Signs of Potentially Disruptive Innovation in the Space Sector*

Leopold Summerer
ESA-ESTEC, Keplerlaan 1, 2201AZ Noordwijk, The Netherlands

ABSTRACT
This paper reviews and analyses some specific conditions for innovation in the European space sector. Innovation has enabled the first steps of humans into space and remained a key central parameter ever since. On the other hand, the space sector lacks key parameters encouraging innovation. While governments have put in place instruments to overcome these deficiencies, the current mechanisms seem to address mainly incremental/sustaining innovation. It is argued that this situation might be leaving the space sector prone to changes coming from radical and disruptive innovation. Applying mechanisms developed for understanding disruptive innovation processes in the private sector, two specific current developments in the space sector are analyzed.

1. INTRODUCTION

1.1 Innovation during the early phases of space activities

Innovation dynamics have been studied extensively during the last 50 years, however most of this research is done in and for competitive market environments, where either supply or demand side market forces can be identified as driving forces for innovation, including technology push or market pull driven processes [0]-[0].

Innovation has been central to space activities since our first steps into space. Most of the early successes of space activities, from putting *Sputnik* into low Earth orbit in 1957 to launching humans to the Moon only one decade later, have been enabled by ingenious innovation at all levels, technical as well as organisational [0].

Massive investments by the two cold war superpowers in prestigious missions and strategic space technology have leapfrogged progress in this one specific area, and by doing so created an entire new discipline. With shifting government priorities and therefore challenges and funding after the Apollo area, the rate of innovation in space activities gradually levelled off (e.g. [0]). Space has however remained of strategic interest, technologies are continued to be developed further, new exploits are being achieved but compared to the exponential growth of the first two decades, progress and innovation has levelled and is rather steady since. Some type of space activities that have been successfully undertaken in the 1960s and 1970s still remain far beyond the reach of most nations and even for space faring nations these are still complex, risky and expensive endeavours. Well-known examples include landing humans on the Moon, but also rendezvous and docking, controlled atmospheric re-entry, most propulsion technologies, deep space missions to the outer solar system to name just a few [0].

The evolution of the US civil space budget evolution shown in figure 1 provides a visual representation of this process, demonstrating clearly the investment peak during the 1960s Apollo programme and the subsequent levelling off.

1.2 Space – a government-controlled domain

All early and most current space programmes are carried out or strongly dominated by governmental programmes and choices. Among the main traditional space domains, only the space telecommunications sector has developed a dominant private component. All other traditional space sectors (e.g. launchers, human spaceflight, earth observation, global navigation systems and space science missions) remain subject to dominant government control. Figure 2 shows the funding allocation of European Space Agency (ESA) activities in 2006 as a representative example of relative sizes of the different ESA programmes [0].

Scholarly work on the reason for this situation has been published in the last decades. In addition to the main reasons: the strategic importance of some space-based services and space assets and

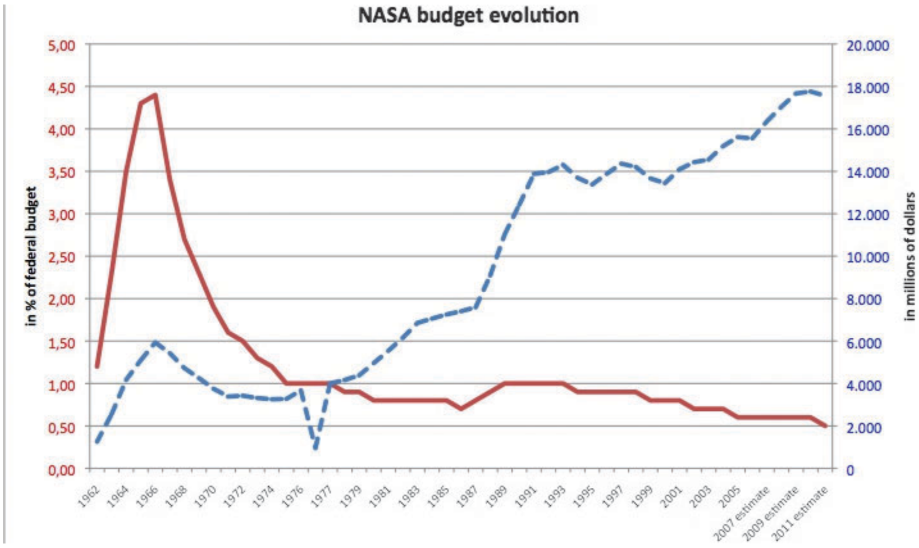

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Figure 1. Evolution of the US civil space budget in percentage of US federal budget spending (left y axis) and in total, non-inflation corrected M$ values (right y axis, dotted line) (graph based on data provided by the US Government Printing Office [0])

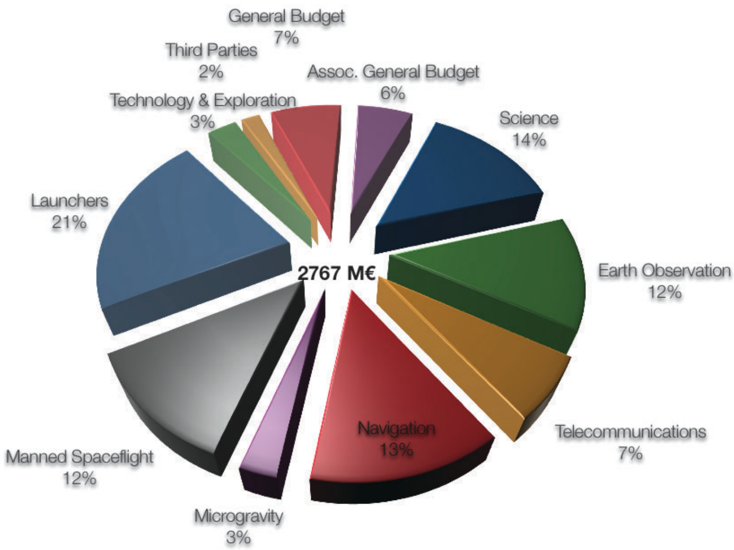

Figure 2. Domain relative repartition of expenditures in 2007 [0].

enhancing scientific knowledge, one of the arguments put forward supporting continuing governmental support for space activities – despite limited success in creating self-sustained private markets – is the importance of space activities for stimulating innovation and developing high technology for the benefit of markets and society as a whole [0][0]-[0].

1.3 Technology transfer from space to non-space sectors

In order to support this process, specific programmes have been put in place by all major space agencies to transfer high technology developed for governmental space programmes to other industries and services. As an example, the technology transfer programme of ESA has published the successful transfer of over 200 space technologies to non-space sectors for applications as diverse as cooling suits for a Formula 1 racing team, ground penetrating radar to detect cracks in mine tunnels and several health-care innovations [0][0]. Similarly, right after the Apollo programme area in 1973/1974 and when spinoff products from space technologies began to emerge, the US National Aeronautics and Space

Administration (NASA) started to record and report these in annual “Technology Utilization Program Reports”. The success of these publications has lead to a more consequential approach and currently NASA’s *Spinoff* publication claims to accomplish these goals [0]:

> “First, it is a convincing justification for the continued expenditure of NASA funds. It serves as a tool to educate the media and the general public by informing them about the benefits and dispelling the myth of wasted taxpayer dollars. It reinforces interest in space exploration. It demonstrates the possibility to apply aerospace technology in different environments. It highlights the ingenuity of American inventors, entrepreneurs, and application engineers, and the willingness of a government agency to assist them. And finally, it continues to ensure global competitiveness and technological leadership by the United States.”

The sole Apollo programme is reported to have led to more than 1500 technology transfers. These examples demonstrate how important innovation is not only for conducting space activities successfully, but also for the justification of continued public support. European ministers have deliberately increased the budget of ESA in the middle of the 2008 economic crisis, with the justification of the contribution of space activities to serve the Lisbon goals.[1]

> “These decisions have particular relevance at the present time, showing as they do Europe’s determination to invest in space as a key sector providing for innovation, economic growth, strategic independence and the preparation of the future.” [0]

In particular, the 4th and 5th European Space Councils in 2007 and 2008 recognized

> “the substantial contribution of space, as a high tech R&D domain and through the economic exploitation of its results, to attaining the Lisbon goals and fulfilling the economic, educational, social and environmental ambitions of Europe and the expectations of its citizens”, “the actual and potential contributions from space activities towards the Lisbon strategy for growth and employment by providing enabling technologies and services for the emerging European knowledge society and contributing to European cohesion”. [0][0]

While innovation mechanisms in the private sector have been subject to substantial research and resulted in a number of important publications, the innovation dynamics of governmental controlled innovation sectors such as space are less well understood [0].

2. THE EUROPEAN SPACE SECTOR – INNOVATION IN A MONOPSONY MARKET

The market structure of competitive free markets dominated by private enterprises is substantially different from the market structure of the European space sector. In order to analyse its governing innovation mechanisms, this section first describes some relevant fundamental parameters of the space sector and then analyses if and how some fundamental conditions for innovation are fulfilled.

2.1 Structure of the space sector

Since its creation after the Second World War, space has been dominated by government investments, government priorities and government programmes. Among the main space activities, only space telecommunication has developed a dominant private sector [0][0].

This situation is reflected in the overall investments in space. In 2006, worldwide government spending for space programmes was about $61 billion. The commercial market, dominated by satellite communications led to space segment investment of about €4.2 billion in 2005.

About half of all the government investments in space are for military and intelligence applications, underlining the strategic importance of the sector for national security purposes. Worldwide, the space sector is largely dominated by US investments, representing about 80% of all governmental space

[1]The Lisbon goals refer to the to make Europe “*the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment by 2010*.” [0]

spending, followed by Europe with about 15% of the overall share. This comparison however has to be nuanced since it is slightly distorted by currency conversions compared to real purchase power. Actors such as Russia, China and India are already responsible for substantial shares of space launches but have also been increasing their investment in space.

While the pure commercial space market is relatively small compared to the governmental one and dominated essentially by one application, satellite communications, it generates an important downstream market for user equipment and services, which is almost two orders of magnitude larger (about €110 billion) than its space investment and almost double the entire direct space market [0]. In a similar manner the government developed and dominated space component of the global navigation satellite systems (GNSS) have been creating a much larger private sector market. Especially for these applications, space can be considered as attractive *lead market* with the potential to trigger innovation in the downstream market by providing new opportunities for services and creating entire new markets. These generally represent fruitful grounds for the emergence of innovative start-up companies as early entrants exploring new markets. As such it presents an interesting opportunity for governments by offering leverage potential for governments investments. Mechanisms governing these secondary processes, though important, are not covered by the present paper.

Given the direct and indirect dominance of governments on both, the institutional as well as private space market in Europe, the situation is best described as a quasi monopsony with a governmental monopsonist. Especially for scientific and exploration activities, which are usually the technically most challenging type of space missions and thus those with the highest need for technologically innovative solutions, ESA is in the role of a true monopsonist within Europe. Szajnfarber et al. have analysed the mechanisms of this activity domain and reported a blurring of the usually clear-cut distinctions between supplier and buyer for the purpose of achieving the mission objectives [0].

Innovation in a monopsony has received some sporadic academic attention, especially comparing long-term interests by monopsonists to promote innovation on the supply side if the monopsonist is operating itself in a competitive market structure [0].

In Europe, four large industrial holdings are dominating the space manufacturing industry, employing together more than 70% of the total space industry workforce. At the same time, averaged over several years less than 1% of all ESA contracts count for about 70% of ESA's contractual spending and are almost exclusively with the four large industrial holdings. It can therefore be argued that the market structure within the governmental monopsony is that of an oligopsony seen from the subcontractor base and that of an oligopoly if seen from the monopsonist. In 2007, about 30 000 persons were considered as direct space employees in Europe [0].

Public institutions, governments and service providers are the main customers of the European space industry, which operates at the high-end of the space value chain. The main products of the space industry are spacecraft and launchers, including their components and associated services. With a turnover of about €5.3 billion, it is still to be considered as a nice industry embedded into the larger industrial aerospace and defence sector. Market and innovation mechanisms of the space sector are

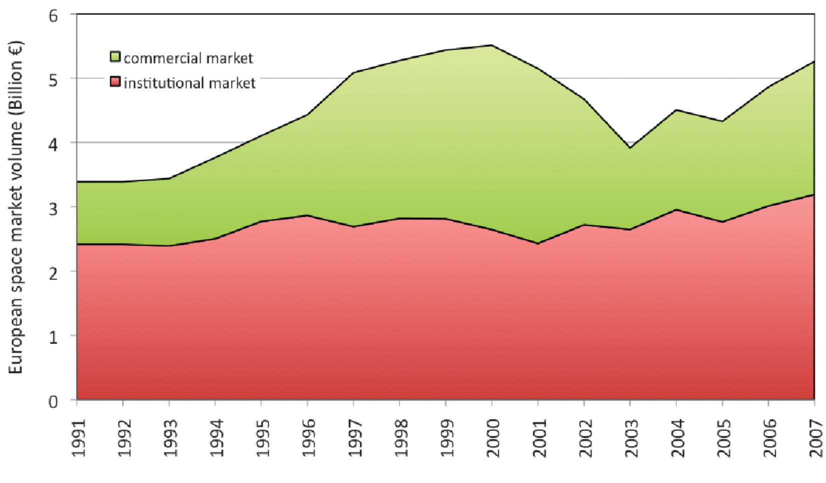

Figure 3. Evolution of the institutional and commercial volumes of the European space market (graph generated based on data published in [8]).

however substantially different from the main aerospace sector. While growing at a stable rate between 1985 and 1995, institutional budgets for space have remained roughly stable since then, only partially and momentarily compensated by increases in the commercial market [0].

For the space segment manufacturers, the two markets are interdependent and the competitiveness of the commercial sector largely depends on the satellite communication industry and indirect government support.

2.2 Conditions for innovation – invention and implementation

This chapter attempts to identify the conditions generally reported as being necessary for innovation to happen or favouring them. The distinction between the two constituting elements of innovation, *invention* and *implementation* is maintained.

Humans have invented under almost any conditions and in all types and forms of activities. Since creativity and inventions can usually not be "ordered", the leveraging factor is creating environments that are favourable for innovation [9][10][0][0]. Following the concept of *emerging innovation* developed by Peschl et al. to enable the processes of innovation to emerge for knowledge creation instead of imposing or forcing it, table 1 and the following paragraphs provide some circumstances that are considered as favouring the likelihood and frequency of inventions to occur [0].

Table 1. Innovation conditions within the European space sector and dedicated European programmes compensating innovation hindering situations.

Conditions for …	Condition descriptions	Conditions in space	Dedicated ESA programmes
… *invention*	• Attractive stimuli, difficulties, challenges	• Challenging objectives (+) • Difficult environments (+)	n/a
	• Culture of openness, high rate of information exchange	• Relatively closed sector (-)	• Innovation Triangle Initiative [0] • Networking Partnering Initiative • Ariadna [0]
	• Readiness for error, encouragement of risk taking	• Risk adversity (-) • Errors / failures not an option (-)	• Basic and Specific Technology Research Programme • Innovation Triangle Initiative [0]
	• Diversity of skilled workforce able and free to recognize and seize opportunities	• Highly skilled & culturally diverse, integrated mobile workforce (+)	n/a
… implementation	• Opportunities and open competitive markets	• High entrance barriers to space market (-) • Governmental distortions of free market forces (-) • Monopsony structures (-)	• In-orbit Demonstration Programme • Small satellite opportunities

2.3 Conditions for innovation in the European space sector

Without expanding this list unnecessarily, space activities clearly fulfil some of these conditions very well. The following paragraphs provide general descriptions of the different conditions listed in table 1.

Space missions are and remain technically very challenging, especially science and exploration missions. Spacecraft have to withstand extremely harsh launch environments and then operate under demanding conditions in an autonomous, autarchic and reliable way for years. There has been arguably not a single science or exploration mission that has not extended the boundaries of technical feasibility in at least one area. While components and technologies are re-used and sometimes spacecraft platforms serve for more than one mission (e.g. Mars-Express and Venus-Express missions), all ESA spacecraft can be described as one-off prototypes, custom-designed and optimised for one specific mission.

Employees in the space sector are very well educated, relatively mobile and from diverse cultural backgrounds. On the other hand, the space sector is a fairly closed sector, with little natural exchanges outside of aerospace and defence. Inventions however, especially radical ones, tend to appear from unexpected, marginal areas, from the intersection of domains, disciplines and as a result of their cross-fertilisation.

Space activities are naturally high-risk endeavours, an association that is justified given historic accident and failure records. Similar to the nuclear industry, this has lead to a risk-conscience mindset of developers and operators as well as innovation in risk management. However, together with the particularity that space offers practically no opportunities for error corrections after launch, this has also lead to a risk-adverse culture, that leaves little freedom for innovation not strictly needed for mission success and leads to technically conservative space engineers and project managers. While this is relevant for incremental changes at subsystem level and thus for *sustaining/incremental* innovation, general overall success also acts as a strong inhibitor against fundamentally new approaches related to *radical/disruptive* innovation.

Without opportunities for implementation, the best invention is likely considered "useless" for organisations that are not pursuing research as main goal. *Implementation* requires the conjunction of an invention with one or more opportunities, which are normally related to some sort of market need or interested "buyers" in a general sense. The European space market arguably lacks essential ingredients of a free, competition-driven, commercial market and thus also some innovation-stimulating effects of these: activities of the monopsonist are highly regulated by free-market distorting rules. These rules have however proven to be essential to reach a critical mass in Europe and allow for the (financial) participation of more ESA member states than technically needed. Furthermore, the "entrance barrier" to space is relatively high; with infrequent and expensive launch costs taking up to 40% of entire mission costs.

Consequently, there are only few flight opportunities for new ideas, new technology and new methods and lengthy processes between the description of a new concept and its implementation in a space mission.

In addition, the inflation-corrected funding of the governmental monopsonist is roughly stagnating since 1995, which is thus incapable to sustain full competition across the supplier range. Due to the absence of a "real market" with alternative buyers, few of the normal competitive market incentives are present to stimulate industrial and private sector investments in innovation.

2.4 Mechanisms to overcome some sector-specifics, innovation-inhibiting shortcomings of the European space sector

In order to address the shortcomings listed in table 1, specific mechanisms have been put in place: Not only to develop mission-enabling technologies but also to overcome the reluctance of projects to include new technology developments not strictly required for the mission objectives by developing these to sufficient technology readiness levels, ESA spends about €400 million per year on space technology R&D programmes, slightly over half of it via programmes like the Basic and Specific Technology Research Programmes and has put in place specific flight opportunities dedicated to testing and qualifying new technology.[2] In this context it is worth noting a persistent and market-distorting imbalance to the US situation, where innovation in the space sector is strongly driven by defence programme spending on advancing space technologies for classified programmes [0].

ESA has also established mechanisms to increase its interaction with the non-space world and to deliberately open up to other disciplines and industries. On the one hand, the technology transfer programmes, focussing primarily on the spin-off of space technologies to other sectors, and on the other hand programmes with a dedicated spin-in component, like *Ariadna* and the *Innovation Triangle Initiative* [0][0].

In parallel, ESA has opened programmatically to new sectors by deliberately positioning space projects as subsystems to larger, market and service-oriented systems and user-driven projects [0].

3. TYPES OF INNOVATION IN SPACE – HOW WELL IS THE SPACE SECTOR PREPARING FOR ITS FUTURE?

3.1 Innovation types

One of the earliest scholarly definitions of innovation goes back to the Austrian economist Schumpeter, who described it as "innovation implies bringing something new into use" [0]. While there are still scholarly debates on the best definition and apparent difficulties in finding a consensus across disciplines, the European Commission has proposed in its 1995 Green Paper on Innovation the following definition, which is used for the purpose of this work [0]:

[2]Activities conducted together with member states of ESA via the ESA General Support Technology Preparatory Programme (GSTP) [0].

> "Innovation is the renewal and enlargement of the range of products and services and the associated markets; the establishment of new methods of production, supply and distribution; the introduction of changes in management, work organisation, and the working conditions and skills of the workforce."

One of the most used differentiations of the innovation process uses the type of impact of the results of the innovation process[3], by distinguishing between processes of *incremental* and *radical* innovation as defined by e.g. Ettlie et al. [0] or *sustaining* and *disruptive* innovation as defined by Christensen [0].

In this definition, *incremental* innovation is characterized by small or relatively minor changes and improvement that do not alter in a substantial way the basic underlying concepts. Incremental innovation strives to *optimise* products and services.

Contrary to this, *radical* innovation is based on a different set of engineering and scientific principles and intends to opens up new markets and new potential applications.

Similarly but from a different angle, the analysis of why established market leaders and well-run companies tend to fail to understand and incorporate disruptive innovation, Christensen defines *sustaining* technologies as those new technologies that "foster improved product performance". While these can be incremental or discontinuous/radical in nature, they all have in common that "they improve the performance of established products, along the dimensions of performance that mainstream customers in major markets have historically valued." [0]. Market leaders are usually championing this type of innovation.

Contrary to sustaining technologies, Christensen has defined *disruptive* technologies as those that "bring to the market a very different value proposition than had been available previously" and that generally "underperform established products in mainstream markets" but offer new qualities that new, typically originally marginal customers value [0].

Radical innovation and disruptive technological changes tend to create difficulties for existing, established market players. One of the reasons for these difficulties are the high levels of uncertainties involved in radical innovation, the unclear customer basis, the usually negative feedback from the established, traditional customers with regards to the potential of the innovation for *their* products and services. These result in *disruptive* technology and to a certain degree also *radical* innovation being associated to higher risk and lower return on investment. It is therefore difficult for established organisations to quickly and early embrace them and re-orient the organisation towards such changes in order to lead instead of react to them, despite being most of the times fully aware of the changes. In competitive, free market environments, this situation leads to opportunities for new entrants and usually small, specialised companies that can sustain their business model based on emerging niche markets and lower profit margins. It is therefore argued that the only way incumbents can embrace disruptive innovation is to create separate, independent entities, unconstrained by core business constraints.

Contrary to *incremental* innovation, which aims to *optimise*, *radical* innovation focuses on changes in the more profound domain of core concepts or base principles. These therefore tend to lead to or require radical changes in the whole structure, society, product, or service (plus its context; e.g., by opening up completely new markets). Radical innovation therefore touches some of the basic assumptions, validated by experience.

3.2 Preparation of the space sector for incremental and radical innovation

> *Hypothesis 1: The European space sector and its main actors excel in managing incremental sustaining innovation within the current government monopsony market.*

Despite the shortcomings of the nature and setup of the European space sector as outlined in section 2 with respect to fulfilling some basic conditions for innovation to happen, the tools and programmes put in place to constantly increase system performances, to reach previously unreachable destinations and scientific precisions are fulfilling their objectives [0][0][0]. Despite sometimes dramatic setbacks, the achievements of the European space sector in all its key activity domains are remarkable, constantly progressing and could in general be considered as satisfying the "customer base".

In addition to solid high-tech engineering, it requires innovation, ingenious engineering solutions

[3]While innovation is still used as well for the process and the product, for the purpose of this paper, the innovation process is considered.

and the solving of numerous unprecedented difficulties to land a probe in an essentially unknown and hostile "world" 1.4 billion kilometres from Sun after seven years and 3.5 Billion kilometres of interplanetary travel (*Huygens* lander on the Saturn moon Titan [0]), to capture and convert enough solar energy at very low temperatures as far as Jupiter in order to put a small spacecraft on an extremely precise rendezvous trajectory with an only 4 kilometre diameter irregular shaped comet travelling at speeds up to 135,000 km/h and landing on it (*Rosetta* mission to comet 67P/Churyumov-Gerasimenko [0][0]); to keep the relative distance of 5 million kilometres arm length between three spacecraft orbiting in a halo-orbit around a Lagrangian point in order to detect the extremely weak expected gravitational waves, the riples in space-time, by keeping a mass inside the spacecraft fully free floating to 3?10-14 m s^{-2} (LISA mission [0][0]); to drill two meter into an essentially unknown Martian soil with only the power of a stronger light bulb harvested from the sun and collecting and analysing the samples with scientific instruments that normally occupy entire labs packed into only a few tens of cubic cm (*ExoMars* mission [0]) or to measure the Earth gravity field and ocean circulations with a 2 cm precision from space (GOCE mission [0]).

Each of these missions, which are just few examples, have developed or are developing technologies that are then likely to be transferred to non-space domains and lead to start-up companies and other space spin-offs [0][0][0]. In this sense, these are constantly pushing the scientific and technical boundaries, providing information essential for science, for the understanding of the universe, Earth and Earth climates and their respective interactions. Strong incremental innovation in industry, academia and agencies is the underlying basis for these achievements. It is driven by the European scientists, providing requirements and scientific needs, managed by the governmental monopsonist via basic technology development programmes and sustained via public support accepting risks spread and shared by many governments.

> *Hypothesis 2: The space sector as a whole as well as its major actors experience difficulties preparing for disruptive or radical innovation, partly due to the successes enabled by incremental, sustaining innovation. However, based on analysis methods of free market, signs of potentially disruptive innovation in the space sector are appearing.*

During discussions about *advanced* space systems and technologies it is not uncommon that scholars and experts specialised in the history of space activities or with personal experience mention that most of these have already been studies and partially developed already during the 1960s and 1970s. One could argue that during the last 25 years, not a single radically-new major programme has been introduced into the governmental space sector. A roughly 50-year-old launch system is still the most reliable launcher to transport humans into Earth obit. Laymen would probably not recognise the difference between the MIR space station launched in 1986 and the current International Space Station (ISS).

To support the proposed hypothesis, we will try to apply techniques developed for the free, competitive market environment in order to identify signs of disruptive innovation in and for the space sector and then analyse how well this apparently highly-successful, though relatively stagnant sector is prepared for these.

We follow a process proposed by Christensen by first analysing the validity of some of the basic assumptions [0]. The European space sector has been created with assumptions that could be summarised as [0][0]:

- Space activities are inherently expensive and none of the national budgets of European states would individually reach the critical mass for substantial space activities;
- Absence of sufficient commercial incentives for the private sector to make the required upfront investments and take the high risks of space activities (combined with a promising growing satellite communications sector that needed governmental support for international commercial viability);
- Strategic importance of an independent access to space;
- Lack of a significant common European defence needs and funding of space assets and space technology;
- Political will to retain European engineers and scientists by providing stimulating, attractive science missions.

At first sight, most of these are still valid and the situation of the European space sector and its main activities has therefore experienced only relatively small changes over the last 20 years: apart from marginal shifts in the relative importance of the different sectors shown in figure 2, most investment comes from civil, government funding via ESA for relatively large, cost-intensive prototype-like spacecraft. Important efforts have been made to increase the efficiency of the process, to improve the performance of space components and systems and to reach ever more difficult destinations and goals. Furthermore, pure commercial activities without governmental support and intervention are rare, access to space is still of strategic importance, mobilising and justifying governmental support and funding to maintain launch capabilities, and even if its role is increasing, the European defence sector is still a relatively marginal player in space [0].

Second, we analyse the type of products associated with disruptive innovation. Disruptive innovation tends to be de-rated and underperform with regard to the primary performance dimensions considered by the main customer base [0][0]. The new "product" may however perform better on alternative criteria that are not considered essential by the lead users and key customers. Typically these are reported to be simplicity or lower cost but with unacceptable cost/quality ratios or reliability levels for the main customer base [0]. Since disruptive innovations start marginal, and of non-disruptive nature in the short run, established organisations risk to fail to take timely action to include this *low-end encroachment* into their business plans.

While the fundamental assumptions are *generally* still valid for space, a detailed analysis including the fringes of the space domain offers a different picture.

> *Hypothesis 2a: Cubesat and microsat activities represent low-end encroachment, potentially disruptive innovation.*

Since several years, university departments and research centres have discovered the usefulness of very small spacecraft [0]-[0]. Compared with traditional spacecraft, these are one to two orders of magnitude smaller and less massive, less reliable, with shorter lifetimes, simpler and faster in their construction and design and orders of magnitude cheaper [0]. Earth observation cubesats are currently designed, manufactured and launched within less than two years and total mission costs of a few hundred thousand Euros [0]-[0]. Usually these spacecraft are launched for free or at marginal costs as so called "piggyback" payloads alongside traditional spacecraft since their volume and mass are quasi negligible [0][0][0].

Initially, these have been mainly used for education purposes. The ingenuity of young engineers, acceptance of a high level of risk and the easy access to the technology have led to first impressive results and the subsequent introduction of more and more sophisticated equipment, enhancing the capabilities of these micro-, nano- and cube-sats to a level already useful for some real scientific experiments and dedicated space applications [0][0]. First launchers dedicated to this market are being studied or already entering the market [0][0].

These space missions present some key characteristics of a potentially *disruptive, low-end encroachment* [0]: they come from and address a different, still marginal market, they are much simpler, cheaper and non-competitive in the traditional space market parameters; traditional space companies are by and large ignoring the market due to very low profit margins[4], which leaves room for new entrants with completely different business models uncommon to the space domain, such as selling standardised space-qualified spacecraft components via an online shop to individual customers of all sorts [0]. Contrary to protective technology approaches in the traditional space industry based on regaining technology investment costs over relatively long lifetimes and high selling prices per piece to few customers, these almost unnoticed market entrants tend to embrace open-innovation and knowledge sharing [0]. While natural links to the traditional space sector exist (some of these potentially disruptive technologies are developed with support from ESA technology development programmes [0] and the missions largely rely on subsidised launch opportunities), their business models are in essence independent from the decision mechanisms of European space programmes. The performance increase rate of these spacecraft is much steeper than those of traditional spacecraft, leading to first signs of market entrance of these into the domain of traditional space applications [0].

[4]Only 5 of the almost 200 registered participants at the *Second European Cubesat Workshop* organised by ESA in January 2009 came from the traditional European space industry.

Furthermore, when comparing the periods 1999-2001 to 2003-2007, the total European turnover with medium to large satellite decreased by about 5%, while the one for small and microsatellites increased by 200% (though still on a much lower absolute value).

While small satellites as such are not new and have even already undergone once a small hype about their potential [0], taking the above signs into account and following the strategy as developed by Christensen and Raynor [0], recent cubesat activities seem to show most of the main characteristics of a potentially disruptive, radical innovation for the space sector. Under the assumption that the mechanisms observed and studied in fully competitive free markets are applicable to the space domain, traditional European space industry leaders as well as the institutional European space sector might need to take these developments serious and deploy proactive strategies to include these fully into their planning and future business scenarios.

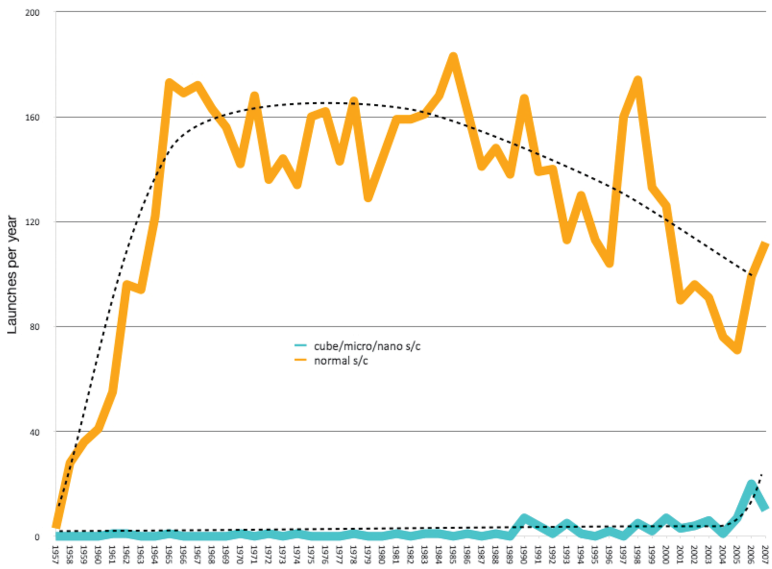

Figure 4. Evolution of worldwide space launches per year.

> *Hypothesis 2b: Space tourism and some other fully private space activities represent potentially disruptive innovation for the space sector.*

The second trend on the margins of the traditional space domain analysed in this paper is related to fully private space activities, including space tourism and sub-orbital spaceflight.

It touches on one of the fundamental assumptions upon which the European space sector has been built as outlined above: investments and risks are too high for fully private space activities. The evolution of the space sector in the 20th century has so far confirmed this assumption. The few private ventures into space have usually not lasted longer than a few years with disappointing results. However, with the beginning of this century, some radically different business models and approaches to space activities have emerged with substantial private funding to a large extent enabled via fortunes made during the first and second internet economic bubbles [0][0].

The first fully privately financed and developed launchers have just entered the market in the low-mass category. In parallel the first fully privately funded launch system to put humans into space, even if still "only" into suborbital trajectories, have been developed and successfully tested. Even if benefiting largely from technologies and expertise developed via government programmes – many of which have been cancelled, leaving frustration with involved space system engineers – these developments followed an approach radically different to the one adopted by space agencies and traditional space system market leaders.

In the US, NASA has been actively supporting private initiatives by providing support in form of government launch market access. As an example, instead of NASA continuing as sole US supplier of goods for the International Space Station (ISS), it has instead recently awarded contracts to two new private space launch service providers: *Orbital Sciences* and *SpaceX* (valued at around $1.9 and $1.6 billion respectively). Each is reported to be responsible for 20 service flights between 2009 and 2016 with each trip requiring delivery of a minimum of 20 metric tons of up-mass cargo to the space station [0].

Similarly, triggered by the success of *Scaled Composite* with its *Spaceship-1* winning in 2004 the fully privately funded *Ansari X-Prize* competition, the airline and tourism industry has started entering the field of space tourism. Though no *real* market in sub-orbital space tourism exists at this time and overall market and technical risks are still high, the *potential* market is very large and a number of companies are prepared to take the risk and are currently entering this market as precursors. Virgin Galactic flights of *SpaceShipTwo* are scheduled to begin operation by 2010 and Virgin Galactic has already collected deposits from individuals for flights [0][0]. Other sub-orbital companies, such as *Rocketplane*, *XCOR*, and *Blue Origin* also are aiming to begin service in a similar time frame.

While there is still incertitude how many of the private ventures are actually going to succeed, by removing one of the main assumptions upon which the space sector has been built, also this development shows characteristics of potentially radical innovation. The dominant incumbent industry leaders have been relatively absent in these early phases of this process and are only slowly reacting to it instead of leading it [0][0]. The innovation creates a new, emergent market in addition and almost independent to the traditional space market. Technologically, the currently most promising concepts are based on aeronautics (horizontal takeoff and landing, plane-like vehicles), thus leveraging on expertise and developments in this mature domain. The basic concepts have been studied and partially developed in since the 1960s (e.g. X-15 spaceplane programme [0]) but never put into an operational system. It is argued that new materials and technology have lowered the cost of such systems by a factor 50, thus enabling the emergence of these new markets and uses [0].

4. CONCLUSIONS

Market mechanisms of quasi government monopsonies as within the European space sector influence innovation mechanisms. Some of the environment and parameters generally acknowledged as favouring the emergence of innovation are absent and have to be compensated via dedicated programmes by the government monopsonist. While space is by its very nature strongly innovation-dependent, has provided and generated radical and disruptive innovation and created entirely new markets and human activity domains during its first decades, it is argued that its innovation focus has shifted towards incremental, sustaining innovation during the last two to three decades. Analysing the mechanisms developed by scholarly works on disruptive innovation mechanisms in commercial free-markets, early signs of potentially disruptive activity domains and radical innovation have been analysed and identified.

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