EUROPEAN SPACE TECHNOLOGY PLATFORM

The Technology Platform for Space Technology

Strategic Research Agenda

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http://www.estp-space.eu

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1 Introduction

During the past few years, Europe saw significant changes: the EU enlargement to 25 states in May 2004, the new global scenario and the aspirations of Europe, the day-to-day renewed threats to security across an enlarged territory, new neighbours and international strains.

Space is an element of increasing vital importance in an enlarged European territory. Today, satellites around the globe send images of rain and windstorms heading our way, television is beamed around the world by satellites, and we are driven to restaurants and theatres by satellite navigation. Such applications of satellite technology have become so familiar that we take them for granted. There are many more to come, as Europe aims to ensure that citizens will have access to all benefits from space, in their everyday lives. Raising concerns with security and the environment in an enlarged Europe, the need to bring humanitarian aid to remote or catastrophe-inflicted zones, the goal Europe has set to become one of the most competitive knowledge-base societies in the world, are driving the needs for technology developments in the space sector.

Europe needs a solid space technological base aimed at deploying competitive and non-dependent future generation of space systems. This cannot become a reality without a stronger commitment to technology research and development, innovation, in-flight demonstration and coordination of resources to answer to these challenges.

Coordination and increase of the efforts in space-related activities is a prerequisite to improve the strategic place of Europe in the world and to reduce dependency from the leader in the sector, the US. Increasing efficiency will require maximising synergies through reinforcing complementarities amongst stakeholders (space/non-space) and avoiding duplications in each element of the value chain.

Both the increase of investment on space technology R&D and the enlargement of the coordination effort are necessary steps to improve the competitiveness of the European Industry vis-à-vis the major world player and the emerging space powers, with which cooperation should be considered where appropriate.

In November 2004, the 1st Space Council recognised the strategic importance of space as a contributor to the implementation of a wide range of European policies. In particular, it recalled the need to make the best possible use of the existing resources and to drive deployment to meet citizen needs:

> *"It is therefore essential to assess the resources necessary and to utilise the available resources in an efficient and effective way at all levels, so that efforts are complementary and avoid duplication, and so that the offer of space based services and infrastructures meet the demand from users, such as the European Union's policies, the Member States' policies and the European citizens"*

In that respect, the *European Space Technology Platform* (ESTP) has been established. It answers to the needs identified by the Space Council and is being set in the frame of the Commission's EURAB report on *European Technology Platforms* after discussions with EC's DG-Enterprise Space Policy Unit. The ESTP is the *Technology Platform* for European space technology implementing the *Vision* for the deployment of space technologies in Europe for the next decade. It will reinforce and enlarge the coordination of the European efforts to establish a sound, competitive and non-dependent space technology base. The ESTP will facilitate interactions between the space sector and related non-space technology platforms and initiatives, support EU policies and enable services to European citizens. Last but not least, it will support the enlargement of the Union by helping the integration of new EU Members States in the space sector along agreed roadmaps.

The ESTP builds on the success of the established European Space Technology Harmonisation process. Since its launch in 2000, approximately 40 technologies have been harmonised, with the participation of all ESA Member States, Eurospace, Industry, more than 700 Professionals from more than 170 European space companies and research organisations. Consequently, the *European Space Technology Master Plan* (ESTMP) provides, today, a comprehensive vision of space technology in Europe, with a complete mapping of the European effort on space technology and a full set of harmonised roadmaps guiding future technology planning.

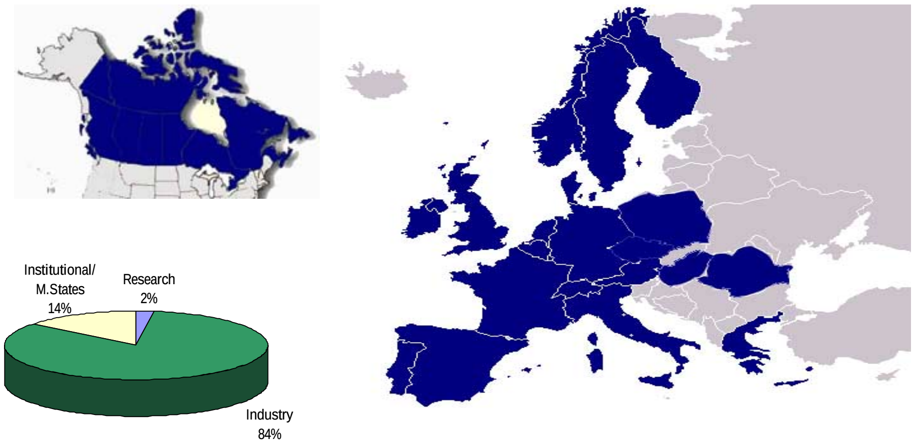

Figure 1 (a) – European stakeholders plus Canada (not to scale), (b) Representation of Industry, Research and Institutional/National organisations (Member States/Space Agencies/EU bodies)

ESTP stakeholders include, today:

- 18 EU member states plus Switzerland, Norway, Romania and Canada
- European Space Industry (over 110 companies)
- Eurospace, representing 90% of the total turnover of the European Space Industry
- Research Laboratories and Universities
- The European Space Agency, National Space Agencies and Organisations (ASI, BELSPO, BNSC, CSA, CSO, CDTI, CNES, DLR, DNSC, Enterprise Ireland, FFG, GRICES, HSO, LUXINNOVATION, NIVR, NSC, POLSPACE, ROSA, SNSB, SSO, TEKES)

It is planned to expand the list of stakeholders in the near future, to include also EU Agencies and Bodies, and the remaining EU member states and relevant Industries and organisations.

The present Strategic Research Agenda (SRA) provides a comprehensive overview on where we are and where we want to go. It demonstrates the commitment of stakeholders to accommodate, in their programmes, a common strategy responding also to the needs and priorities of Europe, including Industrial and National priorities.

The SRA presents the *objectives* of the ESTP and analyses the space *world context,* with focus on space technology; it describes the *landscape of space technology* in Europe, focusing on the major current shortfalls and *technology needs*. The *strategic challenges* are then described, and the way ahead to *realise the SRA* to answer to those challenges - namely in the context of Community programmes (eg. FP7) - is proposed. Stakeholders' roles and responsibilities for the implementation follow the orientations adopted at the 2nd Space Council.

2 Objectives

Boundaries

Space systems, in addition to a unique research instrument, have now become part of the daily lives of the Europe's citizens and a tool for the EU to monitor and enforce its policies (as shown in Chapter 3). Failure to ensure the availability of the needed enabling technologies would make Europe extremely vulnerable vis-à-vis single suppliers (eg. US). For Europe to be sovereign, non-dependence in the provision of critical technologies is essential. Technology dependence will also limit the capabilities of the European industry to adequately respond to the demand of an EU Institutional market and to compete, in global commercial markets, in particular in the area of security.

The ESTP further notices (as illustrated in section 4), that Europe's position as a space power in the world scene may be compromised if the gap in investments with the USA continues to increase and the weak coordination between civil and security related investments is maintained. Synergy between civil and security upstream technology development is a pre-requisite to maintain the European position and joint developments (e.g. in the area civil security applications) must be highly encouraged.

Europe's role is also threatened by emerging powers as China and India, which are replacing technology lag by lower production costs (Chapter 4). For Europe to keep a leading position in this increasingly competitive global environment, it will have to maintain a technological advantage. This can be achieved by a stronger investment in R&D, but also by benefiting from spinning-in technology developments from non-space sectors in areas with affinities to space (eg. materials and nanotechnologies, electronics and embedded systems, robotics, batteries and fuel-cells, etc).

Furthermore, the analysis of the European situation in Chapter 5 shows a continuous erosion of capabilities since 2000 as a consequence of the ending of institutional programmes and severe downturn of the commercial market. Remedy has started with the launch of major institutional programmes such as Galileo and GMES missions. The analysis of the European effort on space technology summarised also in Chapter 5, shows that, although the resources are important (albeit far from those devoted by the USA) they are insufficient to counterbalance the negative trend.

Thanks to the investments of Member States through ESA, national agencies and research organisations, Europe has access to a solid technological and industrial base, mastering most of its needs. However, the mechanisms driving the technology in support of short-term competitiveness are different from those driving technology for strategic non-dependence and longer-term preparation. In summary, Europe is not as well equipped as it needs to be:

- Europe depends on others for some critical space components (e.g. radiation-hardened electronic components, etc.) and dependent of stringent US export-control regulations;
- There are gaps in its development of future technologies mainly caused by insufficient funding. A number of technological breakthroughs must be targeted in support to future applications serving the citizen.
- Europe's limited commitment to security-related space activities leads to technological deficiencies due to insufficient investments in some areas.

Europe needs a broad technological base if it is to be capable of acting independently in space and sustain a space industry that is competitive in global markets. Public support to R&D in space technologies is imperative because of the high costs and risks involved, and the comparatively low returns from commercial and institutional markets.

The environment set within the EU to increase the cooperation on R&D through *Technology Platforms* (aiming at fostering collaborative research and sharing of knowledge, and create long-term competitive partnerships), will facilitate multi-disciplinary cooperation with related space/non-space development and application areas, promoting collaboration in the development of multiple-use technology through harmonised civil and defence R&D programmes.

Objectives

To address the challenges above and ensure the coherence of continued investment in space technology, the ESTP has been set up building and expanding on the success of a pre-existing co-ordinating and harmonisation effort sustained by ESA and its Member States, national agencies, industry and research organisations, complementing it in several strategic areas.

The objectives of the ESTP are to:

- Extend the coordination process to all EU Member States
- Provide a long-term vision for space-technology R&D
- Implement at EU level the vision and a coherent cooperation framework for the deployment of space technologies within the European Space Programme
- Promote actions to reduce European dependence
- Enhance and cross-fertilise technology (promote multiple-use and spin-in) by:
  - Developing synergies between the ESTP and other related non-space Technology Platforms (e.g. in the areas of photovoltaics, fuel-cells, materials, nano-technologies and nano-systems, telecommunications, etc)
  - Promoting joint upstream research on dual-use technologies (civil and security/defence)
- Drive technology R&D strategy in response to EU needs
- Promote the worldwide competitiveness of the European industrial base
- Facilitate international cooperation on technology issues (also for non-dependence).

The diagram below illustrates the structure of the ESTP. The platform is organised around existing instruments to achieve the objectives above, adapting and responding to the enlargement of the European Union and its needs. In addition to what is covered today by existing ESA, national, industry and other research programmes ('today's scenario' in Figure 3), the European Space Technology Platform foresees a particular effort through three strategic pillars.

The 3 SRA Pillars

- *Pillar 1: Non-Dependence* – Development of strategic space technologies needed for Europe's non-dependence; promotion of international cooperation for alternative supplies
- *Pillar 2: Multiple-use and Spin-in* – Synergistic actions with the non-space sector in areas of mutual interest (e.g. embedded systems, photovoltaics, fuel cells, nano-technologies and robotics).
- *Pillar 3: Enabling technologies* – support the implementation of EU policies by developing the technology needed (e.g. in the area of security/defence).

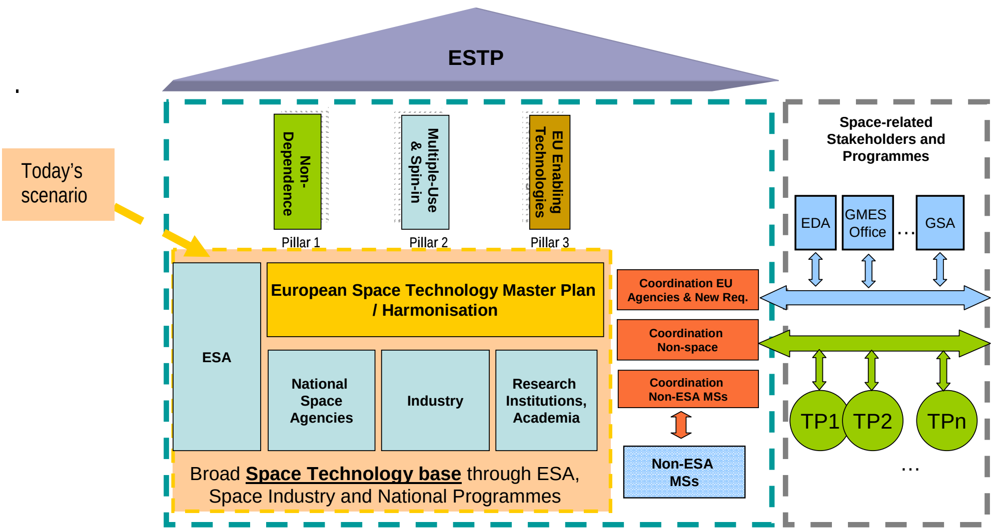

Figure 3 - The ESTP builds on the existing space technology R&D landscape, complementing it with three strategic pillars and additional coordination actions

Pursuing a Vision

The objectives set will prepare the technology base needed for Europe to achieving its Vision in the space sector:

- Ensuring the availability of the next generation user-driven competitive services and applications
  - navigation, Galileo
  - environment & security, GMES
  - telecommunications (broadcast, secure communications, data broadband,...)
  - meteorology
- Acquiring operational capabilities to monitor the environment, globally and locally
  - to act as a global player on the international landscape
  - for independence of assessment (critical areas/situations)
- Maintaining its capability to access Earth orbits without restrictions
  - to preserve the independence of its policies, not limited to space
- Exploring the solar system (robotic exploration)
  - and pondering over the possibility of long distance human space travel
- Pursuing excellence in science
  - ESA's cosmic vision

A phased Implementation

Most of the space technology developments will be done through stakeholder's programmes and funding mechanisms. In specific areas addressing major EU strategic challenges (section 7.3), the ESTP will seek complementary actions and adequate funding from Community programmes (eg. FP7). A roadmap for implementing the SRA is given in Chapter 8.

A phased implementation is sought: The first SRA was produced with strong time constraints to fit the preparation of the calendar for the *7th RTD Framework Programme (FP7)*. Stakeholders understand that ESTP is a major strategic tool addressing a coherent strategy for space technology development and a vehicle to provide the EC with recommendations on a complementary set of actions needed. With this understanding, the ESTP major deployment phases for the period 2007-2013 are:

- Phase 1- ESTP stakeholders to deliver an approved consolidated SRA for the first call FP7 2007&2008 (this SRA).

- Phase 2 - In the medium term (aiming at FP7 calls post-2008), the ESTP will be reinforced, based on results from Phase 1, namely after the kick-off of the actions referred to in Section 8.3 to support Pillar 2 and 3. The SRA will be subsequently updated to support further FP7 calls and the ESTP structure will be finalised.

In the long term (2013 onwards) the ESTP will be shaped to reflect stakeholder's view in the preparation of future EU programmes.

3 Space Systems are part of daily life

Europe is increasingly depending on space systems for many applications of high strategic and economic value and for applications of daily use.

Satellite based **communications**, are part of daily life since several decades. To the first series of ECS, MARECS and national missions, several institutional and private systems have followed and a commercial market has developed. Many trivial actions of our life involve telecommunication satellites, in addition to the well known television and voice communications. In some cases satellites are the only solution such as in remote areas and thus become enablers of development. European industry can compete only if the rules of the market are respected, and if it can count on the availability of the right technology. It would not be possible to compete if e.g. European ADC converters require 10 times more power than those employed by competitors, if the delivery deadline can not be maintained because, say the mounting of electric propulsion has to be delayed due to lack of flow control valves, etc

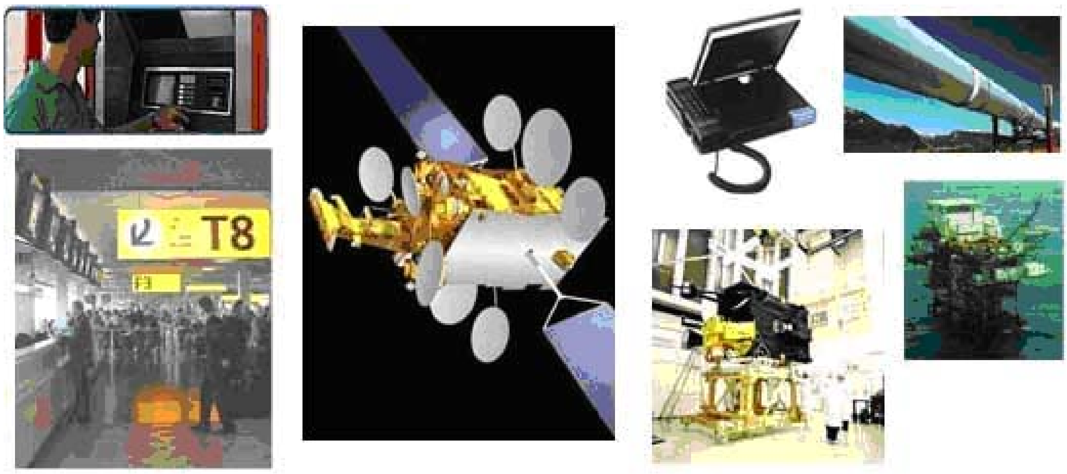

Figure 4 - Telecommunication satellites are essential elements of our life.

Operational **meteorology** is based also on data from European satellites. Six satellites followed to geostationary Earth orbit the first Meteosat launched in 1977. In 2002, the first element of the Meteosat Second Generation (MSG) was launched, followed by a second element by the end of 2005. Two more MSG units are under development. The preparation of the Meteosat Third Generation (MTG) has started. Satellites have allowed a giant step in the accuracy of weather prediction. Europe would not be capable of covering its needs if it would not have the appropriate technology, e.g. detectors in long-wave thermal infrared, high data rate processors, etc.

Met*Op*-A should be launched in 2006 to become the first satellite of the EUMETSAT Polar System (EPS). It initiates the European contribution from this orbit in the context of cooperation with NOAA. Two other Met*Op* satellites are under construction. In the meantime the USA have integrated their civilian and military systems under an Integrated Project Office (IPO) to deploy the NPOESS which will cover also the orbits to be served by Met*Op.* Europe is preparing the generation after Met*Op*, the post-EPS, in the spirit of cooperation, a rooted European tradition, but taking into account the European interest. This would not be possible if Europe would not be able to have the right technology, e.g. long-wave length infrared detectors, Schottky technology for receivers at high frequency as required to measure precipitation or atmospheric composition and thus provide air quality forecasts.

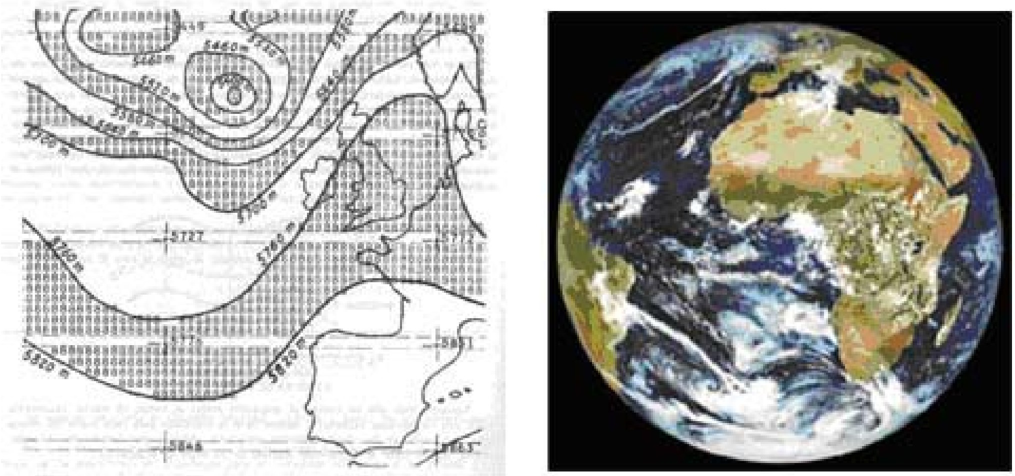

Figure 5 - From the blackboard drawings of the 60-ies to the MSG satellite imagery. The improvement in our prediction skills has increased dramatically

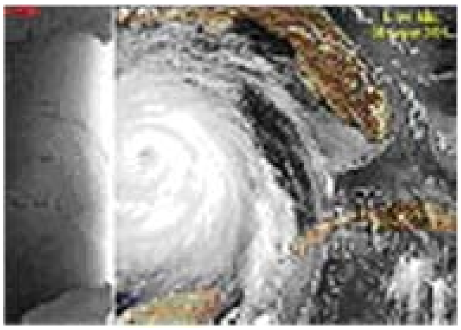

Figure 6 - The eye of hurricane Katrina as seen from an ESA satellite

Satellite based **navigation**, now via GPS and GLONASS, properly reinforced with European assets in EGNOS, has become part of daily life, e.g. with the massive use of palm-tops that include portable GNSS receivers. This is an example of how a cheap device is becoming unavoidable in our daily life but requires behind a high performance satellite system. This will be even more when Galileo is deployed. Galileo is conceived to be inter-operable with GPS but also to provide independence which needs to be ensured in the future. This would not be possible without access to the relevant technology, more compact lower consumption clocks, appropriate RF circuitry, etc

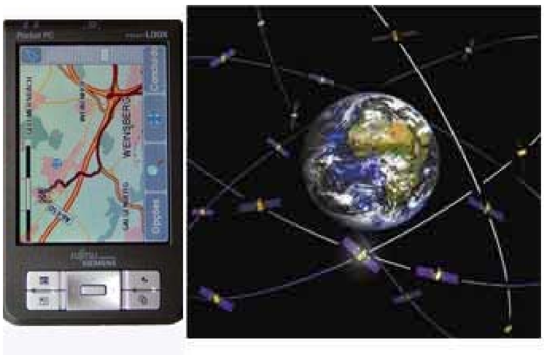

Figure 7 - A palm-top with built-in GNSS receiver. This daily life device requires a 30 satellite constellation with associated highly available ground segment

> *The European GNSS System*
>
> The European initiative in the domain of global satellite navigation systems is being implemented through the *European Geostationary Navigation Overlay Service* (*EGNOS*) and ***Galileo*** systems. EGNOS is well into its initial operations phase in view of being qualified in technical and operational terms by early 2007. For Galileo, a first experimental satellite has been launched and a second one will follow in 2006 as precursors for the four satellites of the *In-orbit Validation* (IOV) phase planned for launch in 2008. Full operational capability is to be established by the Galileo Concessionaire in 2010.
>
> The United States are now embarking on a broad modernization programme, which will span from the presently developed military version, Block IIR-M and Block IIF including usage of the L5 band of the frequency spectrum to the GPS III system that, through a 30-satellite system, will address the future needs of military and civil users over the next 30 years as of the first launch in 2013.
>
> Through the implementation of the Galileo and EGNOS systems Europe will be getting at par with the United States, matching the GPS and its Wide Area Augmentation System (WAAS) with a slight advantage for Galileo, pending the realization of GPS III.
>
> The European *GNSS Evolution Programme* is currently being proposed based on the experience gained during the early GNSS and EGNOS technology developments and the IOV validation system. The *Programme* will be executed by ESA in close cooperation with the European *GNSS Supervisory Authority* (GSA) taking into account that it will eventually become responsible for the European GNSS infrastructure, including its modernisation as provided for in the statutes of the GSA (EC Council regulation N° 1321/2004 from 12 July 2004).
>
> By focusing on the evolution of the infrastructure, the *GNSS Evolution Programme* will complement other R&D initiatives to be undertaken at European and national level, such as those of the 7th FP to be managed directly by the Galileo supervising Authority (GSA), which will focus mainly on service aspects and on fostering the development of enabling technologies for new applications.

Satellite based instruments are used as **data collection systems** (DCS) from sensors located at sea, on remote unattended areas or even from transmitters carried by persons and animals. The operational applications are immense, from environment monitoring to security.

Satellite systems have been used for **search and rescue** purposes since many years. Europe has to be able to have its own means in a cooperative context. This requires technology, e.g. sensitive receivers to pick-up faint signals.

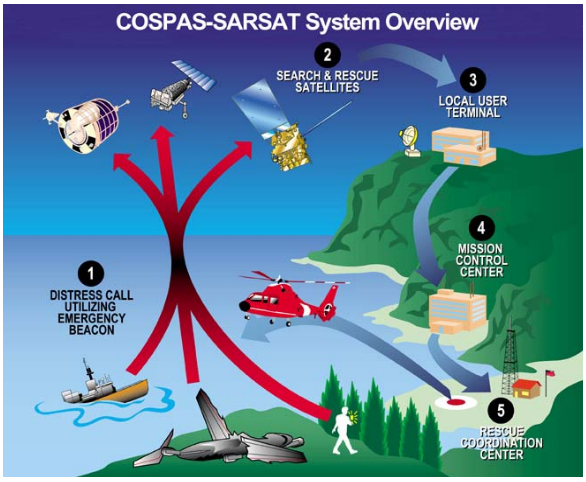

Figure 8 - Space systems are an essential element of Search and Rescue

Remote sensing has been used for operational purposes since the first elements of the SPOT and ERS series. Now several missions at national, multilateral and European level are being readied and will cooperate in the context of the initiative for Global Monitoring for Environment and Security (GMES). As for other undertakings, GMES will represent the European spirit of cooperation, in the context of GEOSS, and independence.

Figure 9 - Some applications of the GMES Space Component

Dedicated missions, the so called Sentinels are being developed as part of the GMES Space Component. This component will provide the data required for services in support of environment monitoring, disaster prevention and management, sustainable development, and other areas. The effort would not be possible if Europe would not have the required technology to build, for instance, the T/R modules of the SAR systems, the detectors for the focal planes, the MMIC for the various sounders, the processors capable of crunching the massive amount of data.

Sentinel-1	C-band interferometric radar mission
Sentinel-2	Multispectral optical imaging mission
Sentinel-3	Mission with an altimeter and wide-swath low-medium resolution optical and infrared radiometers
Sentinel-4/5	Two families of atmospheric chemistry monitoring missions, one on geostationary (S-4) and one on low Earth orbit (S-5). An infrared mission for fire monitoring has been identified as an auxiliary mission

SERVICE	VHR optical/SAR	Sentinel 1	Sentinel 2	Sentinel 3	Sentinel 4	Sentinel 5
European land use / land cover state & changes	■	■	■	■		
Marine & Coastal Environment	■	■	■	■		
Global Change Issues		■	■	■	■	■
Atmospheric Pollution Management				■	■	■
Risk Management	■	■	■	■		
Forest Monitoring	■	■	■	■		
Food Security and Early Warning Systems	■	■	■	■	■	■
Maritime Security	■	■				
Humanitarian Aid	■	■	■			

Figure 10 – Sentinels support to GMES Service Elements (GSE)

GMES – Global Monitoring for Environment and Sustainability

As outlined in EC's COM(2004)65, GMES has to support the following EU objectives and policy domains:

- Europe's environmental commitments, by contributing to the formulation, implementation and verification of Community environmental policies, national regulations and international conventions;
- EU policy areas such as agriculture, regional development, fisheries, transport, and external relations;
- Common Foreign and Security Policy (CFSP), including the European Security and Defence Policy (ESDP); other policies relevant to citizens' security at Community and national levels.

The GMES Advisory Council has endorsed a number of GMES initial services requiring immediate attention in terms of data provision and service development. The Initial services have been derived from on-going GMES projects, funded by ESA (GMES Service Element, ESA Data User Element), the EC (FP 5/6 Integrated Projects, other GMES actions), and Member States.

Subsequently, in its communication on GMES from November 2005, the Commission sets out a strategy for delivering GMES, beginning with the pilot phase of the three first (fast-track) operational GMES services by 2008 (emergency management, land monitoring, and marine services). The communication explains the process for defining the scope of these services, in conjunction with the users, and sets out the Commission's goal to ensure continuity of service, and it also discusses the establishment of appropriate management structures linked to each phase of the programme.

GMES is a joint EC-ESA initiative, with ESA having the responsibility in particular for the financing and implementation of the space component.

Space systems can detect electro-magnetic activity on the Earth's surface, be they communications, radar installations and others. They can provide valuable information on potential evil intentions of hostile elements. Europe shall have the technology required to maintain its own signal intelligence (SIGINT) capabilities.

Security has a new dimension. The perception of threats has changed. Terrorism, organised crime, proliferation of weapons of mass destruction, i.e. risks to civil security, are high in the list. These risks originate outside the borders of the European Union and satellites are an excellent, if often not the only way to monitor the threats and support security operations. Space systems provide contextual information (remote sensing, meteorology, signal intelligence), positioning, location and tracking (GNSS, Search and Rescue), and communication capabilities. Suitable secure architectures should be put in place in support of the security of the citizens and the EU security operations worldwide.

Figure 11 – Artemis/SPOT5 communication, a step towards a network of space assets supporting civil security

This would not be possible without unrestricted access to the appropriate technology, such as optical communication links, reconfigurable payload technologies, etc. and technologies enabling new remote sensing capabilities.

Civil and defence applications increasingly draw from the same technology and there is a growing cross-fertilisation between the two areas. Space technologies are a perfect illustration of this: whether global positioning or earth observation will be used for defence or security purposes is primarily a political decision, not technical.

Space and Security

To answer to increasing concerns on global security, Europe needs to enable new applications, such as higher resolution thermal and hyper-spectral imagery for better monitoring of events, waste dumps, etc, and also the means to monitor and control the effects, such as uncontrolled emigration by more efficient "green" and "blue" border control.

Intelligence and warning systems used to be limited to military matters. However, today's threats are more challenging. Civil intelligence and warning is required to fight terrorism and organised crime that transcend borders. As a consequence, the surveillance, warning, intelligence and communication capabilities needs remain global, but with a different perspective, focussing on lower scale but less precisely defined targets. Space assets can be efficient tools for gathering intelligence for civil security. The pre-requisite technologies need to be developed.

Reflecting the potential of space in helping Europe improving its security capabilities, a Space and Security Panel of Experts (SPASEC) convened by the EC in 2004 strongly recommended in their report issued in 2005 that the security applications of space should be given a high relevance in the forthcoming European Space Programme – ESP.

This chapter has illustrated that Europe is reaping the benefits of past investment in space technology and needs to strengthen these investments in view of new needs. It also illustrates the extreme reliance of Europe on space systems.

Space technologies lend themselves well to address questions which are of large-scale and global nature. Space technology is not the answer to every problem, but it must occupy an important place in Europe's strategy. In the transport and agricultural sectors a number of policy challenges are already being addressed with the help of space technologies; in other areas, such as in the European Security and Defence Policy (ESPD), the first steps are just being given and strong commitment to technology R&D will be necessary.

Europe cannot afford living without space based systems. The sustained commitment from member states through ESA, EC and national programmes, shall guarantee that these technologies are timely available.

4 The world context and the need for action

In 2004, it is estimated that the global business in the space sector was worth $155 billion. In the civil sector, most of the value is related to consumer-end services and terminals for telecommunications and broadcast. At the upper-end of the added value chain, the space infrastructure sector is responsible for the design, development and production of space systems and equipment to fulfil the demand of institutional and commercial customers.

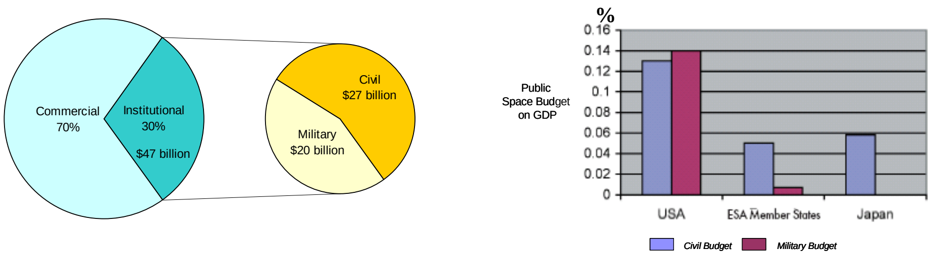

Figure 12 – Estimation (2004) of the space budgets landscape in US, Europe and Japan (Euroconsult, ESA)

If the value of the civil market can be estimated within a certain degree of confidence, figures on military spending are always associated to a high degree of uncertainty. On known military programmes, the US concentrate alone 94%[1] of the worldwide institutional budget (US$18.6 billion in 2004), followed only at a very large distance (5%) by Europe. In 2004, it is estimated that the European expenditure on space-related military applications amounted to €760 million. Considering that the same technology is, in the vast majority of cases, suitable both for civil and military space applications (dual-use), the support to space technology research and development in Europe is just a tiny fraction of that provided by the US to their Industry.

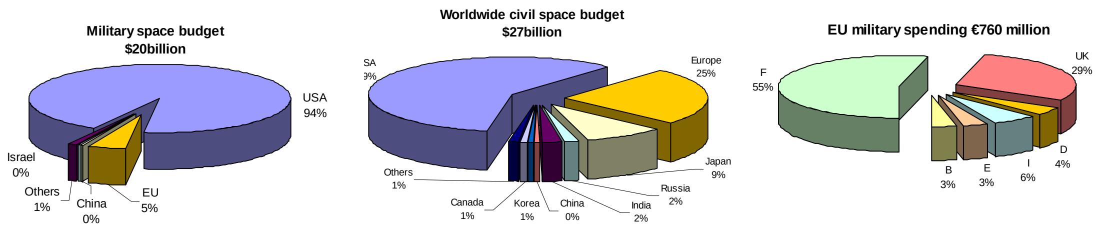

Figure 13 (a)(b)(c) – Estimation[2] of main civil and military shares in institutional space budgets for 2004

The graphics above can only roughly compare commitment to space between Europe and the US. Due to the much higher commitment of the US to military programmes, compared to Europe, and the level of secrecy associated to these, the unbalance is certainly larger that what is shown.

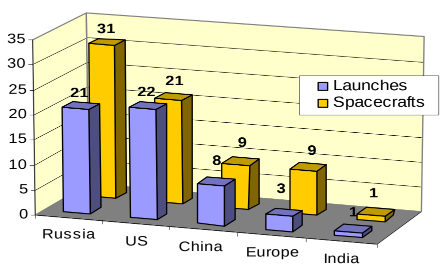

Figure 14 - World space launches in 2004

For Russia or emerging powers like India and China, it would be misleading to measure commitment to space based only on absolute financial indicators without taking into account local purchasing power. In 2004, Russia led Space launches with 21 out of a total of 53 successful launches worldwide[3]. Despite only having a 1% share in public space expenditure (as opposed to 17% for Europe and 75% of the US), Russia carried out more than 40% of the world's rocket launches into orbit in 2004.

[1] *Actual values difficult to estimate due to the fluctuation of the US Dollar. Assumed 1€ =1.2045 USD as of 30.6.05*
[2] *Estimates based on ESA and Euroconsult data*
[3] *Russia: 14 commercial/science and 7 defence launches; US:14 commercial , 3 science, 5 defence launches*

Similarly, China was able to overtake Europe in number of launches, even if Europe managed to launch an equal number of spacecraft with fewer launches. The *China Aerospace Science and Technology Corporation* (CASC), responsible for the development and manufacturing of spacecrafts, launch vehicles and ballistic missiles employs about 115.000 workers (estimation). It includes more than 130 separate organisations, among them 5 research academies as well as manufacturing facilities.

This clearly shows not only how misleading it can be using absolute spending to assess worldwide capacity and commitment to space, but also the potential of cooperation agreements between Europe and Russia and emerging space powers such as China or India.

The strategic importance of space is being recognised worldwide, with increasing political support and raising budgets and capacities in all established and emerging space powers. The USA are still the main player to reckon with in budgetary and technological terms. Space budgets have grown from $25 billion in 1995 to $38.5 billion in 2005, a trend supported by both civil and military investment.

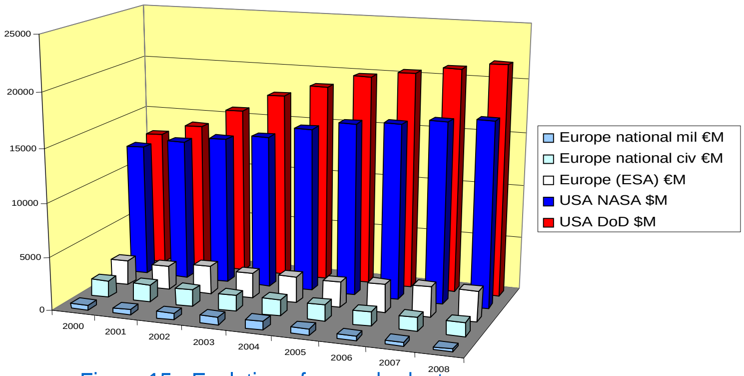

Figure 15 - Evolution of space budgets

In Europe, with the attempt being made to establish a European Space Policy and bring space as a shared competence in the EU Constitutional Treaty, the strategic importance of space is also recognised at political level. However, this had no significant impact yet on the evolution of institutional budgets: European budgets grew less than 25% between 1995 and 2005, compared to a 300% grow in the previous decade (1985 to 1995).

When compared to the US, the European space sector is the result of a completely different political approach and level of Institutional investment. European governments allocate to civilian activities almost 90% of the €6.3 billion space budget. Ministries of Research, Science or Technology fund about 80% of the civil expenditure on space, the remaining 20% coming from Ministries of Industry and Trade, Defence and dual-use applications.

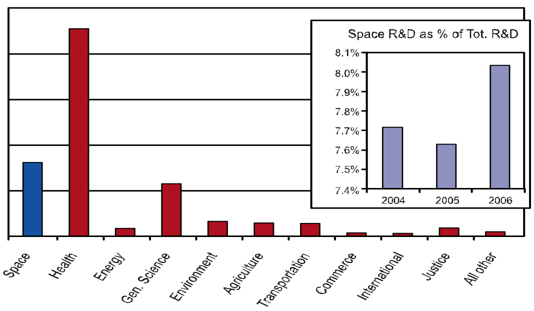

Figure 16 - US investment in R&D, per sector

In particular concerning R&D, the US spending on space R&D accounts for 38% of the world's investment in the area, with approximately 31% funded by the government and more than half of the overall investment being devoted to defence-related R&D. The budget requested for space R&D in the US for 2006 is the highest in the civilian domain, after Health. The NASA share of R&D over the total budget has grown steadily since the 80's to reach over 60% of NASA's total budget (Figure 17-b).

Adjusted for an equivalent purchasing power, China is now second in the world when it comes to investment in space research.

Consequently, the evolutions in Europe and in the world, in recent years, will require an adaptation of technology and Industrial programmes to respond to Europe's new requirements and to leverage its Industrial and strategic potential *vis-a-vis* new competitors.

Europe needs to stay competitive in the world space scene. Without the possibility to leverage on technology developments from a strong military sector, as in the US and other raising powers, it will need a strong commitment to support state-of-the-art technology research and development to prepare for its future and maintain its rank as a significant actor in the space arena.

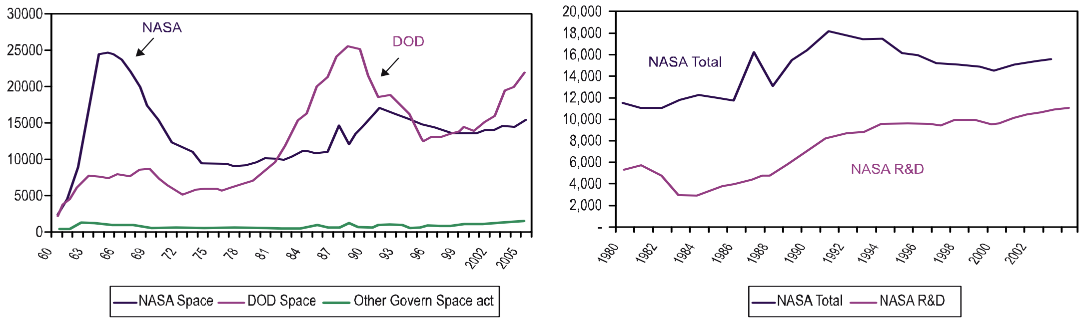

Figure 17 – (a) US Governmental Space activities (mUSD); (b) NASA's share of R&D (mUSD)

Concerning the Industrial landscape, large US companies currently dominate the space sector. In the US, Boeing and Lockheed Martin have announced a joint venture (United Launch Alliance) as an answer to declining commercial and DoD launches. In Europe, EADS and Alcatel/Alenia-Space currently represent the only realities with a competitive scale factor against American leading players.

Over half of the European public spending on civil space applications is channelled to ESA through the contributions received from its Member States, while EUMETSAT is responsible for 7% of the share. National activities account for about 42% of all of the European public spending on space, two fifth of which devoted to defence systems.

Budget sources	Budget destination			
€Million	to National (civ + mil) and other programmes (EU, etc.)	to Eumetsat	to ESA	Total Europe
Austria	11,00	7,34	31,00	49,34
Belgium	5,00	9,09	160,00	174,09
Czech republic	1,30	0,00	1,10	2,40
Denmark	5,00	6,10	28,80	39,90
Finland	13,00	4,53	17,00	34,53
France	929,80	51,56	685,00	1.666,36
Germany	405,60	74,13	631,00	1.110,73
Greece	0,00	4,50	7,20	11,70
Hungary	1,00	1,53	1,20	3,73
Ireland	0,00	2,93	11,00	13,93
Italy	462,10	41,68	363,00	866,78
Luxembourg	0,00	0,68	3,90	4,58
Netherlands	28,00	14,12	72,00	114,12
Norway	28,50	5,50	31,80	65,80
Poland	2,00	5,50	0,00	7,50
Portugal	0,70	3,97	11,90	16,57
Romania	12,00	4,00		16,00
Spain	12,00	21,10	136,60	169,70
Sweden	16,00	8,58	68,00	92,58
Switzerland	0,00	10,05	88,40	98,45
United Kingdom	69,00	52,93	129,00	250,93
Total Europe	**2.002,00**	**329,81**	**2.477,90**	**4.809,71**

Figure 18 - European Institutional funding for space activities in 2005: €4.8 billion

The European Commission has also been contributing to space activities through the RTD Framework Programmes (FP) and the Galileo and GMES initiatives. For the 5th FP (1998-2002), it is estimated that €70 million have been allocated on a yearly basis to space related activities. A similar figure was allocated through the 6th FP (2003-2006) under the Space thematic area in support to Galileo applications, GMES and Satellite Telecommunications, topped with €550million during 2002-2005 in the development of Galileo, under the Union's transport budget.

For the upcoming 7th FP (2007-2013), it is foreseen that there will be a significant increase in the budget for Space and Security Research (although less than what originally forecast), to match growing concerns on security and also as a measure contributing to the fulfilment of the objectives set by the Lisbon strategy.

Public support for R&D in space technologies is imperative because of the high costs and risks involved, and the comparatively low returns from commercial and institutional markets. European research on space technology R&D has been decreasing in relative terms, when compared to the main competitor, due mostly to the increasing spending in US defence budget; but also in absolute terms, as R&D funding has been progressively allocated to mission development and International commitments (eg. ISS). Clearly, this situation will have to be redressed if Europe is to be in the forefront of space technology, preserving and expanding the know-how it has acquired in the last four decades.

5 Civil Space Technology in Europe

Space has been an element of union between European countries for several decades. It has resulted in remarkable achievements and the creation of a solid technological and industrial base supported by institutional programmes and by a competitive position in the commercial markets. Throughout four decades, technology developments have been carried out by ESA and National Space Agencies mainly to respond to scientific and commercial objectives, along a strategy aimed at strengthening National industrial capabilities and competitiveness.

This chapter outlines Europe's current capabilities and commitment from stakeholders in terms of technology R&D and shows the need to complement these with targeted actions backed by adequate Institutional support, hence matching Europe's Industrial space capacity with the political vision and adequate funding to support it.

5.1 Funding

Concerning specifically research and development activities on space technologies, funding is done mainly through National specific programmes and ESA programmes. In total, near to €380 million are invested yearly by ESA Member States in space technology R&D programmes, corresponding to 6% of the total European investment in civil space applications. Within ESA alone, technology R&D programmes amount to 6,5% of ESA global budget.

National Programmes and the European Space Agency have supported the Institutional space technology R&D funding (~€380 million, Figure 18) roughly on a nearly equal basis. This public support has been imperative due to the high costs and risks involved, and the comparatively low returns from commercial and institutional markets when compared with Europe's main competitor, the US, and due to the increasing support to the space sector granted by Governments of emerging space players such as China, India and Brasil.

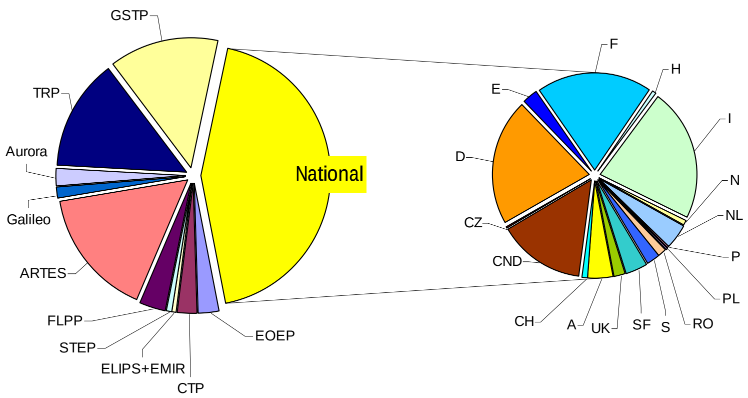

Figure 19 - European space technology R&D: Average yearly budget as of 2005 (~380 million – Source ESTMP)

European National governments have been responsible for the definition of a *de-facto* space policy for Europe, mostly through their steering of ESA programmes, but also through activities conducted at National level, as shown in Figure 18. Globally, about 54% of the investment in space has been channelled through ESA and 5% to EUMETSAT, leaving around 38% of the budget to National military and civil activities and 3% to European Union funded actions.

The shared nature of space in the European Union's Space Programme, the creation of the European Defence Agency, and the need for space to assist the implementation of the Union policies, will present challenges and opportunities to all the players, with a likely change of the space landscape as we know it today.

In 2003, 0.3% of the GDP was invested in the US space sector against only 0.04% in the European Union. This gap is expected to increase significantly with the EU enlargement in May 2004. Europe dedicates, today, only 1.9% of its GDP to R&D, but the Lisbon strategy aims at reaching the target of 3% by 2010.

Reducing the gap vi-a-vis the US will require not only (1) an increase of the level of investment in R&D but also (2) an effective coordination of the existing resources across National programmes in Member States towards the achievement of major common European objectives, de-fragmenting the current scattered scenario and helping to boost European Industrial competitiveness.

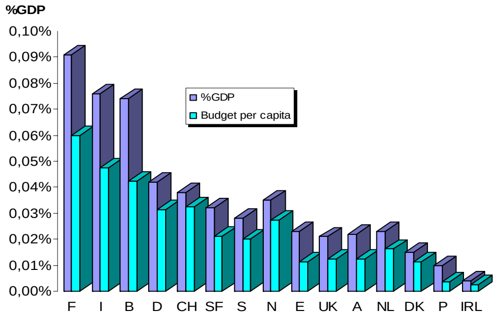

Figure 20 –Public spending on space: per capita and as a percentage of National GDP (Source: ESA)

Therefore, mapping existing strategies, interests, competencies and activities is an asset to the coordination effort. It will improve collaboration of all parties engaging them in complementary activities, without endangering a certain level of healthy competition necessary in most of the activity domains. It will help the actors, new comers in particular, to understand how the space *acquis* can evolve to meet the requirements of tomorrow's applications and to optimise resource usage through the elimination of unwanted duplications. The mapping work is currently one of the scopes of the European Space Technology Master Plan (ESTMP), one of the funding elements of the Space Technology Platform (Chapter 2).

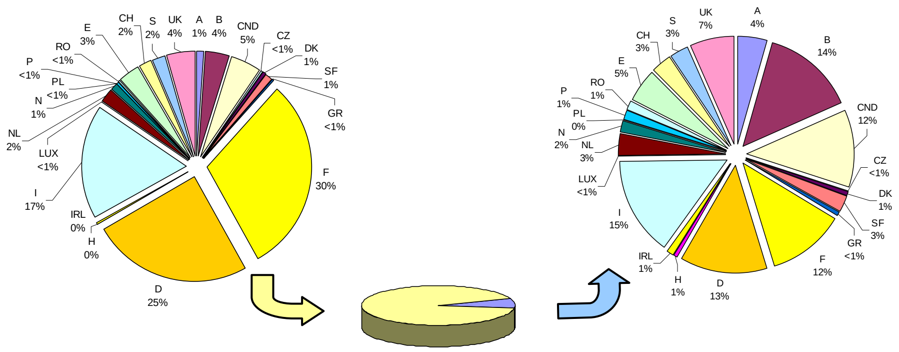

Figure 21 – (a) Yearly Investment in Space (EU+NO+CH+RO+CND) and (b) Space Technology R&D through National and ESA Programmes amounted to approx. € 380 million in 2005 (Source: ESTMP, based on ESA and MS's declared data)

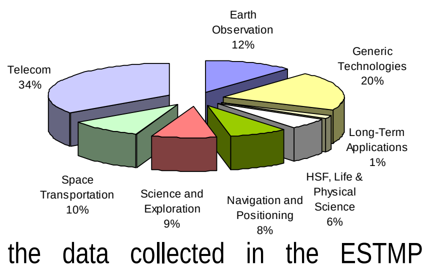

Figure 22 – Share of European investment in space technology R&D, by service domains

From the data collected in the ESTMP, pertaining to National and ESA programmes, telecommunications is the domain where Europe spends the most of its R&D budget (34%), followed by Earth Observation (12%), Space Transportation (10%), Science&Exploration (9%) and Navigation, while 20% of the budget is spent in horizontal R&D activities, applicable across a different number of technology domains (Figure 23).

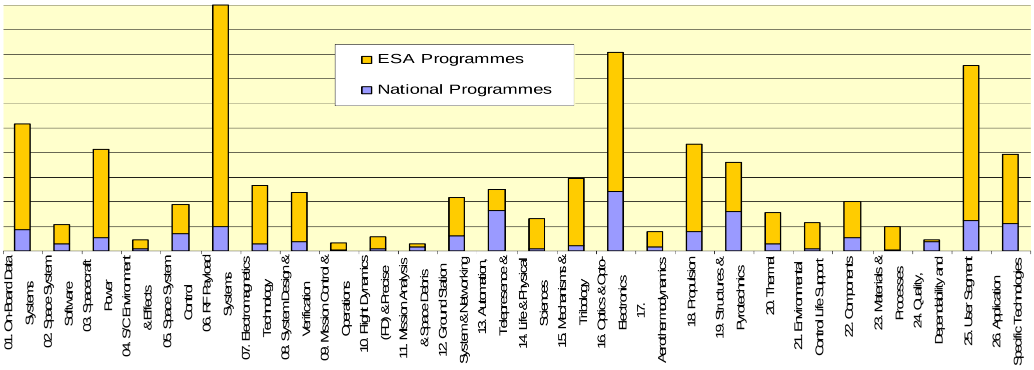

Figure 23 - Contribution of National Programmes to technology domains. Source: HEART database; National data based on Member States' reported activities for 2000-2007 (as of Sep. 2005).

<u>The contribution of the European Commission</u>

In contrast to activities normally funded by Space Agencies, FP6 R&D is focusing on ground-based applications and services using space infrastructures, thereby stressing the benefits for society and markets. Thus, FP6 addresses a different segment of the value-added-chain and complements ESA and National efforts, integrating terrestrial and space-based services in view of the deployment of end-to-end services.

In accordance with the European Strategy for Space, space-related activities within the Commission's 6th Framework Programme for Research and Technology Development (FP6), support has been given to the following areas:

- Satellite Navigation, Positioning and Timing in particular in the context of the Galileo programme;
- Global Monitoring for Environment and Security[4] (GMES);
- Satellite Telecommunications[5];

During FP6, **€235 million** have been available to 'space', under the first block of activities of FP6 through thematic priority 1.4-Aeronautics and Space. For Galileo, the EC contribution took the form of a grant to the EC-ESA Galileo Joint Undertaking that has proceeded with calls in the areas indicated in the FP6 Work-programme.

Further funding of activities related to Space is done under the following FP6 thematic priorities:

- 1.2-Information Society Technologies (**~€50-100 million**)[6]
- 1.6-Sustainable Development, Global Change and Ecosystems (**~€50 million**)

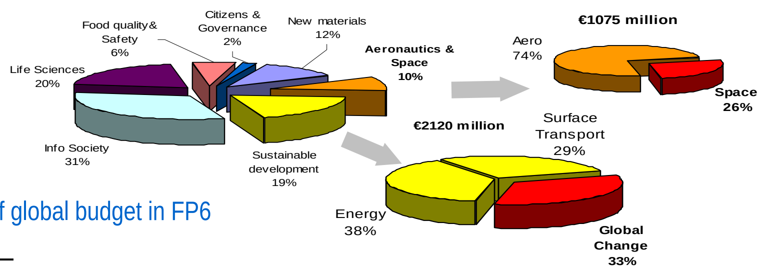

Figure 24 - EC's repartition of global budget in FP6

4 COM(2001)264 15 April 2001 A sustainable Europe for a Better World: A European Union Strategy for Sustainable Development
5 COM(2002)263 final e-Europe 2005 An Information Society for All
6 Estimated maximum allocation out of 3625 M€ from the IST Programme

For the period 2002-2005, the Union made available an additional **€550 million** for the development phase of Galileo via the Trans-European Networks (TEN) programme (an equal amount being provided by ESA).

FP6	**Awarded (M€)**			**€ million**
Thematic Area	**1st call -03**	**2nd call-04**	**3rd call-05**	**Estimated Total**
Galileo	19	67 +13.7[7]	~10	**~110**
GMES	34.2	40	32.5	**106.7**
SatCom	5	20	12.5	**37.5**

Figure 25 - Allocation of funding in FP6's thematic area *Space* (€ million); TEN financing not included

Despite most FP funding being allocated to close-to-the-user services applications, some overlaps do exist between National Agencies and ESA, on one side, and EC funded programmes on the other. This is particularly true for Galileo, GMES and Telecommunications (space segment). For FP7, it is expected that some funding will be available also for technology developments of European strategic relevance, not already contemplated in ESA or National programmes.

It is crucial that a strong coordination and cross-visibility among EC and ESA will be ensured in those domains, to avoid duplication of activities and funding, jeopardising the overall effort being made by stakeholders to maximise the return on investment made in R&D. It is the purpose of the ESTP to indicate the means to achieve strategic objectives, and Chapter 8 indicates the way forward to address this.

5.2 Fragmentation and the need for coordination

Europe indisputably plays a key role in the world space scene. Its capabilities in space are the result of the cooperation of entities united by a common interest (space). National space organisations are organised in very different ways, responding to organisms often with heterogeneous mandates across broader areas other than Space and tailored to serve mainly strategic, economic and industrial interests specific to a country, rather than to Europe as a whole.

Within each of the ESA Member States, the approach to space activities has definitively a broad spectrum, ranging from those cases where Member States have long-consolidated and strong space National programmes, to those preferring the delegation of implementation of space-related activities through participation and full commitment to ESA programmes and marginal investment in National specific space activities.

The coordination of the efforts across all of the European players in space-related activities is therefore a prerequisite to improve the strategic place of Europe in the world and to reduce its foreign dependency.

Coordination needs also to embrace National space technology programmes, representing almost half of the budget that Europe invests on space technology activities. Due to the diversity of policies and interests in the European space mosaic, it was therefore necessary to: 1) map National approaches to technology strategies for any actions to be taken in harmonising technology developments across the players and; 2) to devise a coherent plan for a European R&D strategy for space technology.

[7] *Additional budget allocated by the Aerospace committee for SMEs, additional User Communities and International activities*

5.3 Space Technology Coordination

The process of harmonising and elaborating a future strategy for European space technology was initiated in 2000 in response to the adoption of a Resolution titled Shaping the Future of Europe in Space adopted at the ESA Ministerial Council in May 1999. This resolution notes that

"… the new and demanding challenges of 21st Century call for a concerted European effort, so that Europe achieves its fullest potential international cooperation and world competition"

Subsequently, at its meeting in Edinburgh in November 2001, the ESA Ministerial Council invited ESA and its Member States to pursue, together with the other players in the space sector, the programmatic coordination and harmonisation of technology programmes in Europe and to prepare a European Space Technology Master Plan (ESTMP).

The technology coordination initiative has, therefore, been developed to achieve better-coordinated research and development (R&D) activities among all actors of European space sector and to establish a strong technology base as a key to the worldwide competitiveness of European Industry and to the success of future space missions. The strategy involves establishing a coordinated European Space Technology Policy and preparing a European Space Technology Master Plan, through a process of concertation, coordination, harmonisation and agreement between ESA's Member States, the European Commission, European Industry and ESA itself.

The Technology Coordination Process

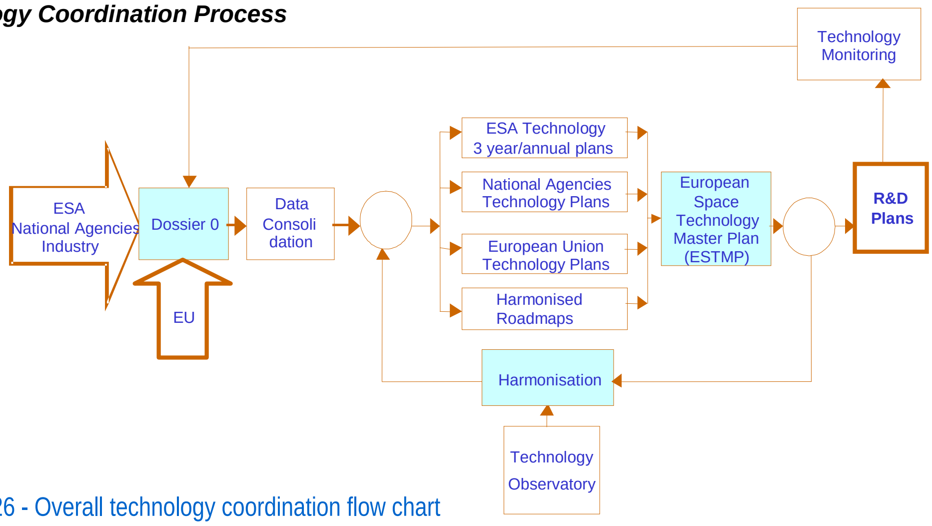

Figure 26 - Overall technology coordination flow chart

The technology coordination and harmonisation process starts with the elaboration of a 'European Space Requirements Document' (Dossier 0) in which all European missions and technology requirements are gathered from all ESA Directorates, National Delegations, Industry and Operators. These requirements are then analysed, consolidated and prioritised.

The European Space Technology Harmonisation process takes into account the various European developments, capabilities and budgets to enhance the complementary roles of the various partners in meeting common objectives and agreeing on European space technology roadmaps.

A further strategic element is the '*Technology Observatory*'. The technology watch supports the whole process and in particular the harmonisation process, with specialised inputs at critical points along the way. The '*Technology Monitoring*' activities close the loop by providing the feedback needed to measure the performance of the process, and to support continuous improvement.

The results of the whole exercise are conveyed into the European Space Technology Master Plan. The 'European Space Technology Master Plan' (ESTMP), also gives a complete overview of planned institutional space technology programmes in Europe and harmonised roadmaps. The actual implementation of R&D contracts is carried out through the various existing ESA or National space technology programmes.

The major elements of the coordination strategy are indicated in the shadowed boxes in Figure 26. Updating of the information pertaining to these elements (Dossier 0, harmonisation and ESTMP) is conducted on a yearly base, while the harmonisation is a continuous process, with harmonised technologies being revisited every 3 to 5 years.

> The ESTP has been created to complement the Harmonisation effort (Figure 3) within the space community to increase its efficiency and competitiveness. It enlarges its range to facilitate spin-in from related R&D communities and to help the integration of new Member States. Last but not least, it complements a successful Industrial policy to meet major European strategic challenges, enabling the next generation of space systems in support of the citizens and EU policies.

As shown in Figure 3, the ESTMP/Harmonisation process is a kernel module of the ESTP and will be pursued along the same principles that have underpinned its creation by ESA, member states, national space Agencies, the space Industry and Eurospace.

6 The European Space Manufacturing Industry

The European space industry, supported by competitive research institute and laboratories, is an essential contributor to our most common daily activities, as indicated in Chapter 3. It also contributes to strengthening Europe's position in the global geo-strategic arena, allowing independent access to space, international scientific co-operation and a strong technological base to support Europe’s strategic decision-making in conflict or disaster situations .

The unique characteristics of the space environment pushes technology to limits never reached before. The space environment is also an unparallel test field in all scientific disciplines, from physics to biology, allowing advances in engineering under extreme environments and situations.

The European space industry overcomes these challenges on a routine basis. It boasts some of the most reliable satellites systems in the world, with an excellent record of availability in orbit, and the most successful launcher family in the commercial market.

Sector overview

The manufacturing arm of the European space sector is the space industry. A relatively small industrial sector with € 6,6 billion total sales (€ 4,4 billion consolidated turnover) in 2005, and direct employment of 28000 with an incredible record of achievements and a strong strategic dimension.

The space manufacturing industry operates at the higher end of the space value chain, and supplies to services providers and public institutions adequate spacecraft and launchers to their requirements.

The development and production of systems serving the 4 main applications of space (telecommunications, earth observation, navigation, and science) are the core business of the satellite segment. A dedicated industrial segment supports the availability of a European launcher capability.

Given the high technological constraints of space systems the European space industry is one of the most RTD -intensive sectors in Europe. RTD is carried out under contracts financed by ESA, member states and third parties (e.g. European Union, Eumetsat), and is also funded internally.

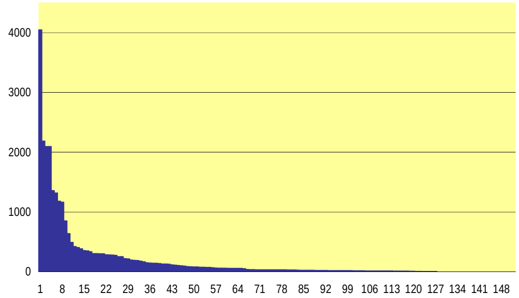

Figure 27 – Distribution of space Industry employment, by company

The European space manufacturing sector is embedded in the large European aerospace and defence groups (EADS, Finmeccanica, Safran, Thales). These groups are directly responsible for more than 75% of the total sector employment. The most important dedicated space units and industrial capabilities are located in EADS Space and Alcatel Alenia Space .

The number of SMEs in the space sector is rather small, indeed, and despite the fact that most industrial activities are carried out in small space units (see the distribution of space employment of the main 150 space units in Europe), these space units are usually fully integrated in larger companies or controlled by larger companies and groups involved (or not) in space activities (e.g. Siemens, Sagem, RWE, Fuchs). SMEs represent less than 5% of the total space industry manufacturing employment, whereas small space units (within larger companies) represent around 20 % of the total.

A technology driven industrial sector

The space sector is highly dependent on technology. Developing and producing hardware destined to operate in space is never an easy task. Space is a harsh environment for man-made artefacts. They have to withstand the traumatic experience of being launched aboard a rocket, and then suffer the longest possible time alone in space, with no refuelling, no maintenance, no servicing... apart from the occasional software upload, reconfiguration, routine testing and occasional repositioning. And while up there they must perform and deliver: producing images and data of the Earth or distant stars, providing telecom signal routing, broadcasting, localisation services etc. Space launchers themselves are large, complex, fully automated systems whose reliability truly represents an engineering challenge.

In space, technology is a critical essential dimensioning factor. Since operational space programmes require technology to be proven to be implemented, technology evolution and validation programmes are an essential enabling factor for new space applications.

Space technology cycles are longer than the average high-tech cycles. From concept validation to actual implementation, climbing the 9 levels of the technology readiness scale to reach full qualification in orbit may take up to 10 years. This situation implies very high technical risks that the private sector cannot bear alone, especially since most of the technological evolutions expected are driven by the requirements of institutional customers.

Technology is also at the core of industry competitiveness; technology readiness and technology improvement are driving factors of the Global competition on the commercial markets for operational launchers and satellites.

Space technology development requires important investments in industrial equipment (including test equipment), SW, tools and protocols development and maintenance.

And last, Space technology is sensitive. Space technology is dual use (military and civil) by sheer nature, thus, space activities and space technology exports are highly regulated by the governments of most space powers. Today, space technology is still excluded from the WTO agreement.

A good penetration of the commercial market

Since 1997 the European space industry turnover is more or less evenly split between institutional customers and the commercial market, European structures have been adapted to support this situation.

The global commercial market is characterised by fierce, technology-driven competition, very high reliability and timeliness requirements and cyclical evolutions (we are currently suffering a particularly low phase of the cycle). With average lead production times of 18 to 36 months for operational space systems, the competitive environment of commercial activities involves high levels of technical and financial risks, not to mention market uncertainties or the hazard related to the risk of a launch failure.

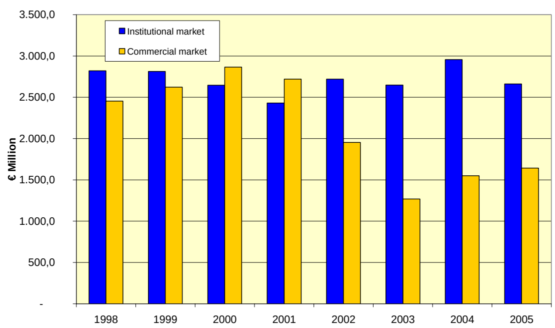

Figure 28 – Institutional vs. commercial turnover 1998-2005

The competitiveness of European systems (30-40% European market share on commercial satellites, 33-60% European market share on commercial launchers) have fuelled the growth of the European space industry in the last decade of the 20th Century.

The commercial side of the business also appears to be the main driving force for changes in the industrial structures. In particular the global nature of the commercial market gives an advantage to large end-to-end system providers.

A sector in Jeopardy

The European space industry suffers from very low to negative profit margins, declining revenues, and employment reduction since the year 2000.

The exceptional penetration of commercial markets by the European space industry is a challenge and a also a threat, indeed, since the telecommunications market downturn of 2000 the sector is losing business every year with subsequent employment reduction and industrial restructuring.

For the first time, industry is confronted with a drastic decrease in the commercial market (telecoms and launchers) with a stagnant-to decreasing institutional market.

With the current commercial market downturn some key resources have become under-critical, jeopardising the sustainability of the whole European space policy.

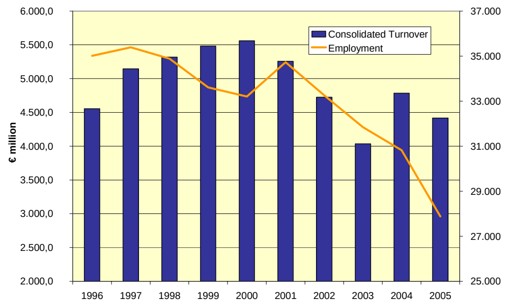

Figure 29 – Employment and turnover evolution (1996-2005)

The preservation of European capabilities is increasingly difficult, innovation is slowed down and cost reduction measures required by customers and implemented at supplier level necessarily increase the technological risk level of European programmes.

The competitive pressure currently met by the European industry is also aggravated by the €/$ exchange rate on the global market for satellites and launch services. Technology preparation has immediate repercussions on the global competitiveness of European industry.

In this scenario, a key element to redress the situation is the creation in Europe of a sizable and stable Institutional market for space applications. It is widely recognised that if the Institutional demand remains at very low level when compared with competing countries, there is a strong risk that the dependence scenario worsens as European manufacturers would not have the means to continue supporting critical technologies, for Europe to be capable of acting independently in space and to remain competitive in global markets.

It goes without saying that the coverage of the risk associated to R&D on technology activities (in particular in the space sector) and the difficulty to assess their return on the investment made, risk capital may be difficult, if not impossible, to procure, and main financing mechanisms will have to be provided through Institutional support via ESA, National and Community technology programmes.

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7 Space Technology Strategy, Needs and Challenges

7.1 Space Technology Strategy

The strategy for technology development in the ESTP builds on the current ESA technology strategy, derived after the overall space strategy. Considering the European role of the Agency and the coordination already conducted with National Agencies and Industry, the ESA technology strategy defines, today an agreed vision for the development of space technology for the coming years.

7.1.1 Boundary conditions

In the international context, the main evolution trends are:

- the US space policy;
- the strengthening of more recent space powers, in particular China and India;
- the evolution of Russia as a key partner for Europe in space.

In the European context, the main evolution trends are:

- ESA Member States' overall contribution to Space is not growing
- the need to federate the demand for space-based services;
- the industrial difficulties and the need to preserve critical competences.

Space is a strategic component for many European policies, to support:

- strategic ambitions, in particular in security and defence,
- economic growth, in particular innovation and creation of a highly skilled workforce,
- knowledge increase, through scientific and exploration missions improving our understanding of our planet, the solar system and the Universe,
- European cohesion, through technical means to transmit and disseminate information, but also through the global adventure and challenge it represents for Europe; space is also a field to illustrate and transmit European culture and values;
- Foreign policy and international relations, as space is a longstanding field for cooperation.

Thus space must be an integral part of Europe's public policies, in particular within the EU framework. Over the last 40 years, European space programmes, whether conducted on a national or intergovernmental basis, have enabled to build a strong and competitive industry, a solid technology base, a scientific leadership, and the required infrastructure for accessing space, which is a sine qua non condition for implementing any European space policy.

The major guideline for the European Space Policy should thus be to ensure the availability and reliability of the space-based services and technologies required to achieve Europe's overall objectives, be they strategic, economic, social, cultural, scientific or technological, and to improve the daily life of its citizens.

7.1.2 The European Space Technology strategy

The ESTP strategy presents where Europe aims to be in terms of technologies in the next decade to respond in a cost-efficient manner to new needs and to remain one of the most competitive actors in the world.

In the context of this document, we define as strategy the combination of the knowledge of the current situation (where we are, where the others are), the top-level objectives, and the developments required to achieve the objectives stated. The following figure gives a graphic representation of this concept.

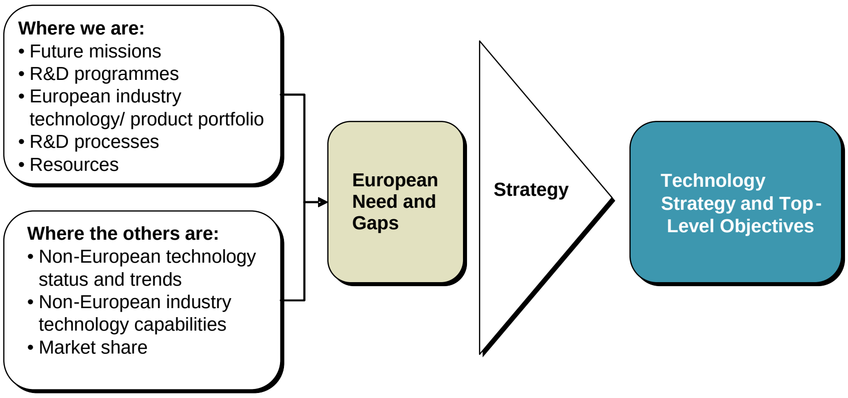


Figure 30 - A representation of the space technology strategy

The European space technology strategy is therefore aimed at pursuing **five main top-level objectives**:

A. Prepare and enable future European space programmes and ensure coherence of technology developments schedule (ad-hoc maturity level) for maximum use by projects in different fields of science and applications (e.g. Science, Earth Observation and Exploration)
B. Foster innovation in architectures of space systems, identification of disruptive technologies, developments of new concepts
C. Support competitiveness of industry in the European institutional markets and in the global commercial markets, while ensuring a balanced participation of all stakeholders
D. Ensure European Technology non-dependence and the availability of European sources for critical technologies
E. Leverage on technological progresses and innovations, outside the space sector to use and adapt them to design new space systems (spin-in). Foster technology transfer for space to non-space applications (spin-off).

<u>A. Prepare & enable future European space programmes</u>

The various European space programmes, especially those dedicated to technology, are the key instrument for implementing the complete technology strategy. Their definition, planning and implementation should therefore be guided by the following principles:

- Develop space based solutions and technologies answering to new enlarged EU needs, to prepare and enable future European Space Programmes
- Ensure end-to-end continuity from technology identification to product, up to in-orbit demonstration, when needed (piggy back, precursor missions, dedicated missions....)

- Promote a European-wide technology coordination and Harmonisation responding to ESA, MS, EU, users community and Industry needs
- Promote basic research through large number of PhD thesis, and networking activities with external laboratories and institutes, to reinforce cross-fertilization between stakeholders and engineering laboratories.
- Ensure timely maturity of products

B. Foster Innovation

The ability to rapidly evaluate, demonstrate and assimilate new emerging technologies is a vital factor in maintaining industrial competitiveness in the medium/ long term, and defining the future world-class space programs. In this context, therefore, Europe should:

- Foster new ideas and new concepts
- Identify and develop disruptive technologies, search systematically for non-space technologies that can be used for space solutions.
- Promote breakthrough innovative high-return technologies
- Develop the new architecture and technology needed for future systems/spacecrafts
- Demonstrate new space-based applications
- Reinforce cooperation with universities/institutes and network with research laboratories to share cost and cross-fertilise experience

C. Support to Industry Competitiveness (Short Term/ Time to Market)

Provide support to the competitiveness of European Industry is one of the key strategy elements to have valuable space projects and missions. In particular the space sector should:

- Maintain competitive European Industrial capabilities and place European Industry at an equal footing with competition on commercial market
- Support a European preference for technologies and products (“Buy European” policy)
- Implement time to market approach for technology
- Play a pro-active role, at technology level, in creating a balanced industrial landscape with appropriate geographic distribution, protection against monopolistic situations and access to a sufficient market volume

D. European Technology Non-Dependence

- Europe shall ensure its non-dependence in support to its sovereignty
- Assess, identify and monitor regularly the European technology non-dependence situation
- Establish dedicated and focused actions to remedy to identified dependency issues
- Ensure an active worldwide Technology survey in a coordinated Technology observatory
- Actively establish technology partnerships on the international scene, identify and secure some technology/product source outside Europe

E. Leverage on Non Space Technology (Spin-in) and Foster Technology Transfer (Spin-off)

- Identify technology areas of common interest with other European non-space research initiatives and programmes
- Leverage on non-space technology (Aeronautics, defence, automotive , information technology, telecommunications,...), enabling the acquisition/master of selected, pre-established technological capabilities (spin-in)
- Benefit from non-space technology progress (e.g. nanotechnologies, micro-systems)
- Match available space technologies with the non-space needs and subsequently provide assistance in the transfer process (spin-off)

7.2 Space Technology needs

A complete landscape of on-going and planned space technology developments, mainly conducted through ESA and National programmes, is comprehensively described in the *European Space Technology Master Plan (ESTMP)*. The requirements for new technology developments are mapped in the *European Space Technology Requirements Document (Dossier0).* Both documents and related databases are updated on a yearly basis.

Furthermore, the ESA *Technology Long Term Plan* (TLTP) presents the technology development objectives and needs for all service domains, to prepare future programmes and support Industry competitiveness, indicating the forecasted ESA funding needed for the coming decade (2006-2015).

The technology requirements and development plans in the three documents above are the result of an extensive consultation and harmonisation involving the whole European space community. The purpose of this SRA is not to repeat the work already done by the stakeholders. Instead, readers are referred to these documents for more detailed information. However, for the sake of completeness the SRA provides, in Appendix B, a listing of the overall space technology needs extracted from Dossier 0, ESTMP, the ESA TLLP[8], and Eurospace's Space R&D Priorities, which are proposed to be implemented through stakeholders' programmes and funding schemes.

Faced with a new worldwide scenario and the increased potential for the use of space in an enlarged EU - as indicated in Chapter 4 - the existing R&D programmes at ESA and National level (conceived to meet the needs of established missions and programmes and support Industry competitiveness) are, however, insufficient to meet Europe's strategic challenges. To achieve the *Vision* of the ESTP and the *objectives* set out by this SRA, it is therefore essential that development in response to the technology challenges presented in Chapter 8 are supported by Community (EC) programmes along the implementation guidelines and the selection criteria in Chapter 8.

The remaining of this section gives an overview of the space technology needs in Appendix B.

7.2.1 Telecommunications payloads

fixed & broadcast, broadband, mobile

Market driven satellite applications, such as fixed & broadcast, broadband, and mobile services, require new developments of payload technology towards higher flexibility and increased processing power. These developments will give European industry access to large satellite markets with increased competitiveness.

Europe shall support the development of flexible payload technologies (active antenna, input-output sections and digital processing – UHF/C/Ku/Ka band) to increase bit rate, allow programmable and reconfigured coverage in orbit, reduce procurements costs and schedules.

7.2.2 Earth observation payloads

GMES, environmental concern, dual use...

Environmental science, climatology and meteorology necessarily address global issues, driven by policies with a local focus. Satellites have the ability to support both global and local levels of assessment of Earth phenomena.

The strategic importance of satellite observation in conflict or natural hazard situations is confirmed as modern societies are increasingly confronted with risk situations. Earth observation payloads are required for:

[8] *ESA Telecommunications Long Term Plan*

- Understanding and continuous monitoring of our planet (Land surface, ocean, ice, atmosphere, biosphere, geology...)
- GMES: Global Monitoring for Environment & Security
- Dual use – ESDP, national programme

Europe shall develop and improve European technologies for SAR and optical instruments (e.g. imagers, spectrometers, LIDARs) with a view to increase accuracy and enlarge field of view, enhance all weather observation capacities and improve revisit time.

7.2.3 Navigation payloads

Independence and autonomy of European policies require the development and implementation, using European products and technologies, of global observation, telecommunications and navigation systems and services.

Galileo signal quality and availability must be guaranteed at all times to all users.

Europe shall improve European technologies for advanced on-Board Frequency and Time Generation and advanced Navigation Payload (flexible, integrity, secure …)

- Increased precision (second generation clocks)
- Increased signal integrity (system, overlay, urban areas)
- Increased system security (anti-jamming, encryption)

7.2.4 Satellite platforms

Competitiveness, new mission/payload requirements...

Requirements put on the space platform will vary depending on the payload and orbital requirements. Some requirements are shared by most missions, starting with stability and extended lifetime. But the technical solutions will vary depending on mission specificities.

While telecommunications missions may prefer larger satellites with particularly challenging power related requirements, future observation missions will have lower mass and power constraints.

Europe shall develop skills and technologies on advanced power systems, and integrated avionics to enhance platform capabilities (power, flexibility, agility, etc.) and reduce system cost and mass. Electric propulsion technologies (see New Space Missions) shall also contribute to platform improvement.

7.2.5 Generic technologies

Data processing system, software and components

To fulfil its ambitions in space, Europe needs a competitive space industry, capable of addressing all markets and all customers' needs with affordable and adapted solutions.

Similarly to platform technologies, data processing and associated technologies play a central role in space systems competitiveness, with important reliability and efficiency aspects. Furthermore the guaranteed access to rad-hard equipment with suitable processing capacities is a key to ensure the independence of European space policies. Actions already undertaken, such as the European Components Initiative, shall be furthered and complemented with other targeted actions.

Europe shall develop high performance data processing systems including advanced software, new architecture and EEE[9] components to improve on board data processing capabilities, improve fault tolerance and autonomy, reduce operations cost.

[9] *Electric, Electronic, Electromechanical*

Structures and Thermal control

Antenna, telescope, solar array, tanks, boosters...

Growing requirements for mass gains with advanced structural properties are driven mainly by economic efficiency concerns that are at the heart of European policy.

New operational and scientific missions in the Earth proximity, and far away, pose new challenges to the spacecraft thermal system, with the need to address extreme temperature ranges. European system must take advantage of advances in technology with the potential to support technologically competitive space systems. Non-dependence is a concern particularly for composites, where Europe shall widen and strengthen its raw materials manufacturing capacities, the availability of fibres is crucial.

Europe shall develop high performance structures (composites, processes, innovative materials) and advanced thermal control technologies (e.g. fluid loops, radiators) to enhance thermal, electrical, and mechanical properties of system/equipment, increase thermal dissipation capacities for high power payloads (mainly RF), and reduce dependence at system and equipment level.

System design

System optimisation, dependence reduction

The modelling of space environment is a concern today, as Europe is launching new missions such as Galileo and exploration programmes. The Galileo orbital environment is not particularly well known in Europe, as it was never exploited before. European simulation tools have to rely on the willingness of other space powers to share relevant information. This is a limiting factor.

Europe shall develop and improve skills and capacities in system, design and engineering tools to support availability of a simulation environment for space systems operation, support development and make available methods and tools for system engineering and verification at launcher and spacecraft level, support development of engineering tools for design and optimisation, and support development of tools for complex mechanical systems.

7.2.6 Cutting edge science

Planet search, stars mapping, subtle gravitational waves detection...

Space science supports the understanding of life and planetary formation. It allows accurate study of the solar system, and provides unique information on the laws and origins of the Universe. Scientific missions pose many technological challenges. First, the purpose of the mission may require the development of a very specific instrument, such as a telescope, which will actually perform the scientific mission. Then the destination of the spacecraft (particular earth orbits, distant planets, the Sun, asteroids, etc.) may require a very specific system approach to support the mission. As with all other space missions, mass constraints are a technology driver, likewise, thermal and power issues are driving factors, as well as radiation hardening and system reliability. Thus technology advances have mission enabling factors. Two issues appear particularly important today: propulsion and formation flying.

Europe shall develop skills and enabling technologies for formation flying (e.g. GNC , laser & RF metrology, system control) and very high power electric propulsion to implement large interferometer, enhance flexibility and redundancy, reduce mission costs, and travel faster and longer distances...

7.2.7 Planetary exploration - robotics

With the Aurora programme, the European path to planetary exploration is well paved. With a coordinated approach to build step-by-step, mission after mission, the required European capabilities, the exploration programme will bring technology to adequate readiness levels to address present and future mission needs with growing ambitions.

Europe shall develop skills and enabling technologies for unmanned exploration missions (re-entry, descent, soft and precision landing, drilling, rover & ascent technologies) to carry out remote sensing of planet environment, achieve robotic exploration and surface analysis, and implement sample return missions.

7.2.8 Current and future launch capability

European launcher policy clearly states objectives of guaranteed access to space, where autonomous capacities to develop manufacture and operate a launcher play a central role.

For the consolidation of current systems and competitive future space transportation, Europe shall develop advanced chemical propulsion technologies, and assess reusable launcher technologies to define possible architectures allowing to reduce recurring cost, ensure reliability, enhance flexibility and availability of service, increase the ISP, and allow re-ignition. Furthermore, the improvement of methods and tools related to launcher design and sizing is critical for the competitiveness and reliability of European launch systems.

7.2.9 Orbital assemblies and manned missions

Technologies for orbital assemblies and manned missions are required to support European commitment towards the ISS exploitation, and ensure significant European participation to ambitious human exploration programmes (the Moon, Mars and beyond)

Space exploration is an inspirational element of the European space programme. Mars remains the main target for Europe. Since the announcement of the new NASA initiative to Moon, Europe must ensure that it has the required level playing filed to be a significant partner to far reaching endeavours.

To fulfil European commitments towards the ISS, and to ensure European presence in manned planetary exploration programmes (the Moon, Mars and beyond), Europe shall consolidate and develop capabilities in the following areas: in-orbit RDV[10], docking, on-orbit servicing techniques and advanced manned modules to increase autonomy for RDV and docking, prepare the construction of large assemblies in orbit, and be an international active partner in future ambitious exploration programmes (robotic and human missions).

7.2.10 Disruptive technologies

Technology watch, and readiness to apply new technologies to space programmes can bring space industry to new heights. Europe shall develop micro/nanotechnologies (e.g. nanotubes) and to investigate the space potential of using new power sources technologies (such as RTG[11] 's use) to support new ambitious space missions, and maintain competitiveness of industry.

7.2.11 Technologies for security applications[12]

"To prepare a strategic research plan for European security by establish and consulting a network of users and technology experts at national and European levels"

[10] *RendezVous*
[11] *Radioisotope thermonuclear generator*
[12] *Input based on results of the project SeNTRE, financed by the EC PASR action. This section may evolve under ESTP Pillar 3*

Space technologies are key technologies for many security missions.

- Knowledge of terrorist groups, systems and vulnerabilities of systems, situation awareness;
- Collect information on weapons and on various actors
- Prepare defence and countermeasures
- During crisis phase for management and command of rescue teams
- Protection of sensitive targets
- Search and Rescue
- Environment protection (man-made pollution) and surveillance

Europe shall develop additional technologies, to fulfil the needs above:

- quick deployment capability of satellites including quick launch capabilities
- quick development time for smart payloads
- anti-jamming, anti-spoofing, anti-piracy technologies
- ground segment capabilities

7.3 Strategic Challenges

The term "strategic challenges" refers to those challenges exerting a decisive influence on the viability of the European space programme in the long term. Rather than affecting one particular domain, the challenges affect all domains and all players in crosscutting manner.

The Strategic Challenges are driven by considerations of Europe's future competitive and non-dependent position on a worldwide scale relative to the big blocks U.S., Japan, China and new entrants such as India and Brasil. Although not exclusively so, they are to a large extend driven by factors external to the space community or even to the European community.

Although, some strategic challenges are already partially addressed by the space community across Europe (including agencies and Industry), responding to these *externally driven strategic challenges* requires strong support from outside the space community. As introduced in Chapter 4 these strategic challenges cannot be addressed alone by the space community, national governments or the space Industry, and they need the commitment of Europe as a whole.

The sections below highlight the areas where Europe needs to act, corresponding to the need to support the 3 pillars of the ESTP.

7.3.1 European Non-Dependence

The more Europe is relying on space systems for daily life applications, the more it has to be able to develop, deploy and consequently ensure sustained European engineering and manufacturing capabilities of space systems.

"Non-dependence" refers to the possibility for Europe to have unrestricted access to any required space technology. "Independence" would imply that all needed space technologies are developed in Europe.

On every European satellite a significant share of components and equipments are procured outside Europe, primarily from the US, but also from Japan and Israel. US supplied components, parts and equipments are used in all spacecraft subsystems, platform as well as all payloads institutional and commercial.

In the 1999 Department of Defence Authorization Bill, the US Congress transferred responsibility for satellite technology to the State Department from the Commerce Department. With this step, a number of important exemptions such as Fundamental Research Exclusion, under the National Security Directive 189, were abandoned. Virtually all procurements for satellite components are now subject to the International Traffic in Arms Regulation (ITAR). Affected by ITAR are all European as well as national programmes and the supply chain of space hardware at all levels: large system integrators, equipment suppliers and universities/institutes.

Even if an export license is obtained, it may induce costly delays into a project. Prominent examples are the difficulties that Europe face in the field of electronics components. In a typical European satellite programme approximately 60% of the EEE components procurement costs correspond to procurement of components from the USA, about 35% in Europe and the remaining 5% in other countries outside Europe. This has led the Director General of ESA to propose and start the European components initiative (ECI) in 2004. The ultimate objective of this Europeanisation action is to reduce substantially (if not eliminate) the dependence on components subject to United States export restrictions (ITAR Certificate).

US export restrictions are not limited to electronic components, ITAR does also mention explicitly all space components or subassemblies - such as propulsion systems, AOCS, antennas, TT&C, cryptography etc.

Therefore it must be considered to:

- Continue the European EEE Component Initiative (ECI) beyond the current emergency action, based on a sound long term basis.
- Start a new initiatives aiming at securing availability of other basic components and subassemblies that might be subject to US export restrictions.
- Support the creation of a supplier base for advanced but currently immature technologies (e.g. Compound Semiconductors)

In this context, a key element is the creation in Europe of a sizable and stable institutional market for *critical space technologies*[13], ideally supported by a "buy European policy" on agency level as well as large system integrator level. However, "buy European" does still require that products from technology developments are available at the right time and the right price. In fact, if the institutional demand remains at low level, there is a strong risk that the dependence scenario worsens since European manufacturers would not have the means to continue supporting critical technologies.

> The ultimate answer to this challenge is to guarantee the availability of essential parts and components, ideally required for a range of applications. Europe will have to provide a capable answer to the European dependency on critical technologies by (1) providing the funding for the necessary in-house development and by (2) fostering international cooperation aiming at diversifying the supply market.

7.3.2 Multiple-use Technologies

Space has been a driver for high-tech such as computers, materials etc. at a time when mass market applications had comparable cycle times and lower investment capabilities. Today, spacecraft computers do not even come close to the performance of notebooks, and some materials technologies used for leisure applications (e.g. composites) have characteristics suitable for use in space missions with minor adaptation.

Today, ground applications are driving technology developments in many areas of relevance to space missions, e.g. electronics, ultra-light materials for aeronautics, etc. Also development and manufacturing procedures for ground applications are leading and there is considerable margin for improvement of practices in the space business learning from other areas.

Figure 31 shows the evolution of the computing power for space and ground systems. Dramatic increase in performance could be achieved if the ground technologies could be systematically spun-in for utilisation in space systems. While ESA's LEON processor will operate at 100 MHz, the processors in our laptop computers run at above 1 GHz. Chips for space are manufactured with 0.35-0.18µm technology while for ground applications 0.09µm is being used. This means that higher levels of integration, higher speed and lower power consumptions could be achieved if ground technologies are used. Space devices integrate around 1 million transistors to be compared with the more than 50 million transistors in ground devices.

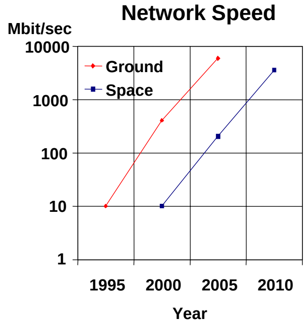


Figure 31 – Performance comparison: ground vs. space systems

This trend is not limited to computers and electronics. Other areas can benefit from ground technologies: in the near future spacecraft could be using fuel-cells, and software architectures and

[13] *With critical technologies being defined as enabling Europe to be capable of responding to its own needs in space and to remain competitive in global market*

methodologies developed for ground applications -with extreme requirements for safety and reliability- can be adapted to space.

The environment being set to increase the cooperation within the European Research Area, through the setting of *Technology Platforms* (aiming at fostering collaborative research and sharing of knowledge, and create long-term competitive partnerships), will not only leverage the potential within specific areas of competencies, but will also facilitate multi-disciplinary cooperation with related development and application areas, such as space.

Coordination shall not be limited to the activities directly related to space technology development. There should be a strong interest in coordination with other areas for timely and systematic spin-in of technologies developed for ground applications in view of their use for space. The reasons are higher performance, enhancement of non-dependence and reduction of costs.

Spinning-in ground technology for use in space systems contributes also to non-dependence, which is essential if Europe has to rely on space systems for strategic and daily applications as explained in Chapter 3. By sharing technologies with ground applications, it is guaranteed that:

- Engineering and manufacturing capabilities are maintained and enhanced, e.g. for chip manufacturing as explained above;
- Components are available due to the mass market demand

Through space/non-space actions, **space systems costs can clearly be reduced,** as space research will benefit from synergies with other programmes. In the case of FP7 this means that technology research for space is indirectly funded from other lines of the FP7. Costs are reduced by drastic application of the scale effect, e.g. the MEMS rate sensor shown in Figure 32 from the automobile industry is being adapted for use in space.

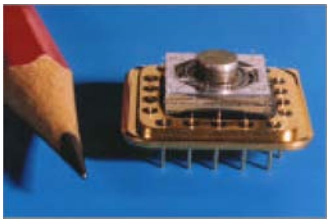


Figure 32 - MEMS rate sensor

The **purpose of Pillar** 2 is to take advantage of the new environment that is being created by the EU Technology Platforms on one side and the definition of the Space Programme and the CSDP on the other, and promote the earliest adaptation to space of new developments conceived for non-space applications (i.e. accelerated spin-in) not only to save costs but also to ensure performance and ultimately develop leading space systems.

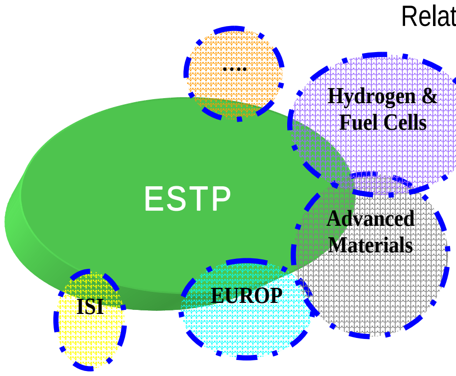
Therefore it is necessary to:

- identify promising synergy potentials and contributing to a 'space technology' observatory
- set up a framework of cooperation with all relevant stakeholders aiming at a durable and mutual profitable collaboration.
- promote the participation of the space community in relevant EC actions and projects through appropriate mechanisms (e.g. EC technology platforms and FP7 instruments) or fora (eg industrial, research, security, …)
- promote synergies between the defence and civil space sectors, aiming at joint upstream research actions and exploration of results

Interaction with related Technology Platforms

Developments along strategic agendas defined in the European Technology Platforms initiative, such as such as in HFC (Hydrogen and Fuel-cells), EuMat (materials technology), Photovoltaics, ISI (Integration of terrestrial / satellite communications) etc, are of relevance to the space sector.

It is key for the sake of avoiding unnecessary duplication and develop needed capabilities (therefore leveraging the investment to be made), that the SRAs of Technology Platforms addressing Space issues will be coordinated with the ESTP SRA, and that the ESTP requirements on upstream technology will be made available and progressively mapped into related technology platforms.



Relations between the ESTP and other TPs will be based on demand-supply interactions: For TPs dealing with upstream technologies (eg. new materials, MEMS, embedded systems, robotics, etc.) the ESTP will be on the demand side. In other areas, such as satellite communications (ISI), GMES or Galileo, ESTP will be on the supply side, ensuring continuity to the investments made in the supply chain and long-term market sustainability. Dealing with synergies across multidisciplinary domains will be a kernel issue in the ESTP technology strategy.

With that respect, bilateral meetings already took place with other TPs and European-wide initiatives early 2006 (ISI, EUROP EuMat, EUROBAT) and further meetings are on the pipeline, with the aim of identifying synergies and collaboration praxis. The situation as of today is described in Appendix C.

> It is crucial that proposed developments in space technology (independently from which TP they will have roots in) will be coordinated with the ESTP.

In summary, the ESTP will promote and pursue ad-hoc collaborations with other technology platforms with the objective to:

- Provide other TPs with requirements for the development of specific technologies (eg. new materials)
- Harmonise requirements and promote joint research on multiple-use technologies (eg. propulsion aeronautics/space/defence)
- Promote the use of relevant technology in the space sector (spin-in)
- Promote the transfer of space technology to other areas (spin-off)
- Supply other TPs and initiatives with a European space technology one-stop-shop.

The implementation of this strategy will be based on support from the EC (refer to 8.3 item B) for interactions with other TPs with the objective defining a concerted approach that will drive specific elements of Community technology programmes in areas such as aeronautics, advanced computing, information technologies etc. (see Appendix C).

7.3.3 Technologies enabling new services for the EU

Europe already possesses many of the capabilities needed to develop the services and applications that will support EU policies. It has deployed operational communication and meteorological systems, adopted an ambitious programme for satellite navigation, timing and positioning (GALILEO) and plans implementing global monitoring and earth observation through GMES. In addition to supporting a wide range of civil policies, space systems can also provide direct contributions to the Union's Common Foreign and Security Policy and its European Security and Defence Policy.

Complementary resources would have to be allocated above all in response to users' demands, as defined by the needs of the different EU policies. To complement ESA's efforts in particular, the Union should act also upstream to support basic research on upstream technologies of multiple-use, but also on those technologies needed to implement new services eg. in the area of security.

Technology development targeted to enable emerging EU applications will be done under pillar 3 of the ESTP. This will guarantee that there will be no wasting of funding, as developments will follow the underlying harmonisation effort and duplications avoided. As for any other technology developments contemplated in the ESTP, requirements will be gathered, fed into the *European Space Technology requirements Document (Dossier 0),* compared with existing or planned mission requirements in other areas, prioritised and, finally, will integrate the *European Space Technology Master Plan* and driving the stakeholders technology plans.

Major lines of development have been clearly identified under Pillar 3.

- Technologies for the Galileo second generation
- Technologies for the space component of GMES
- Technologies for security applications

More lines of development may appear in light with the definition of the European Space Programme (ESP) throughout 2006.

8 Realising the SRA

8.1 The existing framework of cooperation

During the past decades, many European countries have significantly invested in the development of space technology through the European Space Agency (ESA) and National Space Agencies, making Europe a leading player in the worldwide space scenario. As shown in Chapters 4-6, Europe is being confronted with rising U.S. military funds and export restrictions, and the emergence of strong space powers. The know-how acquired during decades and the industrial competitiveness are now at stake.

Aware of this problem, since 2000, ESA, Member States an Industry got together to optimise public investment in space technology R&D, fill strategic gaps and reduce unnecessary duplication, and improve the competitiveness of European space Industry. The nature and success of this exercise make the European Space Technology Harmonisation/ESTMP process the underpinning elements of this SRA. To increase the outreach of the process at EU level and to prepare for the implementation of the European Space Programme (including co-funding from the EC). the ESTP has been created.

Today's stakeholders include:

- 18 EU member states plus Switzerland, Norway, Romania and Canada
- European Space Industry (over 110 companies)
- Eurospace, representing 90% of the total turnover of the European Space Industry
- Research Laboratories and Universities
- The European Space Agency, National Space Agencies and Organisations (ASI, BELSPO, BNSC, CSA, CSO, CDTI, CNES, DLR, DNSC, Enterprise Ireland, FFG, GRICES, HSO, LUXINNOVATION, NIVR, NSC, POLSPACE, ROSA, SNSB, SSO, TEKES).

A list of Institutional and Industrial stakeholders is provided in Appendix A.

Space technology is being developed today through ESA and National programmes. As such, these programmes, coordinated through the European Space Technology Harmonisation/ESTMP process form the core of European investment in space technology. A summary overview of the effort being made is given in Section 5.3.

The European Space Technology Master Plan (ESTMP) provides today an extensive outlook of the investment being made in space technology and a vision for the years to come.

8.2 Enlarging the scope: areas where EU support is needed

Openness and Transparency

The ESTP is open to all European actors[14] involved in the development of space technology, and to user communities that benefit from it. All the information exchanged in the frame of the ESTP and the results of the coordination (eg. action plans, Harmonisation roadmaps, ESTMP, etc) are communicated to stakeholders. *Add a ref to the web page*

Implementation guidelines

The SRA of the ESTP conveys the results of the most extensive space technology coordination process in Europe, involving virtually all the space technology stakeholders since 2000. It builds also on the results of discussions with the EC in the frame of the EC/ESA Joint Secretariat and prepares

[14] *EU 25 and ESA Member States. To be noted that, while the Norway and Swiss are not members of the EU they will have full access to FP7 funding, as it was the case in FP6.*

the ground for a coherent deployment of technologies in the context of a European Space Programme.

The implementation of the SRA will be mainly based on the effort and commitment of its stakeholders: deployments of space technology will be, as they have been in the last 40 years, the major responsibility of ESA and National Agencies.

However, the new European challenges identified in the ESTP and mapped in its 3 pillars (plus the additional coordination efforts) will need to be supported through enlarged European Institutional support, namely Community programmes and, in particular, the *7th Framework Programme for Research and Technology Development (FP7).*

Translating the recommendations of the space community (in the SRA) into the necessary tangible support will require a permanent dialogue between the ESTP, the EC's Space Policy Unit in DG-Enterprise, and DG-Research - responsible for the definition of FP7 Work-programmes.

Due to the dynamics of technology evolution (in response to equally evolving space applications and programmes), and in accordance with FP7 work programme updates, the SRA will be updated on a regular basis with an indication of the activities to be supported in the next period. A proposal for space technologies to be supported by the space budget in the 1st call of FP7 (2007-2008) is indicated section 8.3.

These implementation guidelines are not exhaustive. Other financing lines and programmes across Community programmes (eg. CIP, development funds, etc) must also take into account the objectives set by stakeholders in this SRA and respond accordingly, namely when it relates to technology of multiple use or to space technology contributing to fulfil Europe's strategic and political ambitions.

Criteria of selection of actions to be co-funded by Community programmes (e.g. FP7)

A key aspect regarding the joint implementation of programms by ESA and the EC is to guarantee their coordination and to clearly define who will be financing what, to avoid duplications in the implementation of the SRA. The table below shows the process used to identify actions for specific EC support. From all the actions needed, indicated in the SRA (left side of the table), only those not covered in stakeholders programmes but with a clear R&T priority are proposed for FP7 funding. From these, as sub-set is being recommended for funding in the 2007-2008 period; these actions are indicated in Section 8.3.

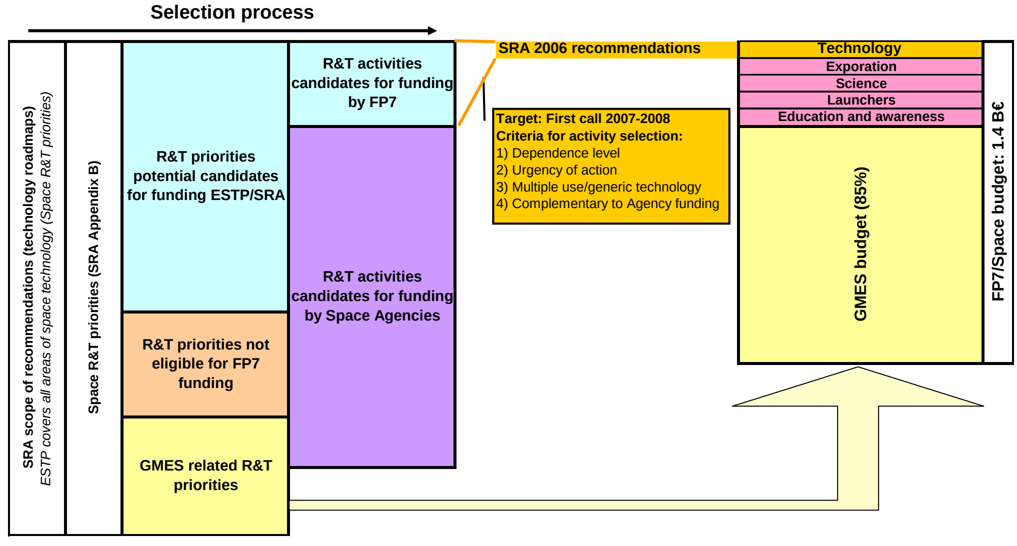


Figure 33 – The criteria used for selection of activities to be funded by EC Programmes ensures complementarity of actions

Complementing existing programmes through the three Pillars

Despite the recognised achievements, in the light of an enlarged Europe, the political aspirations and the increased competition from newcomers, the current level of commitment from institutional stakeholders is insufficient to answer to the new challenges. As such, further to the funding available through national and ESA programmes, it will be necessary to complement current space technology R&D adequately supporting and funding the 3 pillars of the ESTP on (1) *Non-dependence*, (2) *Multiple-use/Spin-in* and (3) *EU enabling technologies.*

The recommended way forward is to:

- Support Pillar 1 (Non-dependence) through a dedicated effort in the Space budget of FP7 and other Community budget lines/programmes (eg. CIP[15])
- Support Pillar 2 (Mulltiple-use/spin-in) on upstream technology of multiple-use through related FP7 priority areas (eg. robotics, information technologies, materials, embedded systems, etc.), incorporating space requirements in Community programmes from the very beginning. The space community will therefore be able to build on basic research in non-space-specific technologies. The specific funds available to space community should be focussed on adapting these technologies for space use.
- Support Pillar 3 (Enabling Technologies) on an ad-hoc basis via related application domains. One specific example relates to security, where space technology R&D needed by an operational space component should be financed through the Security budget in FP7.

It is recognised that there is the need to support additional coordination effort associated with the implementation of the SRA, namely on interfacing with non-space communities and related technology platforms, and with EU member states that are not member/cooperating states of the European Space Agency. This enlarged political and strategic coordination and cooperation must be supported by complementing the current level of investment shared by stakeholders with funding from Community programmes (eg. through a Specific Support Action in FP7).

Beyond the stakeholders indicated in 8.1, the ESTP will be open to:

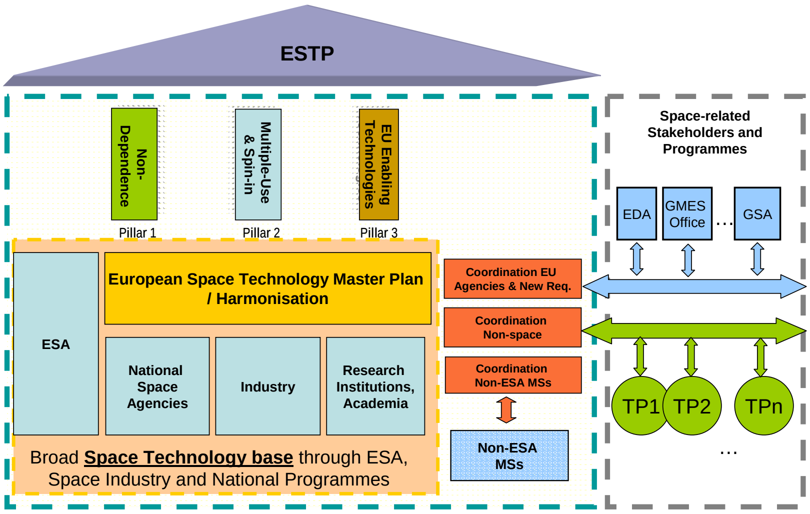
- The remaining EU Member States and relevant Industry/organisations
- EU Agencies and Bodies (eg. GSA, EDA, etc)

It is highly recommended that cooperation with the non-space sector (namely interfacing with other Technology Platforms) will be done in a systematic and traceable way, through regular sectorial[16] coordination in the frame of the ESTP. Major conclusions will feed subsequent ESTP/ESTMP action plan. This will be a concrete step toward the implementation of the SRA.

With respect to International cooperation, a specific action relates to the cooperation with CIS states on space technology issues, in particular in the frame of the ISTC (International Science and Technology Centre[17]). Cooperation with ISTC should be promoted along the following lines:

- Collaboration in the evaluation of ISTC space–related proposals
- Identification of technology requirements matching EU needs, to feed next ISTC calls
- Establishment of network of experts (interfacing with ESTP)
- Organisation of workshops on space technology bridging European and CIS space Industry

[15] *EC's 'Competitiveness and Innovation Programme', under by DG-Enterprises, targeted mainly to SMEs*
[16] *eg. materials, fuel-cells, robotics, etc*
[17] *ISTC ; www.istc.ru*



ESTP ELEMENT	Financing mechanism
Pillar 1 - Non-Dependence	FP7's Space budget + CIP
Pillar 2 - Multiple-use	FP7 within respective thematic priorities
Pillar 3 - Enabling Technology	FP7 along application lines (Galileo, security, etc.)
Extended (ESP) Coordination	Specific Support Actions in FP7
Existing Coordination	Funded by stakeholders
Stakeholders' Programmes	Funded by stakeholders

Figure 34 - Implementing the SRA and additional investment required

ESA Implementation Framework - NewPro

In parallel to the discussions leading to the setting up of the ESTP, a new programme named *NewPro* was proposed and endorsed by the ESA Ministerial Council held in December 2005. NewPro is the ESA framework for implementing the SRA, showing clearly the commitment of ESA's member states in implementing the SRA. NewPro is currently in a 3-year Interim Phase, covering the first two pillars listed above and some actions for civil security, namely technology reference and proof of concept studies.

8.3 Proposed list of actions to be funded in 2007 by EC's FP7

In the short-term, for space technology, it is proposed that the FP7 thematic priority on space will support (1) Non-Dependence. In particular, the following actions under bullet (A) below need immediate action in 2007, to reduce critical ITAR dependence[20].

<u>A) From the FP7 *Cooperation Programme* – Space & Security theme – Space budget line</u>

- Action (1).1 - Digital components (€ 8m total / €4m FP7) – at the heart of every computer and data processing device; data processing tasks are critical operations on every spacecraft.
  - o Deep sub-micron technology
  - o High-capacity reprogrammable Field Programmable Gate Arrays (FPGA)
  - o High-speed digital/analog and analog/digital converters (DAC/ADC)*
  - o High Speed Serial Links (HSSL)*[21]

[20] *ESA will seek co-financing from its Member States for these selected non-dependence activities matching its programmatic objectives*
[21] *(*) activities are related and shall be carried out in parallel*

- **Action (1).2 – Microwave components** (€6m total / €3m FP7) – used in telecommunication and payloads, navigation satellites and earth observations/science instruments such as radars.
    - Gallium Nitride (GaN) technologies
    - Schottky diodes for high-frequency applications

B) From FP7 *Capacities Programme*

The additional coordination effort needed to support Pillar 2 and Pillar 3 and the seamless integration of EU 10 will come from appropriate FP7 concertation supporting tools (e.g. SSA, NoE, etc). In particular regarding the creation of sustainable interaction between the ESTP and other TPs, under pillar 2, the ESTP will seek to foster the creation of working groups along thematic areas, open to experts from ESA, National Agencies, the Space Industry and Research Labs, aiming at promoting spin-in, innovation and reduction of deployment costs in the space sector. The estimated cost of the action proposed to the EC is €1million/year.

C) From FP7 *Cooperation Programme* - Space & Security theme – Security budget line

(C.1) Exploratory action on synergies between space, security and defence technology research (Pillar 2 – dual-use);

(C.2) Identification, consolidating and harmonisation of technology needs for security of space assets and security from space (Pillar 3 – security), based on some work already done[22]. This action will be pursued promoting a close interaction between technology experts and users or users representatives (eg. civil protection, ESA/EC GMES office)

SRA Implementation - the complementing role of the European Commission:

- It is fundamental that Community Programmes related to space technology will be coordinated with the space community under the umbrella of the ESTP.
- The ESTP-SRA **shall be the basis for the preparation of FP7 work-programmes** with affinities to space technology. In particular,
    - FP7 work-programmes related to space technology, including yearly revisions, should be prepared in close coordination with the ESTP governing structure;
    - This SRA proposes, today, a list of actions to be supported by Community Programmes for 2007. Future releases will comprehend an updated list of actions agreed among stakeholders, for inclusion in work-programmes beyond 2007.
- **The enlarged scope and coordination effort** will have to be matched by **Community funds** aiming at structuring the European Research Area (eg. through a SSA).
- The vision and strategy expressed by the space community through **the SRA shall be taken into account in the preparation of Community programmes** from the very beginning, FP7 in particular, **not only in the area of Space but also in areas where space has specific needs upstream** (*demand*: e.g fuel cells, embedded systems, etc) or in areas where it can *supply* technology to enable new services (eg. security).
- Considering the expertise available at European level through ESA and the Framework Agreement of cooperation between ESA and the EC, it is highly recommended **to *externalise* to ESA the FP7 *Space* budget related to space technology**, for implementation of the strategy in this document, in particular to what concerns **non-dependence.**

[22] *E.g. Sentre project, under EC's PASR*

8.4 Conclusion

Europe must ensure the appropriate technology preparation with a strong technology policy, based on an enlarged coordination and well integrated into an overall European Space Policy, to preserve European positions on the global arena and ensure technological readiness in line with European programmes and policy requirements.

Space-technology readiness requires a strong political commitment and additional financial support with adequate funding schemes (up to 100% of development costs) from European Member States, to meet European Space ambitions in due time (e.g. security applications, environmental applications, telecom…) and enhance industry's worldwide competitiveness and ensure European non-dependence through the development of strategic technologies.

Efforts must focus on identified development priorities complementing existing programmes. They must cover all phases of the development cycle to reach the required levels of maturity, including demonstrators (ground and flight) reducing risks and costs on future programmes.

9 References

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6. ESA Space Technology Strategy - ESA/C/WG-M(2005)7, issue 1, 6 July 2005
7. ESA Space Technology Long Term Plan - ESA/IPC(2005) 74, rev.1, 17 November 2005
8. ESA Long Term Plan 2006-2015 – ESA/C(2004)130

Appendixes

Appendix A STAKEHOLDERS (AS OF JUNE 2006)

4LINKS Limited	UK
ABSL Space Products	UK
ALCATEL ALENIA SPACE	FR
ALCATEL ALENIA SPACE ANTWERP	BE
ALCATEL ALENIA SPACE ETCA	BE
ALCATEL ALENIA SPACE IT SpA	IT
ANALYTICON Ltd.	UK
APCO	CH
ARIANESPACE S.A.	FR
ASI - Agenzia Spaziale Italiana	IT
ATMEL	FR
ATMOSTAT	FR
AUSTRIAN AEROSPACE GmbH	AT
AVIO SpA	IT
BAiE	ES
BNSC - British National Space Centre	UK
BONN HUNGARY Ltd	HG
C.N.I.M.	FR
CAP GEMINI FRANCE	FR
CARLO GAVAZZI SPACE SpA	IT
CDTI	ES
CESI	IT
CLUSTER WALLONIE ESPACE	BE
C-MAC Frequency Products SAS	FR
CNES	FR
CONTRAVES SPACE AG	CH
CRITICAL SOFTWARE	PT
CSA - Canadian Space Agency	CND
CSO - Czech Space Office	CZ
DANOTEC	PT
DASSAULT AVIATION	FR
DEIMOS Engenharia	PT
DLR - German Aerospace Centre	DE
DNSC - Danish National Space Center	DK
DUTCH SPACE	NL
E2V Technologies	FR
EADS ASTRIUM	FR
EADS ASTRIUM GmbH	DE
EADS ASTRIUM Ltd.	UK
EADS CASA Espacio	ES
EADS SODERN	FR
EADS SPACE Transportation GmbH	DE
EADS SPACE Transportation SA	FR
EC - DG–Enterprise and Industry	EU
EDISOFT SA	PT
EFACEC	PT
ENE	BE
ENTERPRISE IRELAND	IRL
ESA - European Space Agency	Eur
ESIL	IRL
ETIENNE LACROIX	FR
EUROSPACE	EU
FFG - Austrian Research Promotion Agency	AT
FILLFACTORY CYPRESS NV	BE
FPPS/SSP - Federal Public Planning Service	CH
GALILEO AVIONICA SpA	IT
GALILEO INDUSTRIES GmbH	DE
GCS GmbH	AT
GEOVILLE GmbH	AT
GRAFTON TECHNOLOGY	UK
GRICES	PT
HOLOS	PT
HPS	DE
HSO - Hungarian Space Office	HR
HTS	CH
HTS	DE
IABG	DE
INASMET	ES
INDRA ESPACIO S.A.	ES
INETI	PT
INTESPACE	FR
INTUNE TECHNOLOGIES	IRL
JENA-OPTRONIK GmbH	DE
JOANNEUM Research	AT
KAYSER-THREDE GmbH	DE
KONGSBERG DEFENCE & AEROSPACE	NO
KONGSBERG SEATEX	NO
L'AIR LIQUIDE	FR
LIP	PT
LOGICACMG	UK
LUSOSPACE	PT
LUXINNOVATION G.I.E.	LUX
MAGNA STEYR AG & Co KG	AT
MAROTTA Ireland Ltd.	IRL
MAROTTA UK Ltd.	UK
Ministry of Development – General Secretariat for R&T	GR
MODULIGHT, Inc.	SF
MT Aerospace AG	DE
NIVR, Netherlands Agency for Aerospace Programmes	NL
NOHMIA Ltd.	UK
NORSPACE AS	NO
NSC - Norwegian Space Centre	NO
OHB SYSTEM GmbH	DE
OMNIDEA	PT

ONERA	FR
OPEN ENGINEERING S.A.	BE
PATRIA Advanced Solutions OY	SF
POLSPACE	PL
QINETIQ	UK
RETEC	FR
ROCKWELL COLLINS	DE
ROSA - Romanian Space Agency	RO
RUAG Aerospace	CH
RWE - Space Solar Power GmbH	DE
SAAB ERICSSON SPACE AB	ES
SABCA	BE
SAFT	FR
SAGEM	FR
SAMTECH Italia Srl	IT
SAMTECH S.A.	BE
SCISYS Ltd.	UK
SENER Ingenieria y Sistemas S.A.	ES
SESO	FR
SIRA ELECTRO-OPTICS Ltd.	UK
SNECMA	FR
SNSB - Swedish National Space Board	SE
SODITECH	FR
SOFRADIR	FR
SONACA SA	BE
SPACE SOFTWARE ITALIA	IT
SSO - Swiss Space Office	CH
ST Microelectronics SA	FR
STORK AEROSPACE	NL
SURREY Satellite Technology Ltd.	UK
SWEDISH SPACE CORPORATION	ES
SYDERAL SA	CH
TECNOLOGICA Componentes Electronicos S.A.	ES
TEKES	SF
TELESPAZIO SpA	IT
TEMEX Neuchâtel Time	CH
TERMA A/S	DK
TESAT-SPACECOM GmbH & Co.KG	DE
THALES Electron devices	FR
THALES Research and technology	FR
THALES Systèmes Aéroportés	FR
TICRA	DK
TNO	NL
UKISC	UK
UNINOVA	PT
VEGA Group PLC.	UK
VITROCISET SpA	IT
VOLVO AERO CORPORATION	ES
XPERION Aerospace	FR
ZSW	DE

Appendix B OVERALL SPACE TECHNOLOGY NEEDS

Telecommunications

Commercial market
Citizen benefits
Dual use

European Policies

Satellite telecommunications infrastructures and services have unique characteristics, unshared by terrestrial based communications solutions. These characteristics, (such as the almost complete invulnerability to ground hazard, the rapidity of regional to global deployment, or the undiscriminating coverage of a geographical area) can have particular appeal to public authorities, for civil and military applications.

- Wide-coverage broadband access
- Enhanced coverage for civil protection and public security systems
- Advanced mobile systems in commercial areas
- Prepare technologies required for next-generation systems
- Dual use (with non-dependence concerns)

Commercial services

Telecommunications services are the main application of satellites. Video applications (live feed, local network feeds, direct to home broadcast, etc.) are now leading the market for satellite services in Europe. As satellite solutions have well proven their many advantages for broadcast applications, recent technology and market evolutions have shown great potential offered by space systems for the distribution and broadcast of multimedia content and value added services to mobile and internet networks for residential and professional users.

- TV Broadcast/Video applications - HDTV (high definition), DTH
- Broadband access
    - Internet/intranet, other multimedia applications and services
    - Transition of VSAT systems from narrow band to broadband
    - Secure communications
- Mobile services - Mobile multimedia (3G), Future nomadic systems (4G)
- Backhaul / Trunking
    - Internet Backbone
    - Backhauling for terrestrial systems: 3G, 4G, WIFI, WiMax

Competitiveness

European industry competitiveness requires a technology preparation comparable to its competitors. Satellite coverage must now be flexible to evolving customer needs, and support the regular increase of data transfer needs. And there is still margin for the reduction of cost per bit transmitted.

- Flexibility
- Large bandwidth
- Reduce cost/bit transmitted

Technology trends

Next generation communications satellites will support a wider extent of services and solutions, taking advantage of advances in computing power, energy generation and storage, on spacecraft with extended lifetime.

The increasing strategic use of satellite assets requires protecting the integrity of satellite communications.

- High data rate
  - Ka-band, Ku band
- Security:
  - encryption,
  - anti-jamming/piracy
- In orbit flexibility/versatility:
  - re-configurability
  - agility

Needs

Market driven satellite applications, such as fixed & broadcast, broadband, and mobile services, require new developments of payload technology towards higher flexibility and increased processing power.

It is needed to support development of flexible input/output sections and digital processing technologies (UHF/C/Ku/Ka band) to

- increase bit rate
- allow programmable and reconfigured coverage in orbit (zone and frequency) to adapt the configuration to the market needs during the satellite lifetime and, to be able to move satellites within a fleet at different orbital locations
- reduce procurements costs and schedules

Technology Roadmap

(Reter to key at the end of the appendix)

Flexible payload (UHF/C/Ka/Ku band) - Flexible input/output sections and digital processing	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **Antennas for in-orbit re-configurations**										
Passive antennas such as steerable zoomable spot beams, BFN (beam forming network) for passive antennas with switches or variable power dividers	7-A	TRL5		TRL8						
Active reconfigurable antennas with analog or digital BFN, either DRA (direct radiating array) or FAFR	7-A	TRL3				TRL8				
Technology MEMS for flexibility associated to Reflect Array Antenna	6-A	TRL3				TRL8				
Switching devices for channel-to-beam allocation with fine granularity										
IF processor, medium bandwidth Digital Transparent Processor, RF/IF/BB converters, optical technologies for large bandwidth…	6-C	TRL5		TRL8						
Wideband Digital Transparent Processor, regenerative Circuit or Paquet OBP, ADC/DAC at IF or RF,…	6-C	TRL3				TRL8				
☑ **RF power flexibility**										
Multi-Port Amplifier (MPA), flexible TWTA (travelling wave tube amplifiers) with medium dynamics, SSPA	6-C	TRL5			TRL8					
Flexible TWTA with high dynamics, …	6-C	TRL4				TRL8				

Earth Observation Missions

Environmental concerns Resources management
Civil security
Citizen benefits
Dual use

European policies

The "non intrusive" specificity of space solutions takes benefit of the borderless nature of Space which enables them to operate globally and permanently without legal restrictions across territorial or maritime boundaries nor controlled air spaces. This enables the space assets to collect and distribute data on a broad scale without restriction of access which is a necessary condition for adequate situation awareness and analysis. Space, by providing access to global and homogeneous data, as well as providing telecommunications and precise navigation represents the backbone of GMES. Most of the required sensor technologies (active and passive) have now been validated, and incremental efforts are required to attain, by the time GMES-1 is launched (in 2011), operational status.

- Understanding and continuous monitoring of our planet (Land surface, ocean, ice, atmosphere, biosphere, geology...)
- GMES: Global Monitoring for Environment & Security
  - Climate change, water resources management, atmospheric trace gas compositions, disasters forecasting, ...
  - International treaties implementation and Safeguarding World Heritage sites (Kyoto protocol)
  - Civil protection assistance (earthquake, flood monitoring, pollution tracking, ...), crisis management and humanitarian aid support
- Dual use – ESDP, national programme

European Programmes

Quite a number of European technology validation and operational programmes for Earth Observation will be launched in the next decade exploiting a wide range of sensor technology solutions, from active to passive, in the optical and RF wavelengths.

For these solutions to reach the operational maturity required to address to the fullest all GMES issues, additional funding (with adequate funding structures) is needed.

GMES Current and planned capabilities

Further to the ESA plans to deploy the *Sentinels* in support to GMES (Chapter 3), several Member States, EUMETSAT and third-party operators have developed or are in the process of developing satellite programmes, which should be key elements of the GMES space component. These programmes fulfil primarily their own (national or EUMETSAT) objectives, but may offer some spare capacity for GMES.

Of particular interest are commercial missions such as RapidEye and very high-resolution missions, some of them already used in GMES Service Element (GSE) projects. The UK-led Disaster Management Constellation (DMC) can potentially provide rapid access to data as required for risk management. Further, TopSat is an interesting demonstrator of low-cost, very high resolution imaging mission.

The majority of the GMES services currently defined relies on the availability of radar and optical imagery from ENVISAT (ESA), ERS (ESA), Radarsat (CSA/CND), SPOT (CNES/F) and Landsat

(US/NASA). Other satellite data is used but to a much lesser extent. Continuation of these satellite observations is a prerequisite for the sustainable operation of services, which is a major objective of GMES. This requires commitment for the availability of observations for a long period of time, typically longer than 10 years, in order to reach acceptance of these new services by the user community leading to eventual financial sustainability.

ESA	ERS 2 (1996-2005)
	ENVISAT (2002-2007)
	PROBA (2001-2005)
National	TerraSAR-X (1 satellite, 2007-2011) - Germany
	Cosmo Skymed (3 satellites, 2007, 2008, 2009 - 2013) – Italy
	Radarsat-2 (1 satellite, 2006 - 2012); C-band constellation (TBC) - Canada
	Pleiades (2 satellites, 2008, 2009 – 2015) – France
	SPOT-5 (2002 - 2007) – France
	Bird (2001-2005) Bi-spectral Infrared Detection – UK
	TopSat (2005-2006) – UK
EUMETSAT	Jason 1 (2001-2007); Jason-2 (with CNES, 1 satellite, launch 2006) to 211)
	MSG (4 satellites, launch from 2002); MTG (2015 TBC)
	MetOp (3 satellites, from 2006-2020); Post-EPS (2019 TBC)
Third-party missions	DMC (constellation of satellites, from 2003-2006) – UK
	RapidEye (4 satellites, 2007-2013) - Germany

Figure 35 – ESA, National, EUMETSAT and 3rd party potential contributions to GMES space component, with expected launch dates

ERS, ENVISAT and SPOT are reaching the end of their expected lifetime. ERS-2, launched in 1995, already doubled its nominal lifetime; SPOT-4, launched in 1998, surpassed its nominal lifetime by two years and ENVISAT and SPOT-5, both launched in 2002, have an expected lifetime until 2007. The Landsat-7 scanning imager has failed two years ago.

In September 2005, ESA presented a draft declaration on the *GMES Space Component Programme*, based on a gap analysis starting from the GMES space observation requirements, which are compared with European missions assumed to be in orbit during the period 2006-2013. As guaranteed independent access data for European users is a key criteria for GMES, non-European missions were only considered in cases where no European solution can be provided within the time frame envisaged. GMES will need to rely on such external data sources in particular during the build-up phase.

Technology trends

Next generation operational Earth observation systems are expected to provide greater accuracy of observation, with more frequent provision of updated data.

These requirements will be achieved by combining systems and sensors with complementary technical characteristics. But all these new more powerful Earth observation instruments pose new challenges to space systems as a whole, particularly with regards to mass, power dissipation, thermal stability, and data processing aspects.

- Lidars
- SAR
- Hyperspectral Instruments & Spectrometers
- High resolution imagers

Needs

Environmental science, climatology and meteorology necessarily address global issues, driven by policies with a local focus. Satellites have the ability to support both global and local levels of assessment of Earth phenomena.

The strategic importance of satellite observation in conflict or natural hazard situations is confirmed as modern societies are increasingly confronted with risk situations

It is needed to develop and improve European technologies for SAR and optical instruments (e.g. imagers, spectrometers, LIDARS) technologies with a view to:

- Increase accuracy and enlarge field of view
- Enhance all weather observation capacities
- Improve revisit time, Quasi-continuous observation

Technology Roadmap

(refer to key at the end of the appendix)

Passive optical instrument technologies (high resolution, wide aperture instrument)

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Mirrors										
Very low mass/large diameter - New materials (ceramic, ...)	16-A	TRL5		TRL8						
Deployable - new concept for GEO observation	16-A	TRL4				TRL8				
Coating	19-C	TRL5		TRL8						
Detector arrays (high resolution, multispectral, visible and Infrared) and associated technologies										
APS (active pixel sensors) technologies	16-A	TRL5	TRL8							
IR technologies	16-A	TRL5			TRL8					
Cryo-cooling devices (IR instrument)	20-B	TRL5		TRL8						
Interferometry technologies/components										
Beam splitters, filters, wide band antireflection, …	16-A	TRL5		TRL8						
Transmission of light through electro-optical systems										
Optics to fibers coupling system	16-B	TRL5				TRL8				

High resolution wide swath SAR

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **Polarimetric interferometry SAR: Active phased array with large front end integration**										
Advanced (generic) TR Modules	6-C	TRL3				TRL8				
Generic power supply units (converter)	6-C	TRL3				TRL8				
Arrays technologies	16-B	TRL3				TRL8				
Radiators	20-D	TRL3				TRL8				
Data storage, Processing and Transmission (Modular Control Electronics)										
Advanced core radar processing electronics	1-A	TRL4		TRL8						
Data compression algorithms	1-B	TRL5		TRL8						
Solid state mass memory	1-B	TRL5		TRL8						
Advanced modulation (for high data rate)	1-A	TRL5		TRL8						

Laser systems technologies

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
LIDARS										
High efficient laser pump source	16-B	TRL5		TRL8						
High power laser diodes	16-B	TRL4		TRL8						
Innovative highly resolving filters	16-A	TRL5			TRL8					
SAM (Scattering-Attenuation Meter) detectors, array detectors	16-A	TRL5		TRL8						
Space qualification of solid-state lasers (lifetime)	16-B	TRL6		TRL8						
☑ **Optical communications, optical metrology, opto-electronic components**										
High-power single mode laser sources	16-B	TRL6				TRL8				
High-power amplifier	22-B	TRL5				TRL8				
Secure optical communication technologies through atmosphere	16-A	TRL5					TRL8			

Navigation

Commercial applications
Citizen benefit
Dual use
International cooperation

European policies

Satellite based navigation and positioning services have been in operation since the US department of Defence launched the GPS system in the seventies. Originally available only to military users, the service was gradually made available for the development of civilian applications turning satellite navigation into a vast market at the space segment and ground segment levels.

European initiatives in the domain of global satellite navigation are being implemented through EGNOS and Galileo, addressing the needs of both civil and military users through the development and implementation of a fully European system.

Galileo will be operational in 2011, serving civilian and military users alike with a guaranteed signal allowing the development of a services and terminal market with the establishment of a growing customer base.

While technologies the first generation Galileo system are being validated, Europe shall prepare for system evolutions.

International cooperation

There is an international cooperation dimension to the programme, from nations outside the EU, which has the potential to add international value that would benefit the entire world.

Agreements have already been signed with China and Israel and discussions are under way with India, Russia, Brazil, South Korea, Mexico, Australia, Argentina and Ukraine. Moreover, the signature of the EU/US agreement on 26 June 2004 established the full interoperability and compatibility between GALILEO and GPS, thus giving a strong boost for the GNSS market, which is potentially considerable.

Competitiveness

European space industry has risen to the challenge of Galileo, and has itself invested significantly in the programme. With the advent of the future PPP for operation of the system, European industry and commercial institutions will become further investors to an equivalent level to the public sector.

At full operation, Galileo will be run as a business partnership between the public and private sectors, and profits would be ploughed back into further development and system replenishment. Like any business, its investments must therefore be well protected, and failure to take such protective measures could damage the business.

Markets and applications

- Air traffic management
- Road traffic monitoring and driver assistance
- Railways applications
- Agriculture and fishing

White Paper figures on users and revenues (hardware and associated services) in the navigation market:

- 2000 : European users : 6 million ; world revenues: €14 millions
- 2010 : European users : 100 million ; world revenues: €50 millions
- 2020 : European users : 250 million ; world revenues: €155 millions

Technology trends

- Increased precision (second generation clocks)
- Increased signal integrity (system, overlay, urban areas)
- Increased system security (anti-jamming, encryption)

GNSS Evolution (EC and ESA roles)

The main objective is to prepare for evolutions and upgrades of the European GNSS Infrastructure (EGNOS and Galileo) with a view to subsequent implementation in the respective operational systems.

A number of mission and system exploratory studies have already been carried out as part of the *GNSS Support Programme Step 1* and the 6th FP activities under the management of the GJU. Some of these studies led to the selection of candidates for system upgrades or evolutionary steps which were defined in sufficient detail to allow them to proceed directly into a technology development phase for subsequent demonstration (e.g. broadcast via EGNOS of additional alarm messages or messages enabling coverage extensions).

In order to address all the above issues, a number of mission analyses and system exploratory studies will be launched with the aim of identifying, preliminary defining and sizing the system evolutions or upgrades to be considered for introduction in the European GNSS Infrastructure in the time-frame 2010-2030.

The following is a preliminary list of topics to be addressed by the studies:

- EGNOS coverage extensions
- Interoperability with other systems (e.g. WAAS, GLONASS, GPS, COMPASS and GAGAN)
- Evolution of standards and impact on EGNOS and Galileo (e.g. civil aviation SARPS, 3G mobile)
- Alert messaging broadcasting
- High Accuracy Services (10 cm level) using WRTK (carrier phase ambiguity) techniques on GPS/Galileo signal, high accuracy ionospheric models from EGNOS and regional differential corrections
- Evolution of EGNOS towards a Multi-Constellation Multi-Standard Regional system (MRS)
- EGNOS generative dual-frequency navigation payloads
- Definition of service for combined use of E5a/E5b signals in Galileo using AltBOC modulation
- GPS integrity dissemination via Galileo
- New additional signals in Galileo (L and C-band)
- Higher power navigation signal for deeper signal penetration and enhanced availability
- Integrated value-added data dissemination services at higher bit rate
- New signal modulation and access techniques for increased robustness
- Spot-beams and reconfigurable satellite coverage to match the different market needs and service areas
- Higher orbit determination accuracy

- Higher time transfer and synchronization accuracy
- On-board satellite integrity determination
- Extended satellite autonomy
- Reduction of operational and maintenance costs
- EGNOS and Galileo service definition re-assessment

On the basis of the requirements and baseline architectures resulting from the above studies, *System level Preliminary Design* activities for these evolutions will be performed for space, ground and user segments to derive the functional and performance requirements of the various enabling technologies to the required operational level.

Today's examples of needed technology development include miniaturization of receivers, reduction of power-consumption, integration with other sensors or complementary functionalities, increase in performance being precision or robustness, extended in-door coverage, combined use with local elements.

In the context of the ESA's *European GNSS Infrastructure Evolution Programme* (EGEP) it is proposed to carry out technology activities in the areas listed below, to be supported by ESA and Community programmes (FP7). EGEP is being proposed by ESA to its member states, a decision is expected end-2006[23].

Title	Description	Fund	Implement
Development of Enabling Technology for Applications	• receiver miniaturisation • receiver integration with sensors • technology development for in-door applications • antennas • search and rescue beacons development	FP7	EGEP
IEV System Exploratory Studies (Phase A)	To identify capabilities and to specify critical technologies, predevelopments and verification development plan, and to consolidate those in coherence with the operational infrastructure evolution plan managed by the GSA/GOC.	ESA	EGEP
IEV System Definition Studies (Phase B)	To carry out the necessary system definition activities.	ESA	EGEP
IEV Technology, Equipment and Subsystems developments	• To apply latest technological developments to new generation equipment or to improve its current design to make to facilitate maintenance and sustenance. • To develop European components. • To develop sub-systems for supporting test and demonstration of new capabilities.	ESA	EGEP
IEV Pilot Systems Development	To develop pilot systems where significant evolutions are envisaged. This would cover typically a pilot system of new generation Galileo satellites (timeframe 2010) or a new type of EGNOS payload with associated ground segment.	ESA	EGEP
IEV End-to-End Assembly Verification and Demonstration	Verification and demonstration campaigns of new capabilities and the pilot systems.	FP7	EGEP
IEV Integration into Operational Infrastructure	When the benefits of new technologies and developments are technically verified and demonstrated to the candidate user communities, their integration into the operational infrastructure (EGNOS or Galileo) can be envisaged by the GNSS Supervisory Authority. When	FP7	EGEP

[23] *Decision to be taken after ensuring Galileo additional costs (as of May 2006)*

	such evolution is decided, the GNSS Evolution Programme will support, in a specific co-funded programme element wit the GSA, their further development (*), integration , qualification and procurement of the recurring hardware elements if needed. (*)if not done already at the adequate quality level as part of the technology development.		

Needs

Independence and autonomy of European policies require the development and implementation, using European products and technologies, of global observation, telecommunications and navigation systems and services.

Galileo signal quality and availability must be guaranteed at all times to all users.

Technology Roadmap

(refer to key at the end of the appendix)

Next Generation Navigation System	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **On-Board Frequency and Time Generation**										
Long term stability, low mass, low cost and low volume clocks for Galileo 2nd Generation	16-B	TRL4								TRL8
Cesium clock development	16-B	TRL4					TRL8			
Technologies for Intersatellite link	26-B	TRL2								TRL8
Development and Qualification of Laser Diodes	16-B	TRL2								TRL8
Advanced Navigation Payload (flexible, integrity, secure, …)										
Enhanced Performance and programmable signal generation	26-B	TRL3							TRL6	
Technologies for new cryptographic systems (including ground segment)	26-B	TRL5							TRL8	
Technologies for GEO/GTO spacecraft/launcher navigation	26-B	TRL6								
Navigation integrity (signal)	26-B	TRL3							TRL6	
Ground Frequency and Time Generation										
Development of atomic clocks	16-B	TRL3				TRL7				

Technologies for Security Applications (SeNTRE)

The role of SeNTRE is to establish a European network to identify user needs at European, National and multilateral levels (Top down and bottom up, bilateral exchange). It identifies European/common capability needs and research priorities for comprehensive security missions using the structures provided by the Security Mission Industry Groups (SMIG) network to engage with a large industrial and research community. It provides the EC with a broadly supported view of the key technology needs in Europe (define the priorities for filling the gaps and propose a programme for achievement of EU PASR)

SeNTRE suggests a strategy for Europe in the field of comprehensive security and identifies key research issues for FP7 ESRP, to start in 2007

1. Space technologies are key technologies for many security missions
2. There is a very strong need for adaptation of space technologies to new security missions, taking into consideration the needs and requirements of the usersR&T projects should be launched to develop these capabilities for security missions and security applications

The SeNTRE project has three main components:

1. Developing a Strategic Research Plan for the first ESPR (2006 – 2013);
2. Stocktaking of available technologies and identification of needed technology development to meet the capability needs;
3. Identification of current and future capability needs in Europe through end-users on the basis of agreed scenarios and missions.

SeNTRE results are the following:

1. A strategic research plan containing a list of prioritized short, medium and long term actions;
2. A database of missions and technologies;
3. An organized platform of users and technology experts for future consultation;
4. A methodology to organize and analyze the security needs at the operational level

Technology roadmap

(refer to key at end of Annex)

Dedicated space technologies for security applications (SeNTRE)

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Earth observation										
Moving Target Indicator (MTI) technologies (satellite, Long Endurance UAV, and surface)	TBC	TRL3					TRL8			
Technologies for new cryptographic systems (including ground segment)	26-B	TRL5							TRL8	
Navigation/Telecommunications										
Anti-jamming, anti-spoofing, anti-piracy technologies		TRL5			TRL8					
Rapid on-orbit operation and Quick launch capability (satellite launch on-demand, replacement of failed satellite, …)										
New upper stage propulsion (incl. tanks)	18-A	TRL4					TRL8			
Light weight structures (composite, …)	19-G	TRL6				TRL8				
Storable low cost technologies	19-G	TRL3					TRL8			
System tools & methods improvement (incl. Cost reduction & robustness improvement)	8-C	TRL3				TRL8				
Launch system optimisation (incl. ground operations, mainly for quick launch capability)	9-A	TRL2					TRL8			
Quick deployment capability of satellites - Small satellite technologies										
Low cost, short life time, storable building blocks/elements	8-D	TRL3					TRL8			
Adequate mission control Centre and dissemination data	9-B				TRL6		TRL8			
Rapid integration and tests	8-D				TRL6		TRL8			
Ground segment										
End-to-end system validation and simulation	8-C			TRL5			TRL8			
Processing capability/Grid technologies	25-A			TRL5			TRL8			
Data segmentation / fusion	25-A			TRL5			TRL8			
Data and product storage, exchange and dissemination	25-A			TRL5			TRL8			
User friendly data and product	25-A			TRL5			TRL8			
Interoperability with "non-space based" platforms	25-B			TRL5			TRL8			

Satellite platform

Competitiveness
New missions
Payload requirements

European policies

Space based solutions will provide supporting tools to major European policy concerns in the future. Platform technologies thus have a widespread potential of interest for a wide variety of space systems users, in the civil, military and scientific domains. The satellite platform is the workhorse of the satellite. It carries and maintains in operational conditions the payload that provides the service or scientific observation. Among the major tasks the platform takes care of, there are: energy storage and delivery, and station keeping.

Technologies to perform and improve these functions are essential to satellite systems competitiveness. Some also have a dimensioning effect on mission possibilities.

Therefore platform technologies are addressed in complement to payload priorities, to ensure that European industry can match the needs and challenges of future missions and instruments.

- Ensure the competitiveness of space based applications
- Prepare technologies required for next-generation systems
- Support innovation and demonstrate new space-based applications
- Dual use

Competitiveness

Competitiveness of space based applications requires a competitive industry with competitive products. Satellite applications markets are technologically driven, as each proven technology advance put on the market gives a clear competitive advantage to its owner. Some technical characteristics, such as flexibility, agility or reliability over extended periods have particular appeal to system users, for economic reasons. Similarly mass reduction is always a winning strategy.

- Flexibility and agility
- Reliability, extended lifetime
- Cost and mass reduction

Technology trends

The key identified trends with regard to platform development technologies are related to power and mass issues. Power needs require the improvement of solar generator technologies, and the improvement of battery efficiency. Advances, notably in miniaturisation, MEMS and materials technology, now allow to pursue mass and power budget improvements on the platform through equipment integration, sensor hybridisation and electric propulsion.

- Power delivered enhancement
  - Multi junction solar cells
  - High efficiency batteries
- Integrated avionics equipment
- Hybridisation of sensors
- Electric propulsion

Needs

Requirements put on the space platform will vary depending on the payload and orbital requirements. Some requirements are shared by most missions, starting with stability and extended lifetime. But the technical solutions will vary depending on mission specificities.

While telecommunications missions may prefer larger satellites with particularly challenging power related requirements, future observation missions will have lower mass and power constraints.

- Telecoms
  - Large platform - Alphabus
    - Power: 12 to 19 KW
- Science and Earth observation
  - Minisatellites platform (mass: 200 – 500 kg)
    - Power: 0.1 to 1 KW
  - Microsatellites platform (mass: < 200 kg)
    - Power: 0.01 to 0.1 KW
- All missions
  - High stability
  - Fine attitude control
  - Extended life-time

It is needed to develop European skills and technologies on advanced power systems, and integrated avionics to

- Enhance platform capabilities (Power, flexibility, agility,...)
- Reduce system cost and mass

Development of electric propulsion technologies[24] shall also contribute to platform improvement

Technology roadmap

(refer to the key at the end of the appendix)

Highly integrated avionics/GNC technologies for platforms	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Miniaturisation										
MEMS sensors, wireless technologies, low cost sensors	15-A	TRL4			TRL8					
Data processing/Software										
Smart FDIR S/W, advanced S/W Techniques, integrated on-board processing technology	5-A	TRL4			TRL8					
☑ **Hybridisation of sensors, …**										
GPS/inertial/star sensing, …	15-A	TRL4				TRL8				
RF Sensing for TC Platform	15-A	TRL4		TRL8						
☑ **New GNC designs for Earth observation (Stabilisation, agility)**										
Mini CMG for Agile Small Platform	15-C	TRL3		TRL6		TRL8				

Power generation and storage technologies	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **Solar array technologies**										
Multiple junction GaAs cells (>3), Solar array concentrator, Advanced cover glass/OSR Supply	3-A	TRL4			TRL8					
Thin film technology	3-A	TRL3					TRL8			
Battery										
Supercapacitors	3-B	TRL3				TRL8				
Higher efficiency Li-Ion battery	3-B	TRL5			TRL8					
Next generation High efficiency batteries (advanced lithium and others)	3-B	TRL2					TRL8			
Fuel cells										
Conventional	3-A	TRL5				TRL8				
Regenerative, life time improvement	3-A	TRL3				TRL8				

Cutting edge science

Science, knowledge & excellence
Long distance/duration missions
New mission concepts

European Policy

Scientific purposes have driven the early ages of space research, for reaching outside Earth boundaries gives access to the cosmos, and to unique positions from where Earth and the universe can be observed, and explored.

Space science supports the understanding of life and planetary formation. It allows accurate study of the solar system, and provides unique information on the laws and origins of the Universe.

Scientific missions pose many technological challenges. First the purpose of the mission may require the development of a very specific instrument, such as a telescope, which will actually perform the scientific mission.

Then the destination of the spacecraft (particular earth orbits, distant planets, the Sun, asteroids, etc.) may require a very specific system approach to support the mission. As with all other space missions, mass constraints are a technology driver, likewise, thermal and power issues are driving factors, as well as radiation hardening and system reliability. Thus technology advances have mission enabling factors.

Two issues appear particularly important today: propulsion and formation flying.

The improvement of spacecraft propulsion efficiency within strict mass constraints to increase the distance the spacecraft will be able to travel. Electric propulsion has the peculiar advantage of requiring much less propellant than chemical propulsion systems. On the other hand, electric propulsion can only achieve high thrust if it has available power, but it can deliver continuous low

[24] *"Electric propulsion" as a technology priority is addressed in the New space missions domain – exploration missions are the main driver for high power electric propulsion development*

thrust for very long durations, and with a good power budget. The thrust of electric propulsion systems can be improved to reach values above 5 kW. With these demonstrated Europe will be able to consider a new step in space travel.

Formation flying is the ability to orbit a group of spacecraft with the autonomy to preserve their relative positions one with the other. This of course requires very accurate control systems on each spacecraft to acquire (and process) precise information about other spacecraft's positions, and to apply corrective action when needed (micropropulsion). The satellites shall also be able to think as a group, and in relation to the others, to achieve system efficiency. This requires special algorithms and processing architectures.

Competitiveness

The R&T priorities identified for space science have a vast potential of applications to many space missions. In the scientific domain, of course, for which they are the main development driver, but also in other domains, after they have been validated.

Electric propulsion, with less power requirements, is already used on commercial telecommunications satellites. Advances in this area may support the competitiveness of future European systems.

Formation flying technologies will enable completely new concepts and innovative system architectures, such as the ability to distribute an instrument across many spacecraft. Formation flying technologies will have application in further science missions (large telescopes), with benefit for all space sciences, but also in future operational missions for Earth observation and surveillance. European system control technologies are already well recognised, and have the potential to support European leadership

The required technological advances, particularly on sensor accuracy, will support enhanced control systems on many future spacecraft.

Technology trends

- Formation flying
- High-resolution imaging using aperture synthesis
- Large telescopes & Interferometers
- Optical and RF metrology
- Mid-infrared observation
- Deployable technologies
- High ISP

Needs

It is needed to develop European skills and enabling technologies for formation flying (GNC, system control, ...) and very high power electric propulsion[25] to

- Implement large interferometer
- Enhance flexibility and redundancy
- Reduce mission costs
- Travel longer distance and faster (high ISP)

Technology roadmap

(refer to key at the end of the appendix)

[25] *Electric propulsion and optical technologies are good examples of cross fertilisation*

Formation flying technologies	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **System control, GNC**										
RF, laser measurement	16-A	TRL5			TRL8					
Optical sensing and metrology	16-A	TRL4			TRL8					
Integrated optics	16-A	TRL4				TRL8				
Fringe measurement (delay line)	16-A	TRL6				TRL8				
MEMS based sensors: optical, inertial	15-A	TRL4		TRL8						
Formation acquisition & control algorithms (GNC)	5-B	TRL5			TRL8					
☑ **Micro/Mini propulsion**										
Coarse actuation: cold gas, HET, ion	18-B	TRL4		TRL8						
Fine actuation: FEEP	18-B	TRL5		TRL8						
Fine actuation: Micro-ionic propulsion	18-B	TRL4			TRL8					

Next generation very high power electric propulsion (>5kW)	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Engines (P>5KW; throttability)										
Plasmic thruster (HET)	18-B	TRL5				TRL8				
Plasmic thruster (HEMP: High efficiency multistage plasma)	18-B	TRL4				TRL8				
Ion thruster	18-B	TRL4				TRL8				
Power processing technologies										
Power supply, … (dependence only on some components: e.g. MOSFETs, HV components)	3-D	TRL4			TRL8					
Propellant technologies										
Gas formulation, …	18-D	TRL4			TRL8					
Associated test facilities										
Test bench, …(no test bench above 5kW in Europe, Centrospazio facility shall be avialable in 2008)	18-D	TRL4		TRL8						

New space missions

Planetary exploration - robotic
Mission specific requirements
System autonomy
International partnerships

European planetary exploration programmes have recently made major leaps that enable Europe to consider with confidence extending the reach and scope of its planetary exploration programme.

Mars Express, the first European spacecraft to orbit another planet, reached Mars orbit at the end of 2003. Now it is Venus Express, taking advantage of a common technological base, which has been launched on November 2005 and is now entered into Venus orbit.

Only months after Rosetta was launched in 2004 for an 11 year cruise (with four gravitational slings) to reach a comet, the Huygens probe landed successfully on Titan after its 7 years journey to Jupiter's Moon.

Smart 1 trip to the Moon of 2003 proved the efficiency of electric propulsion for transfer to another planet.

Planetary exploration missions, initially based on robotic concepts, share common technological characteristics with space science missions, but have added requirements that must be addressed separately. These are related to the peculiarity of the descent, landing, and planetary roving phases. In the case returning a planetary sample is considered, the issues of leaving the planetary surface (ascent), travel back and eventually penetrate the Earth atmosphere (re-entry) and land safely add more technology requirements to the mission.

Thus, planetary missions are particularly challenging in terms of technology, and are the flagships of space programmes. Planetary missions are often carried out in partnership with other nations (such as with the Huygens probe, that was safely carried to Titan by the Cassini spacecraft provided by NASA), and technical expertise in critical areas of exploration mission supports an even participation of Europe in international endeavours.

After having successfully assessed the capability of European built systems to orbit and land on other planets, Europe shall now further and consolidate its re-entry and descent capabilities (e.g.

aerobraking, thermal protection) and master soft landing technologies to eventually achieve the capability to land more sophisticated equipment, including rovers.

In order to enable the first sample return missions, and later human missions, adequate European capabilities in ascent technologies shall be developed.

European policies

With the Aurora programme, the European path to planetary exploration is well paved. With a a coordinated approach to build step by step, mission after mission, the required European capabilities, the exploration programme will bring technology to adequate readiness levels to address present and future mission needs with growing ambitions.

- Exploration—Aurora
  - Robotic and human exploration of the solar system, with Mars, the Moon and the asteroids as the most likely targets.
  - Search for life beyond the Earth
  - Stimulate new technology
  - Inspire the young people of Europe to take a greater interest in science and technology
- International cooperation

Mars timeline

Activities	Characteristics	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Exo Mars	Entry Descent and Landing, Rover						Lch					
Mars sample return	Aerobraking,Rover, Ascent vehicle,											Lch
Automatic Mars mission	Propulsion for transfer											

Definition phase	
Main development phase	
Launch	Lch

Technology trends

- Entry and Descent systems
- Soft and precision landing systems
- Aerobraking
- Rover
- Drilling and coring
- Ascent vehicle
- RDV in orbit

Needs

It is needed to develop European skills and enabling technologies for unmanned exploration missions: Re-Entry, Descent, Soft and precision landing, Rover, Drilling and Ascent technologies to

- Carry out remote sensing of planet environment
- Achieve robotic exploration and surface analysis
- Implement sample return missions

Technology roadmap

(refer to key at the end of the appendix)

Re-Entry, Descent, Soft and Precision landing, Drilling, Rover and Ascent technologies	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **Re-entry, descent technologies**										
Aerobraking	15-R	TRL6						TRL8		
Aerocapture	15-R	TRL3						TRL6		
Atmospheric (re)entry technologies (thermal protection, ...)	19-G	TRL5				TRL8				
Navigation	5-A	TRL4				TRL8				
High speed re-entry technologies	19-G	TRL4				TRL8				
Aerothermodynamics modelling	17-A	TRL5		TRL8						
☑ **Soft and precision landing technologies**										
Parachutes, airbags, …	19-G	TRL3				TRL8				
Soft landing, sensor/vision-based GNC with propulsion braking system	15-R	TRL2				TRL7		TRL8		
Precision Landing Navigation and sensors (Cameras, Lidar)	15-R	TRL2					TRL6			TRL7
Rover technologies										
GNC algorithms & micro sensors	5-A	TRL3				TRL7				
Autonomy & reprogrammability	5-A	TRL3				TRL7				
Miniaturized Avionics	5-B	TRL3				TRL7				
Mechanisms	15-J	TRL3				TRL7				
Advanced Thermal Control	20-D	TRL3				TRL7				
Power generation	3-A	TRL4				TRL7				
Ascent technologies										
Vehicle optimisation tools	19-G	TRL3					TRL6			TRL7
Propulsion	18-C	TRL3					TRL6			
RDV	15-H	TRL3					TRL6			TRL7
Specific technologies										
Miniaturised sensors/altimetry/landing site survey	15-A	TRL3				TRL6		TRL8		
Next generation of drilling technologies	15-J	TRL4						TRL8		
Seamless communications coverage and compact	16-A	TRL3				TRL6				
Planetary protection	19-G	TRL3					TRL8			
High efficiency power source	3-A	TRL3				TRL6		TRL8		

Orbital assemblies and manned missions

International context
ISS commitments
Human aspects
Assemblies

In 2005, the international context around human spaceflight activities has evolved significantly.

The US Space shuttle return to flight relieves some of the uncertainties pending on the future of the International Space Station programme. Nonetheless the completion of the ISS and its exploitation have yet to be secured.

Europe, in fulfilment of its commitments towards the ISS programme, will need to launch the Columbus facility and roll out the ATV in operational conditions within the next four years. Critical technologies are still to be developed for European systems to acquire the necessary skills to perform autonomous in orbit RDV, docking and servicing.

Europe will take advantage of ISS facilities to start preparing for human exploration missions.

Ambitious human exploration programmes are being announced by Europe's main partners in the ISS. NASA is now announcing the return of humans to the Moon by 2018 with an ambitious programme (104 B$) destined to extend human reach to other planets.

At a lesser scale, but with similar determination, China, since proving its capability in human transportation systems, is now furthering its human spaceflight programme.

Europe cannot stay behind. Technologies for advanced manned modules for space exploration are still in very early stages of definitions (concept validation), and can have long development cycles ahead of them. Activities on regenerative life support systems, and on the means to build large assemblies in orbit shall start with no delay.

Competitiveness

The technologies to build and deploy large structures in orbit, especially related to autonomous rendez-vous and robotics, may act as enablers for on-orbit servicing approaches.

These are already required for the maintenance of such a large structure as the ISS. Similar technologies could be applied to servicing other spacecraft in orbit, to extend its operational lifetime for example.

The ability to deploy large structural elements in orbit is a competitive advantage for the supply of large structures such as reflectors, antennas, booms etc.

European policies

Technologies for orbital assemblies and manned missions are required to support European commitment towards the ISS exploitation, and ensure significant European participation to ambitious human exploration programmes (the Moon, Mars and beyond...)

Space exploration is an inspirational element of the European space programme. Mars remains the main target for Europe.

Since the announcement of the new NASA initiative to Moon, Europe must ensure that it has the required level playing filed to be a significant partner to far reaching endeavours.

- ISS commitments
    - Essential step towards space exploration
    - On orbit servicing
    - Life and physical sciences
- Exploration - Aurora
    - Human exploration of the solar system, with Mars, the Moon as the most likely targets.

Human planetary roadmap

Activities	Characteristics	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Human Mission technologies	In situ Resource Utilisation									Lch		
Human moon mission	In situ Resource Utilisation											
First human mission to Mars	Habitats & Life Support											

Technology trends

- Autonomous RDV
- Deployable structures
- Habitat
- Advanced regenerative life support
- On-orbit servicing

Needs

It is needed to consolidate and develop European capabilities for in-orbit RDV, docking, on-orbit servicing techniques and advanced manned modules to

- Increase autonomy for RDV and docking
- Prepare the construction of large assemblies in orbit
- Be an international active partner in future ambitious exploration programmes (robotic and human missions)

Technology roadmap

(refer to key at the end of the appendix)

In-orbit RDV, docking, on-orbit servicing techniques

		Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑	**GNC - Autonomous RDV**										
	Autonomous RV Navigation Technologies	5-B	TRL5					TRL8			
	Software	5-B	TRL6					TRL8			
	Support mechanisms	5-B	TRL6					TRL8			
	Sensors	5-B	TRL6					TRL8			
☑	**On-orbit servicing techniques**										
	Robotic arm	13-B	TRL6			TRL8					
	Remote control visual inspection systems	13-B	TRL3				TRL8				
	Enabling space debris reduction (cleaning) technologies	13-B	TRL3				TRL8				

Advanced Manned Modules, Technologies for Space Exploration

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Regenerative Life Support (closed cycle)										
Physico-chemical regeneration of water and air	21-A	TRL3								TRL8
Closed cycle waste management	21-A	TRL3								TRL8
Inflatable/Gossamer Structures										
Gas generator for inflatable structures	19-C	TRL3		TRL8						
Building blocks, flight experiment, …	19-C	TRL3				TRL8				

Access to space

Guaranteed access to space
Consolidate current launcher
Future reusable launcher

By the end of the decade, the European spaceport in Kourou will accommodate three different launch systems (Ariane, VEGA and Soyuz), providing effectively Europe with an increased potential for autonomy with regard to its space launch needs.

Until then, for Europe to secure a guaranteed access to space, the Ariane 5 system needs to be further consolidated to maintain operational capabilities at affordable conditions.

Hence, cost reduction concerns are the main driver of advances in chemical propulsion technologies. Cost strategies seek to reduce propellant cost and to improve engines efficiency. Adequate design and engineering tools are required to ensure system reliability in current and future systems.

Europe also needs to prepare the future with new launcher developments. Reusable technologies are a most exciting area of investigation, with a long term view but in continuity with existing development capacities available in the European space industry. Technology developments related to atmospheric re-entry and propulsion aspects (including from a materials point of view) are critical for future European reusable launch systems.

Competitiveness

Competitiveness of a launcher system relies on many elements.

The robustness and reliability of the launcher are key, especially for customer confidence. The technical robustness of the launcher is only guaranteed by a robust and healthy development and manufacturing industry in Europe.

Reliability can be vastly improved with more frequent launcher operations. A stable launch rate helps to maintain the required know how at the appropriate readiness level and supports launcher competitiveness too. Hence the necessity to market the launcher to all potential customers is needed to maintain launch rates.

The flexibility of operations, i.e. the launcher capacity to accommodate varying passenger requirements in terms of mass, volume and destination also plays an important role in launcher competitiveness. As do also pricing policies of course.

What is true for current systems, stands also true when new systems are developed.

- Flexibility, reliability, robustness
- Launch cost reduction
- Performance enhancement
- Technologies required for next-generation launchers preparation

European Policies

European launcher policy clearly states objectives of guaranteed access to space, where autonomous capacities to develop, manufacture and operate a launcher play a central role.

- Autonomous and competitive space launch capability for
    - Successful exploration and exploitation of space
    - Guaranteed European strategic independence in the space sector

Technology trends

- Architecture optimisation / simplification
- Margins enhancement
- Mass and cost reduction
- Industrial processes improvement, including methods and design tools
- New propulsion system

Needs

It is needed to develop advanced chemical propulsion technologies, and assess reusable launcher technologies to define possible architectures allowing to

- Support Reduce recurring cost
- Ensure reliability
- Enhance flexibility and availability of service
- Increase the ISP
- Allow re-ignition

The improvement of methods and tools related to launcher design and sizing is critical for the competitiveness and reliability of European launch systems

Technology roadmap

(please see the key at the end of the appendix)

Advanced chemical propulsion technologies	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Low cost solid propellant										
Low cost propellant formulations (New oxidizers, Low cost materials...)	18-A	TRL4				TRL8				
☑ **Green/low toxicity propellants and thrusters**										
Replacement of MMH / NTO and hydrazine	18-D	TRL4				TRL8				
Low cost/high performance (including re-ignition) cryogenic propulsion										
Propellant tanks in titanium - Low thickness	19-G	TRL4		TRL8						
Tanks, propellant storage and management - Advanced materials (composite and metallic)	19-G	TRL3				TRL8				
Engine robustness, re-ignition, and health monitoring	18-A	TRL3				TRL8				
LOX - HC propulsion - Cooling system, hot gas injector design (e.g. staged combustion), ...										
Cooling system	18-A	TRL4				TRL8				
Hot Gas injector design (staged combustion)	18-A	TRL4				TRL8				
Ablative thrust chamber	20-C	TRL4				TRL8				
Design and engineering tools enhancement										
MDO	17-A	TRL3				TRL8				
Architecture simplification/optimisation	17-A	TRL3				TRL8				
Margins enhancement	17-A	TRL3				TRL8				

Launchers: Reusable launcher technologies	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **Propulsion system**										
Reusable engine	18-C	TRL2								TRL8
Reusable tanks - Advanced materials (composite and metallic)	19-G	TRL2								TRL8
Earth landing technologies	19-G	TRL2								TRL8
☑ **Atmospheric re-entry technologies**										
Reusable structure, health monitoring, reusable thermal protection	19-G	TRL2								TRL8
Reusable actuators and mechanisms	19-G	TRL2								TRL8

All missions

Data processing, SW & Components
Data processing power & speed
Advanced architectures & SW
Non dependence

Data processing tasks perform critical operations on a spacecraft. Increased data processing power and speed are required at all levels of space systems, to perform control tasks on the system and its payload, or to perform data processing, transfer and storage tasks related to the mission.

Processing architectures will vary (depending on the mission), from distributed to centralised, but the main building blocks, (such as processors, memories, data links, SW etc.) will share the common characteristics needed to perform in the space environment.

Critical requirements are the ability to withstand space radiations (rad-hard equipment), and to operate in the peculiar thermal environment of space (extreme temperatures, issues with thermal dissipation and stability etc.).

Today relevant space qualified European technologies cannot always match the space systems customers requirements, and most of the times non European solutions are preferred.

The critical role played by data processing technologies within the overall space system creates a dependence situation with limits the reach of European ambitions, and of European space policies, including technological and strategic international partnerships (e.g. cooperation with China, or India). Indeed most of these technologies are procured in the US where they are covered by export limitations (ITAR).

If Europe wants to be one of the world leaders in space activities and programmes, achieving technological non dependence on critical items is a mandatory step. Then, data processing and associated SW and technologies shall be a priority.

Systems improvement

The improvement of future European space systems data processing capability relies on architecture and equipment aspects, as well as on hardware and SW aspects.

Processing power and speed require new processors and memories, and software will be adapted to take full advantage of new and enhanced processing capabilities. But power and speed will put additional strain on the thermal environment of the system. All these technical issues, and others, have to be addressed.

Another concern, is related to the guaranteed access, and affordability, of the required technologies and solutions. Thus the use of commercial (COTS) supplies is investigated (for system cost reduction). Mass reduction strategies are also pursued.

- High performance on board data processing
- Safety margins, for system design optimisation
- COTS procurement
- Mass reduction (high performance structures, materials)
- Power dissipation (thermal constraints)

European policies

To fulfil its ambitions in space, Europe needs a competitive space industry, capable of addressing all markets and all customers needs with affordable and adapted solutions.

Similarly to platform technologies, data processing and associated technologies play a central role in space systems competitiveness, with important reliability and efficiency aspects.

Furthermore the guaranteed access to rad-hard equipment with suitable processing capacities is key to ensure the independence of European space policies. Actions already undertaken, such as the European Components Initiative, shall be furthered and complemented with other targeted actions.

- Ensure the competitiveness of space based applications
- Prepare technologies required for next-generation systems
- Support innovation and demonstrate new space-based applications
- Non dependence reduction on critical components or equipment

Technology trends

- Advanced EEE components
  - High speed proc. (>1Gips)
  - DSP (1 Gflops)
  - GaN technologies
- Advanced software technologies
  - Automatic code generation
  - COTS
  - New languages
- High performance data processing
  - Real time processing (Mass memory storage and Data compression)
  - High speed link, high data rate (optics, ...)

Needs

It is needed to develop a European high performance data processing system including advanced software, new architecture and EEE components to improve on board data processing capabilities.

- Fault tolerance and autonomy

- Reduction of operation costs
- Support high demanding payload processing needs increase

Technology roadmap

(refer to key at the end of the appendix)

Advanced EEE components: Electronic and Microwave Parts (in accordance with ESCC agreed roadmaps)

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Digital electronic components										
Support and maintenance of existing European CMOS technologies	22.B.II	TRL7	TRL8							
Advanced CMOS technology	22.B.II	TRL3			TRL6					
High speed ADC	22.B.II	TRL3			TRL6					
High speed DAC	22.B.II	TRL3			TRL6					
High Speed Serial Link (3 to 10 Gbps)	22.B.II	TRL4			TRL6					
High capacity reprogrammable FPGA	22.B.II	TRL3				TRL6				
High speed DSP (1 GFlops)	22.B.II	TRL2				TRL7				
High speed General purpose processor	22.B.II	TRL5			TRL7					
IP core library and SOC	22.B.II	TRL5			TRL7					
Microwave components										
European GaN technology	22.B.VII	TRL3			TRL7					
Development and qualification of European RF devices (PLL, mixers, amplifiers)	22.B.III	TRL4			TRL7					
Generic components										
Power MOSFET transistors (low voltage and high voltage)	22.B.II	TRL4			TRL8					
Development of European passive components	22.B.I	TRL5		TRL8						
MEMS (RF, …)	22.B.VII	TRL4		TRL8						
Packaging										
Thermal management, heat transfert issues (for components packaging)	22.C.I	TRL4			TRL8					
High pin count packages (BGA, CSP) and High density printed circuit board	22.C.I	TRL5		TRL8						
Hybrids (RF & non microwave) & MCM (multi-chip module) & Flip chip	22.C.I	TRL5			TRL8					

High performance on board data processing technologies (Fault tolerance and autonomy)

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **Architectures and technologies for next generation compact data systems, which emphasizes high performance processing capability**										
hardware/software architecture specification, co-design & test tools	1-A	TRL5		TRL8						
High performance data reduction and processing	1-A	TRL5		TRL8						
Architectures and technologies for next generation high performance data systems (multi-processing, high throughput, high reliability, high-dependability, low power consumption)	1-A	TRL3				TRL8				

Advanced on board Software technologies (Highly critical, dependable, fault tolerant/autonomous systems)

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
☑ **Reliability & complexity management**										
Software definition, design, development and test tools	2-B	TRL5		TRL8						
Advanced software technologies for high criticality or high integrity applications including usage of COTS	2-A	TRL5		TRL8						
Processes and technologies to accomodate software components of different criticality levels within highly critical applications	2-B	TRL3				TRL8				
Life cycle time reduction & maintainability										
Automatic code generation tools for complex & ultra-reliable systems (replacement and extension of US tool suite)	2-B	TRL2				TRL8				

Structures & Thermal Control

Thermal and mass/structure concerns have always driven space technology evolution.

In the vacuum of space thermal exchanges are made extremely difficult, and temperature ranges are extreme. Power dissipation issues become critical as spacecraft size increase. Thermal stability requirements at payload level also apply constraints on system design. And while some equipment (e.g. laser sources, radars) generate large amounts of heat which needs to be managed, other equipment (e.g. optical detectors, mirrors) may require very low temperatures locally to perform optimally.

Thermal control technologies are thus essential. Future solutions include active systems, based on fluid circulation, passive systems, for radiation, and cryomachines to generate extreme cold.

Thermal concerns are also addressed at system architecture and structure level.

Thermal properties of materials play a role in the system definition, and advances in material technology have immediate applications to space.

Composite materials have shown great versatility to substitute other materials on spacecraft and launchers. They are notably appreciated for their thermal and electrical conductivity, mechanical performance and high temperature range.

Properties of composites can be tailored to support the needs of a wide range of equipment, such as antennas, telescopes, solar arrays, tanks, boosters, with important mass savings and enhanced properties. New industrial processes are required by the implementation of composites.

Composite materials are at the base of cutting edge space systems. Access to these technologies is required to maintain and develop European space industry technological competitiveness

Price and availability on industrial basis (qualification level) are driving parameters in composite materials selection

European policies

Growing requirements for mass gains with advanced structural properties are mainly driven by economic efficiency concerns that are at the heart of European policy.

New operational and scientific missions in the Earth proximity, and far away, pose new challenges to the spacecraft thermal system, with the need to address extreme temperature ranges.

European system must take advantage of advances in technology with the potential to support technologically competitive space systems.

Non dependence is a concern particularly for composites, where Europe shall widen and strengthen its raw materials manufacturing capacities, the availability of fibres (high conductivity, low density) is crucial.

- Ensure the competitiveness of space based applications
- Support technologies required for next generation systems
- Leverage technological progresses and innovations
- Foster technological excellence
- Non-dependence

Systems improvement

Improvements in system structure, from a material and design/architecture point of view will provide significant advantages in terms of mass and overall system efficiency. Composite materials are now being used on wide range of equipment used aboard spacecraft and launchers. They support such different applications as ultra stable mounting mechanisms (for very large to very small equipment), sun shields or propulsion combustion chamber.

Advances in thermal control technologies similarly affect the space system at all levels, from equipment to architecture to improve overall efficiency and range of operations

- Mass reduction (high performance structures, materials)
- Power dissipation (thermal constraints)

Technology trends

- Structure
    - Stiffness/low mass/thermal properties/electrical combined properties
    - Moisture insensitive (non hydroscopic) properties
    - Functional coatings
- Advanced thermal control

- o High capacity heat pipes (500 w/m)
- o Phased loop (10 to 1000 kw.m)

Needs

It is needed to develop high performance structures (composites, processes, innovative materials like gossamer technologies,...) and advanced thermal control technologies (e.g. Fluid loops, radiators, cryomachines) to

- Enhance thermal, electrical, mechanical properties of system/equipment
- Increase thermal dissipation capacities for high power payloads (mainly RF)
- Reduce dependence at system and equipment level

Technology roadmap

(refer to key at the end of the appendix)

High performance structures (for enhanced thermal, electrical, mechanical properties)

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Composites for low mass structures (solar array, antennas, tanks, boosters, thermal protection…)										
Carbon fibres production (PAN, …)	19-G	TRL4		TRL8						
Matrix/Carbon composites (CFRP, GFRP, AFRP, …)	19-G	TRL4		TRL8						
Carbon-carbon composites (C-C, MMC, CMC…)	19-G	TRL4		TRL8						
Industrial and manufacturing processes: Curing, NDI (Non destructive inspection, …), …	19-F	TRL3			TRL8					
☑ **Innovative materials**										
High performance metals (gossamer technologies, …)	23-A	TRL3				TRL8				
Ceramics	19-B	TRL5		TRL8						

Advanced thermal control technologies

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fluid loops (Micro fluid loop for EEE parts is included in advanced EEE components domain)										
Single phases loop using mechanical pumping (miniaturisation)	20-A	TRL3				TRL8				
Two-phase loop (mechanical pumping) for high power rejection	20-A	TRL2			TRL8					
Two-phase capillary loop technology improvement	20-A	TRL5		TRL8						
Passive technologies										
High efficiency radiators and MLI (Multi layer insulation)	20-D	TRL5			TRL8					
Smart thermal paints & coatings	20-D	TRL5			TRL8					
Cryomachines										
Stirling coolers (down to 4k)	20-B	TRL4		TRL7						
Pulse tubes & adiabatic	20-B	TRL3			TRL7					

System design

Reduced development cycles
Reduced technical risk
Non dependence

In the space manufacturing sector, simulation, modelling, system design, engineering and verification activities are core processes. They represent a key know how for industry, to be mastered in house for risk mitigation purposes. They also require hardware and software tools with significant investment efforts that is hardly amortised.

As testing opportunities in real conditions (in space) are a very rare resource (limited launch opportunities for technology validation), space system and equipment development rely heavily on ground test and simulation equipment as well as on design and modelling software tools.

Modelling is first required of the space environment where the system is required to operate. The ability to accurately simulate a variety of space conditions (recreating orbit elevation, distance from the sun, planetary environment etc.) is the first key to optimised design. Inaccurate models lead to over-designed systems (more costly) in order to reduce risks.

The spacecraft itself can be accurately simulated (the virtual spacecraft concept) to assess system issues and equipment interfacing. The virtual spacecraft will simulate all phases of the spacecraft's lifetime, from the early development stages to end of operational life.

Design, engineering, testing and validation tools are needed at equipment and system level. They have to be interfaced and require commonly shared protocols.

Systems improvement

The complexity of future missions puts the emphasis on system engineering aspects, and better control of technical risks.

The improvement of system design tools and processes will impact significantly all levels of the system development cycle - with cost benefits on the development itself, and on the final system.

In some cases commercially developed tools could be integrated in the process.

- System design optimisation
  - safety margins (environment models)
  - reduction of technical risk
- Better management/control of system related issues
- Complete system lifecycle simulation, from development to end of life
- Use of COTS tools

European Policies

The modelling of space environment is a concern today, as Europe is launching new missions such as Galileo and exploration programmes.

The Galileo orbital environment is not particularly well known in Europe, as it was never exploited before. European simulation tools have to rely on the willingness of other space powers to share relevant information. This is a limiting factor.

Similarly, the exploration of new planets associated to far reaching space travel widens the scope of space environment modelisation, to include new planetary environments, the future destinations of European missions.

- Ensure the competitiveness of space systems
- Support technologies required for next generation systems
- Non dependence

Technology trends

- System, design and engineering tools
  - Suitable models for MEO, upper LEO orbit
  - Suitable industrial tools for system design

Needs

It is needed to develop and improve European skills and capacities in system, design and engineering tools to

- Support availability of a simulation environment for space systems operation
- Support development and availability of methods and tools for system engineering and verification at launcher and spacecraft level
- Support development of engineering tools for design and optimisation
- Support development of tools for complex mechanical systems

Technology roadmap

(refer to key at the end of the appendix)

System, design and engineering tools (Tools related to "access to space" activities are addressed in the relevant section)

	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
System design processes										
Virtual Spacecraft & virtual AIT	8-B	TRL3				TRL8				
Concurrent engineering	8-B	TRL5		TRL8						
Space environment										
Modelling, protective design and test	4-B	TRL5		TRL8						
Radiation measurement	4-A	TRL5		TRL8						
Thermal, mechanical, multi disciplinary software tools										
Mechatronics solutions, ...	19-A	TRL6			TRL8					

Disruptive technologies

Mass/power constraints
Multiple-use research
Technology watch
Spin-in

Space has been at the leading edge of technology for decades. Advances in computing and materials were driven by space research as much as it was benefiting from them. Today space is rarely a leading sector in terms of integrating new technological advances (electronics, materials, etc.), especially since technologies to be used in space need to undergo costly qualification processes, and customers usually prefer proven technological solutions.

Space industry is now primarily an integrator of proven ground technologies, and is lagging behind other industrial sectors in such areas as electronics, materials, or power generation.

Advances in nanotechnology and power generation systems exhibit very high potential of benefit if applicable to space systems. Indeed mass and power constraints are major drivers of space systems design and act as mission limiting factors.

Disruptive technologies may allow to rethink the way space systems are conceived with potentially major leaps for both scientific missions (e.g. very long distance travel) and operational missions.

Technology watch, and readiness to apply new technologies to space programmes can bring space industry to new heights.

Competitiveness

Power sources

As spacecraft are given the ability to travel longer distance with advances, particularly in autonomous navigation systems and on electric propulsion systems, new issues arise as the spacecraft moves away from the sun. Power becomes scarce, and alternate power sources to solar generators have to be considered to provide the energy required by spacecraft operations. Very high efficiency (in terms of mass and power budget) power generation concepts are appealing to space systems requiring power autonomy away from the sun.

Nanotechnologies

Due to the difficulty of reducing significantly launch costs, and the limits in spacecraft mass and volume put by the available launcher supply, the optimisation of spacecraft volume and mass budgets is at the heart of mission and spacecraft efficiency.

From this point of view nanotechnologies have immediate appeal to space applications.

Critical space applications of micro and nano technologies will be in the areas of

- thermal control
- nanotubes/smart structures
- propulsion

Disruptive solutions are potential enablers of new space missions

- Mass constraints drive miniaturisation strategies
- Power requirements (space travel, payload) demand new power generation technologies

European programmes

European space technology programmes cannot yet address the necessity to integrate rapidly into space programmes the advances made on ground technology.

A most important step to leverage ground technology advances in space is the validation and qualification process by which the technology ability to withstand space conditions are proven. This step is required by most customers for operational space systems, but with the chronic insufficiency of technology validation programmes with suitable flight opportunities, the array of concepts, technologies and products available for space programmes does not grow rapidly.

European efforts should support adequately the speediest use for space applications of technologies developed in other sectors.

Today only very few European initiatives have specific provisions for this.

- ESA Innovation Triangle Initiative (ITI)
- Exploration of the solar system and universe

Technology trends

- Miniaturisation
- New power sources
- Innovative materials

Needs

It is needed to develop micro/nanotechnologies (eg. nanotubes) and to investigate the space potential of using new power sources technologies (such as RTG's use) in space to

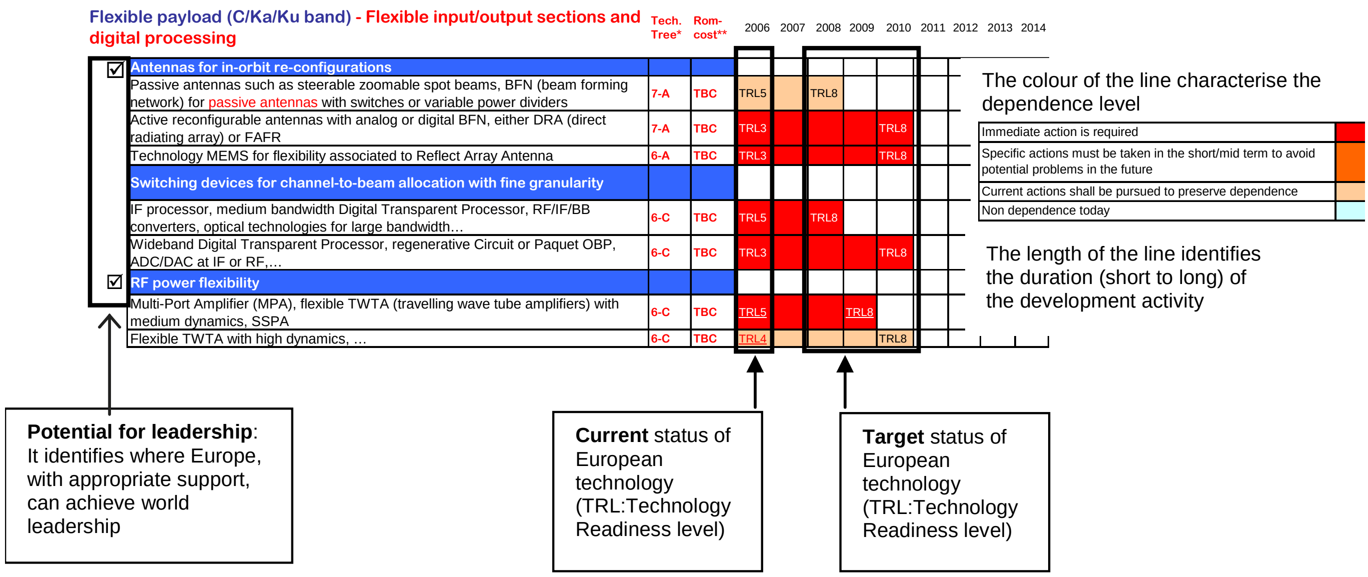
- Support new ambitious space missions
  (integration of new power sources in European systems)
- Maintain competitiveness of industry

Technology roadmap

(refer to key at the end of the appendix)

Technology breakthrough	Tech. Tree	2006	2007	2008	2009	2010	2011	2012	2013	2014
New power sources (for high power needs)										
Handling of RTG's (Radio-isotope Thermoelectric Generator) and RHU	3-A	TRL2				TRL6				
Alternative solutions for high power sources (Nuclear, Solar, Hydrogen...)	3-A	TRL2				TRL6*				
Micro/Nanotechnologies										
Heat pipe for micro applications (e.g. processor cooling…)	20-A	TRL3				TRL6				
Nanotubes, nanomaterials, Supraconductivity 4K RSFQ, …	23-A	TRL2				TRL6				
Micropropulsion	18-C	TRL2				TRL6				

How to read a technology roadmap



TRL: Technology Readiness level

1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
9	Actual system "flight proven" through successful mission operations

Appendix C COOPERATION WITH RELATED EU TECHNOLOGY PLATFORMS AND INITIATIVES

Robotics (EUROP TP)

State of the art and current use in space

R&D investment in space Automation and Robotics (A&R) at ESA and at National Space Agencies has totalled several tens of €million, with ESA effort being funded by ESA technology programmes (TRP and GSTP) and dedicated to:

1) study of robotic applications: how robots could be in space
2) "space-conversion" of existing terrestrial robotics technology: adaptation to the environmental and operational constraints
3) development of new A&R technology (i.e. with no terrestrial heritage) for space

The investment made has allowed developing state of the art technology as well as creating and maintaining space A&R industrial capabilities needed to serve European space missions. In the field of Space A&R has benefited from national/industrial interest and R&D development leading to an oversupply of excellent technology, far exceeding the amount of flight opportunities.

Nevertheless R&D at ESA/National Agencies pursued in the last 20 years, has made its way into major space projects:

1) the European Robot Arm (ERA), scheduled for launch on the ISS in 2007
2) the ExoMars rover, currently in phase C/D and scheduled for launch in 2011
3) ConeXpress-OLEV entering phase C/D in mid 2006.

A&R technologies have been an enabling factor in a number of missions studied/being studied at ESA and at National Space Agencies, such as:

- Orbital robotics: essentially robot arm systems for
  - Space-station assembly and maintenance. Examples: Spider (I), AMTS, MISSIS (D), EUROPA (I) EUTEF, Eurobot
  - Satellite servicing in GEO or MEO. Examples of studied systems/missions: GSV, ESV (D)
- Planetary robotics: mobility systems (rovers, moles and aerobots) for the exploration of high gravity bodies (e.g. for Mercury, Moon, Jupiter, Europa). Examples: Venus micro probes, Mercury's Bepicolombo Rover, Moon's LEDA rover, Mars rover navigation system (F), the MIRO driller rover, Exomars.
- Small body robotics: mobility and sampling systems for low gravity bodies (comets and asteroids). Examples: Rosetta drill, sampling and distribution system (I).

Vision for the future

There is universal agreement that the A&R will play an essential role in Space Science and Exploration (space power production, space manufacturing, space mining) and in the development of innovative commercial space applications (satellite servicing, large space infrastructure). These missions will see:

- *Robot Assistants:* helping Astronauts to perform their task quicker, safer, with higher quality and more economically.
- *Robot Agents:* working into hostile and dangerous areas and acting in place of humans to perform assembly, maintenance and production tasks in autonomous way

- *Robot Explorers:* venturing in the hostile and remote planetary environments for exploration and science. Coping with and taking advantage of the peculiar environmental conditions to achieve long duration and extensive range missions.

Europe has an excellent research and industrial base in manufacturing automation and service robotics, areas with large commonalities with space robotics. However, it cannot be expected that the technology needed for use in space applications will be made available by the non-space community.

This is because terrestrial developments do not consider/address the specific needs and constraints of space missions. Space robots need to survive launch and landing loads and to operate in vacuum (for orbital applications), under null or reduced gravity, under extreme radiation exposure, extreme temperatures, extreme lighting and contrast conditions, in an extremely remote environment. Some terrestrial technology can be adapted to be compatible with these constraints, some other require development from scratch (either because there is no terrestrial analogue or because the terrestrial analogue cannot be implemented in space).

Hence funding of Space A&R is needed to undertake these adaptations/new developments, which are not likely to be funded otherwise. Furthermore, R&D in Space technology A&R will keep on producing benefits to the non-space sector, as it was the case in the past.

Impact on space applications

Automation and Robotics is being used as basis for major space missions (especially in NASA) and it is being considered for a number of new missions. For these missions, A&R is clearly perceived as:

- mission enabling: it is not possible to achieve the mission goals without robots (e.g. exploration of Venus, Europa)
- mission enhancing/supporting: robots provide earlier/larger results as complement/pathfinders to humans (e.g. ISS, Moon/ Mars exploration)
- cost saving: robots replace humans to make missions/applications viable (e.g. satellite servicing by humans is technically feasible however clearly unaffordable for commercial operators)

Priority actions

ESA has a clear mandate to fund “Space-only/mainly” R&D for A&R i.e.:

- R&D in new technology which does not have application in terrestrial A&R
- “Spatialisation” of existing terrestrial technology (adaptation to space environment and resources)
- R&D in technology which <u>has</u> application in terrestrial A&R but has no other funding

Besides the self-imposed limitations (terms of reference), the insufficient level of funding and the rigid structure of the funding programs mean that the R&D is/has been limited in:

- Breadth: not all R&D fields needed by space can be pursued
- Depth: subjects that require upfront research have to be discarded
- Time span: while on one side there is inability to look to future term research on the other there is no scheme that allows the creation of products from lab proven technology

The establishment of EU technology platforms, related to Space and robotics, provides an ideal complement to ESA’s activities, as they would allow to:

- Enlarge the breadth of R&D in Space A&R (EUROP)
- Provide upfront R&D (EUROP)
- Allow R&D to turn into products (ESTP) for strategic non-dependence.

In particular the following actions should be pursued:

Initiate Upfront R&D in:

- *Resilient and frugal autonomous robots*: terrestrial robots may rely always on 1) help from humans, 2) large energetic and computational budgets. None of this is available for space robots, which, on the contrary, have to manage autonomously any foreseeable problem while working with minimal resources. There is hence the need to develop low-energy autonomy/resiliency technologies. A possible strategy to come to solutions is to work on *biomimetic* systems research.
- *Cooperating robots/humans:* Space tasks entail working in environments or handling of physical systems, which both have dimensions much larger than the robot itself. This is why *human-robot/robot crews* or *robot swarms* are advocated. The use of multiple systems not only allows coping with the dimensional contrast but also allows building robustness in the robot solution through system redundancy. However research into self-organisation of the work and cooperation needs to be carried out.

Initiate Space A&R product making:

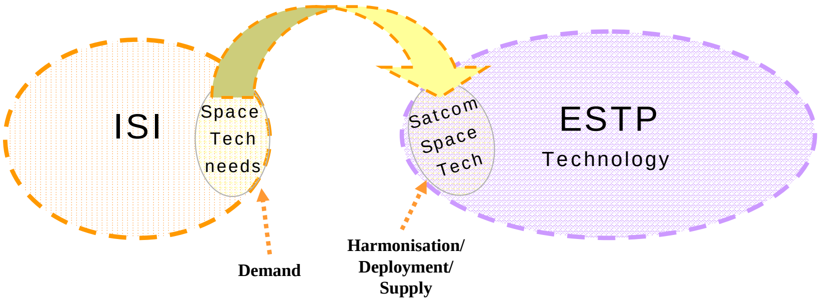
- *Robotics Building Blocks*: after many years of R&D, European Agencies and Industry have produced several robotics systems and components, which would be ready for mission if their qualification level would be adequate. However there is neither an ESA funding programme suitable for qualification, nor the willingness of mission programmes to invest in the generic qualifications of these systems. As consequence, missions who could make use of robots either do not apply such technology or resolve to buy non-European components. There is a need to bring the many European developments to the stage of ready-for-flight products.

Integral Satcom Initiative (ISI)

The Integral Satcom Initiative - ISI (www.isi-initiative.eu.org) brings together all aspects related to satellite communications, including mobile, broadband, and broadcasting applications, security systems and applications, and the integration of data communications with navigation, Earth observation and Air Traffic Management systems, both for commercial and institutional/ governmental applications. ISI is committed to contribute to several EU and ESA policies, in sectors such as ICT, Space, Security, Transport, Development, and Environment.

Representatives of ESTP and ISI met in Brussels on 21.03.06 to discuss the way forward in addressing the future challenges in the exploitation of space with European technology. A strong spirit of collaboration clearly emerged from the meeting, whereby both parties recognized that coordination and synergy are the key ingredients to achieve significant results for European industry. The two platforms agreed that it is essential to stimulate public and private investment in these strategic fields by strongly presenting the case to the EU and ESA Member States, in order to stand up to the harsh challenges that are posed by the rivalling actors from the US and Asia. In particular:

- ISI will address all aspects related to satellite communication systems architecture design, services and applications, issues related to the harmonization of the regulatory regimes, and the preparation and promotion of standards, especially those that see as principal actors European industries and operators.
- The ESTP will extend the efforts being made by ESA and its Member States in harmonising the plans for the development of technologies for space-based systems to include spin-in and dual-use, will promote the development in Europe of critical technologies for non-dependence, and will foster the deployment of technologies enabling new EU applications.



Representatives of both platforms agreed on exchanging information on a regular basis and work along a joint strategy concerning space technology, where ISI will be on the demand side and ESTP will be on the supply side (responsible for harmonisation, prioritisation and deployment). In particular:

- Upon identification of technology development needs, ISI will take into account the plans agreed by Member States reflected in the European Space Technology Master Plan (ESTMP) and in particular the ESA Telecommunications Long Term Plan, avoiding any unnecessary duplications.
- ESTP will incorporate in its technology planning process the requirements expressed by ISI and provide recommendation for implementation in stakeholder's/community programmes as appropriate.

Hydrogen and Fuel Cells (HFC)

ESA has interest and a significant experience in the field of fuel cells for human spaceflight (activities carried out in the frame of the Hermes programme) and for planetary exploration. Previous activities include assessments on photocatalytic methods to produce fuels for solid oxide fuel cells on Mars.

ESA is currently conducting research on advanced power systems, in particular aiming to assess novel fuel-cell concepts and hydrogen storage/production technologies. Cryogenic storage of hydrogen is a key aspect for propulsion, in particular for launchers.

In June 2004, a summary of the know-how acquired by ESA in the area of Hydrogen and fuel-cells was presented to DG-Research. *Infodays* and conferences on *Sustainable Energy Sources* have regularly been attended by ESA, with the objective of identifying synergies between EC and ESA programmes.

Cooperation on a more structured and regular basis is now sought under the frame of bilateral relations between ESTP and the HFC Technology Platforms.

Batteries (EUROBAT)

According to EUROBAT the 2004 world rechargeable battery market was valued at 19 B€ of which more than one half was automotive. In the near future (3-7 years) there is expected to be a large increase in hybrid and electric vehicles as well as aircraft, train and ship battery applications. In addition there will be a continuing growth of battery powered consumer devices. In the longer term will be added the storage requirements needed to complement renewable but intermittent energy sources such as wind, solar and wave when they make up a significant proportion of generating capacity. With these and other future applications it is clear that this market will grow substantially.

In the foreseeable future space applications will represent but a tiny part of this market so it is clear that batteries will continue to be a technology where space relies on "spin-in" from terrestrial developments.

70% of space battery business is for telecommunication spacecraft, where the main driver for future developments is to increase specific energy in order to reduce launch cost or increase useful payload. This is seen as extremely important by European prime contractors since it increases their competitiveness in the World market. Most other space applications also benefit from batteries with high specific energy but other factors such as cycle life, specific volume, rate capability and extreme temperature performance may dominate in particular cases.

It is fortunate that the rechargeable battery needs of telecommunication spacecraft are rather similar to those for electric vehicles. As a result ESA and CNES have been able to qualify lithium ion batteries for space ahead of the other space powers by adopting the electrochemistry already developed for electric vehicles and concentrating on space-specific aspects such as packaging and life-testing. The existing terrestrial development also brought the advantage that a large investment in industrial scale production facilities was already in place. Two generations of electrochemistry have already been space - qualified and are flying both on ESA and on commercial telecommunication spacecraft whilst a third will be qualified in 2006 for Alphabus and Galileosat.

In the same time frame Europe has also qualified batteries based on small commercial cells from SONY (developed mostly for the camcorder market) which are also already flying on a number of scientific and earth observation spacecraft.

At the time of writing some 70 future space programmes worldwide have baselined one or other of these European Li-ion battery types. Once a few years of flight operation have been demonstrated it is expected that the remaining more cautious telecommunications spacecraft operators will make the switch away from nickel hydrogen. The reason for this rapid adoption is that lithium ion offers more than a twofold improvement in specific energy compared to previously used nickel hydrogen technology (and threefold compared to nickel cadmium) coupled with a much improved round trip efficiency, much lower self discharge and at least comparable cycle life. Since 2000, this technology has been chosen for all new ESA programmes.

Hybrid electric vehicles are also driving the development of high rate lithium ion technology, needed for peak power and regenerative breaking. This type of cell is also under qualification for powering the thrust vector actuators of the Vega launcher. Most future launchers are expected to require similar batteries as a result of the trend from hydraulic to electric thrust vector control.

Despite the present advanced position of European lithium ion space batteries, Europe is under very strong competition from the Far East which has almost a world monopoly of lithium ion cell production for small consumer devices and a formidable ongoing research effort. The first Japanese telecommunication satellite with large cell lithium ion batteries was launched in 2005. When one considers the Japanese lead in the development of hybrid electric vehicles and the expectation that they will soon switch from nickel metal hydride to lithium ion, it is clear that the competition in cost and performance of the larger cells needed for these spacecraft will increase still further.

This synergy of space and electric vehicle requirements is expected to continue into the future. The specific energy at cell level has already been increased from 135 to 165 Wh/kg and it is likely that this can be further increased beyond 200 Wh/kg by the application of nanotechnology to electrode optimisation. Currently electrode performance is limited mainly by the lithium diffusion rate within the electrode active material particles which limits the choice of electrode chemistries. With nanostructured electrodes the diffusion path lengths are much shorter which opens up the use of a much wider selection of electrode materials including those which are lighter, cheaper and/or produce a higher cell voltage than at present. Although cost is not such a strong space driver, the need for long cycle life in electric vehicles should ensure that cost / performance tradeoffs will not lead to technologies unsuitable for space (This may be less true for future small consumer cells where cycle life is less important than initial performance). The interest in nanotechnology for batteries creates another link with the EuMat (materials technology) platform.

To meet the competition it is mandatory that Europe pool as much as possible its available research and development efforts. This has already started with organisations like ALISTORE. ESA can then focus its available R&D budget on topics which, although directed towards space requirements, are complementary to terrestrial efforts. To foster such links, ESA-sponsored PhD project opportunities and possible membership of ALISTORE are under investigation.

The main development efforts which are specific to space applications result from the hostile environment and exceptional reliability requirements. For example mechanical resilience during launch and cycle life need to be rigorously demonstrated. Single failure tolerance at battery level requires detailed knowledge of cell failure modes and where necessary implementation of bypass devices. Battery management electronics has to prevent cell voltage excursions outside acceptable limits and ensure cell state of charge balance. Since space applications frequently aim to use batteries close to their capability limits, understanding of the factors which affect battery performance and the development of electrical, thermal and aging models to aid power subsystem design are also highly desirable. Limited commonality with terrestrial requirements may exist (a trend towards battery integrated systems for terrestrial applications is, for example, identified by EUROBAT) and in some cases there may be spin-off opportunities. Space applications with unusual requirements such as operation at low temperature (planetary probes and rovers), exceptionally high shock requirements or unusual geometry constraints (microsatellites) will require a similar approach of choosing an existing electrochemistry which most closely meets the needs followed by limited design changes to meet the space environment. This approach suggests the desirability of early life/performance testing of a wide range of commercial cell types including cells with immobilised or polymeric electrolyte (ruggedness and flexible geometry). The COTS approach will continue to be attractive for low cost space missions.

Of the three technologies covered by EUROBAT's strategic research agenda, lead-acid, nickel - metal hydride and Li-Ion, only the Li-Ion SRA is relevant to space. Whilst lithium ion technology appears established for some considerable time into the future (at least 10 years), other more radical battery concepts, currently in the early stages of development such as the lithium - organic polysulphide couple may eventually allow the specific energy to be further increased beyond 300 Wh/kg. A ESA activity (in its TRP programme) looking at cells targeting 250 Wh/kg will start in 2006. The ultimate in specific energy available from a rechargeable chemical battery would be from a reversible or regenerative hydrogen-oxygen fuel cell. However the latter's greater complexity and lower roundtrip energy efficiency most likely means that fuel cells will eventually supplant some but by no means all space lithium battery applications.

In summary, space batteries are going to continue to exploit developments made for terrestrial applications ("spin-in") and space agency funding will mostly be used to adapt, characterise and qualify these for space. A continuing improvement in lithium-ion cell performance, especially specific energy, cycle life and cost is expected as a result of the development of new electrode materials and electrolytes. Nanotechnology is likely to play an important role in electrode improvement. To obtain specific energies in excess of about 250 Wk/kg will require a departure away from lithium ion to more radical electrochemistries and at their current early stage of development it is by no means certain that any of them will be able to meet all space requirements. Eventually reversible or regenerative fuel cells may displace lithium batteries from some but by no means all space applications.

These battery developments for space programmes will in general not be mission-enabling but will nevertheless be very important in terms of cost and competitivity for commercial programmes and in terms of cost and performance for non-commercial applications.

Advanced Materials

The space sector has large interest in the research that addresses advanced materials. This is a very vast domain which can find application in a majority of space domains and involves a significant number of experts from very different horizons (material, components, systems (electrical and mechanical), etc). The need for advanced materials is already patent for launchers, scientific missions (specially for harsh environment scenarios) but also for other generic technologies such as MEMS or semiconductor devices. Activities already started by ESA and by the European space community in the field of advanced materials are therefore spread over several domains of expertise and deal with very different technologies such as GaN, SiC, SOI but also Nanotechnologies. The objectives of these activities can range from material development up to concept demonstration after prototype manufacturing.

A meeting took place in February 2006 between EuMat and ESA representatives, which highlighted specific synergies between the Advanced Material Technology Platform and space related programmes. It is desirable that cooperation between ESTP and EuMat is pursued rapidly as this will facilitate the visibility of the European space community on state-of-the-art development in the area of advanced materials, while contributing to define user requirements to EuMat and identify applications for technology developments in the platform.

However, other technologies needed by space, such as Nanotechnology and, in particular Nanomaterials (Carbon Nanotubes, Nanopowders, etc) or MEMS, do not seem to be sufficiently addressed today within EuMat. Hence, to meet the needs of the space sector, the ESTP shall also establish close collaboration with other platforms (e.g. ENIAC) addressing technologies not sufficiently covered in EuMat.

Nanoelectronics and Embedded Systems (ARTEMIS)

Assessments are being carried out in ESA on new and emerging technologies for possible use in space. This includes nanotechnologies for use in biological contamination detectors or life marker chips (for both human and robotic space missions). Ongoing studies address also the potential of nanoelectronics as enabling technique in the development of new light detectors, such as e.g. high operating temperature infrared sensors, or in space solar cells.

Studies on embedded systems are also foreseen in the near future, especially for application on distributed networks of sensors for planetary exploration, or on health monitoring systems in launch vehicles or space suits.

ESA and the space community has a clear interest in both areas from an application standpoint, but development efforts for space are still at an embryonic stage. Hence the interest in establishing a regular cooperation with Technology Platforms addressing these issues to assess (in the mid-and long-term) the projected evolution of European capabilities on nanoelectronics and embedded systems and its potential for use in space.

Aeronautics (ACARE)

Specific areas of collaboration between ESTP and ACARE relate to the possible application of state-of-the-art aeronautics technology to the development of reusable launch systems. This includes areas such as advanced structural materials and concepts, GN&C and avionics systems, health-management systems, new developments in aerodynamics (especially flow control, BWB concepts and drag reduction mechanisms), component miniaturisation and advanced airbreathing propulsion concepts based around ram/scram technology. Cooperation in this area will lead to a better understanding on how currently-developed aeronautical technologies could be meaningfully applied to European launchers, and whether technologies being developed by the space community could have application in aeronautical systems.

An earlier example of collaboration between ESA and the EC is the water recycling system for Airbus. A number of ESA contracts address areas such as man-machine interfaces, habitats, intelligent structures, etc.

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