The Future is our Business

- How ESA prepares its technology

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Introduction

Many people in all walks of life pay lip service to the fundamental importance of technology in our modern world, but few understand its true significance and role in our fast-evolving and ever-changing enviroment. For organisations such as ESA, however, which focus on Research and Development, it is an area of primary importance, a driving force that is at the very core of its existence.

To those on the outside, technology is often perceived as exciting, but mysterious – a stereotyping that is compounded by the jargon of technology, with words such as prototype and engineering model. In contrast, many working on the inside would describe technology and its associated disciplines as a vibrant and dynamic environment.

Another misconception about technology is that it only deals with the future. Any consideration of technology should look not only to the future, but also to the past. We must use the lessons that we have already learnt to stimulate our creativity and to develop new ideas.

Despite this, and underlying all the instrumentation and infrastructure, one vital element is often overlooked – the human element. People are ultimately what technology is about, and it is people that make the difference. This was explicitly acknowledged in the first ESA Technology Master Plan, in which it was stated that: *"...the ESA TMP shall make provisions to assure the motivation of staff for technology development"*. It is further acknowledged by the fact that the ESA Awards scheme, which relies on peer recommendation for choosing its winners, has technology teams and engineers as regular nominees.

What is Technology?

At this stage, it is worth differentiating between three closely related areas:

– Technology, which is the practical application of knowledge so that something entirely new can be done, or so that something can be done in a completely new way.
– Scientific research, which encompasses the discovery of new knowledge from which technologies can be derived.
– Engineering, which involves the use of technology to solve specific technical problems.

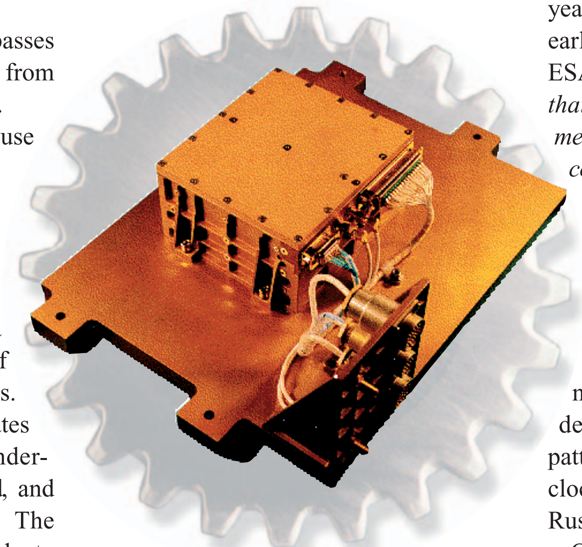
Because a scientific result or an engineer's idea can rarely be translated directly into an item or a product, the development of technology is a step-by-step process. The completion of each step validates the ideas, provides a greater understanding of the phenomena involved, and confronts the theory with reality. The experience thus gained allows people to move forward to the next stage with increased confidence. When put together, all of these steps form the development process – the 'D' in R&D.

Lower risk, higher cost

Technology effectively addresses a risk-reduction process, risk being understood here as the risks and uncertainties associated with performance, cost and schedule. What would be the likely consequences if a project were initiated without first ensuring that the technologies needed are available? Three of them are already well known, namely under-performance, schedule delays and cost overruns.

Throughout the development stage, one common truth persists: when investments are made in a particular technology, it begins to mature. The process of testing and analysing progressively reduces the risk involved in selecting that technology. At the same time, its readiness for use increases. 'Maturity' is reached when the level of confidence in the technology and the level of risk involved are deemed to have reached acceptable levels. The technology is then ready to be included in a product or a project, or to have something built around it.

As mentioned earlier, all technology starts with people – for instance, scientists making a discovery, or engineers having an idea. The first step is to check out and demonstrate the feasibility or validity of this idea. But to finally translate the idea into a product or project can take an enormous amount of time and effort. More people and materials will be needed as the development work progresses, as each step requires a greater effort for its completion. The closer you come to the final product, the more stringent are the requirements, the more accurate the manufacturing needs, the more realistic the tests – and ultimately, the greater the costs.



The first European Rubidium Ultra-Stable Oscillator for space application

In other words, the cost increases as the development cycle progresses, whilst at the same time, the level of risk involved decreases. Nevertheless, an increase in funding does not imply a proportional reduction in development time.

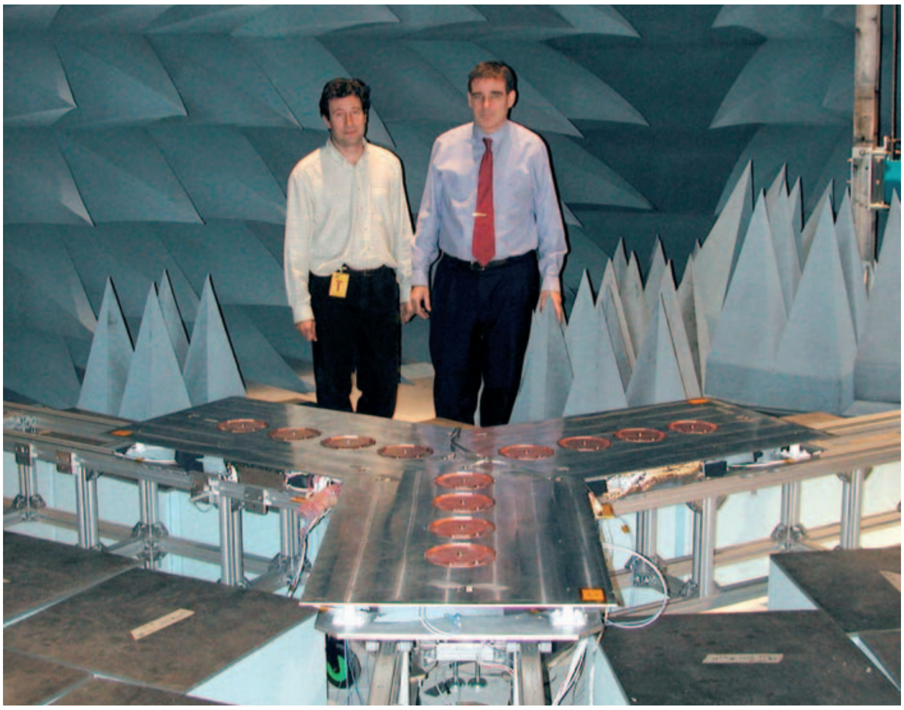
How does technology evolve and mature?

As we have seen, technology usually matures through a series of sequential steps, starting with the initial exploratory studies that support a pioneering idea. These are usually based on very broad views. In the case of space technology, the end result that is aimed at is usually a flight-qualified product that will be integrated onto a spacecraft.

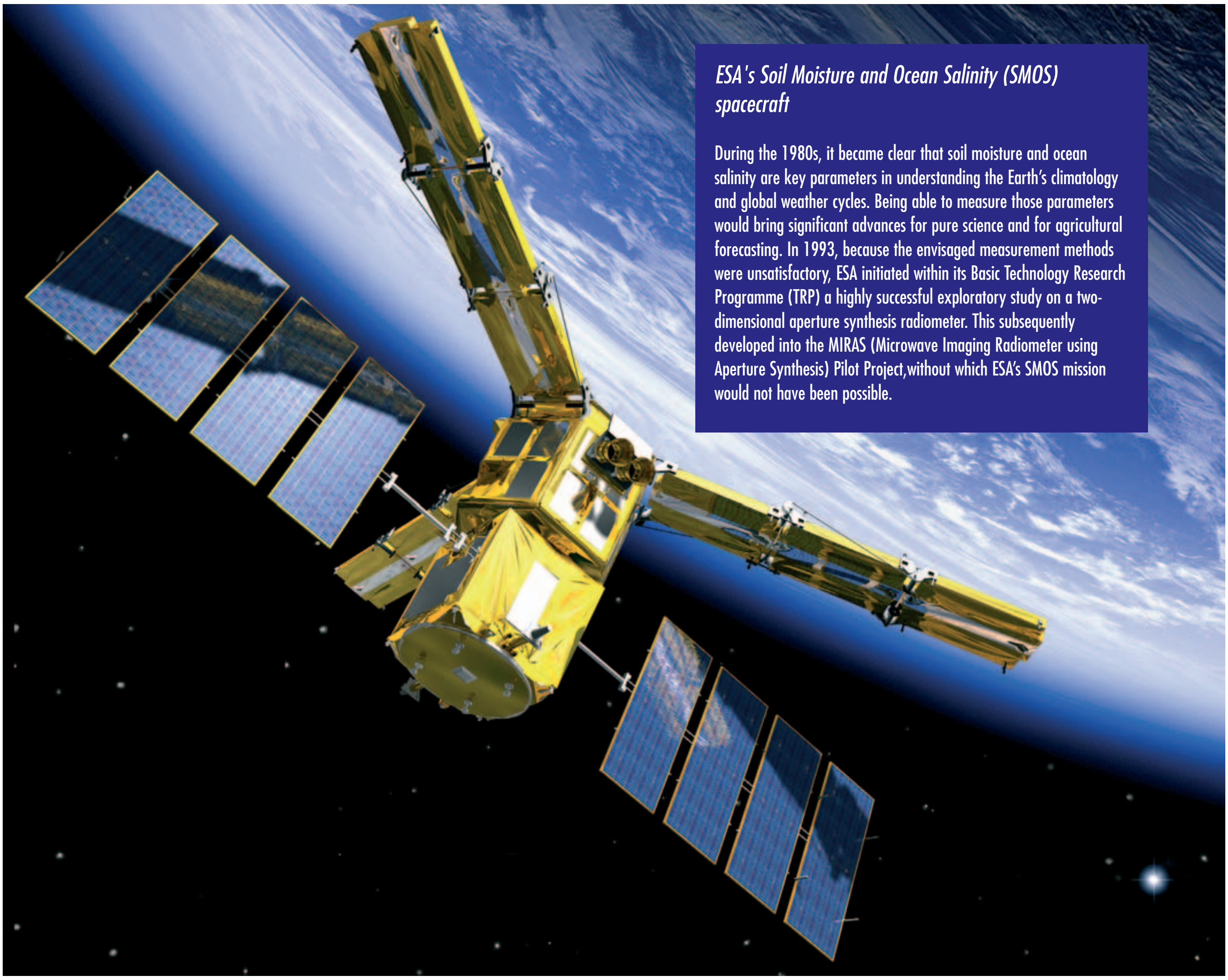
The process, however, is rarely that straightforward. It involves an enormous amount of both curiosity and foresight on the part of the people involved – factors that have been major driving forces for ESA's technology. For example, some 15 years ago, Stephen Feldham headed the early development of ultra-stable clocks at ESA. He says: *"Not only did we recognise that it would be fascinating to be able to measure time accurately, we also realised it could be a very important asset for Europe. We therefore tried to build clocks that were more accurate, smaller and lighter than any existing at that time."*

The result of this initial curiosity was technology that has since been developed into the European Galileo navigation system. However, technology development rarely follows a linear pattern and the first European rubidium clock for space was actually intended for a Russian radio-astronomy project.

Other factors that affect the way in which ideas develop include personal backgrounds and experience. These can help in the identification of the right problems for solution, and can also provide a considerable amount of motivation. Manuel Martin-Neira helped to conceive the MIRAS pilot project on which ESA's Soil Moisture and Ocean Salinity Mission (SMOS) is based. He recalls: *"My father and grandfather were forestry engineers, and I knew about the importance of measuring soil moisture for this community, and the problems involved in measuring it…I was fascinated by the idea of trying to apply radio-astronomical techniques (a field in which I had some experience) to problems here on Earth."*



MIRAS Pilot Project testing in progress



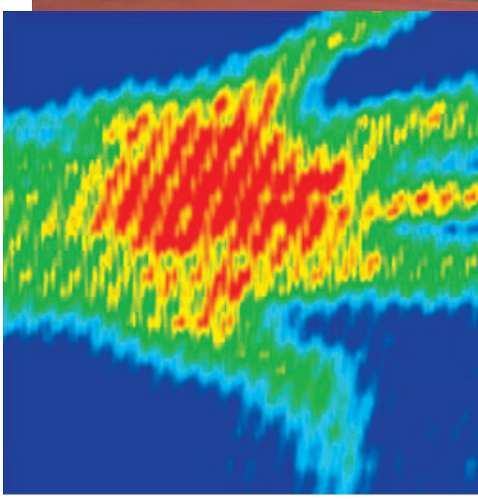
ESA's Soil Moisture and Ocean Salinity (SMOS) spacecraft

During the 1980s, it became clear that soil moisture and ocean salinity are key parameters in understanding the Earth's climatology and global weather cycles. Being able to measure those parameters would bring significant advances for pure science and for agricultural forecasting. In 1993, because the envisaged measurement methods were unsatisfactory, ESA initiated within its Basic Technology Research Programme (TRP) a highly successful exploratory study on a two-dimensional aperture synthesis radiometer. This subsequently developed into the MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) Pilot Project,without which ESA's SMOS mission would not have been possible.

The StarTiger project

In a pilot project to test the StarTiger concept, 11 hand-picked scientists and engineers drawn from seven European countries spent four months in 2002 at Rutherford Appleton Laboratory (UK) developing a terahertz imager, a technology that did not exist but was regarded as highly desirable. The pilot project was successful, and in January 2003 was honoured with an ESA Award.

The world's first terahertz image of the human hand is shown below left

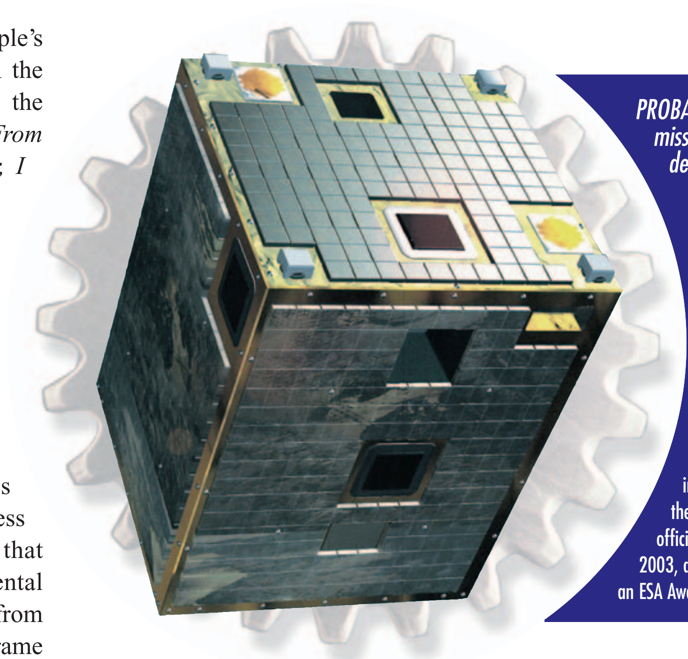


The intrinsic value of different people's experience was even more evident in the StarTiger initiative. Peter de Maagt, the originator of the concept, remarks: *"From my experience as a diving instructor, I know about the value of teamwork."*

Developing Technology for Space

For space programmes, the technology-development cycle tends to have a very long lead time, typically ten years. Consequently, a mission-development time frame is likely to be of similar duration (unless it relies totally on technologies that already exist, need a few incremental developments, or are being adapted from terrestrial applications). The time frame can sometimes be even longer, as demonstrated by the 30 years of development that has been needed before using electric propulsion operationally.

Primarily, space technologies exist to enable missions or applications, be they the result of planned developments or unexpected breakthroughs. The space-technology development process, from exploratory study to flight-qualified product, is driven by two key forces. The first is an identified need for an anticipated future mission, or 'mission pull', using technologies that are already within reach. The second is the advent of a new technology that promises advantages over other alternatives for future space projects, namely the 'technology push'.



PROBA, ESA's first small satellite mission for technology demonstration

In 1996, a small mission dedicated to in-orbit technology demonstration and Earth environment monitoring was proposed as part of ESA's GSTP-2 programme. PROBA (Project for On-Board Autonomy) is a small spacecraft equipped with a set of technologies that provide advanced on-board functions to support mission operations with minimum ground involvement. It proved so successful that the mission was extended to cover an official Earth Observation Campaign in 2003, and the PROBA team was proposed for an ESA Award in 2002.

Developing Technology within ESA

Technology is indispensable when it comes to building satellites and payloads, and sending them out into the inhospitable environment of space. It is therefore hardly surprising that 'technological research work' is a mandatory element within the ESA Convention.

Although technology lies at the heart of ESA's activities, it can be difficult to quantify what proportion of them directly involve technology. Some 90% of ESA's budget is spent on contracts with European industry and universities. Although this is for R&D in its widest sense, it also covers such aspects as systems studies and engineering, manufacturing, production, testing, launching, and mission operations. However, technology development can also be quantified in terms of its growing maturity, with each step in the development process being formalized in terms of a 'Technology Readiness Level' (TRL), with a scale of 1 to 8 reflecting the extent to which the technology has been proven in a realistic situation.

In this scenario, 'technology' within ESA is associated with activities from TRL levels 1 (technology concept and/or application formulated) to 4 (component or breadboard validation in the relevant environment). In exceptional cases, it will include TRL 5, based on a system/ subsystem model or prototype demonstration in a relevant environment – either on the ground or in space. In this case, the space environment is required to fully demonstrate readiness of the technology.

The introduction of ESA's R&D landscape and technology maturity scenario provides the possibility to cover the complete cycle of developments. *"We see it as a major achievement that it was possible to develop an integrated ESA-wide Technology R&D Programme in Support of Future Scientific Missions.... Initial technology developments, leading to an experimental feasibility verification, are pursued with funding from ESA's Basic Technological Research Programme (TRP). The Science Core Technology Programme (SCTP) focuses on reaching a higher level of technology maturity by developing engineering models, before the start of the definition phase of a scientific project"*, says Giorgio Bagnasco, the SCTP Coordinator.

The Future is Our Business

The future of technology development depends on its people, but the content of ESA's technology programmes must be in line with the Agency's future mission scenarios as well as the development of the commercial space segment. However, this is not an automatic or self-standing process – it requires active participation from people with both ideas and experience.

Michael Eiden, Co-Chairman of the Working Group on Science relevant for the preparation of TRP 2004-2006 and GSTP-4, explains: *"One of the most important points is that everybody is able to express themselves and to confront and defend their ideas against those of others."* He adds: *"…Given all the new elements, the preparation of a new TRP Plan for Science is now more challenging than it was in 1985, when I first participated to such an exercise."*

The process of setting up new plans for the TRP and GSTP programme is based on the use of interdisciplinary Working Groups, composed of experts drawn from all ESA Directorates, covering the following themes: Earth Observation; Science/ Robotic Exploration Preparation; Human Spaceflight/Manned Exploration Preparation; Space Transportation/Re-entry Technologies; and Generic Technologies and Techniques. Their work is guided and reviewed by Advisory Panels at senior-management level, with the final endorsement being provided by an ESA-wide forum. The process is currently on-going, with new three-year plans for TRP 2004-2006 and GSTP-4 due to be published early in 2004.

Despite the complex process involved in establishing a new R&D plan, it has to be remembered that technology R&D for space applications has to progress quickly. Many fascinating problems remain to be tackled and the following are just a few examples of the challenging and very forward-looking technologies that are currently being explored:

– A wireless spacecraft, replacing complex cables and connectors, which represent a significant amount of dead weight on every spacecraft as well as being a potential source for failure. ESA is therefore currently investigating (within the TRP) a way of using either radio-frequency or optical devices to eliminate or substantially reduce the need for cabling.

The new lightweight Inflatable Re-entry and Descent Technology (IRDT) demonstrator

The IRDT made its first test flight in February 2000, supported through ESA's Basic Technology Research Programme and the International Science and Technology Centre (ISTC). The technology is designed to reduce the mass and cost of future re-entry systems for visiting the planets and for returning to Earth. A second test-flight is planned for 2004.

– Wide band-gap semi-conductors, demonstrating the value of a completely new class of semi-conductor material that could overcome many of the limitations of today's silicon-based devices.
– Radically new ultra-light structures, looking at the feasibility of structural concepts based on inflatable devices.
– Active Intelligent Materials, exploring a new class of intelligent materials for space applications (e.g. artificial muscle).

It is worth remembering that, as with all R&D projects, there is always a chance of failure. However, the outcome of such investigations ultimately has the potential to shape the future face of space.

Technology Co-ordination in ESA

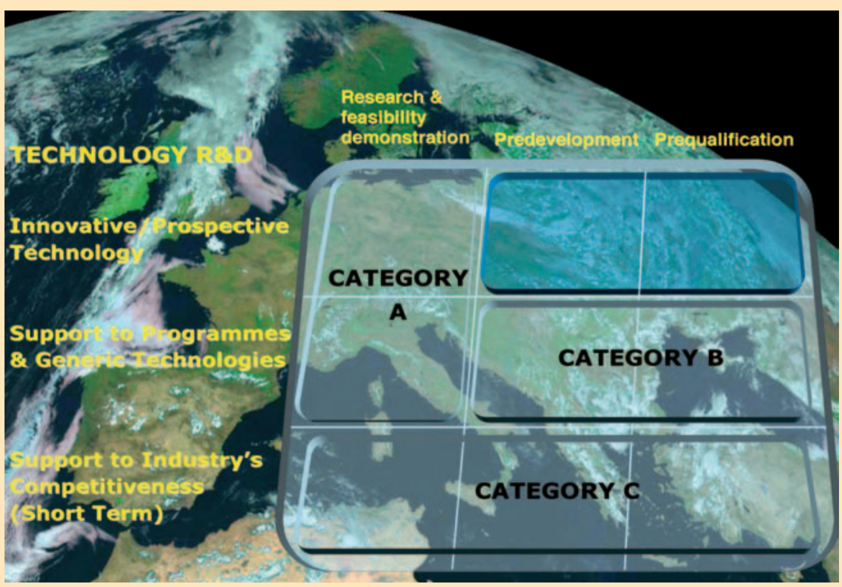
About 8% of ESA's annual budget is currently being spent on technology development, with a total of 250 million Euros spread over six Directorates. Technology planning is therefore well established within the Agency, which has published its 'Blue Book' on the ESA Technological Research & Development Programme on a regular basis since the late 70s.

However, the 1990s saw a need for revisiting the co-ordination effort, driven primarily by three factors:
- A change towards developing technology as a base for the selection of missions – i.e. missions driven by technology, such as in the Earth Observation Programme.
- The completion of many large programmes such as Artemis and Envisat and the preparation of follow-on programmes.
- Acquisition of the central role in the co-ordination of technologies in Europe.

Within ESA, technologies serve three major aims, which are related to the short-, medium- and long-term needs, and are therefore strategically distinct:

– **Innovative/Prospective Technologies:** exploration of high-risk technologies and concepts to secure a leading position for the European space community in the long term.
– **Support to Programmes and Generic Technologies:** to support the technological aspects of every ESA projects, through the development of new products and processes.
– **Technologies that Support Industry Competitiveness:** to enhance existing products and processes, allowing rapid responses to European demands for global competitiveness.

ESA has built an R&D landscape that combines these different aims with the prevailing level of technological maturity:



Technology falling into Category B is embedded in the mission-orientated, preparatory programmes (e.g. for Science, Earth Observation and Human Spaceflight), while those primarily occupying Category C are conducted through application-specific industry-oriented programmes (such as ARTES for Telecommunications).

A strong bridging component is assured by the mandatory Basic Technology Research Programme (TRP), which covers exclusively Category A and addresses the emerging stages for the whole spectrum of space technology. The optional General Support Technology Programme (GSTP) complements the technologies developed in the preparatory programmes and responds to industrial demands for focused support.