop}} = e^{\frac{\Delta v}{w}} - 1 \tag{3}$$

Different estimations are reported for a propulsion module (assuming a bipropellant system with $w = 2800$ m/s) for different velocity requirements is given in Table 2, where the development and production costs are estimated by Koelle (1991).

2.5. A Financial Model of Space Debris Mitigation Projects

Among the different innovative solutions for debris mitigation, space tethers seem to be the most promising one in the short future. A tether satellite (Van Pelt, 2009) is a satellite connected to another by a thin cable called a tether. The "space tether" idea has its origin in the late 1800s. The idea became more popular in the 1960s, and subsequently NASA examined the feasibility of the idea and gave direction to the study of tethered systems, especially tethered satellites.

- **Electrodynamic tethers** are long conducting wires, such as the one deployed from the tether satellite, which can operate on electromagnetic principles as

Table 2. Cost and mass estimation of an additional bipropellant propulsion module for a given velocity requirement Δv *(Koelle, 1991)*

Δv **(m/s)**	300.0	400.0	500.0
Fuel mass (kg)	97.1	132.8	170.5
Propulsion module (kg)	115.3	157.8	202.5
Development cost ($3M)	21.0	24.5	27.7
Production cost ($M)	6.3	7.3	8.3
Launch cost (add.) ($M)	1.4	1.9	2.5
Total cost (add.) ($M)	28.7	33.7	38.5

Cost is given in FY02$M

generators, by converting their kinetic energy to electrical energy, or as motors, converting electrical energy to kinetic energy.

- **Momentum exchange tether** is a long thin cable used to couple two objects in space together so that one transfers momentum and energy to the other. A tether is deployed by pushing one object up or down from the other.

We base our business model on Tethers Unlimited, Inc. (TUI). TUI is working to develop technologies to reduce the population of space debris by addressing both the challenge of preventing creation of debris by new spacecraft and the challenge of removing existing space objects. To enable cost-effective end-of-mission disposal of spacecraft, TUI is working to develop and qualify several ‘deorbit modules’ that will provide fully-autonomous end-of-mission deorbit capability for LEO spacecraft with very low mass and cost impacts to the spacecraft program.

TUI has a promising history of development and funding. Started by Dr. Robert P. Hoyt and Dr. Robert L. Forward in 1994, TUI has performed successfully on over 40 contract efforts with a wide variety of government and industry customers (Table 3).

TUI Products

Terminator Tape™

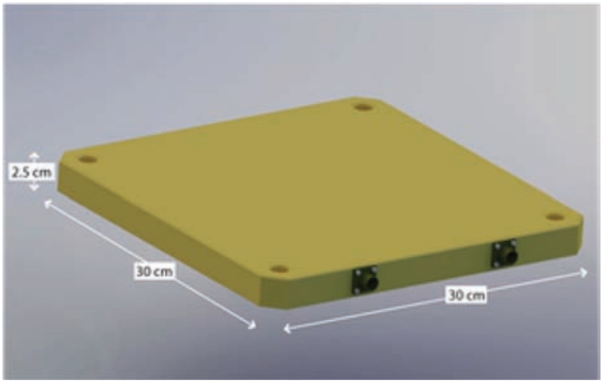
The Terminator Tape module (Figure 17) is a pizza-box shaped unit, 30 cm x 30 cm x 2.5 cm, which mounts to any surface on the spacecraft. The module’s mass is less than 3 kg.

When the host spacecraft has completed its mission, the module will then deploy a 250 meter long conductive tape. Gravity gradient forces will then orient the tape

Table 3. TUI clients

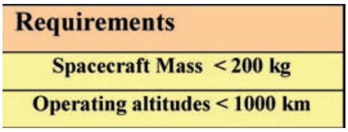
Government	Industry
DARPA – STO, TTO	Nothrop Grumnan
NASA, MSFC, GSFC, LaRC, GFC, JPL	Boeing
AFRL – PR, VS	Lockheed Martin
Army – AMC	Millennium Space Systems
Sandia National Laboratories	Blue Origins
Navy – SPAWAR, ONR, NAVFAC, NAVAIR, NFESC	Excalibur Almaz
	Triton Systems, Inc.

Figure 17. Terminator Tape configuration (Courtesy Tether Unlimited, Inc.)



along the local vertical direction. This tape will significantly increase the aerodynamic cross-section of the satellite, enhancing the drag it experiences due to neutral particles. In addition, the motion of this tape across the Earth's magnetic field will induce a voltage along the tape. This voltage will drive a current to flow up the tape, with electrons collected from the conducting ionospheric plasma at the top of the tape and ions collected at the bottom. This current will induce a 'passive electrodynamic' drag force on the tape. The enhanced aerodynamic drag and the passive electrodynamic drag force will lower the microsatellite's orbit, deorbiting it within 25 years.

Figure 18.



Requirements
Spacecraft Mass < 200 kg
Operating altitudes < 1000 km

Once the module is fully qualified, TUI anticipates offering flight units at Cost < US$100,000

Terminator Tether™

For heavier spacecraft, operating at altitudes above higher altitudes, or requiring very fast deorbit (within a few weeks or months, rather than years), TUI has been working for over a decade to develop and test a "Terminator Tether" module that will utilize active electrodynamic drag to rapidly deorbit LEO spacecraft (Figure 19).

Upon activation, the Terminator Tether module kicks itself away from the host spacecraft, deploying a 5 km long conducting tether. The motion of the tether through the Earth's magnetic field will cause a voltage to develop between the ends of the tether. The system incorporates technologies that enable the tether to make electrical contact with the conducting plasma in the ionosphere, enabling a current to flow up the tether. This current in turn interacts with the Earth's magnetic field to produce a drag force on the tether system that rapidly lowers the orbit of the spacecraft over a period of several months until it burns up in the upper atmosphere.

The Terminator Tether module will typically mass 1-2% of the mass of the host spacecraft, a significant mass savings compared to the 5-20% mass allocation required for using thrusters to deorbit the spacecraft. Because the tether system can utilize the currents and voltages generated by the tether to power itself, it is not reliant upon power from the host spacecraft, and thus can deorbit spacecraft that have malfunctioned.

No information about the foreseen cost of this product.

Figure 19. Principle of electrodynamic tether propulsion (Courtesy Tether Unlimited, Inc.)

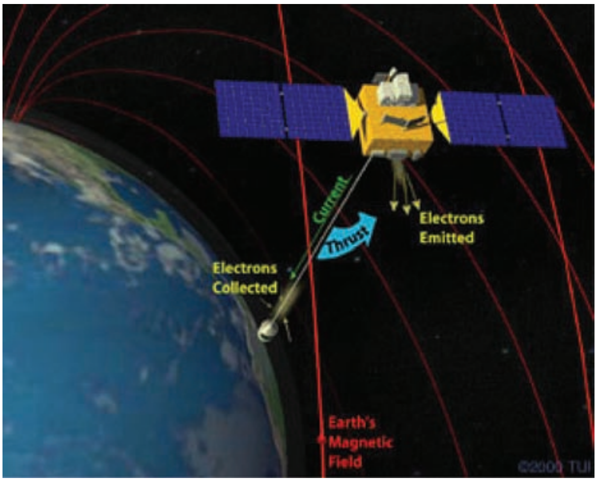
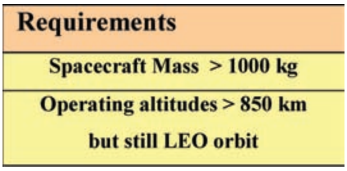


Figure 20.



Requirements
Spacecraft Mass > 1000 kg
Operating altitudes > 850 km but still LEO orbit

Latest Test Results

Tethers have not yet been used as fully operational equipment, but various promising experiments have already been performed in space. Most were relatively unimportant add-ons to missions with some mass and volume to spare, but there have also been some for which the demonstration of one or more applications of tethers was a major objective.

In order to highlight the complexity of tether systems such as dynamic stability, meteoroid risk and orbital life time (Bendish and Wegener, 2001), two latest flight results are hereby presented:

- ***MAST experiment***

The Multi-Application Survivable Tether (MAST) experiment is an investigation designed to use picosatellite spacecraft connected by tethers to better understand the survivability of tethers in outer space. It was launched as a secondary payload on a Dnepr rocket on April 17, 2007 as a part of the CubeSat program. It includes three picosatellites which were intended to separate and deploy a 1 km (0.6 mile) tether. The experiment hardware was designed under a NASA Small Business Technology Transfer (STTR) collaboration between Tethers Unlimited, Inc. (TUI) and Stanford University, with TUI developing the tether, tether deployer, tether inspection subsystem, satellite avionics, and software, and Stanford students developing the satellite structures and assisting with the avionics design. The experiment is currently on-orbit. As of April 25, 2007, TUI had made contact with the “Gadget” picosatellite, but not with “Ted”, the tether-deployer picosatellite. Researchers believe Ted has separated from Gadget, and at least a portion of the tether has been deployed.

- ***YES 2 experiment***

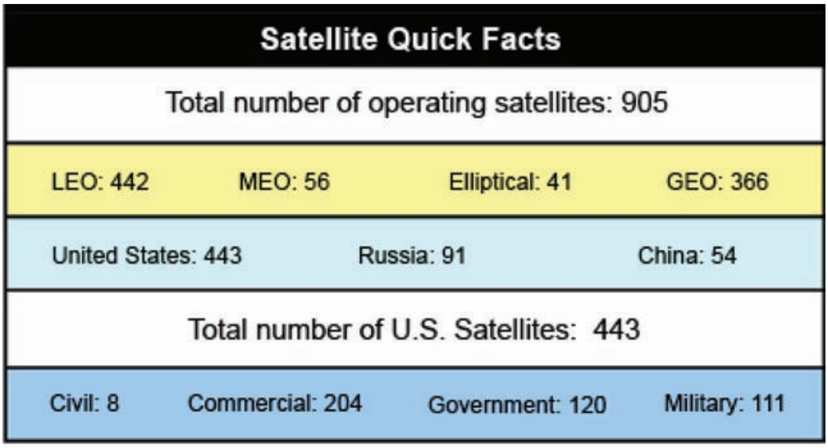
The European Space Agency (ESA) launched a 31.7 km tether (of which 30 km were to be deployed) YES2 (Young Engineers’ Satellite 2) on September 2, 2007 Almost five hundred students from all over Europe worked on YES2 experiment in conjunction with prime contractor Delta-Utec. Tether deployment was completed in two controlled stages mostly as planned, but due to an electrical failure occurring near the end of deployment, the tether overdeployed to its full length. From the mission data it could be demonstrated that the capsule was nevertheless released into a near-nominal re-entry trajectory. No signal from the capsule was received after landing, possibly due to a water landing, harsh impact or scorch of the re-entry. With the 32 km tether deployment, YES2 broke the world-record previously held by SEDS (20 km).

Estimates of the Current Needs for Space Mitigation Technologies

We base our market analysis on the Union of Concerned Scientists (UCS) Satellite Database (available at http://www.ucsusa.org), which is a listing of the over 900 operational satellites currently in orbit around Earth. UCS main goal is to provide a currently updating the database that can is to create a research tool for specialists and non-specialists alike by collecting open-source information on operational satellites and presenting it in a format that can be easily manipulated for research and analysis (Figure 21).

Focusing on TUI products, which can be mainly used for LEO satellites, the analysis of the UCS database shows an interesting quota among the total satellites annually launched in the last twenty years. Moreover Figure 22, despite some oscillations, which are mainly due to the availability of funds, shows a positive trend.

Figure 21. Numbers are based on the entries in the current database



Satellite Quick Facts

Total number of operating satellites: 905

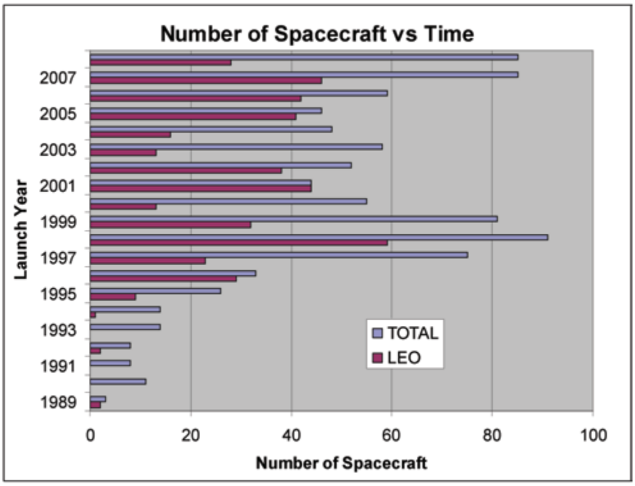
LEO: 442
MEO: 56
Elliptical: 41
GEO: 366

United States: 443
Russia: 91
China: 54

Total number of U.S. Satellites: 443

Civil: 8
Commercial: 204
Government: 120
Military: 111

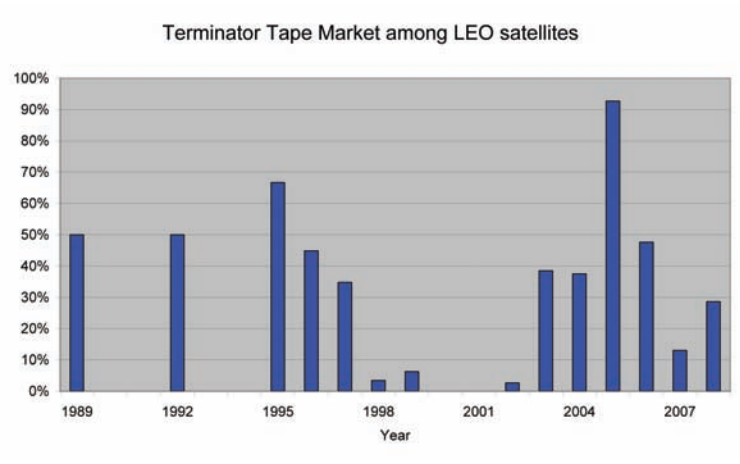
Figure 22. Number of satellites launched over the last two years



Project Revenues for Each TUI Space Mitigation Product

In order to estimate the revenues for each TUI space mitigation product, it is important to further analyze the specific market relative to the LEO satellites. As shown in Figure 23, there has been an increase on the potential candidates for Terminator Tape, micro satellites in low orbit. This outcome follows the global tendency in reducing satellite mass by miniaturizing their electronic and mechanical systems.

Figure 23. Number of satellites launched over the last two years



As shown in Figure 24, we next extrapolate the potential market for Terminator Tape till year 2030 using a propagation model.

Finally, we select a price strategy for each product. As already published by TUI, the Terminator Tape has a fixed promotional price. Due to the lack of visibility on the hardware/development cost and the peculiarity of this product, a pricing-based cost strategy was adopted. In fact, due to the specific and unique characteristic of such system, the price can be set based on the saving costs with respect to a nominal debris mitigation methods, mainly using de-orbit maneuvers. Based on this analysis a possible approach would to proposing an average of 50% cost reduction using the Terminator Tether.

Applying a fixed-cost price for Terminator Tape and a price, which results in a 50% cost reduction if compared with the normal de-orbit maneuver for the Terminator Tether, the projected annual revenues of the two products are shown in Figure 25.

The results clearly show that TUI should focus more on the Terminator Tether, since it represents the main source of revenues for their portfolio. Even if taking a conservative approach for the chosen pricing strategy, this product shows a promising future. Furthermore, the Terminator Tether can provide much higher performance than the Terminator Tape, since it allows to deorbit a satellite within weeks rather than decades.

At this point is also interesting to highlight that TUI is trying to exploit their space-based capability in different areas. Using their know-how in deployment of long tethers in space, TUI has developed a technology to enable high-speed deployment of optical fibers underwater. This "Underwater Optical Tether Deployer" (UOTD)

Figure 24. Terminator Tape potential market 1990-2030

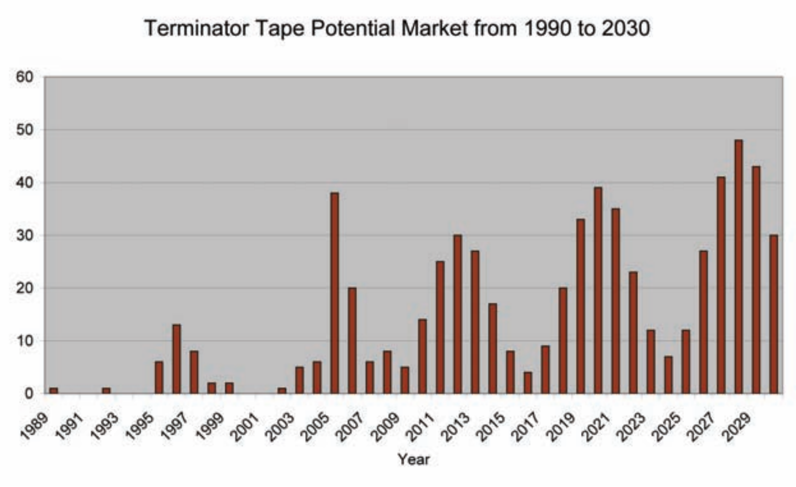
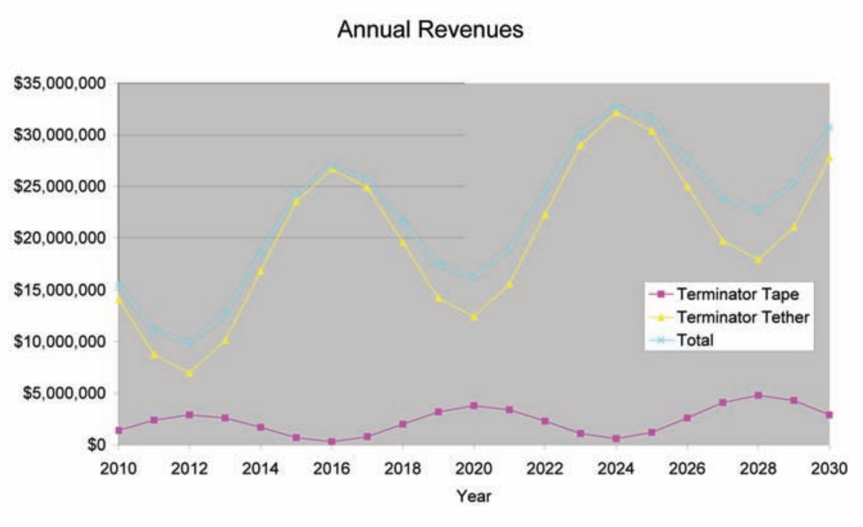


Figure 25. Projected revenues for the Terminator Tape and Tape and Tether



is a precision-wound optical fiber pack designed for use in submarine-launched buoys to provide a capability for two-way, high-bandwidth communications for submarines even when they are submerged and moving at high speeds. This optical communications link will provide a revolutionary capability for Navy submarines to participate in full networked warfare operations.

3. AN ANALYSIS OF A LONG-TERM INVESTMENT OPPORTUNITY: SPACE SOLAR POWER

First described by Glaser (1968), Space Solar Power (SSP) is a technological concept that aims to transform solar energy in space into electricity on earth. An SSP system consists of 1) one or more satellites in Geostationary or other earth orbits which collect solar energy and convert and transmit this energy to Earth, and 2) one or more rectifying antennas (rectennas) that receive the transmitted energy and convert it into electricity. The interest in SSP by the US government has proceeded in several cycles. First, in 1979 the US Department of Energy developed a 5 gigawatt Solar Power Satellite Reference System. The system design was technologically feasible but prohibitively uneconomical under the cost structure at the time. NASA revisited SSP in 1995-1996 by commissioning a Fresh Look Study to determine whether a Solar Power Satellite could deliver energy to be converted into electricity on earth and used directly into the power grid at competitive price and much lower startup costs than the original 1979 designs. The results from the collaboration of more than 100 experts in various fields that participated in the Fresh Look study are summarized in Mankins (1997).

Even though the Fresh Look Study resulted in several promising new engineering solutions and innovative designs, a series of follow-up economic studies and reports still deemed SSP uncompetitive as an alternative to traditional sources of energy on earth (Macaulay, et al 2000). Consequently, any significant investments in further research or testing of prototypes by US government agencies were abandoned for the time being. By 2007, the combined spending of NASA and the US Department of Energy to study SSP was less than \$100M. In comparison, the US Government has spent more than \$20B in the pursuit of nuclear fusion research.

Regardless of the diminished US government involvement, work on SSP was never abandoned completely. Moreover, many of the technologies required for the construction of a functioning SSP system continued to evolve and improve, gradually increasing the chances of the advent of an economically feasible system. In 2007, the National Security Space Office (NSSO) – an office within the structure of the US Department of Defense – sponsored an open source interactive collaboration forum which gathered more than 170 active researchers working on various issues related to SSP. The outcome of this extensive collaborative effort was a detailed Architecture Feasibility Study (National Security Space Office, 2007). The study rekindled the interest in Space Solar Power (the study refers to it as Space-Based Solar Power) in the public media, resulting in dozens of newspaper articles, video documentaries, radio interviews, press conferences and other events (the National Space Society maintains a current list of links at http://www.nss.org/settlement/ssp/index.htm#links). Advocates for SSP even posted a white paper on the Obama-Biden's transition site change.gov (change.gov, 2008).

3.1. The Value Added of Space Solar Power

There are several characteristics that make Space Solar Power attractive to pursue. We denote these characteristics as SSP value drivers. The *first SSP value driver* is the much larger solar intensity in orbit relative to the solar density on earth. The solar intensity in orbit is 1366W/m^2. Solar intensity in sunny regions on earth is not more than 250W/m^2. The average daily solar power reaching the ground is about 10 times smaller than the solar power in orbit (Georgia Institute of Technology, 2006). The 10 times number is derived as follows. The US ground average is 4.78 kWh/m^2 per day, which translates into 1745 kWh/m^2 per year. In orbit, the same average equals 11930 kWh/m^2 per year, or 6.84 times the US ground average. In addition, the US ground average has to be reduced by a factor of 1.5 or more for the effect of dust, smog, heat, and other atmospheric factors. Also, a Texas Utilities study finds that peak performance of ground solar power generation was achieved in spring and fall, while peak power needs in the US are in summer and winter. The Georgia Institute of Technology (2006) document also mentions "global dimming" – a process causing loss of sunlight of 2-3% a year in the Northern hemisphere perhaps due to pollution and other human activities, which makes the efficiency differential between space and ground solar power generation likely to increase with time.

The *second SSP value driver*, which is also mentioned in the change.gov (2008) White Paper, is scalability. The NSSO (2007) report states that "*A single kilometer-wide band of geosynchronous Earth orbit experiences enough solar flux in one year to nearly equal the amount of energy contained within all known recoverable conventional oil reserves on Earth today*." Most other energy resources on Earth are either in limited quantity or, in the case of ground solar, require large use of land. In contrast, adding an extra gigawatt of solar power generation requires one or more Solar Power Satellites in orbit and a receiving antenna (rectenna) on earth with a surface area anywhere from 1 to 50 km^2 depending on the wave length used to beam the energy down. The key scalability advantage of the rectennas is that they are 90% transparent and can be deployed in farmland, allowing for crops to grow or cattle to graze underneath. Additionally, the rectennas, even at the current technology levels, are very efficient in the transfer of microwaves into electricity and have much lower heat rate (the leakage of heat associated with electricity production) relative to conventional solar arrays, nuclear, or fossil fuel power generation.

The *third value driver* is reliability and continuous availability. If a Solar Power Satellite is deployed in Geo-Stationary Orbit (GEO), it is directly lit by the Sun and can produce energy at peak power 99% of the time. Most renewable energy technologies on earth are available intermittently (solar, wind, hydro), while the continuous energy production capabilities of nuclear power are associated with strategic hazards and limited supply.

The *fourth SSP value driver* is easy access anywhere on earth. Ground solar or any electricity produced on earth cannot easily reach remote areas that are not on the electric grid (or their access to the electric grid has been destroyed). In such areas, one has to transport fossil fuels to generate energy when needed. SSP can be beamed to any area that has an installed rectenna (rectennas are relatively cheap and quick to install). This feature of SSP makes it very attractive for providing energy in areas hit by natural disasters and other emergencies or for supply of energy to forward military bases.

The following table from a NSSO PowerPoint presentation (see National Security Space Office, 2007b) provides a comparison of most energy technologies today and demonstrates effectively the value proposition for Space Solar Power (Table 4).

Table 4. Comparison of Different Sources of Power

Source	Clean	Safe	Reliable	Base-load
Fossil Fuel	No	Yes	Decades remaining	Yes
Nuclear	No	Yes	Fuel Limited	Yes
Wind Power	Yes	Yes	Intermittent	No
Ground Solar	Yes	Yes	Intermittent	No
Hydro	Yes	Yes	Drought; Complex Scheduling	
Bio-fuels	Yes	Yes	Limited Qty – Competes w/Food	
Space Solar	**Yes**	**Yes**	**Yes**	**Yes**

3.2. Effects of SSP on Climate Change

The value drivers identified in Section 3.1 are not the only positives of Space Solar Power; it could also reduce significantly man-generated greenhouse emissions. Ongoing Space Solar Power generation does not produce any greenhouse gases and the production and installation of SSP systems is relatively clean. The emission of greenhouse gases in Earth's atmosphere can be reduced to virtually zero if production is done on the Moon and the system's components are launched from there using magnetic space launch systems (see Section 3.3). Currently, electric generation accounts for nearly 2 Billion tons of carbon dioxide or a third of the US total emissions. The majority of these emissions are generated from coal-burning plants (Bois, 2008).

In addition to low greenhouse emissions, most of the heat from Space Solar Power generation is emitted in orbit far from the Earth biosphere. The transmission of the power to Earth using microwaves and the transfer of microwaves to electricity by rectennas are both extremely efficient and have as a result very low heat rate. Most other power generation technologies including ground solar have heat rates higher than 50%. These high heat rates can change ecosystems and climate patterns locally or even globally.

Even if Space Solar Power accounts for all energy production and carbon emissions due to power generation are reduced to nil, the majority of carbon emissions are still generated from transportation. The onset of plug-in electric vehicles can reduce these emissions for individual or public ground transportation. Nevertheless, electric power directly cannot fuel air transportation or large trucks going long distances. Abundant Space Solar Power can provide a solution to this problem as well by providing the energy for production of synthetic hydrocarbon fuels. The process of synthesizing hydrocarbons requires hydrogen, which can be produced from water using electric energy from SSP, and carbon which again can be obtained from atmospheric carbon dioxide using large amounts of electric energy (presentation by Roger Lenard, President Heliosat, Inc.). A natural result from the hydrocarbon synthesis is that transportation activities will on net not generate any new carbon emissions – and the human civilization will close the carbon cycle. Moreover, the process of producing carbon from carbon dioxide can be performed independently from hydrocarbon synthesis with the goal of reducing the existing levels of carbon dioxide in the atmosphere. Converting carbon dioxide to carbon resolves many problems with carbon dioxide sequestering and storage currently faced by oil producers and coal power plant operators.

3.3. Potential Markets for SSP

There are at least four distinct markets for Space Solar Power. Two of these markets are high marginal value and respectively can bear high prices per kWh sold, but they are limited in size. In these markets, the alternatives to SSP are costly and leave a lot of room for SSP to compete. The other two markets have large volumes but very competitive prices at the moment. In these markets, SSP has to compete with low-cost alternatives and would require either large economies of scale or government incentives.

Power in Remote Areas

The first market for SSP is the provision of energy to remove areas off the electric grid. Of all four markets we discuss in this section, SSP is likely to penetrate this market first. The main customer for this market is the US Department of Defense both for supplying energy to forward military bases and for using energy in relief of areas hit by natural disasters and other emergencies. Currently, the US military spends as much $200/gallon of oil and $17/kWh to supply its forward bases in Iraq and Afghanistan. In addition to the monetary costs which are relatively easy to estimate, there are incalculable human costs, as many of the US casualties in Iraq were incurred by fuel convoys supplying military bases. With these high prices, a provider of SSP can charge at least $2 and as much as $20 per kWh supplied (see the analysis of Heliosat, Inc. business model below).

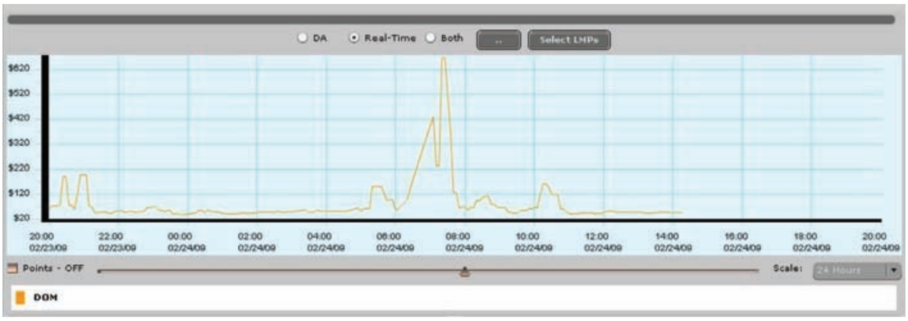
Power for In-Space Systems

The second market for SSP is supplying energy to other systems in orbit (see Macaulay and Davis, 2001 for a comprehensive study on using SSP for in-space power supply). A large percentage of the mass of space systems is dedicated to power production and storage. A SSP system in orbit that can beam energy to satellites can significantly reduce satellite mass requirements and extend their useful life that is usually determined by the functional life of their energy systems. The prices for energy used by orbital systems are extremely high – in the order of magnitude of $1000/kWh, but the market for such energy supply is limited. Still, the list of potential users includes in the short term – Geostationary and low-earth-orbit communication satellites, global positioning satellites and other military aircraft, the ISS and future space stations; in the longer term – space tourism facilities, in-orbit spacecraft servicing and repair systems, and space manufacturing facilities. Moreover, abundance of energy in orbit could create novel transportation methods from LEO to GEO and reduce the cost of reaching GEO dramatically. Last, in-space energy availability through SSP can provide opportunities for more effective space debris capture and removal and for deorbiting satellites from GEO.

Peak-Load Power

The third market for Space-based Solar Power is peak-load power supply. As many other renewable energy technologies are most effective in off-peak periods, SSP can provide a solution that can compete with peak-load systems currently employed by electric utility companies – these are predominantly based on fossil fuel and are much less efficient than base-load power sources. The estimates for peak-load wholesale prices are between $0.15 and $1.00 per kWh. The $1 per kWh is actually a ceiling currently set by the US government. Figure 26 shows a snapshot of wholesale electricity prices in one day in February 2009 in the state of Virginia, available in real time from the website of PJM – the Regional Transmission Operator for the Northeast US. The prices are per mWh and even in the winter, for a brief period in the morning wholesale prices reach $650 per mWh or $0.65 per kWh. The final price for the consumer, of course, will be even higher.

Figure 26. Intraday wholesale pricing of electricity in the state of Virginia from PJM, available at: https://edata2007.pjm.com/eData/index.html



Although peak-load electricity is higher priced, it is a poor fit with the SSP functionality. SSP can provide energy 99% of the time while peak-load electricity is needed for only a few hours a day and mostly during the summer and winter seasons. Nevertheless, peak-load power supply can be an attractive part in a portfolio of markets for a SSP system. Moreover, an SSP system can start and stop beaming energy to a rectenna almost simultaneously and an SSP system in LEO could potentially provide peak-load energy to multiple geographic markets located in different time zones.

Base-Load Power

The last market for SSP is the provision of base-load electricity for the nationwide power grid. In order for SSP to be competitive with the current base-load costs (averaging \$0.05/kWh for coal and nuclear-generated energy), either the prices of the current sources have to increase by at least one order of magnitude, or SSP systems have to be deployed in large numbers and at much lower cost than what the current technology allows (see the analysis of Space Energy, Inc. business case below). A possible mechanism for increasing the prices of existing base-load energy technologies (predominantly coal and nuclear) is imposing a carbon tax on fossil fuel generation, respectively a tax for disposal of nuclear fuel. Both technologies rely on resources in limited supply and with time their prices will naturally increase.

3.4. Major Problems with Space Solar Power and Possible Solutions

In Sections 3.1 to 3.3, we discussed the many attractive features of Space Solar Power, but so far very little investment has been made to launch working or even prototype SSP systems. There are several reasons for the lack of progress in implementing SSP concepts. All of these revolve around major technological and political challenges that any successful SSP provider has to solve. We outline four major challenges below – 1) high launch costs; 2) high production costs of in-orbit power equipment; 3) high in-space equipment assembly costs; and 4) political and strategic concerns.

Launch Costs

Launch costs for unmanned flights to LEO are at least \$2,000/kg; costs to reach GEO, where most designs require Solar Power Satellites to be installed, are at least ten times higher. At prices in the order of magnitude of \$25,000/kg, large-scale SSP systems are not economically viable at current energy prices. One key technological challenge that any private company operating in the SSP market has to resolve is how to reduce the launch prices by at least one and preferably two orders of magnitude.

There are several technological paths that lead to dramatic reduction in GEO launch costs (for more details see Georgia Institute of Technology, 2007). First, the increased number of flights and mass launched when SSP systems become operational will result in natural economies of scale and decrease in launch prices. As the launch volume increases, small technological improvements and costs reductions through newer launch vehicles can further decrease prices. Elon Musk, CEO of SpaceX, testified before the US Senate Committee on Commerce, Science, and Transportation Hearing on Space Shuttle and the Future of Space Launch Vehicles on May 5, 2004: "Dollar cost per pound to orbit dropped from $4000 to $1300 between Falcon I and Falcon V. Ultimately, I believe $500 per pound or less is very achievable." A more recent presentation by Preble (2008) projects that launch prices to LEO will reach $100/lbs at around 1,000 flights per year, without any major changes in existing technologies.

The second approach is to use existing rockets to transport a SSP system to LEO and then move the system to GEO using a variety of novel technologies, some of which are still at the design stage. Olds et al (2000) argue that an aggressive launch price goal of $400/kg to LEO, at 500 flights per year is achievable with one or more concept technologies. They further demonstrate that their chosen concept technologies can achieve GEO launch prices of $800/kg.

Instead of using existing rocket technology to transport the SSP systems into orbit, one can use an entirely different and promising approach – magnetic space launch systems. Currently, a private company – LaunchPoint Technologies (http://www.launchpnt.com/portfolio/space-launch.html) is developing such systems for commercial launch to LEO or further. Their website states: *"Consider that the first magnetic launch systems are expected to propel payloads into orbit at a cost of roughly $750/lb, already a significant improvement over the current rocket-launched cost of around $4,000/lb. Now realize that the total cost to orbit might eventually drop below $100/lb, and it soon becomes clear how vitally important this technology is to the future of space."*

An even more innovative approach to reduce launch costs is to harvest most resources needed for the construction of SSP systems on the Moon, produce the equipment there and then launch it from the Moon to GEO. The energy cost to transport load to GSO from the Moon is twenty times smaller than the energy costs to transport the same load from earth. The launch from the Moon can also be easily done with magnetic launch systems instead of rockets (Georgia Institute of Technology, 2007). A similar idea involves the capture of a near-Earth asteroid, moving it to GEO, harvesting its resources and constructing the main components of the SSP systems directly in GEO. Other, more science-fiction, ideas include building a Space Elevator or a Lofstrom Loop (see van Pelt, 2009 and respective Wikipedia articles).

The ideas and concepts are there; the technological paths necessary to reduce launch prices to economic levels are well understood; the only questions that remain are what private, state or hybrid companies will implement the designs into practice and when these low price levels will be achieved.

Costs of In-Space Power Equipment

The second major challenge faced by SSP companies is the high cost of the in-space power generating equipment. Currently, there are two proposed designs to capture the photons from the Sun and transmit them to Earth – using photovoltaics (PV) and using solar dynamic systems. The photovoltaic panels currently used on satellites and the ISS cost more than $300 per watt generated. This price needs to drop by a factor of 100 for SSP to be comparable to the $0.60 costs to install an extra watt of capacity for peak-load power production on Earth (unpublished white paper from Gregg Ehlers – electric power industry expert at Invensys) and the even lower costs per watt installed for base-load power generation cited in Macaulay, et al (2000). A Georgia Institute of Technology (2006, p. 23) report predicts that space-quality PV thin-film cells will drop to less than $1/W, if enough volume is produced. There are ground-based solar panels that are about to reach $1/W (see Keshner and Arya, 2004), but we are not there yet.

Solar dynamic systems seem more promising to achieve a large cost reduction in a short time frame. Heliosat, Inc. claims that using existing combined cycle technologies in a SSP system will cost as little as $3/W installed.

Costs of In-Space System Assembly

Once launch costs and production costs are reduced to the necessary levels presented above, there is still one remaining cost hurdle to be overcome for a profitable SSP system installation – in-space assembly costs. It is difficult to judge what these costs truly are even today. ESA currently quotes prices of EUR 15,000 per kg for assembly on the ISS, but this is a manned operation in LEO. Assembly of SSP systems will likely be completely automated or remotely controlled. The assembly costs need to drop to less than $1,000/kg for SSP to be competitive. Again, significant economies of scale can be achieved with installing larger structures in bigger numbers and through learning and R&D.

Strategic, Political and Legal Concerns

Besides costs to produce, launch and assemble an SSP system, there are various political and strategic concerns that may hinder the development of SSP into a major source of energy for the US or other countries. First, there are fears for the security and safety of SSP. The general population, out of lack of familiarity with the concept, fears that the technology is intrinsically harmful to humans and other life. This is mainly due to the expected use of microwaves for transmitting the power generated in orbit to earth. Although large-scale SSP systems will beam power in the 2 gHz range with projected intensity of only 25% of sunlight reaching earth, there are still no studies of the long-term health effects of exposure to microwave radiation.

Even if the technology under normal operating parameters is not harmful to humans, there have been concerns expressed in the popular media that SSP could be weaponized on demand by the owning nation and serve as a weapon of mass destruction (or perhaps a weapon of mass sterilization of males in unfriendly countries). Such fears can be alleviated with efforts to popularize SSP, performing more thorough studies of microwave radiation safety and keeping the SSP systems independent from military control.

There is also the concern that once a large network of SSP systems is operational, a rogue nation or terrorist organization can obtain the capability to blow a satellite in GEO and cause catastrophic damage to the whole network with the resulting space debris and the likely advent of the Kessler Syndrome. Not only is the hardware vulnerable to attack, but also the software used to control and synchronize the SSP energy generation and transmission. A large-scale hacker attack could shut down the whole network. These concerns can be resolved with the involvement of all space-capable nations in the operation of SSPs and ensuring the security of the data transmission protocols between the solar power satellites and earth control.

Last, there are several legal issues dealing especially with property right over GEO "parking spots" for the space power satellites. GEO is a scarce resources used by communication and military satellites. Installing a large number of space solar satellites in GEO will likely exhaust much of this scare resource, which is currently not sufficiently regulated. Similarly, the frequencies at which energy will be beamed down have to conform to the existing standards set by the International Telecommunication Union (ITU). Again, these issues can be resolved with broad collaboration involving many countries in addition to the US.

3.5. Financial Models of Two SSP Systems

Several previous studies have focused on the financial modeling of SSP systems – Macaulay, et al (2000), Charania and Olds (2000), Fetter (2004) and Globus (2009) among others. In this chapter we take a simple approach to modeling investments in SSP projects (for the most detailed and sophisticated financial model and thorough scenario and sensitivity analyses well beyond the scope of this chapter, we direct the reader to Charania and Olds, 2000). We identify the following 10 key inputs that determine the financial performance, measured by Net Present Value (NPV) or Internal Rate of Return (IRR), of a SSP project: 1) production costs per W installed power; 2) mass of in-orbit SSP system equipment per kW installed power; 3) assembly costs per kg of SSP system mass; 4) launch costs per kg of system mass; 5) maintenance costs/system depreciation through time; 6) system useful life; 7) annual in orbit energy output in kWh; 8) efficiency of energy transmission from orbit to earth; 9) price per kWh of sold power on Earth; and 10) investment cost of capital (hurdle rate).

We present results from the financial models for two SSP systems. The first system provides 1 megawatt of power and supplies military forward bases with electricity. This system is based on designs developed by Heliosat, Inc. The second SSP system provides 1 gigawatt of power and supplies base or peak-load power for the national electric grid. This system is based on designs developed by Space Energy, Inc. with filled-in data from other studies of gigawatt power SSP systems.

A Financial Model of a 1 Megawatt SSP System

Heliosat, Inc. is a very young startup founded by Roger Lenard who has patents on various pieces of the Heliosat, Inc. SSP concept. The solar to electricity production solution of the Heliosat system is combined cycle solar dynamic with power of 1 megawatt. The beaming solution is to use 12 gHz frequency. At this transmission frequency, the diameter of the antenna in orbit will roughly be 300 m, the diameter of the ground rectenna will equal approximately 1 km. The system is designed to supply forward military bases with electricity year round.

In the financial model of this system we use the following values for parameters 1 to 10 (most of these parameters were provided to us by Roger Lenard):

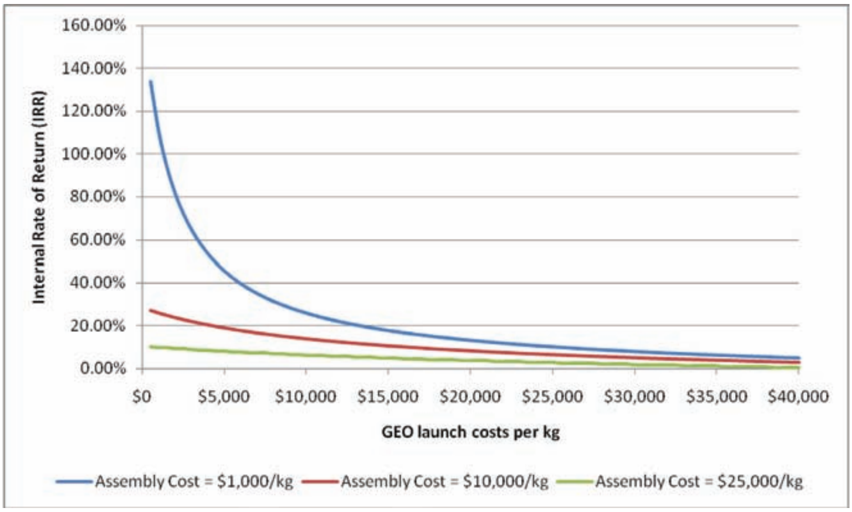
1. **Production costs:** expected to equal $3/W
2. **Equipment mass per kW power:** (specific power density) will equal 3.5 kg/kW
3. **Assembly costs:** unknown, will vary in sensitivity and scenario analysis
4. **Launch costs:** unknown, will vary in sensitivity and scenario analysis
5. **Maintenance/depreciation through time:** very small, presume only 1% reduction of system output annually
6. **System life:** equals 25 years

7. **Annual in-orbit energy output:** (presume 99% of time system is lit by the Sun) = 10^3*365*24* 0.99 = 8.67 × 10^6 kWh
8. **Combined efficiency of transmission from space to earth:** assume equal to 65%
9. **Price per kWh sold power:** assume equal to \$2 per kWh (can vary between \$1 and 10 per kWh)
10. **Cost of capital:** vary between 10 and 25%

Figure 27 presents the Internal Rate of Return calculated by the financial model when varying GEO launch costs from \$500/kg to \$40,000/kg and three values for assembly costs \$1,000, \$10,000 and \$25,000 per kg. If assembly costs are in the order of magnitude of the quoted prices from ESA for ISS assembly, even at a very optimistic value of 500/kg GEO launch costs the system does not have IRR above 10%. In contrast, if assembly costs are driven down to \$1000/kg, the system has IRR above 20% for GEO launch costs of \$13,000/kg and IRR above 10% for launch costs of as much as \$25,000/kg. These numbers can be achieved with minor improvements of current rocket technology.

The Heliosat system has plenty of upside potential. First, the assumed price of \$2 per kWh paid by the US military is well below what the military currently pays to provide forward bases with electricity. Second, the model assumes that all outlays are made in Year 0 and does not account for any flexibility of investments conditional of future developments. Such flexibility, called real options in the financial

Figure 27. Sensitivity of the IRR of Heliosat's SSP System to GEO Launch and In-Space Assembly Costs



literature, can increase the value of a project in highly-volatile markets. Third, government investments in R&D to reduce production, assembly and launch costs or improve the transmission efficiency can only improve the IRR of the system. Similarly, government guarantees of debt or equity capital invested in a startup venture like Heliosat can lower the hurdle rate to below 10%.

A Financial Model of a 1 Gigawatt SSP System

The financial model of this system is based on designs by Space Energy, Inc. (www.spaceenergy.com). Space Energy, Inc. is a startup company incorporated in Switzerland that has already raised a significant amount of seed capital and has attracted most preeminent scholars in the SSP field as scientific consultants. The Space Energy SSP system is based on thin-film photovoltaics and beaming of energy down to earth at wave length around 2 gHz. Space Energy is targeting the base-load power market. At the moment, it is difficult to glean hard values for most of the parameters 1-10 from Space Energy's website and presentations, so we pick these values to the best of our ability. The values used in our model are as follows:

1. **Production costs:** unknown, will vary in sensitivity and scenario analysis
2. **Equipment mass per kW power:** (specific power density) will equal 0.7 kg/kW
3. **Assembly costs:** unknown, assume $500/kg – much lower than the 1 megawatt system due to economies of scale
4. **Launch costs:** unknown, will vary in sensitivity and scenario analysis
5. **Maintenance/depreciation through time:** very small, presume only 1% reduction of system output annually
6. **System life:** equals 25 years
7. **Annual in-orbit energy output**: (presume 99% of time system is lit by the Sun) = $10^6 * 365 * 24 * 0.99 = 8.67 \times 10^9$ kWh
8. **Combined efficiency of transmission from space to earth:** assume equal to 65%
9. **Price per kWh sold power:** assume equal to $0.30 per kWh (can vary between $0.10 and 0.50 per kWh)
10. **Cost of capital:** vary between 10 and 25%

Figure 28 presents the Internal Rate of Return calculated by the financial model when varying GEO launch costs from $200/kg to $16,000/kg and for three production cost values– $5, 10 and 20/per watt installed power. As opposed to the Heliosat's design which uses relatively cheap power generation technology, Space Energy intends to use thin film photovoltaics. These currently are at very high prices per watt installed (see Section 3.4) and driving their prices down below $10/W is critical for the IRR of the Space Energy system to reach values above 10% at reasonable launch costs. Overall, we view the gigawatt system as a more long-term investment that requires significant improvements in current technologies in order to add value to investors. Again, our model does not incorporate any flexibility of Space Energy's management to respond to future market developments (real options) which could increase the value for investors dramatically.

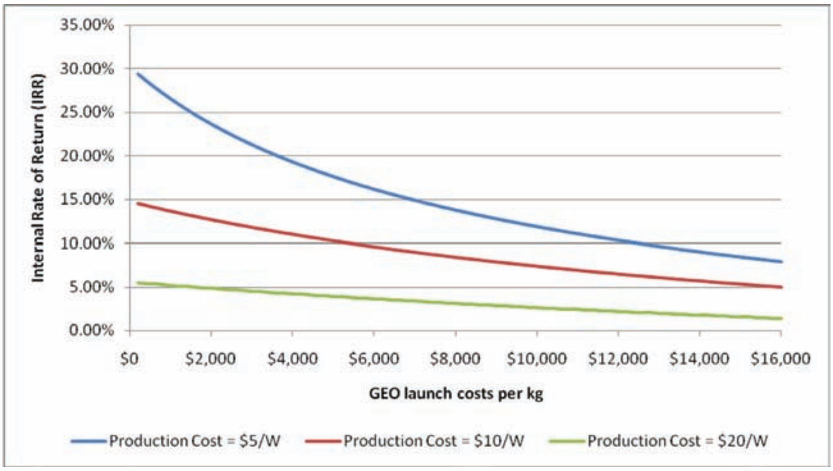
4. FINANCING SOURCES AND MECHANISMS

All space commercialization projects require significant amount of capital for up-front investments in R&D, manufacturing and operations. The two space industries we analyze in this chapter fit this description as well. A major component of any business case analysis is thus a discussion of available sources of capital. In this section we focus on two major channels for financing business ventures in Space Debris Mitigation and Space Solar Power – a private funding channel and a hybrid private-state channel.

4.1. Private Funding Sources

There are at least four major sources of private capital for projects in Space Debris Mitigation and Space Solar Power – 1) well-established corporations and their

Figure 28. Sensitivity of the IRR of Space Energy's SSP System to GEO Launch and Production Costs



corporate venture capital units; 2) independent venture capitalists and other private equity investors; 3) customers; and 4) public equity and debt markets.

Well-Established Corporations

Investments by well-established corporations is perhaps the most likely source of private funding for Space Debris Mitigation and SSP. Large corporations have the know-how and experience to deal with long-payback projects; they also have access to more diverse funding sources including their operating cash flows. Some large corporations are already investing in SSP. For example, Mitsubishi Electric is currently developing an SSP system that consists of a large number of small satellites (Mitsubishi Electric, 2009). The system is designed to beam power in the form of low-intensity microwaves to urban areas. The microwaves can be used to charge laptops, cell-phones and other electronic devices and can remove the need for batteries. Companies like Lockheed Martin or Raytheon that have long been involved in aerospace ventures including government contracts are also well-positioned to develop space debris or SSP solutions, either independently or in joint ventures with smaller companies.

Large corporations like Intel have in the past funded venture capital units (Corporate Venture Capital), which have been successful in investing in high-tech startup companies. These Corporate Venture Capital funds provide the parent company with access to attractive startups for acquisition targets or joint ventures. A similar corporate venture capital unit can be funded by any of the major aerospace corporations to invest in startups developing space debris mitigation or SSP technologies.

Venture Capital and Other Private Equity Investors

Since the 1940s, venture capitalists (VC) have funded thousands of high-tech startup companies both in the US and around the world. Successful VC investments include companies like Microsoft, Apple and Intel. VCs have high appetite for risk and unproven technologies with high upside but large uncertainty. Both of our space industries fit this risk profile and could be prime candidates for VC funding. SSP is especially attractive to alternative energy VCs who in 2008 invested more than $4 Billion in more than 350 companies (PriceWaterhouseCoopers, 2009). One of the companies we analyze – Space Energy Inc. has already attracted some capital from VCs or other private equity investors.

Customers

Another provider of capital to startup ventures in SSP or space debris mitigation could be customers that have signed long-term contracts and have prepaid for a large amount of services or products. Space Energy, Inc. intends to use Power Purchase Agreements with several key clients to fund their initial capital expenditures and subsequent expansion. Similar purchase agreements can be designed for space debris removal services and space debris mitigation products to be signed by satellite operators.

Public Capital Markets

Although public capital markets in the US amount to more than $30 Trillion, very little of this money is readily available to fund directly ventures in the two space industries we analyze. In order for a company to access public markets, it usually needs an established business model, a history of generating sales, and to be either currently profitable or expected to become profitable in the near-term. The three companies we analyze in this chapter do not meet these requirements and will not be able to secure public equity or debt funding at this stage. When their technology matures and there are working prototypes and recurring revenue, then public markets will provide the necessary funding for large capital expansions. Public markets are also important down the road as an exit channel for venture capital and other private equity investors, who consider investing in startups and usually prefer to exit their investments in an IPO.

4.2. Hybrid Sources

We argued in Sections 2 and 3 that privately-financed companies in both Space Debris Mitigation and SSP could be economically viable. Several such startups have already attracted enough private capital to initiate operations. Besides significant profit opportunities, both industries can generate large positive externalities (public goods) for society. It is frequently shown in economics that markets and private capital usually provide an insufficient amount of public goods due to the lack of mechanisms for firms to capture the full benefits of their products and services. This is where the government usually steps in and subsidizes the production of public goods, or in some cases the government assumes complete control over such public goods provision (e.g. national defense, postal services, or primary education). Below we analyze several mechanisms through which the US government can support companies operating in Space Debris Mitigation or SSP.

Private-State Joint Ventures

Space like other frontiers has already benefited from private-state joint ventures. Chapter 4 of this book discusses the collaboration between government agencies and corporations to develop communication satellites culminating in the creation of COMSAT and its subsidiary INTELSAT more than 40 years ago. A recent paper by the Space Solar Power Workshop at the Georgia Institute of Technology (Georgia Institute of Technology, 2008) advocates the creation of a Sunsat Corp. modeled after COMSAT. This corporation will be partly-owned by the US government, partly-owned by large corporations with expertise in space technologies, and will also offer shares to the broad public similar to COMSAT, which became publicly traded in 1963. There are several benefits of such hybrid entity including direct access to public capital markets and government funding, pooling of the intellectual property and technological expertise of government and private research efforts, and securing more robust political support for the development of SSP.

Albeit at a smaller scale, Space Debris Mitigation can also motivate the creation of a state-private joint venture along similar lines to Sunsat. This venture has to include not only US members but also participants from all other space agencies, private satellite operators and even Sunsat (if it is created), because all of these parties have a stake in space debris mitigation.

Government-Sponsored Venture Capital

Another strategy for government support of investments in high-tech industries has been to sponsor and extend guarantees to privately-operated Venture Capital funds that are mandated to invest in specific industries or in companies at the seed or early stage of development. A current program of this type is administered by the European Investment Fund (EIF, http://www.eif.org/) with the focus on small companies. The European Investment Fund matches a certain percentage of private money invested in Venture Capital funds that participate in the program, essentially guaranteeing a minimum return to their investors. Such structure can be easily modified to support startups operating in space-related business, in general, and our two industries, in particular. The involvement of professional Venture Capitalists is beneficial, because they have the expertise to first identify viable startup companies and afterwards lead these companies to financial success, usually though an initial public offering (IPO) or a high-valued company acquisition.

Government-Guaranteed Debt Issuance

Besides matching private equity investments into Venture Capital funds, the government can also guarantee debt capital that flows into companies generating positive externalities for the economy. In the US, a debt guarantee program designed to support small companies was created by Congress in 1958. The program is centered on privately-managed Small Business Investment Companies (SBICs) that invest predominantly in small companies and in exchange finance themselves in part with government-guaranteed debt. The SBIC program is functionally similar to the government-sponsored Venture Capital funds, but instead of capital matching the government allows private equity investors to leverage their own capital with debt at subsidized interest rates. The charter of the SBIC can easily be extended to include startup companies in space-related businesses.

Government Serving as an “Anchor” Client

The last hybrid mechanism to finance space businesses is for a government agency to become an “anchor” client of the businesses and enter in long-term purchase agreements similar to the ones discussed in Section 4.1. NASA (or other government agencies that deal with satellites) can become an “anchor” client for a company that offers space debris removal and commit to a long-term contract to pay annual and per-kg fees. The NSSO (2007) report recommends that the Department of Defense can become such “anchor” customer for a company operating small-scale SSP systems similar to Heliosat, Inc. Government customer commitments can be used by the space debris removal and SSP companies to raise either equity or debt financing and make the necessary capital expenditures to become operational.

4.3. Effects of Current Financial Crisis on the Financing of Space Businesses

The financing of any startup firms including space-related businesses is strongly affected by the ongoing financial crisis. After the beginning of the crisis in August 2007 with the collapse of bank-sponsored special purpose vehicles investing in US subprime debt securities, it has spread to virtually all capital markets. Moreover, many governments around the world have committed sizeable funds to support the ailing financial services industry and capital markets. The US alone has committed more than eight trillion dollars in various programs to capitalize banks and other financial institutions, provide liquidity to debt markets, and stimulate the economy. On one hand, these government expenditures have led to record budget deficits and will result in decreased funding for any discretionary programs including NASA and other government spending in space research and development. On the other hand, the stimulus package passed by the current White House administration includes several programs for funding alternative energy sources, which can benefit SSP ventures.

A similar story unfolds in the private funding of high-tech ventures. Capital markets around the world are in disarray. The appetite for risk among investors has decreased which has lead to the shrinking of equity and high-yield debt markets and capital flight into treasuries and other safe assets. The statistics of amount of capital raised via initial public offerings (IPOs) tracked by Renaissance Capital (2010) demonstrate the lack of capital to finance young companies. In addition to decreased availability of capital to fund public companies, there are significant capital outflows from hedge funds and LBO private equity funds. All of these developments hinder the financing for startups in space industries.

Regardless of the doom and gloom in capital markets, a "Next Big Thing" technology can spur investor's hope and can resume the flow of capital into risky ventures. The yield in US treasuries is at historic lows and there are many investors sitting on the sidelines waiting for the next attractive opportunity to arrive. It happened with the Internet in the 90s and real estate following the 2001 recession. Space is an appealing frontier, alternative energies as well. SSP is at the intersection of both space and alternative energy and could be the "Next Big Thing." By association, Space Debris Mitigation can also benefit from investor interest in SSP, because it supports all activities in space. Perhaps the next market bubble, which could begin once the crisis is over, will be in space-related industries spearheaded by SSP.

5. CONCLUSION

In this chapter, we develop the business cases for projects in two space industries – Space Debris Mitigation and Space Solar Power. We base our analysis on existing startup companies that currently provide products and services in these industries (Tethers Unlimited, Inc in Space Debris Mitigation) or are in the process of raising capital and product development (Heliosat, Inc. and Space Energy, Inc. in Space Solar Power). Based on our financial models, we believe both industries provide attractive opportunities for the flourishing of startup companies like the ones we analyzed or the profitable deployment of capital by established corporations.

Notwithstanding the large upside potential of both industries we analyze, there are still many risks that make these industries currently unattractive for most investors – unproven technological concepts, long payback periods, large upfront capital outlays. Yet, the fact that several startup companies have chosen to operate in these industries and have already attracted private capital is encouraging, although due to the large positive externalities of both industries and the risks involved, it is likely that private capital alone will lead to underinvestment in the "common good" aspects of each industry.

This is where some government support could be immensely valuable. We discuss the channels through which the government can stimulate private investment in Space Debris Mitigation or SSP and conclude that SSP could especially benefit from hybrid private-state investment vehicles sponsored or guaranteed by the US government. The payoffs for the government from capital expenditures supporting space industries come in the form of several positive externalities – 1) creation of STEM (science, technology, engineering and math) jobs; 2) technological spillovers; 3) energy security and lessened reliance on foreign resources; and 4) the reduction of the impact of human activity on the climate.

We hope that the ongoing financial crisis through its impact on both government spending and capital markets does not eradicate all investment in space research and exploration and the commercialization of space technologies. We also view this crisis not only as a risk to any private space endeavors, but also as an opportunity to deploy some of the money from the $787 Billion economic stimulus package into space-related activities with large value added like Space Debris Mitigation and Space Solar Power.

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Glossary

Itokawa Asteroid is one of the smallest ever celestial object with around 600meters length and a surface covered with boulders and craters.

Konstantin E. Tsiolkovsky's 16 Stages of Space Exploration are the following (I) creation of rocket airplanes with wings, (II) progressively increasing the speed and altitude of these airplanes, (III) production of real rockets-without wings, (IV) ability to land on the surface of the sea, (V) reaching escape velocity (about 8 Km/second), and the first flight into Earth orbit, (VI) lengthening rocket flight times in space, (VII) experimental use of plants to make an artificial atmosphere in spaceships, (VIII) using pressurized space suits for activity outside of spaceships, (IX) making orbiting greenhouses for plants, (X) constructing large orbital habitats around the Earth, (XI) using solar radiation to grow food, to heat space quarters, and for transport throughout the Solar System, (XII) colonization of the asteroid belt, (XIII) colonization of the entire Solar System and beyond, (XIV) achievement of individual and social perfection, (XV) overcrowding of the Solar System and the colonization of the Milky Way (the Galaxy), (XVI) the Sun begins to die and the people remaining in the Solar System's population go to other.

Key Performance Indicators (KPI) are indicators used for assessing and comparing the success of the results from the different projects during different project phases of market evolution

Commercial Crew Development (CCDev) is a NASA program that aims at encouraging the development of technologies and competencies that will encourage the development of commercial human space-flight services.

Planetary resource utilization refers to lunar and planetary resource utilisation, such as extraction, processing, and manufacturing of useful materials (e.g.

propellants etc.) and system elements. For example Helium-3 for fusion fuel, ferrous materials for construction or platinum group materials.

Intelligent Self-Sufficient Robotic Systems are systems such as high mobile, dexterous and autonomous robotics (i.e., advanced versions of conventional "rovers") as well as UAV-like vehicles, system, etc.

Taykonaut is a Chinese cosmonaut or astronaut

Interoperable systems, processes and technologies commonly interfacing between each other. S/W solutions, such as Open Software solutions can contribute to increasing the interoperability between various space craft sub-systems.

Commercialization of space technology does not involve the transfer of technology ownership right to the user or the commercial operator, but just the user pays a certain fee for "renting" the infrastructure. Commercial companies can use space technology as an utility. They can keep the IPR rights from their projects and also have the option to buy marketing rights. The rights can be different types, full rights for 100% investment or shared ones with other companies that are part of the project.

Marginal cost pricing sets up the prices for certain services based on marginal costs which are usually the incurred costs by agencies for flying a commercial payloads to the ISS

Institutional customers are national and intergovernmental civil space (and defence), meteorological agencies (i.e. ESA, NASA, EUMETSAT, NOAA).

Commercial customers in the space industry are commercial satellite operators and launch service providers.

Launch service operators are responsible for the integration and operation of commercial launch services to institutional and commercial customers. Launch service providers are companies such as United Launch Alliance (ULA), Arianespace, and International Launch Services or Sea Launch.

Suppliers in the space industry are system integrators, subsystem suppliers, equipment suppliers, as well as service and ground support companies.

System integrators are the companies that have the competencies and knowledge to design, develop and integrate a complete satellite. These are companies such as Lockheed Martin and Boeing in the USA, and EADS Astrium and Thales Alenia Space (TAS) in Europe.

Subsystem suppliers are companies that design, develop and produce space-based subsystems (i.e. solid booster, solar generator, engine, etc.).

Equipment suppliers are companies that develop and produce equipment for the successful integration of space systems and of subsystem spacecraft levels (solar cells, EEE components, valves, mechanical parts, software suppliers).

Services and ground support companies are companies that provide ground system design, development, manufacturing, operations of non-commercial systems (including raw data sales from EO satellites), and engineering services (ASD- Eurospace (2008))

Economies of Scale exist when production of a certain product or service is increased due to high demand and then product or services costs of production fall.

Economies of Scope are created when the production of a certain good is less expensive when produced jointly with other products.

GMES Sentinels are the next generatation of Earth Observation missions. Sentinel-1 is a SAR radar for the provision of land and ocean services, Sentinel-2 is a high resolution optical imaging missions. While, Sentinel-3 has optical and infrared radiometers for ocean and global land monitoring. Sentinel 4 and Sentinel 5 will be for atmospheric composition monitoring.

Nascent phase of market evolution is when new markets are created, first-time buyers appear and markets are strongly regulated by governments.

Frenzied phase of market evolution is when markets start to expand and profits raise.

Turbulent phase of market evolution can be defined as the one during which profits are at their highest and there is a stable group of competitors.

Mature phase of market evolution is when profits of companies start to reduce and government withdraw from the commercialization process and consolidation processes of companies.

ISS markets are classified by research and development (R&D) and the emerging ones.

R&D ISS markets are classified by biotechnology, health, nutrition, new materials and environment ones

Emerging ISS markets are ones such as education, sponsorship, broadcasting, space-flight and infrastructure.

Space Based Solar Power (SBSP) is generated when a satellite is launched in LEO and collects solar energy, that is converted into electricity by "photovoltaic" solar panels and then is transmitted the energy to ground based stations through microwaves or laser waves.

Competitiveness measures the ability of a company to sell and supply goods and services in a certain industry.

Oligopoly is described as a market structure in which there are a few players, that sell homogeneous products and services and there is high market-entry barriers. The Oligopoly market structure incorporates different oligopoly theories, such as the cartel, price leadership theory, the game theory, the prisoner's dilemma and the kinked demand theories.

Space industry competitiveness index (SCI) measures three major dimensions in the space industry: government, human capital and industry, in several space countries (e.g. USA, Europe, Russia, Japan, Canada, India, China, South Korea, Israel, Brazil).

European Space Agency (ESA) prime objective is to encourage European space industry competitiveness and, at the same time, maintain the fair return of national investment in regional space companies. ESA is managed by 18 ESA member states and each member state funds the activities of the agency. Member states allocate funding to ESA programs based on their R&D needs and national competencies and later a part of this budget is allocated back to the national space companies in the form of contracts. ESA national delegations make sure that the interests of their companies are protected and materialised in contracts.

ESA geographical-return rule is used when the value of contracts granted to national space companies corresponds to the percentage of ESA member states' investment in the space agency (ESA, 2009). The ‘fair return’ rule is calculated based on an ‘industrial return coefficient’ that calculates the ratio between the ESA share of a country in the weighted value of contracts (ESA, 2009)

Space patents are the product of inventions that companies make using space-based technologies for future interplanetary missions.

Space debris is defined as any man-made object in earth orbit that is not deployed by any working systems

Kessler Syndrome is a scenario, proposed by NASA consultant Donald J. Kessler (Kessler, 1999), in which the volume of space debris in Low Earth Orbit is so high that objects in orbit are frequently struck by debris, creating even more debris and a greater risk of further impacts. The implication of this scenario is that the escalating amount of debris in orbit could eventually render space exploration, and even the use of satellites, too prone to loss to be feasible for many generations. With a large enough collision (such as one between a space station and a defunct satellite), the amount of cascading debris could be enough to render Low Earth Orbit essentially impassable.

Scarcity is the condition in which human wants are greater than the resources available to satisfy them.

Space economics is a science concerned with the description and analysis of the design, development, production, distribution and use of products and services, derived by the use of space-based technologies.

Interplanetary economics is a sub category of space economics and deals, with the description and analysis of the design, development, production, distribution and use of space-based products and services, used on Earth or celestial bodies (i.e. Moon, Mars, asteroids) and also human-made artificial spacecraft, stations and transfer vehicles.

Gross Domestic Product (GDP) shows the percentage that national governments invest in space exploration. Gross Domestic Product measures the total market value of all final goods and services produced annually within a country.

GDP expenditure approach totals the spending of the final users of goods and services. GDP is calculated by totalling consumption (C), investment (I), government purchases (G) and next exports (EX – IM).

Space products can be spacecraft, including satellites, and suborbital and spacecraft launch vehicles and parts of balloons, dirigibles, and spacecraft not elsewhere specified. Or any products which are tested or produced on board a space station and marked as "space product".

FAA economic impacts are quantifiable interactions between consumers and producers that result from a change in final demand for a product or service. These impacts track the financial transactions that occur throughout the production of a good or service, and they are measured in terms of increased economic activities, earnings and jobs.

Cost Benefit Analysis (CBA) contributes to the identification of project's options, the definition of the investment required and the definition of expenditures groups and stakeholders. CBA is a widely used in the aviation industry and supports private investors, trans-national stakeholders, service providers and aircraft operators to understand the benefits and the resources they need to commit to a project.

Direct economic benefits are increased employment, revenues from sales, new markets, increased cost savings and technology reliability and interoperability. Technology reliability also incorporates safety.

Indirect economic benefits are considered free publicity, technology innovation, international partnerships and environment protection.

About the Contributors

Stella Tkatchova is a Space Business Engineer at RHEA System S.A. a leading Belgian SME space company. She has the unique opportunity to work on business development of new projects, marketing leads development, proposals preparation and the development of projects related to space-based technology innovation, management, and new space applications (i.e. disaster management, etc.). She was awarded a Master of Science (M.Sc.) in space studies from the International Space University (ISU), France and a PhD from the Faculty of Aerospace Engineering, Industrial Engineering Group, TUDelft (The Netherlands). In parallel to her PhD research she worked for several years as a contractor at European Space Agency (ESA)-ESTEC on industrialisation and marketing of the ESA ISS on-board facilities at ESA Commercial Promotion Office (CPO). She started her career working on the market analysis study for the expected revenues from the geomatic applications for the Galileo navigation system and the cost drivers for Metop-A at ESA Cost Analysis Division. Since her childhood in Sofia, Bulgaria she has always dreamt of interplanetary exploration and therefore, developed a strong passion for researching the commercialization of space-based technologies for future interplanetary space missions, future space markets and ways for benefits identification and strategies for creation of public private partnerships for encouraging space technology industrialization. Her passion lead her into setting up a discussion forum in the International Journal of Space Technology Management and Innovation, of which she is the Chief Editor. She believes that space-technology can offer to non-space companies the unique opportunity to exploit technologies, that will result in the development of new markets, applications and technologies. Commercialization of space technology will bring direct and indirect benefits to society in the areas of science, environment protection, disease prevention, energy generation and technology innovation.

Gianluigi Baldesi is an Aerospace Engineer at the European Space Agency in Estec centre (The Netherlands) since 2003. He is currently coordinating simulation activities on dynamics in the Mechanisms Section of the Directorate of Technical and Quality Management (TEC) in order to provide new capabilities and essential expertise in supporting several European aerospace projects (such as VEGA, ATV, ISS payloads, Galileo,etc.). Furthermore, Gianluigi is also technical officer of relative technology development programmes. He holds a 2nd Degree Master (postgraduate) in "Satellites and orbital platforms" from "Sapienza", University of Rome (Italy) and a "double" Ph.D. in Systems Engineering with honours on "Modelling, Control Design and Simulation for a launch vehicle: from linear to nonlinear methods" from "Sapienza", University of Rome (Italy) and ISAE, ex SUPAERO (France). In parallel with his main activity in ESA, Gianluigi is also extremely interested on transfer and commercialisation of space-based technologies (such as Space-Based Solar Power projects, and creating a Space Debris Bounty system). The views expressed in this author's chapter are purely personal and do not necessarily reflect the views of any entities with which the author may be affiliated.

Pierre Lionnet, Director of Research at EUROSPACE* BA in Economics and finance (Univ. of Nancy-F) and Masters in Industrial management of innovation (University of Strasbourg-F). Pierre joined EUROSPACE in 1994 as a research Analyst after an 18 months period as a hired contractor for the European Space Agency. In EUROSPACE he was gradually given full responsibility over a series of studies and research activities for internal and external customers in the technico-economic domain, as well as in the policy area. He is now Director of Research heading all research and studies activities of the Association. In 1996 Pierre established the pilot survey of European space manufacturing industry activities, according to recognised statistical methodology for industrial sectors. Now in its 14th year, *EUROSPACE facts and figures* has become the reference source worldwide for European space industry economic data.Since 1998 Pierre was given management responsibilities on selected EUROSPACE Working Groups, Panels and Committees, in such diverse areas as: GMES, Navigation, Security & Defence, Standards, Components, Research & Technology. He now heads all technical working groups of Eurospace, and manages the space industry markets working group.In addition to its core EUROSPACE responsibilities, Pierre's expertise was put to the service of various European initiatives, such as Invesat (a Europe Innova project) where he acted as member of the Advisory Board, he also supported European space policy development, as an expert for the French and European Economic and Social Council in 2003 and 2004. Pierre is also an ISU alumnus (SSP93).

Memberships:

- IAF Technical Committee on Space Economics
- ASD Data Analysis committee
- ASD R&T Commission

* Eurospace is the association of European space industry, federating expectations and interests of the space manufacturing industry since 1962. Eurospace members are the main space companies in Europe, representing 90% of the total space industry employment in Europe.

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Michel van Pelt has a Master degree in Aerospace Engineering from Delft University of Technology in The Netherlands, specialising in System Engineering and Rocket Propulsion. He has been working as a cost engineer at the ESTEC centre of the European Space Agency since 1998. He is involved in a variety of ESA space projects, for which he prepares cost estimates and analyses of financial proposals. In addition he has developed several cost models. Besides his cost engineering activities, he regularly works in ESTEC's Concurrent Design Facility as cost engineer, system engineer or team leader for feasibility studies on new spacecraft and launchers. Most recently he acted as team leader for the XEUS and IXO X-ray observatory spacecraft studies that were performed in the CDF, and which involved some 20 experts. He is also author of the popular science books "Space Tourism", "Space Invaders", and "Space Tethers and Space Elevators", all published by Springer/Praxis.

Index