SP-470
November 2000

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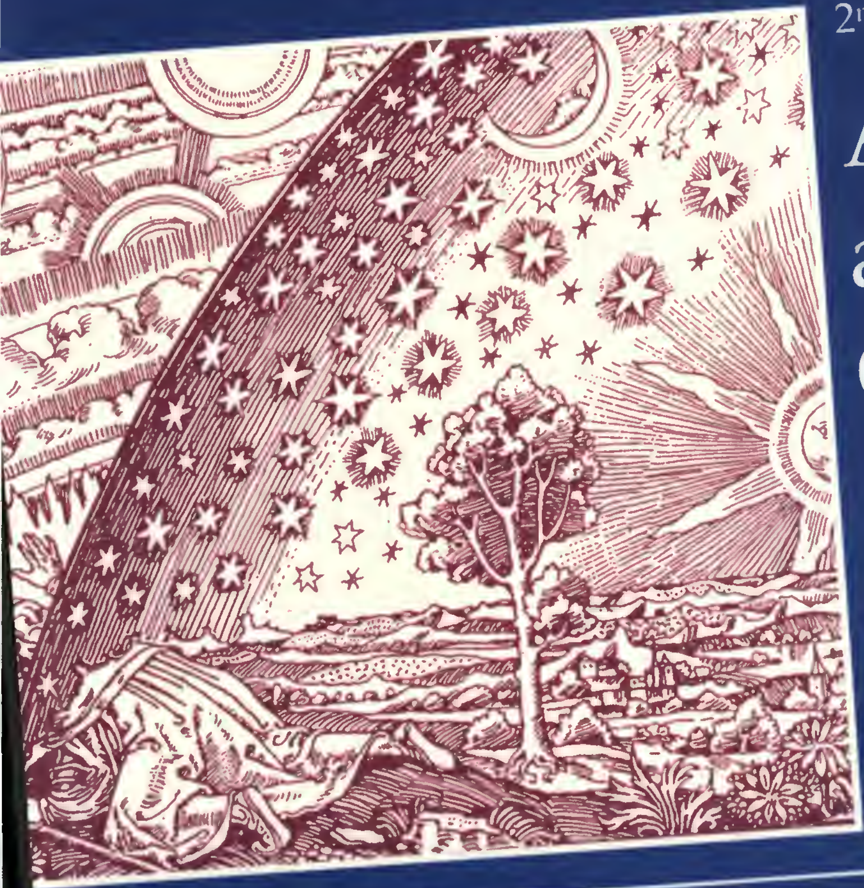

2nd Conference on

Academic and Industrial Cooperation in Space Research

Graz, Austria
15-17 November 2000

European Space Agency
Agence spatiale européenne

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Academic and Industrial Cooperation in Space Research

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Organised by the European Space Agency
in cooperation with

Austrian Academy of Sciences
Austrian Federal Ministry of Transport, Innovation and Technology
Austrian Space Agency
Joanneum Research
Technical University of Graz

European Space Agency
Agence spatiale européenne

Cover Image:

Various ideas have been proposed concerning the origin of this woodcut, ranging from an early 16th century woodcut ("The Emergence of Science" J.D. Bernal) to an unspecified source of 1911 ("Exobiology in Earth Orbit" NASA). It actually first appears as a black and white image in Camille Flammarion's "L'Atmosphère: Météorologie Populaire (Paris, 1888) and is supposed to have been made by him in order to make propaganda for the flat-Earth theory - its caption reads "Un missionaire du Moyen-Age raconte qu'il avait trouvé le point où le ciel et la Terre se touchent....". However, the more popular theme attributed to the woodcut is the common desire to discover and explore space.

Short Title: **SP-470 - 2nd Academic-Industrial Cooperation Conference**

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Compiled by: R.A. Harris
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and
David Raitt
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PROGRAMME & CONTENTS

Wednesday 15 November 2000

10:30 Coffee Break

11:00-12:30 **Other Forms of Cooperation**
Chairman: W. Riedler, Austrian Academy of Sciences, Austria

12:30 **Closing Session**
Chairman: D. Raitt, ESA-ESTEC, The Netherlands

K. Pseiner, Managing Director, Austrian Space Agency

13:00 End of the Conference

Conference Objectives

David Raitt, ESA-ESTEC, The Netherlands

Ladies and Gentlemen!

This is the second time that ESA has held a conference specifically on the cooperation and relations between universities and industry and we are delighted that it is once again being hosted in Austria – this time in Graz in recognition that much of the Austrian space industry is located here. We extend our thanks to all the various bodies involved for their generous and continued support in this event.

As noted at the conference in Vienna two years ago, basic research in the space field is often carried out in universities; such efforts, however, may not always be taken full advantage of by the space industry nor Agencies responsible for space activities. And it is this situation which ESA is attempting to redress through various programmes. So, like the 1st conference, this 2^{nd} one is intended to be a forum for reviewing major highly innovative R&D activities underway in European universities and research centres and assessing their potential applications to space, as well as evaluating success in generating, transferring and commercialising innovative technologies and knowledge.

The main objectives of this conference in Graz, then, are to bring together staff from universities, research centres and industry, with a view to reviewing and exchanging experience and ideas on frontier research activities in specific fields of potential interest to the space sector, and seeing what expanded role ESA should play in stimulating and fostering further innovative R&D. It is hoped that the Conference will once again provide further recommendations in these areas for the formulation of policies and procedures for the effective transfer and use of research, knowledge and personnel in the space domain between universities and research centres, the local industrial environment, and ESA.

Some 45 proposals for papers were submitted for consideration for inclusion in the conference and from those a selection was made to create what we hope is a balanced and interesting programme. As you will see, there are two distinct themes: one focussing on highly innovative research and technologies and their possible development and application to space; and the other focussing on academic-industry cooperation and harmonisation issues as well as case studies of relevance to the space sector such as science parks, university spin-outs, technology transfer and lessons learned. We trust that you will find this mix stimulating and that you will go away with new ideas and a better understanding of what is happening in academic-industry cooperation in Europe today. We also count on getting your feedback on how to improve further our links with the academic community and their links with the space industry.

Thank you for coming!

Cooperation in Space

Chairman: A. Atzei, ESA-ESTEC, The Netherlands

THE HARSH ENVIRONMENTS INITIATIVE

Building Partnerships in Harsh Environments

R. J. Robinson (1), J. I. Clark (1), J. A. Whittick (1) and P. Brisson (2)

(1) C-CORE, Robert A. Bartlett Building, St. John's, Newfoundland A1B 3X5 Canada
(2) ESA/ESTEC, Noordwijk, The Netherlands

(T) 709-737-8354 (F) 709-737-4706 E-mail: Bob.Robinson@C-CORE.ca

ABSTRACT

Since the mid-eighties, academia, industry and government have made significant moves towards the creation of mutually beneficial research and development (R&D) partnerships to maximise their investment. A trend that has required the different collaborators to rethink how they approach their operations, both internally and externally, to face the issues and challenges that result from joint public-private technology applications development. Public research institutions need to match their objectives to achieve scientific excellence and the diffusion of knowledge with the commercial goals of industrial partners. Industry, especially small and medium-sized enterprises (SMEs), must create efficient innovation networks that include partners from public research to complement their own core competencies and lever limited resources. It is necessary to create a framework to mesh the needs of all partners in a way that bridges geographical and cultural gaps.

C-CORE is a Canadian research and development corporation, with 25 years experience, that builds international partnerships to develop commercial products and services for its clients launched the Harsh Environments Initiative (HEI) in 1997. The HEI is an international network that identifies transfers and adapts technologies developed by European and Canadian space agencies into terrestrial environments. Its thrust is to determine the uptake of space technologies by resource industries, i.e., oil & gas and mining, both of which undertake industrial operations in inhospitable terrestrial environments.

The paper will provide insight into the operating philosophies of the HEI and the 'lessons learned' since its inception. Selected programme activities will be highlighted to illustrate the HEI's 'market-pull' approach and the benefits that have accrued to HEI Network partners.

INTRODUCTION

The HEI with the support of the European Space Agency (ESA) and the Canadian Space Agency (CSA) is a successful demonstration of public-private co-operation in Canada and Europe where innovative R&D takes place with partners from universities, research institutions, large companies and SMEs.

In 1990, ESA initiated the Technology Transfer Programme (TTP) to stimulate the wider use of technology developed by the European and Canadian space communities. The goal of the programme is to promote the transfer of innovative technology from space to non-space applications. To help do so, ESA set up a consortium of European technology brokers called the Spacelink Group. Spacelink is primarily responsible for 'technology-push,' the European-wide extraction and marketing of potentially transferable space technologies.

The determination of market demands in non-space resource industries and to search for space solutions, 'market-pull,' is the basis of technology transfer in the HEI, which extends the reach of ESA's TTP by enhancing Spacelink's role. The HEI requires that industrial priorities be established; partners be identified to do feasibility and demonstration projects; and sufficient funding sources (shared among collaborators) be secured to integrate space technologies that meet user-requirements with the objective of commercialising the results.

TECHNOLOGY TRANSFER & THE HEI

It is well acknowledged that public research and development can be a significant contributor to the economic growth of industrialised nations. The problem, however, of identifying and transferring technology from government and university institutions and facilities to private industry is also well documented. Industries, large and small, often associate large government funded organisations with long delays, bureaucratic red tape, little commercial motivation and limited intellectual property protection.

Technology transfer is broadly defined as the process of conveying a product, process or knowledge from a 'donor,' in this case either ESA, CSA, research groups or space-capable companies, to a 'receptor,' i.e., an industry user. In the context of the HEI, technology transfer is a planned, active multi-partner process, which typically involves industry and value-added developers. The technology that is transferred includes, but is not limited to knowledge, physical hardware, software, intellectual property know-how and methodologies, which are ultimately commercialised.

Several crucial factors influence the technology transfer process—factors that act as either barriers or constraints. Whether these factors are a positive or negative influence depends on external and internal circumstances. Regardless, successful technology transfer is based on the competent management of complex systems to cause synergy among collaborators. Technical ability is the most controllable internal circumstance, however, external factors such as those described next, are more difficult if not impossible to control:

- economics related to global trade agreements, supply and demand and availability of industry and government investment;
- social values and business philosophies rooted in culture and historical reaction to new technology;
- political framework, i.e., stability, protection of monopolies or local industries;
- legislation and regulations imposed on industry by local governments or authorities; and
- legal aspects: intellectual property rights, transfer agreements, licensing, patent rights and royalties.

THE HEI

The initial focus of the HEI was on industrial operations in the oil & gas and mining resource economies of Canada and Europe. C-CORE with its HEI partners in Canada and Europe have built a constituency that recognises the space sector as a source of advanced technologies that can significantly enhance business imperatives. Industries operating in harsh or geographically remote terrestrial environments are faced with several major challenges: keep costs down, minimise the impact of their industrial operations on the environment, and guard human safety. It is these operational necessities that create the opportunities for the HEI.

The primary objectives of the HEI are three-fold:

i. identify and integrate technologies, products and expertise, developed for space into the harsh environments of the resource sectors on earth;
ii. open markets in the non-space industrial sectors for European and Canadian SMEs using their expertise and products developed for space; and
iii. build momentum in the resource sectors to promote and instil recognition of the value of space-based technologies as a solution to operational challenges associated with hostile terrestrial environments.

Within the framework of the HEI (*ref.* Figure 1), European SMEs with space technologies are poised to find ready access to the North American market through strategic alliances with collaborators. In Canada, the focus is to continue current activities in oil & gas and mining, and expand the scope of the HEI into new resource sector areas, i.e., the forestry and pulp & paper sectors.

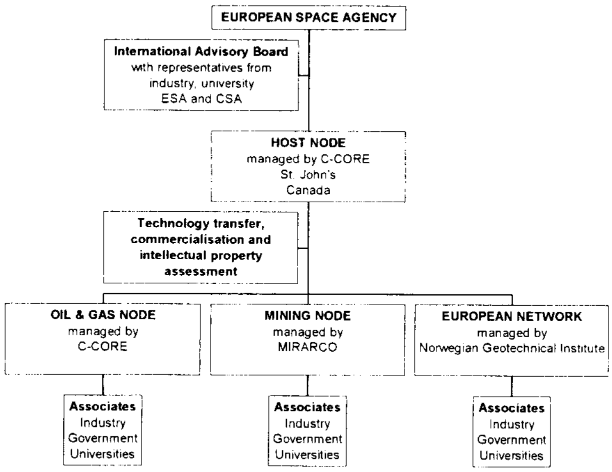

Figure 1 HEI Organisational Chart

HEI priorities are based on industrial areas that offer market driven applications for European and Canadian space technologies with particular attention to commercial opportunities to encourage the participation of SMEs in HEI initiatives. With an eye to identifying and crystallising activities for the HEI Network, industry workshops were conducted in Europe and Canada in 1997, 1998 and 1999:

- *Space Technologies Transfer Opportunities in Mining*, organised by MIRARCO as part of TELEMIN 1 and 5th International Symposium on Mine Mechanization and Automation, Sudbury, Ontario, Canada, June 1999
- *The Harsh Environments Initiative Workshop*, organised by ESTEC and C-CORE, Noordwijk, The Netherlands, January 1999
- *The Application of Advanced Space Technologies to Improving Efficiencies in the Petroleum and Mining Industries*, organised by C-CORE, St. John's, Newfoundland, Canada, July 1998
- *The Application of Space Technologies to Deepwater Oil and Gas Operation, Arctic Development and Underground Tunnelling*, organised by Norwegian Geotechnical Institute, C-CORE and ESA, Oslo, Norway, February 1998
- *Operations in Harsh Terrestrial & Marine Environments – Oil & Gas Operations Workshop*, organised by C-CORE, Calgary, Alberta, Canada, November 18, 1997
- *Mining Node Workshop on Application of Space Technologies to Operations in Harsh Terrestrial Environment*, organised by MIRARCO, Sudbury, Ontario, Canada, November 14, 1997

These workshops identified ideas and applied engineering topics, and recommended priority areas for a multi-year HEI. They also ensured that the Network maintained its focus on the operational challenges faced by the marine and land based industry sectors. The industrial direction provided by these workshops has also significantly contributed to the expansion of C-CORE and MIRARCO's industrial knowledge base.

Node		HEI Activity
Oil and Gas	1.	PetroGraFx - An Image Analysis Tool for Reservoir Engineering
	2.	Pipeline Integrity Monitoring
	3.	Radar Reflectors for Ground Motion Detection from Space
	4.	AUV Mission Simulator
	5.	Iceberg Analysis
Mining Node	6.	SMART / FAMOUS - Sensori-Motor Augmented Reality for Telerobotics
	7.	SMART / GINGER - Evaluation of Ground Penetrating Radar
	8.	Fragmentation Analysis
	9.	Geosensing - Advanced Imaging for Mining or Tunnelling Operations
	10.	Effluent Probe

Table 1 HEI Activities

More now than ever, industry is driven to find and implement cost-effective technologies that promote safety while reducing adverse impacts on the environment. Extensive communication through personal meetings, workshops and publications have built a constituency that recognises space industries, particularly the SMEs and space agencies, as a source of advanced technologies that can significantly affect these business imperatives.

The activities (*ref.* Table 1) have as their main thrust the development and provision of specific solutions to operational challenges brought to the HEI by major companies in the oil & gas or mining industries. As a result of the success of these activities, the HEI has gained a very favourable reputation in these resource sectors. The HEI has demonstrated that improved operational efficiencies and cost reduction can be achieved by the adaptation of technologies first developed by the space industry. HEI work thus far has created momentum towards significant future opportunities for all participants in the HEI.

The offshore petroleum industry is now moving to conduct exploration and production in deepwater—at depths not thought possible a decade ago. Very little of the conventional shallow water technology can be used in deepwater resource development. Without exception, companies that operate in deepwater or that promote deepwater operations have been very responsive to the concept of the HEI. Drilling, positioning, robotics, intelligent systems, new control and communication protocols that have been developed for space applications are eminently transferable to the deepwater setting. The same is true in mining. The work that C-CORE and its prime Canadian partner, the Mining Innovation, Rehabilitation and Applied Research Corporation (MIRARCO) of Sudbury, Ontario, Canada, have been doing with the mining industry has attracted international attention. There is now widespread interest in the use of new technologies for the automation of mining activities, remote assessment of minerals, transportation, processing and refining.

The Arctic is assuming increased prominence in relation to future world energy and minerals demand. Arctic development has been cyclic over the last half century and it is once again on the rise. Pipelines to carry resources from reservoirs that have been identified for many decades are now being planned again. The industry is committed to improving operations, safety and efficiency to reduce risks to the environment by using the best available technologies. Arctic development offers unique opportunities to adapt technologies and products from the harsh environments of space.

Broadening of the focus of the HEI to include the forestry and pulp & paper sectors is particularly appropriate, as operations are carried out in harsh forest environments, including extreme weather and terrain. The general challenges facing this industry, to become more cost-effective while reducing adverse environmental effects, are aligned with those in other resource industries. There will be opportunities for synergies among the forestry and pulp & paper projects and those in the Mining and Oil & Gas Nodes, particularly in the areas of teleoperation and monitoring of equipment, remote-sensing applications and automated visual inspection of production.

WHY DOES THE HEI WORK?

The HEI does not try to predict which space technologies are 'winners,' but rather focuses on the creation of 'winning partnerships' from which flow successful technology transfers into which space technologies can be integrated. No matter how competent an organisation is, whether it be public or private, or how much effort it invests, successful technology transfer will fail if there is no commercial need.

A key element in the successful implementation of the HEI is C-CORE's project management capabilities acquired over the past 25 years. C-CORE has developed a project management framework that effectively manages research and development risk for its industry clients. It is a framework that ensures the on-time delivery of high quality products and services that incorporates financial accountability and effective reporting.

To increase the chance of a successful technology transfer, C-CORE has adopted a corporate vision that places a high importance on the continued learning of the operational environment faced by the world's resource sectors. A vision that also places emphasis on direct interaction between the researcher and end-user based on interpersonal communication. This because technology transfer between donor and receptor is not a linear or orderly process that involves the mere exchange of information. In practice, technology transfer is often characterised or subject to changing circumstances, context and people, which demands each participant be capable of understanding each other's viewpoint.

The HEI project management process requires that a clear demonstration of a space technology or technologies is available for integration into the project. An International Advisory Board, made up of industrial leaders and research experts, is crucial to the successful implementation of HEI programmes. The Board provides direction and advice to the HEI partners, advice that is necessary for HEI activity to:

- keep pace with the economic and operational needs of industry;
- keep stakeholders aware of the benefits of technology transfer;
- bring new strategic partners into projects; and
- ensure a viable range of new downstream commercialisation opportunities.

Underpinning the work of the Board is a commercialisation assessment process, which is done early in the research and development cycle of all HEI initiatives. The main decision elements of the commercialisation assessment are to:

- review and advise on commercialisation plans as indicated in each project summary sheet;
- provide advice on the most appropriate strategy to commercialisation;
- ensure that industry partners that can use or commercialise the project products are identified and involved in early state of development of the project; and
- review potential need for finances and ensure proponents have potential financing groups informed and involved at an early stage.

The commercialisation path (*ref.* Figure 2) proposed for the technology is reviewed and a business model established for technology transfer. A preliminary market analyses of downstream sales is done to estimate the potential markets and royalty return to ESA. This quantifies the potential achievable economic returns early in the HEI project development cycle.

Intellectual property management is also a key element of the HEI. For each project:

- the background technology is documented and a value is assigned to it; and
- the envisaged HEI foreground technology is identified at the start of the project.

Effective communication within the HEI Network is essential to the space technology identification efforts, i.e., finding a compatible match between donor and receptor. This is because it is not enough just to identify the right space technology (or technologies) for a particular HEI activity. Rapport, both corporate and personal, is necessary to drive and sustain the successful transfer and downstream commercialisation of a technology. Hence, a great deal of importance is placed on relationship building between HEI parties.

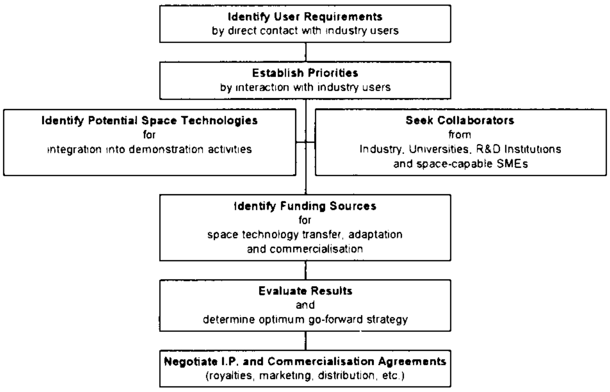

Figure 2 HEI Commercialisation Framework

The HEI Network's success to date is in many respects due to its ability to create an environment with the right mix of research, applied engineering and business. A mix, which permits human resource expertise to produce value-added intellectual property, driven by the commercial need of a client. The HEI is also structured to provide timely feedback to the programme's main proponent, ESA. A key element in the research and development technology transfer process is the involvement of experts, notably ESA and CSA technology gatekeepers who contribute a diverse wealth of space technology knowledge and experience.

LESSONS LEARNED

In technically pure form, i.e., as delivered to space agencies, space technologies are not directly useable in a terrestrial application. A condition that has been validated by both C-CORE and MIRARCO led HEI teams. To illustrate using the following HEI activities:

- Space Application Services (SAS), Belgium, a space capable SME, has developed a space telerobotic technology called Flexible Automation Monitoring and Operation User Station (FAMOUS). C-CORE and SAS have been collaborating to assess the automation needs of an unstructured underground mining environment, to transfer and commercialise FAMOUS for use by the mine industry end-users.

- MIRARCO, C-CORE's main HEI partner, has been working closely with RST Radar Systemtechnik, Switzerland, another space donor, to develop and commercialise RST's ground penetrating radar technology, originally designed for use on planetary rovers, and render it mine ready to assess the integrity of the rockmass by 'seeing' beyond the rock face.

In both cases, what project managers discovered early in the HEI programme is there exists a fundamental difference in mind-set between technical professionals who operate in the space industry and those that do business with the resource industries—each measures success differently.

In the space sector, success is a function of constructing the desired technical solution for a space agency or large prime contractor using a systems engineering method within a predetermined contractual arrangement. The latter is a systematic approach that does not always factor in the cost-benefit of the deliverable. The HEI, whose focus is to identify and ultimately commercialise a space-based solution for an industry end-user must always keep the issue cost versus benefit well out in front.

To conceptualise a commercially viable solution, the HEI acts as a tool to bridge this 'cultural gap.' It does so through productive communication and direct, hands-on interaction between the donor and the receptor, e.g., a mine site visit. This has proved to be particularly effective in the case of European donors such as SAS and RST working to commercialise their technologies in a mine environment.

Space technology identification is a time consuming and labour intensive process. Typically, HEI teams must perform detail investigations of ten potential technologies, for every one selected for integration into a specific HEI activity. This is a significant HEI challenge because for business, particularly SMEs with limited labour and financial resources: time is money and lost opportunity.

Leverage opportunities for technology providers. In many cases, the expenses incurred by technology providers to explore new opportunities are funded with the support of other industry and government programmes—programmes that would otherwise not have been made available for this purpose. Since 1997, ESA's investment in the HEI as resulted in matching fund leverage ratio of 1.56 EURO in external investment for every 1.0 EURO from ESA.

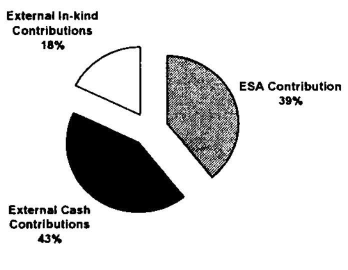

Figure 3 Breakdown of HEI Funding Sources

The HEI Network has been very successful (*ref.* Figure 3) at levering ESA's contribution with both cash and in-kind contributions from external sources.

EUROPEAN HEI OPPORTUNITIES

In February 1999, C-CORE commissioned a 10-month feasibility study called, *The Application of Space Technologies to Oil & Gas Development in Deepwater, in the Arctic and Underground Tunnelling*, to expand the scope of Canadian HEI activities into Europe. The study was done by the Norwegian Geotechnical Institute (NGI), in co-operation with the Helsinki University of Technology (HUT).

The study addressed space-related technologies, which conceptually, hold promise for use in harsh environments. It also included a list of initial links with space-capable suppliers and developers that are potential collaborators in the HEI. Generated were conceptual designs for projects, which could use advanced space and space-related technologies to address specific engineering needs in harsh marine environments.

In Europe, the deepwater and Arctic operational challenges will require space technologies in robotics, communications and sensors to support their projects in sensing of the seabed and arctic ground conditions. Tunnelling issues investigated by HUT Node focused on geoprobing, equipment and system reliability and remote characterisation of the terrain that will bring in space technologies in software and controls. Also identified, were opportunities for joint Canadian and European activities.

CONCLUSIONS

The key benefits of the HEI are distributed among primary industries, space-capable SMEs, and sponsors of space technology development. Primary industries, at which this initiative is directed, will realise increased production at lower cost and with diminished risk to both personnel and the environment. Space-capable SMEs, supporting the primary industries, will develop new expertise, create niche markets for their products or services and establish collaborative ventures with foreign partners to address a global market. Other important benefits include:

- A greater return-on-investment by the sponsors of space technology development, because of the development of dual market applications, which allow governments—the principal supporters of space programmes—to recoup more of their investment through taxation and other means, such as increased employment and commercial activity.

  Increased opportunities for HEI partners in the oil & gas, and mining sectors for transfer of space technologies into the resource sectors. Thus far, the HEI has some 25 technical team members working with over 70 partners.

- The potential volume of business products and services resulting from HEI demonstration projects is estimated in the millions of EURO over the next ten years; ESA's return-on-investment would be through technology transfer agreements, which would specify royalty distribution to the partners.
- Donor SMEs and other space companies will have new non-space opportunities for their products and services because strategic alliances between Canadian and European SMEs will open up new markets in North America. For many SMEs this diversification may, at a minimum, provide financial buffering from business cycles in their traditional markets.

COOPERATION IN SPACE RESEARCH - A NEW APPROACH IN GERMANY

Dr. S. Saupe
German Aerospace Center / DLR e.V.
Strategy Development
D - 51170 Köln, Germany
phone +49-2203-6013371, fax +49-2203-65790, e-mail stephan.saupe@dlr.de

Abstract

In early 1999, a new aerospace coordination initiative was started in Germany: The so-called Trilateral Memorandum ("memorandum for future cooperation in aerospace research") was signed by the Deutsche Forschungsgemeinschaft (DFG) together with universities, by DaimlerChrysler Aerospace (Dasa) and by the German Aerospace Center (DLR). It aims at improving the overall efficiency of aerospace research through intensified coordination and cooperation of the research institutions. High-level agreements on research areas, scientific workshops and young scientist programs shall help to establish competence centers and secure recruitment of young scientists. The recent moves of integration in the European aerospace industry gave new momentum to the partners of the Memorandum.

This presentation reports on the intention, the realization, and the effects of the Trilateral Memorandum. It starts with an outline of the framework conditions for aerospace research in Europe in order to clarify the intended contributions of the Memorandum. It then gives an overview on the coordination and the activities within the network. The results of the first year of work and both direct and indirect effects are presented. This includes the most recent steps of broadening the partnership. Finally, a short outlook is given.

Framework Conditions

Any player doing research in the field of aerospace in Europe is acting in a complex environment influenced by institutional or company interests and political interests, both on national, European and international levels. Within this context, different forms of competition go along with joint interests and cooperation.

The two dominant structural influences on this European aerospace research scene are the *industrial structures* and the *funding mechanisms* (i.e. politics in the end). Other, more practical influences are coming from public opinion and from the recruitment side.

The following reflections are based on a bird's eye view onto the European aerospace sector and simplify this complex field in order to work out some aspects related to the Trilateral Memorandum.

*How do **industrial structures**, concentration and internationalization affect aerospace R&D in Europe?*

Compared to the U.S., the relations of European aerospace actors are made more complex by multinationality. National aerospace industries are competing nationally, in Europe and globally, while partly cooperating in European consortia at the same time. As well, research establishments and universities supporting industry are nationally organized, yet do cooperate, e.g. within EU projects. The formation of the transnational companies Astrium and EADS in 2000 were remarkable moves and the most recent steps in a process of European industrial integration in the aerospace sector. If looking from a global perspective, these steps towards joining forces were quite logical in a sector with big international companies and strong global competition.

Those merger steps aimed at overcoming two major difficulties. Firstly, the national European competitors were not big enough to compete effectively with the big global players in the U.S. Secondly, European consortia like Airbus Industrie always had to consider and balance the different interests of its multi-national industrial members (and their governments) e.g. through defined work-share quotas. This did not necessarily lead to the best overall result. A recent example of this second difficulty is the discussion about the site for the final assembly of A 3XX.

With the latest steps of integration, the European aerospace industry has strongly changed its structure. Forming transnational companies is a qualitative step from the national mergers that we saw until recently; the possibility to clearly allocate a company in one country is no longer given. Instead of several national companies roughly of equal size, now there are only one or a few transnational companies and some others, now "medium-sized". Unchanged are the small and medium-sized enterprises (SMEs), which are mostly completely national.

The established ways of communication, coordination and cooperation are already influenced by this and will change further. Universities, research establishments and SMEs can no longer "automatically" count on their "national brothers", because any transnational European company will look for partners and subcontractors on a European map. One has to assume that competition among the smaller players, both nationally and internationally, will intensify within the next few years. Smaller companies may have severe difficulties to compete successfully with EADS or Astrium.

What will be the outcomes of intensified competition? Which competition intensity is required to reach an overall optimum in a sector that still strongly depends on public funding and politics? How will national governments and funding agencies, EU and ESA react to these changes in industrial structure? Return coefficients, i.e. quotas, may clash with the intended resource allocations within EADS or Astrium. Or will internal competition develop within these companies, probably leading to an internal increase in efficiency? Up to what extent will the big transnational companies influence politics? Can the companies turn into highly efficient global players while acting in a politically influenced funding environment?

This leads us to the second major question: *How do the **funding mechanisms** of national agencies, ESA and EU influence aerospace R&D in Europe?*

In space research and the space sector, public funding still being the most important source, relations are shaped by the funding mechanisms. In aeronautics, public funding provides important extra money and clearly influences R&D. ESA and EU are the dominant institutions for public R&D funding in aerospace on the European scale.

Within ESA projects, complete projects or work packages are distributed among the ESA member states based on competence and proportional to their financial contribution to the ESA budget. The return coefficients work similarly to the national quotas in the Airbus consortium mentioned above. ESA projects do lead to European cooperation, yet work packages are quite often allocated in one country and a lot of the actual work is accomplished within national networks of industry, research establishments and universities. Thus, work is firstly separated politically and secondly between basic research, applied research and industry.

The allocation of work packages may be based on tenders, but reflects on talks and agreements between industry and government representatives, also in ESA boards. National industrial competencies and interests form the basis for this. This mechanism preserves a dominant role of industry in aerospace R&D, which is based on industry's economic impact and its capability to carry out big projects. Universities and research establishments participate in space projects by convincing industry of their competencies. The mechanism also preserves national borders between research institutions. This is reinforced by projects of national space agencies, who in their allocation of funds follow and reflect national borders anyway. Here, industry has a similarly strong position.

The European Union's approach to multi-nationality is slightly different: Projects, e.g. in aeronautics, require European project consortia that fulfill two conditions. Firstly, a minimum of 50% industry participation is required to ensure the economic usefulness of the projects. (Nevertheless, the projects shall encompass pre-competitive R&D.) Industry experts also play an important role in the process of defining funding programs. Secondly, project partners from different countries are required, but no fixed national quotas exist. Some consideration to overall national re-financing is given ("just-retour"), but primarily there is a competition of consortia with different European composition. Applicants have relative freedom to suggest projects within a defined program, whereas space projects of ESA have to be defined beforehand. This goes along with a lower funding percentage of EU projects; industry's interest is stronger, so it is usually required to contribute to the project costs by 50%.

The actual and future formation of transnational companies will have some influence on ESA and EU as well as on national projects, because their handling of allocation aspects has to be adapted. ESA and EU are already changing the rules for participation of SMEs to prevent EADS or Astrium putting them out of business. The changing industrial structures also will have to be taken into account in the discussions on linking ESA and the European Commission. An expected outcome of this process may be - similar to the above discussion of the direct effects of transnational companies - a trend away from fixed work shares and towards more supra-national competition.

For national funding agencies and institutions, at least two scenarios can be foreseen: Either, they might simply change their contract partners to the national sub-companies of the transnational firms. This will not lead to major changes in funding mechanisms. Alternatively, the trend towards European integration might be furthered and accelerated through more European and less national spending, thus probably creating new supra-national funding mechanisms and organizations.

In this context the influence of European associations like AECMA (European Association of Aerospace Industries) or EREA (European Association of Research Establishments in Aeronautics) could become more important. They might give advice to European institutions in establishing a well-balanced system of research funding mechanisms with the new industrial structures. A European network of university institutes active in aerospace research is currently being set up.

Two totally different, but still important framework elements for aerospace research in Europe are public perception of aerospace activities and recruitment.

What influence is coming from the side of ***public opinion*** *onto the European aerospace sector?*

Activities within the aerospace sector are both highly visible and strongly dependant on public funding. Public acceptance thus is a crucial point for maintaining or increasing the volume of activities in aerospace research even if the percentage of commercial activities will increase. Dominant transnational companies receiving remarkable public funding might be observed with some concern by the general public. Thus, in addition to the continuing need for good public presentation of any initiative or project in aerospace, the diversity of actors active in aerospace research should be emphasized more actively in the future. Who can do that?

How does ***recruitment*** *effect the European aerospace sector?*

People are the basis of every success story. All European aerospace actors need well-trained, creative and committed young scientists and engineers in order to achieve good results. Starting in the mid-1990s, the actors became increasingly alarmed by declining numbers of engineering students and graduating engineers. Without young scientists and engineers studying, doing research and entering research establishments and industry, future success will be in danger. This problem has become apparent especially in Germany and it has called for joint action. Probably this was the main trigger to start the initiative described in the following.

The Trilateral Memorandum

Acting within this field of "coopetition", i.e. competition and cooperation, DLR in 1997 initiated talks with its German industrial and university partners about possible forms of coordination and cooperation. This was not only motivated by the framework conditions described above, but also induced by the intention of DLR to intensify its national "bridging function" between academia and industry. The overall aims were to achieve a more efficient research and to secure young talents for a long-term success of the aerospace sector. Coordination should help to reduce parallel work, to close gaps and define interfaces, i.e. to better "synchronize" research and development in universities, DLR and industry. Through this, a better organized work-sharing network of actors should be established. Of course, only part of the research of the actors could be and was intended to be influenced by this approach. From the beginning, it was intended and clearly stated that this effort was part of a European approach, because the partners wanted to improve their national coordination in order to become more valuable European cooperation partners.

In January 1999, the head of the executive board of DaimlerChrysler Aerospace (Dasa), Dr. Manfred Bischoff, Prof. Manfred Fricke as a representative of the universities active in aerospace, the secretary general of the Deutsche Forschungsgemeinschaft DFG ("German Science Foundation"), Dr. Reinhard Grunwald, and the head of the executive board of DLR, Prof. Walter Kröll signed a Memorandum of Understanding (MoU), now called Trilateral Memorandum. The partners agreed upon the aims of intensifying coordination efforts in R&D and promoting and supporting the education of young scientists and engineers in aerospace. The planned activities were joint R&D projects, continuous research colloquia and different means to promote young scientists and engineers. A high-level coordination board should guide and bring forward all activities and initiatives.

The Trilateral Memorandum was intended and designed as an umbrella MoU, which gives the direction and sets the frame for further action at all levels. It is a statement of policy and strategy, which changes the preferences for future projects and measures towards more intense coordination and cooperation. In order to accelerate the process of adaptation and implementation, the partners combined this general orientation with concrete measures: The coordination board will discuss and decide on subjects and thematic main foci, it will create new forms of cooperation and start new programs - and it has the power to do so.

Representation in the Coordination Board

In the coordination board, the three partners industry, DFG/universities and DLR were to be equally represented; the partners agreed on each having three seats on the board. This was no critical point, as the board should not vote on issues but find a consensus on every topic discussed. As it was intended from the beginning to include all German industry, but only one company was participating in the MoU in 1999, Dasa took only one seat of the industry side. The board was willing and prepared to broaden the industrial representation.

Before the coordination board could meet, a fair representation of the numerous university institutes and their interests had to be found. The acceptance within the communities was the central goal in this context; only with wide acceptance, the MoU would be worth the effort and lead to an operational group and to stable results in the intended way.

The German aeronautics institutes had formed an information network shortly before, and the speaker of this network was willing to take over an information role into and from the coordination board of the MoU. This was confirmed in a strategic meeting of aeronautics representatives from universities in July 1999.

At and after a similar strategic meeting with university representatives from space research in October 1999 the possible sub-disciplines to be represented were discussed. In order to concentrate on central issues and in analogy to the aeronautics institutes, the partners agreed to focus on the field of space transport. A speaker of a "Sonderforschungsbereich" of DFG was willing to represent the relevant university institutes until an official speaker was selected.

According to the temporarily reduced presence of Dasa, i.e. industry, DLR also only named one representative for the coordination board, Prof. Kröll. It has to be mentioned that DLR can only bring in its research activities into the process of the Memorandum; the agency role of DLR must stay independent of the thematical coordination efforts, because this is a task taken over from the German federal ministry of research and education.

The First Meeting of the Coordination Board

The coordination board of the Trilateral Memorandum met for the first time in November 1999. The board firstly discussed some organizational issues. It decided not to work with fixed rules of procedure, it elected Prof. Kröll as its speaker for two years and it agreed on the offer of DLR to set up a scientific secretariat at DLR. The secretariat shall organize, prepare and bring forward the issues of the MoU. The way towards coordinated research programs or joint projects was also agreed upon: Based on continuous reciprocal information about strategic aims and foci, the board will discuss special subjects and initiate trilateral colloquia on these. From the colloquia, joint working groups shall elaborate and substantiate coordinated research programs or joint projects. The subjects shall both be of scientific interest and have technological innovation potential in order to be important for all partners.

The coordination board also decided to approach the German Aerospace Industries Association (BDLI) officially and ask it to join the Trilateral Memorandum. This would broaden the basis in the industrial community and lead to a higher level of acceptance, because the interests of all of the aerospace companies were represented.

Three subjects of common interest were already identified in this first meeting: Technologies for future re-usable launchers, low-noise air traffic and simulation tools. In all of these fields, scientific colloquia should be organized.

Concerning the common interest to promote young scientists and engineers, the board agreed on a new instrument that should both foster direct cooperation and the promotion of young scientists and engineers: Joint teams of young scientists shall work on visionary subjects for a period of 3 to 5 years. Within a project plan they shall have enough freedom to pursue new ideas and concepts. From these groups, bigger projects can develop.

First Activities

In February 2000, a workshop on the German future launcher program ASTRA took place. The experts from the three partners discussed the possibilities of an intensified participation of university institutes both in principle and in technical details. That was followed by numerous bilateral talks and meetings at working level.

In April 2000, Dasa agreed to start a systematic analysis of the fields of work and of interest within the three partners, but the start of the analysis was delayed due to the enormous changes during the time of the formation of EADS.

In May 2000, DLR intensively prepared the joining of the industry association BDLI to the MoU and tried to organize a public signing ceremony at the ILA 2000, the International Aerospace Exhibition in Berlin. All questions were clarified and detailed agreements reached on the representation in the coordination board. However, no date could be identified at the ILA, where all partners could be present, so the ceremony had to be postponed.

In early July, DLR suggested four joint projects to be initiated; three in the areas mentioned above plus one on future airplane configurations. In September, the results of the first selection for external funding of the universities are expected.

From September to November 2000, a series of colloquia on low-noise air traffic are planned. The first one focuses on the capabilities of numerically predicting airframe noise with turbulent flows, within the second one the possibilities of applying the tools and methods to flows in aeroengines are investigated and within the third one the results will be summarized and presented to the coordination board. Following this colloquium, the second meeting of the board will take place where the joining of BDLI is to be signed.

Other Effects and Lines of Action

In parallel to these concrete actions and decisions and not to be underestimated, the Trilateral Memorandum influences the actors conducting aerospace research in Germany and probably in Europe in other ways. It is the first time that such an agreement was signed at high level. Its pure existence is sending signals into the three communities involved:

Within the organizations Dasa/EADS and DLR, the Memorandum changes the general guidelines for action. Projects and programs that are being prepared should take this new strategic goal into account. Initiatives that include and promote cooperation with the partners will be given a higher priority, similar to those that are based on a proven good coordination.

Within the university aerospace community and for DFG, the changes in preferences and procedures are less obvious and stringent. On the one hand, the university institutes are well integrated and represented in the MoU, but on the other hand, they are fairly independent actors. University institutes will watch for advantages and new chances for project funding or industry contracts with the Memorandum. DFG as an independent public funding organization has its binding statutes and procedures. The representative of DFG may take up ideas or suggestions, but the coordination board and the secretary general of DFG cannot overrule the established ways of evaluating and selecting projects for DFG funding. Maybe in the medium term, the funding principles of DFG may explicitly attribute a positive value to cooperation and to proven coordination efforts, because these increase the overall economic and scientific outcome on the national and European scale.

All of these possible paths of influence have their own characteristics, target groups and time constants, i.e. delays. It takes some time until new objectives like this coordination and cooperation effort can become reality in projects and in the way of thinking. But the partners of the Trilateral Memorandum are convinced that this MoU was the right step to foster efficiency and quality in the aerospace sector.

Additionally, the Memorandum has effects outside the actual partners. Already in the design phase of the MoU, industrial enterprises watched what Dasa was doing so they wouldn't fall behind in important areas. Several companies and the German Aerospace Industries Association BDLI expressed their principal interest in joining the MoU quite early. Since mid-2000, the details for expanding the industry representation to BDLI are accepted by all partners and BDLI and hopefully at the time of this conference, BDLI will be a partner of the Memorandum.

In the field of politics, several ministries watched the initial process of creating such a Memorandum with a little suspect. It was made clear by the partners that they didn't intend to bypass the ministries or to shortcut established information paths. The new initiative aimed at improving the programmatic talks between and the organization of the actors in a bottom-up way in order to increase the overall efficiency in this sector and to supplement initiatives of the ministries. The ministries are invited to all trilateral colloquia initiated by the partners and directly informed about other steps or initiatives like the expansion to BDLI.

The Memorandum finally helps to coordinate and intensify the public appearance of the complete aerospace research scene. The MoU gives a good framework to present activities, initiatives and projects in aerospace research. Through the Memorandum, the public can see that aerospace research is not just conducted within a few transnational companies, but also - and probably with a higher relative percentage - within a variety of small companies, university institutes and research institutions. In addition, the public can see that the researchers themselves are working on intensifying coordination and cooperation, also in order to improve overall efficiency of the public money invested.

Conclusions and Outlook

The partners of the Memorandum agree that the recent mergers in the European aeronautics industry increase the need for coordination and cooperation. The existence of only few transnational European companies and the fact that ESA and the EU will continue to approach each other will keep on changing the framework conditions mentioned above. In parallel to an intensified "horizontal networking" between partners of the same kind (research establishments and universities, respectively), which may even lead to new organizational forms of cooperation, the formation of European centers of excellence becomes most important. Transnational companies will no longer automatically approach their national partners if they need scientific or technical expertise, but they will look for the best on the European map.

At this moment, there still is some parallel work in university institutes, research establishments and companies across Europe. This is natural looking at the historical development and it is necessary for competition. However, focusing and concentrating the efforts in certain fields should increase the overall efficiency in the future. Not everyone has to do everything. A European sorting or separation of activities and competencies in aerospace reminds of Adam Smith's classical model of work-sharing. Mixed groupings of university institutes, research establishments and small and medium-sized enterprises (SME) will build centers of competence and excellence. Of course, this is not limited to national borders, but at the moment in most cases contacts to national partners are best. We expect - in this phase - mostly national efforts that will continuously expand to European level. These centers of excellence can be, but don't need to be co-allocated with the respective parts of the transnational companies. Means of modern data exchange reduce the need for physical proximity.

Due to the big changes in the industrial landscape, initiatives like the German Trilateral Memorandum will become an important support for SMEs, university institutes and research establishments, because these can help them to develop and strengthen special competencies and participate in or even lead centers of competence. In work-sharing networks on a national or European basis, they can secure their future and stay important partners or subcontractors of the big transnational players. The Memorandum broadened to

BDLI will offer exactly this support to the member firms of BDLI.

The Trilateral Memorandum may become a model for research coordination and cooperation in Europe, especially in the light of transnational companies.

Summary

The Trilateral Memorandum is a German initiative that aims at establishing European and national centers of competence in aerospace research. Its approach could be a model for the establishment of European centers of competence, also outside the aerospace sector. These centers will be increasingly important partners for transnational and national companies and agencies; single companies or institutes would have more and more difficulties to stay an attractive partner or contractor on the European scale. The MoU aims at reducing uncoordinated and parallel work in order to increase the overall efficiency in the aerospace sector. The partners of the Memorandum do not stick to the letters and words of the signed text, but intend to make it a living partnership.

In this article, the Memorandum's environment is roughly analyzed and its organization and functioning is described. The results of the first year of work are reported and show first steps and concrete examples of coordination. To the Partners of the Trilateral Memorandum, the recent changes in the European industrial aerospace structure demonstrate that the Memorandum is a move into the right direction of linking the aerospace researchers more closely.

ITALIAN PARTICIPATION IN THE MARS EXPLORATION PROGRAM

E. Flamini[(1)], F. Angrilli[(2)], R. Bianchi[(3)], J. Campbell[(4)], F. Capaccioni[(3)], A. Cisbani[(5)], L. Colangeli[(6)], A. Coradini[(3)], M. Cosi[(5)], S. Debei[(2)], A. Ercoli Finzi[(7)], S. Espinasse[(1)], P.G. Magnani[(8)], G. Magni[(3)], R. Mugnuolo[(1)], A. Olivieri[(1)], E. Re[(8)], A. Terribile[(9)]

[(1)] Agenzia Spaziale Italiana, Viale Liegi, 26 00161 Roma – Italy

tel: +39 06 8567298 fax: +39 06 8567304 e-mail: flamini@asi.it

[(2)] CISAS Università di Padova, Via Venezia, 1 35131 Padova – Italy

[(3)] CNR-IAS-Reparto di Planetologia, Area di Ricerca di Roma-Tor Vergata, Via Fosso del Cavaliere 00133 Roma – Italy

[(4)] Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91109-8099 – USA

[(5)] Officine Galileo, Via A. Einstein, 35 50013 Campi Bisenzio (FI) – Italy

[(6)] Osservatorio Astronomico di Capodimonte, Via Moiariello, 16 80131 Napoli – Italy

[(7)] Politecnico di Milano-Bovisa, Via La Masa, 34 20158 Milano - Italy

[(8)] Tecnospazio S.p.A., Via Montefeltro, 8 20156 Milano - Italy

[(9)] Tecnomare S.p.A., 3584 San Marco 30124 Venezia – Italy

Abstract

Agreements have been signed between the Italian Space Agency (ASI) and ESA and NASA for the exploration of Mars. These agreements initiate the participation of the Italian scientific community as well as the Italian industrial community in the international program to explore Mars. ASI and NASA have agreed to co-operate in a long-term systematic program of robotic exploration of Mars sustained by a series of missions to Mars in support of their respective strategic goals. ASI is expecting to participate in the future missions with the provision of a subsurface drill and a scientific package. The drill will be capable of drilling and collecting several samples and delivering them to instruments located within a scientific package fixed on a landed platform. The goals of the investigations are to study physical and mineralogical properties of bulk soil and dust (atmospheric and surface) as well as geochemical, structural, radiation and geophysical properties of subsurface materials to a depth of 0.5 meters.

1. Introduction

The Italian Space Agency (ASI) is a founding member of the International Mars Exploration Working Group, at this point composed of representatives from all space agencies interested in Mars exploration. Recently an agreement was signed between ASI and NASA for collaboration in the exploration of Mars. This agreement facilitates the participation of the Italian scientific community as well as the industrial community in the international program to explore Mars.

To date the collaboration has been focused on the NASA Mars Surveyor Program (MSP) lander missions. It primarily addresses robotic elements for soil and sub-soil sample collection and in-situ scientific investigations, with ASI provision of a deep drill (hereafter called DEEDRI) and a micro-laboratory capable of housing scientific instrumentation (hereafter called IPSE: Italian Package for Scientific Experiments).

2. Background

In order to assess the interests and the expectations of the Italian scientific community, ASI organised a dedicated meeting held on Pantelleria Island in September 1998. During that meeting, a set of instruments was proposed for:

- Atmospheric measurements (1)
- UV luminescence (1)
- IR spectroscopy & mineralogy (1)
- Panoramic spectroscopy (1)
- Ground thermal gradients and conductivity(1)
- dust flux (1)
- Elements abundance (1/2)
- Cathodic-luminescence (2)
- X Diffractometry (2)
- Dust dynamics (2)
- Alpha-Proton-X ray spectroscopy (1)

With regard to technical maturity, these instruments were classified as either:
(1) based on proven technology ready for 2003;
(2) based on technology requiring further development.

In April 1999, ASI issued an Announcement of Opportunity for scientific payloads to be housed both in

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DEEDRI or within IPSE for the Mars Sample Return missions MSR 2003-2005. In September 1999, an international workshop was held in Rome for the presentation of the proposals received in response to the AO. The selection of the proposals based on the advice of international referees immediately followed.

The guidelines provided for the selection of the scientific instruments for the proposed Italian package for Mars exploration were based on the Pantelleria Meeting recommendations and the ESA Exobiology Package. Also the scientific instrumentation expected to be flown onboard other landed missions was considered in order to understand the complementary role that an Italian science package could play and to maximise the scientific return of the missions.

Most of the instruments were proposed on the following assumptions:

- the 2003 lander mass budget was ranging between 10 and 12 kg;
- its external envelope was of 450x350x300 cm.

The samples could be obtained from various depths by the sub-system DEEDRI.

By October 1999, the selected instruments were approved by ASI and presented to NASA. Beginning early in December 1999 the NASA Mars program began a replanning process in response to the loss of the Mars 98 missions. However, ASI continued to support the completions of the Phase A studies for the selected instruments.

3. Development strategy of the scientific payload for the future Mars missions

The experiments selected by ASI to perform investigations on the surface of Mars will be placed on the DEEDRI and on the IPSE sub-systems located on the landed platform. Innovative design approaches that incorporate technological advances in lightweight, high performance instruments were solicited during the selection process. On this basis experiments were selected for detecting chemical trace elements at the landing site, for defining the relationships between aeolian transport and atmospheric properties, for measuring the radiation dose at the Martian surface, and for determining the mineralogical and textural properties of different layers down to 0.5 m under the Martian surface.

The design, realization and delivery of these instruments will be carried out in the framework of collaborations between ASI, academic institutes and Italian industries. The participation of the academic institutes will be significant for the definition of the requirements and for the development till the breadboard phase, with Italian industries having the subsequent major role in realization and delivery of flight models.

The Principal Investigator (hereafter called PI) of each instrument will carry out related scientific research. At the same time he/she will be responsible for the development of the instrument being supported by industrial partners.

During the 1st phase of the project the PIs defined the scientific requirements and the instrument general configuration in the framework of the foreseen missions. A preliminary design of the experiment was developed by the reference industry in agreement with the scientific group. This preliminary configuration was reviewed by the PI and the industrial partner in order to identify the feasibility critical items due mainly to:

- the utilisation of new technologies;
- the severe Martian environment (wide temperature range);
- the limited available resources during the mission (mass, volume, power);
- the planetary protection requirements and cross contamination.

The industrial partners undertook a preliminary procurement investigation in order to verify the availability and adequacy of commercial sub-systems and components. They identified which sub-systems had to be designed and developed especially for the project.

Analysing the development tests results and the research results, scientific and technical requirements were iterated in order to realise the best trade between scientific return and feasibility. This concluded the project phase A.

After phase A, the activities will be carried out in a co-operative and complementary way between the PI, supported by their own academic and technical team, and the industrial partner. The responsibilities will be shared in the following manner:

- The PI will be responsible for final instrument specifications especially for concerns related to scientific aspects. The feasibility and the functionality of the instrument will be tested on a Demonstration Model (hereafter called DM) that will be developed by the academic team in collaboration with the industry. Such a model will allow verification of the capacity of the selected instrument configuration to satisfy the scientific requirements and to validate the technological solutions adopted. The PI will have to prepare a preliminary calibration plan and functional test plan applicable on the DM to test it and on the Engineering Model (EM), Qualification Model (QM) and Flight Model (FM).

- The industrial partner will assume the responsibility to define the specifications of the different sub-systems of the instrument. Part of its duties will be to design in detail the configuration of the instrument taking into account the results of the scientific analyses and of the developing test, updating the related analyses and considering all the mission requirements. The industrial partner will identify the different components and those considered as critical, and will generate specifications and select the provider. Using either development breadboards or DM, the industrial partner will test experimentally the critical technologies and realise the instrument.

A very important aspect of the combined activities between PI and industrial partner is the definition of the philosophy for the scientific performances estimation and the calibration processes.

By the end of this so-called B phase, the instrument state of development will be:

- technical and scientific specifications defined;
- DM available;
- complete architectural design with the related analyses available;
- specifications of the critical parts for procurement defined;
- part list complete;
- preliminary calibration plan.

The next phase (C/D) will concern the effective realisation of the following models:

- STM for the thermo-structural qualification;
- EM for the functional verifications;
- QM for the qualification;
- FM for flight.

In the following, we will describe the state of development of some of the instruments proposed for the future Mars missions in the framework of the strategy just described.

All the previous activities are developed with ASI financial support. The ASI role during the instrument development is twofold: the ASI Scientific Directorate is in charge of the evaluation of the scientific quality and of the development status of each experiment; also, the ASI technical staff is in charge to evaluate the congruity of the industrial contracts and to define and monitor the different project milestones and the associated deliveries.

4. DEEDRI

The DEEDRI concept has been developed by Tecnospazio, under direct guidance of ASI, as a multipurpose tool to be used in different space missions. In fact a similar sampler device has been already developed for the lander of the Rosetta mission.

The original drill, during the assessment and the Phase A, was modified in order to be used as a real scientific system. In fact, after the selection of the experiments to be housed in the drill, the drill mechanical structure and its electronics were changed accordingly. Moreover it was also foreseen to calibrate the drill torque force in order to use it as a tool to characterise soil mechanical properties. The scientific team, therefore, was also involved in the definition of the new drill configuration.

DEEDRI is a robotic sampling system capable of collecting sub-surface samples to depths ranging from 0.5 to 2 m. The samples can be of solid type or powder. It consists of three major elements: a robotic arm, a drill box and the associated electronics. The robotic arm is a manipulator capable of displacing and holding the drill box for the operations (stowage/deployment, Mars surface approach, drilling operations, positioning for delivery of containers to possible return vehicle, positioning for sample delivery to scientific instruments). The drill box contains the key elements to perform the sample collection and distribution operations: the drill rod, the sample containers transfer device and the related mechanisms.

5. Instrument selected for DEEDRI: MA_MISS

MA_MISS is a miniaturised near-infrared (0.8-2.8 μm) imaging spectrometer designed for studies of Martian subsurface layers. The instrument will be integrated into the drill and will be able to provide an image of a "ring", to determine the composition and granularity of different layers, and to identify the mineralogy of individual grains.

During the A phase of the project, the detector requirements have been defined by the PI. On this basis Officine Galileo looked for potential constructors and started to investigate costs and performances. A preliminary design of the mechanical configuration has been prepared for the architectural verification. It takes into account the final part of the drill and the results of the related thermal analysis.

Having identified the optical fibres as a critical item, a dedicated research has been carried out giving particular attention to the level of space qualification. The electronics design was focussed on miniaturisation of the electronic components and reduction of harness volume.

6. IPSE

IPSE is a scientific autonomous micro-laboratory for Mars soil and environment analysis providing the capability to serve, handle and manage scientific miniaturised instruments accommodated inside its envelope. The IPSE concept has been developed by the CISAS group of the Padua University in strict co-operation with the prime contractor Tecnomare. IPSE is a challenging project in which state of the art solutions were included. Its general configuration is based on a structure with an external envelope to fit within the available room on the lander deck. A small robotic arm is stowed inside the envelope and provides the capability to deliver soil samples to the instruments from the DEEDRI.

The first version, now under development, will have basic capabilities but the philosophy of the design is to have a modular system that will evolve with each launch opportunity. Its general configuration for the 2003 MSR mission is based on a structure with an external envelope to fit the available room on the Lander deck and featuring 10 kg mass, inclusive of four scientific instruments described hereafter.

A small robotic arm with either 3 or 4 degrees of freedom is normally stowed inside the IPSE envelope and provides, during operations, the capability of delivering soil samples to the instruments taken from DEEDRI.

IPSE is designed to operate in Martian environmental conditions and for a lifetime of one Earth year with the aim to be upgraded at each launch opportunity. This means that it will be able to operate at severe temperatures and low pressures in a sandy and windy atmosphere.

The IPSE structure will contain power conditioning for the various users, and electronics for system and thermal control, and communications and instrument data handling. IPSE is equipped with a processing unit, allowing for a high degree of operational autonomy and flexibility in the operational sessions. A modular philosophy has been implemented to allow the maximum level of de-coupling between IPSE and the experiments. It will feature the following main capabilities:

- Autonomous thermal control. A dedicated insulating cover has been studied to fulfil the thermal requirements both in terms of power and in terms of temperature.

- Electrical interface with the Lander to provide and manage power supply to all IPSE subsystems and to the scientific payload.

- Communication interface with the Lander to receive high level commands, telecommands from ground and to transmit the collected scientific data, housekeeping and status parameters.

- Control of the robotic arm for sample handling, sample collection from the drill, sample delivery and discharge to scientific instruments.

- Sample preparation prior to analysis. In case of dusty or soft soil samples, the sample will be slightly compressed prior to measurement to reduce it to a proper layer. This preliminary operation provides a way to evaluate correctly the proper sample position underneath the instruments for optimal focusing.

- Control of the micromechanisms for sample motions parallel and normal to the focal plane for optimal focusing and execution of two dimensional spectral analysis.

- Processing capabilities, including housekeeping functions, scientific measurements scheduling and instruments power on/off, data acquisition, compression, temporary storage and transmission to the Lander.

7. Selected instruments for IPSE

IRMA (Infra Red Microscope Analysis)

The industrial prime contractor is Officine Galileo, the same as for the ESA-ROSETTA VIRTIS instrument and has been involved in the project since the beginning, due to the limited development time available. Thus, there has been a positive transfer of the experience gained in the VIRTIS development. Moreover, there is a strong and fruitful interaction between scientific and technical teams, and all the decision concerning the instrument configuration and layout are thoroughly examined against their implications on the instrument performances.

The present plan of development foresees a prototype (breadboard) production in the CNR laboratory for the investigation of the critical parameters (spectrometer temperature, spatial resolution, etc.) and for the spectroscopic analysis of analogs samples of Martian soils. The prime contractor will use the results to modify and optimise the instrument design. The required models are then produced by the prime contractor, while the PI shall retain responsibility over the scientific calibration activity.

IRMA is a hyper-spectral microscope for the in-situ mineralogical analysis of Martian samples. It works in the 1-5 μm spectral range, with a spectral resolution of 8 nm. Its spatial resolution is 38 μm and the overall field of view is compatible with the sample dimension collected from the DEEDRI drill (12 mm diameter).

The investigation carried out by IRMA has the goal to quantitatively characterise the mineral abundances (down to a 1% abundance levels), and the micro-physical properties of Martian subsurface samples.

The in-situ measurements have the considerable advantage with respect to remote sensing observations of permitting an unprecedented spatial resolution allowing removal of mineral identification ambiguities due to the contamination of the spectroscopic features by the atmospheric gases and aerosols. One of the main tasks of the experiment will be the assessment of the present and past interactions among Martian surface materials, hydrosphere and atmosphere through the study of the mineralogical products of these interactions (weathering).

MA_FLUX (MArs X FLUorescent Experiment)

The MA_FLUX instrument is realised in an Italian/French (CNR-IAS, Planetology, Rome/Institut de Physique du Globe de Paris) co-operation that sees CNR-IAS and CEA/DSM/DAPNIA/Service d'Astrophysique as providing the instrument concept and test, and an industrial part (Laben SpA, Milan) that is investigating the thermo-mechanical and electronics design.

MA_FLUX will investigate the Martian surface using the X-ray fluorescence technique, thus allowing the detection of the major and trace chemical elements in the Martian soil, down to a few ppm, using simultaneously the gamma scattering method and the X-ray fluorescence technique. This instrument investigates the interior of samples to a depth ranging between one mm and one cm. Furthermore it defines precisely the X-ray absorption capacity of samples and permits the estimation of the abundance of elements heavier than iron.

By analyzing the Compton and Raleigh scattered photons at different energies and at different angles, it will be able to estimate the abundance of the major elements. By analyzing the hard X-ray fluorescence features, this system should evaluate the chemical composition of the trace elements within a few ppm.

MAGO (Martian Atmospheric Grain Observer)

The MAGO project is an international consortium including Italy (Osservatorio Astronomico di Capodimonte, Istituto Universitario Navale and University "Federico II"in Naples), Spain (Instituto de Astrofisica de Andalucia, Granada) and United Kingdom (University for Space Science of Kent).

The hardware development is performed in collaboration with Italian and Spanish industrial partners. Officine Galileo in Florence is responsible for the overall management at industrial level.

MAGO measures cumulative dust mass flux and dynamical properties of single intercepted particles as a function of time. It allows determination of grain mass, size and shape distribution, and dynamic behaviour of airborne dust.

It is a single instrument including three different detection sub-systems (three micro-balances using quartz crystals as detectors of mass deposition, a grain detection system based on the detection of the scattered/reflected light produced by the passage of single grains through a collimated laser light "curtain", and an impact sensor (piezoelectric sensor) for the detection of the momentum released during the impact of single grains on a sensing aluminium plate.

These measurements have never been obtained so far and will greatly improve our capability to interpret and describe processes such as aeolian erosion, redistribution of dust on the surface, transportation and weathering, circulation and climate evolution. The measurements by MAGO have a crucial role also in terms of the identification of hazards for elements sensitive to dust deposition and, in a wider perspective, for the human exploration of Mars.

MAGO is a versatile instrument that can be easily integrated also in small payloads targeted to the exploration of the Martian dust environment. The MAGO sub-systems are similar to or derived from concepts already developed for the GIADA experiment on board the ESA-ROSETTA space mission and, therefore, benefit from the development program already carried on for this application. The instrument combines technologies used in past space missions i.e. impact detectors based on piezoelectric devices with newly developed concepts.

MARE-DOSE (MArs Radioactivity Experiment-DOSimeter Experiment)

The MARE-DOSE instrument will be realised with a Italian effort of scientific institutes and national space industries. The preliminary phase of design of MARE-DOSE (Phase A) and the subsequent manufacture and tests of the DM are under the responsibility of research institutes (CNR and Perugia University) with the contribution of technical aspects from industry. During the Development Phase the hardware and management activities concerning all the deliverables (hardware, software and documentation) will be carried out under industrial control, with researchers retaining control over scientific requirements and performances definition. The test activities on the DM will continue in the research institutes, thus providing useful input for the detailed design of the experiment. This approach will allow considerable reduction of costs, while ensuring that the instrument will meet the scientific requirements imposed during the design phase as well as the overall mission design.

At present, the detector has been defined together with the power supply and data acquisition system. A mechanical and optical architectural design has been developed considering the possible locations within IPSE. A model for the thermal analysis has been implemented for the operation phase and for survival during the cruise phase, and a preliminary electronics architecture has been designed.

MARE-DOSE is an experiment for monitoring the β and the γ radioactivity during the Earth to Mars cruise phase and at the surface of Mars, in the range 30-300 keV. It consists of lithium-fluoride doped pills which can be exposed to the radiation, reset and readout by heating the pills within a thermo-luminescent process during heating cycle and the emission of an optical signal flux proportional to the absorbed dose.

8. Conclusions

As a conclusion, it can be said that the effective collaboration between academic institutes, main actors up to the breadboarding, and industrial partners, main actors for the design and manufacturing, for the Mars Exploration program relies on a solid experience previously acquired working on other missions (e.g., CASSINI; ROSETTA) and it represents an efficient way to transfer knowledge and know-how between the organisations involved. A detailed description of all the studies carried out during the phase A is provided in the reference.

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Innovative Technologies and Space Applications (1)

Chairman: A. Atzei, ESA-ESTEC, The Netherlands

PERSPECTIVES FOR MICROSYSTEMS TECHNOLOGIES IN SPACE APPLICATIONS

Daniel Estève
Directeur de Recherche au Laboratoire d'Analyse et d'Architecture des Systèmes du
Centre National de la Recherche Française
(LAAS-CNRS)
7, avenue du Colonel Roche – 31077 Toulouse cedex 4 – France
Phone : 33 5 61 33 64 03 – Faxe : 33 5 61 55 35 77 – e-mail : esteve@laas.fr

Abstract

The aim of this Conference is to demonstrate that time is coming for Space Industries to increase their effort for including microsystems technologies in Space. We remind that the concept of microsystem is born more than ten years ago and has been the subject of an enormous effort in basic research and prototyping. We summarize what seems to us available in the offer "Microsystems". On the base of two examples of recent studies conducted in LAAS-CNRS, Toulouse: IR earth horizon sensing and Si-micromachined microthrusters, we show that the date of 2005 for starting industrial developments is still a good realistic planning...

Microelectronics is born in the Sixties, based on the invention of the bipolar transistors, some years ago. The Silicon planar process opened the industrial phase by allowing electronic circuit integration. Since this period, the industrial sector is growing at a rate of + 15 % by year in turnover, with an increasing complexity of the products (Moore Law).

This extraordinary success is due to the collective character of the fabrication process: instead of considering component by component, the process is able to work in batch of several tenth of wafers, containing each, thousands of elemental components... The price of one component calculated as the ratio of the total process cost on the number of fabricated devices is very low, allowing Microelectronics to diffuse in all the products whatever the industrial sector is.

Space Industry has taken a large benefit of this Microelectronics diffusion character and has introduced very fast integrated circuits in the satellites electronic Design.

What is the situation of Microsystem technologies ten years after the concept proposition and the first demonstrations. The microsystem concepts apply and develop the microelectronics principles: integration and collective fabrication of multidisciplinary system including: sensor and actuator with signal treatment. Well known examples (mechanical sensors, inkjets, vision systems) demonstrate the industrial potential impact of the concept. In each previous cases, the improvements in costs and performances have imposed the new products in the world market versus classical devices... But in these cases, the volume of the market is important enough to support the technological developments. The question is: what can be done when the market volumes are too small, as it is the case for the Space Industry needs ?

Some interesting ways are explored with the support of Public Research Organization by:
- developing microsystems foundries,
- offering access to microtechnologies for non-electronics disciplines and industrial sectors,
- recycling and re-using microelectronics facilities converted for microsystems fabrications,
- activating an offer in microsystems design.

1. Space and Microsystems

Basically, Space is interested in device miniaturization because weight and volume are an essential factor of expenses related to satellite design and fabrication but mainly because of the potential cost reduction in smaller launchers use.

That evidence has been often expressed these last years but there is some real difficulties for Microsystem development in Space:
- microsystems technologies are non-mature ,
- it takes a very long time to qualify products in Space procedures,
- development costs are still too important for adapting existing microsystems in Space conformity.

Let us also note that there are some more strategical reasons: USA and Europe are, since a long time, engaged in the big launcher option able to maintain a human presence in Space. This strategical option is not compatible with the parallel development of new concepts for small but low cost launchers.

But it is clear that microsystems technology is improving and Space Industry has to take into account new offered perspectives. Some exploratory missions have been organized for testing a new policy based on low cost satellites, reduced time to market... Successes and checks leave open an indecisive prospective for the next years. However, the question has changed and is more: when and how microsystems technologies will be inserted in real space applications ? Our advise is that this question has to be discussed without any a priori on the penetration way:

- as microsystems insertion in conventional satellites,
- as a global concept for micro and nano satellites.

2. Evaluation of Microsystems Application Opportunities in LAS-CNRS experience

In 1996, LAAS-CNRS and MMS (Matra Marconi Space) presented their conclusions on Microsystems perspectives in Space, in a pre-study sponsored by CNES in France. They conclude on industrial possibilities starting, function by function, in 2005. For illustrating that evaluation, they suggest to test two domains:

- *The micropropulsion* taking into account the perspectives of miniaturized satellites (5 kg-50kg) and some experiences at LAAS-CNRS on silicon-propergol integration.
- *The IR vision systems* considering new perspectives of micromachining Si devices in bolometric arrays.

Fortunately, Research activities have been conducted in these domains with the support of CNES agency, giving us the possibility to appreciate more precisely the delay for real microsystems applications in Space.

We will consider first the general situation.

2.1. 3D Si based assembly technologies

In Si-circuit technology, the active part is occupying the only last five microns in the upper part of the substrate. It is clear that large improvements are available for reducing volume and weight of the electronics assembly. Different possibilities are explored for future use.

a) Base chip assembly: in Europe, an industrial offer exists with $3D^+$ Company based on a stacked silicon bared chip process where the chips are interconnected on the lateral face of the "cube". This process was designed for microelectronics applications and extended for microsystems within an ESPRIT project called BARMINT [1]. Beyond electronics circuits, BARMINT demonstrate that it is possible to assemble fluidic and optical devices through the $3D^+$ procedure. Factors of ten are possible in compactage performances.

b) Flip-chip reports have to be recalled even if the process has been developed and used long time ago. Flip-chip report is a good candidate in microsystems when we have to interconnect the sensor and its electronics.

c) U.T.C.S. process (Ultra Thin Component Stacking) is a new attempt to reduce size and weight. It is based on the use of a thinned chip. A running European project UTCS [2] give us some indications of what can be reached: chips are thinned to 15 μm and reported on the interconnections substrate. At this thickness level, thin film procedures can be applied from chip to chip located on successive layers of active components. Compacting factors of ten are yet possible compared to $3D^+$ procedure.

2.2. Modules interconnection

The previous presentation show that microsystem technologies conduct to compacted modules autonomous, intelligent,...

On the electrical point of view, signal can be connected by wire or wireless. Integration of HF emitter-receiver open these opportunities and recent developments in optoelectronics indicate that optical solution can be envisaged for interconnection.

But some constraints can come from the fluidic and thermic aspects: LAAS and LEN7 [3] have explored these questions in a recent study for ESA.

2.3. The situation of the microsystem offer

In microsystem integration, we face the difficulty of compatibility of multidisciplinary technologies.

In the basic approach, the ambition was to reach a monolithic integration on Silicon substrate: sensors, actuators and signal treatments on the same chip. This option is today covered by some experimental procedures (TIMA/CMP) in the US and Europe. The basic process is a VLSI process on which we add a final micromachining step.

An other possibility (MUMPS) is to start with a specific surface micromachining process to realize the sensors and actuators but the signal treatment has to be added on a second chip.

Practically, the industrial option is to assemble several chips in a compact 3D process like described in item

2.2. In this quite open option, what can be available for 2005 industrial applications ?

a) *Mechanical sensing (MEMS)*: pressure and accelerometers, gyrometers,... are already available even if adaptations and improvements have to be realized for specific space applications.
b) *Optical devices (MOEMS)*: microlens, micromirrors,... are available as isolated components or as array designed for image applications (LAAS has developed a scanning mirror: 400 Hz ± 15°).

Different solutions have been proposed and experimented for interchips connections.

Considering visible imaging, APS, CCD and other Artificial Intelligent retines are available. In IR imaging, the microbolometric option is already proposed (see item 3).

c) *Fluidic devices* are the field of very active researches supported by the bio-medical applications (bio-chips).

Specific fluidic devices like "ink-jets" have already shown then industrial capacity by occupying the printing market.

Some new perspectives are related to the concept of "Lab on a chip" aiming the total integration of bio-medical reactors.

Gaz fluidic is a recent field of efforts for micropropulsion applied to the attitude control of micro and nano satellites (see item 3).

3. Two examples of microsystems designed for Space applications

Following a pre-study estimation, two parallel studies [4] were launched three years ago for designing and fabricating prototypes in IR earth horizon sensing and in Si-microthrusters. The ambition was to evaluate the microsystems approach and evaluate the improvements and difficulties.

3.1. The earth horizon sensing

The idea was to take benefit of the opportunity of microbolometric array that avoid heavy and expensive cooling systems used in quantic detection.

The microsystem developed is based on a Boeing array (320 x 240) but similar components are now available in Europe (SOFRADIR). Our MIRES project (Micro Infrared Earth Sensor) has been already defined. It includes three micro-bolometers (14-16 μm) positioned at 120°. The sensing objective is to provide a system which compute the pitch and roll depointing Satellite.

A prototype has been built and evaluated:
- performances are compatible with Space specifications (18° aperture, 0, 1° sensitivity),
- dimension electronics including optics is less than 250 cm^3.

This example demonstrate first that microsystems give a very elegant solution for horizon earth sensing by using Si micromachined chip, second that optics impose some limitations in compacting the function. In our case, optics is for more than 50 % in the global volume occupied by the sensor.

3.2. The Si-Micromachined Micro-thruster

Silicon micromachined substrates support the thermal ignitor on a very thin membrane (1/2 μm) and the propergol tank. When ignited, membrane is broken and gas flows... Beyond the advantage of a very compacted device, the interest is to be able to build an array of microthrusters allowing to have a quasi-proportional command for the attitude or altitude control of the microsatellite.

Basic demonstration (16 elements array) is already achieved. We start on a three years program with two main objectives:
- to develop modelling and basic technologies (MICROPYROS, CCE-FET project)
- to design and prototype more demonstrative devices for Space applications (CNES support).

The example shows that microsystems can give very innovative and attractive solutions to classical problems encountered in Space applications. The planning is still compatible with a 2005 horizon for the industrial developments.

4. Conclusion

Development of microsystems technologies is very fast. First supported by Automotive applications (mechanical sensors), it takes now benefit of bio-medical prospectives.

Two examples of specific space application project: IR earth horizon sensing and Si-Microthruster show clearly that short term perspectives are open by microsystems technologies.

In parallel with large market size opportunities, it is urgent to launch an European voluntary program on microsystem in Space.

5. Acknowledgements

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APPLICATION OF SHAPE MEMORY ALLOYS TO ROCK SPLITTING: A SUCCESSFUL EXAMPLE OF CO-OPERATION BETWEEN SPACE RESEARCH AND INDUSTRY

Stefano Carosio, Donato Zangani, Eric Parker

D'Appolonia S.p.A.
Via San Nazaro, 19
16145 Genova (Italy)
Tel: +39 010 3628148
Fax: +39 010 3621078
E-mail: stefano.carosio@dappolonia.it

Ian Sutherland

Brunel Institute for Bioengineering (BIB)
Brunel University
Uxbridge, UB8 3PH, UK
Tel: +44 1895 271206
Fax: +44 1895 274608
E-mail: ian.Sutherland@brunel.ac.uk

1. Abstract

The Shape Memory effect has been known for over thirty years. Valuable know-how about Shape Memory Alloys has evolved from their investigation and application in Space Programmes. Specific expertise developed in the BIO-SAMPLE project by Brunel Institute for Bioengineering (BIB) was identified by D'Appolonia as having potential for reducing the use of explosives in the ornamental stone sector. Explosives can cause serious damage to the final quality of the material as well as environmental and safety problems.

A rock splitting tool based on Shape Memory Alloys has been developed by Ripamonti, D'Appolonia and BIB, in tight cooperation with a group of European Small and Medium sized Enterprises (SMEs).

This paper will provide an overview of the main research tasks and achievements. It will demonstrate how the background and problem solving approach of a space academic institute can address real industrial problems and be instrumental in reaching a successful outcome.

2. Introduction

Stitch drilling is a method used in most quarries to extract a block of regular dimensions and shape. In stitch drilling, a series of holes are drilled along the splitting line (see figure 1).

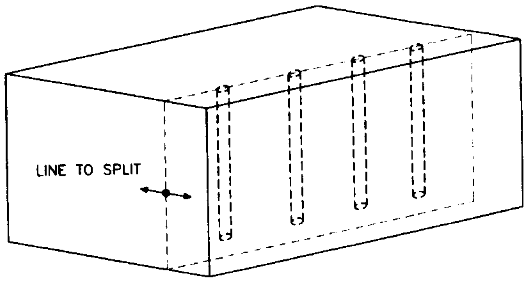

Figure 1: schematic view of stitch drilling

The stone is then dynamically split along this line by means of "soft" explosives or by means of wedges driven into the holes with hammers. Alternative static solutions are the use of hydraulic systems or the use of liquid clays which expand in the holes as they dry. All these techniques have current productivity and quality limitations. Specifically, stitch drilling is a time consuming and expensive processes, and explosive splitting often damages the stone block by uneven breaking. These factors increase costs and lower quarry production.

This problem is highly relevant for quarries and represents a huge business opportunity for companies active in the machine and tool sector. The Italian company Ripamonti, which has been investigating novel stone splitting methods for the past 20 years, is in an optimal position to benefit from technology development.

3. Matching the industrial need with space know-how

Shape Memory Alloys (SMA) are materials which have the ability to return to a predetermined shape when heated. This process is directly related to an internal thermo-dynamic transformation from the martensite to the austenite phase. These alloys are generally composed of Nichel and Titanium in approximately equal parts. If the SMA encounters resistance during the phase transformation it can generate extremely large forces (400 MPa) and displacements (6-8%). When they cool down their original shape can be easily recovered, due to their low yield stress (around 80 MPa).

Although the shape memory effect has been known for over thirty years, valuable know-how about Shape Memory Alloys is related to their investigation and application in Space Programmes. Typical applications concern the automatisation of routine tasks while astronauts are busy performing research projects in space. During space experiments samples need to be turned off regularly. One way of doing this is to make clutches or hinges from SMA that will turn a sample when it reaches a certain temperature. This was the case in the BIO-SAMPLE project developed by Brunel Institute of Bio-Engineering (BIB), whose objective was to develop equipment needed in micro-gravity to handle samples of living organisms (i.e: fish, insects, plants) in a completely automated laboratory.

Within the Technology Transfer Programme, the European Space Agency (ESA) set-up early in the nineties an international network of technology brokers, "The Spacelink Group", responsible for promoting secondary applications of space technologies by identifying relevant industrial needs and identifying promising technologies and know-how. In this framework, D'Appolonia, Italian representative of The Spacelink Group and member of EARTO (European Association of Research and Technology Organisations), identified the expertise developed by BIB in space research as having the potential to substitute the use of explosive in the ornamental stone sector.

Ripamonti was impressed by the level of force released by these smart materials when heated, and, with the support of D'Appolonia, investigated the feasibility of the concept. The results of this preliminary study revealed the immense potential for SMA to address the requirements of the stone industry.

Based on the support of the European Space Agency and of the CRAFT Programme of the European Commission, a rock splitting tool based on Shape Memory Alloys has been developed by Ripamonti, D'Appolonia and BIB, in tight co-operation with a group of European SMEs.

The system exploits the main characteristics of Shape Memory Alloys (capability to return to a predetermined shape when heated, generating large forces and displacements) to solve the typical problems met in splitting operations (high costs for the holes drilling and low quality products). The system is composed of two splitting shells, containing the SMA actuators and a heating system electrically actuated. The design of the system has been conceived in order to minimise the content of SMAs and to protect the system from the external harsh environment of the quarries, while providing a compact device easy to use.

A schematic view of the operation of the SMA splitting system is shown in Figure 2.

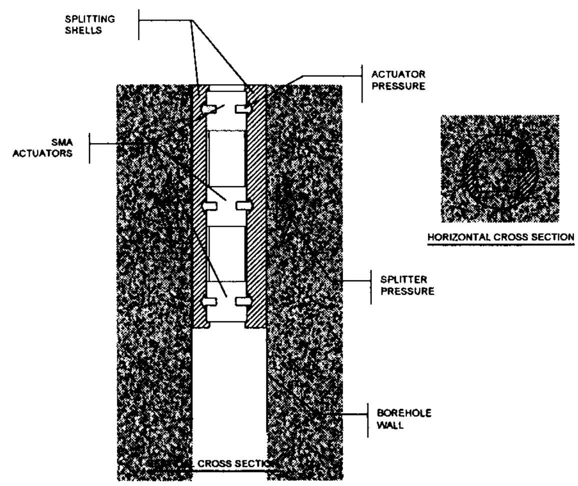

Figure 2: Schematic view of the splitting system

Laboratory testing on small scale stone blocks validated the developed model and demonstrated that the system is able to fulfil the requirements of the application in terms of forces and displacements, as shown in Figure 3.

Figure 3: block split during laboratory trials

The system generates an optimal distribution of concentrated forces and displacements over the whole length of the hole. The advantage from an operational point of view is to 1) extract a block with perfect shape and dimension, 2) eliminate internal block damage and 3) improve the quality and reduce the need for finishing operations or loss of material.

Furthermore the system can be operated concurrently with other quarrying operations, without the need to evacuate the surrounding area. These features, together with the possibility of operating the new splitting system in different climatic conditions, lead to an increased production rate.

4. Description of the Research Work

The research work has included the production of SMA actuators in sufficient shape and number to perform the experimental work, and the development of an extensive experimental study related to the analysis of the behaviour of the shape memory alloys and their characterisation. Several prototypes of splitters have been manufactured and an extensive laboratory and on-field experimental programme has been performed to validate the theoretical predictions.

The main results obtained within the framework of the research performed include:

- Modelling of splitting condition: fracture mechanics was used to evaluate the force required to propagate a sub-critical crack through the material surrounding the borehole wall towards an adjacent hole. Closed form solutions were compared to the results of numerical analyses. Experimental results were in good agreement with the theoretical predictions.
- Development of methodologies for the design and development of large SMA actuators: particular attention has been devoted to the heat treatment, pre-loading and heat activation of the samples, as these are absolutely vital to their performance.
- Manufacturing of Prototypes and testing: several prototypes of the system have been designed and manufactured. A preliminary design of the system has been extensively tested in laboratory for the optimisation of the configuration. An advanced design of the system has been successfully tested in the field with different types of stone and working conditions.

The main breakthroughs of the research work include:

- development and characterisation of large SMA actuators;
- development of a mechanical configuration able to modify the number of SMA actuators according to the force required for a given material and a mechanical design to put the external shells into intimate contact with the borehole walls, allowing complete exploitation of the forces and displacements available;
- development of a cost-effective heating system integrated within the mechanical configuration;
- development of a fixing and positioning system capable of operating the splitters in series within the borehole.

4.1 Modelling of splitting conditions

The aim of the task was to develop a model able to describe the phenomena occurring in rock splitting by varying the rock mechanics and the working parameters. The analysis took into account the distribution of stresses and displacements to define the requirements of the system for the development of basic prototypes.

A theoretical model based on rock fracture mechanics was developed to predict the required breaking force given the drill hole diameter, spacing and rock fracture toughness. The model indicated that the rock deformation before fracture is negligible. From a practical standpoint some non-linear behaviour is expected, and a small amount of deformation will probably occur. As far as the forces are concerned, Figure 4 shows the estimated breaking force for splitting operation of granite and marble.

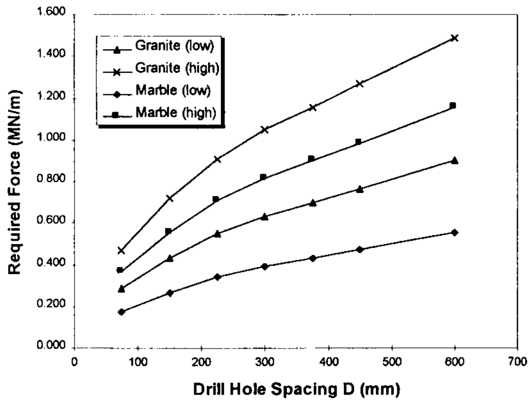

Figure 4: Expected Breaker Force

4.2 Development of methodologies for the design and development of SMA actuators

The objective of this task was to assess the behaviour of the SMA actuators. The evaluation of the performances of the actuators in terms of forces, displacements and reproducibility was fundamental for the final update of the design of the splitter.

The laboratory tests performed have comprised the investigation of the effect of pre-load on recovered load and on sample movement during activation, and the investigation of the heat transfer for the activation. The main conclusions from these test results show that:

- SMA actuators are capable of storing large amounts of force which is released on heat activation;
- Repeated loading does not significantly affect the performance of the material.
- The temperature of heat treatment is very important to the performance of the SMA actuators. Excessive heat treatment produces samples which cannot produce much force on heat activation.
- Careful selection of the heat treatment temperature for each batch of material will ensure optimum actuator performance.

4.3 Manufacturing of prototypes and testing

Several prototypes of the system have been manufactured for the trial of the system.

The objective of field trials was to evaluate the performance of the system. Small blocks of different types of ornamental stones were used to simulate on-field working conditions. Using the results of the laboratory trials, an optimised design of the splitting system was defined to enhance performance. The main characteristic of the new configuration are:

- The ability of it being used in harsh working conditions
- That different splitters can be used in series at different depths in a single hole
- That it incorporates a new fixing and positioning tool, which directs the generated forces along the splitting line,
- That it incorporates a mechanism to fully exploit the forces and displacements generated by the SMA actuators fulfilling the requirements of the end-users.

Advanced trials of the prototypes have been performed using blocks of marble and granite made available by the several quarries.

The results of the trials were satisfactory and the results obtained with the small-scale blocks in the laboratory have been substantially confirmed. The system has been demonstrated to be applicable for the squaring of blocks of ornamental stone in the most critical situation, namely with the splitting plane perpendicular to the bedding plane.

Figure 5 shows the crack propagated in a block along the splitting line. The crack generated by the splitters is clearly visible. The crack connects all the holes along the desired splitting plane and propagates towards the edges of the block.

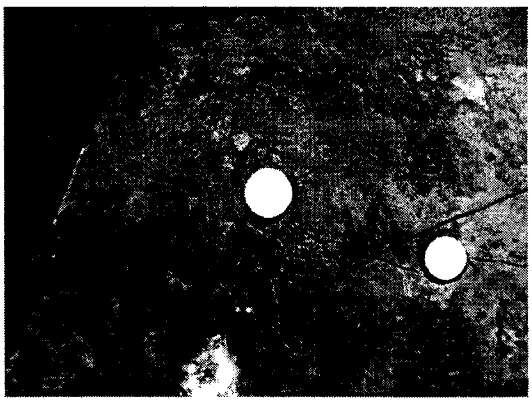

Figure 5: Rupture of a block along the splitting line (the devices have been covered for confidentiality reasons)

5. Academic and Industrial Co-operation: Lessons Learnt

Brunel Institute for Bio-engineering represents a typical example of an academic institute involved in space research, whose structure is open to co-operation with industry. Their work in the space domain is a catalyst for deriving new technologies and expertise which may be transferable to more terrestrial applications.

However, the promotion of co-operation between academic institutes and industry is no easy matter, even when there is awareness on both sides of the benefits to be gained from interaction and a desire to collaborate, as it was for Ripamonti and BIB.

Experience gained in the past reveals that typical obstacles which can impede academic and industrial co-operation include the following:

- Different objectives and missions;
- Different motivations for collaboration;
- Different attitudes towards collaboration;
- Different notions of time;
- Different management styles;
- Different notions of confidentiality;
- Different intellectual property right approach.

These difficulties are even larger when considering technologies or expertise deriving from space research, as their adaptation needs further work to address the industrial requirements in terms of performance, reliability and costs. The link between space academic and industrial domains is therefore a critical topic.

The Technology Transfer Programme of the European Space Agency (ESA) has been set up with the goal of stimulating secondary applications for technological developments supported by ESA, its Member States and Canada.

The availability of Brokers specialised in technology transfer from space, such as The Spacelink Group, to support Academic Institutes is a key to success, as demonstrated by this project. It is in fact crucial for space academic institutes to engage people and give them responsibility within the internal technology transfer programme. This task is made more difficult because specific training programmes for educating technology transfer managers are missing. The dilemma for the academic institutes consists of engaging either scientists who usually lack experience in management or in taking on people with a business background and trying to train them in technology.

The advantages offered by space technology transfer specialists to academic institutes go beyond the establishment of a co-operation framework with industry. In fact, in most of the cases the industry counter-part is a Small and Medium sized Enterprise (SME) with reduced budget to allocate for collaborative projects. Such small projects do not seems to be particularly valuable for a space academic institute, especially if they do not cover their costs which is a rather common problem with SME projects.

Technology Brokers offer networking opportunities, allowing grouping of SMEs with similar needs and expectations along the industrial value chain. Reaching a critical mass in terms of resources drastically reduces the risk of academic institutes having financial losses. Furthermore the support of Technology Brokers provide the expertise in preparing technical and financial documentation necessary to apply for International or Nationally funded programmes aimed at the adaptation of novel technologies, leaving academic and industrial resources available respectively for research and business core missions.

Last but not least, the project demonstrates the valuable role played by Research and Technology Organisations (RTOs) in partnering with academic and industrial partners to address and adapt space technologies towards the fulfilment of the market requirements and expectations.

6. Conclusions

The project proves how non-space sectors can benefit from the expertise developed by academic institutes within space programmes. The main result of the research is a new splitting apparatus for squaring operation in quarries, characterised by low extraction costs compared with the costs of competitive systems, and with great advantages in terms of safety and productivity. Several prototypes of the system have been manufactured and tested in the laboratory and in the quarry.

The system represents a significant step forward in the current state of the art and demonstrates how the background and problem solving approach of a space academic institute opportunely addressed towards real industrial problems is instrumental in achieving a successful outcome. This is confirmed by the active co-operation given by the industrial partners.

The process undergone from the identification of the need to the definition of the strategies to industrially implement the final achievements highlights how Technology Brokers represent an effective approach for space academic institutes in establishing a co-operation framework with industry.

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A BIMANUAL FORCE REFLECTING INTERFACE TO STUDY HUMAN INTERLIMB SYNERGIES

E Gallasch[1], M Fend[1], HP Taferner[1], B Wronski[1], D Rafolt[2], IB Kozlovskaya[3]

[1]University of Graz, Department of Physiology, Harrachgasse 21, 8010 Graz, Austria
Phone: +43/316/380-4265, Fax: +43/316/380-9639, email: gallasch@kfunigraz.ac.at
[2]AKH-Wien, Institut für Biomedizinische Technik und Physik, Austria
[3]Institute for Biomedical Problems, Moscow, Russia

ABSTRACT

In continuation of the Austrian-Russian microgravity programs AUSTROMIR and RLF, we developed a versatile test interface to study features of bimanual movement control. The interface consists of two levers driven by powerful angular voice coil actuators (± 40 Nm) with embedded displacement and torque sensors. The two levers are either controlled bilaterally (intrasubject configuration) or unilaterally by two subjects (intersubject configuration). Function and force field dynamics of the interface are determined by the DSP software, which processes the sensor signals and drives the two actuators at a rate of 1 kHz. The software interface was implemented with LINUX-RT, allowing the quick exchange of DSP control parameters, synchronous transfer of measuremental data and flicker-free video animation of the levers positions and torques. Applications of force reflective devices in neuromotor research, as well as potential applications in space research, such as in remote experiment control, are discussed.

1. INTRODUCTION

Human movement control intrinsically underlies processing of gravitoinertial and backpropagated forces. Experimentally the effects of gravitoinertial forces on motor output are studied with platform motions and during orbital space flights. Such experiments have shown that goal directed movements quickly adapt to a new force environment and only smaller deviations [1] and tremors [2] are observed during the adaptation phase. Backpropagated forces also lead to adaptation effects. For example, if we write a word on a rough surface, our nervous system adjusts the muscular drive to achieve the desired trajectory. To study such adaptation effects, artificial force fields, transmitted to a limb under movement, may be used. To utilize this experimental approach we started our work on force reflecting interfaces [3].

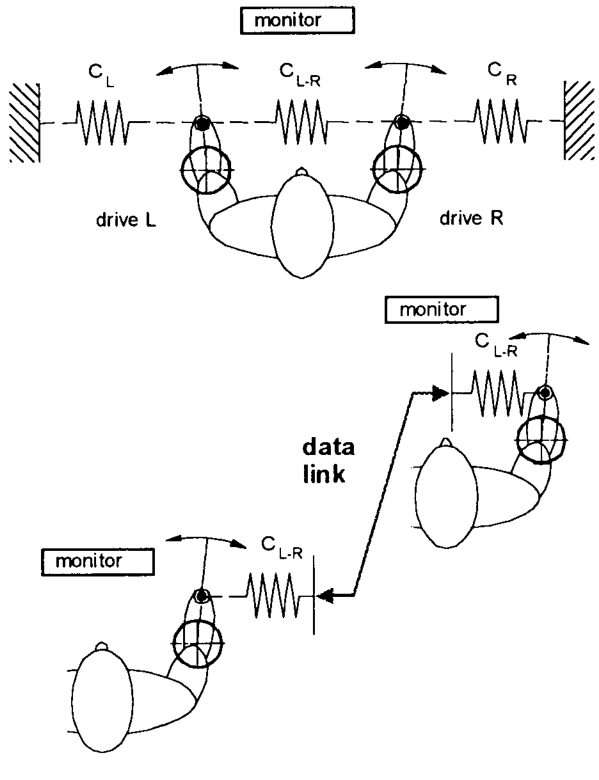

Figure 1. Principle of the bimanual interface in intra- and intersubject configurations The types of force fields are shown by springs.

This paper now focuses on a bimanual prototype, we developed to study features of interlimb movement control, see upper Fig. 1. Normally our brain automatically coordinates both arms, although in many daily tasks we are not aware of this. If we want, however, we can move both arms quite independently. Paradoxically this independency is partially lost during simultaneous limb motions, a problem musicians know when performing complex polyrhythmics. This kind of intrinsic interlimb coupling was described by neuronal cooperative phenomena [4] and obviously reflects the interaction of 'higher' voluntary motor programs with phylogenetic older autonomic control schemes (central pattern generators), necessary for posture and locomotion in our 1 g field. To test this hypothesis time varying, bilateral force fields are needed.

More complex becomes the situation when interlimb coordination between two subjects is considered. Here the subjects can use haptic (force fields), visual and acoustic cues to synchronize their motor actions. Principally such an intersubject coordination also works over distance by using an interface with means for transmission of the limbs force to movement relationships [5]. To study features of intersubject movement control, the interface has to be splittable into two units and interconnectable by a bi-directional data line, see lower Fig. 1.

2. DESIGN OBJECTIVES

In a first approach, a test interface for singe joint forearm movements in the horizontal (see Fig.1) or vertical axis (not shown) will be sufficient. As most of the neurophysiological tests are performed without handgripping, the forearms have to be tightly coupled to the interface (by levers and fixators) so that limb and interface actuation work in parallel. In order to achieve a high precision over the full contraction range of the forearm, the design requirements for the interface actuation were:

- a bandwidth of 0 - 20 Hz for static force fields
- a low passive friction between stator and rotor
- an absolutely ripple-free actuation (<10 mNm)
- a linear signal input/ force output relationship
- a torque output dynamic of ≥ 50 dB
- low inertia of the rotor (< 0.01 kgm^2)
- a maximal torque output of 40 Nm (10% ES)
- angular motion in the range of ≥ ± 20°

Generally pneumatic and electromagnetic direct drives fulfill these demands. Here we decided for an angular voice coil actuator (galvanometer principle), mainly because of its linear signal input/ force output relationship, which makes the control easier. To avoid any movement induced friction caused by back-EMU, this actuator must be operated by a current pump. Disadvantages of this actuator type are a relative big size to torque relationship and the limited angular range. Direct drive actuators with a slotted magnetic design (reluctance principle) would by be an alternative for future designs [6].

To synthesize the experimental force fields and to provide the coupled bimanual operation of the interface the following basic functions have to be generated:

- arbitrary force profiles over time and angle
- arbitrary spring stiffness over time and angle
- arbitrary viscous damping over time and angle
- unstable loads (negative stiffness/ viscosity)
- fusion of sensory input signals over time
- master-slave operation of both actuators

To realize these output functions, a digital control design for real-time processing of the sensor signals is needed, see chapter 4. Preexperiments with a floating point DSP have shown that a processing rate of 1 kHz (according control delay of 1 millisecond) is sufficient to synthesize the required output functions within the desired 0- 20 Hz bandwidth [3]. On the other hand there are many less time critical functions such as visual animation of lever positions, transfer and storage of measuremental data, and data transmission for teleoperation. For these functions a commercial PC-computer should be used.

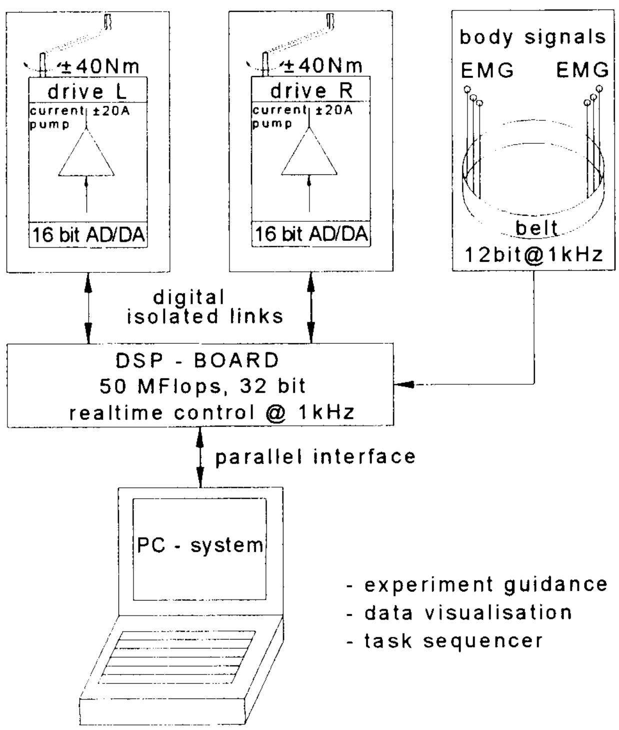

Figure 2. Hardware configuration of the bimanual interface with DSP control unit and PC user interface.

Fig. 2 shows the basic hardware configuration, that was chosen for the bimanual interface. The two sensor-actuators, and optionally a belt for physiological signals, are process-controlled locally via a floating point DSP (TMS320C31-50). Belt and actuator subsystems are isolated galvanically to avoid interference problems due to longer cables in local remote applications. The software for experiment guidance and data handling was set up on a standard PC with LINUX-RT.

For teleoperation and remote applications two PC/DSP systems (see lower Fig. 1) are connected bi-directionally via private network (Internet, ISDN). For data exchange the UDP-protocol with a rate of 100 Hz is actually used.

3. INTERFACE MECHATRONICS

Each side of the interface side consists of a lever driven by its angular voice coil actuator with embedded angular displacement and torque sensor, see Fig. 3. The actuator's rotor was designed as a flat, four pole coil assembly, freely moving in the air gap of four magnetic field loops, forming the stator. In the air gap a field strength of about 0.8 T was obtained by using standard rare earth permanent magnets (NdFeB36, Edmund Scientific Co, USA). The most important electro-mechanical specifications are:

- rotor: ∅ =25 cm, M =1.41 kg, Iz =.0055 kgm^2
- winding: R =1.22 Ω, L = 4.97 mH
- torque constant: 1.76 Nm/A I_{max} = 23 A (10% ES),
- first mechanical resonance (blocked lever): 145 Hz
- total weight: 15.5 kg (with aluminium housing)
- capacitive angle sensor: Trans-Tec Inc, Mod. 600

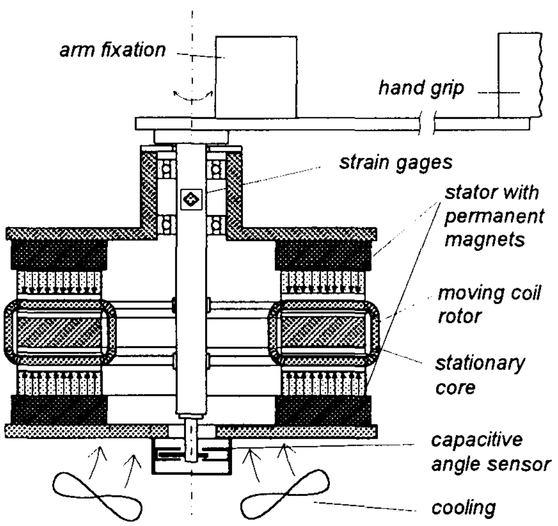

Figure 3. Mechanical design of the actuator. The shaft carrying the coil assembly (rotor) is pivoted by two ball bearings and attached to the forearm lever.

The electrical design of the actuator was constrained to protect humans from dangerous voltages. To achieve low voltage operation (< 50 V), the coil resistance was chosen low (1.22 Ω). To drive the coil, a voltage controlled current source based on a FET H-bridge with a shunt resistor for internal voltage feedback, was developed. With an input voltage of ± 5 V an output current of ±20 A, corresponding to a torque of about ±36 Nm is achieved. The realized bimanual system in shown in Fig. 5.

4. CONTROL- AND USER SOFTWARE

The control software has to be downloaded from the PC to the DSP-board via the parallel printer port. A timer on the DSP-board is used to wake up the control software each millisecond. Within this time window the AD/ DA converters are read, the control algorithms are executed and data transfers between DSP and PC are performed by activating a LINUX-RT task.

A typical control design is shown in Fig. 4. Inputs are the sampled lever angles α_R and α_L, and outputs are the actuator currents I_R and I_L. The processing structure of each actuator is the same, it consists of the input signal mixing stage, the filter stage and three parallel controllers. Coupled operation of both actuators is achieved by the matrix operation in the input mixing stage, with k as parameter, see below. The filter stage is used to selectively remove noise from interferences and mechanical resonance. Filters, but also controllers are defined by rational transfer functions. The transfer parameters (numerators and denumerators) are downloaded from the MATLAB programming environment.

The functions of all three signal processing stages can be made time variant. Eight arbitrary functions generators were implemented to provide additive ⊕ and multiplicative ⊗ variations, see Fig. 4. These function generators are also used to signal the given α's on the video display (moving markers for tracking tests). Additionally to the functions over time, functions over angle were provided in each signal path. Both functions together are used to synthesize the complex force fields needed for the neurophysiological investigations.

To give an example of coupled operation, consider one controller in each signal path, each set to a constant P, and the factor k in the mixing stage. With k = 1 the inputs α_R and αL are not mixed. In this case any lever deflection produces a proportional restoring torque according to a mechanical spring and a subject 'feels' two independent springs (C_L and C_R in Fig. 1). With k = 0.5 both inputs became subtracted, thus producing an unreferenced spring between both levers (C_{R-L} in Fig. 1). This kind of input coupling can also used for intersubject coordination, remote sensing (kinesthetic interface) and master-slave control.

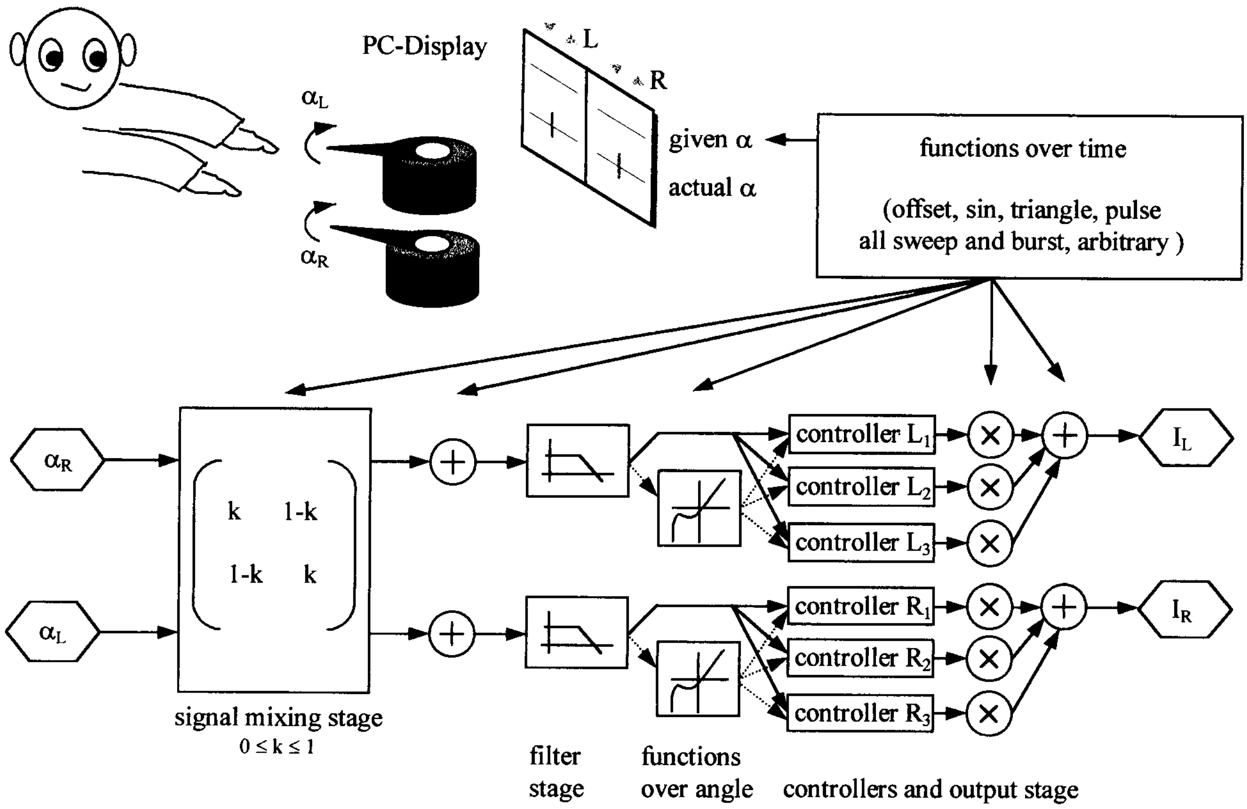

Figure 4.Layout of the DSP control software

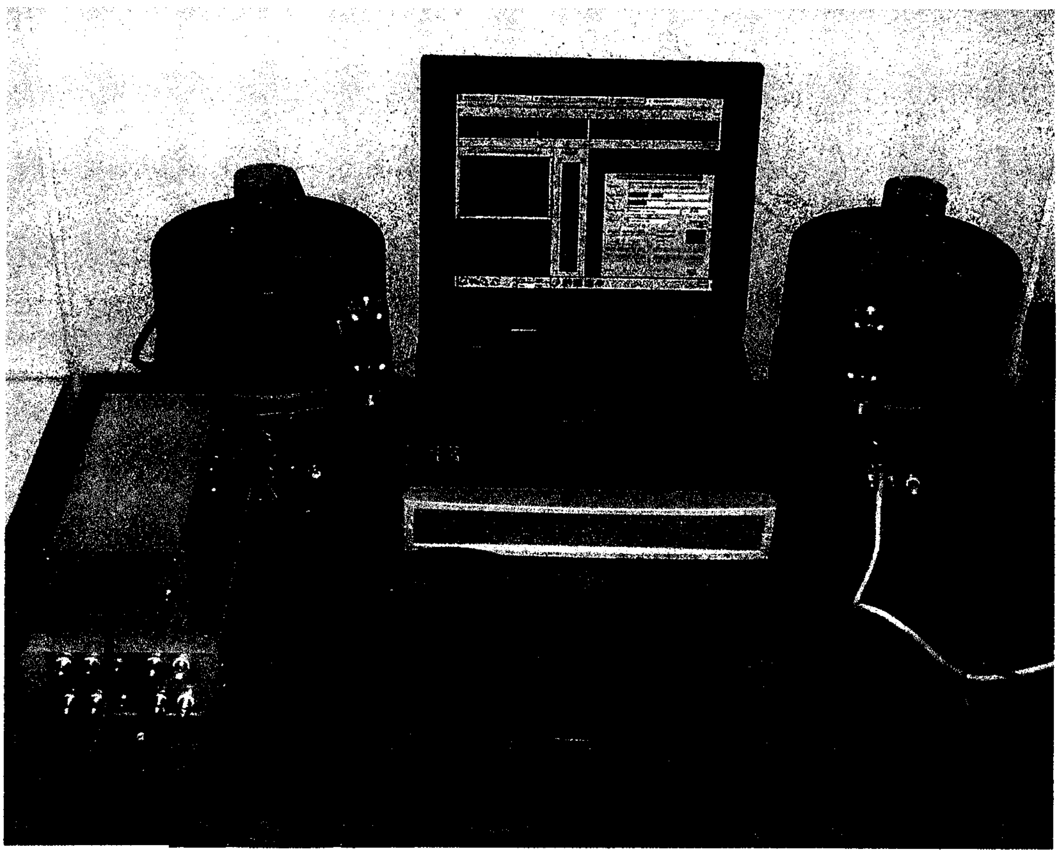

Figure 5.First prototype of the bimanual force reflecting interface

The user software uses the time slot within the 1 kHz DSP cycle for bi-directional data transfers. To synchronize the PC-process with the DSP cycle, LINUX-RT proved very stable. Additionally to the data transfers, the user software provides means for real-time video control, experiment guidance and teleoperation with a splitted DSP/ sensor-actuator system (lower Fig.1). Video control includes flicker-free animation of markers for given and actual α's and torques, a scope function for the following of signals in the controllers and sliders for trimming of control parameters with the systems mouse (e.g. levers zero positions, stiffness and damping).

Experimentation with this interface includes various movement tasks with specific parameter settings (gains, couplings, controller types et.). Typically such a subtask is first tested out by trial and error before several subtasks were combined to form an experiment [7]. To support such kind of flexible experiment set up, a data bank system to store the implemented subtasks, and a sequencer to schedule an arbitrary lists of subtasks was implemented on the PC. The subtask lists include dialog boxes with sounds for interactively guiding the subjects through their experiment.

5. TEST AND EVALUATION

The precision of the uncontrolled sensor-actuator system is mainly determined by the shaft's rotational stiffness, the frictions of the ball bearings, and the sensors noise. The shaft's stiffness was tested by the first mechanical resonance with blocked lever, it was measured at 145 Hz (+26 dB). Coulomb friction, was tested by the minimal current by which the rotor starts to move. I_{break} typically is at 5 mA, correspondingly to a torque of 9 mNm. Viscous friction was tested by electrically applying a torque impulse, and fitting the measured deceleration response to a $(1- e^{-t/\tau})$ function. The estimated friction (with amplifier) was in the range of 95 mNs. The sensors noise was measured within 0-400 Hz. Typically values for the angle sensor (signal output 100 mV/°) are 25 μVpp, and 3.75 mVpp for the torque sensor (signal output 100 mV/Nm).

The dynamics of the controlled sensor-actuator system additionally depends on the algorithms and the processing hardware. The processing hardware induces a 1 millisecond control delay, tending to make feedback control unstable. Actually this is the case if an ideal spring-like behavior has to be synthesized from the levers displacement signals alone (double integrator problem). For stable operation, therefore, a velocity or viscous component in the controller's transfer function is necessary (Fig.5). As such a component needs a differentiation of the displacement signal, there are limitations due to measuremental noise. With adequate compensations in the control path the following specifications were actually achieved:

- range of torsional stiffness: 0 ....± 203 Nm/ rad
- range of viscous damping: 0 .... ± 4.3 Nms/ rad
- closed loop bandwidth: 0 to 28 Hz (-3 dB)

The bimanual performance was practically evaluated by remote sensing a soft- and hardelastic body. Therefore the bodies were fixed in the plane of the left lever. Then the right lever was used to manually compress and sense the bodies viscoelastic behavior. As it is difficulty to describe the qualitative aspects of these tactile sensations, the right levers torque to angle relationships are shown in Fig. 6. From the different stiffness slopes one can easily distinguish between the two bodies. The third - high sloped - curve was achieved, when the left lever was hard-blocked. It shows the internal systemic stiffness of the bimanually coupled interface.

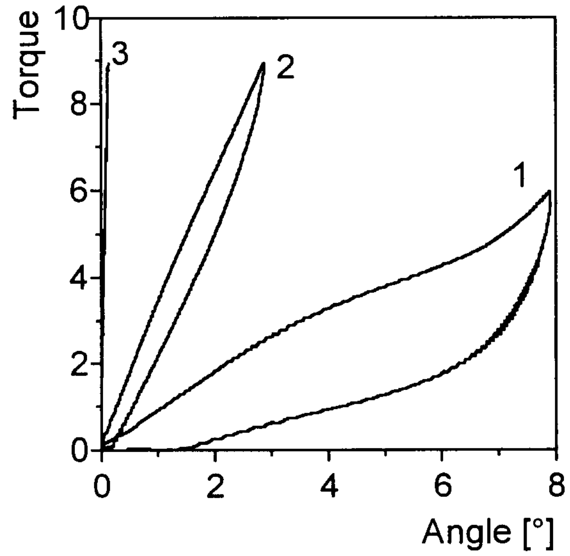

Figure 6. Remotely sensed torque to angle curves produced by a soft- (1) and hardelastic (2) body.

6. SPACE RESEARCH APPLICATIONS

Although originally designed for physiological research there are potential applications of force reflective devices in space research. One may distinguish between man to man and man-machine applications. A typical man to man application is a teleoperated two-point interface between a ground and space station as sketched in lower Fig. 1. In combination with visual and auditory cues, such an interface would improve interactive experimentation with cosmonauts, for example to assess the adaptive mechanisms of human movement control. Practical applications would be: diagnostics of movement disorders by ground experts, ground assisted ergometry, palpatation of soft tissues, or even minimal invasive surgery [8]. One problem arising with space applications is the bi-directional transmission delay. Here tests with a simulated time delay of 1 second (according to a distance earth-moon) showed problems with the lever's zeropoint stability and its controllability. Here further developments in the control design are necessary to overcome these problems.

In contrast to devices for man to man applications, force reflective man-machine interfaces are more in common. Typical space applications are remote steering of vehicles and teleoperated master-slave systems. During critical flight phases, space vehicles often have to be steered by hand. With some haptic feedback, derived from the vehicles state variables, the steering movements might become more skillful than with visual cues alone. Further one may think about scenarios, were the automatic control of a space vehicle has become so complex, that it needs the cooperative control of two or more experts. For example one crew member controls the altitude and of a lander, and the other one the landing position. Both members stay in haptic contact through their force reflective devices. For such kind of intersubject applications force reflective devices with two or more degrees of freedom are needed. To learn such intersubject skills, virtual games, for example to safely land a space vehicle on an asteroid with local gravity field anomalies, may be created.

In the last ten years, there was a certain interest on force reflective interfaces in virtual reality research [9]. Typically such a virtual enviroment is created through visual flow fields (head mounted display) and body motions (platform movements). Commonly open loop interfaces, such as a finger sensing glove, or a 3-D pointing mouse are used for manual interaction. These interfaces have limitations, however, as they do not make use of the outstanding haptic sense. Once explored, this sense may be built in to telerobots, thus enabling a more intelligent machine-exploration of planetary surfaces. In contrast to the autonomic telerobots, master-slave robots are more directly coupled to the human controller. With a few exceptions, most current existing master-slave robots are of the open loop type and therefore can not fully transfer the humans sensorimotor capacities.

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Keynote Speech

A NEW INTEGRATED SCIENCE-ENGINEERING SCENARIO FOR RESEARCH AND INDUSTRY COOPERATION

Alessandro Formica
F&P Associated Consultants, Milan, Italy
Via Sismondi, 4 – 20133 Milan, Italy – Phone/Fax +39-02-7012.7719 – E-mail ale.formica@iol.it

Abstract

New challenges characterize innovative technologies development : increasingly complexity and a widening range of scales involved. Relationships between science and engineering are also changing. Technology development and engineering are ever more dependent on scientific knowledge. As a result of this situation, costs and times to develop innovative systems are not decreasing, instead, they are positively going up (Single Stage to Orbit systems are a classical example). Evolutionary improvements over classical R&D and engineering methodologies are not up to the challenge, and a new Integrated Science-Engineering Framework, based on the Multiscale concept is needed. Multiscale represents a new "Unifying Paradigm" i.e. a common theoretical context and language to enable a real integration of science and engineering visions, models, and methods. This new framework is the field where we can build a new cooperative scenario between research and industry and define new planning methodology for complex R&D and engineering processes.

Background

New challenges are characterizing the present research and technology innovation scenario : the increasingly complexity of high-tech systems and the related R&D and engineering design processes, the widening range of scales and disciplines involved in the design of high-tech systems, the ever more conditioning environmental issues. Physical phenomena which, in the past, were classical scientific territories, are, today, directly at the root of new technologies and devices in key industrial sectors such as electronics, electro-optics, sensors, materials and materials processing. We are seeing the birth of a micro and nano scale engineering fully based on scientific principles. As a consequence of this situation, times, costs, and risks to develop really innovative technologies and systems, are positively going up, not down : examples are Reusable Launch Vehicles (RLVs) and new propulsion systems (nuclear fission and fusion, matter anti matter, ionic...). Reconciling ambitious performance improvement with realistic development and production costs and times for high-tech innovative products and processes is a strategic challenge for the research and engineering world. We are, if not in a crisis situation, surely at a "stagnation point" as demonstrated by the growing difficulty to develop innovative technology and systems at affordable price. This is a major and strategic motivation for a transition to a new research and engineering environment. The technology scenario is changing but we fear that research, industry, and academia communities are slow to adapt to this evolution. The definition of a new "unified vision" for science and engineering and, accordingly, of a new integrated R&D and engineering framework, will be a key goal. In the "Twenty-Second Annual Colloqium on Science & Technology Policy" organized by the American Association for the Advancement of Science (AAAS), Washington, DC, April 23-25, 1997, scientists, politicians, and industry executives clearly identified the development of new interaction schemes between science and engineering as one of the most critical issues for the definition of more efficient R&D and innovation politicies and strategies both for the civil and defense sectors. In the same occasion, Daniel Goldin, NASA Administrator, clearly pointed out the key relevance of science-engineering integration. Unfortunately, his words did not find a wide echo in NASA programs. The "Computational Materials Program" mnaged by NASA Langley is a notable exception. It is useless to talk about research and industry cooperation if we do not recognize that relationships between science and engineering are deeply changing and, accordingly, we necessarily need a new language and a new theoretical framework to understand and manage this evolving scenario. New cooperation schemes and new planning strategy for complex innovative technology developments, will come out from the new integrated science-engineering framework. The thesis of this document is that we need a new formalism to integrate data, information, and knowledge from a number of different disciplines (multiphysics), a wide range of scientific and engineering time and space scales (multiscale), and multiple methods (theory, computation, experimentation).

New concepts and methods such as multiscale and science-based engineering, and science-engineering integration, are taking shape and begin to be common in several key fields and technological areas such as, energy, nuclear weapons, materials, chemistry and chemical engineering, environment, and defense. Unfortunately, this process is developing essentially outside the space field which is not leading way.

That is true even if several of the fields and issues dealt with in the current multiscale programs are of strategic interest for space such as materials, materials processing, electronics, propulsion,...... Large scale and scope programs have been already started by US Department of Energy (DoE) and US National Science Foundation (NSF). Inside the US Department of Defense several multiscale programs are ongoing. A large number (ever increasing) of the most important US universities already launched multiscale science-based initiatives and programs. Situation in Europe is more fragmented. The wide range of fields covered by multiscale science-based programs is a demonstration that this new approach has a general value for R&D and engineering and it can have a deep inpact on innovative technology development strategies for space and aerospace.
We point point out that this new framework implies a cultural revolution more than an evolution in the methodological area. This is the major obstacle.

A New Integrated Science-Engineering Framework

The "Integrated Science-Engineering Framework" is based on a new theoretical paradigm (multiscale) to integrate science and engineering visions, languages, methods, cultures and strategies and dealing with systems of increasingly complexity. Multiscale entails the integrated and synergistic use of different computational, analytical, and experimental techniques with different degrees of space and time resolution which, until now, have been developed and applied in different stages of the R&D and engineering process following a fragmented vision and strategy. As the name implies, multiscale models synthetize information and knowledge from a broad range of length scales, from the continuum to the atomistic level. An innovative integrated science-engineering R&D and design methodological environment based on the multiscale paradigm will also be defined in the following. This new theoretical and methodological context enables us to conceive innovative cooperative environments and strategies to be implemented thorugh Virtual Distributed Science-Engineering Environments (VDSEEs), and new planning methods for complex R&D and engineering processes.

The envisaged framework will ease knowledge transfer between the different stages of the R&D and engineering process by developing a "unified vision" for the whole research and technology innovation process. In the new science-engineering context, engineering can become an important driver for science, overturning historical relationships and dependencies and putting the bases for a new way of doing science and engineering. Not only advances in science can be stimulated and driven by technology progress and the need of solving specific technological and engineering problems but research strategies will be more and more influenced by technology roadmaps and viceversa.

A new theoretical paradigm and language (multiscale)

Multiscale is the theoretical foundation of the integrated science-engineering framework. The multiscale approach enables the definition of a more general framework to establish clear correlations between needs, objectives, and advances which characterize the different stages of the research, development, and engineering process. Today these environments use different methodologies, concepts, metrics, and drivers making knowledge transfer a long and expensive process. The systematic transfer of information and knowledge from the higher resolution levels to the lower ones and viceversa (combination of bottom-up and top down approaches) makes it possible the development of really integrated science-engineering visions and models.

Multiscale, as interpreted in this study, goes beyond the classical reductionist approach. It enables the development of systemic models that consider the global behavior of complex systems as a whole integrating representations and information across multiple scales and disciplines. Computational methodologies represent the true expression of the multiscale knowledge and they play the role of "Knowledge Integrators and Multipliers" (KIM) synthetizing classical analytical and experimental models, methods, and knowledge. Multiscale is not only a new method to deal with complex systems, as interpreted by most of US and European programs, but it can represent, as already pointed out, a new powerful "Unifying Paradigm" i.e a common theoretical context and language to enable a real integration of Science and Engineering visions and models.

The "Unifying Paradigm" concept is well described by Greg Rodin, Texas Institute for Computational and Applied Mathematics and Department of Aerospace Engineering and Engineering Mechanics, University of Texas at Austin. The Rodin' team has set up a collaboration with the Caltech's Materials and Process Simulation Center (MSC), directed by William Goddard by developing a full hierarchy of modeling and simulation techniques from the atomic scale to the continuum. The Rodin' words are highly significant:
"For now, National Partnership for Advanced Computational Infrastructure (NPACI) has already made the connection between two communities (Scientific : Caltech – Engineering : Texas) who have long looked at the same problem at different levels of detail.........At the same time, we are also bridging a major gap that has traditionally separated the physics and engineering communities. NPACI has constructed that bridge."

Multiscale is not limited to the computational field (today, practically all the multiscale programs are computationally centred ; that is a serious limitation to be overcome) but it extends to experimental and testing methodologies and technologies allowing so the development of true integrated multiscale and multidisciplinary R&D and engineering design methods. A fundamental objective of multiscale is to improve the reliability and the range of applicability of the macroscale (engineering) models which can be based on a rigorous theoretical knowledge and no longer on an empirical and semi-empirical approach. The understanding gained from multiscale modeling is crucial to develop approximate but rigorous computational models to be used in the daily engineering activities and for design optimisation purposes. In this prospect, multiscale is a key basis to implement the "Simulation-based Design" approach in the innovative technology development field.

A key point of the proposed science-engineering multiscale scheme is that engineers cooperate with scientists without having to directly manage the complexity of the scientific issues. Engineers define what information they need to meet specific technological, design, and operational requirements. Then, they interactively cooperate with scientists and take direct advantage of the outcome of the scientific process.

The basic multiscale paradigm is that "continous" macroscopic long range, long time scale behaviour can be expressed in terms of multiscale hierarchies of variables and interscale interaction rules. The typical multiscale algorithm iteratively constructs a set of system descriptions at a sequence of different scales, combining local processing at each scale with various interscale interactions. Key to the multiscale approach is the identification of the physico-chemical phenomena and variables needed to describe the dynamics at each space and time scale and the related relationships, from the continuum down to the atomic scale.

The development of a multiscale strategy entails:

- the identification of the physical phenomena occurring at different space and time scales needed to describe the dynamics of a system at a predefined level of accuracy and detail.
- the definition of the schemes to transfer information across the different scales. A fundamental goal is to establish rigorous theoretical connections between macro constitutive equations, microscopic atomistic models and mesoscale phenomena
- the selection of a well defined set of computational, experimental, and analytical procedures and the definition of the sequence through which such procedures are used

Each set of procedures at a certain scale level is used to improve reliability, accuracy and range of applicability of theories and models at the immediately higher scale level.The ultimate objective of the multiscale approach is not to substitute the study of one scale for the study of another scale, but it is to develop a unified and coherent picture of different complementary descriptions.

<u>Integrated science-engineering R&D and design methodological environment</u>

The design of innovative technology products and processes, meeting ever more severe operational, performance, economic and environmental requirements, calls for models which go beyond the classical empirical and semi-empirical approach and a space and time "averaged" knowledge. A fundamental objective of modern engineering is to predict the behavior of a technological system for its whole life-cycle and taking into account the full spectrum of the interactions between the system and its operational environment for nominal and off-nominal conditions (design for life-cycle, safety, and environment). This task requires understanding, predicting, and controlling a complex set of physical, chemical, and biochemical phenomena spanning a wide range of space and time scales. In this context traditional subdivisions between science and engineering are blurring. This is the context where we can shape the new cooperation landscape for university, research, and industry. Multiscale offers the strtegic opportunity to directly use scientific methods to solve technological and enginering problems and integrate scientific methodologies inside engineering practices.

The new science-engineering methodological environment develops around a specific set of methodologies :

(a) integration of multiscale theoretical approach, multiscale computational methodologies, multiscale experimental&testing techniques and methods, working at different, scales, resolution, and degrees of fidelity.

(b) multiscale data management, analysis, and fusion

(c) multiscale system design

(d) "multiscale scientific and engineering information analysis" which guides and shapes the new approach

In the new framework the classical deterministic appproach is integrated with statistical methods to efficiently deal with the ever more pressing need of improving reliability and predictive capabilities of computational and experimental/testing models (uncertainties management).

In the following paragraphs we will examine in more details the set of methodologies which make up the new environment :

(a) multiscale methodological integration

Almost all the existing multiscale programs centre only or mainly on a multiscale computational methodology. Even if there is integration, it is between multiscale computational methodologies with single scale experimentation&testing. Classical single apparatus and single scale experimental/testing techniques will be more and more complemented by an integrated "multisensor and multiscale" approach to get a comprehensive view of complex patterns of multidisciplinary phenomena spanning a wide range of scales. Multiscale modeling&simulation can provide information that is difficult or even impossible to obtain by experiments and yields new insights to be used as a basis to conceive new experiments. In turn, data and information get by new experiments serve to develop more accurate and reliable theories and computational models. Simulation and experiments, jointly, provide critical tests of the updated theories which, in turn represent the needed basis to develop new experimental/testing strategies, and so on. It is an interactive interplay. Methodological integration means not only integrating theory, modeling&simulation, and experimentation&testing, it means also integrating scientific theories, models, and experimentation with engineering theories, models, and tests. This multiscale methodological integration is intimately linked to the capability of reliably discovering new relations and pattern for complex phenomena and processes which underly the behavior of new technologies. It is a "methodological interactive interplay". This is the real meaning of the proposed "Knowledge Integrator and Multiplier" (KIM) concept and methodology. Modeling&Simulations, viewed as "Knowledge Integrators and Multipliers", can serve as a powerful laboratory through which we "fuse" information and knowledge to make discoveries and reach a fundamental understanding of emerging elusive phenomena. The synthesis of different scientific and engineering methodologies is the real way for innovating technology. A demonstration of the validity of this statement comes from the following examples :

Example 1 : X-33 Hydrogen Tank. The limits of the classical engineering approach for a first-of-a-kind hardware, can be seen, for instance, in the story of the X-33 hydrogen composite tank which, on November 3, 1999, at Marshall Space Flight Center, failed to pass key sructural tests. The tank was the largest and most complex composite honeycomb structure yet made, and key to the success of Venture Star. Traditional engineering methods were unable to get an in-depth understanding of the behavior of the composite tank and the related manufacturing processes.

Example 2 : Space Safety Engineering. The analysis of the causes of the Shuttle Challenger 51-L flight explosion reveals the limits and problems of a phenomenological approach to reliability analysis and safety issues. According to accident Commission findings, the loss of the Space Shuttle Challenger was caused by a failure in the joint between the two lower segments of the right Solid Rocket Motor. The specific failure was the destruction of the pressure seals that are intended to prevent hot gases from leaking through the joint during the propellant burn of the rocket motor. The failure was due to a faulty design unacceptably sensitive to a number of factors. These factors were the effects of temperature, physical dimensions, the character of materials, the effects of reusability, processing and the reaction of the joint to dynamic loading. The origin and consequences of the O-ring erosion and blow-by were not understood. The Nobel prize Richard Feynman highlighted that a mathematical model was made to calculate erosion. This was a model based not on physical (science-based) understanding but on empirical curve fitting. Several uncertainties surrounded the formula and constants in the formula. The critical dependence of erosion from low temperature was not clearly understood and... the accident happened. The following Feynman's statement *"when using a mathematical model careful attention must be given to uncertainties in the model due to the lack of a real physical understanding of the phenomena accounted for"* describes the challenges and the trends for reliability and safety engineering.

(b) multiscale data management, analysis, and fusion

New multiscale data management, analysis, and fusion methods and techniques begin to be developed outside the space field, in particular in the biomedical and environmental areas. One of the most striking problem in the R&D and engineering process is to get an unified vision of the huge amount of data which characterize the whole process. Today, we have a lot of not communicating data bases which lead to a completely fragmented knowledge. Correlating different data bases and knowledge, under the umbrella of a "Unified Vision", will be a key target for the next future.

(c) multiscale system design

Complexity and system engineering issues are increasingly determining the structure of the R&D and engineering processes and the methodological approach. The challenge is to optimize the total system, rather than the individual components to better handle a wide array of conflicting requirements. New multiscale methods enable the design of hierachical multilevel multifunction systems and structures which tightly integrate different technologies which perform different functions at different scales. A full exploitation of the potentialities intrinsic to nano, micro, meso technologies is intimately linked to the capability of integrating the hierarchy of these different technologies at different scales inside a "coherent" multifunctional and multilevel design In this way, these new technological solutions will be really able to reshape and redesign complex space systems : from satellite to rockets, to probes.

The interactions between different components and technologies involve an extremely wide range of time and geometrical scales and several different physico-chemical phenomena, in some cases not completely understood and characterized from a theoretical point of view. This situation does not reflect on design methodologies which are still not able to integrate different representation and analysis schemes. Multiscale system design approach opens the way to new strategies for complex systems control. A combination of new sensors, meso, micro and nano systems, and distributed computing systems, can lead not only to innovative control schemes but a wealth of revolutionary engineering and manufacturing solutions provided that we will be able to integrate all the scales and disciplines involved. New sensors will be able to deliver not only "averaged" data and information, as in the past, about space and time variations of key physical and technological variables (pressure, temperature, chemical composition,....) but the detailed map of local values and rates at different levels of resolution and time and space scales. This kind of information can also be used to develop and validate off-line physical models no longer based on an empirical and semi-empirical (averaged) knowledge but on a first principles understanding of the physical reality. Highly detailed real-time models to control technological systems will grow out of this new level of understanding and will run on an array of distributed HPC systems. A "Revolution in Technology" can emerge from this scenario.

(d) multiscale scientific and engineering information analysis

The new proposed R&D and engineering strategy also requires a new general methodology to guide and orchestrate the integration among the different methods at different scales and resolution levels, and assess when, to what extent, and if, multiscale and integration are really needed. It is absolutely obvious that not for all the cases and tasks, a multiscale methodology is a real need. For that reason, we define the "multiscale scientific and engineering information analysis" methodology which includes two fundamental steps :

Multiscale Information Analysis (linking information with R&D and engineering tasks)

- identify the critical (scientific and engineering) information in the different steps and for the different tasks of the R&D and Engineering design process
- define the related levels of resolution and accuracy
- correlate phenomena occurring at different time and space scales (from continuum down to atomic scales, as needed) and elucidate the related cause-effect relationships. This step enable researchers and engineers to correlate science and engineering issues inside a general unified vision.

Multiscale Information Flow Analysis (Linking information with information sources and define the overall process architecture)

- analyse the overall information flow pattern inside the different stages of the R&D and engineering design processes and, for each task, correlate information and information sources (experiments, tests, computations, analytical formulations)
- identify the relationships and the interdependencies among the several information sorces at different scales (experiments, tests, probabilistic and deterministic computations, analytical formulations) to determine the general R&D and engineering strategy

This kind of analysis is carried out by multidisciplinary teams made-up by scientists, technologists, and designers

New Cooperation Environments and Planning Strategies

Virtual Distributed Science-Enginering Environments

Advances in Computing, Information, and Communication (CIC) tecnologies makes it possible to create a new structural and operational contexts for R&D and engineering based thorugh the implementation of Virtual Distributed Environments (VDEs). VDEs connect in seamless way a wide array of resources physically distributed in a wide geographic area : experimental and testing facilities, data management and computational systems, digital libraries, research and engineering teams working in different disciplines. Technology offers the opportunity to shape new cooperative landscapes but technology represents only the "structural layer", we need a "methodological and conceptual layer" which can not be a simple adaptation and extension of well established methodologies and practices. Technology revolution should be paralled by a cultural and methodological revolution. This is the critical point. *The most critical issue for the developement of new cooperation schemes is methodology not technology.* Multiscale is surely not the new "Gospel Truth" but it represents a "cultural and methodological environment" where academy, research, and engineering communities can build new common languages and visions. Many people talk, today, about a "two way" cooperation between research and academy, from one side, and industry, from the other side, but, without new methodologies, how can we realize it ? The technology innovation scenario is more and more characterized by the interaction among a lot of scientific and engineering teams which represent different cultures, disciplines, experiences, ways of mind, and methods and that have different drivers, objectives, needs and success evaluation criteria. How can we overcome these divisions and form really integrated multidisciplinary groups which follow a common unified vision and a coherent strategy ?

How can we shape global strategy which can effectively take advantage of a very large pool of resources ? Furthemore, the complexity of the R&D and engineering process is positively increasing and researchers and designers have to manage and analyse a really huge amount of information. How can they turn this ocean of data, which represent different space and time scales and different disciplinary areas, into useful and meaningful knowldge, taking also into account that the needs and the points of view of the different groups are absolutely not homogeneous ? We do not see tools and methods to establish clear correlations among the different visions and models which characterize the different stages of the R&D and engineering process, reconcile research and engineering visions, and transfer scientific knowledge into engineering model and practices. Accordingly, in the present scenario, scientific computational, experimental and theoretical advances often do not have a direct impact on engineering. Transferring information and knowledge along the whole R&D and Engineering chain is an extremely long, costly and painful process.

Advanced graphic and virtual reality technologies are a very important asset but not the ultimate solution to the problem. New multiscale data assimilation and fusion methods will enable the definition of common analysis and interpretation schemes, to rationally share, integrate, and manage the huge amount of data and information associated with modern research and development activities. The simple availability of more and more on-line resources (experimental/testing facilities, research and engineering teams working in a plethora of different fields, data bases, and computing facilities), is believed to be a sufficient condition to streamline the process and make it more efficient. Technology is overshadowing methodology. We need an intellectual and methodological framework which goes beyond the classical barriers and subdivisions among scientitic and engineering fields. VDE technologies combined with the multiscale science-engineering framework hold the power of transforming the way people work and open the way to the definition of a completely new structure and organisation for the R&D and engineering world. We have today tools to deal with single aspects and tasks of the R&D and engineering design process but we do not have rational tools to rationally design the whole process following a unified vision and approach. It is also worthwhle highlighting that, if it is true that the lack of information represent a negative status, it is also true that the a flood of information can represent an even more dangerous situation. Multiscale can represent a valuable basis to turn Virtual Distributed Environments (VDEs) into real Virtual Distributed Science-Engineering Environments (VDSEEs) to redefine cooperation schemes and strategies for industry-academia-research.
A major problem is that present integrated environments in the space and aerospace environments are essentially engineering oriented. Examples are NASA Intelligent Synthesis Environment (ISE), Numerical Propulsion System Simultor (NPSS) from NASA Glenn Research Centre, and Virtual Product Initiative (VPI) from Lockheed. They make no clear distinctions between the development of evolutionary technologies and products, where research, if any, is short term and low risk, and the development of innovative technologies and products, where experience and knowledge of researchers and deginers are limited, data sets are fragmented or lacking at all, research activities are, normally, high risk and medium/long term. Attempts to build real VDSEEs are being made in the environmental, chemical, and chemical engineering fields. For instance, a Joint Institute for Molecular-Based Engineering and Science has been established by ORNL and the University of Tennessee (UT) to provide a focus for industrial, academic, and government R&D based on new molecular-level approaches. Also inside the National Computational Science Alliance (NCSA) and National Partnersips for Advanced Computational Infrastructure (NPACI), we can see the definition of a new science-engineering cooperation landscape. The following statement of Prof. John Wilkins – Ohio State University – well describes this new cooperation philosophy which underlies some of the NCSA research activities :
"Increasingly the electronic structure community wants to study systems that range from microscopic to macroscopic in space and time. These multiscale needs necessitate an interdisciplinary approach in science, engineering, and computing. The Alliance offers a network to effectively connect these communities".

This is a fundamental need for a transition to a real "Information-Driven" cooperative and planning framework for research and industry. Today, correlations among research and engineering and the different issues which characterize the different stages and tasks of the whole R&D and engineering process are essentially "qualitative". No systematic correlations between information needed in a task with information needed in other tasks, in the same or different process stages, taking into account, in a systematic way, the related uncertainties. No rigorous correlations among information, uncertainty, and information sources. That makes very difficult to assess how progress at fundamental scales (atomic, molecular, micro, and meso) can affect macro technological solutions and system architectures. The new planning framework can help us to timely and rationally evaluate alternative technology development paths. Multiscale can be the basis upon which we can build a "Virtual Time Machine" for technology development.
This situation is well exemplified in the materials science and enginering field by the classical : strucure – property – performance – processing problem.

Each item correlates with different information obtained with different methods and tools, from different teams (industry-academia-research), for different tasks. Can single scale approaches, isolated science and enginering views, separated methodological strategies lead to a "rational cooperative planning" ? It is a rethorical question. The proposed planning process is interactive and iterative, and it can be implemented through the use of specific modeling and simulation tools and methodologies. Many professionals talk, today, about a "two way" relationships between the industrial world, from one side, and the academic and research world, from the other side. However, a real "two way" partnership between the two worlds implies a new theoretical, conceptual, and methodological background able to correlate, *in a quantitative way*, science and engineering models, scales, needs, and goals. Uncovering and defining this complex pattern of correlations is a key step to build new technology roadmapping and planing strategies.

New Planning Methods

The multiscale science-engineering approach opens the way to the definition of new methodologies to shape and plan the overall architecture of the R&D and engineering design process and related cooperative scenario between research and industry. In the new multiscale science-engineering framework we can define a new integrated planning and roadmapping methodology based on two fundamental concepts and methods : *science-engineering information space and multiscale scientific and engineering information analysis.* These new methods allow us to answer the following key questions :

- what is the right information and the right level of accuracy and resolution we need in the different stages of the R&D and engineering process ?
- what physical length scales are important and how good models and codes are to be to get the information identified as fundamental to successfully address a specific research, technology development and design task ? How "good" means evaluating how much "physical realism" should be incorporated into the models, how deep the scales hierarchy taken into account is to be, what level of uncertainty is embodied into the models.
- what combination of different computational, analytical, and experimental/testing methodologies at different levels of resolution do we need to get the right information at the right level of accuracy and completeness for the different tasks in the different R&D and design stages ?

A critical step for the "rational design" of the R&D and engineering processes is a proper selection, integration, and sequencing of computational and analytical models and experimental/testing methodologies with varying degrees of complexity and resolution. To do that we have to define the " Science-Engineering Information Space" associated to each methodology. This kind of conceptual context is an important step to define how cooperative efforts are to be organized among the different disciplines and methods. Multiscale is also key to correlate advances in basic and applied research and methods with technology development and engineering.

science-engineering information space

For each method (analytical, experimental/testing, and computational) the objective is to define in a rigorous way what we call the "method attributes" :

- tipology of the information
- level of resolution and fidelity
- degree of reliability (uncertainty mangement),

and correlate them which, globally, represent the "Information Space" with the "method variables". For a computational method, "method variables" are : physics, numerics, model dimension, discretization techniques, computing power. Correlating "method variables" with the information we can get from a method is being already made but in a semi-empirical way. Seldom, for instance, we quantify the degree of reliability of the information we obtain or we rigorously evaluate the relative weight of the several "method variables" as function of the "method attributes".

Three considerations underly the definition of this concept:

- the need of rigorously correlating advances in methods with the capability to innovate technology and meet ever more severe performance and operational requirements.Without correlating in a quantitative way information we can get from a method with the information needed to advance technology and/or define a new engineering solution, we will never be able to rationally assess technology development paths and related alternatives.
- the need of rationally defining the role of each method inside the more general R&D and engineering design process and the interdependencies among the different methods
- the need of tracking and planning the development path (methodological roadmapping) for each method by assessing the related dependencies by different disciplines (cooperative scenario)

Similar considerations can be extended to experimental and testing methods. In such a way, "methodological roadmapping" will be directly linked to "technology roadmapping" The "science-engineering information space" concept can also be instrumental to define the right mix between different methodologies inside a complex R&D and engineering design process because it allows to rigorously assess information and uncertainty connected to each method..

multiscale science-engineering information analysis.

The following scheme is proposed to implement the multiscale scientific and engineering information analysis methodology in the planning context :

Step one : Requirements Analysis

- Identify the operational requirements to be met by the full system. Identify the requirements to be satisfied by the hierarchy of subsystems and components which made-up the full system. Identify the interactions between the full system, sub-systems, and components.

Step two : Technological Analysis

- Identify key technologies areas : materials, sensors, propulsion, structures, control systems, manufacturing, etc, thought to be needed to achieve the above identifed requirements. Identify critical technology variables and the related multi-technology integration challenges.

Steo one and two represent the classical "requirements-driven" technology roadmapping analysis. We propose to complement it with an "information-driven" analysis based on multiscale and the previously defined "science-engineering information space" concept. .

Step three : Multiscale Information Analysis (linking information with R&D and engineering tasks)

- identify the critical (scientific and engineering) information and related uncertainties in the different steps and for the different tasks of the R&D and Engineering design process needed to develop and validate technologies and perform technologies integration and design tasks
- correlate phenomena occurring at different time and space scales (from continuum down to atomic scales, as needed) and elucidate the related cause-effect relationships. This step enable researchers and engineers to correlate science and engineering issues inside a unified vision and sketch the cooperative scenario.

Step four : Information Flow Analysis (Linking information with information sources and define the overall process architecture)

- analyse the overall information flow pattern inside the different stages of the R&D and engineering design processes and, for each task, correlate information and information sources (experiments, tests, computations, analytical formulations) using the "science-engineering information space" concept and taking into account uncertainties
- identify the relationships and the interdependencies among the several information sorces at different scales (experiments, tests, probabilistic and deterministic computations, analytical formulations) to determine the general R&D and engineering strategy

Conclusions

The US Defense Advanced Research Project Agency (DARPA) recently started the "Accelerated Insertion of Materials" (AIM) program which addresses several of the issues dealt with in this article by devising a set of new methodological approches very near to the ones here described. The analysis at the root of the AIM program matches our conclusions : to really streamline the R&D and engineering process and its management and planning, we can not go on adapting existing methodologies and hoping that the availability of more and more powerful computers, more and more capable networking and software systems will automatically solve problems. Breaking computing speed, networking bandwidth, and computational model dimension records can be a necessary condition to streamline the R&D and engineering process but it is still to be demonstrated that is also a sufficient condition. We have to develop and implement new strategies, methods and concepts. Space field, once in a time leader in the technology innovation field, should take up the gauntlet by defining, also, a wide and qualified range of cross-disciplinary collborations with other fields such as chemistry, energy, and chemical engineering.

Innovative Technologies and Space Applications (2)

Chairman: E. Wagner, Fraunhofer Institute, Germany

"DEVELOPING CRYOGENIC SOLID ROCKET MOTOR TECHNOLOGY FOR SPACE PROPULSION"

Roger Lo[1)], Harry Adirim[1)], Volker Weiser[2)], Jens Laßmann[3)]

([1)]Aerospace Institute at Univ. Techn. Berlin, Germany; [2)]Inst. Chem. Eng. at Fraunhofer Soc., Berghausen, Germany; [3)]ASTRIUM GmbH, Bremen, Germany)

Contact: Prof. Dr. Roger Lo, Aerospace Institute, Marchstr. 12, 10587 Berlin, Germany
Tel.: +4930-314-21081, Fax: +4930-314-21306, Email: roger.lo@t-online.de

Abstract

Under the sponsorship of the German Aerospace Center DLR, Cryogenic Solid Propulsion (CSP) is now in its 4th year of R&D. The development proceeds as a joint international university-, small business-, space industry- and professional research effort (Berlin University of Technology / Aerospace Institute, Berlin / Bauman Moscow State Technical University, Russia / ASTRIUM GmbH, Bremen / Fraunhofer Institute for Chemical Technology, Berghausen). It aims at introducing CSPs as a novel type of chemical propellant that uses frozen liquids in modular solid rocket motors. CSPs thrive at once on the high performance levels of liquid propulsion and the simplicity and reliability of solid rocket motors. High performance, low cost, low pollution CSP technology could bring about a near term revolution for chemical Earth-to-orbit boosters and other high thrust propulsion. In the long run it could easily surpass conventional chemical propulsion because it is better suited for applying high energy density matter than any other mode of propulsion.

1. The concept of CSP

Any conceivable chemical rocket propellant combination (including any environmentally benign „green propellant") can be used in solid rocket propellant motors if the definition of solids is not restricted to "solid at ambient temperature" [1]. The CSP concept includes all suitable high energy propellant combinations, but is not limited to them. Fig.1.1 shows the typical specific impulses of chemical rocket motors at standard expansion ratio. The benchmark of applied chemical high energy propulsion is LOX/Hydrogen with an Isp of 390 s. To go beyond that mark, tripropellant metal combustion and / or exotic compounds such as Fluorine or Ozone would have to be used. Most of these propellant combinations are not acceptable by to days standards of pollution control. However, they mark the upper performance limit of conventional chemical propellants. Only HEDM, High Energy Density Matter (se upper right of Fig.1.1) would yield even more chemical energy. In this realm, the use of frozen Hydrogen is mandatory, because HEDM relies on what is called "matrix isolation" where isolated singe atoms are stored in a frozen matrix [2] that prevents their recombination. Not available to day, this technology might be a future extrapolation of CSP-propulsion.

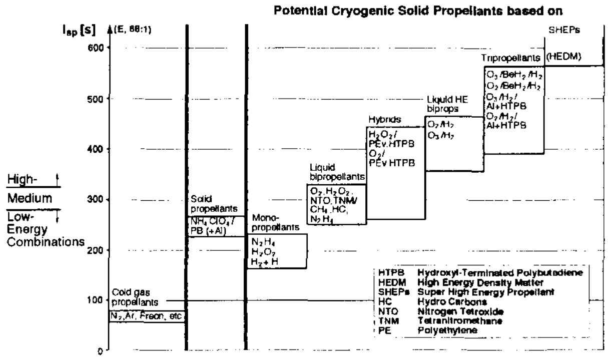

Fig.1.1: Isp ranges of chemical propellants [3].

Chemical propellant combinations of the highest known values of Isp or density can thus be used in rocket motors with all solid propellant grains. The concept was accepted as "potentially revolutionizing chemical propulsion technology" at the January 1998 Advanced Propulsion Workshops of the International Academy of Astronautics [4]. It could be tested and fly in the 2010 - 2015 time frame.

As Fig.1.1 shows, any liquid or hybrid bipropellant combination is (Isp-wise) superior to any conventional solid propellant formulation. While CSPs do share some of the disadvantages of solid propulsion (e.g. lack of cooling fluid and preset thrust-time function), they definitely share one of their most attractive advantages: the low number of components that is the base for high reliability and low cost of structures. In this respect, CSPs are superior to liquid propellant rocket motors with who, they share the high Isp performance.

For many CSP combinations mixtures of reactants as in conventional solid propellants can not be used due to their elevated reactivity. The concept of Modular Solid

Rocket Propellants solves this problem. It opens a whole new area of chemical propulsion because quasi premixed combustion (as with solid propellants) is replaced by boundary layer combustion in an arrangement that was dubbed "Multilayer Internal Hybrid Combustion".

Fig.1.2 shows a typical solid grain in "disk-stack" configuration. The example uses frozen Oxygen (SOX) and Propane.

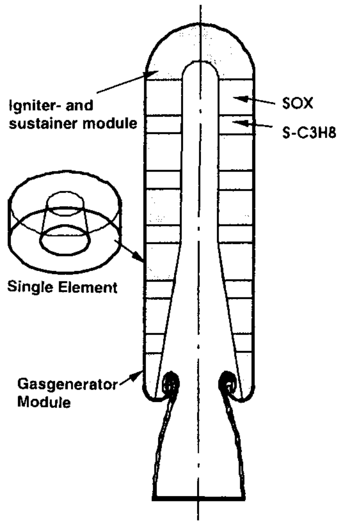

Fig.1.2: Modular disk-stack motor.

Many other geometrical configurations other than the internal conocyl burner of Fig.1.2 are feasible.

2. Experimental results of CSP combustion

Experiments were carried out with cylindrical "disk stack" burners and "rod-in-matrix" end-burners. Modular propellant grains offer a new degree of freedom for controlling combustion rates. There are many other geometrical solutions.

Fig.2.1: CSP rod-in-matrix combustion at ambient pressure (SH_2O_2 [85%] / Polyurethane).

3. Performance modeling of CSP launchers

3.1 Performance analyses

So far, ongoing analyses have not shown any insurmountable problems in areas of concern, (such as cooling equipment and its operation during fabrication and launch) neither were there problems with thrust to weight ratio of uncooled but insulated Cryogenic Solid Boosters (CSBs) which ascend into their trajectory while leaving the cooling equipment at the launch pad.

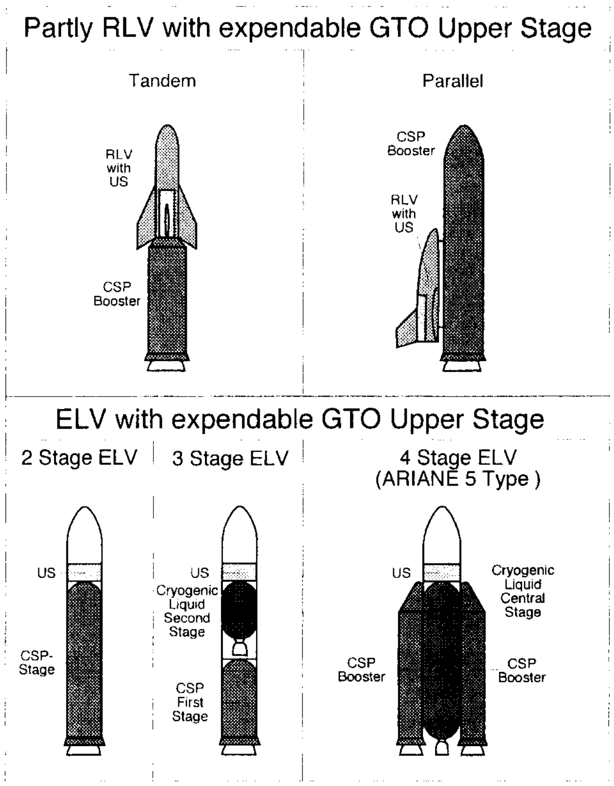

Fig. 3.1: Conceivable applications of CSP-motors (green) in semi-reusable (RLV) and expendable (ELV) launch vehicles.

In performance calculations for new launchers with CSP-replacements of boosters or existing stages, ARIANE 5 and a 3-stage launcher with CSP - 1st stage (Fig. 3.1) serve as examples in a two step procedure. In a first step, expendable launch vehicles in the payload classes of 6.8 and 12 Mg into GTO were analyzed. Based on the results obtained, further launcher categories are now also being analyzed in the second step. These include semi reusable launch vehicles, small launchers like VEGA, as well as very big ELVs (HLLV-Class).

3.2 Comparability and general design process

In order to achieve maximum possible comparability the central stage (EPC) and the upper stage (EPS) remain unaltered. This can cause disadvantages with individual propellants under consideration. Decreasing booster dry mass for example causes higher acceleration at the end of the thrust phase. Assuming that other parts of the rocket remain as they are, the constraints for acceleration, heat-flow-density and dynamic pressure also remain unchanged. Since all these parameters are coupled with flight-velocity, lighter rockets reach critical parameters sooner than heavier ones.

The first step of modeling variations comprised replacement of the two solid-boosters EAP with CSP motors. The central-stage EPC and the upper-compartment remained unmodified. This yields two alternative concepts based on ARIANE 5: a launch-system with the same payload-capacity (6.8 Mg in GTO), and a system with the same launch-mass (746 Mg). Because maximum take-off acceleration was chosen as with ARIANE 5, the burning time of the Cryogenic Solid Boosters was not the same as that of the EAP.

3.3 ARIANE 5/CSP with constant payload

For keeping payload-capacity in the reference orbit constant, the modeling of a rocket system essentially requires a process of iteration, in which the propellant mass is varied as central parameter and - with the help of a CSP mass-model - all other dimensions of the booster are derived accordingly. The process is repeated until the payload resulting from GTO track-optimization corresponds with that of the model ARIANE 5 in sufficient approximation.

Under the assumptions made, the application of cryogenic SOX/SH_2–boosters lead to a clear reduction of the launch mass. This is essentially caused by the lower propellant mass while the dry-mass is hardly reduced due to the low overall density of this bipropellant that results in large combustion chamber dimensions. This implies that hydrocarbon-booster combinations would appear more advantageous from an economic point of view. In particular, hydrocarbons, such as solid Methane (SCH_4) or frozen kerosene (SRP1) promise very simple handling. The coldest material present in the combustion chamber determines the bulk motor temperature. Used with SOX, the hydrocarbons must be subcooled to SOX temperatures. However, the melting region of kerosene lies much higher than the melting point of Oxygen, and hence it grows quite attractive in combination with higher-melting oxidizers. The savings due to lesser requirements of insulation equipment should lead to a clear weight-reduction in comparison to the lower melting fuel combinations.

In the following Fig. 3.2 an overview of the results with ARIANE 5-versions is presented. Vis-a-vis ARIANE 5 the launch mass of the CSP-launcher with same payload capacity is decreased by about 30%.

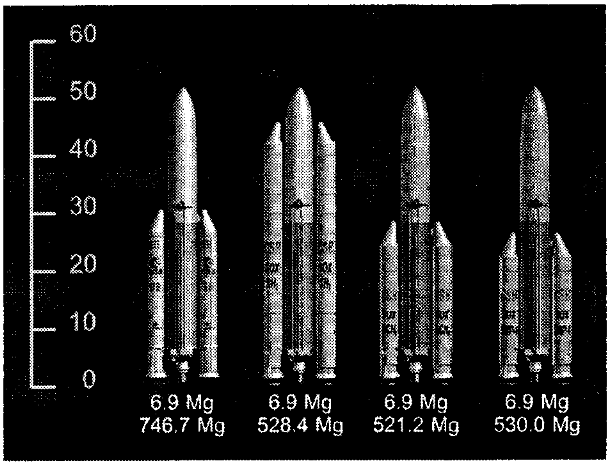

Fig. 3.2: ARIANE 5 derivatives with constant payload. Height in [m] is shown, from left to right, of: ARIANE 5/EAP, ARIANE 5/CSP-SOX/SH_2, ARIANE 5/CSP-SOX/SCH_4 and ARIANE 5/CSP-SOX/SPR1.

3.4 ARIANE 5/CSP with the constant launch mass

Results obtained with mass modeling of ARIANE 5-derivatives with constant launch mass are shown below. Booster diameters were increased to 3.7 m due to the higher mass at the CSP propellant optimum. Resulting payloads were down-scaled, taking into account the mass changes of propellants and structures of the upper stage EPS, leading to the values shown in Fig. 3.3.

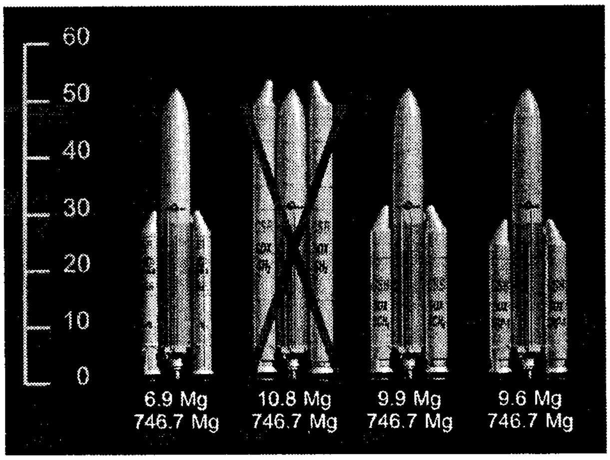

Fig. 3.3: ARIANE 5 derivatives with constant launch mass. Height in [m] is shown, from left to right, of: ARIANE 5/EAP, ARIANE 5/CSP-SOX/SH_2, ARIANE 5/CSP-SOX/SCH_4 and ARIANE 5/CSP-SOX/SPR1.

As Fig. 3.3 suggests, all launchers are able to lift approximately 10 Mg in GTO. Concerning the structure mass of the boosters, the kerosene-version yields the best results, followed closely by Methane-CSB. The SOX/SH_2-version shows the highest structure mass and has the largest dimensions. It awaits to be analyzed whether a distribution of the CSP-propellant to three or even four boosters would not yield better results.

3.5 Performance Modeling of a 3-Stage Launch Vehicle with CSP-1st Stage

Another concept examined was a hypothetical European Evolved Expendable Launch Vehicle EEELV, based on replacing the two solid-boosters EAP of ARIANE 5 by a single CSP-1st stage. The second stage was adapted from the ARIANE 5 central EPC just by changing the length of the cylindrical segments. An imperative structure-reinforcement of the EPC was not taken into account in the first step. The Upper Compartment consisting of the upper stage EPS with AESTUS-engine, VEB, payload and payload-adapter as well as fairing was used without changes.

As a reaction to the trend to higher accelerations as shown above, an adapted thrust-profile was chosen for these stages. Also for this launcher, the payload was calculated through an iteration of the initial value and adapted to the reference-mission of ARIANE 5-EAP. As central parameter the propellant mass was varied and determines all other dimensions of the booster along with the CSP mass-model. The process was repeated until the resulting GTO payload agreed with that of the ARIANE 5 in good approximation after trajectory optimization.

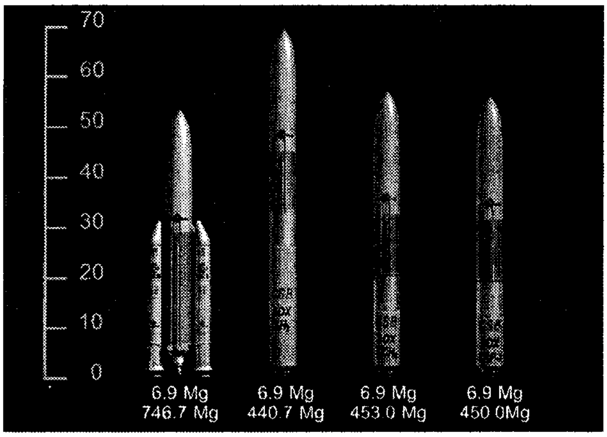

Fig. 3.4: ARIANE 5 derivatives with constant payload. Height in [m] is shown, from left to right, of: ARIANE 5/EAP, EEELV/CSP-SOX/SH_2, EEELV/CSP-SOX/SCH_4 and EEELV/CSP-SOX/SPR1.

By using a classic staging optimization, the most favorable propellant distribution between first and second stage was determined. It should be considered that in case of larger 1st stages and consequently higher altitude stage-separation the EPC VULCAIN-engine must be ignited in vacuum.

Due to the limited performance of the VULCAIN engine the propellant mass of the second stage had to be kept smaller than the optimized result of approximately 118 Mg. Application of the VULCAIN II engine currently under development or planned VULCAIN III engine would lead closer to the optimum.

Clearly, under the assumptions used, the application of CSP-1st stages leads to a substantial reduction of launch mass. Again, this is essentially caused by the reduced propellant mass while the masses of structures remain more or less constant (Fig. 3.4).

4. Cost assessments

Cost calculations have been made by one of us (ASTRIUM) and demonstrated the cost saving potential of CSP propulsion.

For estimating development, production, ground facilities, and operating cost, the parametric cost modeling tool has been used in combination with cost estimating relationships (CER's). Parametric cost models only allow comparable analyses, therefore ARIANE 5 in its recent configuration has been estimated using the same mission model as for the CSP launcher.

Generally, it has been assumed that a development can be made with limited risk, i.e. all required technology have reached adequate maturity.

Operating cost are based on a three year time frame. Assuming an annual launch rate of 8, 24 missions in total have been used for spreading indirect operating cost and learning curve effects.

When considering the first three years of launch operations no considerable cost difference can be seen between ARIANE 5 and the 3-stage CSP reference launcher. Increased development cost of the CSP booster are compensated by smaller recurring cost. This leads to a considerable cost saving potential later on in the system life cycle. A comparison of the life cycle is shown in Tab. 4.1.

The results of these cost comparison are just preliminary. They are based on the assumption, that CSP stages can be reproduced within the tolerances typically required by space launch vehicles, and that any technical risk can be mitigated by economical solutions.

	ARIANE 5 Cost [M€ '95]		3-stage CSP Cost [M€ '95]	
Management		6.9		6.2
Launcher H/W		91.6		77.8
Boosters	34.8		22.5	
Solid Propellant	8.6		10.4	
Lower stage	32.0		28.7	
Upper stage	5.4		5.4	
Upper section	10.7		10.7	
Ground operations		28.4		27.7
Liquid propellants		0.3		0.2
Ground segment maintenance		1.3		1.3
System improvement		3.9		4.1
Insurance cost		3.6		3.2
Cost per flight excl. Development		136.0		120.6
Development Amortization		257.4		274.3
Cost per flight incl. Development		393.5		394.9

Tab. 4.1: Comparison of life cycle cost.

As conclusion of these cost assessment can be stated, that the utilization of cryogenic solid propulsion promises a considerable cost savings potential.

CSP development is one of the few areas of true innovation in the old field of chemical high thrust propulsion, if not the only one. Academic and industrial cooperation is crucial for the high risk R&D work required. It will take the combined capacities of all experts involved to unlock the promises of clean, high Isp CSP propulsion for chemical Earth-to-orbit transportation in many decades to come.

5. Conclusions and consequences

In the fifth year of experimental and theoretical research, the technology of Cryogenic Solid Propellants is now well established as a means for high performance, low cost and low pollution space rocket propulsion.

The feasibility demonstration was achieved in the first two steps of an ongoing procedure in seven steps, where every further step has depended or will depend on the success of its predecessor.

The seven step procedure is here referred to as a "Hardware Related Phase Plan for Developing CSP Technology":

- Basic search for "Show Stoppers" (1996 - 1997; successfully finished).
- Laboratory Phase 1 (1997 - 1999; successfully finished): First combustion experiments. Demonstration of ignition and combustion of frozen model propellants at ambient and elevated pressure levels.
- Augmented Laboratory Phase 2 (2000 - 2001; ongoing): Test firings with 2 Inch CSP grains. Investigations with modular model propellants (front-end and internal burners) preparatory work on SOX technology, cooling- and insulation.
- Small / large test bed scale (2001 - 2004): establishing combustion parameters of SOX/hydrocarbon (Polyethylene or other); ignition and quenching; development of gas generators, sustainers; insulation; methods of grain production; operation of a cryo-mock-up.
- Scaled-down application motors (2004 - 2007): Development and test of demonstrator scale models in battleship style; development of procedures for series production and operation.
- Full scale application motors (2007 - 2010): 100-150 Mg of propellants; conclusion of development of propellant production procedures; full scale firings; development of a prototype (booster or stage size).
- Development of flight hardware (2010 - 2015).

The hardware development would of course have to be accompanied by proper programmatic and political measures. The establishment of a European approach to CSP technology could proceed in the following steps:

1. Invitation of European solid propulsion research organizations and industries to partake in the CSP venture.
2. Inclusion of CSP research in the ESA technology research program (TRP).
3. Incorporation of CSP R&D in the mandatory ESA program.
4. Integration of CSP stages and vehicles in hardware planning.

The potential benefits of CSP technology are huge. It is strongly suggested to launch a European effort for their in-depth evaluation.

6. Abbreviations

CSB	Cryogenic Solid Booster
CSP	Cryogenic Solid Propulsion
EAP	Etage d'Accélération à Poudre
EPC	Etage Principal Cryotechnique
ESA	European Space Agency
GTO	Geostationary Transfer Orbit
SH_2O_2	Solid Hydrogen Peroxide
HEDM	High Energy Density Matter
IAF	International Astronautical Federation
LH_2	Liquid Hydrogen
LOX	Liquid Oxygen
SH_2	Solid Hydrogen
SHEP	Super High Energy Propellants
SOX	Solid Oxygen
SRP1	Solid Kerosene
USAF	United States Air Force

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FEASIBILITY OF A CO/O_2 FUEL CELL TO BE USED ON MARS

T.Pipoli, J.O.Besenhard, M.Schautz*.

Institute for Chemical Technology of Inorganic Materials, Technical University of Graz, Stremayrgasse16, 8010 Graz, Austria.

Tel: +43-316-8738264, fax: +43-316-8738272, e-mail: f537pipo@mbox.tu-graz.ac.at.

** ESA-ESTEC, Keplerlaan, 1 Noordwijk, The Netherlands.*

ABSTRACT

Scientific landers and rovers collecting data on the surface of Mars utilise batteries to generate the required power during eclipse periods, and their operational life is presently limited by the batteries lifetime. The duration of their missions would be extended with the employment of fuel cells instead of batteries, which could be indefinitely fuelled by hydrogen and oxygen transported from the Earth, in a regenerative system, or by fuels directly produced on site, utilising the natural resources of the planet.

A feasibility study was performed, under an ESA contract, and the experimental research is currently underway, at the Institute for Chemical Technology of Inorganic Materials of the Technical University of Graz, to investigate the possibility to drive the decomposition of Martian atmospheric carbon dioxide by solar radiation, into carbon monoxide and oxygen, which can be used to fuel solid oxide fuel cells.

INTRODUCTION

The exploration of Mars has received in the past years and is at present receiving a great interest; numerous scientific missions are planned to study the atmospheric, geological and morphological properties of the planet. The comprehension of the climate changes which occurred on Mars will provide us a deeper knowledge not only of the history and characteristics of the red planet itself but also of the Earth climate, and will help in the prediction of possible future modifications of the terrestrial environment.

Carbon dioxide forms the 95 % of the Martian atmosphere and the products of its reduction, carbon monoxide and oxygen, can be utilised as the fuel and the oxidant for the operating of solid oxide fuel cell plants. The decomposition of carbon dioxide can be obtained via photoelectrolysis, induced by solar radiation.

This photocatalytic reaction could provide the fuels for stable refuelling stations for SOFCs operating on small landers, allowing a longer operational life of the scientific missions and avoiding risky and heavy transportation of fuels from the Earth.

SOLID OXIDE FUEL CELL

The solid oxide fuel cell (SOFC), is an all solid-state power system, based on the use of a solid ceramic yttria–stabilised zirconia, as the electrolyte, nickel–zirconia cermet as the anode and strontium doped lanthanum manganite as the cathode.

The ceramic electrolyte is an excellent conductor of negatively charged oxide ions at temperatures between 800 and 1000°C.

The solid oxide fuel cell functions equally well with the use of hydrogen and/or carbon monoxide as the fuel, and the presence of carbon dioxide has no effect on its performance.

At the anode, hydrogen and carbon monoxide react with oxide ions transported through the electrolyte to form water and carbon dioxide; this is accompanied by the release of electrons to the external circuit. The electrons from the external circuit react with oxygen at the cathode and produce oxide ions.

The overall process is hence the reaction of oxygen with hydrogen to produce water and of oxygen with carbon monoxide to produce carbon dioxide:

Anode reaction:

$$H_{2(g)} + O^{2-} \rightarrow H_2O_{(g)} + 2e^-$$

$$CO_{(g)} + O^{2-} \rightarrow CO_{2(g)} + 2e^-$$

Combined anode reaction:

$$aH_{2(g)} + bCO_{(g)} + (a+b)O^{2-} \rightarrow aH_2O_{(g)} + bCO_{2(g)} + 2(a+b)e^-$$

Overall cathode reaction:

$$\tfrac{1}{2}(a+b)O_{2(g)} + 2(a+b)e^- \rightarrow (a+b)O^{2-}$$

Overall cell reaction:

$\frac{1}{2}(a + b)O_{2(g)} + aH_{2(g)} + bCO_{(g)} \rightarrow aH_2O_{(g)} + bCO_{2(g)}$

The high operational temperature and the consequent tolerance to impure fuel streams make the SOFC ideal for utilising hydrogen and carbon monoxide from natural gas or carbon dioxide in the specific case.

The high quality waste heat can be used either in bottoming cycles or to provide process heat.

SOLAR RADIATION ON MARS

The mean solar constant value at the top of the Martian atmosphere is 590 Wm^{-2}. Carbon dioxide in the atmosphere absorbs radiation with wavelengths shorter than 190 nm, and the dust absorbs and scatters light in the visible and near infrared region of the spectrum. Due to the very low thickness of the atmosphere and the small occurrence of ozone, the surface of the planet is exposed to high levels of solar ultraviolet light.

The intensity of the irradiation is attenuated during dust storms, but it was estimated that at normal incidence, and for optical depths of 5 almost 200 W/m^2 are still available[(1)].

The maximum, minimum and mean daily averaged insolation on the planet, as a function of latitude are represented in figure 1.

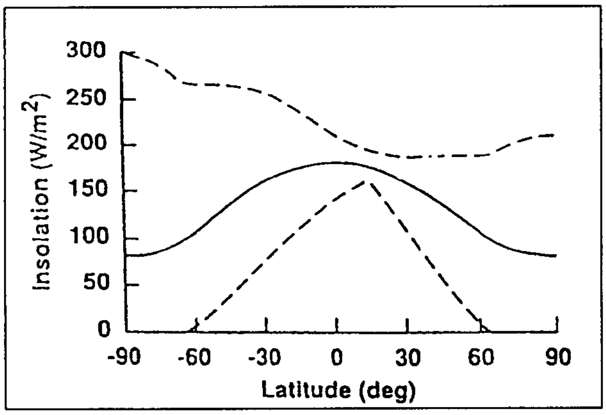

Figure 1. Annual insolation on Mars (from T.R. Meyer, C.P. McKay, "Using the resources of Mars for human settlement", Strategies for Mars: A guide to human exploration, Vol. 86, chapter 19).

SYSTEM DESCRIPTION

The subject of the research project is the development of a system for the decomposition of carbon dioxide, based on heterogeneous photocatalysis.

Finely powdered titanium dioxide, exhibiting excellent photocatalytic activity, long durability and high specific surface is employed as the catalyst.

The reaction can be performed in a flat vessel, equipped with a quartz window. Titanium dioxide is mixed with nickel nanoparticles and a binder, in a fine slurry, and painted in a thin sheet on the internal side of the quartz window.

When the semiconductor is irradiated by light with wavelengths shorter than 415 nm, one electron is promoted from the valence band to the conduction band, creating a positive vacancy in the valence band:

$TiO_2 + h\nu = h^+_{VB} + e^-_{CB}$,

where h is the Planck constant = $6.6256 \cdot 10^{-27}$ erg·sec and ν is the wave frequency.

The generated charge carriers react with carbon dioxide on the catalyst leading to its dissociation into oxygen and carbon monoxide in the gas phase.

A simplified schematic of the photophysical and photocatalytic events that may occur on the semiconductor, under irradiation, are shown in figure 2.

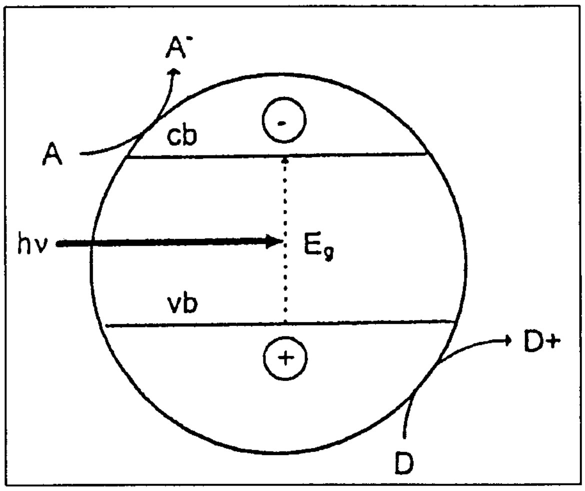

Figure 2. Photophysical and photocatalytic events that may take place on the semiconductor under irradiation (from "Heterogeneous photocatalysis, Transition metal ions in photocatalytic systems" M.I. Litter, Applied Catalysis B: Environmental 23, 1999, 89-114).

Nickel, in finely dispersed reactive form, by direct interaction with CO, at normal pressure and at a temperature of 80°C, forms the nickel-tetra-carbonyl complex $Ni(CO)_4$, which is liquid at normal conditions and can be easily separated from the gas phase.

The oxygen can be then collected through a valve and fed into the cathodic compartment of the fuel cell.

By heating at 200°C, the complex is decomposed into gaseous carbon monoxide and nickel metal again. Carbon monoxide can hence be separated through a vent and fed into the anodic compartment of the solid oxide fuel cell, while nickel metal remains in the catalyst, and reduction of atmospheric carbon dioxide can be further processed.

The energy required for the thermal steps can be obtained by utilisation of the solid oxide fuel cell waste heat. A start up heater and a pump are required to achieve the operative temperature necessary to initially start the fuel cell and to compress the carbon dioxide from the atmosphere into the photocatalytic reactor.

The system needs to be designed to resist under the hard atmospheric conditions of the planet and should be placed, as far as permitted by the mission requirements, in an optimal position in order to receive long and efficient solar radiation.

The proposed process permits to obtain, at the same time, the production of oxygen and carbon dioxide and their separation, which would be not easily performed by other methods, without sacrificing precious electrical energy.

The isolation of the two gases from each other cannot take place efficiently through a separation membrane since the two molecules are very similar in volume.

The utilisation of photoelectrochemical cells has also been considered, since they are divided in two compartments where oxygen and carbon monoxide gases are separately evolved, but the system would be more complex and present more stringent maintenance requirements and corrosion problems.
The process is schematically reported in figure 3.

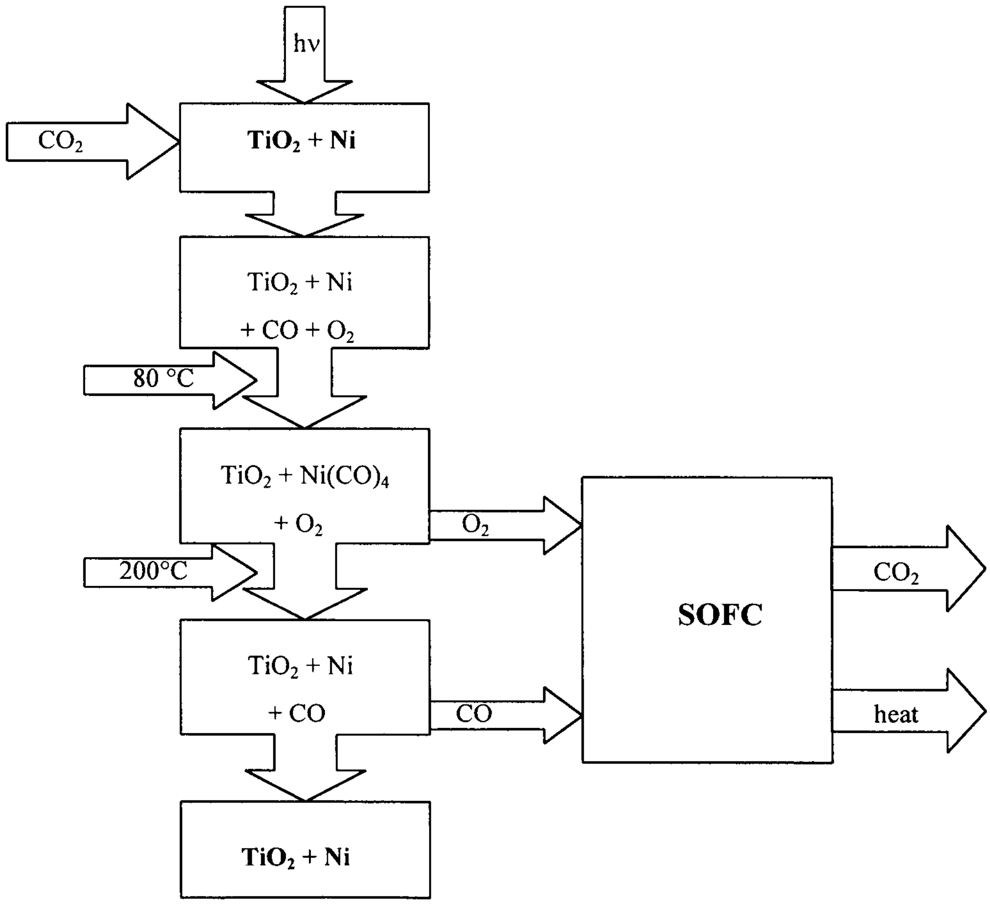

Figure 3. Schematic of the proposed process.

EXPERIMENTAL DETAILS

A series of preliminary experiments was performed to investigate the feasibility of the reaction.

The experiments were run in a quartz cell, Hellma Q.S. 117.100, with a volume of 3.5 ml and a light path of 10 mm. The cell was gas-tight sealed with a Teflon screw cap equipped with a silicone rubber septum, which allows the cell to be filled with CO_2 and gas samples to be taken through a needle.

TiO_2, Degussa P25, (70% anatase and 30 % rutile), with a particle diameter of ca. 24 nm and a specific surface of 50 m^2/g, was incorporated in a proprietary matrix, able to permit the contact and adsorption of the CO_2 on the semiconductor, at different concentrations, and the mixture was magnetically stirred to obtain an homogeneous suspension.

A portion of the suspension was painted on one of the two quartz walls of the cell and the cell was then sealed and flushed with high purity CO_2, (AGA 5.2, 99.9992%), for ca. one hour to eliminate air or argon for the samples prepared in the absence of air.

The cell was then irradiated, with a 1300 W high-pressure Hg lamp, Heraeus Q 1023.

Before and after irradiation an FTIR spectrum of the sample was taken.

Every hour a small sample of gas was withdrawn with a gastight syringe and analysed via gas-chromatography.

PRELIMINARY RESULTS

Initially only suspensions of titanium dioxide in the matrix, in the absence of nickel, were prepared.

The effects of the addition of nickel metal are presently under study.

The production of carbon monoxide and methane as a by-product was revealed by gas–chromatography and FTIR spectroscopy. Oxygen could not be detected.

The production rate was observed to increase with irradiation time.

The formation of methane indicates the presence of OH groups on the surface of the TiO_2. Further experiments are under development, employing TiO_2 catalyst, previously submitted to a calcination process to eliminate OH groups on the surface and avoid methane formation, consequently increasing the overall production rate of carbon monoxide.

CONCLUSIONS

A feasibility study was performed, in the period from February 1999 to July 2000, concerning the photocatalytic decomposition of carbon dioxide into carbon monoxide and oxygen.

The experiments were run, so far, on laboratory scale and were only aimed to verify the possibility for the reaction to be driven. Further investigation so as the optimisation of the reactor and of the overall process are planned.

The first results, even if preliminary, are encouraging. It was demonstrated that the splitting of CO_2 on titanium dioxide via solar radiation is feasible even if the carbon monoxide production rate, with the present process set up, is still very low. We believe that the system optimisation will eventually lead to higher efficiencies.

A second phase of the project will involve the optimisation of the experimental reactor.

A third phase will consist in the final set up of the reactor and of the overall process, including the solid oxide fuel cell, and the verification of the system performance and efficiency.

ACKNOWLEDGEMENTS

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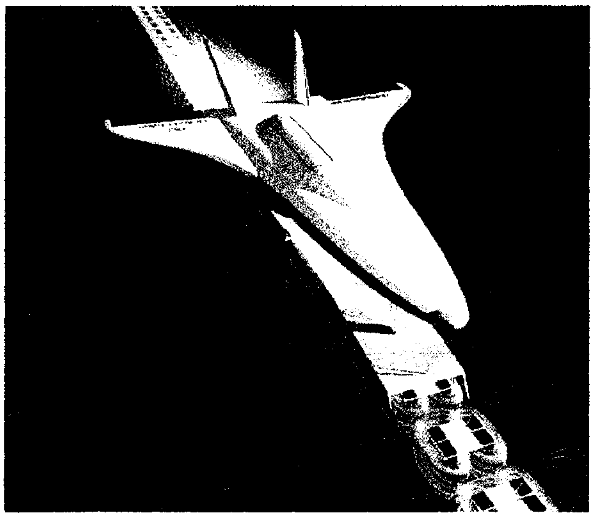
ELECTROMAGNETIC LAUNCHING OF SPACECRAFT

by Professor B.V. Jayawant and Dr. J.D. Edwards

School of Engineering and Information Technology
University of Sussex
Falmer, Brighton BN1 9QT
England
Tel: +44 (0)1273 606755
Fax: +44 (0)1273 678452
email: b.v.jayawant@sussex.ac.uk

Abstract:
This paper describes the development of electromagnetically levitated and propelled platforms for launching spacecraft of up to 50 tonnes. The objective of this research, which is being carried out under the sponsorship of NASA and PRT Advanced MagLev Systems, is to eliminate the need for the first stage rocket in a launch system. This, in turn, means that the platform has to achieve speeds of 720 km/h (600 miles/h) before the spacecraft leaves the carrier. A novel system has been developed in which the carrier platform is levitated by a succession of coils excited by 1-ph currents and propelled by a double sided linear induction motor, with windings in the airgap, of a configuration which has been called "waffle winding". A 15 m (50 ft) demonstration system has been built and demonstrated in the U.S.A. at Huntsville, Alababa.

Electromagnetic launching of spacecraft

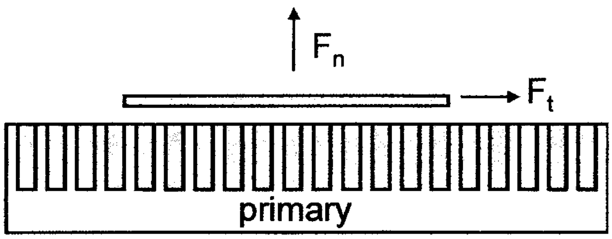


1. Introduction:

The origin of this research stems from work carried out by members of the Power Electronics and Control Group at the University of Sussex on combined eddy current levitation and propulsion at mains frequencies (50 Hz) using a concept known as "Magnetic Rivers"[1]. These have utilised single sided linear induction motors, with a special configuration of 3-ph windings which provides, not only axial thrust, but vertical lift force on conducting sheets such as aluminium (Fig. 1).

Two deficiencies were highlighted during early phases of this research. The first one is that the magnetic river is a single sided or airbacked machine. The NASA requirements have been given as levitating a mass of 75 tonnes comprised of 50 tonnes for the spacecraft plus the second stage rocket and 25 tonnes for the carrier to be accelerated at 2 g. A single sided linear motor of a reasonable size can be shown to be incapable of providing such forces. A second and more serious drawback is that both the lift and thrust will diminish as the speed of the levitated conducting material approaches the synchronous speed determined by the geometry of the windings and the excitation or supply frequency.

Slip in linear induction motors



Air backed secondary

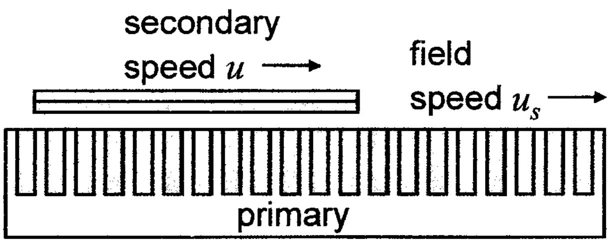


Figure 1

Proc. 2nd Conf. Academic & Industrial Cooperation in Space Research, Graz, 15-17 November 2000, ESA SP-470, November 2000

2. Launch Requirements:

It will be deduced from the introduction that the requirements of launching satellites by electromagnetic means entails very high acceleration and, therefore, large tractive forces. However, the operating time is extremely short (Table I). Thus normal transport norms do not apply i.e. large power requirement and power loss can be acceptable, as also, efficiency is unimportant. Since the linear motor is ground based and long and the carrier adds to the total weight to be levitated ad accelerated both the stator and "rotor" masses need to be minimised.

Table I: Example Specification

Vehicle mass	50 tonnes
Carrier mass	25 tonnes
Final speed	200 m/s
Acceleration	2 g
Track length	850 m
Accelerating time	9.3 s
Motor max. output	290 MW (at final speed)
Motor average input	290 MW (50% efficiency)
Energy consumption	2700 MJ (750 kWh)

Reliability in electromagnetic launch systems is of prime concern and hence proven technology such as linear induction motors offer considerable potential in eliminating the first stage rocket, thus reducing the costs of launching satellites and even spacecraft.

3. Levitators and Linear Induction Motors:

Single sided linear induction motors as shown in Fig. 1 exhibit tractive and lift forces which are a function of the speed of the magnetic field relative to the conducting secondary i.e. $(U_s - U)$. As the speed U approaches the synchronous speed U_s both forces diminish rapidly. Secondly, a single sided machine or airbacked secondary is a highly inefficient machine. This renders the concept of magnetic rivers inappropriate for the kind of application envisaged here.

3.1 Levitation

In the light of these factors it was decided to use separate levitators excited from 1-ph supply at power frequencies (50 Hz or 60 Hz) and a double sided linear induction motor for propulsion. The configuration of the levitators is shown in Fig. 2. This employs an array of U-shaped electromagnets to induce currents in aluminium channels. The channels, one on either side of the carrier, form part of the vehicle support structure. Currents induced in the channels are most intense in the region between the magnet poles, where they interact with the transverse component of the magnetic field to give a force of repulsion between the channels and the electromagnets. The channel flanges provide a low-resistance return path for the currents. This shape also enhances, quite considerably, the lateral stability, if the channels are not wider than the electromagents.

Induced current in channel

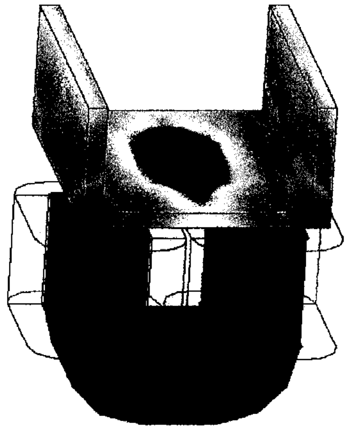


Figure 2

An AC induction levitation system has been designed for a 15.25 m (50 ft) demonstration magnetic levitation track in the U.S.A. on the basis of computer modelling with a 3-D finite element electromagnetics package and laboratory tests. This uses electromagnets based on commercial strip wound C-cores as used in transformer manufacture, with a pole width of 32 mm and a distance of 64 mm between pole centres. The working gap between poles and the channels is 20 mm, excited from a 60 Hz supply and supports a 58 kg load. To explore the effects of scale, geometrically similar electromagnets have been modelled and results extrapolated for the requirements of the specification given in Table I. The minimum airgap is then assumed to be 80 mm and to support a 50 tonne, load pole area is 128 mm × 128 mm with pole spacing of 256 mm, and the power requirement is worked out as 7600 kW. A further innovation envisaged and incorporated on the 15.25 m (50 ft) track is to add similar tracks on either side of the carrier to increase the lateral stability. These together with the levitation tracks then form a balanced 3-phase load.

3.2 Linear motors

In view of the inadequate performance of airbacked (single sided) linear induction motors attention was focused on double sided machines. This results in an overall configuration as shown in Fig. 3.

Prototype Airgap Winding LIM

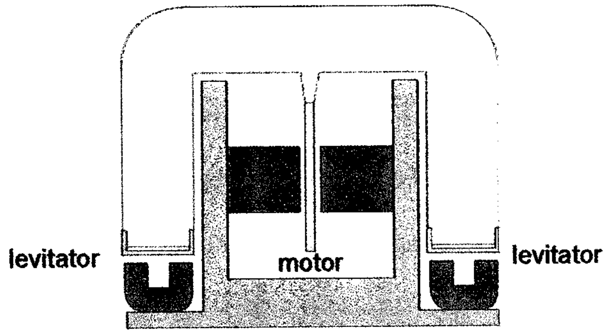
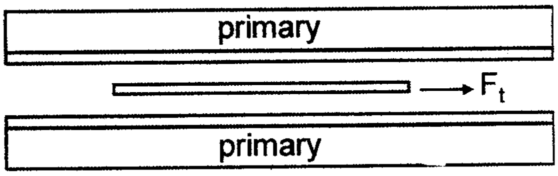


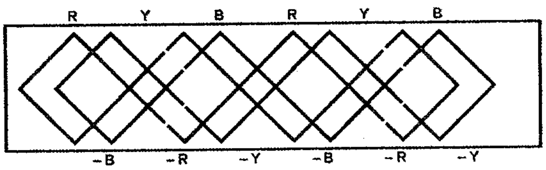
Figure 3

The double sided motor shown in the middle has a vertical aluminium plate acting as a secondary. While in the first prototype built, the stator windings were diamond coils embedded in slots. The complexity of such construction and the fact that the end windings do not contribute to the thrust led to the third innovation i.e. the use of windings attached to the faces of stator laminations. The windings as shown in Fig. 4 have been called "waffle windings"[2].

Airgap Winding LIM



Principle of the Waffle Winding



Practical Waffle Winding

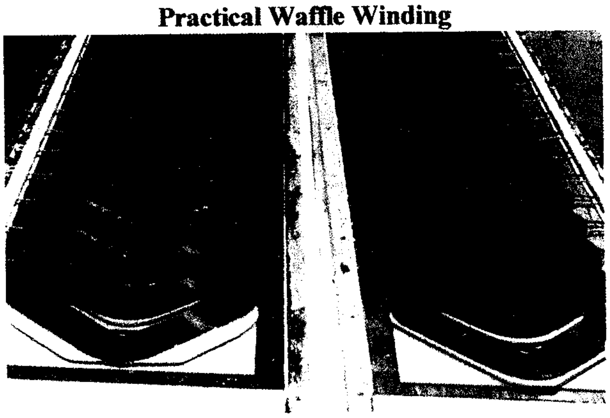


Figure 4

The equivalent circuit representation of induction machines (Fig. 5) shows that the I^2R loss in such windings will be larger but for short term applications, as in the present case, the elimination of end winding leakage reactance has the effect of reducing the reactive kVA as also the total weight of the stator. Table II shows the performance comparison of conventional diamond windings in slots as against surface mounted waffle windings for the same tractive force.

Induction Motor Equivalent Circuit

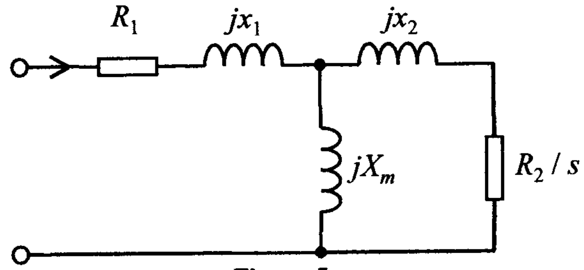


Figure 5

Table II: Performance Comparison

Quantity	Conv.	Waffle
Airgap length (mm)	30	30
Pole pitch (mm)	300	300
Tractive force (kN)	10	10
Secondary I^2R loss (kW)	150	150
Primary I^2R loss (kW)	30.4	69.6
Apparent power (kVA)	1054	534
Power factor	0.314	0.692
Primary mass (kg)	761	392

4. Conclusions and Future Work:

The 15 m demonstration system built at Huntsville (Alabama) shown in Fig. 6, was completed in September 1999. It is to be used to launch the model aircraft shown in the figure this year.

Demonstration System

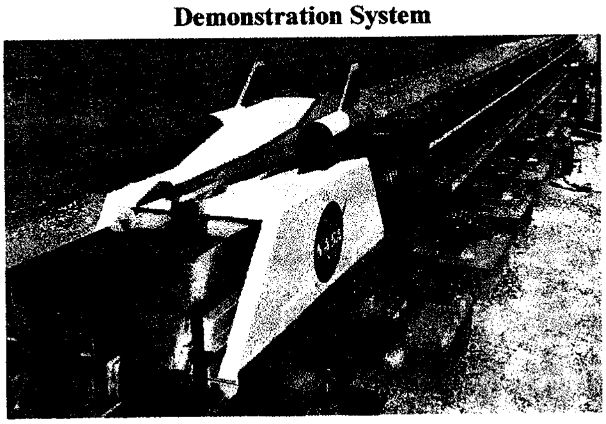


Figure 6

Future plans consist of a 60 m, dual track system to support a 225 kg carrier plus a model shuttle weighing 200 kg sitting on it. It is intended to achieve speeds of 320 km/h. The power supply to the motor and the levitation/stabilising coils at this stage will be inverter controlled to keep the slip, i.e. $U_s - U$, constant.

5. Acknowledgements:

The work described in this paper is part of a multimillion dollar NASA programme, sponsored at the University of Sussex by PRT Advanced MagLev Systems.

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Academic-Industry Collaboration

Chairman: E. Wagner, Fraunhofer Institute, Germany

A UK STUDENT NANOSATELLITE

S.E. Hobbs[(1)], T.S. Bowling[(1)], S.B. Gabriel[(2)], A.R. Tatnall[(2)], and M. Snelling[(3)]

(1) Cranfield University, UK

(2) University of Southampton, UK

(3) Astrium UK

College of Aeronautics, Cranfield University, Cranfield, Bedford, MK43 0AL, UK
Tel. +44 (0) 1234 750111, Fax +44 (0) 1234 751550, s.e.hobbs@cranfield.ac.uk

ABSTRACT

This paper presents a university-led, industry-supported nanosatellite project. The project is one activity of the Aerospace MicroSystems Technology (MST) Applications Partnership, which involves universities and industry in the UK to develop MST for aerospace. The UK student nanosatellite is planned to be the first of a series of missions with Partnership involvement.

Work started in 1999, and has to date accounted for approximately 10 person-years' effort (staff and students). The objectives of the mission are (1) to develop a nanosatellite for early MST demonstration in space, (2) to train young engineers, and (3) to transfer technology.

The current baseline is for a satellite of mass < 5 kg with 3-axis attitude control and a lifetime of 12 months in a low-Earth polar orbit. It is intended to fly two identical satellites to test concepts in collaborative flying and provide limited redundancy. The baseline design is practically complete and detailed design is starting for a launch in 2003.

Students are strongly motivated and enjoy active interaction with industry. The next project stages will be challenging and also potentially highly rewarding.

INTRODUCTION

This paper presents a university-led, industry-supported nanosatellite project. The project is one activity of the UK Aerospace MicroSystems Technology (MST) Applications Partnership (AMSTAP), which involves universities and industry in the UK to develop MST for aerospace.

AMSTAP's members are Astrium, the Rutherford Appleton Laboratory, and the universities of Cranfield (College of Aeronautics, School of Industrial and Manufacturing Science) and Southampton (School of Engineering Science). AMSTAP was formed with support from the British National Space Centre (BNSC).

An initial report by AMSTAP for BNSC recommended that a series of technology demonstration missions be started in the UK to gain flight experience with MST, train personnel, and encourage industry - university collaboration and technology transfer. The subject of this paper, the UK student nanosatellite, is planned to be the first of these missions.

The concept of the nanosatellite is that it should be ready in a short period to carry MST for flight experience in space. The experience gained will benefit all involved as well as building a space pedigree for elements of MST. The objectives of the first nanosatellite are to:

- enable early demonstration of MST in space
- provide training in space engineering and MST
- transfer technology to UK space industry

These objectives, together with the limited resources available, have led to the university-led, industry-supported project model adopted. The involvement of Cranfield and Southampton universities and their students (undergraduate and postgraduate) ensures that the training element is satisfied (with added benefits of enhanced student motivation and improved learning by participating in a "real" project). Student involvement also allows much of the design work to be carried out at low cost. Technology transfer comes from staff of AMSTAP's industrial members being involved as consultants who are able to monitor the project as well as provide guidance at key stages.

The objective of early demonstration of MST in space requires a satellite that can be designed and built relatively quickly (despite limited resources). A nanosatellite is appropriate for a university project, and using "conventional" technology for the core functionality maximises the likelihood of success with minimal development work required - MST will be demonstrated mainly as payload elements.

The next section summarises MST in aerospace, and space in particular. Then, the project organisation and the current baseline design are described. The final section discusses the project so far and outlines the key remaining tasks.

MST IN AEROSPACE

MST is a significant and growing activity worldwide. Techniques developed initially for microelectronics are being applied to develop systems which combine data processing, sensing and actuation at micron scales, with the benefits of extremely high levels of integration and the possibility of low cost mass production. MST has huge potential - especially in applications such as space which need to maximise performance within tight mass and power constraints.

Elements of MST which are already making their way into aerospace include solid state gyros and accelerometers as parts of integrated inertial sensor packages, a wide variety of other sensors (e.g. monochromators), and the ever increasing computing power available.

Some of the key characteristics of MST for space are:

- High degree of integration; low power and mass
- Intelligent systems, which may be distributed
- Redundancy leading to improved reliability
- *Potential* for mass production at low cost

Initial consideration of MST in space has led to an awareness that conventional ways of design may not be adequate. Issues such as integration, packaging, testing may all need new approaches which a programme of flight testing MST will allow us to explore. It is also important to be aware that industrial sectors such as microelectronics, medicine, automobiles and consumer electronics are likely to provide many of the key innovations, i.e. technology transfer and adaptation to the space sector is likely to be necessary.

PROJECT ORGANISATION

Staff from the universities lead the project and are responsible for reviewing student research, defining objectives, identifying the baseline, and managing the project. The main resources are the time and expertise of staff, and the time and enthusiasm of the students. The total effort committed to date represents approximately 10 person-years, with this level of resource available each year.

Most of the work to date has taken place at the universities of Cranfield and Southampton with a relatively informal degree of coordination. Following preliminary design work by staff, student projects ran during the academic year 1999/2000 at the universities as either group projects or individual research projects. These have led to the current baseline design (described below).

Individual research projects are closely supervised by one member of staff and allow specific topics to be researched in depth. The group projects [1,2] involve from 6 to 22 students and cover a much greater breadth. The group projects are also supervised but it is not desirable to provide detailed guidance at all stages - one aim of the group project is to give students experience of organising and working effectively as part of a group on their own initiative. Industry support was provided by Astrium, RAL and the UK's Defence Evaluation and Research Agency.

Significant constraints are the need to work within the academic year structure and the priority that must be given to students' academic requirements. These mean that projects must fit within particular timescales and must contain a correct balance of elements to develop students' abilities and allow convenient assessment. Most students stay with the nanosatellite project for only part of one academic year so that continuity is also an issue. The staff participation (including that of AMSTAP's industry members) and also research students at the universities provide the continuity to allow the project to progress.

The next major milestone in the project will be the Preliminary Design Review, with the Critical Design Review expected in early 2001. The current goal is to be ready for launch in 2002.

The MST for demonstration will come from any of a wide range of sources. An Announcement of Opportunity is planned once payload interface definitions are finalised to invite collaborators to propose MST payloads. Selection criteria will include availability within the project timescale, contribution to MST demonstration, and compatibility with the wider AMSTAP objectives.

BASELINE DESIGN

The baseline design is being refined (summer 2000), and is based on the results of studies carried out by staff and students over the previous 18 months.

The current concept is for two identical nanosatellite spacecraft to be built and launched. Two spacecraft can test and demonstrate concepts in collaborative flying (which underlie many space MST applications) and also provide a degree of redundancy for the mission as a whole (at reduced capability). The spacecraft will carry MST, primarily as payloads (which may differ between the two spacecraft).

Success (!) is a high priority for the mission and so a conservative approach will be taken in the design of the key spacecraft subsystems (power, communication, data handling, etc.), mainly using conventional miniature technology (the timescale also encourages this approach). Similarly, since a launch of opportunity is envisaged it is important to be able to guarantee that any partner spacecraft will not be put at risk and so a conservative structural design will be adopted. MST may be incorporated in the "bus" if it is low-risk or (at least partially) redundant.

Mission	MST demonstration
Concept	2 identical nanosatellites with "conventional" bus design carrying MST as payload; able to test / demonstrate MST and related operational concepts
Orbit	Low-Earth, polar; uncontrolled except for gentle manoeuvres
Lifetime	12 months
Mass	< 5 kg (inc. payload)
ACS	3-axis (coarse - magnetorquer)
Power	~ 8 W (avg., total inc. payload)
Communication	Single ground station, 10-30 kbaud

Table. Summary of current baseline design.

A low Earth polar orbit is suitable for many potential applications, is relatively benign, and is accessible by a launch of opportunity (a launch to GTO could also be used but would reduce mission lifetime and compromise performance). A nominal mission lifetime of 12 months in LEO is expected. Orbit control may be used but only for manoeuvres of the spacecraft relative to each other, not for orbit maintenance. (Coarse) 3-axis attitude control permits a wide range of applications and will be achieved with magnetorquers (pointing accuracy of 2° with stability of 0.1° s^{-1} expected). The power available (to the spacecraft and payload) should be 5-10 W (mean) and a communication bandwidth of 10-30 kbaud is expected. The baseline assumes a single ground station at 52° N (UK latitude) which provides contact for 10-20 min each day for polar LEO orbits.

A clear payload interface definition allows a design where payload and bus can be separated. Examples of devices envisaged for MST demonstration include:

- Solid state gyros
- Surface Acoustic Wave devices
- Advanced imagers (e.g. active pixel sensors)
- Miniature electric propulsion
- Miniature sensors and actuators

As this is a technology demonstration mission, several operational phases are envisaged to allow different experiments to be performed during the mission lifetime.

DISCUSSION

Even at this early stage the project is generating significant benefits and technical results; we hope too that in due course it will lead to significant progress in the use of MST in space.

Achievements to date include (1) several successful student projects with cohorts of students given a broad training in space engineering and an appreciation of the potential of MST, (2) a clear baseline design for the nanosatellite, and (3) active, fruitful collaboration between universities and industry in an area of developing technology.

The challenges of the project are also becoming clear. In particular the issues of resourcing and managing a project which is based in two universities, has to involve students, and work within the academic year are significant. Nevertheless, the benefits of involving students and using them as a resource for the project are significant. It is clear that having people able to commit a significant fraction of their time to the project helps maintain the project's momentum and provides necessary continuity. As the project approaches formal design reviews it moves into a new phase where more rigorous project management will be required.

Industry involvement in the project has been very beneficial. Practising engineers have been keen to work with students, and students have appreciated this contact and made good use of it. The students' work brings industry into contact with a wide range of sources that might not otherwise be identified. A real practical benefit for the project is the contribution by Astrium of the spacecraft structure - this adds credibility to the project and will also reassure launch partners about the spacecraft's integrity.

CONCLUSIONS

Of the objectives identified for the project real achievements have already been made in two areas (training of students and technology transfer with industry). The first, more tangible, objective of providing early demonstration of MST in space is underway. Achieving *early* demonstration with limited resources is a particular challenge but the project is making progress towards launch within 2-3 years.

The project is expected to demonstrate two major benefits of industry - university collaboration: (1) the enhanced learning experience for students when involved in appropriate collaborative work with industry, and (2) effective technology transfer from research groups to industry to keep industry at the leading edge technologically. Both groups of partners in the collaboration have much to gain.

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CO-OPERATION BETWEEN INDUSTRY, EXPERTISE INSTITUTES AND UNIVERSITIES FOR THE DEVELOPMENT OF ESA'S FIRST EARTH EXPLORER MISSION GOCE

A. Selig, M. Smit, R. Hoogeveen, P. de Groene
Space Research Organization Netherlands (SRON)

Contact details:
Dr. A. Selig
Space Research Organization Netherlands (SRON)
Head of division Earth Oriented Sciences
Project manager GOCE-SID
Post address: Sorbonnelaan 2, 3584 CA UTRECHT, the Netherlands
Fax: +31-30-254 0860
Tel: +31-30-253 5650/5705
e-mail: a.selig@sron.nl

Abstract

GOCE (Gravity field and Steady-State Ocean Circulation Explorer) is the first Earth Explorer Core Mission selected for full execution within ESA's Earth Observation Envelope Programme. GOCE is scheduled for launch at the end of 2004. The main objective of GOCE is to determine the earth's gravity field with high spatial resolution and high and homogeneous accuracy.

SRON as expertise institute for scientific space research took the lead in co-ordinating and performing the preparatory activities in the Netherlands. Its goal is to acquire a coherent set of activities in the B and C/D phase valuable for both the scientific user and the participating institutes and industry.

A unique aspect of the GOCE mission is that the science instrument, the gradiometer, will also be used as a sensor to provide information on satellite angular accelerations and linear accelerations to the satellite attitude control system and drag free control system. In addition to the realisation of the science instrument being an industrial responsibility, this interdependency of science instrument and satellite is a strong argument for a very well organised co-operation between industry and various (science) institutes. Such a co-operation should be defined in the whole project life cycle up to and including the operational phase.

In particular the traditional partitioning between science "best performance against any cost" and industry "best profit against any performance" needs a re-calibration. With the GOCE project as an example, the details of the co-operation of SRON with industry and several science institutes and universities will be outlined. Part of the work described here is performed within the SID consortium, a collaboration of SRON with IAPG (TU-Munich) and DEOS (TU-Delft).

1. A fundamental difference

ESA's Living Planet Programme can be roughly divided into the application-driven Earth Watch Missions and the scientific research-driven Earth Explorer Missions. The latter missions will be funded within an overall envelope optional programme, the Earth Observation Envelope Programme (EOEP). GOCE is selected as the first Earth Explorer Core Mission to be realized within the EOEP.

Comparing the Explorer Missions of the EOEP with the astrophysics space missions like ISO, XMM and FIRST of ESA's Science Programme, there is a fundamental difference in the approach to realisation of the scientific instruments. In the Science Programme national scientific institutes are responsible for the realisation of the scientific instruments, where in the EOEP this is European industry. As a consequence the overall scientific, programmatic and financial structure of the missions is a priori different, although both types of missions have a scientific objective. In table 1 on page 5 some of the most noticeable consequences for mission realisation in the two programmes are summarised. It is clear from table 1 that for missions belonging to the EOEP a well-defined co-operation between scientific institutes and industry is a necessary condition to guard the scientific integrity and performance of the instrument. As will be clarified in the following section, for the GOCE project this is even more important because of the interdependency of satellite control systems and scientific instrument.

2. GOCE: Integrated payload and satellite systems

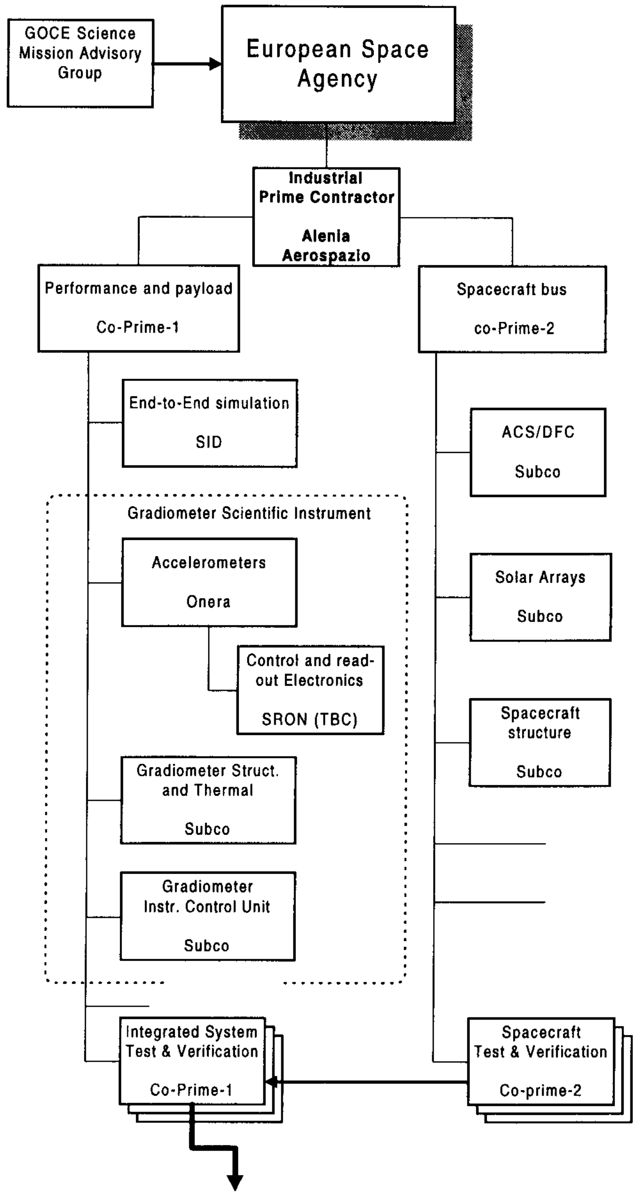
GOCE will utilise two space techniques: Satellite to Satellite Tracking (SST) by means of an on-board GPS/GLONASS receiver for orbit determination and retrieval of the long and medium wavelength components of the gravity field, and Satellite Gravity Gradiometry (SGG) for the retrieval of the gravity field down to the short wavelengths. The 3-axis gradiometer instrument is a new technological development. It consists of six accelerometers on three perpendicular axes. Each measures in three orthogonal directions. By taking differences in pairs, the perturbation due to residual non-gravitational forces, such as atmospheric drag acting on the satellite, can be eliminated. The difference signals are a direct measure for the gravity gradients from which the gravity field (gravity anomalies and geoid) at short horizontal scales can be deduced. The geoid is one of the higher level science data products of GOCE.

By taking the sum signal on each axis, the linear accelerations due to atmospheric drag are measured. Accelerations in the direction transverse to the gradiometer axes are also measured. These contain information on the satellite angular accelerations. With the eighteen degrees of freedom of the gradiometer instrument, it is possible to measure and separate the gravity gradients science signal and the linear and angular satellite accelerations. The satellite drag-free and attitude control system, which makes use of ion and cold gas thrusters, uses these accelerations measured by the gradiometer together with Star Tracker data to compensate for the atmospheric drag and to keep the satellite as much as possible Earth-pointed. Thus, the gradiometer science instrument is also used as a sensor for the satellite drag-free and attitude control system. This interdependency of the satellite control systems and the scientific instrument has severe implications for the project organisation concerning mission scenario development, system design, hardware development, and test & verification of satellite and instrument.

3. GOCE project organisation

The GOCE project is presently (August 2000) awaiting to enter the phase B which is expected to start in November 2000. Requests For Quotations/proposals (RFQ) have been sent by ESA to potential prime industry bidders. In turn potential prime industries have sent proposals to potential subcontractors, etc. In figure 1 a possible GOCE project structure is shown. It must be stressed that this is only an interpretation of the author and certainly not the approved final structure. Moreover, figure 1 is not complete. Going through figure 1 it is noticed that the interaction between science and industry mostly takes place at the left side of the diagram. This is where the scientific performance of the instrument must be realised.

Figure 1. A possible structure of the GOCE project



4. Co-operation between industry, expertise institutes and universities, significant for the GOCE project

Following figure 1 the various interactions are explained in some detail.

4.1 European Space Agency (ESA)

ESA is the executive of and overall responsible for the mission within the boundary conditions of geographical return to national industries of the European countries. The geographical return to a country depends on its financial contribution to the EOEP. With input from the MAG, ESA must establish a flow down of the highest level of scientific requirements to mission requirements in such a way that unambiguous interpretation by the industrial prime contractor is guaranteed.

4.2 GOCE Science Mission Advisory Group (MAG)

The MAG members are selected by ESA from scientific institute and university groups representative for the scientific user communities of the mission. For GOCE these are geodesy, solid Earth and oceanography. The main task of the MAG is to define the highest level of scientific requirements and to guard the scientific integrity of the mission. Other tasks are related to (advice on) scientific data processing and absolute calibration (with e.g. other gravity missions like CHAMP and GRACE). It is clear that in order to derive realistic mission requirements, a close co-operation and a common language between MAG/ESA and the industrial prime contractor is necessary. The process of adapting the mission requirements may continue as far as in the phase C/D of the project.

4.3 Industrial Prime Contractor (Alenia Aerospazio)

The industrial prime contractor is overall responsible for realising the mission in agreement with the mission requirements, and in agreement with costs and schedule as specified by ESA. In particular the industrial prime contractor is responsible for the realisation of the spacecraft bus *and* the scientific payload. The end product for the industrial prime contractor is a satellite with calibrated scientific instruments. This responsibility continues into the operational phase E.

4.4 Co-Prime-1, Co-Prime-2 and ACS/DFC subcontractor

It is not unlikely that the industrial prime contractor will select two co-prime contractors: Co-Prime-1 responsible for scientific mission performance and payload realisation, and Co-Prime-2 responsible for the realisation of the spacecraft bus. Assuming such an organisational structure, it is expected that the role of Co-Prime-1 is also fulfilled by (a sub-team of) the industrial prime contractor.

Since the gradiometer instrument is also a sensor of the ACS/DFC, the industrial prime contractor must supply Co-Prime-2 with gradiometer performance updates in parallel to the hardware development under Co-Prime-1. This will allow the ACS/DFC subcontractor to develop and test a "traditional" system, i.e. without the gradiometer hardware, but taking into account the predicted performance of the gradiometer sensor. At the end, Co-Prime-2 will deliver the fully tested spacecraft systems (with in particular the ACS/DFC) to Co-Prime-1. The latter will be responsible for the integrated system tests including the gradiometer (electronics) hardware.

4.5 End-to-End Simulation (SID space expertise consortium)

The industrial prime contractor, being responsible for the realisation of the scientific payload and scientific performance of the mission, needs a tool for continuously guarding the mission requirements and the deduced sub-system requirements during all phases of the project life cycle. End-to-end simulation is such a tool. Development and operation of end-to-end simulators is one of the most important subjects for co-operation between industry and space expertise institutes in the GOCE project.

The SID consortium consists of SRON (Space Research Organization Netherlands), IAPG (Institut für Astronomische und Physikalische Geodäsie, TU-Munich, D) and DEOS (Delft institute for Earth Oriented Space research, NL). The combination of the expertise institute for scientific space research, SRON, and the university institutes DEOS and IAPG constitutes the essential support to industry for the realisation of a scientific mission like GOCE.

All three institutes of the SID consortium have a long experience in dedicated fields of space research. SRON concentrates on hardware development and test of scientific space instrumentation. DEOS focuses its activities on the analysis of high precision geophysical measurements, made with recent and coming satellites, to address the details of the global gravity field and the motions of the solid and fluid Earth. The IAPG fields of research in the SID collaboration are satellite gradiometry and space-borne methods for gravity field determination.

Due to the interdependency of the payload and satellite ACS/DFC (see chapter 2), the end-to-end simulators must include both payload and satellite. The ultimate simulator is closed loop, which means that the gradiometer sensor read-out data are fed into the (simulated) satellite ACS/DFC system, which in turn affects the satellite dynamics, causing changed gradiometer sensor reading, etc. "End-to-end" means that the simulator comprises detailed models of all aspects of the mission, such as the atmospheric drag, the generation of the gravity field and the determination of the GOCE orbit with GPS (DEOS), the dynamics and electronic measurement process of the gradiometer including calibration procedures (SRON, IAPG), the satellite dynamics and ACS/DFC systems (Alenia), and the (simplified) retrieval of the "as measured" gravity field in terms of spherical harmonic coefficients or the geoid (DEOS, IAPG). With the end-to-end simulator the impact of satellite and payload hardware and/or mission scenario (changes) on the scientific end-products can directly be assessed.

Quoting the ESA ("Granada") report for mission selection SP-1233 (1), clarifies the objectives of end-to-end simulations:
"The GOCE end-to-end simulator plays a fundamental role in the following mission planning and execution phases:
- during the mission design phase, as a means for determining the expected scientific performance and for validating the error budget (and thus the specifications that are derived from it for all system elements)
- in parallel, to set up realistic procedures for scientific data reduction, based on representative 'raw' data
- during the mission implementation phase, to consolidate the expected scientific performances, given the measured performance of all the elements, tested separately and together, as far as possible
- during the mission operation planning, as a means to test the in-flight operation sequences, with particular regard to the gradiometer set-up and calibration
- during the mission itself, as a means for interpretation of the flight data."

Another important objective of the end-to-end simulator is related to integrated system test & verification. The numerical models of the end-to-end simulator will serve as the basis for a real-time system test bed. When (flight) hardware of payload and satellite becomes available the electronics units will replace the corresponding numerical models of the end-to-end simulator allowing for the so-called "hardware in the loop tests". One of the most important units in these tests is the accelerometer control and read-out electronics. Dutch industry (Fokker Space and NLR) together with SRON may play an important role here in supporting the (co) prime contractor's activities.

As a result of the simulation data the industrial prime contractor may decide on a redistribution of the error budgets to various hardware systems or even change the mission scenario. Because of such a severe potential impact in the project a direct and open co-operation between the industrial prime contractor and the space expertise consortium in the process of interpretation of the simulation data, real-time test data and flight data, is essential. Alenia and the SID consortium have proved the effectiveness of such a co-operation during the (extended) phase A, which can be taken as an example for future missions.

4.6 Accelerometers (Onera) and accelerometer control and read-out electronics (SRON-TNO-NLR, TBC)
Note: The following about the accelerometer contractor (Onera) is an interpretation of the author. Reality might be different.

Next to the co-operation between industry and space expertise institutes for the end-to-end simulations, which is manifest mainly at integrated system-payload level, detailed development of the scientific payload is another area which requires close co-operation between academic institutions, space expertise institutes and industry.

"The GOCE gradiometer payload will be based on special Accelerometer Sensor Heads which have been developed by Onera, who is therefore in a position of sole source supplier for that item", as quoted from the ESA Invitation To Tender. It is clear that any new type of sensor for a scientific space mission has a long history of laboratory research and development. In case of the realisation of a new sensor development in a scientific space mission, it is important to understand the main objectives of the payload developer. Roughly speaking the following options can be distinguished (1) recurrent production (strictly commercial), (2) a line of technology development and (3) the scientific use of the payload data. In the case of GOCE the accelerometers are part of a technology development line: A new generation of post-GOCE accelerometers are under development at Onera for application in future missions like the fundamental physics mission LISA (Laser Interferometer Space Antenna for the detection of gravitational waves).

In order to interpret the rough payload data for scientific use, in other words to be able to perform a scientific quality assessment on future flight data, it is very desirable that a space expertise institute with close connection to the scientific user is involved in the development and test of the read-out system of the payload. This is similar to astrophysics space missions of the ESA Science Programme where the prime investigator is closely related to or from the same institute that is main-responsible for the realisation of the payload.

SRON as expertise institute for scientific space research has both a long history of hardware development and test of scientific space instrumentation, *and* a long term scientific programme with international partners for the use of future GOCE data. Within that framework, SRON has been preparing the last four years for a hardware contribution to the accelerometer control and read-out system. Therefore, anticipating on future scientific use of the flight data, the combination of Onera and SRON for the realisation of the GOCE accelerometer payload, as indicated in figure 1, would be an optimal solution for the GOCE project. The above arguments for such a co-operation are enhanced by the synergy with the other potential SRON/SID tasks on end-to-end simulation and integrated system-payload test & verification.

5. Conclusion

Within the project life cycle of the GOCE project two major areas have been identified for an academic-industrial co-operation. Such a co-operation must not be seen as a "nice to have" but as a necessary condition for mission realisation. These two areas are (1) on integrated satellite-payload system level, the end-to-end simulations and system test & verification, and (2) on payload level, the development and test of the accelerometer control and read-out system.

Table 1. Some differences in realisation of scientific missions in ESA's Earth Observation Envelope Programme and astrophysics missions in ESA's Science Programme

Feature	***Earth Observation Envelope Programme***	***Astrophysics missions***
Overall mission responsibility	*ESA*	*ESA*
Instrument scientific responsibility	*EXTERNAL: ESA and/or Mission Advisory Group (selected from various institutes)*	*INTERNAL: Prime Investigator within institute responsible for realisation of instrument*
Selection of main-responsible for instrument realisation	*Based on expertise, costs and geographical return*	*Based on expertise*
Instrument realisation	*Industry*	*(consortium of) national institute(s)*
Financial structure for instrument realisation	*Within boundaries of ESA geographical return*	*National funding*

BEAGLE2 - A Case Study in Academia-Industry Cooperation

ABSTRACT:

Beagle2 is the British-led lander to be carried on ESA's Mars Express spacecraft to Mars in June 2003. The project was started in 1997 by an academia-industry consortium seeking to take advantage of the Mars Express opportunity but without any firm backing at that time. The Consortium has had to battle to be accepted and attract funding. Along the way it has forged novel alliances and evolved a working method that is embracing very close collaboration between large and small industry as well as between industry and academia. The project is also trailblazing public/private fundraising and has to cover a significant proportion of its costs through sponsorship. This is not without some controversy in certain quarters and many questions have been raised that will be pertinent to future projects.

The Consortium organisation has evolved from its initial loose grouping, where every partner had to pay its own way to keep the project moving, to a more focused one with clearer roles and responsibilities. Indeed the organisation is still evolving in response to the financial pressures upon it. The team exploits the different strengths and expertise from its diverse grouping to optimise its working methods and cope with the unusual demands of this challenging project. Not the least of these was working on incremental funding and the fact that Beagle2 is much more than a conventional experiment on a spacecraft but is a self-contained, free-flying space vehicle for several days in its own right before it lands on Mars.

The intent is to present a brief outline of the mission and its background but concentrate on the Consortium teaming arrangements and working practices along with some lessons-learned. This will include looking at some of the causes of tensions and the inevitable misunderstandings that occur with a large grouping working in an informal manner. 'Scientist versus engineer' has not been a problem within Beagle2 but understanding how each operates has been quite an experience. Certain elements within industry have major problems in grasping the idea of working informally with universities, especially when even the industrial partners are working on Gentlemen's agreements. Dealing with the different accounting practices is a major challenge. It is also necessary to minimise the total cost and alternatives to industrial norms are still being sought where the full majesty of systems geared to large projects (like a commercial communications satellite) are not the most suitable and using university facilities presents an alternative option. Above all, the scientific excellence of the end product must be protected and the team must not fall into the trap of believing its own propaganda so technical checks and balances are essential. Communication between members is of the essence and, despite extensive use of electronic means, personal contact is still invaluable; something that close geographic proximity allows without too heavy a burden on time and money.

AUTHORS:

John Thatcher, Astrium Ltd,
Beagle2 Consortium Industrial Manager

Dr Mark Sims, Leicester University
Beagle2 Consortium Project Manager

CONTACT DETAILS (Prime Author):

John Thatcher
Astrium Ltd
EOS (UK) COB205
Gunnels Wood Road
Stevenage
Herts
SG1 2AS
England

Tel +44 1438 774382
Fax +44 1438 778912
email john.thatcher@astrium-space.com

Satellite Mobile Communication and Navigation Signal Propagation and Quality Studies – an Ideal Field for Academic and Industrial Cooperation.

by
Walter L. Randeu[1,2], Erwin Kubista[2] and Martin Friedrich[1]

[1] Institute of Communications and Wave Propagation (INW)
Technical University of Graz
Inffeldgasse 12, A-8010 GRAZ, AUSTRIA
Tel. +43-316-873-7443, -7449, Fax +43-316-463697

[2] Institute of Applied Systems Technology (IAS)
Joanneum Research Forschungsgesellschaft mbH
Inffeldgasse 12, A-8010 GRAZ, AUSTRIA
Tel. +43-316-876-2510, Fax +43-316-876-2502

Abstract

Modern satellite communication and navigation systems for mobile applications have - due to limited power budgets - only small propagation margins, *i.e.* they are rather vulnerable by propagation impairments imposed by the atmosphere and the environment. Already in the planning phase of such systems care must be taken to understand the type and extent of all such disturbing effects which can occur on the path between satellite and ground equipment.

The design and implementation of such systems is - for reasons of technology and capacity - usually a task for the specialised industry, often exercised in the frame of consortia established from the limited number of European major players in that field. The detailed investigation of atmospheric propagation conditions and impairments, however, is by tradition a field treated by the academic research domain, not only out of the scientific interest, but to some degree also due to lacking economical attraction. It is therefore not surprising that system definition and design studies carried out by industry need support and consultation in matters of ionospheric, tropospheric and environmental wave propagation from the academic domain.

This paper describes a number of such co-operations between the authors' organisations and the European space industry, and the results achieved and experiences made therein. The reported projects cover a wide spectrum of techniques applied, ranging from experimental assessment to detailed modelling and computer simulations for the determination of signal distortion and interference to be expected in future systems. Both fields of application, *i.e.* mobile communications and navigation, have been dealt with in such joint activities which are deemed having generated fruitful results for both sides.

1. Introduction

Satellite based mobile communication and navigation systems are presently undergoing rapid developments. The reason for the boom in these areas can be found in mainly two domains, i.e. the demand from the end user side and the attractivity for relevant industry being highly interested to open fields for new products and applications, considering mobile communications and navigation as primary technology and market drivers.

Ground based mobile communication systems are well established today, with powerful extensions – like UMTS – already being beyond the definition and standardisation phase. Involving satellites in mobile voice and data transmission is primarily justified by a satellite's wide coverage, being superior to base stations on the ground. For example, in mountainous areas it is technically difficult and economically not viable to achieve complete coverage with conventional ground based systems, although this would be required by search and rescue applications. Coverage and accessibility matters are also the reason for involving satellites in navigation systems, as successfully demonstrated by USA's GPS and Russia's GLONASS. Originally designed and built for military applications only, steady improvements in receiver technology and signal processing methods have brought these systems to beneficial civil use also.

The advantage of wide coverage achieved by communication and navigation satellites is hampered by large distances between the spaceborne and the ground segment, making the link power budget a critical item. Furthermore, atmospheric weather disturbances in the ionosphere as well as in the troposphere must be taken into account as sources of signal degradation, manifesting as attenuation, amplitude and phase scintillation, depolarisation and dispersion. Finally negative effects caused by the ground environment, e.g. in the form of blocking/shadowing or multiple reflections (multipath propagation), have to be considered in design and operation, so that service reliability and quality can be guaranteed at certain required levels.

While matters of system design and technological development and implementation are full in the hands of the competent industry, the field of wave propagation, closely interrelated with atmospheric and meteorological research, is by tradition an academic area confined to a few specialised research institutions. The primary reason for may be that – at a first glance – studying wave propagation is considered as financially unattractive profession, with rather infrequent practical applications resulting in – mostly hidden – revenues. The true reason, however, may lie in this area's interdisciplinary nature, requiring a certain build-up and concentration of competence in a number of scientific fields, outside the economical possibilities of production oriented industry.

The establishment of critical masses in the fields of ionospheric and tropospheric wave propagation has successfully been achieved at the authors' institutes in Graz. Relevant research work was mainly funded under ESA/ESTEC Contracts and goes back to the early 70ies, originally oriented towards propagation impairments on fixed satellite links, applying indirect methods (e.g. radiometer diversity measurements at 12, 20 and 30 GHz [1,2]) as well as direct ones (satellite ground stations receiving satellite beacons), later on enhanced by multi-parameter weather radar [3,4] for high-resolution remote measurement of precipitation fine structure along Earth-satellite radio links. An extensive set of abilities, data bases and tools has been collected, allowing to model, simulate and predict on a statistical basis microwave propagation impairments by the atmosphere and the environment at any frequency of interest.

Examples of the exploitation of this competence in projects dealing with mobile communication and navigation systems are described below, complementing the industrial partners' experiences in managing and carrying out large projects and providing access to required technology. Positive and negative experiences made and results achieved are highlighted.

2. Land Mobile L/S-Band Beacon Terminal

A typical example for co-operation with an industrial partner in this area was the project called 'Equipment for Wide-Band Airborne Multivisibility Assessment'. The goal for this project was to develop a measurement platform that allows wide-band mobile measurements at L- and S-band frequencies in combination with video recordings of the surrounding environment. Joanneum Research with it's Institute of Applied System Technology (IAS) acted as the prime contractor for this activity with RESCOM (Denmark) as an industrial subcontractor. The responsibility of RESCOM was the adaptation and installation/integration of the measurement equipment in the provided measurement platform (ESTEC's Land Mobile Beacon Terminal) whilst the responsibility of IAS was the design of the measurement concept, the development and implementation of the software for the data acquisition system and the data analysis and evaluation. Furthermore a short measurement campaign was carried out to validate the correct working of the equipment and the software.

Fig. 1 shows the mobile terminal during test runs in the city of Graz, with a slowly flying helicopter carrying beacon transmitters simulating the space segment.
Figs. 2 and 3 provide looks onto equipment inside the Mobile Terminal, while Fig. 4 shows transmitters in and antennas attached to the helicopter [5 – 9].

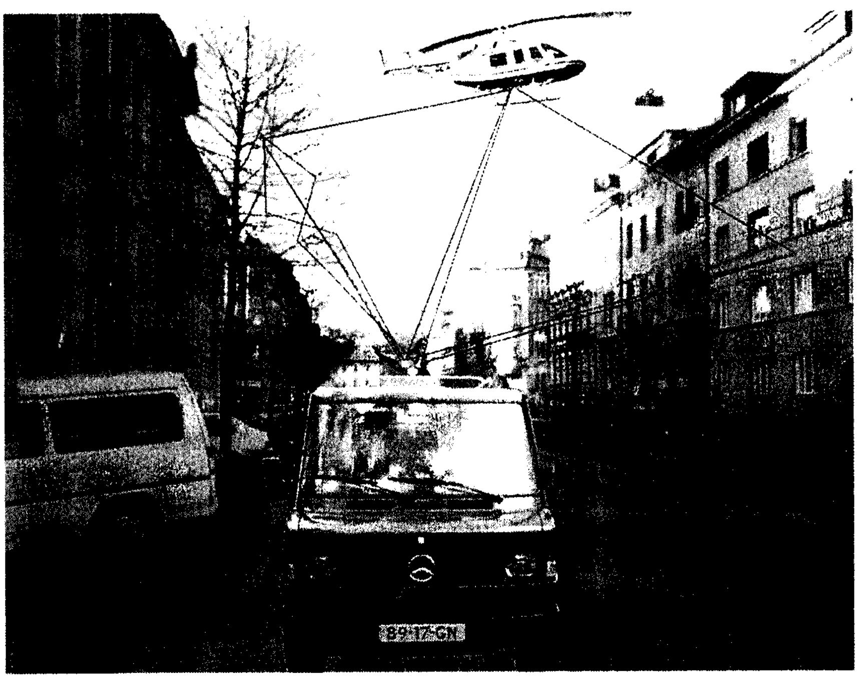


Fig.1: Test run of ESTEC's Land Mobile L- and S-Band Beacon Terminal (LMBT) in the city of Graz (Conrad-von-Hötzendorf-Strasse). The space segment is simulated by a slowly flying helicopter carrying L- and S-band beacon transmitters. Received signals are recorded and analysed with respect to shadowing (blockage) and reflection (multipath propagation), and their correlation with type of environment.

Fig. 2: View onto the equipment in the LMBT (through the van's side door). The rack on the left hand side contains the receivers for the L/S-band and the Ka-band equipment, the data acquisition system, a 24-channel combined GPS/GLONASS receiver as well as video equipment (VCR, video combiner) for recording the surround view.

Fig. 3: View into the LMBT from the back side, with open doors. Protruding from the roof are the L- and S-band receiving antennas, mounted on a rack which also holds four video cameras used for documenting the surrounding environment. The gyro stabilised parabolic Ka-band antenna can be seen in its lower parking position.

The synergy in the co-operation with the industrial partner was that the team was able to draw on IAS's know-how in carrying out mobile propagation measurements, thus ensuring the usefulness and the comfortable handling of the equipment, as well as on RESCOM's experience in the development of state-of-the-art equipment that conforms to industry standards, thus providing high reliability of the measurement equipment generated under this activity.

One of the problems encountered during the execution of the project was, that the co-ordination of the time schedule proved to be rather difficult. The reason for that could have been, that RESCOM being an SME with about 20 employees, had to fit in this, for them rather small project in terms of financial aspects, within their daily schedules. Since the product to be developed had

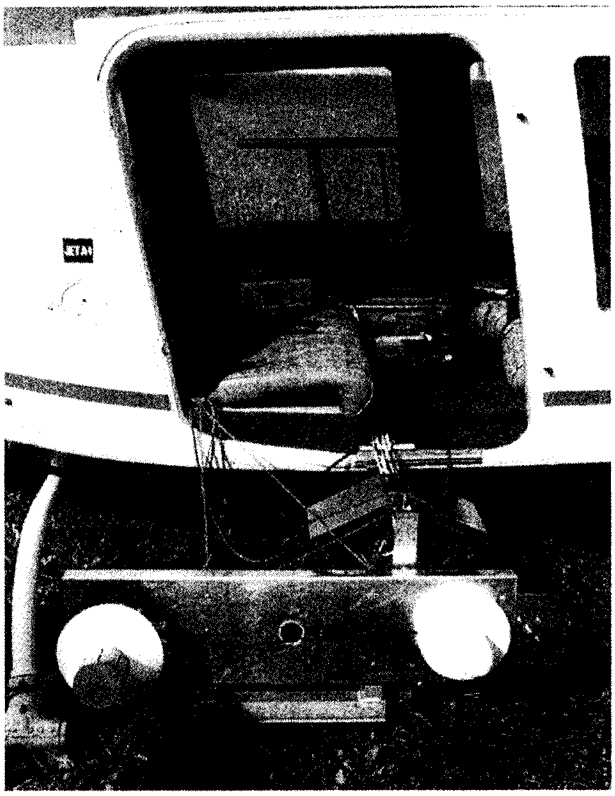


Fig. 4: Helicopter simulating the space segment for test of the LMBT.
Transmitter and monitoring equipment reside in the interior, besides and on the back seat, while the L- and S-band transmit antennas are located outside, on a plate which can be tilted 90 deg down so that antenna axes are pointing vertically to the ground. A 12-channel GPS receiver in combination with a vertically pointing video camera is used for accurate helicopter position determination during the measurement ride.

no direct follow-up in form of a serial product that was close to market demands, the project was obviously not considered to be of high priority. The main benefit for RESCOM was apparently the fact that they gained knowledge in dealing with wide-band applications at L- and S-band that may become important in future projects (like in the development of equipment for UMTS).

3. SQPCS

A further example for an industrial / scientific relationship in this area is a project called 'Service Quality Assessment for Ka-band Satellite Personal Communications' [10]. In current satellite communication systems (mainly in L-band) the propagation parameters are considered as being just constant values in the link budget calculation. The general concept in nowadays systems is to have a geostationary satellite and a moving receiver and the channel has a rather small bandwidth. Future systems, e.g. UMTS, TELEDESIC, EURO-

SKYWAY, will have a much higher bandwidth with different quality requirements for the various services (IP over satellite, voice, video-on-demand, messaging and rescue services, ...). The conventional way to assess the service quality of a satellite based communication system is to use the so called nominal bit error rate (BER) as a single threshold. If the system has a bit error rate that is less than the system's nominal threshold for a requested percentage of time (e.g. 99 % of a year) is considered as working ok, otherwise it fails.

In this project the system hardware and signal conditioning/processing simulation was combined with a time varying propagation channel that was obtained by performing rather complex propagation simulation being close to real world situations. These simulations include ray tracing algorithms applied to virtual cities (as illustrated in Fig. 5) in which the receiving mobile terminal is travelling around as well as Low-Earth-Orbit satellite constellations needing to consider switching between satellites. The results of this propagation simulation are fed to hardware simulations where different coding schemes can be tried. The simulation then results into a time series of bit errors that can be analysed with respect to the different block sizes and block distributions of the various services.

The team working on that project is made up by ALENIA (Italy) as the industrial partner that has a direct interest in these aspects (EUROSKYWAY is a project run by ALENIA), two consultants from Universities (University of Vigo in Spain and the Politecnico di Milano in Italy) and is led again by IAS.

The work is split such that ALENIA's responsibility lies in the implementation of the hardware simulation where they have a rather extensive experience and in assisting the scientist in the project by keeping them in line such that the test cases used in the project are as close as possible to near future real applications. On the other hand the scientists in the group had to press rather hard in getting the support for the test cases without short term benefit for ALENIA (i.e. CDMA systems).

4. Contributions to GALA

A third example for industrial/science partnership is the project GALA funded by the EU with Alcatel as a prime contractor [11]. The consortium consists of about 80 companies that are all working on system design aspects of the European satellite navigation project GALA. IAS's part in this project is being a subcontractor to Alcatel, working in close relationship with ASTRIUM to provide simulation software for the propagation channel to be used in ASTRIUM's hardware simulator. The effects that need to be simulated are ionospheric and atmospheric attenuation and delay in their long- and short-term behaviour. Furthermore the situation needs to be classified in terms of average, best or worst conditions. In order to supplement IAS's know-how consultances were made with the Institute of Communications and Wave Propagation of the Technical University of Graz. This concerns in particular modelling of ionospheric effects, like total electron content (TEC) and scintillation (index S4, see Figs. 6 – 8).

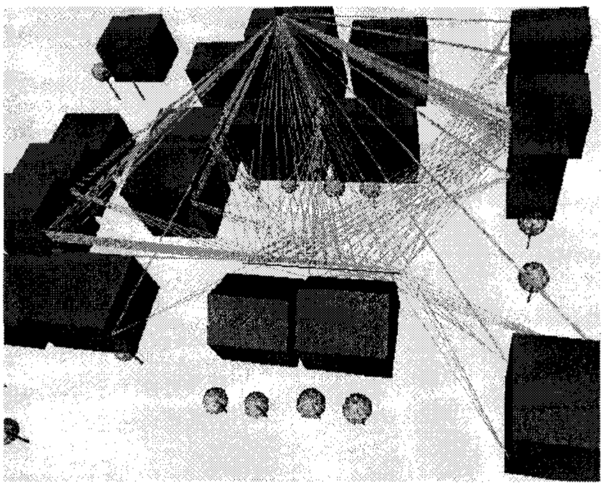


Fig. 5: Virtual city with radio signal rays originating from a single transmitter (black point in the upper center), illustrating the complex propagation situation to be expected for mobile communications in such or similar environment. Impairments include shadowing, blockage, reflection, diffraction and resulting multi-path (discrete delay dispersion).

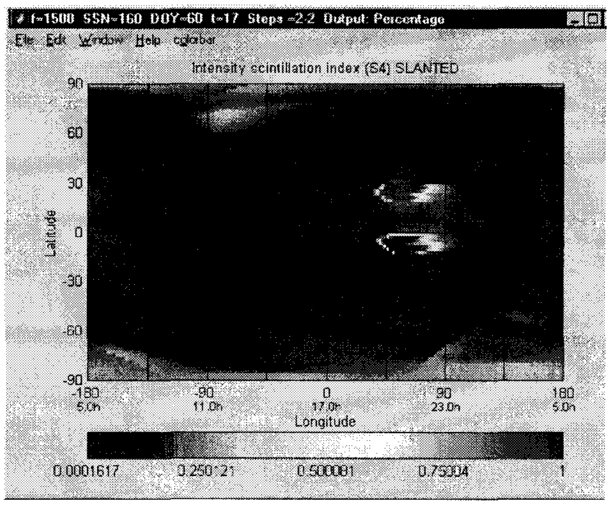


Fig. 6: Ionospheric Scintillation index (S4) for an oblique path through the ionosphere with variable local times (17.00 at the Greenwich meridian). It is seen that scintillation intensity changes with time of day. The largest scintillations occur shortly after local sunset (approximately 21.00 local time). Such data are needed for characterising amplitude and phase scintillations induced by ionospheric multi-path propagation.

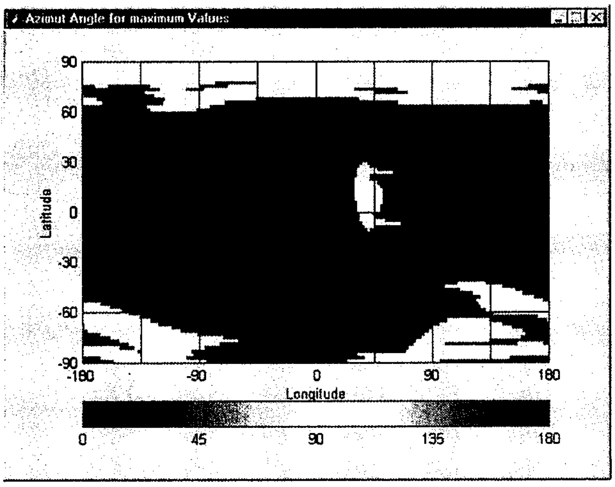


Fig. 7: Link azimuth angles of Fig. 6 where S4 maximises. This figure stresses the need for taking into account link orientation in ionospheric propagation scintillation modelling and prediction.

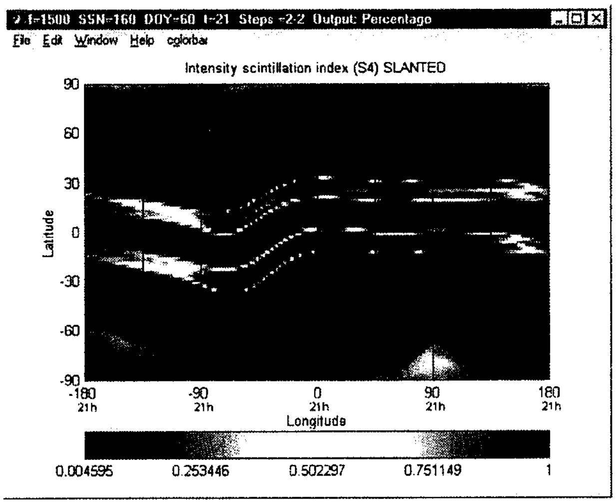


Fig. 8: Scintillation Index S4 for an oblique path through the ionosphere and globally constant local time. One can clearly see two regions of enhanced scintillations on either side of the geomagnetic equator, however changing their latitude position with longitude, which further complicates global models for the influence of ionospheric scintillation on satellite mobile communication and navigation systems.

One of the difficulties in setting up this project – which is still on the way - was in the long discussion needed for clarifying the intellectual property rights. This even had some impact on the timing of the work and the project's rather tight time schedule.

5. Conclusion

Cooperation between industry and academic research units when carrying out space related projects has shown to be a feasible, sometimes the only possible mechanism for bringing together individual competence from different fields, and to merge them to obtain best possible results. The standard situation is that the industry partner is acting as main contractor vis-a-vis ESA or the EU Commission, contributing his experience in organising and managing large projects and efficiently deploying individual tasks to specialised internal sub-units or external partners, usually belonging to the circle of academic research and educational institutions, like universities and research organisations, maybe private or government sponsored ones.

Another mechanism resulting in co-operation between academic research units and industry concern specialised studies issued by ESA or the EU, intended to open new fields of competence and technology. In such projects the contributions of industrial and academic partners are generally balanced. In most of such cases the academic partner overtakes leadership in developing new concepts and ideas, while the industrial partner performs the tasks of technological prototyping and proof-of-concept validation.

During the joint projects described above some difficulties showed up in that it's not always easy to match the partners' time schedules. Industry is used to adhere to rather strictly planned timetables, necessary when reproducing readily developed standard products. On the other side, academic research institutes are sometimes confronted with unexpected difficulties during the inventive and development process, making schedule revisions necessary. But also the reverse situation could be observed, when industry supplied instrumentation needed by the academic part for carrying out experimental campaigns, did not conform to specifications and had to be adapted, causing heavy troubles with the industrial partner's strict time planning.

Another problem area experienced concerns communication, not from a technical point of view, but rather from the semantic aspect. Academic researchers and industrial manufacturers are – dictated by their original intentions and objectives – speaking different languages, needing moderation between. Above described co-operations showed that the optimum in error- and trouble-free exchange of information can be achieved when the industrial partner's delegate himself comes from the research domain.

Altogether, in spite of the problem areas mentioned, co-operation between industry and academic institutions forms an inevitable element in modern technology invention, development and application. This also and especially applies to the field of space or space related research and developments, where many new tasks and requirements can only be mastered by merging competence and experiences from both sides.

Acknowledgement:
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Innovative Technologies and Space Applications (3)

Chairman: N. Jensen, ESA-ESTEC, The Netherlands

MOSES - A MODULAR CCD SENSOR ELECTRONICS FOR SPACE AND EXTREME ENVIRONMENT APPLICATIONS

Harald Michaelis, Thomas Behnke, Matthias Tschentscher,
Hans-Georg Grothues, Ekkehard Kührt, Gerhard Neukum

DLR, Institute of Space Sensor Technology and Planetary Exploration
Rutherfordstr. 2
D-12489 Berlin
GERMANY

Phone:+49(30)67055-364
Fax: +49(30)67055-384
E-Mail: harald.michaelis@dlr.de

Abstract

In the DLR Institute of Space Sensor Technology and Planetary Exploration has been developed the highly integrated space-qualified CCD camera electronics MOSES (**MO**dular **S**ensor **E**lectronics **S**ystem) in very close co-operation with the Tecnotron GmbH, a medium sized German company.

MOSES has been designed to withstand very harsh environmental conditions as they exist in space and in terrestrial areas with extreme environmental conditions. In particular, the electronics can be operated at very low temperatures, less than −150°C. Thus, MOSES is well suited for deep space projects and investigations in the polar regions of the Earth. The highest operational temperature of MOSES is only limited by the dark current behaviour of the integrated CCD detectors. For that reason, MOSES was proposed by US and French space science teams for application with the Solar Probe mission as the baseline of all CCD camera electronics. Compared to other existing concepts, the MOSES sensor electronics consists of interconnected single modules which allow a simple adaptation to very different application requirements without any major (and costly) redesigns. Therefor it is easy to implement a new CCD detector which is best suited for a special application, for example. Also it is very easy to adapt the readout speed or to exchange the signal chain in order to run the CCD camera at a higher radiometric resolution. Moreover, it has been demonstrated that MOSES can be easily adapted to the required digital interface by an internal Field-Programmable Gate Array (FPGA) with an external programming option. The present MOSES cube offers a 14 bit dynamics range with readout rates ranging from 100 ksps to 5 Msps. For the existing and space qualified MOSES-D electronics was used a 1kx1k frame transfer CCD detector from Thomson (THX7888).Two other configurations for application in very high resolution space camera systems are in design presently.

The modules can be folded to a very compact cube (about 50 x 50 x 30 mm^3 in size) or to a customer specified special configuration. The mass amounts to less than 80 to 100 g and the normal power consumption using a 1k x 1k CCD detector is about 2 W.

MOSES provides a very cost effective solution for usually very expensive space camera systems. The electronics can withstand radiation doses of more than 30 krad without degradation in performance. It also can be fabricated for high-performance commercial applications where costs are of more importance than for space projects.

MOSES modules are used in the ROLIS Descent and Downlooking Imager of the Rosetta Lander as well as in the Super Resolution Channel (SRC) integrated in the High-Resolution Stereo Camera (HRSC) developed for the European Mars mission 'Mars Express'.

Furthermore, the MOSES CCD sensor electronics was implemented very successfully in a pilot project for automated early forest fire recognition in Brandenburg/Germany. More details about the technical concept and the applications are going to be presented during the conference.

1. Introduction

The camera group of the DLR Institute of Space Sensor Technology and Planetary Exploration is developing imaging instruments for scientific space missions, ground based astronomy and other space and airborne applications. The key subjects of the group are

- Investigation in new imaging technologies (sensor configurations, imaging concepts, evaluation and specification of new imaging detector arrays)
- conception, design and development of imaging systems for space and ground-based applications
- Investigation and design of high performance sensor electronics (e.g. miniaturisation, harsh environment, low noise, high data rates).

The members of the camera group have an average of over 15 years experience in the design and development of imaging instruments. Examples are the development of sensor electronics for the Cassini mission (DISR) and the imager for Mars Pathfinder (IMP), which were developed in Germany at the Max-Planck-Institute for Aeronomy (led by Uwe Keller). Another example is the development of the High Resolution Stereo Camera (HRSC) at the DLR (led by Gerhard Neukum), which was originally designed for the Mars-96 mission.
One of the present main activities of the DLR camera group is the participation in the Rosetta mission with the VIRTIS experiment (an imaging spectrometer) and the ROLIS imaging experiment.

2. The Concept of MOSES

The idea behind MOSES is to design a high performance CCD electronics which can be used in many space imaging systems with a minimum of redesign. One reason for this approach is to reduce the costs and time of development of new space imaging instruments.
Typically the configuration of a CCD electronics for camera systems has more ore less the same structure as shown in the electronic block diagram in Fig 1:

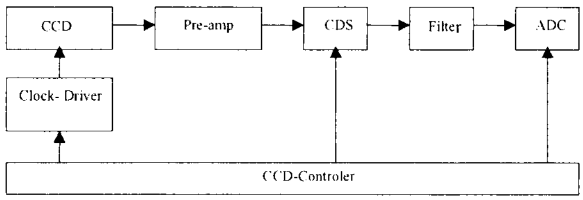

Figure1: Block diagram of the CCD sensor electronics

Therefore we came to the simple idea to implement the different functional units of the block diagram into individual modules and to assemble them into a 3-D stack. The main modules are as follows:

Table 1: The Modules of MOSES

Module	Function	Remarks
1.CCD Module	Focal Plate with CCD, bias, pre-amplifier, DC-decoupling and the mechanical i/f to the optics	depends on CCD (typically between 512x512 and 2kx2k)
2.Clock driver module	set of medium/low impedance clock drivers with TTL/CMOS inputs	medium impedance serial clock; low impedance vertical clocks
3.signal chain	amplifiers, CDS and analog to digital converter	typ. 12 –16 Bit 100 ksps – 1 (1-5) Msps
4.CCD-controller	CCD sequencer (FPGA) and digital data/control interface to the data-processing unit	can be programmed (CCD timing, windowing, readout speed)

We called this concept Modular Sensor Electronics System (MOSES).
In MOSES each of the module has some flexibility like change of the CCD timing according to the specific CCD architecture, change of the readout rate or adaptation to a specific external digital interface.

3. MOSES-D: MOSES for the Descent/Downlooking Imager of the Rosetta Lander

We decided to implement this concept first in the Descent/Downlooking-Imager of the Rosetta-Lander – called ROLIS. This imager is based on a 1k x 1k FT-CCD detector by Thomson (TH7888). In order to get a wide dynamic range a 14 Bit ADC- converter was chosen in the Signal Chain-Module which can run at different readout rates between 100 KSps than 5 MSps. The timing for the CCD and the digital interface to the

DPU is handled by a FPGA, as previously successfully done for the Mars Pathfinder Imager.

3.1. The first breadboard of MOSES

In order to assemble the CCD electronics into a very compact configuration each module was chosen to have the same size. The first breadboard has a dimension of 2" x 2" and the components are assembled by using an inexpensive chip-on board technology with FR4- substrates (standard epoxy PCB). The breadboard is shown in Fig. 2
The electrical interconnection between the modules is achieved by simple pin row connectors, assembled on the board ends as seen in Fig. 2. The big advantage of this approach is that the modules can be tested, repaired and redesigned independently. This 3-D concept was successfully tested and used first in a high performance commercial prototype camera system for automatic fire detection in forests. This technology, however, is not well suited for the ROLIS – Descent/Downlooking-imager because of the extreme environmental requirements of the mission.

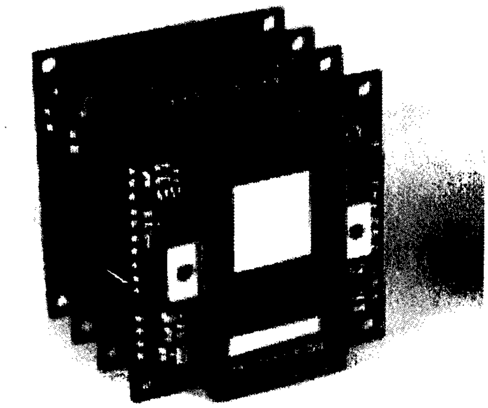

Figure 2: Breadboard of MOSES-D with THX 7888

3.2. MOSES-D for the Rosetta Lander

3.2.1. Technical and Environmental Requirements of ROLIS-D

The ROLIS imaging system has to withstand harsh environmental conditions without major performance degradation. One of the main requirements of ROLIS-D is to survive and operate at temperatures down to about 120°K with minimal power consumption (2 –3 W). The optics has to provide high resolution images at ranges between infinity (during descent) and about 0.3 m (after landing) with a field of view of about 60° and a resolution of 1 mrad (1mm/pixel at 1 m distance). After landing, multispectral images have to be taken in at least 4 spectral channels (red, green, blue, NIR). Furthermore the instrument has to survive the cosmic radiation environment during the long cruise to comet Wirtanen (8 years) without the possibility of heavy radiation shielding due to the mass budget of less than 400 grams. The main technical requirements are summarised in Table 2:

Table 2: Technical Requirements of ROLIS-D

Item	Spec
Resolution (IFOV)	1 mrad/pix
Field of View (FOV)	1 rad (60° x 60°)
Focus	adjustable (infinity, close up)
Depth of Focus	≈ +/- 100 mm @ 300 mm
Multispectral Imaging	(≥4): red, green, blue, NIR
high dynamic range	> 80 dB
good SNR	100 (low noise)
low mass	400g (incl. Electronics)
low power	≈ 2 W
low temperature operation	≈ 150°K
simple el. Interface, low thermal conductivity	no separation between detector and detector electronics
protection	against radiation (30 krad at 1 mm Al), dust, condenses

The board and interconnection concept finally selected for ROLIS is based on a rigid-flex 3D-interconnection between the boards. Each of the board-modules consists of a specific layer structure with Molybdenum layers incorporated in the prepreg (polyamid-glass). This technology enables the operations of the electronics at temperatures down to less than 120K without stress on the components. The final board configuration is shown in Fig. 4.

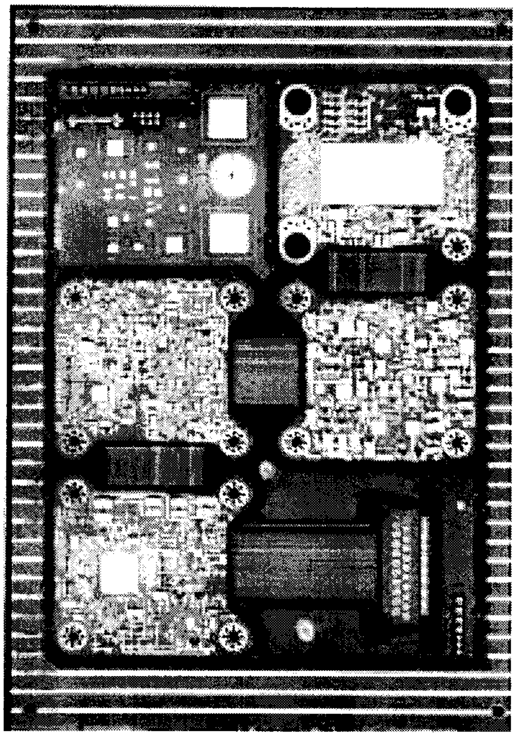

Figure 3: The MOSES 3-D detector electronics in unfolded configuration (module size:48x52 mm², weight:10g)

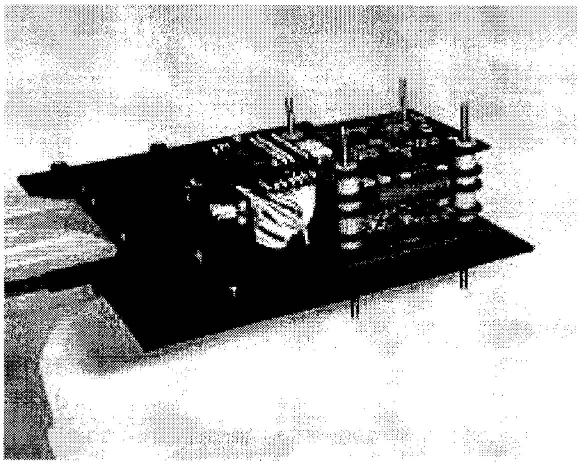

Fig.4: MOSES folded and integrated with an additional controller (MICE- motor and LED- controller)

After final integration of the first engineering unit of the ROLIS-D the camera was tested from very low temperature of -160°C to about +80°C with many cycles. Another critical item was the test with condensed material as snow. This test was also successfully performed as shown in Figure.5.

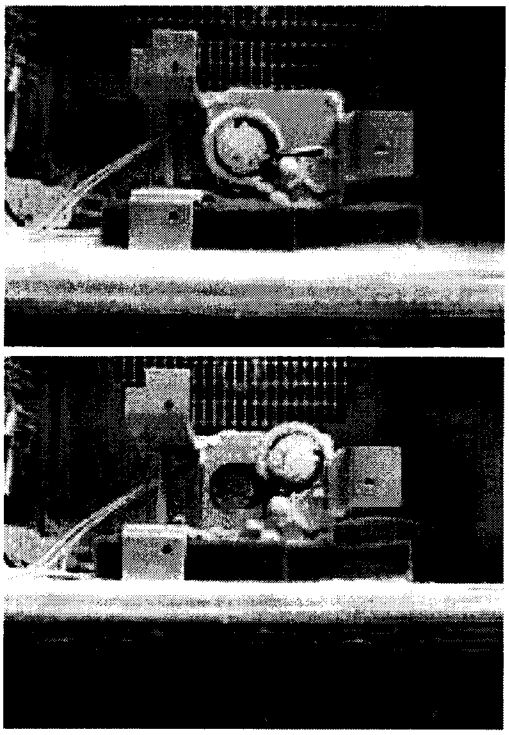

Figure 5:ROLIS-D excenter mechanism with IFL closed (above) and opened (below) during an icing test

3.2.2. The Performance of MOSES-D

With application of limited resources concerning mass, volume, power, and the requirement of high reliability of components for space instrumentation we obtain the following key parameters of the MOSES electronics for the ROLIS imager:

Table 3: Measured Performance of MOSES-D with THX7888

Parameters	**Value**	**Remarks**
Pixel readout time	3.2 µs	
Resolution	14 bit	
Total noise in darkness	13 e⁻ rms	@200°K
CCD noise	12 e⁻ rms	@200°K
Electronic noise	5 e⁻	
Responsivity	7 µV/e⁻	
System gain	20 e⁻/DN	
Dark current	1700 e⁻/sec 1100 e⁻/sec 2000 e⁻	Image section @ 10°C Memory section @10°C Serial register
Antiblooming control	Yes	
Peak QE	18%	with THX7888

The first engineering unit of the ROLIS imager is shown in Fig. 6.

Figure 6: The ROLIS-D STM unit with infinity lens closed

4. Examples of MOSES-Applications

According to our experience MOSES can be used in a lot of space applications and even in commercial camera systems where high performance is required. Before the MOSES electronics for the ROLIS imager was completed it has been possible to implement the MOSES electronics into a new commercial prototype camera 'AWFS'. AWFS is a CCD-camera system for automatic fire detection e in forests . The AWFS prototype has the same MOSES-configuration as used in the first breadboard (see Fig. 7).

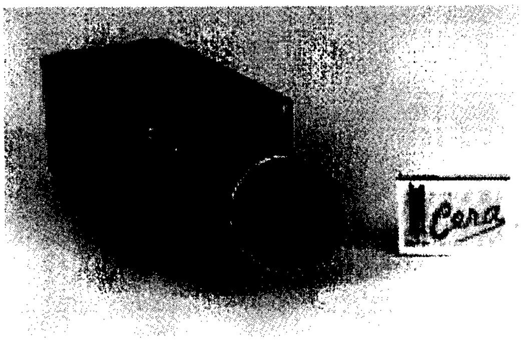

Figure 7: The AWFS, camera with MOSES

In AWFS the MOSES camera electronics was assembled in a rotating digital camera with a special filter and an innovative software. The AWFS-camera was installed and tested on three observation towers in Brandenburg, Germany, during the 1999 forest fire season. It became apparent that the main requirement for absolute reliable smoke detection was met. The false alarm rate due to weather and harvest activities commonly remained below 1%, which is well acceptable. Other improvements will be effective soon. The testing forest authority confirmed that the system is mature for service and easy to use. The number of systems will be increased therefore. Moreover, other German states and some European countries are very interested in this technology.
Another example is the application of MOSES in high resolution space imaging systems. We have submitted s proposals to both, ESA and NASA for the application of MOSES for high resolution imager called SRC. In SRC, MOSES will operate with another CCD and at higher readout rates up to 4 Msps. One SRC imager is shown in Fig.8.

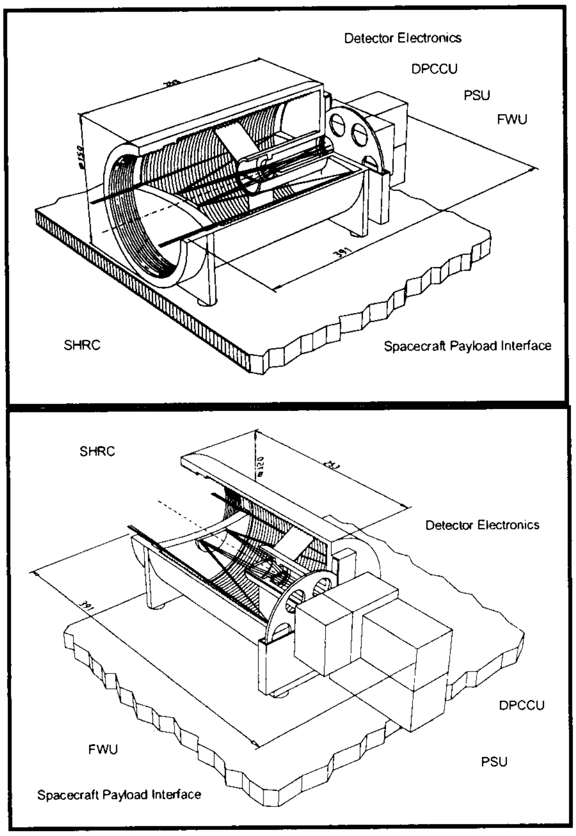

Figure 8: Super High Resolution Camera with MOSES

Furthermore, it is confirmed to implement the same MOSES based high resolution imager as the super high resolution channel of the High Resolution Stereo Camera (HRSC) for the European Mars-Express mission (ESA). In this imager MOSES will be used with a Kodak CCD- detector for very short integration times and better QE. The proposed imager is shown in Fig. 9 together with the HRSC- camera.

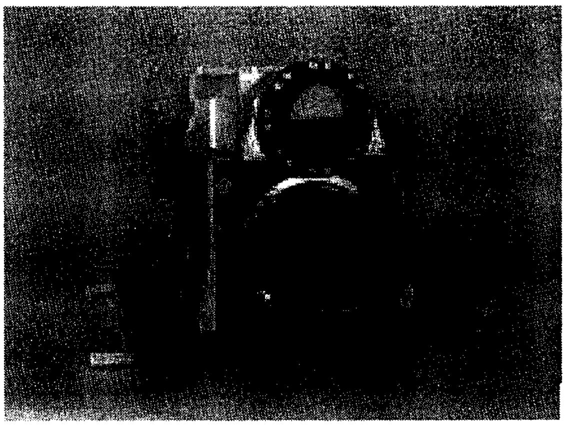

Figure 9: The SRC channel of the HRSC-camera

5. Summary

A modular 3-D CCD electronics – called MOSES - has been developed for the Rosetta Lander Imaging System ROLIS. The MOSES electronics has been designed to withstand harsh environmental conditions. The parameters of MOSES have been characterised and show very good performance at low power consumption. The MOSES concept enables high flexibility and the adaptation to specific instrument requirements in a cost-effective way. The MOSES electronics can be used in many space applications and even in commercial camera systems where high performance is required.

Acknowledgement

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INNOVATIVE X-RAY OPTICS DEVELOPMENT

René Hudec[1], Ladislav Pína[2], Adolf Inneman[3], Zbyněk Melich[4]

[1]*Astronomical Institute, Academy of Sciences of the Czech Republic, CZ-251 65 Ondřejov, Czech Republic*
(Phone 00420 204 620128, Fax 00420 204 620110, email rhudec@asu.cas.cz)

[2]*Czech Technical University, Faculty of Nuclear Sciences, Prague, Czech Republic*

[3]*Reflex s.r.o., Novodvorska 994, 142 00 Prague 4, Czech Republic*

[4] *Optical Development Workshop, Turnov, Czech Republic*

ABSTRACT

We report on the program of design and development of innovative X-ray optics for space applications in the Czech Republic. Having more than 30 years background in X-ray optics development for space applications (for use in astronomical X-ray telescopes onboard spacecrafts, before 1989 mostly for Soviet and East European INTERKOSMOS program), we focus nowadays on novel technologies and approaches such as very wide field X-ray optics of Lobster Eye type, thin shell replicated mirrors, as well as studies of light-weight mirrors based on innovative materials such as ceramics. The collaboration includes teams from the Academy of Sciences, Universities, and industry. We will describe and discuss both the history of the development of X-ray optics in the Czech Republic and the developed technologies and approaches as well as recent activities and developments including our participation on the ESA XEUS mirror technology development based on the Agreement between ESA and Czech Government.

1. INTRODUCTION

Major scientific achievements of the last two decades of X-ray astronomy are closely related to the use of imaging X-ray telescopes. These telescopes achieve much better signal/noise ratio than X-ray experiments without optics - this allows e.g. the detection of faint sources. The use of X-ray optics further allows imaging, precice localization, photometry, spectroscopy, variability studies, and estimation of physical parameters of X-ray emitting regions (temperature, electron density...). The space experiments with X-ray optics are also well suited for monitoring of X-ray sky for variable and transient objects including X-ray novae, X-ray transients, X-ray flares on stars and AGNs, galactic bulge sources, X-ray binaries, SGRs (Soft Gamma Ray Repeaters) and X-ray afterglows of GRBs (Gamma Ray Bursts). The X-ray optics represent an important part of numerous past, recent, and future space projects (EXOSAT, ROSAT, Einstein, RT-4M Salyut 7, Fobos, AXAF, XMM, ABRIXAS, BeppoSAX, ASCA, XEUS...). In the laboratory, there are numerous applications of the X-ray optics e.g. in plasma physics, laser plasma, biology, crystallography, medicine, etc.

We report on the development of X-ray optics in the Czech Republic. Based on 30 years of experience and on wide cooperation between Academy, Universities, and industry, we focus nowadays on development and design of innovative X-ray optics prototypes such as very wide field X-ray lenses, double sided reflecting flats, micromirrors, as well as on light-weight materials for future applications. The development and the Academy-industrial collaboration is supported by several grants provided by the Czech government and by the Grant Agency of the Czech Republic. In July 2000, an Centre for advanced X-ray technologies has been established at Reflex Prague, supported by the Ministry of Industry and Trade of the Czech Republic. Based on the collaboration agreement between the ESA and The Czech government, we also concentrate on participation on future ESA scientific satellite projects such as XEUS. The participation in recent and future ESA space programs is also expected to be further supported by the participation of the Czech Republic in the Scientific Experiment Development Program (PRODEX) of the ESA (since June 2000).

2. THE VARIOUS TYPES OF X-RAY OPTICS

According to the physical processes involved, one can divide the X-ray optics into the following groups:

- diffractive optics (Fresnel lenses + pinholes): not useful for space due to small apertures
- refractive optics: limited use, not useful for space
- reflective optics, based on total reflection (grazing incidence)
- reflective optics, based on normal incidence (multilayers)

In this paper, we will concentrate on reflective X-ray lenses (mirrors).

Wolter optics: The Wolter type optics[1] is in wide use in space-borne X-ray astronomical experiments (ROSAT, EXOSAT, Salyut 7, Fobos, XMM, AXAF..). It is based on double reflection on two surfaces (requirement for a superior imaging – the Abbe sine condition). Depending on the combination of surfaces, there are various modifications (Wolter I, II, III types), mostly used is the Wolter I type (paraboloid + hyperboloid).

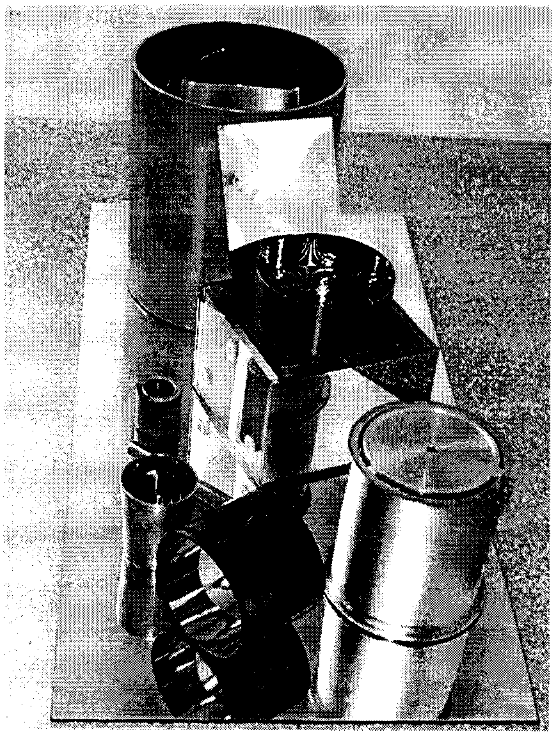


Fig. 1: Replicated grazing incidence X-ray optics developed by the Czech Academy-University-Industrial collaboration

Double-cone approximation of Wolter optics: The Wolter surfaces can be approximated by less laborious and hence less expensive conical profiles. These mirrors have lower imaging quality but in many cases larger collecting area since the conical shells can be made very thin. These mirrors usually represent high throughput systems, and can be preferably used in foil telescopes (SODART).

Conical, ellipsoidal and paraboloidal optics: These mirrors with only one reflection find most of their applications in the laboratotry either as collimating or focussing and/or imaging elements.

Kirkpatrick-Baez optics: This configuration is used mostly in experiments not requiring large collecting area (solar, laboratory). Recently, large modules of KB mirrors have been suggested also for stellar X-ray experiments[2].

Normal incidence optics: This optics requires the multilayer deposition on the mirror surface allowing its use under normal incidence. The use of multilayers results in narrow spectral range, and in the past has been used mostly in solar experiments (TEREK Fobos, TEREK KORONAS...) as well as in laboratory applications.

Lobster-eye optics: This optics has been suggested in 70ies for very wide field X-ray imaging but not yet used in space mostly due to severe manufacturing problems. Recently, the first test modules are available for both the Schmidt as well as for the alternative Angel configurations[5].

The development and manufacture of various types of reflective X-ray optics are heavily affected by manufacturing problems, making their production laborious and hence expensive. The most dominating problems can be summarized as follows: (1) the required microroughness is < 3 nm, in many applications however < 1 nm, (2) the X-ray optics is frequently represented by hollow inner surfaces, and (3) there are very strict requirements on the slope errors and shape deviations.

3. THE REPLICATED X-RAY OPTICS

3.1 EARLY STAGES

The early stages of the X-ray optics developments in the Czech Republic are closely related to the INTERKOSMOS Space Programme (Soviet and East European equivalent of ESA operated until 1989). All of the X-ray imaging telescopes onboard Soviet spacecrafts were equipped with the Czech X-ray optics (exception: X-ray normal incidence mirrors in the special channel of the TEREK telescopes onboard the Fobos and Koronas spacecrafts). Later on, also the laboratory applications have started. In almost all cases, replicated grazing incidence mirrors of various geometries, types and arrangements have been designed and developed. The replication technology proved to be powerful tool in solving numerous and various different problems and demands.

- 1969 first considerations started
- 1970 first X-ray mirror produced (Wolter 1, 50 mm)
- 1971 Wolter 1, 80 mm
- 1976 Wolter 1, 115 mm
- 1979 first mirrors flown in space (two Wolter 1, 50 mm, Vertikal 9 rocket)
- 1980 Vertikal 11 rocket (two Wolter 1, 50 mm)
- 1981 first large Wolter 1 mirror (240 mm)
- 1981 Salyut 7 orbital station, RT- 4M stellar X-ray telescope (Wolter 240 mm, double nested objective)

- 1985 applications for plasma physics, EH 17 mm, PP 20 mm
- 1987 first high quality X-ray foils for foil mirror X-ray telescope (SODART)
- 1988 Fobos 1 Mars probe, TEREK X-Ray solar telescope
- 1989 KORONAS I X-Ray mirror, Wolter 80 mm
- 1990 first micromirror (aperture less than 1 mm)
- 1993 collaboration with SAO, USA, WF X-Ray optics started
- 1996 first Lobster Eye test module produced, Schmidt geometry
- 1997 Lobster Eye Angel geometry project started
- 1999 first Lobster Eye test module produced, Angel geometry

Total number of X-ray mirrors produced: more than 50
Total number of mirrors flown in space: 8
Total spacecrafts with Czech X-ray optics: 4
Total number of space experiments with Czech X-ray optics onboard: 8

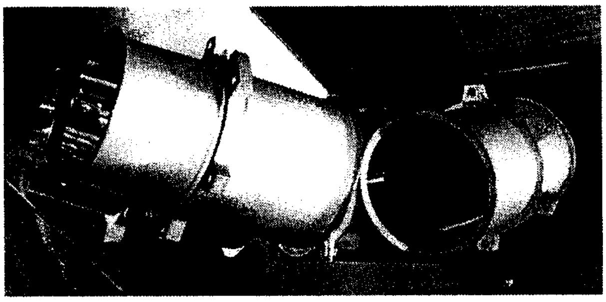


Fig. 2: The Wolter 1 X-ray mirrors for the KORONAS satellite, 1989.

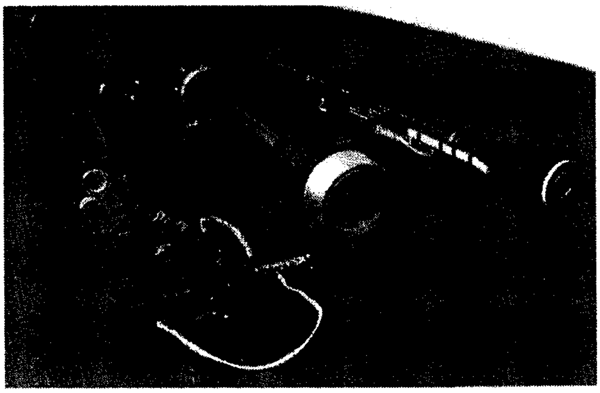


Fig. 3: The three inner channels (from left to right: EUV channel, X channel, coronagraph channel) of the TEREK X-ray telescope and coronagraph, Fobos 1 spacecraft, 1988.

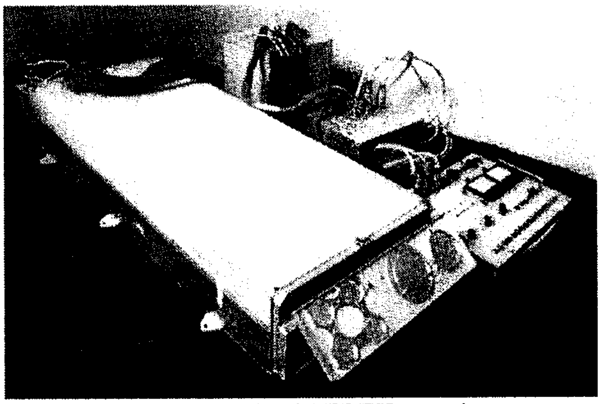


Fig. 4: The assembled TEREK experiment.

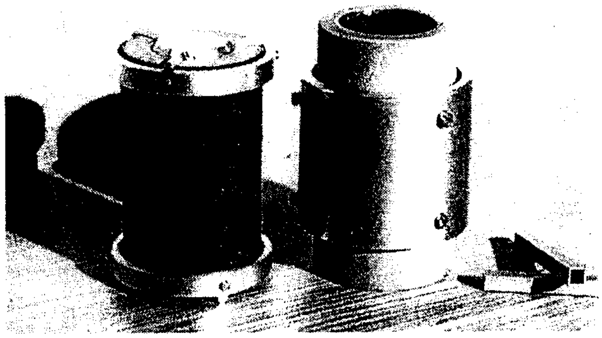


Fig. 5: Microscopic X-ray mirrors (from the left to the right: EH 17 mm, PP 20 mm, Lobster test channels)

3.2 TECHNOLOGIES

The mirrors have been produced by various replication technologies:

- 1970 Heavy Replica Technology: heavy electroforming of X-ray mirror shells from polished glass masters, wall thickness 5-10 mm
- 1978 Replica Epoxy Technology tested: epoxy replication of gold evaporated glass masters
- 1980 Replica Epoxy Electroforming Technology: thin electroformed shells reinforced by epoxy
- 1981 as above but carbon fibre filling involved
- 1982 super-thin test Wolter shells for hight throughput telescopes
- 1983 flat master replication: production of X-ray reflecting foils for foil X-ray telescopes (SODART, RENTGEN SPEKTR GAMA)
- 1990 first micromirrors (aperture ~ 1 mm) produced
- 1993 first double - sided replicated flats for Lobster telescopes of Schmidt type
- 1998 first replication of Angel geometry Lobster Eye cells

3.3 REPLICATION TECHNIQUE

The idea of replica technology is to create perfect copy of negative shaped master and of smooth surfaces. This is very suitable if the negative shape is easier to be produced.
The two main advantages of the replication in X-ray optics design and construction are as follows:

- the production of negative shapes is less laborious
- the produced shells may be much thinner than is possible with classical technologies (important for light-weight high throughput nested arrays)

The replication by electroforming has been used in the Czech Republic for development and production of X-ray mirrors since 1967. Since then, the technology has been further developed and modified. A number of modifications exist, meeting different demands. The replication is perfectly suitable for the production of X-ray grazing incidence optics since external surfaces can be much easily grinded and polished than inner cavities (especially in the case of small apertures). The masters are of high quality optical glass, glass ceramics or metals. It should be noted that the replication technology in X-ray optics is applied by different groups in various different modifications.

3.4 CHARACTERISTICS

The basic characteristics of by electroforming replicated X-ray mirrors can be summarized as follows.

- Reflecting surfaces: electroformed Ni, or electroformed Au, or evaporated/sputtered Au. Other materials are also possible as well as additional coatings.
- External surface-structure: metallic (Ni), or CF/epoxy, or sandwich.
- Parameters: the mirrors are polychromatic from 10 keV to optical wavelengths. They have a high reflectivity, up to 90% depending on the wavelength and the grazing angle (e.g. 60% at 0.83 nm and 1 deg incidence angle). The mirrors have smooth surfaces analogous to surfaces of masters. Thickness uniformity is of order of 2%.
- Additional technologies: multilayers may also be applied to achieve better energy coverage (hard X-rays up to 100 keV). Superpolishing and/or surface quality improvements by lacquer coating are also possible.

3.5 ADVANTAGES

The replicated X-ray mirrors have numerous advantages which can be summarized as follows.

- Wide variety of geometries is possible: Wolter I, II and III systems, conical, ellipsoidal, paraboloidal, flats etc.
- Light-weight and thin shells are possible. This is important for high throughput X-ray optics (nested arrays with many shells) and for space applications in general.
- Multiple replication of identical elements is possible, minimizing the price of final mirrors.
- There is no need to grind and to polish small inner cavities - negative shapes are to be polished
- There are almost no aperture limits including both very small (below 1 mm) and very large (more than 500 mm) apertures
- There is large number of various applications
- The surfaces are resistant to space and/or laboratory environment (cleaning possible, no heat degradation)
- The replicated Au surfaces are more smooth than evaporated surfaces

3.6 SUMMARY OF X-RAY ASTRONOMICAL MIRRORS PRODUCED

Approximately 50 mirrors have been produced between 1970 and 1999 as well as numerous tests for technology purposes:

- Wolter 1 mirrors for space applications, apertures 40 to 240 mm. They have been used onboard satellites as imaging elements in X-ray solar and stellar telescopes .
- Bent foil mirrors/flats foils. X-ray reflecting foils produced from float glass masters with sizes up to 300 x 400 mm. Thickness homogenity better than 2%. Wide range of foil thickness from a few microns up to 1 mm. Designed for the SODART foil X-ray telescope and analogous projects.
- Lobster-eye wide-field X-ray optics, Schmidt geometry, various modules, size of the flats 80 x 100 mm and 23 x 23 mm.
- Lobster-eye wide-field X-ray optics, Angel geometry, various test modules, a/L (aperture/length) ratios of about 50-80.

3.7 SUMMARY OF LABORATORY MIRRORS PRODUCED

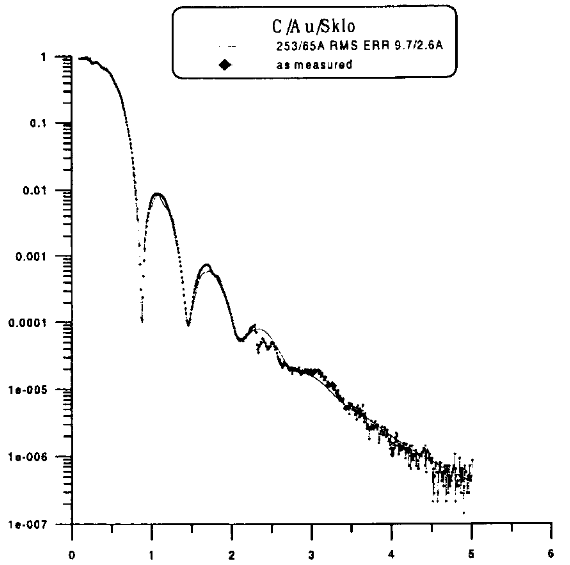
The replication technology has also been applied in numerous ground-based and laboratory applications which are listed below.

- PP (paraboloid-paraboloid) microscopes, aperture 20 mm
- EH (ellipsoid-hyperboloid) Wolter microscopes, aperture 17 mm
- Conical, ellipsoidal, paraboloidal mirrors
- Micromirrors of conical, ellipsoidal, and paraboloidal profiles
- Foils including those for foil X-ray telescopes
- Flat and bent mirrors

4. RECENT AND FUTURE ACTIVITIES

4.1 LOBSTER-EYE WIDE-FIELD X-RAY TELESCOPES

The widely used Wolter objectives have a very limited FOV (typically of order of 1 degree or less) so they are suitable for pointed observations but not for monitoring and surveys. The wide-field X-ray optics has been suggested in 70ies by Schmidt (orthogonal stacks of reflectors)[3] and by Angel (array of square cells)[4] but has not been constructed yet. With this type of reflective X-ray optics, up to 180 deg FOV may be achieved.



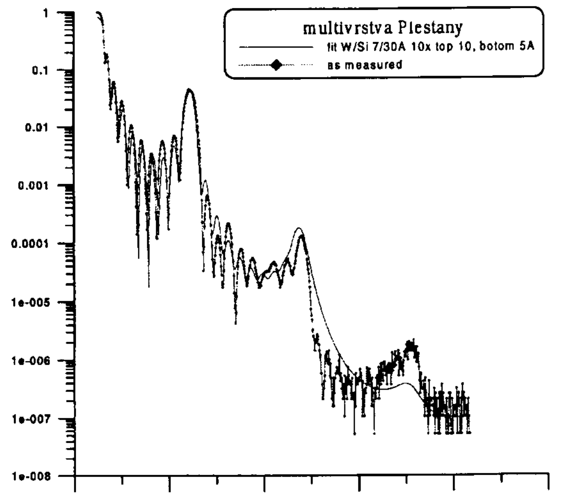


Fig. 6, 7: The X-ray reflexivity measurements for DESAG float glass 0.3 mm thick sample covered by 20 W/Si multilayers (up) and float glass 2.3 mm thick of Czech production (Teplice) covered by C/Au layers (down).

The difficult production of Lobster eye (LE) lenses has caused the significant delay between their theoretical description and their construction and real use. The possible solution is offered recently by the replication technology. Recently, the first Lobster-eye X-ray telescope prototypes have been successfully finished. The prototype of Schmidt geometry represents one module and consists of two perpendicular arrays of double-sided X-ray reflecting flats (36 and 42 double-sided flats100 x 80 mm each). The flats are 0.3 mm thick and gold-coated. The focal distance is 400 mm from the midplane. The FOV of one module is about 6.5 degrees. More such modules may create an array with substantially larger FOV. Improved Schmidt test modules have been finished in 2000 with aperture/length ratios of up to 80, based on 0.1 mm thick gold-coated glass plates spaced at 0.3 mm[5].

For the Angel geometry, numerous square cells of very small size (about 1x1 mm or less at lengths of order of tens of mm) are to be produced. This is much more difficult than the Schmidt arrangement mentioned above. Nevertheless, the recent results indicate that this demand can be also solved by modified innovative replication technology[5].

Three test Angel LE modules have been produced so far: (1) a linear module with 47 cells of 2.5 x 2.5 mm 120 mm long, f = 1.3 m, (2) a 2D module with 6 x 6 cells, dimensions and f as above, surface microroughness 0.8 nm, and (3) a L-shaped module of 2 x 18 cells with parameters as above. Another LE Angel test module is in development: 2D module with 96 x 96 = 9 216 cells 2.5 x 2.5 mm, 120 mm long, f = 1.3 m.

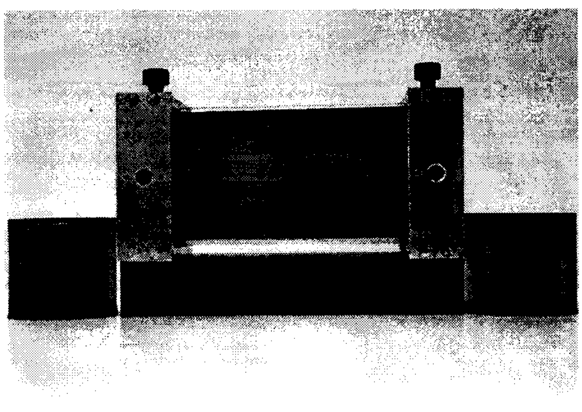


Fig. 8: Lobster-Eye telescope prototypes, Angel(in the center) and Schmidt (left and right) arrangements

The LE X-ray telescopes are extremely important since the discovery of X-ray afterglows of Gamma Ray Burst (GRBs) sources in 1997. The expected rate of GRBs is 1 per day, however the theoretical prediction assumes larger beaming angle in X-rays if compared with gamma rays, hence the actual rate of X-ray afterglows is expected to be substantially larger (nearly

10 x or even more) than the rate of GRBs, hence about 10 X-ray afterglows are expected daily. The sensitivity of LE telescopes is sufficient enough to detect the recently discovered X-ray GRB afterglows. It should be also noted that the localization accuracy of the LE telescopes is of order of 1 arcmin, substantially exceeding the recent localization accuracy of most gamma ray instruments (2 deg and more). It is hence obvious that the LE telescopes are expected to provide a substantial contribution to the science and statistics of GRBs. The additional science of LE X-ray telescopes includes supernova explosions, high energy binary sources, AGNs, blazars, X-ray novae, X-ray transients etc.

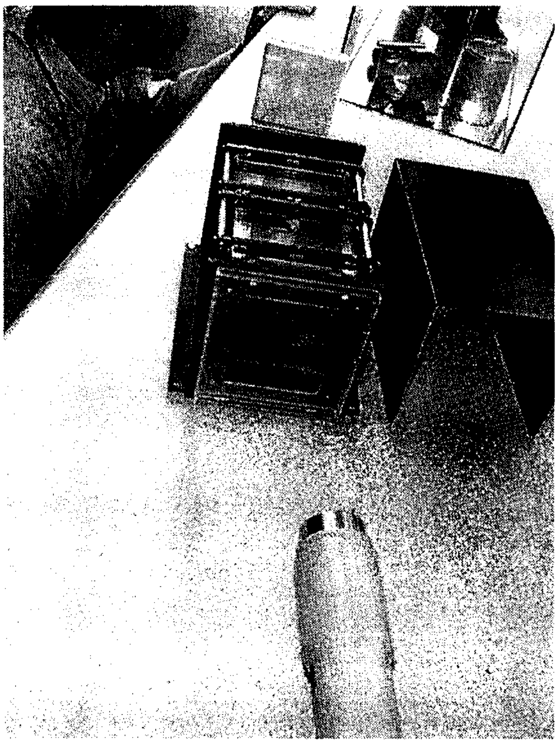


Fig. 9: Schmidt X-ray telescope prototype illuminated by laser beam

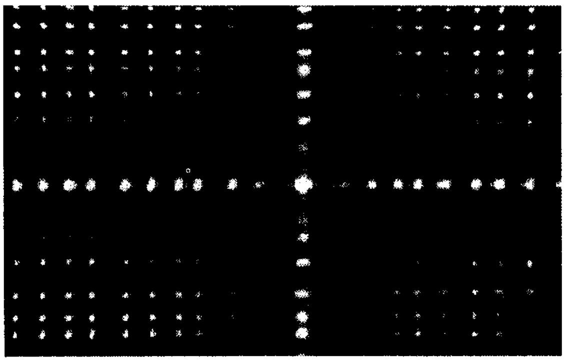


Fig. 10: Optical image of distant point-like source imaged by a Schmidt telescope prototype (image area 8.6 x 6.5 mm)

4.2 LABORATORY X-RAY OPTICS

Numerous applications exist for the replicated reflective X-ray optics e.g. in the plasma physics, nuclear fusion, biology, crystallography etc. with various geometries and arrangements with apertures below 20 mm and, in some cases, even below 1 mm[6]. Examples: micromirrors, PP systems, EH systems, Wolter mirrors, X-ray microscopes. Recently, micromirrors are in development for the X-ray laboratory experiment onboard the International Space Station / SS (protein crystallography).

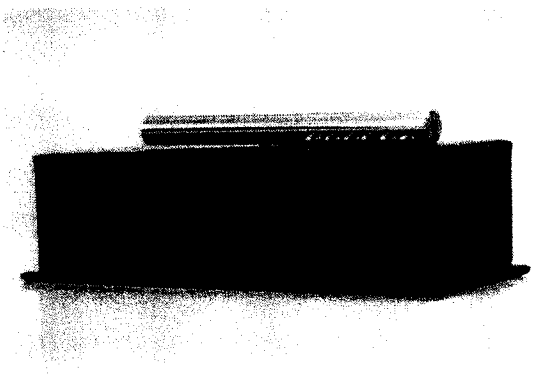


Fig. 11: X-ray micromirror

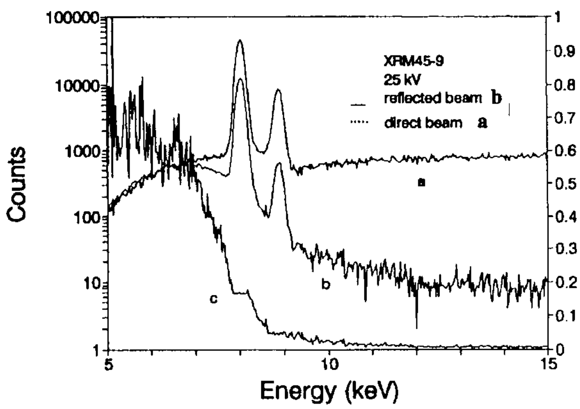


Fig. 12: X-ray reflectivity measurement of X-ray micromirror

4.3 XEUS

Based on our experience in innovative X-ray optics development, we have been invited to participate in development of new technologies related to the ESA XEUS X-ray mirror modules. The goal is to develop technologies for high quality mirror shells with improved mechanical stability, reduced wall thickness, and resulting decreasing weight.

At moment, we have developed first bended test gold coated reflecting flats. They are replicated from high quality float glass masters. We are also work on the design of mirror system based on thin (100 microns) shaped glass plates. The further activities focus on study of fully new techniques and technologies such as replication of light weight ceramics as well as production of light mirror shells based on amorphous metals and/or glossy metals. New collaborating institutes and industrial firms (e.g. The Institute of Plasma Physics of the Academy of Sciences of the Czech Republic, and the High School for Chemistry and Technology in Prague) have been contacted in the Czech Republic, with extended background and experience in the above mentioned technologies. They are joining our collaboration now, bringing new ideas and experience on new innovative technologies and their applications in advanced X-ray optics development. We expect that the first test mirrors/shells based on this extended collaboration will be available by the end of the year 2000.

5. DISCUSSION

The extended Academy-University-Industrial cooperation described in this paper is based on long experience in technologies related to the design and development of X-ray optics. The recent activities focus on development of innovative X-ray optics and new technologies.

The basic activities described in this paper are related to the replication technology. The (replicated) grazing incidence X-ray optics shows some advantages if compared with other types of X-ray imaging and focussing elements which can be summarized as follows:

- Wide energy range (no narrow window)
- Large collecting area
- Resistant to heat and other environment influences
- High reflectivity, over 90% depending on the grazing angle
- Wide field systems are possible
- Cost-effective production
- Arrangements are possible which could hardly be effectively produced by classical methods such as thin and multiple shells, multiple and nested arrays etc.

The grazing incidence X-ray optics is in use within space experiments already for 30 years. Despite of this, some innovative types of the X-ray mirrors are still in the development phase. Moreover, the requirements for future missions are much higher than for those in the past so new and innovative technologies are necessary. The future of astronomical grazing incidence X-ray optics can be briefly summarized as follows:

- segmented large aperture mirrors (e.g. XEUS)
- high throughput optics/very thin light-weight shells
- wide field imaging systems, FOV >> 1 deg
- better surface quality (< 1 nm), reduced slope errors, arcsec angular resolution, new technologies
- better spectral coverage – multilayers and other additional layers, imaging in hard X-rays up to 100 keV

For laboratory applications, improved imaging quality and superior angular resolution (X-ray microscopes) are required.

These needs require innovative technologies for the future:

- superpolishing: to achieve superior angular resolution and high efficiency
- application and/or replication of multilayers: to achieve a better spectral coverage (for hard X-rays, up to 100 keV)
- improving the surface quality: to achieve superior angular resolution and high efficiency
- innovative measuring techniques
- very large apertures: to achieve high detection sensitivity
- very wide-field of view systems: to achieve WF X-ray monitoring of the sky
- very large collecting areas: to achieve high sensitivity

ACKNOWLEDGEMENTS

The development of innovative X-ray telescopes is supported by the grant 105/99/1546 provided by the Grant Agency of the Czech Republic. We further acknowledge the support provided by the ROTAN Laboratory, Physical Institute of the Academy of Sciences of the Czech Republic (X-ray reflectivity measurements), by the Optical Development Workshop of the Academy of Sciences of the Czech Republic (mandrels developments and production), by the X-ray Astronomy group at the University of Leicester, UK and Reflex Prague (X-ray tests of LE telescopes), by the TTS Prague (gold-coating), and by the Astronomical Observatory Brera, Italy (microroughness AFM measurements). The Reflex Prague acknowledges the support provided by the Ministry of Industry and Trade of the Czech Republic within the Project FB-C3/29 „Centre of advanced X-ray technologies".

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DESIGN AND DEVELOPMENT OF MULTILAYER PRINTED REFLECTARRAYS

Jose A. Encinar and J. Agustín Zornoza
Polytechnic University of Madrid
ETSI Telecomunicación, Ciudad Universitaria s/n, 28040 Madrid,
Phone: +34 91 549 5700 Ext. 356, Fax: +34 91 336 7348, e-mail: encinar@etc.upm.es

Abstract

Multilayer reflectarrays, composed of stacked arrays with rectangular patches of variable size are proposed. A progressive phase distribution on the reflector surface is achieved by adjusting the dimensions of the patches. A technique is presented for the designed of dual polarization reflectarrays that yields all the dimensions for the photo-etching mask. A two-layer prototype has been design, built and measured, and a superior bandwidth performance has been verified, compared to conventional single layer reflectarrays. Research is on progress in order to design shaped beam reflectarrays, and to get further improvements in bandwidth by compensating the differential phase delay with the frequency dependence of the radiating elements.

1. Introduction

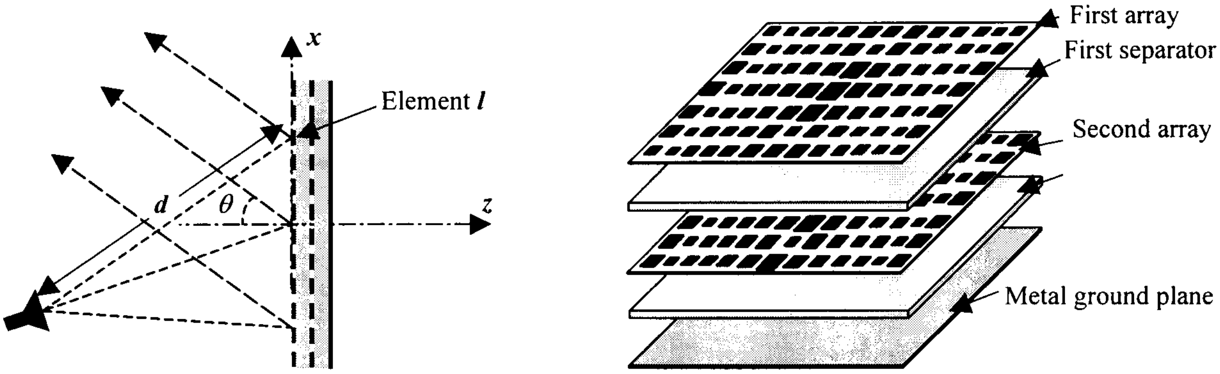
Microstrip reflectarrays are a type of antennas that combine the advantages of reflectors and phased arrays. Reflectarrays are easier to manufacture than reflector antennas and present less distortion and cross-polarisation at the cost of a narrower bandwidth. In addition, reflectarrays can perform several functions that reflectors can not, such as multi-beam, conformal beams or change of polarisation, based on a local full phase control for each polarisation. Comparing to phased arrays, the reflectarray eliminates the complexity and losses of the feeding network and exhibits a higher efficiency.

A printed reflectarray is a planar reflector antenna that consists of an array of microstrip patches on a grounded substrate with a certain tuning to produce a reflected field with progressive phase when illuminated by a primary source, see figure 1(a).

A classical implementation to provide the progressive phase shift of the reflected wave consists of microstrip stubs of different length attached to the radiating patches [1]. The tuning stubs contribute to the dissipative losses, although in a smaller quantity than in microstrip arrays, because the total length is much smaller. The stubs are usually bent to be accommodated in the array, and they produce spurious radiation that degrades the cross-polarisation levels.

The phase control can also be achieved by varying the resonant dimensions of the patches [2], eliminating the losses and cross-polarisation introduced by the stubs. This technique allows simple manufacture, based on photo-etching procedures. However, the phase variation versus size is non-linear and it changes very rapidly with frequency, due to the narrowband of the radiating element. As a consequence, the phase distribution is very sensitive to the manufacture tolerances and to frequency changes, limiting the reflector bandwidth.

The main limitation of reflectarrays is their very narrow bandwidth, less than 5%, which is even reduced for large reflectarrays. This limitation makes reflectarrays not usable for most commercial applications, particularly in space, where large reflectors are required.



(a) (b)

Fig. 1. Two-layer reflectarray with patches of variable size. (a) Reflectarray illuminated by a feed. (b) Multilayer structure.

There are several causes that limit the bandwidth [3]. The more restrictive ones are the narrowband of the radiating elements and the differential spatial phase delay. Usually, microstrip patches on a thin dielectric layer are used as radiating elements, and its very narrowband limits the bandwidth of moderated size reflectarrays.

The differential spatial phase delay is due to the different lengths from the feed to each patch location in the reflectarray. The different lengths produce a different phase delay at each location, which is compensated by the reflection coefficient at the central frequency. Since these lengths can be many multiples of the wavelength for large reflectors, the phase delay varies along the reflectarray in a range of several times 360°, and several zones are required in the reflectarray. Due to the zones limited to a 360° range, the phase delay is only exactly compensated at the central frequency, but there is an error when frequency changes. This error increases, and consequently bandwidth decreases, as the f/D ratio of the reflector decreases. This band limitation is the same that occurs on reflectors with zones, and it is the most restrictive for large reflectarrays with small f/D. To overcome this limitation, the differential spatial phase delay can be compensated locally in the reflection coefficient, either, by eliminating the zones, i.e. using a delay compensation, or by an appropriated variation with frequency of the reflection coefficient phase.

In this paper, an innovative multilayer reflectarray, developed at Polytechnic University of Madrid is described. A patent application has been presented for the reflectarray and its design procedure [4]. The reflectarray is based on a multilayer configuration of patch arrays, where the phase of the reflection coefficient is controlled by adjusting the size of the patches, as shown in figure 1(b). A periodic cell is shown in figure 2 for two layers. This configuration can ameliorate the bandwidth limitations of reflectarrays, by first drastically increasing the bandwidth of the radiating element, and second by compensating the differential phase delay. In addition, using stack patches, a smooth phase variation is obtained that reduces the sensitivity of the electrical characteristics to the manufacture tolerances. The proposed multi-layer configuration can be directly applied to the design of shaped beam reflectarrays [5], and it can be a low cost alternative to onboard conformal reflectors.

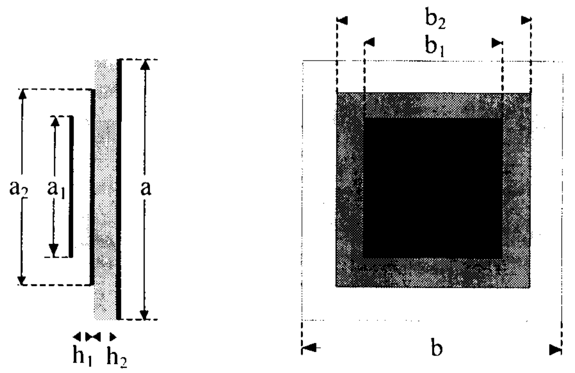


Fig. 2. Periodic cell

2. Multi-layer vs. single-layer reflectarrays

The phase control by varying the patch size is based on the fact that, when a plane wave impinges on an array of resonant patches on a grounded dielectric substrate, the phase of the reflected wave varies when the size of the patches is modified. The modulus of reflection coefficient is equal to one, if there is not grating lobe or surface wave generation, because of the ground plane. In those conditions, the only losses are due to dissipation in the dielectric separator and on the metal patches. Using very-low loss materials, such as foam or honeycomb, the efficiency of the reflectarray can be similar to that of a reflector.

To design a reflectarray, the phase of the reflected wave should have a progressive variation over the whole surface, and this implies that phases in the whole range from 0 to 360° should be used for the reflection coefficient. The phase range to be obtained by varying the resonant length is close to 360° for thin substrates and decreases for thicker substrates. For a thickness smaller than $\lambda/10$, a range larger than 300° can be obtained, which allows practical designs. However, due to the narrow band behaviour of microstrip patches, the reflection phase versus resonant length is highly nonlinear, showing a high slope near resonance and very slow variations near the extremes, as shown in figure 3. Due to the high slope near resonance, the reflectarray is very sensitive to manufacture tolerances. In addition, the reflection phase is very sensitive to frequency variations near resonance and almost

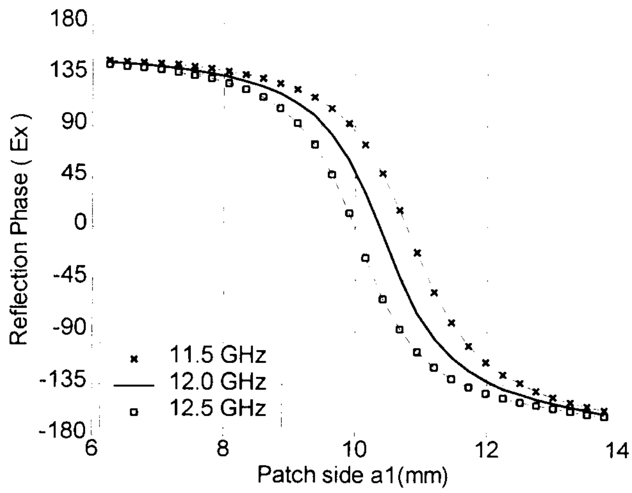


Fig. 3. Phase of reflection coefficient at normal incidence for a periodic array of squared patches on a grounde substrate versus the patch side a_1 at three frequencies (a=14mm, h=1mm, ε_r=1.05).

independent near the extremes. As a consequence, the phase distribution on the surface of a reflectarray with patches of different sizes changes with frequency, producing a very narrow-band behaviour. By increasing the dielectric thickness, a smoother phase variation is obtained, but in that case, the total phase range is reduced to less than 300°, and no practical designs can be achieved.

A smooth phase variation within a range larger than 360° can be obtained by using stacked arrays. An array of metallic patches behaves as a resonant circuit, and the phase range is limited to 360°. By stacking several arrays, a multi resonant behaviour is obtained and the phase range can be several times 360°. Then, the dielectric thickness of each layer can be increased to obtain a smoother and more linear phase variation.

Figure 4 shows the phase of the reflection coefficient, for a periodic structure with two and three stacked arrays of squared patches as a function of the patch size. For a central frequency of 12 GHz, a 14x14 mm period and 3mm thick ROHACELL as separators, a smooth phase is obtained when the patch side on the first array is 0.7 times that on the second array, as shown in figure 4(a). Also, it can be seen that a similar phase variation is obtained at different frequencies, which means an important improvement of the element bandwidth.

For a three-layer structure with patch side on the first and central arrays 0.7 and 0.9 times that on the last array, respectively, a larger phase range is obtained due to the three resonant screens. The phase range greater than 360° that can be obtained with three or more stacked arrays can be used to reduce the number of zones in the reflectarray, and consequently to improve the bandwidth by reducting the error due to the differential spatial phase delay. In addition, increasing the number of layers provides more degrees of freedom in order to compensate the differential phase delay with the frequency dependency of the reflection coefficient by optimisation procedures.

3. Design procedure

To obtain a progressive phase shift for the reflected wave, the size of each array element must be adjusted in both layers, and the periodicity is lost, although the period size is maintained in the whole multilayer structure. The phase of the reflection coefficient is computed independently for each elementary cell, assuming local periodicity. It means that for each cell, a periodic multilayer structure with the dimensions of the particular cell is analysed. Multilayer periodic structures composed of several stacked arrays of rectangular patches and dielectric interfaces over a ground plane are analysed by the technique proposed in [6].

Assuming that the primary fed is located so that the reflectarray is in the far-field region, the phase of the incident wave at each cell is proportional to the distance from the fed and, the required phase of the reflection coefficient to achieve a reflected beam in a given direction θ_0 is determined. To obtain the appropriated phase distribution on the surface of the reflectarray, the dimensions of the stacked patches are adjusted in each cell by a zero search routine, that calls iteratively the analysis routine. For dual polarisation, *x* and *y* dimensions are independently adjusted to obtain the appropriated phase distribution for the *x* and *y*

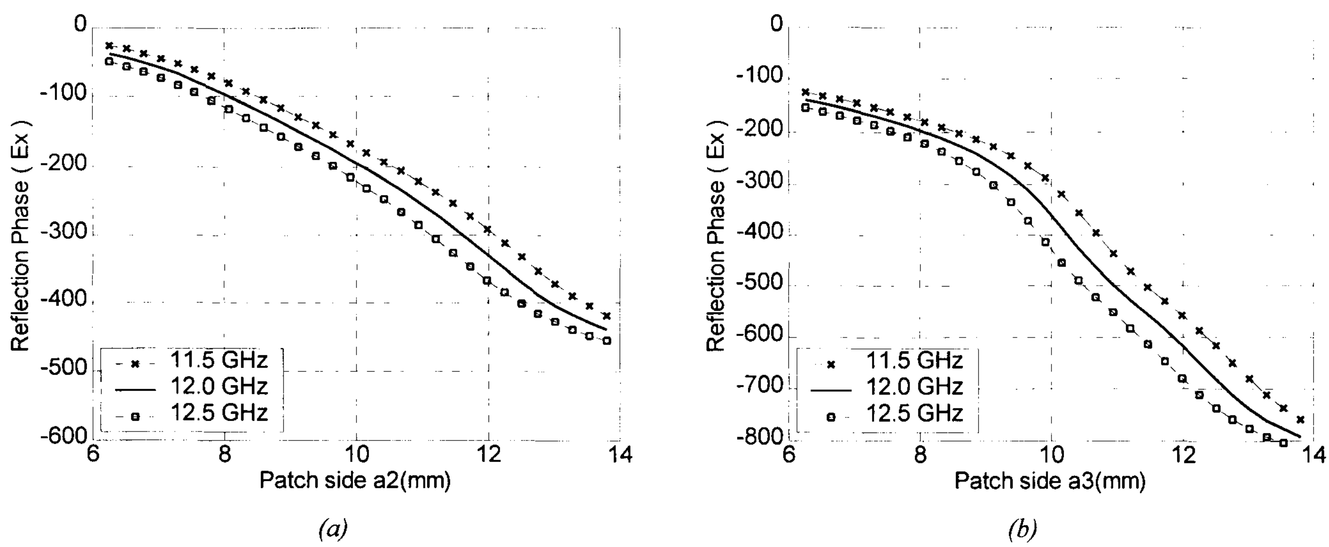


Fig. 4. Phase of reflection coefficient at normal incidence for a multilayer periodic structure, defined in Fig. 2 for two layers, versus the patch side of the array closer to the ground plane. (a_1=b_1, a_2=b_2, a=b=14mm, h_1=h_2=3mm, ε_r=1.05). (a) Two array layers (a_1=0.7a_2). (b) Three array layers (a_1=0.7a_3, a_2=0.9a_3).

polarised fields. First, the relative patch size in each stacked array is maintained fixed, and the dimensions are adjusted for a progressive phase at the central frequency. In order to improve the bandwidth performance, a further refinement can be performed by adjusting all the dimensions in each cell to achieve an appropriated phase distribution at different frequencies in the working band, using an optimisation routine. A code has been developed for the design of multilayer printed reflectarrays, which yields the photo-etching mask of each array. The same procedure allows to adjust the patch dimensions in each cell for any phase distribution, in order to achieve shaped beams.

The radiation patterns for the designed reflectarray are computed from the amplitude and phase on each periodic cell. Also, the cross-polarisation patterns are obtained from the $E_{x(y)}$ reflected field in each cell when $E_{y(x)}$ is incident.

4. Experimental results

To validate the design method, a 40cm diameter circular reflectarray was designed and built to radiate a beam at θ_0=19°, at 11.95 GHz. The reflectarray consist of two stacked arrays of variable size rectangular patches in a periodic cell of 14x14mm, separated by 3mm thick Rohacell. The feed is located at coordinates x_f=-116, y_f=0, z_f=340(mm). Figure 5 shows the masks of the two arrays obtained from the design program, and figure 6 shows a photograph of the prototype. The arrays were cut from a cooper clad kevlar skin using a cut plotter, and the rest of the material removed. After manufacture, tolerance errors of 0.2mm were measured.

Figure 7 shows a good concordance between theoretical and measured radiation patterns on the *x-z* plane for E_x polarisation. Similar radiation patterns are obtained for the orthogonal polarisation. Radiation patterns are presented in figure 8 at different frequencies to check the bandwidth. At the extreme frequencies, the radiation patterns are similar, with some increase in sidelobe levels and small gain variations. Measured gain was 31±0.15dB within the band 11.5-12.4 GHz, that coincides with a 0.28dB predicted gain variation. The characteristics of the prototype are compared in table I with measured results of other X-band one-layer reflectarrays described in the literature [7], [8]. A superior performance is observed

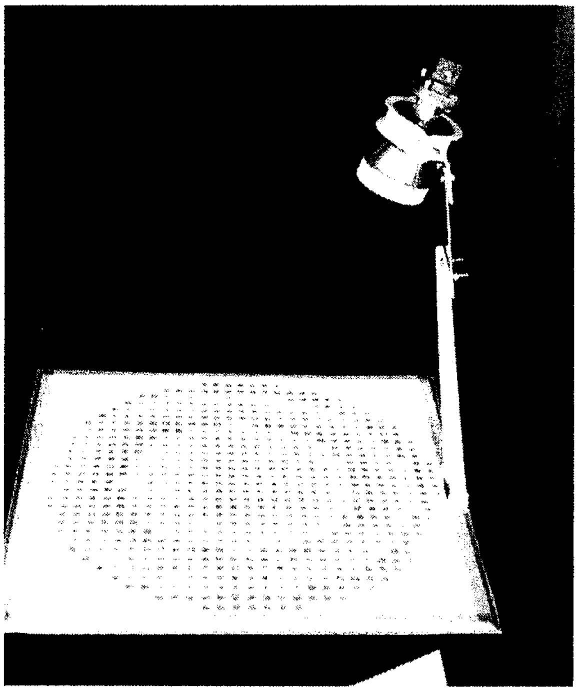


Fig. 6. Prototype of two-layer reflectarray.

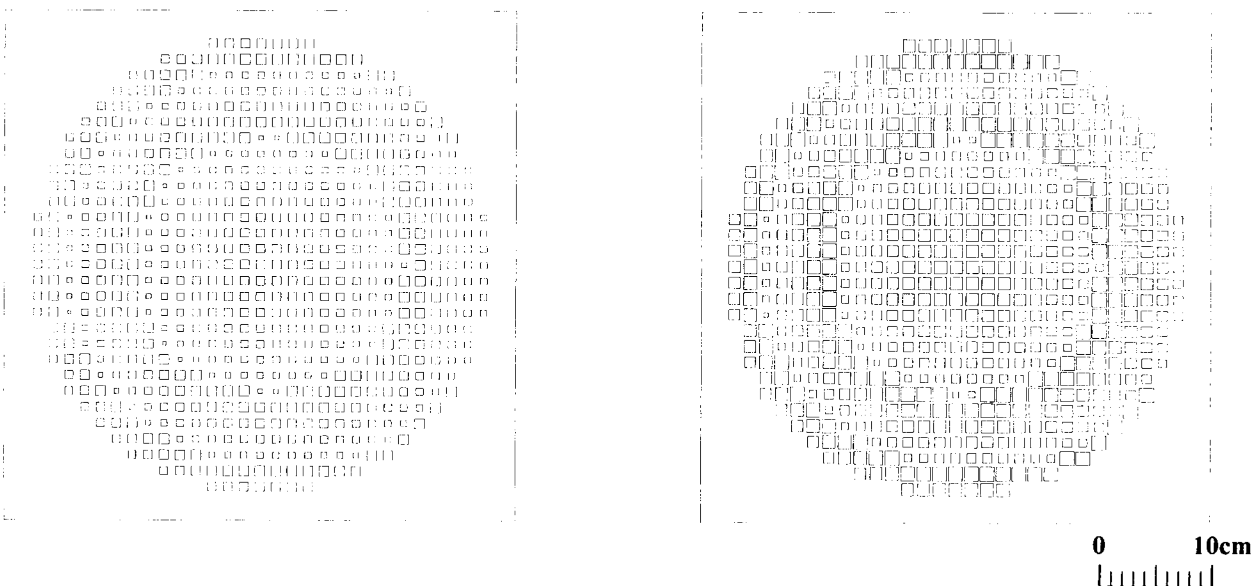


Fig. 5. Masks of a 406mm diameter two-layer reflectarray. (a) First array. (b) Second array.

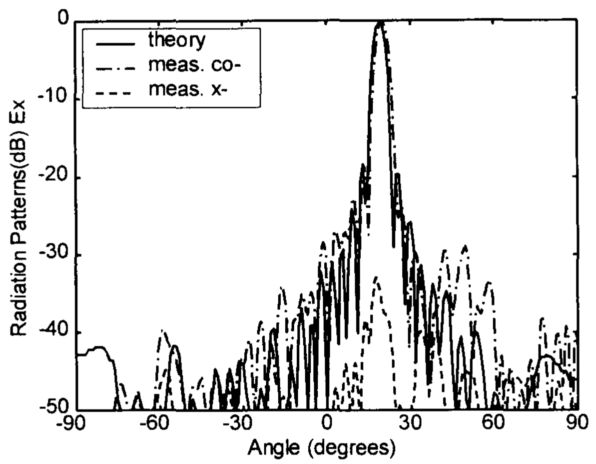


Fig. 7. Theoretical and measured radiation patterns on the x-z plane for E_x polarisation at 11.95GHz.

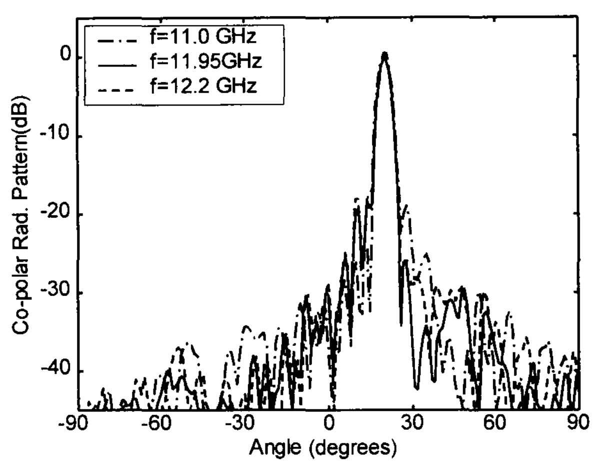


Fig. 8. Measured radiation patterns on the x-z plane for E_x polarisation at different frequencies.

for the two-layer prototype in gain, gain stability, bandwidth and cross-polarisation. These results show that a larger bandwidth is obtained with a two-layer than with a single layer reflectarray. The cross-polarisation measurements show a maximum of –26dB, which is even lower than the levels in [7], where a cross-pol reduction was proposed by cancellation using symmetries. It was checked that the –26dB cross-polarisation was generated by the feed, and we expect to achieve lower levels for the reflectarray.

	Reflectarray in [8]	*Reflectarray in [7]*	*Two-layer prototype*
Central freq. (GHz)	9.75	9.075	11.95
Frequency band (GHz)	9.5-10.0	8.85-9.5	11.5-12.4
Frequency band (%)	5.1	7.2	7.5
Polarisation	linear	dual linear	dual linear
F/D	0.9	0.87	0.84
Radiation angle (degrees)	25	30	19
Surface/λ^2	261.6	383.0	205.5
Maximum directivity(dBi)	34.7	36.2	33.8
Measured directivity(dBi)	-	-	32.47
Measured gain (dBi)	30.5	33	31
Gain variations (dB)	1.5	3	0.3
Cross-polar level (dB)	≤ -17	≤ -25	≤ -26

Table I. Comparison of two- and one-layer reflectarrays

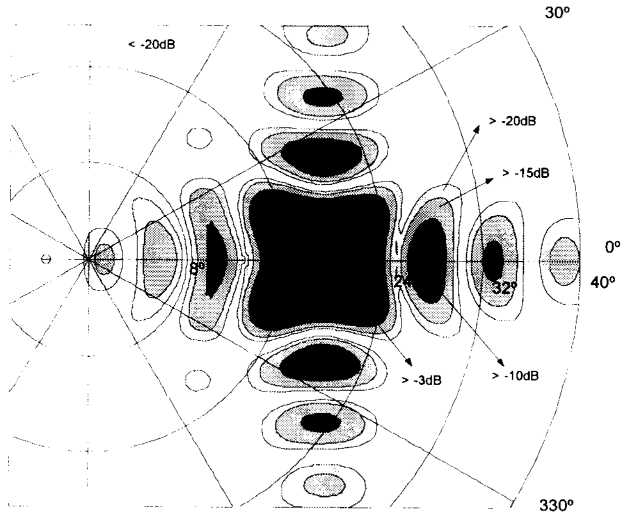
5. Research on progress

During the design procedure, the dimensions of the patches are adjusted to synthesise the appropriated phase distribution on the surface of the reflector. For the previous results, a progressive phase distribution was obtained, to simulate the behaviour of a parabolic reflector, but the same procedure can be applied to synthesise an arbitrary phase distribution. The amplitude is imposed by the feed, as in reflectors, but using phase-only synthesis, phase distributions can be reach that produce multiple beams or a particular shaped beam.

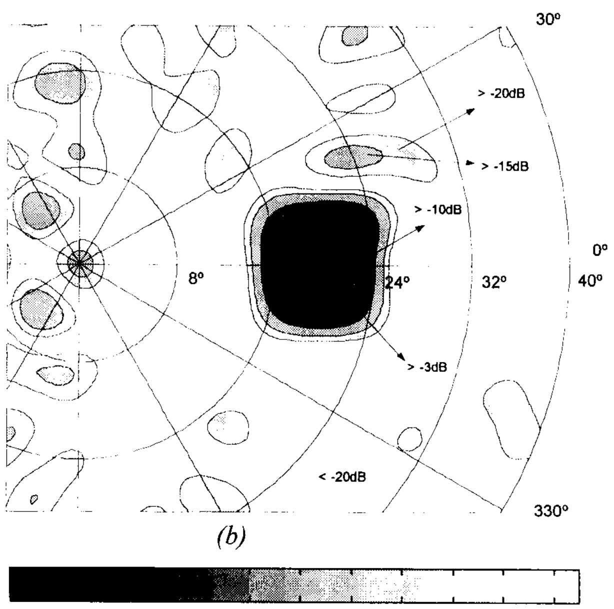
First, multi-beam applications were investigated. The phase corresponding to the superposition of several beams was obtained on the surface of a reflectarray illuminated by one feed, and a multi-beam radiation pattern was achieved. Due to the constrain on the amplitude distribution, the sidelobe levels were high (-10dB), but they can be reduced by phase-only optimisations. When the several beams are close one to each other, a contoured beam is obtained. This technique is used to get a starting phase distribution for contour beam optimisations.

For multiple beam applications with different channels, such as those used in communications with frequency reuse, a cluster of feeds can be used, in a similar way than in a multi-fed reflector. Then, the reflectarray is design to generate a beam associated to each feed.

Some techniques based on phase-only synthesis are been implemented to obtain the appropriated phase distribution to achieve a shaped beam with reduced side lobe level. As first examples, shaped beams with simple geometries as a rectangle or a triangle have been obtained. As the initial phase distribution we consider that corresponding to the superposition of several beams that approximately gives the desired shaped beam. Then, optimisations routines are used to match the radiation pattern to that defined as objective. Figure 9 shows a zoom of the radiation pattern at 11.95 GHz for a 40 cm diameter reflectarray, for the initial phase distribution and after the optimisation for a rectangular shaped beam. The amplitude was obtained considering the field radiated by the feed as a cosine to the power of 4. The amplitude at the borders was –7.5dB, relative to the maximum. It can be seen that the sidelobe level is reduced from –10dB to –15dB, at the cost of a slight degradation of the beam shape. A further improvement can be obtained by using larger reflectarrays. Figure 10 shows the mask for the first array of a two-layer reflectarray that generates the radiation pattern of figure 9(b).



(a)



(b)

Fig. 9. Theoretical radiation patterns for a square shaped beam reflectarray. (a) Initial pattern. (b) After optimisation

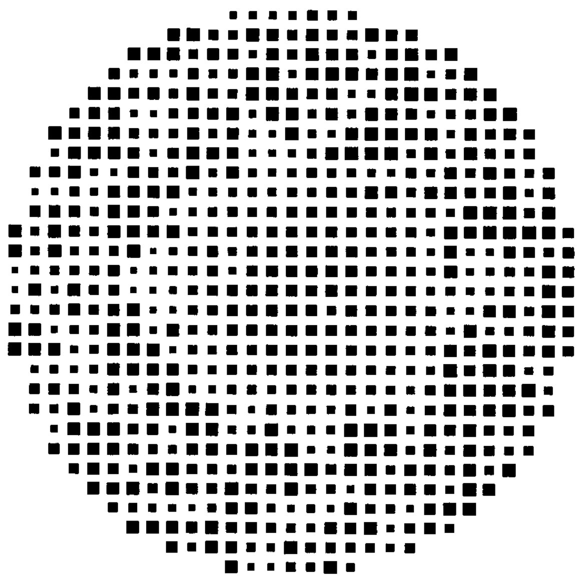


Fig. 10. Mask for the first array of a two-layer reflectarray corresponding to the radiation pattern of Fig. 9(b). The dimensions of the patches in the second array are 1.4 times that of the first array. The rest of dimensions are the same as for the prototype of Fig. 6

For real reflectarrays in space applications, the large dimensions make the classical synthesis techniques be impractical. To reduce the computer time, we have implemented FFT algorithms for the computation of radiating patterns, and we are working to reduce the number of variables in the optimisation.

On the other hand, to increase bandwidth, we are working on the compensation of the differential spatial phase delay by the frequency dependence of the radiating elements. We hope that satisfactory results can be obtained by using three array layers and optimisation routines to fulfil the phase requirements at several frequencies within the working band.

6. Applications to space

Planar reflectors based on printed patches presents several technological advantages. They are easy to manufacture by conventional photo-etching techniques, using space-qualified materials, such as kevlar skin and honeycomb. The manufacture technology has already been developed for dichroic subreflectors, and reflectarrays with three or more array layers can be build using well known procedures. Multilayer printed reflectarrays would allow an important reduction of cost and time of manufacture, especially for shaped beam or multi-beam reflectors in space applications.

Since no electrical contact is required between patches, they can be applied to deployable reflectors. In particular, for advance satellites given UMTS services large deployable antennas should be required. Planar reflectors can be packed more compactly, saving volume for the launch, and also the mechanisms for deployment are simpler, as those used for solar panels. However, for large reflectarrays, the bandwidth is drastically reduced, and some more effort must be done to improve the bandwidth. Also, multilayer printed reflectarrays can be of practical interest at Ka band for multimedia applications, because at these frequencies the relative bandwidth is smaller than at X-band.

From the viewpoint of electrical characteristics, reflectarrays present smaller cross-polarisation levels than offset reflectors, and can be used for dual polarisation, as an alternative to the dual grid reflectors.

In addition, the reflectarray can be designed to introduce a constant phase shift between polarisations, in order to change polarisation, for example, from linear to circular. Then, reflectarrays can be used in applications that require circular polarisation, by using simple linear polarisation feeds.

7. Conclusions

It has been demonstrated that, by using two array layers, the electrical performances are less sensitive to manufacture tolerances and the bandwidth increases, compared with one-layer reflectarrays. A further increase in bandwidth can be achieved by accounting for the phase dependence of the reflectarray elements, in order to achieve the appropriated phase distribution on the reflector surface within a frequency band. The research is on progress, in order to reach further improvements on bandwidth and to design multi-beam and shaped beam reflectarrays.

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Institutional Activities in Space Cooperation

Chairman: N. Jensen, ESA-ESTEC, The Netherlands

Space and Spacecraft-related Research & Technology Activities at the Aerospace Institute of TU München

H. Baier, P. Eckart*
Chair of Lightweight Structures, *Division of Astronautics
Technische Universität München
85747 Garching
Germany

ABSTRACT

Various space-related activities are ongoing at the Aerospace Institute of Technische Universität München. These activities comprise numerical analyses, as well component, experiment and system design and development.

This paper provides an overview of current space-related research and technology activities and cooperations at the Aerospace Institute of TU München. A recent focus has been in the areas of microspacecraft design. These activities are therefore described in more detail.

INTRODUCTION

The Aerospace Institute of Technische Universität München is part of the Department of Mechanical, Chemical and Aerospace Engineering. A new Department building with outstanding facilities has been opened in 1997 and is located at the university campus in Garching, a small town just a few km north of Munich (see Figure 1). The Department comprsis seven Institutes and the Aerospace Institute consists of six Chairs (see Figure 2).

Most space-related activities are taking place at the Division of Astronautics and the Chair of Lightweight Structures. Their activities and projects are, therefore, presented in more detail in this paper. However, extensive research in the areas of hypervelocity flows, hypersonics propulsion and orbital mechanics is also ongoing at the Chairs of Fluid Mechanics, Propulsion Systems, and Flight Dynamics, respectively.

Table 1 provides an overview of current space-related research and technology activities and cooperations at the Aerospace Institute of TU München.

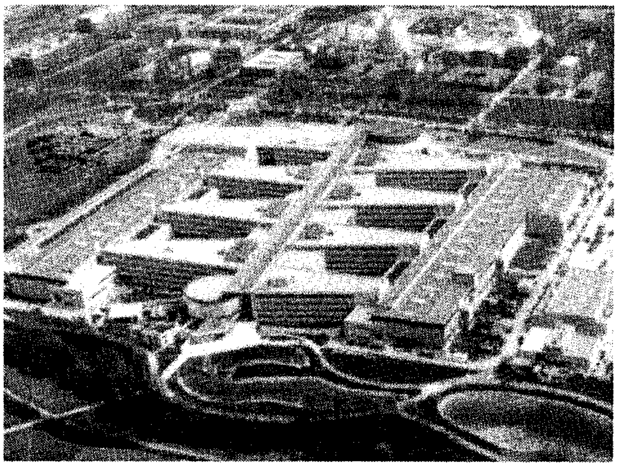


Figure 1 TU München - Department of Mechanical, Chemical and Aerospace Engineering

Proc. 2nd Conf. Academic & Industrial Cooperation in Space Research, Graz, 15-17 November 2000, ESA SP-470, November 2000

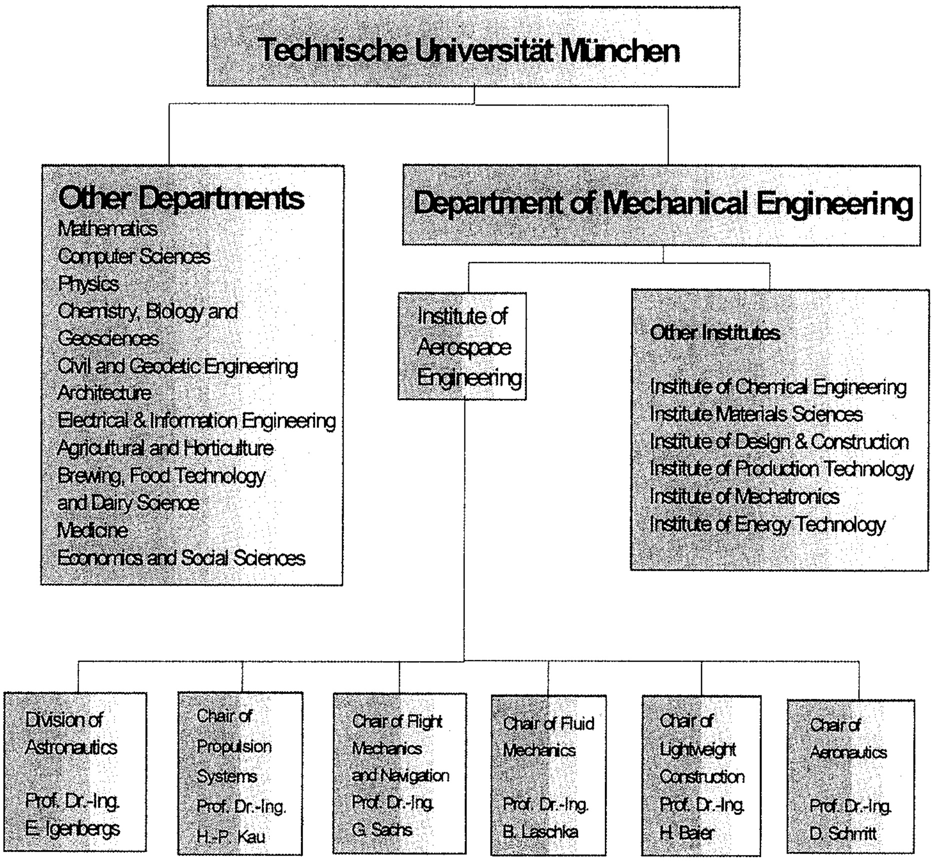


Figure 2 Organizational Structure of the Technische Universität München

CHAIR OF LIGHTWEIGHT STRUCTURES

The space related activities at the Institute of Lightweight Structures in general deal with structures and mechanical subsystems as well as their interaction with thermal control, performance control etc. Specifically, they are related to:

- Fiber composites and structures
- Precision and adaptive structures
- Cryogenic structures and related material properties
- Multidisciplinary design optimization techniques

and are funded by the Institute itself, as well as by research contracts, including space industry. Some examples of these are briefly described in the following.

Apart from different research and developments in *composite structures* in general, which also include manufacturing and testing, investigations in *large deployable reflectors* to be applied for communication, earth observation or science have been and are still carried out in cooperation with University of Tbilisi, Georgia: These latter activities are partly funded by ESA and the German Academic Exchange Service. New and challenging concepts especially related to membrane structures and reflecting surfaces have been established, and the manufacturing and testing of some laboratory models along with in depth analysis and simulation would be the next logical steps.

Precision structures require careful design of (fiber composites) materials and components, and together with adaptivity the consideration of the interaction with sensing and control loops. The *adaptive structures* concepts is investigated both for (static) shape control as well as active damping. Different multidisciplinary modeling techniques have been established together with optimization tools to determine structural and control parameters simultaneously. Correlation of

Table 1 Space-related Research and Technology Activities at the Aerospace Institute of TU München

Project Name	Description	Partner(s)
AROMA	Automation & robotics to support human missions to Mars	Kayser-Threde, DLR, VHS, HTS, and others
Ariane 5 Tank Structures	Crygenic structures – materials and behaviour	MAN
BayStar One	Proposal for a German small sat dust counter mission to L1 of the Sun-Earth system	Astrium, MPI, DLR
Best-in-Space	Virtual center for (potential) users of navigation services	-
Computer Testboard based on the ERC 32 Processor	Development of a computer testboard for a microspacecrafts	Kayser-Threde
Compact Magnetic Bearing Reaction Wheel	Reaction wheel for microspacecrafts	TU Dresden, Astrofein
Deployable Structures	Large deployable reflectors	ESA, DAAD
LunarSat	Lunar microorbiter	SSTL, Astrium, Kayser-Threde, and others
Microspacecraft Platform	Platform with a Δv-capability of up to 1,500 m/s	Astrium
μ-Mars	Proposal for a German small sat mission to Mars	Astrium, DLR and others
Munich Dust Counter	Dust counter flown on the Japanese missions HITEN (to the Moon) and PLANET-B (to Mars), and on the German mission BREMSAT (in Earth orbit)	Kayser-Threde and others
Munich Space Chair	Astronaut restraint device onboard the MIR space station	Kayser-Threde and other
MuSSat	Computer-based tool for satellite design (Phase A)	Astrium
S2C2	Computer-based satellite design center (Phase A)	-

results with those of laboratory models require the use of precision measurement techniques and control loops.

Activities in *cryogenic structures* are related to material and structural behavior of components of Ariane 5 and its future modifications, as well as with mechanical and material data of precision instruments applied under cryogenic conditions. While mechanical properties especially of carbon fiber composites do not necessarily degrade at low temperatures, it are the hybrid material components and joints which could cause problems. In order to avoid these, detailed knowledge of material data and properties is required, which poses some challenging problems for measuring especially small quantities such as coefficients of thermal expansion at temperatures typically below 100 K. Special test setups and techniques have been developed and are continuously improved both in basic research tasks as well as in cooperation with space industry.

Multidisciplinary *design optimization* techniques are now extended also into the very early design stages for determination of appropriate if not *optimal mechanical configurations* of satellites. Techniques based on combinations of genetic algorithms, feature technologies as well knowledge engineering will be used in an activity which is going to be extended to practical benchmarks together with space industry.

Further examples and *photographs* of the related infrastructure applied to laboratory models can be seen in our *homepage* www.llb.mw.tum.de.

DIVISION OF ASTRONAUTICS

The Division of Astronautics comprises on the average about 20 people, including professors, researchers, Ph.D. students, and staff. The major research areas of the Division of Astronautics are:

- Spacecraft design and mission studies
- Space experiment development and operations
- Micrometeoroid simulation
- Systems engineering
- Materials development

The main task of the spacecraft design group in recent years was the LunarSat project (see next section).

Another major project of the Division of Astronautics is the Munich Dust Counter (MDC), which is able to detect mass and velocity of micro-meteoroids. In the past, the MDC has flown on two missions: the Japanese HITEN mission (1990 to 1993 in the Earth-Moon region), and the German BREMSAT mission (1994 to 1995 in Earth orbit). At the moment, the MDC is onboard the Japanese PLANET-B mission on its way to Mars. It will reach the red planet in 2004.

The Munich Space Chair (MSC), that has been developed at the Division of Astronautics is on-board the MIR space station since 1996. Currently, the MSC is adapted for use on-board the International Space Station.

The members of the micrometeoroid simulation group have developed, for example, the Plasma Dynamic Accelerator and were co-investigator of NASA's LDEF experiment.

The systems engineering group is mainly working on a design environment for satellites, the modelling and simulation of communication satellites, the optimisation of satellite concepts, the safety of changing processes, models of a time schedule for the development of cars, and, most recently, on the development of a virtual user center for applications using space-based navigation systems.

Finally, the materials development group has recently developed a demonstrator facility for plasma-puls treatment of materials surfaces.

The Division closely co-operates with ESA, NASA, the Japanese Institute for Space Science (ISAS), DLR, DaimlerChrysler Aerospace, BMW, the Universities of Surrey (UK) and Uppsala (S), and many other research institutes, universities, and companies, both locally and around the world. More details can be found at http://www.lrt.tum.de/.

MICROSPACECRAFT DESIGN

LunarSat

The core of the microspacecraft activities at the Aerospace Institute of TU München is the LunarSat mission which was proposed in 1996 after the ESA Summer School 'Mission to the Moon'. The Division of Astronautics of the Technische Universität München essentially developed into the Engineering Centre of the project. Supported by the local space industry, a growing team of up to 20 professors, research assistants, and students from Munich and different European countries worked on LunarSat from early 1997. The LunarSat science efforts also involved several of the Alpbach participants, co-ordinated by the Swedish Institute for Space Physics in Uppsala which essentially became the LunarSat Science Centre. Between March 1997 and March 1998 LunarSat was part of the EuroMoon Project that was halted by ESA Council. After this decision, a continuation of the project was pursued by a team at the University of Surrey / Surrey Satellite Technology Ltd. in collaboration with the original LunarSat Team. A LunarSat Phase B Study was funded by ESA and conducted between July 1998 and March 1999. In April 1999 a LunarSat Phase CD Proposal was presented to the ESA Council. The Council acknowledged the quality of the work and applauded the approach of involving many European universities and students in the design process, but it did not approve the funding proposal for Phase CD. Instead, it requested to investigate the possibility of setting up an ESA microsatellite program.

During Phase B, the LunarSat project emphasised new working methodologies. Innovative project management was in place to facilitate control of the project by the three main centres. Especially, the level of documentation employed was consistent with the low-cost philosophy of the mission. Also, innovative cost reduction techniques were utilised and commercial off-the-shelf technology (COTS) was employed as far as possible to minimise cost.

Benefits of International Cooperation

A broad bandwidth of communications underpinned the leadership and management of the project. Given the rapid and low cost nature of the project the communications focused upon methods which offer good value. The Internet, World Wide Web and computer based digital TV techniques are used extensively. Decisions are mainly confirmed using telephone conferences.

Furthermore, science and engineering students and young professionals were supported by experienced experts from industry, acting as advisors. Using this method, contacts between the participating universities and the industry were initiated and ideas exchanged. In such a co-operation, the universities and students:

- Benefit from the experience of industry,
- Are exposed to the "real world" of spacecraft engineering,
- Are provided with an opportunity to learn "on the job" and gain working experience beforeactually entering the professional life.

Industry, on the other hand, benefits from this venture by having the possibility to:

- Test new design and engineering methods,
- Have insights into a variety of new and unconventional ideas, and

Get in touch with potential future employees that are highly motivated and talented.

Within the frame of the LunarSat Project, a number of students left their universities temporarily to work on the LunarSat Project, either as interns in industry or as exchange students at foreign universities. These students spent time off their home institutions, for example, at TU München, ESOC, TUM, ESTEC, Politecnico di Milano, Dornier Satellite Systems, and Univ. of Surrey / SSTL. Numerous cooperations with companies, institutions, and organisations developed during the course of the LunarSat project. These include, for example, Astrium, German Aerospace Center (DLR), ESTEC, ESOC, IABG, and Kayser-Threde and provide the basis for further joint activities, especially under ESA's ARCoP Programme.

Microspacecraft Platform

From the LunarSat design, several component and system design activities were spun off, including the development of a compact bearing reaction wheel and of an on-board computer testboard based on the ERC32 processor.

Also, the design of a low-cost microspacecraft platform concept was derived which enables missions which require high Δ-v capabilities of up to about 1,500 m/s, using auxiliary launch opportunities, e.g., from the Ariane 5 ASAP. The proposed concept is extremely flexible and can be adapted to specific mission requirements, thus permitting low-cost missions to Earth orbit, as well as to the Moon, Mars, and selected asteroids. A particular of the concept is its modularity.

Microsatellites have recently become a viable alternative for a variety of applications. This is due to new mission concepts, as well as major advances in microelectronics and increasing availability of commercial off-the-shelf (COTS) components. Although a lot of missions will continue to require large spacecraft solutions, low-cost satellite solutions are becoming increasingly attractive in the light of decreasing space budgets. When compared to conventional development procedures, small satellite projects are mainly characterized by rapid development scales, comparatively low spacecraft development cost, and the possibility to use low-cost, auxiliary launch options.

- A microsatellite, i.e., a spacecraft with a mass of only about 100 kg can have a maximum Δ-v capability of about 1500 m/s, using conventional propulsion technology. Therefore, their scope of missions from GTO is limited to:
  Selected Earth orbits
- Lagrangian points of the Earth-Moon system
- Lunar orbit
- Mars fly-by
- Near-Earth object fly-by

Lunar orbit missions have been extensively analyzed for LunarSat. Preliminary analyses for a Mars missions and Lagrangian point missions have also been conducted.

Assuming a launch on an Ariane 5 auxiliary platform (ASAP), the maximum allowed spacecraft size and mass, as defined in the Ariane 5 ASAP user manual, are 600x600x800 mm³ and 120 kg, respectively. Consequently, the main considerations in selecting a shape for such a microspacecraft are:

- Packaging considerations, i.e., to provide enough volume to contain the subsystem components and to fit within the fairing envelope.
- Structural considerations, i.e., compatibility with the payload and launch vehicle mechanical interfaces and efficient, in-line structural load paths between payload and launch-vehicle

The most important criterion for selection of the spacecraft shape is that it must be able to contain the largest packaged components. Because of the desired velocity capability of up to 1500 m/s aucha microspacecraft requires about 60% of its total wet mass for the propulsion system. This means that the design process is mainly ruled by considerations regarding the required tank volume that has to fit inside the ASAP envelope. Other critical layout criteria are that at launch the spacecraft center-of-mass (C.M.) must be not more than 5 mm away from the center line (ASAP requirement), and that the structural mass has to be minimized. Several spacecraft designs have been investigated.

The proposed microspacecraft is divided into two main segments:

- Payload Bay, which contains all payload and sensors, plus TT&C and OBDH and parts of EPS subsystem of the spacecraft.
- Service Bay, which contains the main thrusters, the propellant tanks and all propulsion elements. The proposed system uses four main thrusters with a thrust level of 22N each, using NTO and hydrazine. Four 1N hydrazine thrusters are used for attitude control, along with three reaction wheels. Also situated in the service bay are the Li-ion batteries and the laser gyros.

Several configurations have been analyzed for the propulsion system, for which five tanks (two for the required fuel, two for the oxidizer and one pressure vessel) are required.

The resulting baseline design uses a symmetrical tank configuration of four propellant tanks (2+2), all mounted on the same level. The pressure tank is mounted below these four tanks, on the geometric center axis. The propellant tanks are located on the tank panel (Middle Tank Plate - MTP) of the propulsion module. This configuration is shown in figure 3.

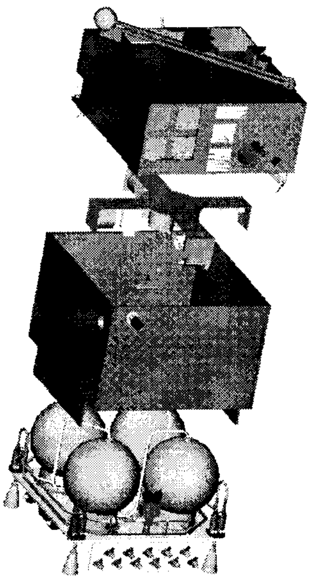


Figure 3 Baseline Spacecraft Configuration

The proposed microspacecraft with a total Δ-v capability of about 1500 m/s uses a dual-mode propulsion system. This means that bi-propellant main engines and monopropellant attitude thrusters will use the same fuel: hydrazine. Due to constraints in size and mass of the spacecraft, a propellant combination with a high energy density had to be chosen.

The proposed baseline design of the propulsion system is composed of:

- Four 22 N main engines using pure hydrazine (N_2H_4) as fuel and nitrogen-tetroxide (N_2O_4) as oxidizer, with a specific impulse I_{sp}=289s and a mixture ratio ϕ = 1.164
- Four mono-propellant (hydrazine) 1N attitude thrusters
- A tank-pressure-feed system with:
  - Propellant storage: (propellant tank structure propellant expulsion assembly) two hydrazine tanks in series as well as two NTO tanks in series with the same diameter, each tank containing a passive propellant management device (surface tension) for fuel expulsion in 0g, with a maximum fill rate of 94% and 1% residual (propellant flow schematic)
  - Tank pressurization: one helium high pressure (177 bar) tank to ensure that the propellant tank maintains the desired pressure
  - Propellant flow control: one pressure regulator, pyrotechnic valves, check valves, pipes, pressure transducers and filters for propellant flow control
- Temperature sensors at critical points
- Heaters

SUMMARY

The Aerospace Institute of Technische Universität München has been presented, along with a variety of cooperative activities with industry and other partners. The benefits of such activities, especially in the area of education and training of students cannot be overemphasized.

In this context, TU München has already benfitted from ESA's ARCoP-Program. This program is considered most valuable to encourage and support future cooperations between academia and industry. The major advantage of ARCoP is that it enables advanced investigations and research projects and serves as a catalyzer for new joint activities which may otherwise have no chance to get started due to a lack of suitable funding schemes.

THE GROUND TRUTH CENTER OBERBAYERN

W. Mauser, H. Bach, P. Köpke , D. Rieger, M. Wiegner

Prof. Dr. W. Mauser: University of Munich, Institute for Geography, Dep. of Geographical Remote Sensing
Luisenstr. 37, 80333 Munich, Germany
Phone: 49-89-2180 6676; Fax: 49-89-2180 6675; Email: w.mauser@iggf.geo.uni-muenchen.de
Dr. D. Rieger: University of Munich, Department of Geographical Remote Sensing
Dr. P. Köpke & Dr. M. Wiegner: University of Munich, Meteorological Institute,
Dep. for Atmospheric Radiation and Remote Sensing
Dr. Heike Bach: VISTA – Remote Sensing in Geosciences GmbH

Abstract

Within the frame of the HighTech Initiative Bayern of the Bavarian Government the Department of Geographical Remote Sensing (IG-GF; University of Munich) established the Ground Truth Center Oberbayern (GTCO), an innovative R&D Center Southwest of Munich. The purpose of the GTCO is to improve the calibration of remote sensing satellite sensors and extend their fields of application.

For this purpose ground based and remote sensing instruments as well as algorithms for data analysis, data enhancement, information extraction and environmental modeling will be developed and validated through pilot projects. Based on the pilot projects, which will cover the fields of agricultural and hydrologic applications as well as environmental monitoring marketing strategies for instruments, enhanced high quality remote sensing data and value added products will be developed. Cooperating partners within the GTCO are VISTA – Remote Sensing in Geosciences, a company specialized on value adding and information extraction in the field of remote sensing and the Department for Atmospheric Radiation and Remote Sensing of the University of Munich. In its final state the GTCO will make its products available on a commercial basis either in the form of value added products or through product licensing.

1. Introduction

The project "Ground Truth Center Oberbayern" started in May 2000, coordinated by the Department of Geographical Remote Sensing (IG-GF) of the University of Munich. Partners are the Department for Atmospheric Radiation and Remote Sensing of the University of Munich and VISTA – Remote Sensing in Geosciences GmbH. Based on the experience of the engaged University Departments in scientific research and the experience of VISTA in the marketing of remote sensing products, value added products shall be developed. The cooperation between the scientific and commercial partners allows the GTCO to offer competitive hard- and software products as well as services. The GTCO bridges the gap between research and commercial application of remote sensing earth observation data.

2. Targets of the GTCO

Developments at the GTCO are based on pilot projects to guarantee a maximum of functionality and reliability of the products. The main investigation area is situated in the alpine foreland south of Munich (Fig. 1). The Department of Geographical Remote Sensing in Munich uses this area as a preferred test-site and therefore

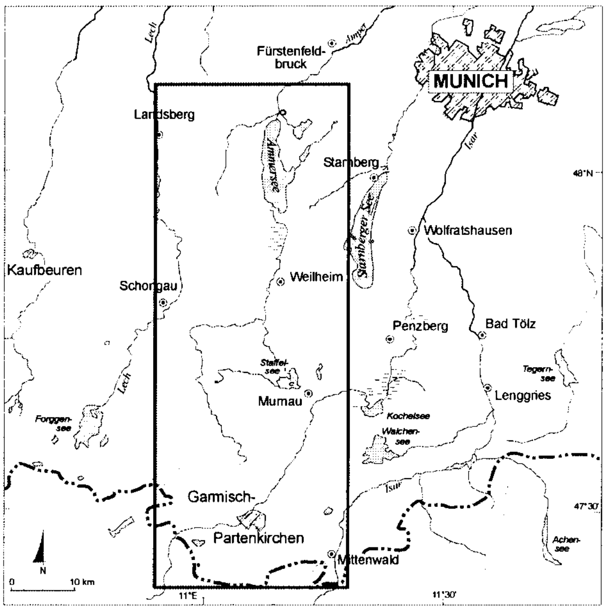


Fig. 1: Study area for pilot studies

possesses a large data pool out of almost one decade of intensive scientific research. Besides several invariable parameters like soil or relief information, many highly variable parameters in time are ascertained in the Ground Truth Area continuously:

- *meteorological parameters* : precipitation, aerosol distribution, radiation (energy balance),
- *hydrological parameters*: discharge, soil moisture, snow cover,
- *vegetation parameters:* land-use, LAI, biomass, growth height, chlorophyll.

The measuring program is adapted and extended according to the specific requirements of the pilot studies. Ground truth data is used to calibrate data of young and planned satellite missions (e.g. IKONOS, PROBA, ENVISAT) relating to land surface parameters.

3. Key aspects of activity

GTCO projects are concentrated on agricultural applications (precision farming), hydrological applications (flood forecasting, water monitoring, cooperative groundwater management) and environmental applications (protection of biotops, damages due to natural hazards). Within these applications the GTCO works on following topics:

1. Derivation of land surface parameters from remote sensing data

For an efficient use of resources many final customers (e.g. farmers) need high resolution data in space and time for different parameters (e.g. land-use, chlorophyll- or nitrogen-content of crops).

The GTCO develops methods to derive these parameters from satellite data. According to the clients requirements different satellites are used. The results are validated by extensive field measurements to be able to offer reliable products.

2. Software development

Software algorithms are developed to transform satellite data into useful information by means of suitable models. For example, in the field of yield estimation these models can offer a very good spatial resolution. Traditional methods, which provide similar resolutions are very time-consuming.

3. Instrument development

The GTCO has its own airborne spectrometer called AVIS (Airborne Visible Infrared Spectrometer). AVIS was developed at the Department of Geographical Remote Sensing at the University of Munich. The system is optimized for the use in the fields of precision farming and environmental monitoring (see Chapter 5.1).

Furthermore additional instruments are under development for the determination of soil, vegetation and atmosphere parameters. The GTCO operates a LIDAR-system, developed and made available by the University of Munich's Department for Atmospheric Radiation and Remote Sensing. It is used for calculating the three-dimensional aerosol content of the atmosphere. This instrument will be upgraded to provide an improved basis for atmospheric correction of satellite data. Additionally the development of a low cost LIDAR for the mobile use is planned (see Chapter 5.2).

4. Consulting and training

The GTCO plans to offer its clients an individual consultancy service for the efficient and cost-effective use of remote sensing products and methods. Thus, the high-quality GTCO-products come with high-quality services, which enable the user to efficiently apply the new information to his special field of interest.

We also carry out training programs for the purpose of handling the developed hard- and software in practice. This service contains the use of GPS and Geographical Information Systems for storing the field data in a georeferenced and spatial system.

4. Pilot studies: Yield estimation

Timely and reliable yield estimation is a powerful tool for cost-effective farming. It helps to optimize price and storage policy, application of fertilizer and pesticides, and monetary decisions in stock exchange, credit and insurance business. This also means, that the environmental impact can be kept at a minimum.

As a result of a pilot study on yield estimation of corn in the Upper Rhine Valley a methodology was developed, which uses daily meteorological data and vegetation parameters as input to an agrometeorological yield formation model (Bach 1998). While the meteorological data can be obtained from standard weather observations, spatial information and time series of vegetation parameters, like leaf area index (LAI), can only be derived from multispectral and multitemporal remote sensing data.

For the study carried out during the growing seasons 1995 to 1999, LANDSAT-TM data were used, which were atmospherically corrected. With its spatial resolution of 30 m x 30 m and its good spectral resolution, the spatial distribution of vegetation properties can be observed. For this purpose on average 4 scenes of the testsite (25 km x 40 km) were available during the vegetation period. The LAI is derived from the normalized difference vegetation index (NDVI) applied to reflectance values. Hence, it is possible to determine time series of LAI on pixel basis, which takes into account the general course of vegetation growth for temporal interpolation between the observations. This information, together with daily measurements of mean air temperature and mean fractional cloud coverage, is used as input to the agrometeorological model, and yield of corn can be estimated up to 6 weeks before harvest (see Fig. 2).

Figure 3 compares the results of the technique described above with official yield statistics on regional scale for the period 1995 to 1999. The estimates based on

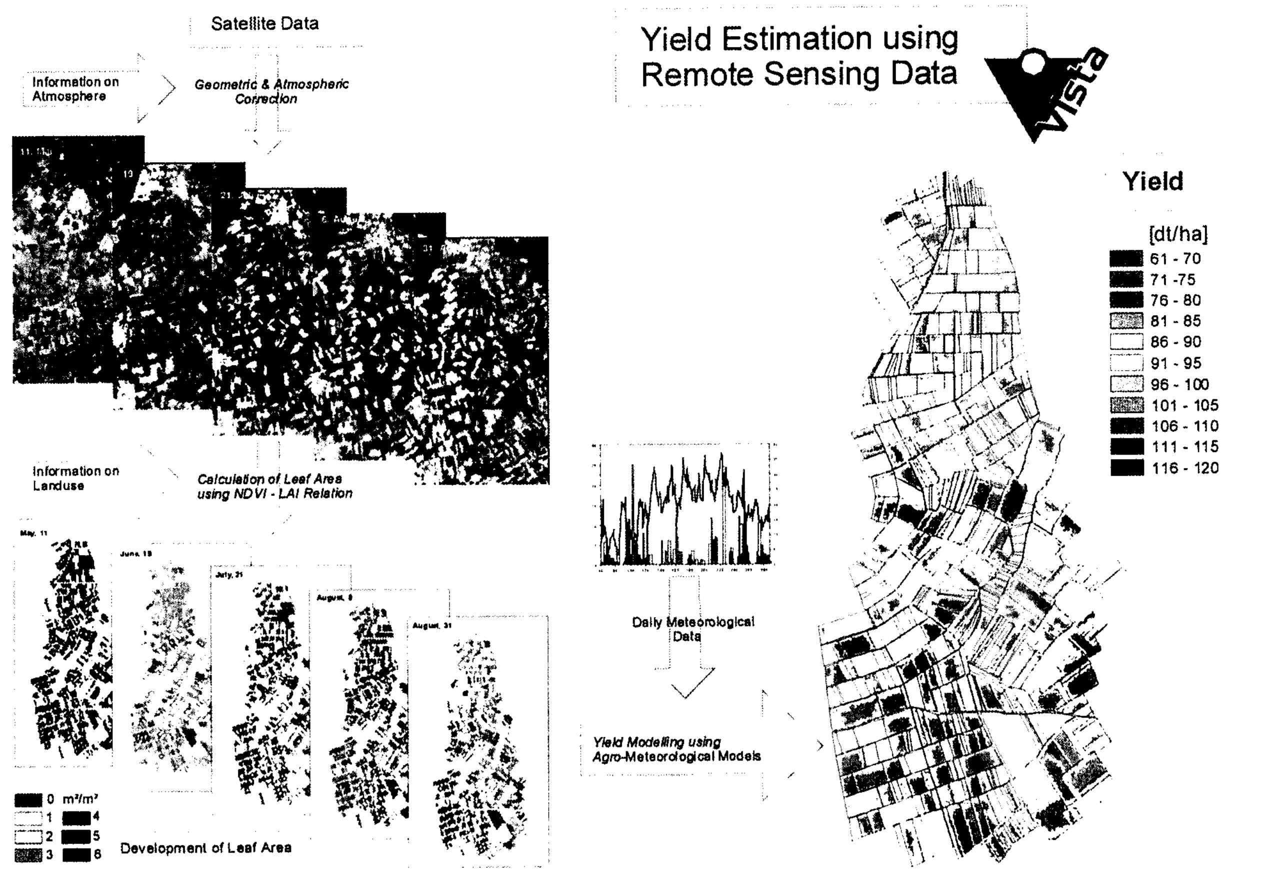


Fig. 2: Yield estimation using remote sensing data together with an agrometeorological model

satellite data are accurate and reliable throughout the whole period. On regional scale for each of the years the deviation to measurements is less than 3 %, although no calibration or adjustments of the methodology in between the years were conducted. On field scale the on average the relative error is 15%. In conclusion reliable and timely yield estimations can be made on regional and field scale using the methodology described above.

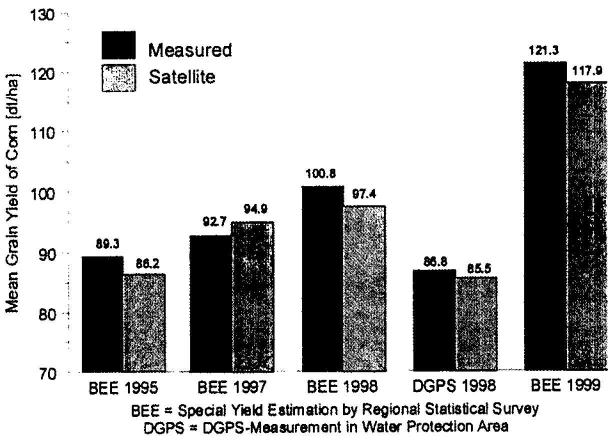


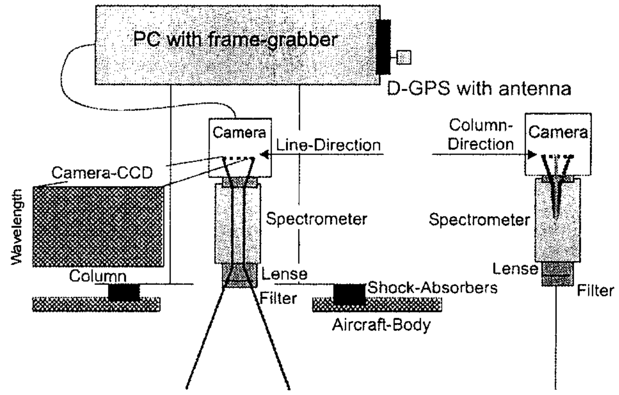
Fig. 3: Accuracy of satellite based yield estimation for maize in the Upper Rhine Valley

The results of this pilot study proof that remotely sensed data and high quality calibration techniques for remote sensing data can greatly improve crop yield estimation, which is important for effective agricultural and environmental management.

5. Instrument development

5.1 AVIS

The GTCO operates an airborne Imaging spectrometer (AVIS, Airborne Visible near Infrared Imaging Spectrometer), that was developed at the Institute for Geography, University of Munich. It is a system with relatively low costs of development. In combination with a cost-efficient operation, it is affordable for public institutions and communities. Hence, GTCO is able to offer a marketable imaging-system for the use in environmental monitoring and precision farming. It closes the gap between classical systems like LANDSAT TM, where the spectral resolution does not allow the derivation of parameters like chlorophyll content or support of fertilization or pest control. On the other hand there are no spaceborne Imaging Spectrometer systems available yet. Airborne Imaging Spectrometers such as DAIS, AVIRIS and HYMAP are



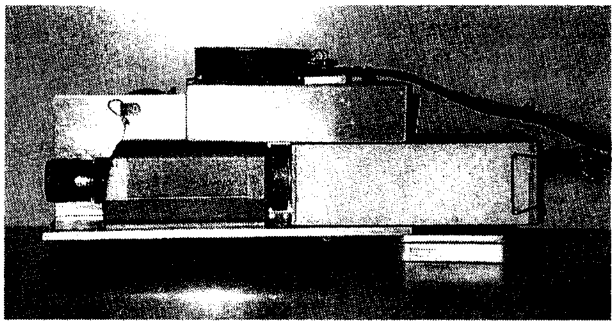


Fig. 4: Hardware components of AVIS

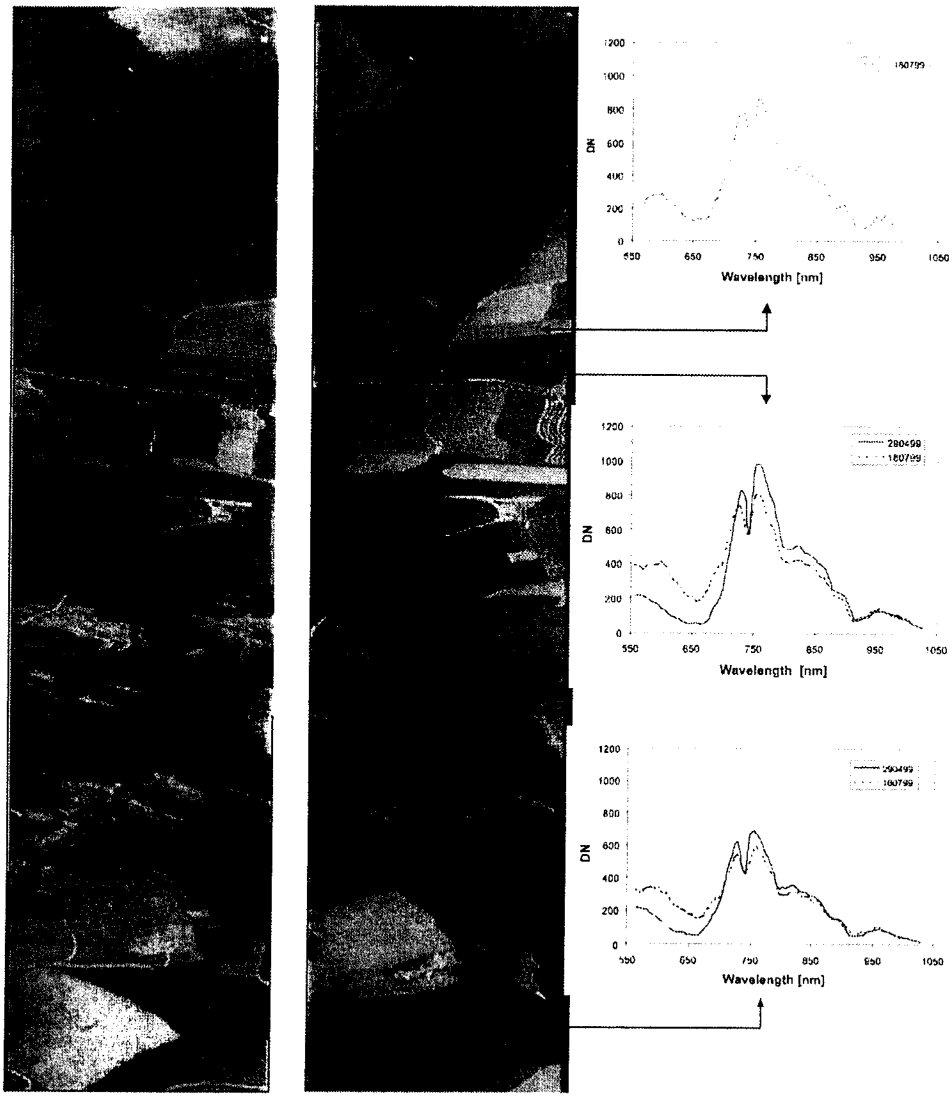
expensive and difficult to obtain for more than one or two observations per year.

The core of AVIS is a 240-channel Imaging Spectrograph (Fig. 4, Specim Ltd). It covers a spectral range from 550 to 1040 nm with a nominal spectral resolution of 2 nm. This spectrograph is mounted between an objective with a focal length of 8 mm and a 2/3" IR CCD black and white camera. Due to the spectrograph slit each recorded image is a line of 390 pixels with a spatial resolution from 2.5 to 10 m, depending on the aircraft altitude. The resulting view-angle is ±34 degrees.

The camera section can be installed in a chassis which fits onto an standard aircraft camera mount. The camera section is connected to a computer via a 11 bit frame grabber card for image data capture and processing which provides near-real-time data. The connected monitor enables the captured images to be supervised during flight. Auxiliary DGPS data including date, time, geographical position, and camera data is recorded.

The experiences made in the first two years in the Bavarian test-site near Munich suggest that this sensor is a reliable tool for the operational monitoring of the environment as well as for the support of farmers in regards to fertilization and pest control. A further enhancement of the system and the application within other pilot studies is planned for the future.

Fig. 5 shows a pre-processed flight line from the 1999 growing season. Depending on land-use the spectra (above = maize; middle = grassland, below = wheat)



Flight-line from the 29.04.99 in 4000 ft

Flight-line from the 18.07.99 in 4000 ft

Fig. 5: Pre-processed flight line near Oberpfaffenhofen/Obb.

show characteristic differences. Two different data sets represent the different phenological stage in the end of April (solid line) and in the middle of July (broken line). The spectra prove the possibility to derive high resolution data about vegetation parameters and vegetation dynamics as well as chemical components (nitrogen-content, chlorophyll-content) from these images.

5.2 Lidar

The Department for Atmospheric Radiation and Remote Sensing of the Meteorological Institute operates a mobile multi-channel-lidar that will be used and upgraded for GTCO-studies. The lidar was designed for determining geometrical, optical and microphysical properties of clouds and aerosols. Special emphasis was put on a compact and robust design so that it can readily be moved to almost any field site. Furthermore, caused by the scanning mechanism of the lidar, it can probe three-dimensional atmospheric volumes. Fig. 6 shows a view of the lidar with a brief technical description.

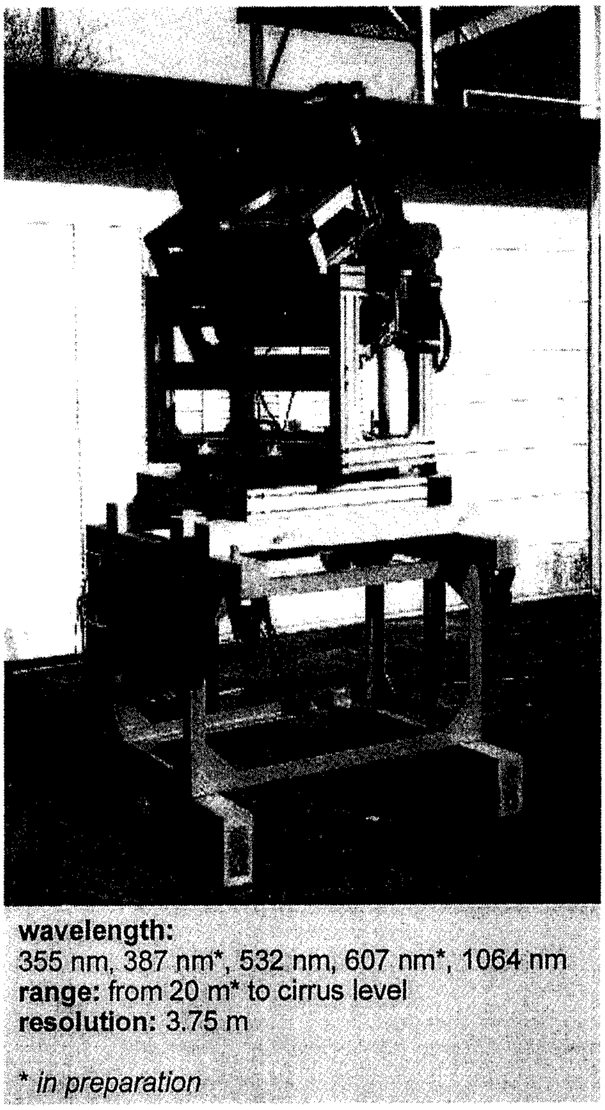


Fig. 6: Multi-channel-lidar for mobile use (photo by W. Carnuth)

The main goal of the lidar measurements are tropospheric aerosols. Spatial distributions can be provided with a resolution of a few meters. These data are beneficial by serving as input for radiative transfer calculations. As a consequence, they will support the calibration of satellite sensors and the derivation of land surface parameters.

Concerning the numerical studies, GTCO plans to develop improved methods for atmospheric correction in combination with remote sensing digital image processing. One of the main activities is the development of radiative transfer models that take into account multiple-scattering, arbitrary aerosol distributions, anisotropically reflecting surfaces, neighborhood effects and orography. These models are part of the proprietary software packages to retrieve land surface parameters.

The required aerosol information with high spatial resolution is – as mentioned - gained from the lidar measurements. Passive measurements with sun photometers and scanning radiometers, all sensitive in the spectral range between about 350 nm and 1100 nm, will supplement the lidar measurements. In particular, it is planned to derive optical properties of aerosols from these data. In addition it is planned to develop an eye-save microlidar, that can easily be operated in the field. The whole equipment will be mobile, to cover the requirements of any customer.

References

Bach (1998): Yield estimation of corn based on multitemporal LANDSAT-TM data as input for an agrometeorological model, Pure and Applied Optics, pp.809-825.

GTCO-Homepage: http://www.gtco.de

Acknowledgement

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ACADEMY-INDUSTRY COLLABORATION ON THE DEVELOPMENT OF SPACE-BASED AUTOMATED MODULE CONTROL SYSTEMS

U. Kirchhoff
Institute for Applied Systems Technology, Managing Director
Wiener Str. 1, D-28359 Bremen, Germany
tel: 49-421-2209222, fax: 49-421-22092-10; e-mail: *sick@atb-bremen.de.*

S.J. Dodds
University of East London, Professor
Longbridge Road, Dagenham, Essex RM8 2AS, London, United Kindom
tel: 44-181-5907722, fax: 44-181-8493547; e-mail: *S.J.Dodds@uel.ac. uk*

V.Yu. Rutkovsky
Institute of Control Scinces of Russian Academy of Sciences, Professor
65 Profsoyuznaya, Moscow,117810, Russia
tel: 007-095-3348730, fax: 007-095-4202016; e-mail: *rutkov@ipu.rssi.ru*

M.L. Pivovarov
Space Research Institute of Russian Academy of Sciences, Professor
84/32 Profsoyuznaya, Moscow, 117810, Russia
tel: 007-095-3331488, fax: 007-095-3107023; e-mail: *mp@stda.iki.rssi.ru*

V.V. Borisov
Central Research Institute of Machine Building, Center Deputy-Director
4 Pionerskaya, Korolev, 141070, Russia
tel: 007-095-5134640, fax: 007-095-5134127; e-mail: *azur@dol.ru*

V.P. Bogomolov
Central Research Institute of Machine Building, Head of laboratory
4 Pionerskaya, Korolev, 141070, Russia
tel: 007-095-5134942fax: 007-095-5168095; e-mail: *azur@dol.ru*

Abstract

The paper presents the results of the joint research activities between European and Russian research institutions in the scope of the EU funded INTAS project 97-00955. The project is aimed at the design of a free-flying automated module (AM). Although the development of the AM is an independent project, the AM can be regarded in the context of the International Space Station (ISS) allocating many tasks to the AM.

1. Introduction

Free-flying automated module (AM) is relatively small spacecraft which consists of a substantially rigid platform (main body) with six controlled degrees of freedom carrying special manipulators for grasping payloads. These payloads may be either rigid or flexible bodies. The idealized manipulator is represented as a system of three rigid links. Distributed masses of links are considered to be concentrated at the hinges and combined with the hinge masses. A simplified payload model is considered as a masses flexible bar with end masses. These assumptions simplify the model while retaining essential dynamic characteristics of the real system.

AM is intended for:

1. Servicing and launching small space vehicles (SSV) from the ISS (navigational, communicational, satellites for remote earth observation, special research modules and others).

2. Servicing experiments which are performed outside of the ISS, ISS's inspection and repair operations.

3. Applying the AM as an experiment platform flying in the ISS's neighbourhood (15% of announced

experiments do not have to be done on board an ISS).

The purpose of the project is to develop new methods for automatic control of the AM. This requires the development of AM control algorithms enabling it to carry out the following: manoeuvre to and mooring with ISS or other spacecraft, manoeuvre to and grasp objects with its manipulators, transport objects to the required point of space, perform maintenance operations on the external surfaces of ISS, carry out manoeuvres for visual inspection of operational and partly assembled space-stations, act as a tug for spacecraft or space station modules and then assist mooring with the station, retrieve drifting and tumbling objects resulting from an occasional accident. At the same time it is also necessary to develop an expert system to facilitate the following: automatic check out of the sequence of operations which the AM must execute for given tasks, target designation for specific AM's where more than one is employed, guidance for operators performing manual control in the case of any control system failure, training of operators engaged in long-term missions on a space station, with the aid of three-dimensional visualisation of the external situation.

Among the project's participants there are applied Institutes: Institute for Applied Systems Technology, Germany (Director this Institute is the co-ordinator of the project) and Central Research Institute of Machine Building, Russia, two Institutes of Russian Academy of Sciences (Institute of Control Scinces and Space Research Institute) and University of East London. All participants solve the project's tasks in close contact. Moreover the preliminary results were discussed at the workshop in ESA/ESTEC and its representatives have direct the project's problems on the most significant tasks of AM designing.

2. Some results

2.1. Optimisation of AM-s configuration

Among the others requirements to AM the following two are very important [1]: optimality of on-board power/energy consumption and safety of AM itself and security of ISS and other space objects to be connected with AM's activities. From the viewpoint of the energy consumption the new task of AM configuration optimality was formulated and solved [2].

As a manoeuvrable transport aid, the AM is moved from one point in space to another point by means of translational control forces F, which are directed through the main body's centre of mass. As a tug vehicle AM is intended for transportation of differently shaped payloads (different masses and dimensions). So the centre of mass loaded AM which, of course does not coincide with the unloaded AM's centre of mass will be different for each type of payload. In this situation the disturbance torque due to forces, F, occurs and it must be compensated by an equal attitude control torque but this would be done at the expense of additional consumption of energy. This is the motivation for formulation the tasks of AM configuration optimality which is realised by the corresponding position of the manipulator's links and payload. In [2] the optimal values of manipulator's links angles were defined and the conditions of physical feasibility of the AM optimal configuration and the conditions of the payload's correspondence to the AM as a tug vehicle were determined. Some types of payload grasping were suggested.

2.2. AM's mathematical model

The AM non-linear mathematical model (MM) were obtained [3]. The expressions of all coefficients as the explicit functions of AM constructive parameters and AM co-ordinates were defined. It was shown that the order of MM can be variable. It is connected with the fact of "hinge necrosis" when the control input on the hinge is switched off. On the basis of this MM all control problems were considered.

2.3. AM's controllability

First of all the task of controllability in the class of the AM's type objects has some peculiarities. They are connected with the mobility of the main body on which the manipulators are mounted and the variable effectiveness of the AM's control organs (different payload have different moments of inertia, AM moment of inertia depends on the position of manipulator's links and payload).

Conceptions of the technical controllability (TC) and the current degree of AM's technical controllability (TCD) were developed.

During AM's functioning the space domain of TC and the concrete value of TCD at any space point of this domain are different due to above mentioned reasons. For the control purposes it is necessary to know the current TC's space domain and TCD's concrete value. So in the frame of the project there was developed method of calculations of these indexes.

It is interesting to note that AM's TC space domain depends on the concrete construction parameters of space object and does not depend on control forces and moments values. In other words the concept of AM's

TC is the structural property that chacterizes current control possibilities.

The concepts of AM's TC and Kalman's controllability have quite different senses for their comparison but nevertheless it is interesting to note that the conditions of Kalman's controllability are necessary ones for AM's TC.

2.4. Two peculiarities of AM's functioning dynamic regimes

One of the main peculiarities of AM's functioning is the many type of flight modes and their different character. It leads to the necessity of satisfying rather contradictory requirements to the control system. For example the tasks of some payloads rescuing or inspection or servicing of some experiments demand the minimization of the time-optimal criterion. For the solving of other tasks (for example repairing operations, assembling ones and so on) it is demanded to guarantee the conditions of safety ("soft") control. In this cases the regimes of long hovering are used and we must optimize the criterion of control energy consumption minimum.

It is very important to mention the using of sliding modes [4], which guarantee the control co-ordinate motion along the switching's surface and so we can have the monotonic and safety processes of attitude control. (The oscillating processes of AM near by the ISS can lead to the collision). But sliding mode is very straind dynamic regime and we can use it for space vehicles control only in the cases when desired co-ordinate control motion can not be realized by more simple methods. As we are to have repeated mooring AM to ISS and hovering it over the ISS's surface and guarantee the safety of these processes we are forced to use sliding mode. In addition we are to minimize the duration of the sliding mode and it is very important task. The one more case of the sliding mode's using is the presence of passages from one flight mode to another. The oscillating process in these zones can provoke repeated false switching of different flight modes.

2.5. Attitude control

Taking into consideration the requirements of reliability this task's solving was sought in the class of relay systems, which demand the most simple control algorithms and have minimum number of units [5]. As the AM are to execute many different task it was suggested two-level regime of control organs work. For high maneuvering the nominal value of the gas-jet or electrical-jet engines thrust is used. But at small displacements of control coordinates lower thrusts are applied. Safety of the switching algorithms on the boundaries of the different regimes of AM-s motion was realized at the expense of the special monotonic processes (sliding mode) at the end of the each type of regime. Rather simple attitude control algorithms were suggested. For the regime of hovering the algorithm which forms the economic stable limit cycle was suggested.

2.6. Translational control near by the ISS

For safety's increasing of the AM-s functioning near by the ISS it is foreseen: 1) the formation of safety corridors of the trajectory's intervals which are tangential to the ISS surface, 2) hovering on the final interval of the trajectory before docking to the ISS surface or in the joining points of the corridors, 3) soft docking to the ISS surface from the state of hovering. These phases of safety maneuvering at the AM's mooring (trajectory 2, initial point, A_2) or at transit from launching pad, A_1 , to the point F on the ISS' surface (trajectory 1) and the phase of hovering before docking (trajectory 3) are depicted on the Fig. 1.

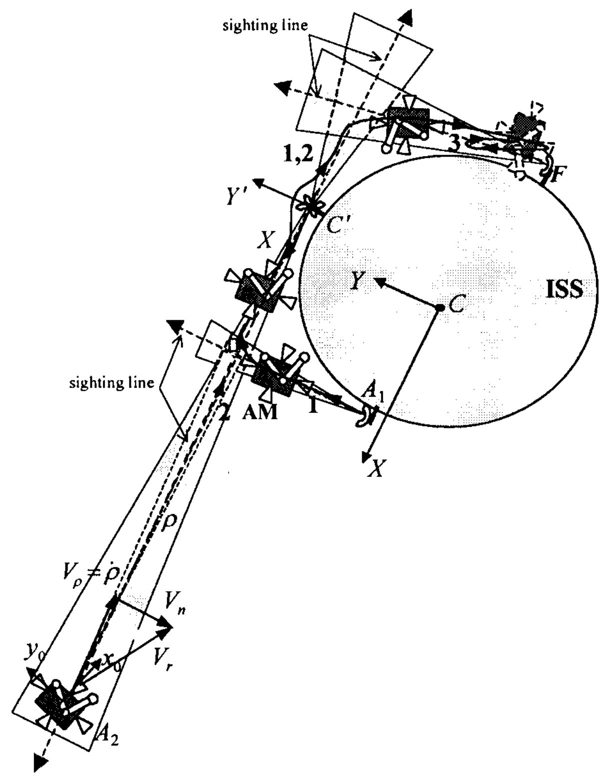

Fig. 1.

In the whole the safety trajectory of AM's flight from initial point (A_1 or A_2) to the final point, F, is organized as broken line of rectilinear segments which coincide with the axes of aerial directional patterns which are formed by radiators mounted on the ISS. Carrier frequency (or other sign) of every radiator must be different from others in order to AM's mooring radio system can identify the moment of AM entering in the zone of the next corridor of ISS's radiator. Conic (or other type) surface bounds the corridor of admissible (safety) motion of AM near by ISS.

At the AM's entering in the zone of searching and mutual capture system the AM's longitudinal axis is oriented along sighting line of the radiator placed in the final or intermediate point of the flight. After that the AM's engines accelerate it to the minimum relevant velocity which is defined by the executed task and the limitation on the disposed deceleration impulse on the interval of the intersection of the i-th and $(i+1)$-th corridors. After acceleration the engine is switched off and the next part of its motion along the i-th corridor it moves by inertia until it enters into $(i+1)$-th corridor. At this moment to the AM the decelerating impulse is applied which on the interval of corridor's intersection are to decrease the velocity approximately to zero. The next step is the regime of hovering and after that the tasks of AM's re-orientation in the direction of the $(i+1)$-th corridor or docking are realzed.

Special points of trajectory are the points of passing by AM of intermediate radiators (for example radiator C', Fig. 1). The AM's passing over this special point can be organized by using only the engines of transversal correction by means of following of sighting line 180-degree command turn.

2.7. The process of docking

The version of relative position and orientation calculation scheme, based on using the optical detector and marked beacons was suggested. For this case the initial distance between the detector and beacons is rather short. To determine the module's location we use one optical detector and two mark beacons, fixed near the setting place on the ISS. Having know the beacons co-ordinates, calculations are reduced to a rather simple geometrical task and we have got the corresponding relations for the computation of automated module's translational and angular co-ordinates.

The method has no limitation on the module's velocity. It is important from the safety point of view. At a close distance from the surface, an algorithm automatically provides for a predefined low (safety) relative velocity. Provided the failure of the control system occurs, the collision of the uncontrolled module with the Station's surface will not lead to the surface damage.

A prototype of the module, working in conjunction with a cable-crane in the test-hall has been developed. The module performs the motion control along translational co-ordinates in the horizontal plane and the attitude control about the vertical axis. The onboard computer uses the approach and mooring control algorithm similar to above mentioned.

Results of computer simulations and experimental tests with the module's prototype confirm that developed methods provide for safety and accurate manoeuvres of spacecraft, exact flying around the Station and precise approach and mooring in the predefined place [6].

2.8. Control in the neighbourhood of ISS

For a long-range flight control (when the initial distance from the Station ~ 10000 m or bigger) there was proposed to apply a significantly modified "three pulses" control [7,8].

The analysis of equations, which describe the module's relative motion, allows to introduce the new dynamic variables and to obtain a simple analytical form of the control pulses definition. This in turn allows us to solve simultaneously three tasks: accurately to transfer the module from the arbitrary point to a given terminal position; to ensure the minimum of the fuel consumption; to exclude the collision with the Station's surface and therefore to ensure the safety trajectory of flight.

In comparison with the normally used complicate relations of "three pulses" method, the new analytical form of control pulses calculation gives the opportunity to analyse in details a complicated dynamical process and select an optimal trajectory of flight.

To provide the module operation there was proposed to apply a specially developed algorithm of control with a 'model'. Briefly, method consists of two main parts:

1. Permanently repeated calculation procedure with a 'model'. A given mathematical procedure performs the filtration of random/ regular errors of measurements and accurate definition of current spatial co-ordinates, velocities, and external forces (including random disturbances);

2. Original scheme of terminal task permanent solution and the construction of a so-called "flexible" trajectory of flight.
   The elaborated method of flight control has a high degree of stability against the random interference, which may occur when executing the dynamic process. It provides for an accurate execution of particular task and minimum energy consumption.

At the present time a package of control algorithms which takes into account various conditions of flight is developed and set of computer simulations of control processes is performed.

2.9. Some special questions

During the flights in the vicinity of ISS AM must execute some turning on the constant angles around its centre of mass. As the AM control organs effectiveness is changed at different payloads and depends on the position of the manipulators links the well known algorithms of optimal control from Pontryagin's maximum principle do not give the result. The task of time optimal (and consumption – optimal at the same time) control by AM turning for the variable effectiveness of control organs was to be solved. At the same time optimal turning near by ISS must guarantee the safety of the station. So the attitude control has to be predicted. For these purposes non-linear algorithms were synthesised. Among them are optimal one and quasioptimal algorithm. Thus the rational and adaptive rational and adaptive rational algorithms were synthesised [9,10].

Anti-resonance control of AM for transportation of highly flexible payload was suggested [11].

It was determined the functional relationship between the payload's grasping point co-ordinates and the intensity of the elastic oscillations excited by the relay control torque's. The global extreme (minimum) of this function is the objective function used for the optimal choice of the load grasping point co-ordinates. This can be used to form an extreme-tuning loop that automatically adjusts the grasping point co-ordinates during the transportation regime (if it is possible to have the sequence of payload's interceptions) or the parameters of control algorithm.

2.10. AM's manoeuvring

There were dedicated soft-hardware creation for target designations issue on AM's spatial maneuvers related to the departure from the station, fly-around of the station or subsatellites, rendezvous with an observation zone, pointing out of observation cameras, AM returning to the station [11].

In the proposed interactive environment of the expert system the operator observing the stereographic image of suspected maneuver zones on the display screen sets the AM displacement vectors on reference points with the help of the three-dimensional graphic cursor.

At AM flight task formation in an interactive mode the hints of the expert system can be used such as observation system orientation display and image views taking into account the observation system characteristic as well as AM motion demonstration during the maneuver and the maneuver's parameters.

The operator's interplay with the expert system is carried out by means of the screen windows of different format in which the input data are formed for control system algorithms and graphic representation models.
The practical utilization of stereoscopic visual means allows to improve perception of observed three-dimensional scene that is necessary for assessment of the observation system operation, allows to execute a visual monitoring of maneuvers sequence and to correct their fulfillment in the interactive mode.

2.11. Touch screens

The man-machine system control is implemented traditionally by means of the operating control (OC) (such as the keyboard, different kinds of switches and handles etc.) and information display systems.

The "touch screens" is intensively developed for informational control systems that allows to select the control commands directly on the display screen by touching the zones of text and graphic information.

However, the space interval between the image appearing on one, inner side of the screen, and sensory surface on another, exterior side of the screen, because of the arising parallax does not allow to obtain the effect of "contact with the surface" of imaged object or operating control.

To exclude this effect it was suggested to use the touch screens jointly with stereographic image systems, in which the stereo image of control panel is displaced to a zone of contact on the outside screen surface due to selection of the applicable parallax [13].

The replacement of real physical panels by computer emulators allows to reduce essentially the weight and overall dimensions of onboard equipment, to reduce volumes onboard assigned for workstations, the terms of control panels, ground simulators and testbeds development for improvement and operation are reduced. The multilingual support of functional legends on control panels is provided, that is essential for the activity of international crews onboard the orbital complex.

Image systems use as the operating control expands essentially the functional capabilities of a man-machine control system, allows to form onboard and on the Earth different control panels including ones which are supposed to be delivered to the station during its operation.

With an information system for operator support onboard, it is possible to use virtual control panels for testing the skills of composite systems control and for definition of the operator's conditions. The presence of the ground segment of such system, communication board channels and control centers scattered on different regions allows to overcome language and spatial barriers, and makes the control system more flexible and reduces its material capacity.

3. Conclusion

Close collaboration of the scientific and applied research institutes on control systems synthesis with intellectual interface make it possible to integrate modern scientific and technological achievements in this domain of activity.

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COMBINING EDUCATION, TRAINING AND RESEARCH IN SPACE: THE EXAMPLE OF CARLO GAVAZZI SPACE AND POLITECNICO DI MILANO

Franco Bernelli-Zazzera
Dip. di Ingegneria Aerospaziale - Politecnico di Milano
Via La Masa 34 - 20158 Milano – Italy
tel. (+39)-02-23998328
fax (+39)-02-23998334
e-mail bernelli@aero.polimi.it

Marco Molina
Carlo Gavazzi Space
Via Gallarate 150 - 20151 Milano - Italy
tel. (+39)-02-38048243
fax (+39)-02-3086458
e-mail mmolina@cgspace.it

Abstract

This paper presents a brief overview of the cooperative effort undertaken by Politecnico di Milano and Carlo Gavazzi Space in the field of space education and research.

The activities carried out within this framework involve in many different ways the placement of undergraduate and graduate engineering students in industry, the cooperation of industry in supervising thesis projects developed mostly within the University, continuous education of industry employee, temporary relocation of industry workers within the University and cooperative research activities performed at both sites. The temporal scale of these activities is extremely variable, ranging from a few months to some years, and the overall benefits must be evaluated in the long term. The benefits are of different types for the partners: the University is kept in close contact with the real world, and the industry adsorbs its engineers and improves their skills in a very smooth way at all levels. In most cases, activities are self-funded by the two institutions.

1. Historical background of the institutions

To understand the significance of the cooperation, the historical development of the two institutions in the field of space activities should be briefly outlined.

A fully developed space engineering course has been introduced at Politecnico only in the last decade, with four specialized courses gradually introduced within the degree in aerospace engineering. Prior to this, only one complimentary course was offered within the degree in aeronautical engineering, and the graduating students would specialize in the space domain in the framework of their thesis project only. It is here recalled that historically the Italian University system has been based until very recently only on five years programs, corresponding to the actual 300 ECTS credits to be achieved (the so called "laurea"). In this study program, training in industry is not compulsory, and the interested students can either develop their thesis in cooperation with industries or simply spend a stage period.

In parallel to this wider offer within the aerospace engineering degree, in the last three years a new level of courses has been introduced, corresponding to 180 ECTS credits to be achieved in three years (the so called "diploma universitario"). Within this shorter study program, no specific space qualification is given, although all the basic fundamental subjects of the aerospace engineering culture are covered. All students enrolled in this program must gain some credits with an industrial training period.

The current number of students completing their studies in aerospace engineering at Politecnico di Milano is of 180 in the five-year program, 40 of them specialized in space engineering, and 40 in the three-year program. The majority of graduating students (75%), refer to the Aerospace Engineering Department for what concerns thesis projects and/or stages in industry.

Carlo Gavazzi Space SpA is a small high tech company that has been working for more than 15 years in the Aerospace field.

Located in Milan, Carlo Gavazzi Space employs about 110 engineers with experience in all technical disciplines required for the development space. The company has the necessary infrastructure for the development and integration of space systems.

The original field of activity of Carlo Gavazzi Space was the development of on board electronics and electrical ground support equipment. The company has now evolved expanding its capabilities to include the development and integration of space systems.

Carlo Gavazzi Space is one of the founding member of AIPAS, the Association of Italian Small and Medium Size Enterprises (SME).

Today, the fields of activities are:

1) LEO Infrastructure and International Space Station Utilisation
2) Small Satellites
3) Telecommunication Services
4) Hardware and Software Products for Space Systems
5) Ground Support Equipment
6) Ground Stations
7) Earth Observation

Carlo Gavazzi Space SpA has consolidated the role of system responsible through participation to programs such as the international Neurolab (European contribution) where the Company has assumed the responsibility of the structure and avionics, the development of the Italian Advanced Technology Mini-satellite (MITA), whose demonstrative flight has been on July 15th, 2000, and the study of the four Italian scientific missions AGILE, SAGE, STRATUS and REFIR. Currently, the Company is Prime-Contractor for phases B and C/D of EUTEF (European Technology Exposure Facility) Programme.

In the field of education, Gavazzi Space has activated all the necessary links with the University and the Institutions in order to be able to offer a broad range of services. In particular in the past two years Carlo Gavazzi Space has been part of the Operative structure of DELCOSI, a EU projects of DG Innovation for improving the 'transfer by heads' from the Academy to the Industry.

About 80 % of the company employees are coming from Politecnico, and 20% in particular from the Politecnico Aerospace Department.

Last but not least logistics helps us, allowing to go from Gavazzi Space premises to Politecnico within a quarter of hour.

2. Overview of cooperation activities

The above points and the present situation at Politecnico and Carlo Gavazzi Space show that there are many reasons why, even considering only education aspects, academic and industrial institutions can fruitfully cooperate in a variety of situations. Out of all the possibilities, the most developed cooperative activities are here presented.

- *Placement of undergraduate engineering students in industry.* It represents the first contact of the engineering student with the industrial world, and it is an integral part of the education process. The student is assigned a very specific and practical task to be completed in a few months under the supervision of one industrial tutor. All the activities take place in industry. One recent example deals with the structural analysis of a payload interface.
- *Cooperation of industry in supervising thesis projects developed mostly within the industry.* Although all students completing a five-year University education must develop a final thesis, its development in industry is an optional part of the education process. In this case, the student is assigned a very broad subject, usually to be completed in a semester or even more under the supervision of one industrial and one academic tutor. Most activities take place in industry. In this respect, a recent topic regarded the attitude control strategy for a foreseen new mission.
- *Cooperation of industry in supervising thesis projects developed mostly within the University.* The student is assigned a topic agreed with the industry, usually more theoretical than those of the previous case, to be completed in a semester or even more under the supervision of one academic tutor and with advises from industry when necessary. Most activities take place at the University, and the last example dealt with the design of a small computer unit made of non-space qualified components.
- *Placement of graduate engineering students in industry.* It can be seen as the end of the conventional education process and the first job of the graduate. In the first months, the fresh engineer moves from the University to the industrial attitude. In order to soften this transition, the technical skills developed during thesis find a natural prosecution in the company; for example the thermal design of a ISS laboratory instrument, subject of a thesis in its preliminary phases, is the main task of a young employee, inserted as specialist in the industrial team.
- *Continuous education of industry employee.* It is a traditional continuous education program: the knowledge of the industry engineers is broadened with subjects not studied in the regular curriculum or with state of the art theories.
- *Temporary relocation of industry workers within the University.* It is the opposite of the previous, with state of the art practical knowledge being transferred from industry to University, to develop and complete small projects such as a microsatellite.
- *Cooperative research activities performed at both sites.* It is the high end of the cooperation, in which the specific skills of industry and University are joined to develop long-term research activities. Currently, a study on a support structure for

physiological experiments on board the Space Station is under study. It is the only activity for which the partners seek together external funding.

3. Placement of students in industry

As integrating part of the education process, some 300 hours of industrial training in the industry are foreseen for students attending the three-year courses "diploma universitario". Carlo Gavazzi Space hosts these students in Aerospace Engineering in its Mechanical-Thermal engineering Department, while the Electronic Engineers are placed in the Electronic Engineering Department. In both cases, the basic skills of the students have to face with real-world problems and the students are put in a design team, assigning them specific (even if limited in time) tasks.

For what concerns the mechanical design activities the typical skills that are enhanced are the 3-D CAD modeling and FEM techniques. Thanks to the basic courses, all the students coming from Politecnico have basic knowledge on these topics. The industry allows to improve the contact with the manufacturing process: in an SME this is made easier due to the very tight connection between the engineering departments and the people in charge of the final assembly and verification of the space equipment and payloads.

The experience of the lab, either as integration in the clean room of a mechanical assembly, or an electrical test of a space equipment, allows to link in a straightforward way the design process to the manufactured part.

Recently, a student was put in the team in charge for the structural design for standard Payload Modules for a Phase B project (EuTEF) [1].

Thanks to this experience, the student had to practically face with the FEM software (NASTRAN), and, more important, to interface with the mechanical design team, to see how the mathematical model was representing the reality and how to implement into the hardware the output of the calculations.

The student had the opportunity of making, together with the team, an experience of pure design, based on space requirements, becoming able to translate specifications in technical choices.

The company tutor is the official link with the industry structure, allowing a smooth insertion in the design chain. On a yearly basis in Gavazzi Space there are 5 trainees in Aerospace Engineering and 4 in Electronic Engineering, spread all over the year, in order to allow a good and positive interaction with the company tutor.

No more than two students at the same time are in the same department, so that the experience can be managed and the student can have the suitable assistance.

End of the conventional studies period is the placement of graduates in the industry.

In the last three years most of the engineers hired by Carlo Gavazzi Space (more than 80%) were coming from Politecnico.

In some cases (50% of the last appointment) the employee had made his thesis at the Carlo Gavazzi Space premises.

This allows to better exploit the potentiality of the students, and moreover to allow a redirection of the field of interest of the student itself, according to his inclination and preferences.

However, very often the activity where the student is placed is close to the thesis subject, this fact better showing that the thesis are strictly related to the company core business, and are not of marginal interest.

A peculiarity of the SME is that the young employee has immediately to face with economical constraints, that are usually neglected in the standard engineering courses. The direct contact to suppliers, the possibility of issuing a purchase order allows to substantiate the high technical skills - that the University provides - with costs evaluation and trade off capabilities among different technical choices.

The tasks of a young employee are well defined and bounded, in order to allow him/her, at the same time, to get concrete (even if limited) responsibilities.

As a recent example, a student whose thesis had dealt with thermal control of a Deuterium lamp in a BIOLAB Analysis Instrument, became, in the early phases of her hiring the responsible for the thermal tests of this instrument in the CDR phase completion [2].

Usually, an additional time span is needed to finalize the student readiness for operational tasks, this additional education period spanning from 6 months to a couple of years. It then becomes the continuous education, which is later mentioned.

As an example of re-characterization, a student whose thesis was devoted to the development of standardized satellite platforms, in a 1-year period, was redirected to the mechanical engineering activities, becoming the responsible for the system engineering of the RICH project, part of the AMS02 experiment to be flown on the ISS.

In a further, even if single, case, a student that could master the topic of stratospheric platform in a thesis at DLR had the opportunity, thanks to the links between Gavazzi Space and Politecnico, to join Gavazzi Space, and to work in the team responsible for the HELINET platform preliminary design, in the framework of a EU project coordinating several institutions and industries.

4. Cooperation in thesis projects

For the students enrolled in the five-year study program, the thesis project represents the end of the educational period. In the present structure of studies there are no credits given to the thesis, although a revision of the structure is under way, and it will assign credits also the thesis. For the moment, the only requirement for students is that they achieve a minimum level of thesis to be admitted to graduation exam.

Thesis projects represent the first autonomous work of the students. Even under the supervision of a professor, the projects must be developed by students. Through this process, the future engineer learns to face problems with no already given answer, taking decisions and actions on the basis of a self matured knowledge.

The subjects of the thesis projects can cover almost any topic, and are only seldom a mere application of the theories and practices learned by the students in the course of the previous studies. More often, a thesis includes at least some parts of research, and at the highest level they can be pure research works.

In this context, an industrial involvement in the supervision of some thesis can be important for many different reasons. The academic institution is kept up to date with the research needs of the industry, that is to say that there is always the potential hazard that the research becomes driven by itself and not by a real requirement. In an engineering environment this should not happen, or at most be a minor part of the research. On the other side, the industry can benefit from some research that in could not sustain on its own. The work force of the industry, especially the SMEs, is in fact usually concentrated on work that gives immediate economic return, and even when some research is performed it has to be oriented toward a benefit. The thesis work can instead be focused on topics that need to be explored just to be able to tell if there could be a benefit in the near or distant future.

Two examples of studies performed mostly in industry are presented in some detail to clarify the possible achievements. The first example is more close to the industrial needs, the second to an academic study.

The first project presented deals with a mission analysis problem. In the course of the development of a mission already in the phase C/D, the MITA satellite platform built by Carlo Gavazzi Space for ASI), performed by the industry employees, the student started a parallel study to redesign the mission using less constraints than those adopted for the actual design [3]. This allows to gain some insight in the sensitivity of the output (the satellite) with respect to the imposed constraints. This information becomes valuable to find, for a given mission objective, the most demanding parameters, so that for future missions those identified parameters could be, whenever possible, relaxed for that particular satellite class.

The second study presented deals with the study and optimization of the attitude maneuver and control system for a new mission [4]. This study is also performed in parallel to the phase B study, but it is a more theoretical one. The goal, apart from the development of new schemes for attitude control, is to validate the applicability of modern control logic to satellites. In this field, in fact, the majority of applications are based on classical control despite the continuous developments in modern control theory and the numerous numerical studies and simulations concerning spacecraft attitude control.

In both cases, the student works in autonomy in the industrial environment, using the design tools available, and reporting periodically to the academic supervisor. Also, periodic meetings between the industry supervisor, academic supervisor, and student, allow to verify the project status and define and update its progress and phases.

As an example of thesis developed mostly within the University, the case of the design of a small computer unit made of non-space qualified components is reported [5]. In this case the study and hardware developments are typical of an academic institution, having to be developed at very low cost despite some performance degradation. The student therefore interacts with the experts in the industry to check the most critical components and to find appropriate remedies to enhance the functionality of the system in the space environment, since this competence is lacking within the University.

In this case, no systematic industry/academic meeting is planned, and the industrial supervision is sought (and found) whenever the project development need it.

In all cases, both academic and industrial institution gain some knowledge from the cooperation, to be used either in the short or long term, and the students can have a first look at the work environment in which they might be operating in their near future.

5. Cooperative research activities

In the last years there has been a clear change in the way researches are funded by the major agencies. Now it is very rare to find financial support for pure academic research. The general feeling is that this can be done at no extra cost within the resources already available in all Universities. Therefore, important research is supported only if there is a reasonable chance to produce also long term industrial benefits or products. This holds for both national and international research cooperation and funding.

In general the financial support for the research is higher for the industrial partner, due to the intrinsic higher labor cost, at least in the actual Italian situation, and also to the fact that normally the outcome of the research would be a product manufactured in industry.

In this respect, a cooperative research activity represents the high end of an academic/industrial partnership, since it obliges the institutions to manage a long term project. The specific skills of industry and University are joined to develop research activities, the partners share responsibilities and duties, and one of them acts as project leader.

The success and ease to manage the research depends on the level of integration and interaction among the institutions, and therefore it also represents a natural continuation of the cooperation activities exposed in the previous sections, if those are satisfactory.

One good example of this, up to now, is represented by the study of a support structure for physiological experiments on board the Space Station [6]. The experiment consists very roughly in a rotating chair, spinning in an off-axis configuration and carrying an "instrumented" astronaut. It poses some interesting technical and conceptual challenges, due to the particular operating environment. The duty of Politecnico is to solve the conceptual and theoretical problems related to the active isolation of the base plate from the Space Station, to damp the reaction forces produced by the running experiment. The duty of Carlo Gavazzi is in this case to guide and check the consistency of the resulting design, to define the qualification strategy and breadbording activity and to solve the integration and accommodation problems in the Space Station.

Needless to say, the whole research is transparent for the two institutions, so that both have access to the complete results and the final design, and all can follow the main steps of the project. This allows an even better spread of the specific skills of Politecnico and Carlo Gavazzi.

6. Continuous education of industry employee

After starting the working activity the link with the University is not lost, mainly due to the collaboration in researches and in thesis.

The possibility, even for quite young employees, to become rapporteur of students of Politecnico improves and strengthen the link to the University, allowing to keep the contact with the professors and the researchers.

The consultancy of professors allows to keep excellence in fields (like attitude control) where most of the activities don't need big investments.

The basis of this cooperation is a continuous and personal link between the former student and his professor; sometimes this is not framed in a formal scheme, but based on informal basis.

On the other hand mini or micro consultancy contracts (up to 10 kEuro per year) allow to have tutorial for the company employees where the work load for the professor is foreseen continuous and not extemporary.

Some of these contracts are a kind of barter agreement: consultancy in exchange for the use of facilities or test equipment located at Gavazzi Space premises.

Days dedicated to specific topics at the University, seminars held both in the company or at the University are the biggest examples of this living-link between the Politecnico and Gavazzi Space.

7. Temporary relocation of industry workers within the University

For the PALAMEDE project, which aims to build a microsatellite entirely with students resources, using their manpower during thesis development, is on going an experiment of a temporary relocation of a Gavazzi Space employee within the operational structure of the PALAMEDE project.

The primary need on the academic side was to have a permanent reference for the students working at the same time (synchronically), and even more between the students that, starting from the conclusions of other students, had to build their contribution on the basis of preceding works.

Without this permanent link most of the information were lost.

The involvement of a engineer with some years of experience in the industry allows to manage the project with the industrial approach, allowing a continuous flow of data among the responsibles of the different subsystems of the satellite, with internal reviews, progress meetings in a perfect parallelism to the industrial world, inside the university.

This has a great impact on the education of engineers, who can experience the team work still in these concluding phases of their education period.

This market-to-lab experiment is lead putting particular care in the intellectual property policy: the industry is guaranteed against know-how escape.

The time span for such a cooperation is four years, the time assumed to bring at the qualification phase the satellite.

The past of the Team leader allows an easier interface with the industrial world, improving and speeding up the project completion

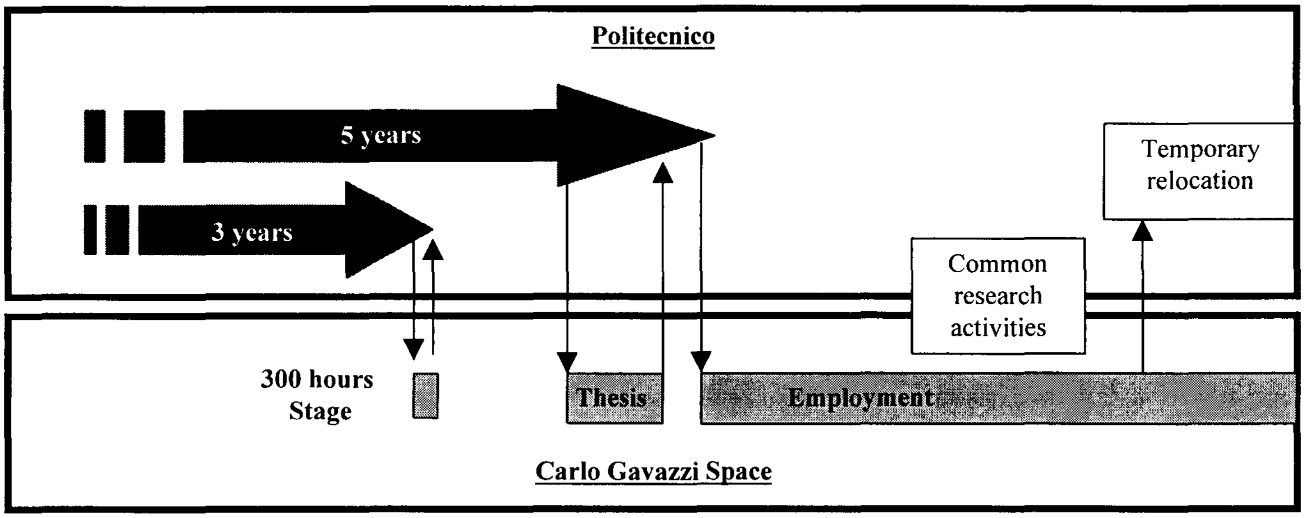
8. Funding

As it should appear evident, all the activities presented can be executed with good will and technical profit only if there are sufficient financial resources on both sides.

In the case of cooperative research this is trivial, since each institution can ask for all the support it needs on the basis of the proposed work share. The other side of this is that the research activity might have to be revised on the basis of the actual funding received. Moreover, it has to be considered that Carlo Gavazzi Space invests 5% of its yearly turnover in research activities.

The placement of students in industry and the cooperative thesis projects are supported with no or very little money flow. For Politecnico these activities are part of the institutional job. Every student must either spend a supervised industrial training period ("diploma" degree) or prepare a thesis project ("laurea" degree) so it is obvious that part of the tuition fees are devoted to this activity. The placement activity is still considered as part of the institutional work load in force of an agreement signed with Carlo Gavazzi Space. Only in some special cases, in which a thesis is seen also as a means of continuing education for the industrial supervisor, there is a dedicated micro-contract signed and some money flow from industry to University.

On the industrial side, the education is considered as an investment, and about 2000 hour-man per year are dedicated by Carlo Gavazzi Space to this activity, either to be tutor of the training students or to support them in thesis development.



Summary of the links between Gavazzi Space and Politecnico

Sometimes the supervision of a thesis is more or less equivalent, in terms of knowledge gained, to a short and very specific continuing education course.

The conventional continuing education activities can be supported in different ways: direct support from Carlo Gavazzi Space, through a micro-contract, or contribution of an institutional educational public body. An average of 7 micro-contracts is issued each year with academic representatives for tutorial of employees, for a total value of about 50 kEuro.

It is clear that these activities are not part of the conventional work load of Politecnico, which therefore needs special funding to perform them. For Carlo Gavazzi these activities can be seen as a cost but also as an investment because of the increase of competence in the long run. This situation is clear also to some public bodies, so this is the reason why it is conceivable to obtain special funding for continuing education. The overall economic benefit on the long run might be worth the support given.

10. Conclusions and future perspectives

Relationship between Politecnico di Milano and Gavazzi Space, started from the common origin of the employees and the academics, has been improved during the years through various forms of cooperation. At the moment it is believed that it covers, as far as typology, far more than the average cooperation between industry and University.

In these activities students play an active role in their education, while the Industry takes advantage of the cooperation for basic research, that an SME could not sustain, and University is kept in touch with the most recent developments of space projects.

The number of students involved is at a steady value of 12 per year, while the staff involved for direct research or supervision is of about five with two key persons on each side. This covers only part of the possibilities and part of the specialties of the two partners.

It is here pointed out that the key of the success of the global cooperation is the personal involvement of the persons, rather than the formal agreements between the Directors of the institutions. The latter are a very useful tool to make the former more straightforward and free of beaurocratic constraints.

For this reason, a sure mean to spread the cooperation to all possible topics would be to get more persons of the two institutions to know each other. The maximum effect would of course be produced by a temporary relocation in the partner company, which should at this point be a sort of exchange in order not to weaken one side. The spirit of this would not be to mix the industrial and academic competence, but rather to let the specific skills be well known to the partners, since it is believed that a distinction of competence and skills can represent the strength of the cooperation.

There are well known examples of small enterprises born within an academic institution and then become independent, though still linked to their originating University. The cooperation between Politecnico and Carlo Gavazzi Space is trying to reverse in some sense the process: given a SME and a University, not distant geographically and of comparable dimensions, the idea for the future might be to make one the industrial partner of the other, or one the educational partner of the other if seen the other way round. This approach could have many benefits for both institutions, since in the current situation the request from the developing countries for many space activities is to combine the industrial product with the education on how to manage and develop it.

For the future, there are still improvements possible in many of the activities presented, mostly connected to the need for a greater flexibility and reciprocal opening. Moreover, the stage will be soon in the future compulsory for all the engineering students, not only for the one attending the "Diploma Universitario" courses. This means that an improvement is needed in order to answer efficiently to this need of education on-the-field.

It is hoped that this will come with time as a natural consequence of the spread of the benefits that the cooperation is producing.

As far as new initiatives are concerned, for the next months the activation of a yearly-basis course is planned, partly funded by the Italian Ministry of University and Research (MURST), for a Thermo-Mechanical System Engineer profile.

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Innovative Technologies and Space Applications (4)

Chairman: W. Riedler, Austrian Academy of Sciences, Austria

THE GRAVITY FIELD MISSION GOCE OF ESA: SCIENCE AND APPLICATION

Hans Sünkel
Institute of Theoretical Geodesy, Graz University of Technology
and
Institute of Space Research, Austrian Academy of Sciences
Steyrergasse 30, A-8010 Graz, Austria

Phone: +43-316-873-6346, Fax: +43-316-873-6845
E-mail: suenkel@geomatics.tu-graz.ac.at

Abstract

The Earth's gravitational field is the integral response to the Earth's mass distribution. The rotation of the Earth turns gravitation into gravity. Thus, the Earth's gravity field contains both gravitational and rotational information.

As an integral response the structure of the Earth's gravitational field represents an important source of information about our planet. Its knowledge is therefore an important source of information which is indispensible for a substantial progress in the geosciences in general and in geodesy, solid Earth physics, and oceanography in particular.

The GOCE mission is based on a sensor fusion concept, combining GPS-based orbitography and satellite gravity gradiometry. The two sensors combined will deliver a gravity field with unprecedented accuracy and resolution. The underlying estimation process requires the solution of a superlarge and fully occupied system of about a 100 million equations. A smart solution strategy, based on a pre-conditioned conjugated gradient approach, has been demonstrated as a very powerful processing tool.

The GOCE derived gravity field will provide a global height reference system at the centimeter level, combined with GPS positioning it will provide useful orthometric heights, combined with seismic data it will enable a significant advance in the understanding of the physics of the Earth's interior, and combined with altimeter data it will allow a precise determination of absolut ocean surface circulation on a global scale.

GOCE: Precursory missions

Considering the limited current knowledge of the Earth's gravity field, and recognizing the importance of the Earth's gravity field, space agencies are currently planning dedicated satellite missions which focus on the determination of the Earth's gravity field and its temporal variations with high resolution and utmost accuracy.

The German CHAMP mission, as the first dedicated gravity field mission, is based on the orbitography concept using GPS high-low satellite-to-satellite tracking (SST): the estimation of the Earth's gravity field derived from the accurate knowledge of the satellite's orbit and the STAR accelerometer measurements of the non-conservative forces which act on the satellite. The CHAMP satellite was successfully launched on July 15, 2000 from the Russian launch site Plesetsk.

After its predicted five year of operation it will have provided the static Earth's gravity field on a global scale with a spatial resolution of about 400 km half wavelength and almost homogeneous geoid accuracy of better than 10 cm. CHAMP will thus improve the current knowledge about the structure of the Earth's gravity field in this spectral range by a factor of about 4.

The NASA mission GRACE is based on a sensor fusion approach combining GPS high-low SST with very precise low-low SST between two low orbiting spacecrafts. The Earth's gravity field is estimated from the accurate knowledge of the satellite's orbit and the low-low SST data plus the measurement of the non-conservative forces which act on the satellite and provided by accelerometers. GRACE will be launched in late summer 2001.

After its predicted five year of operation it will have provided the static Earth's gravity field on a global scale with a resolution of about 150 km half wavelength and almost homogeneous accuracy. However, the utmost goal of GRACE is the monitoring of the temporal variations of the Earth's gravity field in the long to medium wavelength range. GRACE will substantially improve the knowledge of the static Earth's gravity field and provide for the first time a time series of the temporal changes of the Earth's gravity field on a global scale with a resolution of about 500 km half wavelength.

GOCE: Mission objectives and realization

ESA is preparing for the satellite mission GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) as the first Earth Explorer Mission with a foreseen launch date in 2004.

Proc. 2nd Conf. Academic & Industrial Cooperation in Space Research, Graz, 15-17 November 2000, ESA SP-470, November 2000

Similar as GRACE, the GOCE mission is also based on a sensor fusion technique in terms of a combination of very precise orbit determination by means of GPS high-low SST and satellite gravity gradiometry (SGG). The mission will be flown in a nearly circular and polar orbit at very low altitude of 240 to 250 km.

GOCE will provide the global Earth's gravity field, represented by the geoid as the unique equipotential surface at mean sea level, with an accuracy of about 1 cm at a spatial resolution of less than 70 km half wavelength.

GOCE: Core instruments

One of the two core instruments is a dedicated GPS/GLONASS receiver which measures pseudoranges and phases from all visible GPS and GLONASS satellites with a sampling rate of 1 sec. The receiver has a dual role: Its data are used to determine the satellite's 3-D orbit with about 1 centimeter accuracy, and orbit analysis yields the long to medium wavelength features of the Earth's gravitational potential. The 3-D orbit positions provide the precise geolocation of the gravity gradiometer.

The other core instrument is a gravity gradiometer, consisting of three pairs of highly sensitive accelerometers, located in cloe vicinity to the satellite's center of mass (COM). The gravity gradiometer measures gravitational and non-gravitational accelerations combined. The inertial accelerations such as linear and angular accelerations (due to air drag and solar radiation pressure) can be extracted from the acceleration measurements by in-orbit real time common mode processing. These inertial accelerations are almost exactly counteracted by the drag free control system using ion and cold gas thrusters, which is required to prevent saturation of the highly sensitive accelerometers.

The signal's gravitational part are second order derivatives of the Earth's gravitational potential. They can be extracted from the accelerometer measurements by differential mode processing. The second order derivatives are used to reconstruct the Earth's gravitational potential in the short to medium wavelength range.

GOCE: Data Processing

The scientific GOCE data processing is a key element of the mission. Considering the gravity gradiometer's sampling rate of 1 sec and a scientifically operational mission length of 12 months, GOCE can be expected to deliver about a hundred million gravity gradiometer data in terms of the elements of the second order gravitational tensor.

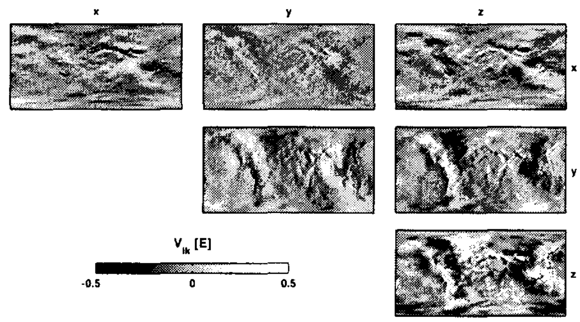

Fig. 1: Observed second order gravitational tensor

The gravitational field, in turn, is modelled by a series of spherical harmonics up to degree and order of about L=300.

$$V = \frac{GM}{r}\left\{1 + \sum_{l=2}^{L}\sum_{m=0}^{l}\left(\frac{a_e}{r}\right)^l \bar{P}_{lm}(\sin\varphi)\cdot\left[\bar{C}_{lm}\cos m\lambda + \bar{S}_{lm}\sin m\lambda\right]\right\}$$

Given the huge number of gravity gradiometer and orbit data, the problem is to optimally estimate the harmonic coefficients. Considering the dimension of both the observation vector and the parameter vector, this (least squares) adjustment problem is a mammoth task of mathematical-numerical type: Given about a hundred million observations in terms of second order derivatives of the Earth's gravitational potential along the satellite's orbit and the orbit itself – determine about a hundred thousand parameters in terms of harmonic coefficients of the gravitational potential plus its temporal variations.

This problem requires the solution of a super-large least-squares adjustment problem which is feasible by applying sophisticated mathematical-numerical techniques supported by massive parallel processing.

The Institute of Theoretical Geodesy of the Graz University of Technology, jointly with the Space Research Institute of the Austrian Academy of Sciences contribute to the GOCE mission through theoretical investigations, feasibilty studies, and the development of processing software, in cooperation with several European academic institutions under the umbrella of ESA. Joint GOCE-related R&D efforts with Magna International Developments Austria / Space Technology are planned.

The data processing software developed by the Graz GOCE team is based on the conjugate gradient method. The algorithm is numerically substantially supported by a smart preconditioning technique which dramatically increases the convergence rate of this iterative solution technique. The processing software is custom-tailored to the specific mission features, and can be considered as a key element in the scientific data processing chain for the GOCE mission.

GOCE: Expected Results

The result of the GOCE data processing will be the Earth's global gravity field as expressed by the geoid as the unique equipotential surface at mean sea level. The estimated geoid will have a shortest half wavelength of less than 70 km and an accuracy in the centimeter range.

Fig 2: The geoid

With a centimeter geoid solution the GOCE mission will satisfy several requirements of the geodetic, solid Earth physics, and the oceanographic community:

- it will deliver a global height reference system at the centimeter level;
- combined with GPS derived geometric heights, it will deliver useful orthometric heights and thus replace levelling;
- it will enable a significant advance in the understanding of the physics of the Earth's interior, in particular if combined with seismic data;
- combined with altimeter data, it will allow a precise determination of the absolute upper ocean circulation on a global scale. This will lead to a substantial improvement in the modelling of the heat budget of the atmosphere/ocean system, and thus in improvement of weather prediction;
- it will provide important information of the temporal evolution of polar ice sheets.

Conclusions

After three decades of planning the geoscientific community will finally see three dedicated gravity field missions be realized, culminating in the GOCE mission of ESA. If successfully flown, GOCE will provide the Earth's gravity field on a global scale with utmost accuracy and resolution. This level 2 product (in ESA terminology) will further be assimilated with other geoscientific data such as altimeter data, seismic data, terrestrial gravity data, sea surface temperature data, etc. and will pave the way into a most exciting scientific era which has one common goal: to understand how system Earth works.

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SATELLITE LASER RANGING: DETECTING SINGLE PHOTONS WITH PICOSECOND ACCURACY

Georg Kirchner
Walter Hausleitner

Austrian Academy of Sciences
Institute of Space Research
Department of Satellite Geodesy

Phone: +43-316-4673-51
Fax: +43-316-4673-41
Email: kirchner@flubpc04.tu-graz.ac.at
walter.hausleitner@oeaw.ac.at

Abstract

At the Satellite Laser Ranging (SLR) Station Graz, distances to about 30 different satellites are measured with short laser pulses - 35 ps - with an accuracy of up to 3 millimeters. The return signals from the satellites - with orbits between a few hundred km and up to about 23000 km above earth - are between single photons and up to a few 1000 photons. To achieve these results, a number of new hardware and software technologies has been developed and implemented in Graz.

A fully automatic data quality control scheme collects the actually measured SLR data of worldwide SLR stations, performs a number of quality checks on these data sets, and provides information feedback for the SLR stations; this ensures reliable, high accuracy SLR data sets for the analysts, and the necessary, fast feedback for the SLR station.

I. SLR Measurement techniques in Graz

1. Introduction

Through the recent 30 years, the accuracy of the SLR technique has been tremendously improved, and it is the most accurate satellite tracking technique available today. About 40 SLR stations are tracking now routinely about 30 different satellites, in altitudes between 400 km and up to 23000 km, and with accuracy between some centimeters to a few mm, depending on station hardware, satellite response etc.

At the Graz SLR station, a number of new techniques, both in hardware and software, has been implemented to achieve measurement accuracy of better than 3 mm for single shots, better than 1 mm for Normal Points, excellent short and long term stability, and significant higher data densities than most other SLR stations.

2. Upgrading the Laser

The laser used in Graz is a flash lamp pumped, passive/active mode-locked, frequency doubled Nd:YAG laser system, producing output pulses at 532 nm with a 10 Hz repetition rate; while the original design delivered 100 ps wide pulses, with a simple passive mode locking dye, we improved this system by shortening the pulse to about 35 ps pulse length, and by adding an active mode locking system, which minimizes amplitude variations to less than 10%. The short pulse length is essential to achieve best accuracy at the single photon level.

In addition, we introduced also a new technique called SemiTrain: Usually, such lasers produce a mode-locked train of 15 – 20 pulses, in constant time intervals according to the laser oscillator dimensions (8659 ps in Graz); only one of these pulses is usually selected, amplified, and sent to the satellite; instead of that, we use all pulses of the second half of the train (usually about 10); this requires slightly more complicated software routines in the post processing, but results in an increase of data densities of 50% to 150%, depending on the satellite, return signal strength etc.

3. Single Photon Detection with SPAD

The return signal from the different satellites tracked by SLR Graz varies from a single photon now and than, up to a few thousand photons per each single shot; to get maximum detection sensitivity, maximum timing accuracy and also maximum dynamic range, we use a Single Photon Avalanche Diode (SPAD), developed and produced at the Technical University in Prague, as a detector; this Silicon Photo Diode has a useful diameter of < 200 µm, thus requiring sophisticated alignment techniques using star tracking to focus all photons

entering the half meter receiver telescope on to the active SPAD surface.
To get the required sensitivity for single photons, the SPAD is operated in the so-called Geiger mode: Short before the pre-calculated time of arrival of the return, the SPAD's operating voltage is set above its break value; any electron now – whether generated by incoming photons or by internal noise – produces a break and creates an avalanche, resulting in a single, uniform output pulse. Thus the SPAD is capable of detecting single photons with a quantum efficiency of about 20%, giving also excellent timing characteristics.
To achieve best possible timing performance, we use a relatively high voltage above break; this results also in exponentially increasing noise (up to some MHz); this would produce a noise break within some 100 ns after applying the voltage above break. To reduce this noise, the SPAD chip itself is placed on a 3-stage Peltier cooler, operating at -60° C; this reduces the noise by at least an order of magnitude to < 100 kHz, allowing range gates for the satellites of 10 µs or more, which is within the predicted orbit accuracy in most cases.
Although these SPADs produce a uniform output pulse at each break, it has been shown that they also produce a significant time walk effect: If the return signal strength increases from single photons up to about 2000 photons, the avalanche pulse of the SPAD occurs up to 240 ps earlier, producing a range bias of 36 mm (Figure 1). We have shown that this dependence on received number of photons not only produces such a time walk effect, but also small variations - about 20 ps for this SPAD - in the rise time of the avalanche pulses; we developed an electronic circuit which uses these small rise time changes to compensate fully automatically all time walk effects over the required dynamic range (Figure 1).

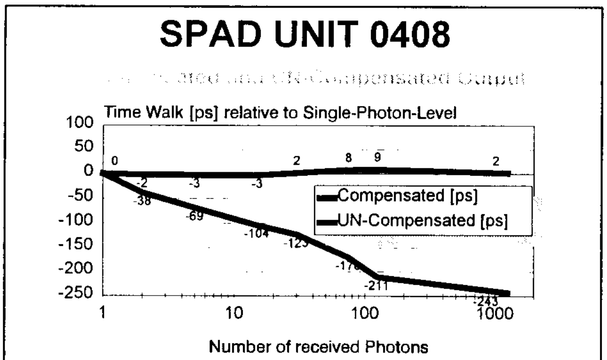

Figure 1: Time Walk Compensation with SPADs

4. Timing with Picosecond Accuracy

During the ranging process, we measure the epoch time of the laser start pulse, and the time interval between start and stop pulse detection.
The epoch timing is done via a commercial GPS Timing receiver, with an accuracy of better than 100 ns; this is fully sufficient for SLR. This device also delivers the required 10 MHz reference frequency for high accuracy time interval measurement.
Almost all SLR stations use a single Time Interval Counter to measure the Time-of-Flight of the laser pulses; this results in limitations of accuracy, inherent non-linearity of the specific counter, some temperature dependency etc.; to avoid or at least minimize most of these draw-backs, we have measured these time intervals during the last years with a cluster of 4 different counters, measuring in parallel, with algorithms to check and control each counter against the others; this allowed not only an improvement of the accuracy (by a factor of 2 for the counters only), but also detection and reduction of counter non-linearity, temperature dependencies etc. (Figure 2).

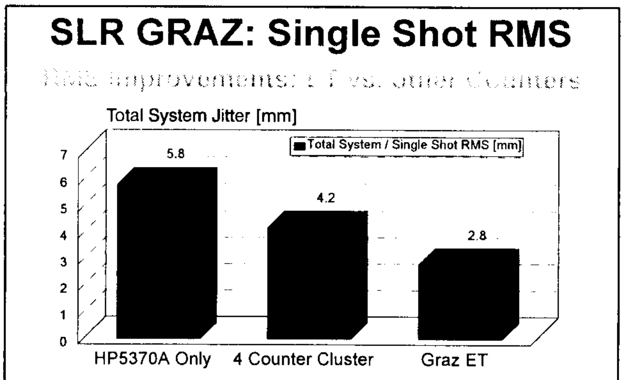

Figure 2: Single Shot RMS to ERS-2, with different Counters

Since a few weeks, we have replaced this counter cluster with a new Event Timer (ET), based on special event timing modules, and implemented with additional electronics, input circuits, power supplies and PC interface in Graz; this Graz ET allows now for time interval measurements with < 2 ps RMS, with non-linearity of < 2.5 ps, very low temperature drifts etc. (Figure 2).
In addition, we have designed and built new pulse distribution systems, which deliver 6 outputs for the fast start/stop pulses to the counters, event timer etc.; it has been designed to minimize jitter contribution (< 1 ps) and temperature dependence (<< 1 ps/°C).

5. MultiColor Satellite Laser Ranging

All SLR measurements have to be corrected for atmospheric refraction; this is done by measuring all relevant meteorological data at the SLR station, and applying a standard model to the data. The accuracy of this correction is usually well below 1 cm, except in some special cases; however, as SLR accuracy at least for Normal Points (see below) is reaching now already the 1 mm level, we are looking for different possibilities to remove this limitation.

One method is to measure the dispersion of the atmosphere along the actual laser path; this can be done by converting part of the laser pulse into different wavelengths, sending all photons simultaneously to the satellite, and measure the time-of-flight of all used colors with an accuracy of 1 mm or better.

In Graz, we have made initial tests with a 3-color SLR system: By converting small parts of the laser energy at 532 nm (max. 60 mJ) by induced Raman scattering into 683 nm (about 10 mJ) and 435 nm (< 2 mJ), in spite of these small energies, we obtained good returns from most geodetic satellites. This proved that even with quite low energies it should be possible to get sufficient high return rates to form Normal Points, which allow the required accuracy of better than 1 mm.

This has been demonstrated by using the 3 colors sequentially, during night time only; to collect sufficient returns – and also to allow daylight ranging – it is necessary to range with all 3 colors – or at least with 2 – simultaneously to any satellite; this in turn requires complete and independent receiver chains for each used wavelength (wavelength filter, SPAD detector, timing device), all with the necessary accuracy. Therefore, we are improving at the moment the timing system by changing to the event timers; adding additional event timing modules – if money is available – and additional SPAD detectors, filters, dichroic mirrors etc. would then complete the Graz MultiColor SLR system and allow simultaneous multicolor ranging measurements with Normal Point accuracy of < 1 mm.

6. Software

The complete software for the SLR station was written in Graz, and runs on standard, low cost PC's; it is designed in a flexible, well structured way for easy improvements and enhancements.

The real time tracking and routine ranging can be done by a single operator; the software is designed for easy operation, and the students employed for this routine job need only a few hours of training to operate the complete, complex SLR system. This real time tracking software performs:

- Automatic calibrations, to evaluate / check / store each hour all relevant parameters of the station;
- Automatic reading / checking / storing of relevant meteorological data;
- Automatic and interleaved tracking of satellites, with easy pass scheduling, and fast pass switching between different satellites;
- Automatic identification of possible returns within the – mainly daylight – noise;
- Automatic optimization of the range gate, which applies the gating voltage to the SPAD;
- Automatic calculation and setting of actual time biases values;
- Automatic tracking optimizations to get as many returns as possible, and to keep the return signal strength between specified levels;
- Automatic offset tracking to reduce return signal strength in case of excessive signals (low satellites);
- Automatic sun avoidance routines to guide the receive telescope around the sun;

All additional programs – for post processing, data handling / checking / mailing, prediction generation etc. are also designed for a high degree of automation.

7. Conclusion

The Graz SLR station performance has been improved continuously since detecting the first returns in 1982, to the present status in the year 2000. The accuracy changed from more than 6 cm at the begin, to the present < 3 mm; while the first passes had usually only a few 100 returns from the satellite LAGEOS, we can have now most times more than 10000 returns, with a maximum of 25000 returns; while we were limited at the begin to night observations only, we are ranging now day and night to all satellites; while the first software package was rather simple and not at all user-oriented, the programs now are doing almost everything for the observer: In many cases, the observer just has to define which pass to track, and the system will do the rest automatically ...

Most improvements were designed and built in Graz by ourselves; thus we built up during the years all the necessary experience to

- Operate / maintain / rebuild ps laser systems;
- Setup optical systems for various purposes;
- Setup and align single photon detection systems;
- Setup timing systems for ultra-fast pulses;
- Build equipment to handle ultra-fast pulses;
- Build equipment for extremely accurate ps time interval measurements;
- Build stable, temperature compensated electronic systems with ps specifications;
- Write convenient-to-use real-time software;
- Write software for data handling / checking etc.

This accumulated know-how is a good basis for future SLR Graz upgrades and improvements, but should offer also significant chances for cooperation with other institutes, and of course also with industry.

II. SLR Data Quality Control

1. Introduction

As today's most accurate satellite tracking technique, SLR makes important contributions to many geodetic and geophysical investigations. The main geodetic applications of SLR are:

- Investigation of the orientation of the Earth in space,
- Geodynamic applications,
- Determination of the Earth's gravity field.

These applications are primarily based on ranging observations to geodetic satellites which are inert, massive spheres solely designed to reflect the laser pulse back to the ranging station. The orbits of geodetic satellites can be computed very accurately, because of their shape and very high mass density which yield an advantageous cross-sectional area to mass ratio and thus minimizes the non-gravitational perturbations acting on the spacecraft. Nevertheless, the accuracy of the orbits is strongly limited by the accuracy of the global SLR data set.

It is therefore a particular concern of both the scientific and the SLR community to deliver SLR data of utmost quality on a global scale. The worldwide network of some dozens of fixed and mobile laser ranging stations is geographically classified into three subnetworks. These are the NASA network, the WPLTN (Western Pacific Laser Tracking Network) and EUROLAS (European Laser Stations).

This global SLR network comprises a quite heterogeneous set of tracking stations from the technological point of view. This fact implicates that the measurements from the individual stations are of different levels of accuracy as well. We therefore implemented a SLR data analysis method which compares the global set of ranging data and judges the accuracy of the individual stations among each other.

2. Range and Time Bias

SLR observations are usually collected at a 10 Hz repetition rate which quickly cumulates to a great deal of data. Therefore these full-rate data are usually transformed to so-called normal points (NP) which are "mean" observations determined by statistical considerations and which represent the full information of the corresponding full-rate data within a certain period of time. The NP generation procedure not only reduces the data volume but also detects and eliminates erroneous data and checks the internal quality of the observations. This is the primary SLR product used by the scientists and analysts for further processing and scientific use.

Normal point observations to the most known and most frequent tracked geodetic satellites - the LAGEOS–1/2 spacecraft - are the basis of our further considerations on the assessment of the tracking quality.

The determination of LAGEOS orbits based on globally distributed normal point observations typically show residuals of a few centimeters to decimeters. There are basically two types of errors or tracking inaccuracies inherent in SLR observations which are described in terms of range and time biases:

- The range bias is a systematic error in the interval time counting, i.e. the measurement of the travel time of the laser pulse which determines the range.
- The time bias is a systematic error in the detection event timing, i.e. an inappropriate assignment of the time tag of the measurement.

Early normal point analyses have shown that there are quite large biases among the different laser systems. The availability of range and time bias values is extremely valuable for the station operators for an early detection and elimination of tracking insufficiencies. Large range biases can be caused by

- incorrect system calibration,
- photon detector problems,
- inaccurate atmospheric refraction model,
- inaccurate station coordinates or other reference points and
- many other optical and electronic sources that systematically affect the overall system.

Time biases are most likely due to

- epoch timing offset,
- event timer instability,
- inaccurate atmospheric refraction correction and
- other systematic effects which are time dependent (e.g. elevation, temperature).

It is very obvious that every individual station of the global SLR network is highly expected to produce zero-biased observations as much as they can.

3. The Data Analysis Method

On behalf of the European laser stations (EUROLAS) the Royal Greenwich Observatory (RGO) started a feasibility study of SLR orbit analysis and normal point quality checks of the EUROLAS stations. G.M. Appleby from the RGO, who performed the study initiated with his work a large era of SLR quality control techniques. In a close cooperation between the RGO and the Space Geodesy Department of the Austrian Academy of Sciences a joint project was initiated aiming at the refinement of the SLR data analysis methods, the automation of the full-scale process and an appropriate preparation of the results for the SLR community as quick as possible. The analysis scheme concentrates on the observations of the

LAGEOS satellites from the EUROLAS stations which are geographically located very close together and provides some 40% of the data volume collected world-wide. This quite dense cluster of near 20 stations provides a unique opportunity to monitor the precision and accuracy of their observations by examining quasi-simultaneous observations from two or more tracking stations of one single orbital arc.
For the orbit determination process we use a software package called SATAN which was developed at RGO.

In the following we focus on the implementation of a fully automated service for routinely performing SLR normal point quality checks.
One basic requirement to make such as system applicable is to realize a high degree of automation.
Since this service is expected to run unattended, i.e. without any manual interaction by an operator at all, the software has to supply itself with all the input data.
On the other hand the information on the quality of the data resulting from the analysis procedure has to be provided to the user and to the observing stations as quick as possible.
For the implementation of the quality information feedback process we make use of state of the art internet services such as e-mailing and web publishing. A clear advantage of sending e-mails in answer to tracking problems is that they are likely to put a slight pressure on the recipients in order to react on the reported problem quickly. Web publishing of the analysis results allows both the creation of complex multi-document presentations, e.g. chronological residual plots and to make use of a large variety of design features to achieve a visually attractive layout.
The automatic system roughly consists of the following main parts:

- Data acquisition
- Quality control
- Information feedback.

The integration of these fundamental tasks into the global SLR environment is outlined in Figure 1.
The three parts of the automatic control system actually consist of several programs:
The **data acquisition** programs collect the data from the individual data sources. This is performed in a sort of polling mode where the individual servers are continuously queried for the existence of new data files. The input data comprise the normal point observations (CDDIS), the Earth rotation parameters (USNO), the initial state vector and other information such as the application of leap seconds, etc. The data to be analyzed are downloaded and provided to the quality control programs.
This part accomplishes the actual normal point **quality analysis** calling the SATAN routines. The analysis is mainly performed in two steps: The long-arc and short-

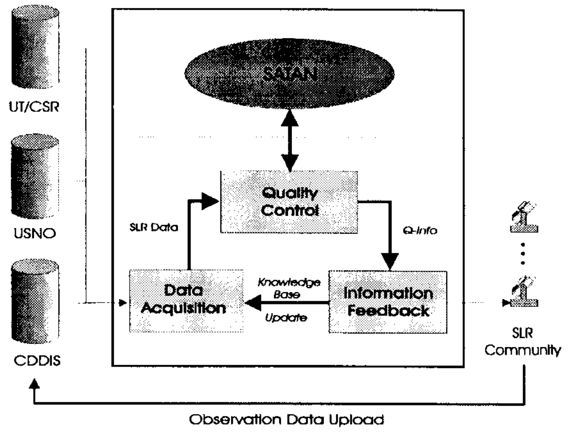

Figure 1: Global structure of SLR NP quality check service

arc orbit adjustment process. The results comprise the short-arc pass biases, i.e. station range and time, but also includes various other statistical information.
This data is then prepared for web-publishing and error sensitive e-mails reporting possible tracking problems are formulated by the **information feedback** programs.
To some extent the system has self learning capabilities. The threshold values used to trigger a mailing event are organized very individually according to the accuracy "usually" to be expected from the respective station. Therefore information is also fed back to the system in order to update the knowledge base used to describe the station characteristics. There are some additional tasks which are very useful in this context: The University of Texas, Center of Space Research (UT/CSR) routinely performs similar analyses using a different method, but also solves for sets of range and time biases. Obviously, the comparison of the UT/CSR solutions with the results obtained from our procedure is of major interest. It goes without saying that an unattended operating system also needs tools for archiving the results and for monitoring the history of the station's tracking quality and its improvement, respectively.

The two main parts of the analysis process will be discussed in some more detail:

The **long-arc process** generates an orbital arc for the period of analysis. One-month orbits of both Lageos satellites are fitted to the normal point data. During the orbit fitting process the initial state vector of the satellite, a solar radiation coefficient and an empirical along-track acceleration are adjusted. In a separate step of the adjustment corrections to the initial set of Earth rotation parameters are computed. A post-fit residual RMS of about 6 cm for both satellites can be achieved where outliers at a 3 sigma level are rejected. Figure 2 shows two plots (from Graz and Matera) of long-arc residuals from LAGEOS-1 and –2 observations. Any systematic trends or outlying points in the observation

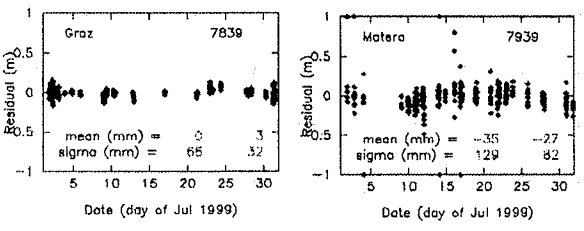

Figure 2: Long-arc residuals from two stations

residuals indicate some biases in the range or epoch measurement, or transient fault in the on-site noise filtering process. The best stations usually produce almost no outliers and show mean residual values close to zero, with standard deviations of about 30-40 cm. This principally reflects the precision of the 30-day orbital model. However, some stations indeed show clear offsets and significant numbers of outlying points. Obviously these residuals could be used to solve for station range and time biases. However, measurement biases determined in this way may be corrupted by imperfections in the applied force model, thus limiting the effectiveness of the long-arc solution for precise determination of system biases.

A **short-arc technique** is therefore applied in the second step which eliminates much of the effect induced by the force model. This method solves for corrections to the long-arc orbit and for station range and time biases. The particular method used here was developed at RGO by A.T. Sinclair and requires that at least two stations quasi-simultaneously track a given satellite pass. For each of these short-arcs a constrained 6-parameter model is used to correct the orbit in along-, across-, and radial direction. However, only observations from a core set of the "best" EUROLAS stations are considered to identify periods of simultaneous tracking. These observations are used to obtain corrected short-arcs with an improved accuracy which usually show a post-fit residual RMS of about 1-2 cm. Figure 3 presents two plots showing the short-arc residuals from two satellite passes simultaneously tracked by several stations. One can clearly see the quite good agreement of observations involved in the left pass and a quite different scenario from the observations of the pass shown on the right hand side.

In the final step pass-per-pass range and time biases are deduced from these residuals. This short-arc technique has the potential to identify subtle biases at the centimeter level and can thus provide an early warning of potential system degradations.

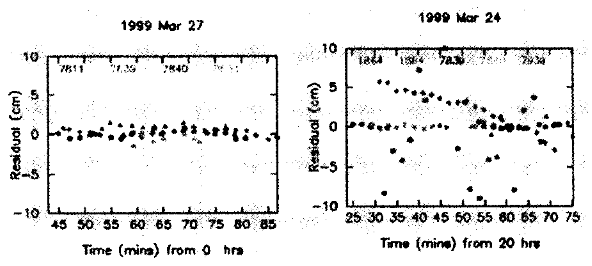

Figure 3: Short-arc residuals of quasi-simultaneous observations of two satellite passes

4. Quick-Look Normal Point Reports

The general concept of providing feedback information on the quality of ranging data as it was implemented in the automatic NP analysis service has proved to be a very efficient way to detect and recover tracking deficiencies in numerous cases. However, the limitations to this concept are that

- due to the application of the short-arc method only simultaneously tracked passes can be considered which make approx. 3-4% of the total amount of observations and that
- alerts are produced only on passes somehow found to be tracked too poor.

Therefore, we decided to go a step further and designed another analysis method which provides pass-per-pass range and time biases for all, even for non-simultaneously tracked passes. These pass biases are merged to so called "Quick-look NP Reports" which are made available to both the ranging stations and the scientific user community. In contrast to the former analysis this procedure does not include a short-arc process, but is solely based on the long-arc orbit adjustment within which range and time bias parameters are solved on a pass-per-pass basis.

A sample of a SLR QL-Report is given in Figure 4.

From a several years of SLR data analysis of both the European and the global data set we found that the Graz-Lustbühel laser ranging facility reaches an excellent performance concerning both the data quantity and data quality. It almost exclusively provides bias-free observations with an enormous long-term stability and thus ranks among the best stations worldwide.

DAILY QUICK-LOOK ANALYSIS REPORT OF 99/10/27

QL · Report for Lageos1/2

STATION		DATE	TIME	SAT	OBS GOOD	OBS REJ	RMS RAW	RMS ADJ	RANGEBIAS (mm)	TIMEBIAS (us)
011	7840	991027	03:09	LAG1	11	0	33	9	5	13
012	7810	991027	15:25	LAG1	16	0	22	17	7	-10
012	7840	991027	15:21	LAG1	18	0	31	9	24	-13
012	7835	991027	19:03	LAG1	14	0	10	6	31	-9
012	7810	991027	22:17	LAG1	14	0	42	10	-34	8
012	7849	991027	20:51	LAG1	13	0	28	7	-15	-3
012	7839	991027	22:11	LAG1	18	0	17	7	-9	2
012	7839	991027	15:21	LAG1	18	0	18	6	7	-11
012	7105	991027	00:31	LAG1	2	0	32	3	2	-4
011	7840	991027	02:43	LAG2	16	0	21	5	23	0
011	7810	991027	16:45	LAG2	18	0	16	13	-6	-1
011	7840	991027	16:59	LAG2	10	0	28	4	6	7
011	7840	991027	20:39	LAG2	16	0	23	4	15	8
012	7835	991027	17:03	LAG2	13	0	32	1	21	-3
012	7810	991027	20:39	LAG2	21	0	12	12	-1	1
012	7849	991027	22:26	LAG2	12	0	15	3	2	2
012	7849	991027	18:27	LAG2	16	0	12	3	-11	-1
011	7839	991027	21:03	LAG2	13	0	14	3	13	-2
012	7839	991027	16:49	LAG2	18	0	17	3	1	4
012	7090	991027	04:47	LAG2	6	0	27	2	37	-19
012	7110	991027	10:09	LAG2	15	0	12	10	9	1

Figure 4: Extract from quick-look normal point report

ILRS Station Performance Cards

In 1998 the CSTG Satellite and Lunar Laser Ranging Subcommission Steering Committee and the IERS Directing Board decided to call for a new kind of cooperation of the international SLR/LLR community in order to

- establish a more formal structured cooperation, to
- improve the operational efficiency of the laser ranging community, to
- define terms on product standardization and to
- support new developments.

This organization, called the International Laser Ranging Service (ILRS), is intended to meet the needs of a global scientific community in an era of diminishing resources by a clear distribution of responsibilities among all the participants. Apart of the role of a pure tracking station the Graz-Lustbühel observatory participated to ILRS as an Associated Analysis Center.

The ILRS quarterly publishes SLR station performance cards which are intended to assess the overall tracking performance in terms of both data quantity and data quality for a variety of satellites. Figures 5 and 6 representatively show an extract of two of the latest station performance cards, demonstrating the normal point accuracy and the bias stability.

This impressively verifies the enormous performance of the Graz-Lustbühel laser site ranking among the world's best satellite laser ranging stations.

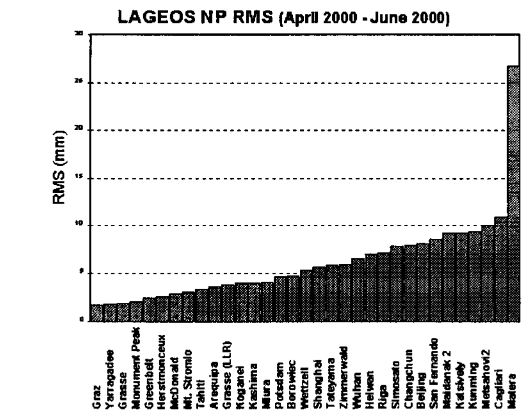

Figure 5: ILRS station performance card on LAGEOS NP RMS

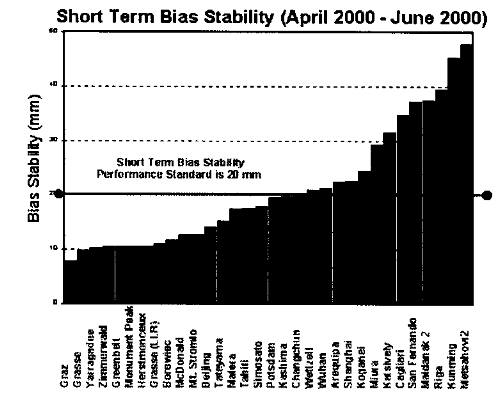

Figure 6: ILRS station performance card on short term bias stability

6 Conclusion

From the very convincing results of the large variety of applications and investigations we finally conclude, that the suggested analysis method in general and the implemented data services in particular are of enormous importance for an improvement of today's SLR tracking capabilities and its integration in solving the very demanding geodetic and geodynamic problems. But it may also be recommended that in an era of cutting science budgets and increasing competition from other space techniques, such as radio techniques, the SLR community has to proceed to improve both the tracking quality and quantity and to reduce satellite tracking costs effectively through an increased level of automation. For the Graz SLR station operation, these goals have been achieved already at a high level.

SATELLITE MULTI-MEDIA SYSTEMS

O.Koudelka, V.Matic, M.Schmidt, R.Temel,
S.Kastner-Puschl J.Ebert, H.Schlemmer, W.Riedler

Joanneum Research; Technical University Graz
Inffeldgasse 12, A-8010 Graz, Austria
Phone: +43 316 465746, Fax: +43 316 463697
Email: koudelka@inw.tu-graz.ac.at

F.Sausen (ND SatCom, D)

J.Hörle (ESA/ESTEC)

Abstract

Due to the enormous growth of the Internet IP-based applications have gained considerable importance. Communications satellites with their inherent broadcast capability have a great potential in delivering high-speed multi-media services to the end-users, particularly in areas with inadequate terrestrial telecommunications infrastructure. Industry is currently very active in the development of multi-media satellite systems which will enter service in the next few years. Skybridge, WEB, Euroskyway and the ASTRA Return Channel System system shall be mentioned as examples. The DVB (*Digital Video Broadcasting*) standard provides an excellent platform to deliver MPEG-II-coded video and IP services. Low-cost receiver equipment compliant with this standard has become available and has successfully entered the market. In the framework of ESA's ARTES program a novel satellite multi-media system based on small VSAT terminals supporting IP and isochronous services such as ISDN has started to be developed. Applications include fast Internet access, integration of corporate LANs, tele-education and tele-medicine.

Keywords: communications satellites, multimedia systems, satellite networking

1. Introduction

The wide-spread use of the Internet has significantly changed the way people communicate. The ever growing demand for bandwidth is however difficult to meet by the operators and service providers. More and more users ask for high-speed access to the Internet. ISDN data rates are already considered slow access. Alternative terrestrial technologies such as xDSL (*Digital Subscriber Line*), cable modems and LMDS (*Local Multipoint Distribution System*) have been or are being developed, promising data rates significantly higher than POTS modems or basic-rate ISDN. Fibre to the home (which provides nearly unlimited bandwidth) is still too expensive. Many new multi-media applications require high bandwidth which is however not available in many areas. Even in the US there is a surprisingly high number of places where about 20 kbit/s over a telephone modem is all the user can get. This is due to relatively thinly populated areas, where high-speed Internet access via cable is economically not justifiable and where ADSL is not feasible because of too long distances to the next exchange. Satellite communications systems can provide efficient solutions there. Compared to terrestrial networks, even to high-capacity fibre-optics systems, the satellite has an important advantage, namely its inherent broadcast capability. New broadcast/multicast protocols and applications benefit from this capability. When making proper use of the broadcast feature, the performance of the satellite-based system compares favourably to many terrestrial solutions. Internet-based applications are highly asymmetric, making them well suited to satellite-based communications systems.

The DVB/DAVIC (*Digital Video Broadcasting*) standard, originally developed for the distribution of digital TV by satellite or cable has been widely accepted. It has been realised that DVB is also a very suitable platform to transport IP packets. This way interactive multimedia systems can be created which use the MPEG transport mechanism. Such systems have been adopted for satellite interactive terminals and terrestrial wireless broadband access (LMDS).

2. Multi-media Developments

ESA considered the emerging multi-service satellite market as an important area already at an early stage. At the beginning of the 1990ies a contract was awarded to the Institute of Applied Systems Technology (IAS, Joanneum Research) and the Institute of Computer Science of the University of Salzburg to study network integration via satellite and to develop a prototype. IAS has been active in the area of integration of local area networks by satellite together with the Rutherford-Appleton Lab. (UK) and the Istituto CNUCE (I) since 1984. An experimental system called SATINE (*Satellite Internetworking Experiment*) was developed which was demonstrated at the EUTECO conference 1988 and at ESA's OLYMPUS Utilisation Conference in 1989. It

supported the interconnection of 80 Mbit/s LANs with ring topology which had many features of an ATM backbone. Digital voice and video were transported together with computer data over same network infrastructure. A dynamic TDMA access scheme was utilised to share the satellite capacity efficiently [1].
Starting in 1992 within ESA's ASTP-IV program a single-frequency TDMA satellite communications system supporting multi-media applications has been elaborated by Joanneum Research and University of Salzburg in collaboration with Technical University Graz [2],[3]. Emphasis was laid on standard LANs, e.g. Ethernet, standard protocols (particularly the IP protocol suite), ISDN and widely used applications such as file transfer, database access, email and video conferencing. The burst modem was procured from Nortel Dasa (now ND SatCom). This modem was developed for the successful SkyWan/ABCS VSAT product.
Thus, the first contacts were established between IAS and ND SatCom.
With the increasing importance of the Internet and the wide-spread use of the World Wide Web the activities were also focused on the efficient use of TCP/IP via satellite links. Despite the common belief in the early 90ies that TCP/IP will not work over (geostationary) satellite links with long propagation delay and comparatively high error rates in case of rain fading, considerable effort was put in the first studies into the investigation of the behaviour of TCP/IP in this environment. It could be shown that a few adjustments of protocol parameters can provide high throughput even in networks with high product of bandwidth and round-trip time. The window size is the crucial parameter. Many standard implementations of TCP/IP use a window size of 4 KB which limits the throughput to 64 kbit/s in case of a round-trip time of 512 ms (overall reaction time on a geostationary satellite channel), irrespective of the link speed. Increasing the window size to 64 KB provides already a throughput of 1 Mbit/s. Measurements of the error behaviour showed another interesting result. Using a satellite channel with a data rate of 2 Mbit/s, error rates of 10^{-8} or better did not result in any noticeable degradation in throughput. At a BER of 10^{-7} the throughput decreased and at a BER of 10^{-6} the performance dropped to an unacceptable level. Link budget calculations for typical satellite systems such as EUTELSAT or INTELSAT showed that error rates better than 10^{-8} can be achieved with an availability of 99.5 % of the time with rather inexpensive VSAT terminals (assuming dish sizes of 2.4 m and 16 W SSPAs) [4],[5]. Even much better robustness in the satellite environment could have been achieved using RFC 1323 and Selective ACK TCP/IP stack implementations.

The prototype system was completed in 1997, tested extensively over Ku- and Ka-band satellites and demonstrated at international conferences and in a field trial by EUTELSAT [6],[7]. Even a small series of gateways was produced together with an Austrian company. Satellite gateways were sold to EUTELSAT and Telekom Austria (Fig.1).

IAS became also active in 1996 in the EU project CRABS (*Cellular Radio Access for Broadband Services*) which had the aim of defining and demonstrating an interactive terrestrial LMDS network for TV, fast Internet access and tele-teaching applications. It became apparent that the gateway architecture could be easily adapted for the requirements of LMDS [8],[9]. The VSATs were replaced by 40 GHz terrestrial radio link transceivers. A burst modem was implemented which could cope with the worse frequency stability and phase noise performance of the LMDS front-ends. Some modifications of the dynamic TDMA access scheme had also to be made. Telenor procured several of these special gateways and has been using them since 1998 in a tele-education trial in Norway. The interesting aspect in this scenario is the combination of a DVB forward link and a TDMA return link based on the modified satellite gateway, an architecture which has been adopted by ETSI for interactive LMDS and satellite systems.

The CRABS project is a good example of a spin-off of technology, developed originally for satellite applications, into terrestrial applications.

Based on the developments and the experience gained in this project, ND SatCom and IAS prepared a joint proposal for the new ESA program ARTES-3 which has been established to increase the competitiveness of European industry in the field of satellite multimedia technology and services. A contract was awarded to the consortium, with ND SatCom as the prime contractor and IAS as subcontractor. The aim of the project was the development of an advanced Multi-Frequency TDMA system which enables to increase the network capacity significantly without changing the transmission parameters, like the antenna size and the transmit power which would otherwise increase equipment cost.

3. The MF-TDMA System

Access to the satellite network is provided by a versatile gateway with scaleable architecture (Fig.2). The core of the gateway is a cell MUX (multiplexer/demultiplexer). Various network interfaces for LAN, ISDN PABXs and devices such as video codecs are connected to the cell MUX. Data from these interfaces are segmented into fixed-length cells and assembled into transmission bursts by the burst assembly module. The cell size has been optimised to ensure minimum overhead and high bandwidth efficiency. Concepts of ATM (*Asynchronous Transfer Mode*) have been adopted to guarantee quality of service. Full compatibility to ATM was not considered suitable since this would have resulted in unacceptable overhead. Furthermore, interest in ATM in the local area had declined towards the end of the 1990ies. Nevertheless, this technological heritage enables full support of Quality of Service (QoS) guarantees for real-time and other types of performance-critical traffic, opening a door towards implementations of QoS-aware IP routing and switching protocols such as IntServ, DiffServ and MPLS.

Capacity on the satellite transponder is assigned two-dimensionally, in time and frequency (Fig.3). The type of traffic, priority and quality-of-service requirements such as delay and delay variation are taken into account.

Centralised control for dynamic capacity assignment is used. The access algorithm in the central master station distributes the available bandwidth periodically among all active stations. The decision is based on the bandwidth requests by the traffic stations. Thus, channel utilisation is optimised.
Central control and monitoring functions, controlled through a standard SNMP interface, are carried out by the master station which is also responsible for synchronisation of all traffic terminals. Configuration, performance, fault and accounting management of individual network elements/stations, as well as whole end-to-end network services is planned to be implemented using the SNMP v2/v3 protocol and commercially available network management tools such as HP OpenView.

Multi-frequency TDMA has the advantage of high network capacity by maintaining moderate transmission parameters for each individual earth station. The frequency agility of the burst modem, developed by ND SatCom, allows to hop between transponders, allowing to efficiently utilise non-contiguous satellite capacity.

Powerful forward-error correction coding has been implemented to guarantee high satellite link performance at low transmit poweror. Convolutional coding with Viterbi decoding as the inner coding scheme and an outer Reed-Solomon code has been chosen. The single-frequency version of the system supports a user data rate of nearly 2 Mbit/s, while the new MF-TDMA version provides up to 3 Mbit/s with identical transmit parameters of the VSAT teminals. In addition, the data rate may be varied from burst to burst. This allows including smaller and cheaper stations in the network with lower channel capacity requirements on the uplink. The new gateway is shown in Fig.4.

For 2 Mbit/s transmissions VSATs with an antenna size of 1.8 - 2.4 m, a nominal G/T of 25...28 dB/K and an 8...16 W SSPA can be utilised, assuming EUTELSAT-SMS type transponders. For higher data rates or edge-of-coverage operations SSPAs with an output power of 40 W have to be considered [10].

4. Applications

Typical applications of the system are

- Business Communications (e.g. connecting a branch office or bank in areas with inadequate terrestrial infrastructure to other offices). In contrast to many conventional VSAT systems fully meshed connectivity at high data rates, offering voice, video and data communications is provided.

- Tele-Education: the efficient support of mixed media traffic offers all communications facilities needed for linking classrooms in different locations, providing full interactivity between sites.

- Tele-medicine: the high-quality voice/video services can be utilised for tele-consultancy between experts, monitoring of on-going surgery and tele-training. The data services are beneficial for supporting e.g. filmless radiology and transfer of medical images (CT, X-ray).

Since the IP protocol suite is supported, all standard applications such as WWW browsing, file transfer, remote log-in, database access and Email can be used, as well as new multicast/broadcast applications. The combination of video conferencing with application sharing, widely requested by users, is well supported by the system. Tele-medicine trials have been successfully carried out in cooperation with the Central Hospital Graz. 3D computer tomography images were transferred via the system at high speed, while medical experts could discuss the case in real time using the video conferencing facilities supported by the system in parallel.

While the earlier version of the satellite communications system used hardware-based video codecs for video conferencing, more recently, IP-based software conference systems have been used since the quality has increased quite remarkably and the costs for the infrastructure are significantly lower.

5. New Developments

The system described before is a typical state-of-the art VSAT system for business users or larger organisations sharing a common infrastructure. This section describes current research activities by IAS which are carried out under an internally funded project. As mentioned earlier, low-cost consumer equipment based on the DVB standard for satellite services has entered the market. For a few hundred Euro a digital set-top box or PC card can be purchased. DVB can deliver up to 40 Mbit/s downstream. IP packets can be encapsulated in the 188 byte long MPEG transport cells, thus providing a fast delivery mechanism from server to client with the advantage of low-cost hardware on the user side. Return links can be provided by different means. The most simple form is a POTS modem or ISDN link. This method is used by the DirecPC system. Using advanced multicast protocols such as the SiMPLE system developed by University of Salzburg, the requirements for the return link capacity can be minimised. Only requests for downloads need to be sent, while not each packet needs to be acknowledged as in a TCP/IP connection [11].

Another scenario involves a satellite return channel. DVB-S can be used for the method for the downlink, MF-TDMA is used in the return link. The integration of the DVB receiver with the MF-TDMA transmitter in the user terminal has a number of advantages. In the outbound direction, the data are multiplexed in a continous TDM stream avoiding any overheads for burst synchronisation. In a conventional TDMA or MF-TDMA system each burst has to be demodulated individually. This requires a rather long synchronisation preamble for the demodulator which can lead to non-negligible overhead if short bursts have to be transmitted. When the main application of such a system is Web browsing, short packets (40 bytes) will dominate in the traffic pattern from client to server. This will lead to low efficiency with respect to the usage of the return link satellite capacity.

When the downstream is based on DVB then each terminal will receive a continuous data stream. From this received data stream a clock signal can be derived which is distributed by the central station. Since all user terminals are essentially locked to this common reference, the situation for carrier and clock synchronisation in the MF-TDMA demodulator of the central station is considerably improved. Short synchronisation words at the begin of each burst are sufficient, reducing the transmission overhead and making short burst transmission efficient. Furthermore, the local oscillators in the user terminals can also be locked to this common reference, reducing the frequency uncertainties and the procedures for aligning frequencies which is a non-trivial problem in a conventional TDMA system. In addition, the reference burst to be transmitted by a master station in a standard TDMA system can be omitted, when a time marker indicating the begin of frame is inserted in the MPEG transport stream at regular intervals instead. The burst allocation plan is also broadcast to all stations and can be embedded into the MPEG transport stream. All this reduces the complexity and subsequently the costs of the user terminal. IAS in collaboration with the Department of Communications and Wave Propagation of TU Graz (INW) has been testing the integration of DVB forward link systems with TDMA return links, combining standard DVB PC cards with the existing single-frequency satellite gateway. In the ESA project ILSE this has been demonstrated with a large European organisation as a user by Telekom Austria, University of Salzburg and TU Graz. High-speed Internet access, transfer of large data bases and video conferencing was successfully demonstrated.

6. Cooperation between Industry and Research Organisations

Informal contacts between ND SatCom and IAS existed already in the development of the single-frequency TDMA system, since ND SatCom and IAS used the same modem. In the ARTES-3 project close collaboration was established. The system definition was carried out jointly. ND SatCom provided inputs taking into account the user and commercial requirements. This was highly beneficial to the project since ND SatCom has the experience of more than 1000 VSAT terminals operational in the field. The hardware platform was defined in co-operation and a common processor, operating system and software development system chosen which made the development process and exchange of elements of the system easy. In the actual implementation there were however differences.

ND SatCom required backwards compatibility with the ABCS/SkyWan product, while IAS was interested in a novel multiple access scheme and networking environment. A major outcome of the project which was successfully completed in April 2000 is the MF-TDMA controller, implemented in an FPGA which is the core of both the new SKYWAN product and the system developed under the ESA contract.

The collaboration was very fruitful. IAS profited from the industrial expertise of a major VSAT manufacturer while ND SatCom received innovative inputs from an experienced research organisation.

It is intended to continue this kind of collaboration between industry and academia whereby IAS will concentrate on the development of new concepts and algorithms, and the industrial partner takes care of product industrialisation and the commercial aspects.

7. Conclusion

The multimedia satellite system developed under ARTES-3 offers higher data rate satellite terminal equipment, suitable to provide multimedia services, particularly where the terrestrial infrastructure is less developed. Standard VSAT front-ends can be utilised to enable competitive terminal prices. The system is compatible with any transparent ("bent-pipe") Ku-/ Ka- or C-band system and can therefore be used in nearly all areas of the world. Novel broadcast/multicast protocols exploit the broadcast nature of a communications satellite. The efficient bandwidth-on-demand access scheme allows dynamic share of capacity and cost-efficient usage of the satellite resources, even if the bandwidth is fragmented and distributed over several transponders. Further developments of the system will include additional network interfaces and protocols, standard network signalling systems and combinations with DVB forward links, advanced coding and synchronisation methods.

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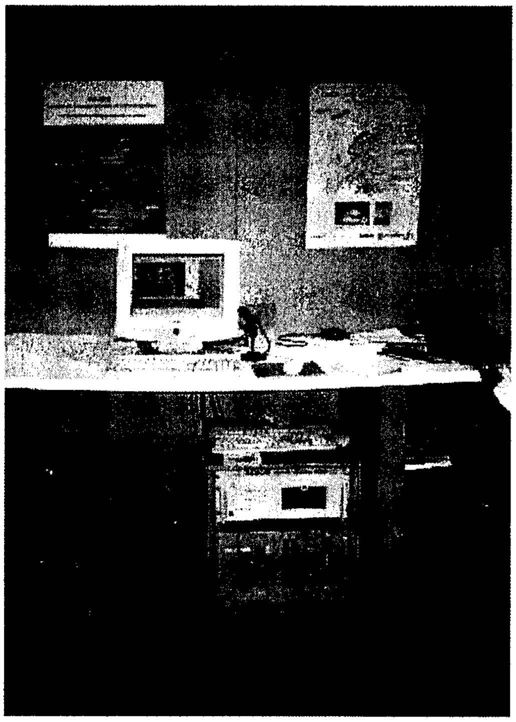

Fig.1: Prototype Satellite Communications System with Applications PC at the UNISPACE III Exhibition

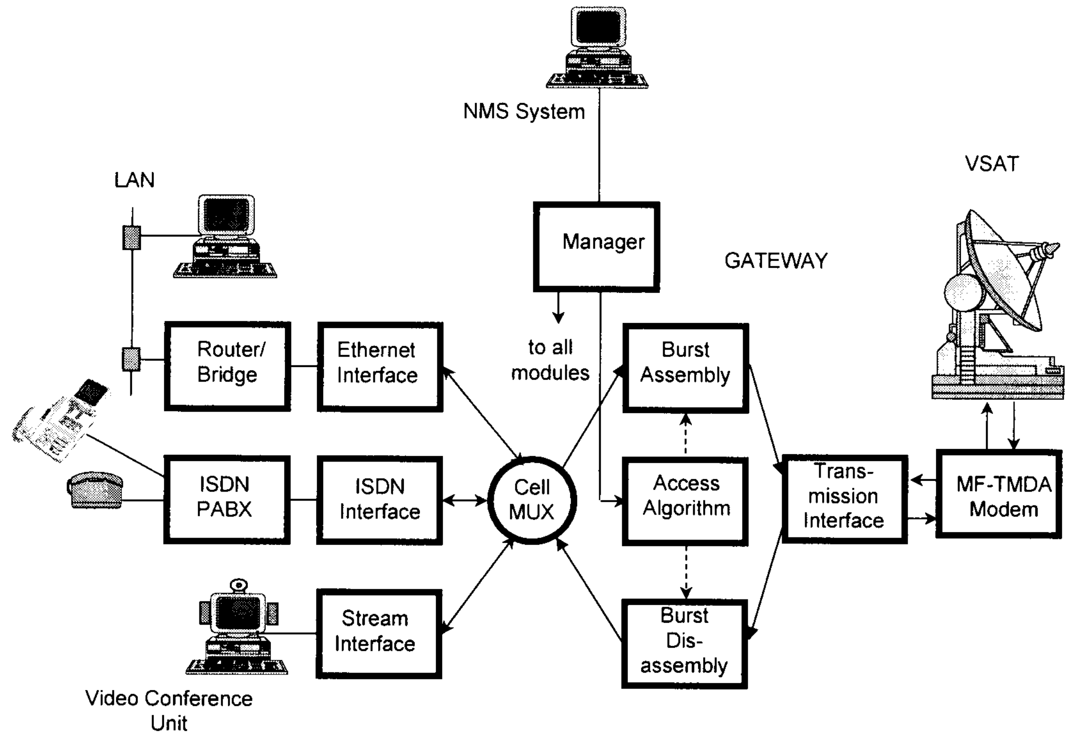

Fig.2: Architecture of the Satellite Gateway

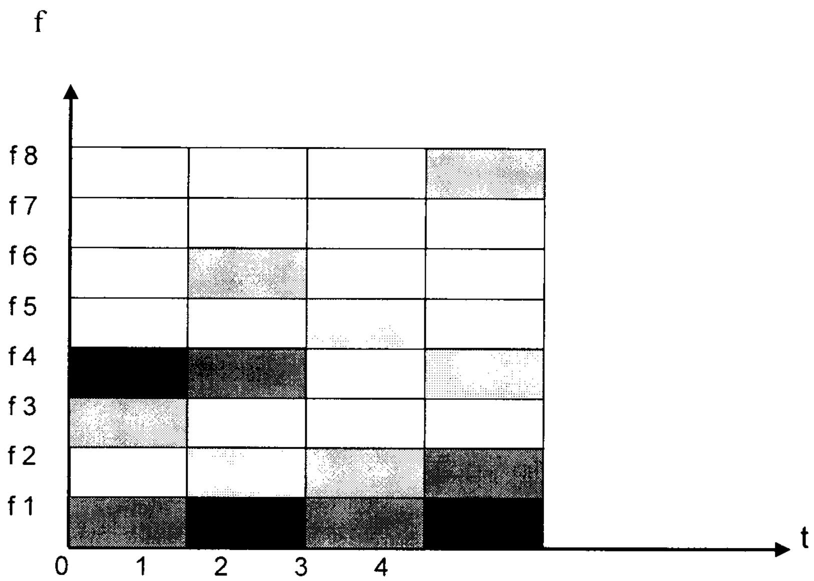

Fig.3: Principle of MF-TDMA Capacity Assignment

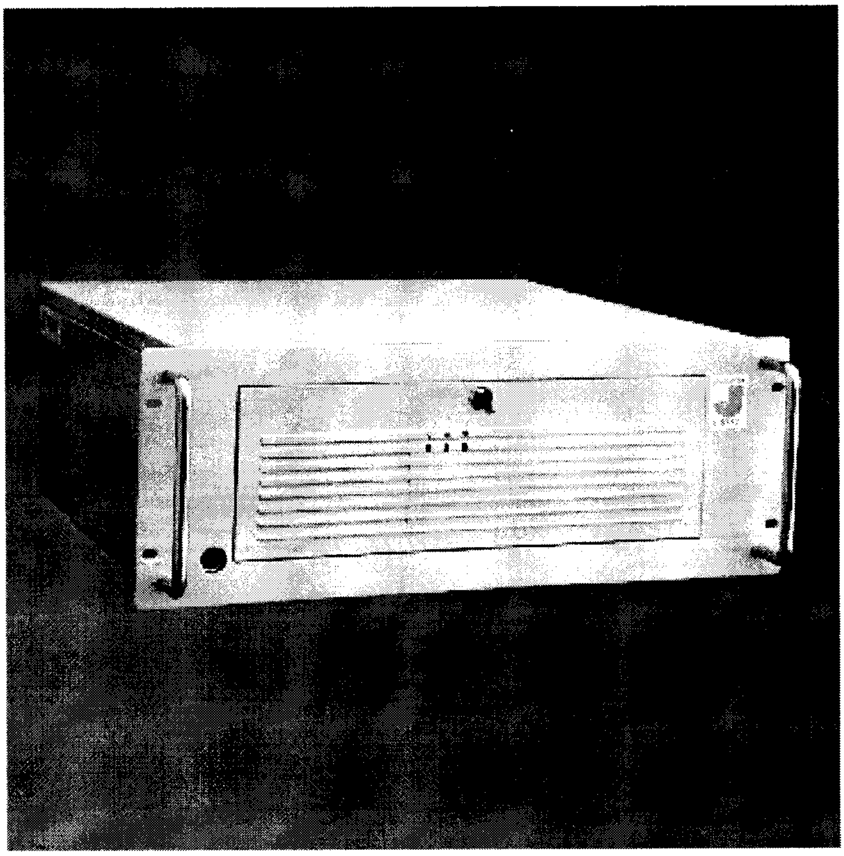

Fig.4: MF-TDMA Satellite Gateway

Other Forms of Cooperation

Chairman: W. Riedler, Austrian Academy of Sciences, Austria

WEB RETAILING OF INNOVATIONS FROM TECHNOLOGY INSTITUTIONS: AN INTERNET APPROACH TO THE MARKETING OF KNOWLEDGE

Hans Rijckenberg
Managing Director
Knowledge Sharing Systems Europe
Weena 257
3013 AL Rotterdam, The Netherlands

T +31.10.412.6078
F +31.10.412.6079
E hrijckenberg@knowledgesharing.com
U www.knowledgesharing.com

Abstract

This article centers knowledge management and technology transfer. Intermediary organizations are facing several barriers and inefficiencies in transferring technologies from the supply side to the demand side. Knowledge Sharing Systems designs, develops, maintains and operates Internet-based knowledge sharing systems that manage intellectual capital and share knowledge. Knowledge Sharing Systems has developed and implemented TechTracS, the automatic knowledge management and transfer system of NASA. Through NASA TechTracS internal and external partners gain insight in technology opportunities and potential spin-offs. Like NASA, academic institutions have difficulty in managing their knowledge transfer process because the process is inefficient and expensive. Web retailing of innovations is an effective strategy that will return numerous benefits. The space sector with all its succesful spinoffs is likely to be a source for innovations. ESA and its technology partners offer a unique sharing of knowledge and to achieve a common strategic goal. By the integration of information systems, knowledge management practices and the Internet into a knowledge network, the technology transfer process could improve.

1 The economy of advanced knowledge

1.1 Know-what, know-who, know-how, know-now

Knowledge is the main economic production factor. In the knowledge economy, all actors need specific knowledge at an appropriate time and location. What advanced knowledge comprises of is not easy to define. Often a difference is perceived between basic knowledge and practical know-how. A definition in tacit (implicit) and codified (explicit) knowledge is another way to distinct knowledge. A party which requires sophisticated knowledge cannot easily find a specific knowledge owner. Especially innovative companies are facing this constraint. Modern enterprises are urged to keep up to date with the latest scientific research and technological developments. Staying tuned with latest developments is the base under permanent innovation. The transfer of knowledge, of vital importance in the network economy, is a people business. Although most business activities are becoming footloose because of the Internet, most knowledge transfer needs face-to-face contacts. The knowledge society depends on a culture of learning and doing.

This article centers the management and transfer of technology knowledge. In the current situation advanced knowledge is being disclosed by specialized intermediary institutions. Such intermediary organizations are facing several barriers and inefficiencies. It is apparent that all available knowledge created is not always being use effectively. The problem is that intermediaries still cannot provide an optimal mode for knowledge transfer. The higher the complexity and cost, the more difficult it is to disperse the knowledge. Due to high transaction costs incurred by the labor intensive process, transfer managers loose precious time in capturing, managing and disseminating the technology knowledge produced by companies. Often the developer of knowledge is not the same person as the entrepreneur. The transfer of knowledge becomes a business in itself, as its economic potential is more and more recognized, besides societal considerations. Small high-tech companies sometimes need specific advice on one technical aspect e.g. the specifications needed for a certain polymer-recycling unit. However, in most cases the questions are quite general, as technological firms often need business advice and non-technical firms need basic technical advice. Questions range from which material to use for a product or how to solve certain technical problems, to what price to ask and how to market. Some sectors are more strategic for new business ventures than other sectors. A web tool that automates knowledge transfer can overcome all such constraints.

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1.2 Knowledge infrastructure

Knowledge infrastructure comprises of universities and other advanced knowledge producers like public research facilities and private laboratories. In the following we discuss these knowledge producers.

1.2.1 Universities

In the past years the role of universities in local and regional economic growth has received increased attention. Universities are involved in various activities such as the creation of new knowledge, the education and training of students and in supplying channels and meeting places for networking. In general, a university has three basic functions:

1. an *educational function*, to teach and train students
2. an *scientific function*, to conduct research in order to improve science and technology
3. an *economic function*, to provide an economic basis to a region, which is not apparent in all countries.

Since the economic role of universities and other knowledge organizations is recognized, the focus on the institution's economic output grows. The traditional exploitation model of the academic output of universities displays the patenting and licensing of academic knowledge. Universities deploy technology transfer agencies (TTA) or technology licensing offices (TLO) to establish and process links with industry. These offices provide services for contracts, patents and licenses. A particular type of academic transfer institutes is found in the United States. American technology licensing offices bring inventions to the market by activities such as evaluation of invention disclosures, filing of patents and identification of companies potentially interested in licensing. They essentially connect academic inventions, venture capitalists and companies. All these different types of cooperation are referred to as knowledge transfer. There are several options available for knowledge transfer:

- *Consultancy.* An advice of a member of the scientific staff to an external customer
- *Graduate research.* Supporting research by engineering students supervised by professors of the scientific staff
- *Contract research.* Fundamental or pre-competitive research elaborated by new research staff and graduates, supervised by the routine scientific staff
- *Facilities.* Usage of university literature search facilities, laboratories and equipment
- *Software and patents.* Development of new software and patents for the commercial market by itself and in cooperation with external partners
- *Start-up and spin-off companies.* Encouragement, stimulation and growth of new businesses based on academic knowledge.

1.2.2 Other advanced knowledge producers

Producers of advanced knowledge exist in public and private form but most knowledge producers have a status as public institution. The academic environment has been created for learning and research. As such, the drive to exploit this knowledge never has been priority in the perception of individual knowledge workers. Governmental institutions bear the image of being ineffective and expensive. Numerous public servants who act as innovation disseminator find their roots in technical professions, law or public service. As they are often coming from other sectors, they cannot be blamed for not being in possession of skills in knowledge transfer. This is a new field in which no curriculum exists yet. Moreover, academic and government environments are not subject to market forces. These communities lack time or have no interest in serving the market. Current modes for knowledge transfer do not release the available knowledge from this context. Therefore innovation is needed in the perception of universities by the outside world, and moreover in the attitude towards the market by universities. An increase of start-ups and spin-offs out of universities play an important role in this process.

Large organizations such as companies and universities can play a substantial role in the creation of knowledge-intensive new companies. However, governments have to provide the incentives for these organizations to actually take part as it is not their main function. The best results will be achieved if cooperation among these institutes will take place in a network structure, which can be adapted to different circumstances. Successful cooperation takes into account the character of the university and the wishes and capacity of the transfer partner concerned. This approach will offer an optimal support structure for spin-offs in which all the missing elements are provided.

1.2.3 Regional knowledge networks

Cooperation between universities, companies and government appear to create a better position for entrepreneurial innovation. Modern enterprises are urged to keep up to date with the latest scientific research and technological developments. Knowledge transfer plays a vital role in this process. To fulfill this need, knowledge institutions are member of knowledge networks. Public and private partners are building regional knowledge infrastructures, networking with knowledge institutions and business. These networks exist in a functional and a territorial form. The term knowledge network denotes a set of nodes together with the links connecting the nodes. Functional knowledge networks consist of special interest groups in specific sectors. Territorial knowledge networks are regional collaborations comprising clusters of actors and activities. In a network approach to universities as urban nodes of knowledge creation, growing attention is given to the analysis of barriers to networking. The potential barriers to networking between universities and the business world can be summarized as follows:

- Small interest in commercialization of knowledge among university academics
- Different aims and lead times of research projects in universities and companies
- Competition and missing links between knowledge sources and intermediaries
- Lack of transparency and appropriate imaging of universities as a source of knowledge
- High transaction costs in translating academic inventions into market products.

The innovation diffusion theory has stated that the higher the complexity and cost, the more time it takes before a technology has reached all potential adopters. The complexity of knowledge networks requires a thorough coordination by local and regional governments. Knowledge networking by companies can adopt different types of organizational modes. Important dimensions are the strength and duration of the ties, associated with different levels of organizational interdependence. From a company perspective, a distinction can be made between casual links with small interdependence (such as short-term consultancy) and links that involve a tight cooperation (such as joint ventures). Empirical studies in various university cities have revealed an overall preference of companies for casual and short-term links with local universities.

The consulting on transfer of know-how and innovation matters involves several actors. Governments, universities, venture capitalists and companies have different roles to play. These actors usually have diverse aims in relation to knowledge, such as improving the competitive edge (firms), the creation of knowledge-intensive jobs (local governments), academic challenges (universities) and profit maximization (investment funds). In addition, the principal actors may perform different roles at the same time. Universities are involved in many activities such as the creation of new knowledge, education and training, and supplying channels (meeting places) for networking. Local governments mainly focus on solving unemployment in their own region, while universities aim for scientific development globally. The interest of companies is mainly targeted on profit and continuity which holds no geographic interest in particular. National government can overcome the barriers by actively coordinating the participation of the relevant parties in these projects. Cooperation in regional networks can be an important improvement to solve the knowledge gap.

1.2.4 Knowledge dissemination by universities

In the regional context there is a need to improve the interaction between universities and business, particularly small and medium sized enterprises (SMEs). Accordingly it is important to qualify the transparancy of academic services and their accessibility. On the other hand, it needs to be emphasized that SMEs achieve most of their practical know-how from other companies, particularly their suppliers and customers. Possible policy instruments for bridging universities and SMEs are:

- establish a service centre for spin-off and start-up companies where academic knowledge can be made accessible, to be managed on a joint basis by universities and companies
- increase the popularity of knowledge transfer by academics to spin-off and start-up companies, for instance by offering incentives
- disperse innovations and new ideas among spin-off and start-up companies by means of meetings and publications
- combine spin-offs from universities and large companies in joint programs and accommodations
- create regional knowledge circles with manufacturers, suppliers and clients as well as universities in order to communicate market-driven research issues
- disclose available expertise electronically by databases and Internet. This solution is presented in Chapter 2.

Knowledge transfer of universities and other scientific institutions to public enterprises are determined by concept. Current solutions for external constraints in knowledge transfer always offer geographically oriented approaches. Some regions possess optimal environmental qualities for innovating activities. Such an environment requires adaptional changes by politicians, entrepreneurs and university researchers. An innovative environment depends on interacting systems; the network of entrepreneurs, research and political decisionmaking. Such an environment requires four major assets:

- human resources by continuous training, education and specialization
- evolution of new technology through research, development and consultancy
- facility management in laboratories, nurseries and services
- spin-off support for new ventures and start-up companies

The geographical format of innovative environments exists in several models. Science -, brain -, business -, trade - and other activity parks appear in an imagination building typology. Such parks generate new activities and provide an optimal situation for research and development, knowledge transfer and application. Organizational and spatial aspects are evident for the succeeding of a technology park. However, when implementing a regional development perspective one cannot forget that spatial integration of a technologically advanced research park is not the same as copying another successful concept, merely of (re)activating potentials which already exist.

1.2.5 Knowledge infrastructure spin-offs

The knowledge infrastructure is recognized as a source for new business. Ideally these institutions foster the process of incubation, development, transfer and exploitation of knowledge. The best place for the incubation of academic spin-offs is the science or technology park. Most universities do not consider themselves as a regional booster for new jobs or a facilitator for new business. As their financial situation has changed, new types of cooperation are sought which force universities to engage in external partnerships. In some countries like the Netherlands and the United States this is already common. In general, the transfer of know-how takes place in various ways. An efficient way is to transfer the bearer of know-how himself and to give him the necessary support to grow into an innovative entrepreneur. The occurrence of such spin-offs can happen because of offensive or defensive reasons or a combination of both. The stimulus can be a declining economical climate and institutional restructuring, or the possibility of innovation, or new business activities. The growth of start-ups and spin-offs comes from larger companies, but also from universities and research institutes. Spin-offs are carriers of knowledge and experience. Their importance is being recognized in large extent.

The improvement of spin-offs from universities faces cultural differences. Academics focus on the long term and are science driven, while enterpreneurs are business driven and are interested in short term profits. The lack of entrepreneurship does not only exist among researchers and scientific students as well as business school students who look for position in big companies rather in spin-off and start-up companies. It appears that they don't have an idea but know well how to sell something. Bridging the two skills is only being operated in a few universities, with MIT and Stanford as the champions. Lessons learned from these spin-off environments generate the following insights. In general, three types of spin-offs take place:

a. Individual employees who start their own company

Individual employees who start their own company based on know-how (experience and knowledge) acquired with their previous employer such as a large company. It can also be another large knowledge intensive organization such as a governmental agency or a university. In practice, it is often quite difficult to make the initial transition from being an employee to becoming an entrepreneur.

b. Spin-offs through privatization

Spin-offs in the format of individual employees who start their own company are relatively uncomplicated in comparison with whole departments, which want to or have to go their own way. These spin-offs need extra support to make survival possible for these companies in the way of long-term contracts, e.g. from 3 up to 7 years. They have a need of a long-term contract with the mother company in order to gain time to be able to develop their own market.

It is clear that it is often easier for a large company to contract the work out to existing companies than to stimulate spin-offs, which often have to start in a saturated market and with relatively expensive employees. However sometimes there are no existing companies to contract the work out to or inside the large company organization the commercial activity can not develop to its full potential. This is often the case in countries where restructuring of industry is taking place. Spin-offs can than be a good alternative for the large companies also for those employees who want to become entrepreneurs. They can develop their new venture in an existing network to the benefit of both parties involving a flexible, relatively cheap contractor.

c. Know-how transfer from research projects

A third type of spin-off is when the know-how of research projects is transferred to interested employees as a basis to start their own company. This can occur when the particular knowledge no longer belongs to the core business. The entrepreneurs aim is to use this know-how as a basis to develop a marketable product.

Large companies can function in that way as the incubating organization that assists in the formation of new companies. Such companies also can provide market introductions and take advantage of their large customer and supplier networks. Some of the reasons are that large companies:

- employ people who are experienced in their own (technical) subject and often some notion of business matters
- as mother company or institution offer general help and often some form of financial support
- possess a good internal as well as external network
- allow the use of facilities such as laboratories at low cost.

2 Management and transfer of knowledge

2.1 The NASA example

The United States National Aeronautics and Space Administration (NASA) sparks innovation and entrepreneurship as a by-product of its R&D mission. With its US$13 billion dollar per annum R&D budget, this institution would number 126 on the Fortune 500 list if it were a company. Like a university, NASA is not subject to market forces as it pursues technology innovation. NASA recognizes that its innovations could have commercial value and they share a goal of moving their technology out of the laboratory environment to companies competing in the marketplace. In this way, NASA acts alike universities. NASA succeeds in developing and maintaining a sophisticated knowledge base. Through its automatic knowledge management and transfer system internal and external partners gain insight in technology opportunities and potential spin-offs.

NASA's commercial technology program is frontrunning among U.S. government agencies. Despite their leadership position they were not satisfied with the volume of technologies being transferred. The number of technologies being adopted by companies was quite low relative to the total amount of investment in R&D and total amount of technologies being reported by NASA researchers and their contractors (companies) or grantees (universities). In researching the cause of this low score the agency discovered that a significant barrier was the lack of management of their technology knowledge. NASA did not know what it knew. Without knowing what they knew NASA was unable to share their wealth of knowledge with companies. And conversely companies faced high transaction costs in searching for and securing rights to NASA technology. To solve this problem NASA invested in a knowledge network called NASA TechTracS.

NASA TechTracS is a relational database Internet application that directly supports "NASA's Commercial Technology: Agenda for Change" as issued by NASA Administrator Daniel Goldin. The Agenda for Change states that "this agenda for change will be implemented through the NASA Field Centers which will coordinate and manage their activities through an electronic network. Designed to create and foster a "virtual organization", the electronic network uses the Internet to connect all Field Centers and Headquarters technology commercialization professionals with each other and the rest of the country".

The NASA TechTracS distributed client/server knowledge network architecture is currently made up of three levels of servers. The three levels comprise the Field Centers, Agencywide, and the NASA Technology Access System (NTAS). The first level consists of a server at each of the ten NASA Field Centers and Headquarters. It is at this level where the majority of data is entered. Each NASA Field Center server uses an AutoAgent, which is a dedicated client workstation, to replicate field center data across the Internet to the Agencywide server. The Agencywide server is the second level. The Agencywide server replicates public data across the Internet to the third level of servers, which is the NTAS. NTAS is the e-commerce component that not only receives public data from Agencywide, but also makes the data available to the public for searching via the web browser http://technology.nasa.gov. As of August 1999, there have been more than 23,000 web requests for additional information about technologies, contracts and success stories contained in NTAS.

Technology Transfer and Commercialization has a lengthy lifecycle that involves many processes and different groups of users. Some of the major processes that NASA TechTracS helps to manage and document include: new technology reporting, contract administration, technology transfer partnership administration, patents and copyright administration, licensing administration, success story tracking and reporting, electronic technology marketing, internal technology award administration, and metrics collection and reporting. Some of the major groups the system support include: innovators, technology transfer professionals, patent attorneys, legislative and public affairs officials, program and project managers, and NASA contractors and grantees. The key to the success of NASA TechTracS is that it first serves as a productivity tool for all stakeholders involved in these processes. By contributing to the productivity to these professionals the system is viewed as a value-adding tool instead of another task. By aiding in the daily tasks, professionals use the system. By using the system they are all converting their knowledge into digital form. From their point of view of the transaction cost of converting their knowledge into digital form is zero, because they use the system voluntarily to make their jobs easier. The innovation of NASA TechTracS is that it links productivity with digitization of knowledge with knowledge sharing and commercialization. The productivity benefits motivate people to use the system. By using the system the knowledge is converted into digital form. Once the knowledge is represented in digital form it can be managed and shared to promote technology commercialization and economic development. It is now easy to bring together experts to assess the technology for commercial value. It is now easy to deliver the technology to retailing agents who work within their respective communities to create partnerships. It is now easy to allow the global economy to search for solutions to their technical problems via a web browser and then to directly request further information.

By implementing TechTracS NASA is able to be a web wholesaler and retailer of its innovations. NASA is a direct retailer via its web page. It is also partnering with organizations whereby NASA TechTracS delivers the data to the partner and the partner then markets the knowledge within its community and brings back to NASA qualified companies seeking NASA technology. The goal of this partnering strategy is twofold: reduce the transaction costs of accessing NASA knowledge and to outsource the marketing of NASA technology to organizations that have an independent incentive to deliver innovation to the community members. NASA's model for technology knowledge management and commercialization can be exported and applied to both technology institutions and regional economic development organizations.

2.2 Towards e-tailing academic innovations

Like NASA, academic institutions have difficulty in managing their knowledge transfer process because the transaction costs are high and the process is inefficient. Focusing on the goal of web retailing – e-tailing – of its innovations is an effective strategy that will return numerous benefits. The first step in implementing this strategy is the digitization of the knowledge. To assure that the knowledge remains current, this process must be incorporated into the daily work of all professionals involved in the innovation and commercialization process. By providing innovators, technology transfer professionals, patent attorneys and other actors with automated tools that improve their individual productivity, they will naturally digitize their knowledge. All people want their jobs to be easier. A university researcher, a government researcher and a company researcher are very similar people.

With the available knowledge now stored in a automated system, the technology transfer professionals can concentrate on delivering this knowledge to the community to spur economic development. Before e-tailing, this process was a traditional labor intensive one where agents simultaneously tried to "push" technology into specific markets and assist companies in finding technologies within the university and "pull" it out. In both instances the large amount of time it takes to make the match and then start negotiation results in high transactions costs. For SMEs these costs are often too high and they abandon their efforts.

The e-tailing of these technologies eliminates many of these time-related transaction costs. Companies can search for themselves for innovations at any time of the day or night. When they discover a technology that interests them, they send an email to the university technology transfer professional. This person now has a solid lead for a commercial technology partnership without spending any time cultivating the lead. Instead he can focus on providing immediate value to the company. Within a short period of time a consensus between the company and the agent can be reached on whether the technology has true potential. If it does then the process of forming a commercial technology partnership can begin. In the event that the university innovator is required as part of this process, the agent offers value to him – the company will be sharing its knowledge with the innovator, who in turn benefits from this exchange.

In addition to improving the productivity of its internal technology transfer organization, the university can establish local, regional, national and international e-tailing partnerships to market their innovations. Because the product is digital, the establishment and implementation of these partnerships are easy and low cost. Execute an agreement and connect a computer to the Internet. These e-tailing partners do the same thing that the university technology agent does with companies in their community or marketplace. The outsourcing of the e-tailing to partners achieves two important goals for the university. First the university expands its reach into ever larger communities that it otherwise would never had touched. Second, it does so at virtually no cost. When this process is understood the university can view the upfront cost of the technologies required by digitizing the knowledge as an investment with a corresponding expectation of a return.

2.3 Conclusive, potentials for ESA and its technology partners

ESA maintains an evolved infrastructure for dissemination of yielded technologies. ESA and its technology partners congregrate to offer a unique sharing of knowledge and to achieve a common strategic goal. The space sector with all its previous succesful spinoffs is likely to be a source for innovations. In the current situation, the dissemination process conducts technology transfer via the traditional mechanisms as brochures and meetings. The paradigm of the old economy is now being translated into the new economy by utilising information and communication technology instruments. However, adding an internet website plus databases to this old working mode performs some disadvantages. By the current huge increase of websites and databases people do not find enough time to visit all these information sources. Therefore, in stead of technology consumers actually going to technology sources, such knowledge should be brought to the people interested in this particular technology. This requires a reverse attitude: from supply oriented towards demand oriented technology transfer practice.

This view implicates certain consequences to the current technology transfer mechanisms. ESA, with its finetuned practice of dissemination, is surveying mechanisms with a focus on matching its technologies available for marketing. According to the business model of Knowledge Sharing Systems some attributes could be added. The marketing of technologies from ESA and its partners necessitates an Internet approach. Web retailing of innovations from technology institutions like NASA has created a community of knowledge by which all actors in the network profit from advanced technology. Input is provided by academic institutions, technology developers and other producers of knowledge.

The purpose of this paper is to preamble that KSS Europe has submitted a proposition to develop and deploy an innovation and management system known as ESA TechTracS. As of the date of submittance of this paper it is not known whether the proposal for ESA TechTracS will be granted. As the status of pilot project will be disclosed, we will display its functionalities during the powerpoint presentation at the conference. To share Knowledge Sharing Systems' business model of technology transfer from space, we outline the functionality of ESA TechTracS. As NASA benefits tremendously from their TechTracS infrastructure, an equivalent system for the European Space Technology Transfer Programme makes sense

If ESA would implement a system dedicated to the management and transfer of technology knowledge, the suppliers and users of ESA would benefit by using the tool to meet their commitments of contributing to the economic growth of their region. These companies have two venues available: first as a means to disperse their technology knowledge to the community and using the system to identify technologies being shared by all the members in their network. Professionals of the Spacelink organization will have available the technologies which could be matched with entrepreneurs who build new companies. The Spacelink members may be able to broker mentoring relationships between these start-up companies and the large corporations that produced the innovation since they share common knowledge and a mission of contributing to the economic growth of the region. Via ESA TechTracS internal and external partners can gain insight in technology opportunities and potential spin-offs. This implies partnering with organizations whereby ESA TechTracS delivers the data to the partner and the partner then markets the knowledge within its community and brings back to ESA qualified companies seeking ESA technology.

This vision is made possible by the integration of information systems, knowledge management practices and the Internet into a knowledge network. It is a new model for technology institutions to leverage their collective knowledge so that the total value of the knowledge in the communities is greater than the sum of its members' individual innovations.

EUROPEAN SPACE TECHNOLOGY TRANSFER ACTION TOWARDS FIRMS

Ir Stas Alain
CRIF Centre de Recherche de l'industrie des Fabrications Métalliques
Rue du Bois St Jean, 12 4102 Seraing, Belgique
Téléphone : 32 4 361 87 00
Télécopie : 32 4 361 87 02
Email : alain.stas@crif.be

Introduction

Initiated 4 years ago, the pilot action, supported by ESA and SSTC, propose to increase the value of space technologies towards non space SME in Belgium. The group is actually form with a pluri-disciplinary Belgian team, the CRIF, a collectif research centre, CREACTION, an Innovation consultancy and Hans Braquené, a legal expert, working together in order to detect generic technologies from space to be adapted in the industrial field and the corresponding SME's, in Belgium, having the capabilities to integrate it.

Four levels of opportunity are mainly aimed towards this pilot action in Belgian :

- For ESA, a possible return on their investment in research and development and the creation of spin off in term of image ;
- For Belgium, a return on university and industrial investment in research and development, the development of the industrial fabric and the creation of new jobs ;
- For Belgium firms, an opportunity to innovate and to become more competitive ;
- For the citizen, better products and services and local jobs.

The proposed paper would review the key success factors and the major problems met during the action. Based on some examples, for each steps, the methodology, followed by the team, will be explained. Finally a first assessment of four years of activities will be presented focusing on numbers of contacts, simple meetings of presentation, meetings with brain storming action, main emerging space technologies and initiated files with the Belgian SME.

Key success factors

One of the major key success is probably link to the complementarity of the different partners involved in the action and their knowledge of the SME in Belgium. Different actions in other field as technical help for CRIF, consultancy for Creaction or expertise for HB has created a kind of confidence with the SME and has facilitate all the meetings, necessary to introduce the ESA technologies. All the informations given through the ESA publications, as the TEST magazine, has also contribute to that success. Finally, it must be mentioned the financial contribution of SSTC and ESA in the action and all the possibilities of researches offered and financed by the EEC, allowing economical factors which has greatly contribute to all the costs associated with the action.

Major problems met

Transfer of technologies is not obvious and is time consumer. Since 4 years, a lot of different problems has contribute to slow down or to stop interesting actions of transfer and of adaptation of technologies issue from ESA:

- When using the way of European research programs to adapt the technology through the financed research, the major factors are mainly the time and the delay and 4 years represent a current situation before considering solutions in other fields than space;
- When trying to create a centre of competence to adapt specific technologies from space to different other non space applications, the main problem is to find budget and competences in multisectorial activities. Building of such reference centre could take 4 to 6 years;
- Adaptation of the technologies to the specifications of the SME is often difficult or impossible due to the great difference encountered in the technical parameters (size, series, cost, weight,...);
- Adaptation is also difficult due to the "incompetence" of some interested SME which would make everything alone;
- Financial aspect due to different market and application is also a brake;
- Due to competition, sharing of cost is often difficult to propose between different SME to develop and to adapt the technology for new markets;

- The commercial weakness and the durability of small companies offering space technologies could lead to problems with the rules imposed by the big companies;
- The following of information and the real interest of involved space companies to diffuse and adapt their technology, outside space, for other markets;
- The weakness of small targeted companies going bankrupt during the transfer;
- Interesting possibilities of adaptation, but in fields not appreciated by ESA such as the military sector;
- The stress and time consumer due to aggregation of technologies in the medical sector;

As seen, the problems are numerous and associated with different factors but after 4 years of shared experience, the team of partners have actually few signals allowing to stop all the transfer process at time.

Methodology followed by the team

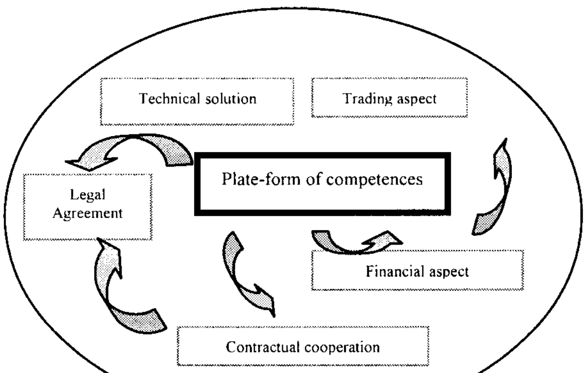
The main outline of the action includes three complementary parts performed at the same time but with different SME:

- The assessment of new requests which result in meeting, introduction of the possible opportunities from space technologies and a selection of specific technologies;
- The assessment of the technological needs requested by the SME and the elaboration of the specifications to be transferred to the owner of the technology;
- The commitment of the offer and the SME with a negotiation of the transfer.

The main objectives of that action are, the final transfer and the technical adaptation of the initiated opportunities, the supplying of a continuous group of SME interested by space technologies, the assessment of technologies in relation with the industrial sectors, the initiation of meetings between the industrial actors from space and the industry and a regular analysis of the result in term of an improvement of the methodology of the Belgian Space Platform with an assessment of the results within the Belgian SME.

A new kind of "brain storming" tools has been progressively developed by the team to allow the contacted industrials to make a best selection of the technological offers, by the way of an integration of the selected technologies with their goals at mean and long term. In addition, the team is also able to propose financial solution by the way of regional, federal and European subsides, to help the SME to develop a new prototype, to perform a feasibility study or to make a market survey. The team will help the SME to write and to introduce a file following the rules and the terms of the specific subsidiary.

The two following examples will illustrate the approach. The first one answer to a need in road and rail transport across Europe. Based on a textile from steel wire, extremely difficult to cut because of the way it is woven, the technology is actually adapted to new markets by the way of a EEC program. The new fabric to develop must be flexible and light while also being suitable for a vandal-proof sliding screen. In that example, the needs of a non space company have lead to a technology developped for space. Implication of partners in different field of activity as ECC research programs and technical assistance have allowed to know and to mixe different opportunities. The second example show a different way of investigation and start from a space technology, the heat pipes. Focussing on different applications, the partners have detected numerous field of application for heat tranfert and the SME associated. By the way of different meeting and the active use of the "brain storming" tool, the idea of a center for competence has progressively born. This center, meeting a lot of different actors, will analyse the opportunities of adaptation of heat pipes in new industrial sectors (medical, steel industry, electronic). Find the actors and the budget to create such a center are the major problems encountered, the action is still in progress.



Assessment of 4 years of activities

Each years, since 1996, more then 2500 catalogues and additional informations are diffuses among SME in Belgium by the way of the partners. It can be considered than more or less 5 to 10 % of real answers are selected and result in a visit and in a possibility of transferring a technology from ESA.

What are the main evolutions to mention:

- The setting up of a real active work allowing dedicated action of sensibilisation in SME and targetting of space technologies for non space applications;
- 3 new tools to perform the possible transfert of technologies, high performance analysis of the stategy to adopt, meeting of creativity and external financement;
- opening to non space consortium for the belgian offers of ESA technologies;

Actions	**1996**	**1997**	**1998**	**1999**	**Total**
Contacts	30	48	49	55	182
Meeting/creativity	25/0	29/0	31/2	47/4	132/6
Interest	26	33	47	59	165
Initiated files	8	10	12	8	38
Documents	9	4	6	5	24
Final Files of TT	-	3	2	3	8

Institutional Framework Requirements for Effective Distributed Innovation Systems in European Space Research

Rainer Hasenauer, Walter Aigner, Dieter Meinhard (HiTec Marketing; www.HiTec.at)
David Mercer, Diane Flynn, Peter Russell, JRA (www.JRAtech.co.uk)

HiTec Marketing, Lothringerstrasse 16/3, A-1030 Vienna, Austria; Tel +43 1 718 25 30 - 15; Fax +43 1 718 25 30 - 50
E-Mail: wa@hitec.at
JRA Aerospace & Technology; CED House, Taylors Close; Marlow; Bucks SL7 1PR ;United Kingdom;
Tel: +44 1628 891105 Fax: + 44 1628 890519 E-mail: mail@jratech.co.uk

Abstract: This paper results from a study and exchanges among HiTec Marketing in Austria, JRA Technology in the UK, and the Technology Harmonization and Strategy Division at ESTEC on the topic of academic-industry relations in the space sector, with a focus on mechanisms that promote collaborative research and development activities that lead to commercial exploitation of technologies and knowledge.

As a leader of the space industry and a champion of space companies in Europe, ESA can play a role in shaping the development of these distributed innovation systems in Europe so that the space industry will derive maximum benefit from their use. This paper presents the study design and work plan, discusses limitations, and draws a picture of the 'positioning spaces' these mechanisms use to define themselves and act within. Preliminary findings will be updated in Graz.

1. Study Design

1.1 Study Objectives

This study was designed to provide an overview of academic-industrial interactions across Europe, such as science parks, interdisciplinary research centres, and spin-out company support, in order to identify good practices that work to promote technology commercialisation. A major aim has been to identify areas in which the space industry could better utilise existing mechanisms and to determine whether any new mechanisms are required to assist with the timely and effective commercialisation of the results of universities' research and technology development (RTD) activities.

Over 20 case studies have been compiled from which lessons have been learned. Cases and recommendations have been developed upon an extensive data-gathering and validation process that included:

- literature research,
- internet-based data collection,
- referrals from industry,
- personal (telephone) interviews with the management of science parks, IRCs etc.

1.2 Limitations

Given the large number of mechanisms / institutions and their diversity (multidimensional objectives) it is neither feasible nor the intent of the study to attempt to identify one single best practice example. Therefore the valuable element in this study has been to identify innovative mechanisms that have already been implemented that improve the co-operation between industry and university research and speed up the time to market of university research outcomes.

Some of the definitions used by the study team to classify the mechanisms might be different from the reader's expectations associated with those terms. As these mechanisms are constantly evolving they often do not match their abstract basic idea any more. This is another complication to identifying a single best practice example.

Given the title of this paper some readers might expect an analysis of distributed workflow in innovation / co-operation projects; this was neither study goal nor is this element of innovation systems addressed in this paper.

2. Types of mechanisms / cases investigated

2.1 Science Parks

The following science parks were examined and documented during the study:

- The Innovation Place, Saskatchewan, Canada
- Otanemi Science Park, Helsinki
- Taguspark, Oeiras, Portugal
- Oxford University, Oxfordshire, United Kingdom.
- Amsterdam Science Park, The Netherlands
- Helsinki Science Park, Finland
- Y-Park Lausanne, Switzerland

For the purposes of this study, science parks have been defined as properties associated with universities, having the following characteristics:

- A contractual and/or formal ownership or operational relationship with one or more universities or other institutions of higher education, and science research.
- A role in promoting research and development by the university in partnership with industry, assisting in the growth of new ventures, and promoting economic development.
- A role in aiding the transfer of technology and business skills between the university and industry tenants.

'Property-based' and 'economic development' criteria were not included in the definition used by the study team, as these types of 'science parks' were not found to be relevant to technology commercialisation practices.

'Good practices' for technology commercialisation which were identified from the literature and from the science park case studies include:

- Surveying tenant companies and local business sectors to identify business/technical needs and skills matches.
- Developing links to funding organisations and business angels to help provide needed capital for projects and company development.
- Provision of business support from managing companies and/or university departments to tenant organisations.
- Provision of training programmes that teach technical staff and entrepreneurs key elements to planning and running technology businesses.
- Including organisation success and economic development as priorities for the park.
- Provision of 'common good' services, such as internet links and 'comfort' facilities.
- Providing SMEs with a surrounding that suggests a high quality organisation, and enhances their reputation.
- Developing non linear (= only at the end of the innovation) but true interaction between industry and academic partners.
- Identification of 'Mode 2'-Type academic partners.
- Discouraging 'non-modularization'/'non-fragmentation' of the co-operation.
- Encouraging individuals who participate in the science park to have a home base in both academic and industry cultures (e.g. industry manager who is also faculty in research institution).
- Provision of other links/ties between the university and industry partners (alumni, nationality,) are highly relevant.

The following graph suggests a space in which science parks can generally act.

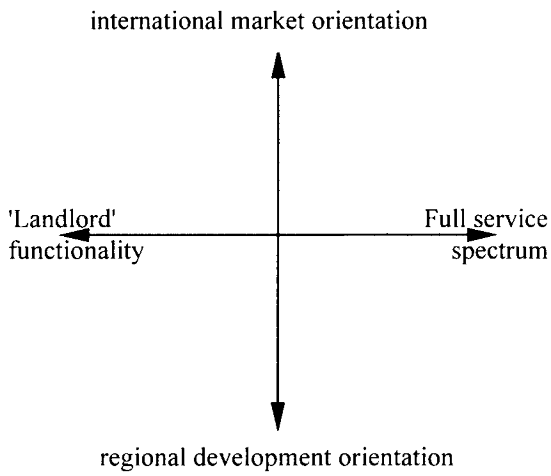


Chart 1: Prevailing dimensions of Science Parks' orientations

The position of a specific science park in this space can be determined by the respective realisation of the dimensions:

- market orientation and
- offered services.

These two dimensions were identified as the main influencing parameters regarding the activities performed by the observed Science Parks.

2.2 Interdisciplinary Research Centres (IRCs)

The following IRCs were examined and documented during the study:

- Österreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.b.H., Vienna, Austria
- Austrian Research Centers Seibersdorf, Austria
- Technische Universität Graz (heading the Austrian Space Cluster)
- Fraunhofer Gesellschaft, Germany
- The Steinbeis Foundation, Germany (SME participation in applied space research)
- The IRC in Materials for High Performance Applications, The University of Birmingham, Central England, UK
- Microelectronics Research Centre (MiRC) and InterConnect Focus Centre, Georgia Institute of Technology, USA
- Space Physics and Aeronomy Research Collaboratory (SPARC), University of Michigan, USA

Within this study, an interdisciplinary research center has been defined as a research institution - whether university or non-university - where interdisciplinary research is taking place. Additionally, the search field is restricted by demanding the following criteria:

- Industrial partners have to be involved in the research activities performed by research institutions.
- Research institutions and industrial partners share physical research facilities (e.g. laboratories).
- Clear technology / science focus of common research activities.
- The research institution was established to be a long term organisation and not for one / some project(s) only.

Based on empirical investigations, the study team suggests to distinguish 5 different IRC-levels (which can be seen in the following graphs) according to the

- composition of institutions and
- realisation of the links between the institutions involved in an interdisciplinary co-operation.

Institutions which were taken into account are:

- University (departments),
- Industry (departments) and
- Grey 'un-institutes'.

But even a joint university-industry IRC (Level 5) does not necessarily make up an efficient transfer mechanism. Often there are joint research efforts with no interference with the academic orientation (low-problem/high methodological orientation).

'Good practices' for technology commercialisation which were identified from the literature and from the IRC case studies include:

- Participants from different disciplines work together (sharing ideas, data, equipment, and feedback) on a regular (if not daily) basis,
- Participants focus on solving real problems, which can be presented to them from outside industry or from user needs within a community,
- Social and professional networks are exploited and grown,
- Social and cultural norms are employed to determine working practice and to share data and IP across institutions and disciplines,
- Funds come from interested parties who help shape the problem requirements, and who will utilise solutions, but who do not necessarily direct the problem-solving process,
- An approach toward long-term problem solving often leads to short-term, implement-able discoveries while addressing areas of research that industry can usually not afford to undertake alone,
- The use of electronic media and 'virtual' collaboration can further promote interdisciplinary research across institutions and geographies.
- Problem / project specific interdisciplinary co-operation of departments acting in one research-organisation to provide useful knowledge to industry partners.

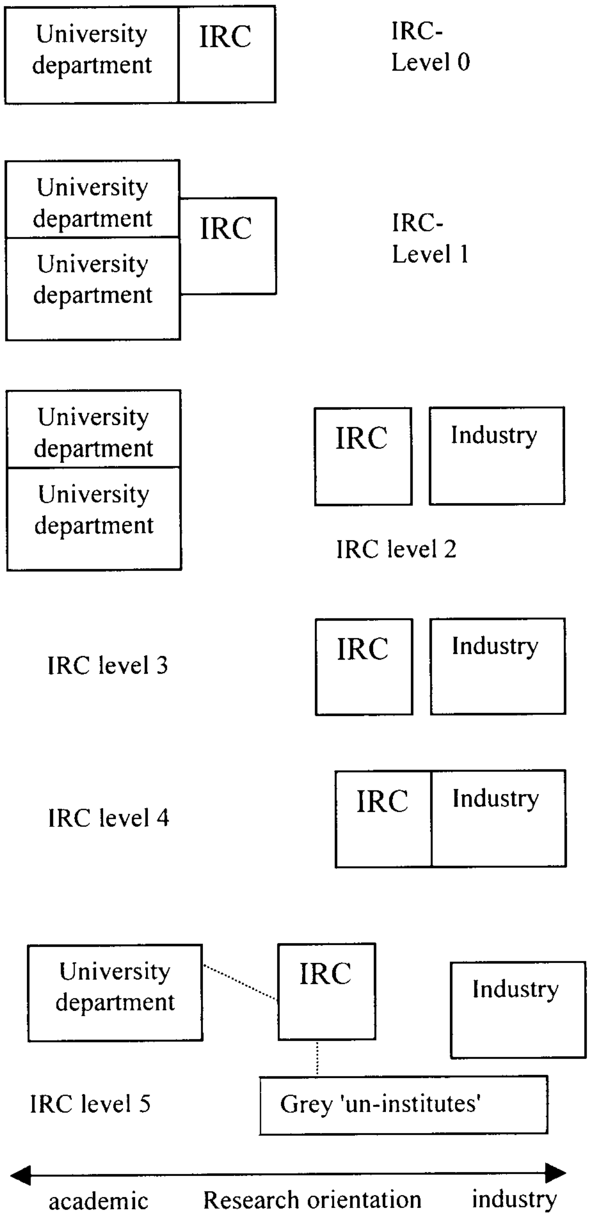


Chart 2: Five Levels of IRCs in academic-industry contexts

2.3 Other mechanisms (Strategic Research alliances, University Spin-offs, Research clusters / networks, Virtual universities)

The following transfer mechanisms were examined and documented during the study:

- Michigan Virtual Automotive and Manufacturing College (MVAC)
- Institution: Imperial College of Science, Technology and Medicine, London; Spin-Out: Innovative Materials Processing Technologies Ltd

- Institution: Vienna University of Technology; Spin-Off: TTTech Time Triggered Technology, Austria; Spin-Out: TTTech Time Triggered Technology
- The Department of Materials, Oxford University, Oxford, UK; SRAs: Ford Motor Company (UK) Ltd, AEA Technology, DERA and Luxfer plc
- EC initiative Europractice

2.3.1 Strategic Research alliances:
An brief literature search identified no particular definition of a strategic research alliance (SRA) and SRAs do not appear to have received much attention as a particular form of academic / industry collaboration or distributed innovation system. Relationships between individual institutions and companies (or groups of companies) may have been the subject of investigation, but this seems to be the extent of the analysis.

This study is examining particular forms of research alliance however – namely those that can be classified as 'strategic'. However the study team identified a number of features of a *strategic* research alliance which could be used to distinguish it from other forms of collaboration. These are as follows:

- The alliance is reasonably long term – at least three years but probably longer.
- There is a joint understanding of an overall direction that the research is heading, but specific targets or outputs are often left open. Deliverables and specific time-bounded projects may well be agreed as the alliance progresses. These typically form subsets of the overall research and development activities.
- The overall direction of the research, and the relationship between the organisations, benefits, complements and contributes to each ones long term business and development strategies (i.e. the direction or work is not dictated by one partner – possibly this is a reflection of the fact that the work is usually funded from a multiplicity of sources).
- The relationships between the partners are typically fairly loose and flexible – and even informal. They are not necessarily enshrined in contracts (and this means that the university's contracts departments may not even have been involved in forming and structuring the alliance – or agreeing activities). Sometimes there will be a broad framework agreement, but even this remains optional.

2.3.2 Spin-Outs:
As with each of the 'distributed innovation systems' we are investigating, there is no universally agreed definition of a spin-out. The terminology varies according to the source of the new venture (e.g. university or large company) and also according to an individual's perspective. For example. Imperial College (London) defines a university spin-out as "a business in which the University and its faculty members have played a substantive part in its foundation, where these founders have equity in the company, and into which intellectual property generated by the founder is assigned". This definition would appear to indicate that the university should have an equity stake in the business, but we have shown that this is not necessarily always the case.

3. Learnings (preliminary findings)

Preliminary findings of the study (as of August 2000) are:

3.1 Research focus and definitions:

- Empirical research and knowledge on the existing mechanisms on institutionalised academic-industry interfaces does not focus on speed of knowledge transfer (time to market; time to break even). Nevertheless an equivalence of those mechanisms and efficient as well as effective innovation mechanisms is widely assumed. Within our study we found distinctive objectives for each mechanism - and none of them is equivalent to shortening time to market explicitly. Therefore the 'speculative' discussion of those mechanisms is most of the time preventing effective solutions. This becomes even more important given the fact that even after years of successful evolution most mechanisms do neither monitor nor strive for shortened time-to-market. The (empirically) clear focus of the existing mechanisms needs to be acknowledged in discussing and designing augmented service offerings and programmes.
- There is a clear tendency for an erosion of the old terms 'science park', 'IRC' and 'strategic research alliance'. To many European Institutions these terms and the associated listings / directories have become marketing tools. Some can even be found under several classifications.

3.2 Effectiveness and efficiency of transfer mechanisms:

- From the viewpoint 'innovation' / 'time-to-market' some types / mechanisms are worth more than others.
- Many of the apparently more successful mechanisms however, do depend on the exchange of knowledge and experience through individuals (the human element) and the mechanisms actually promote this through networking and other forms of institutional interaction.
- Informal meetings (esp. after successful pilot projects) seem to be a crucial element for effective transfer. There '*true problems can be exchanged*

freely'; as soon as formal minutes are taken these meetings seem to be devaluated.

- Many mechanisms are intrinsically interdisciplinary and collaborative in nature. The traditional borders between disciplines have been eroded, and the costs and risks of bringing technologies to market cannot be born alone, even by the largest organisations.
- Some mechanisms rely on the transfer of graduates; - this is a slow / long term programme rather than applicable within innovation-settings. Additionally this can lead to disturbances due to the competition for qualified staff.
- Spin-outs and new start-up ventures seem to be emerging as the preferred mechanism for technology transfer and exploitation by universities and research based organisations. In some areas many 'grey'-non-departments have been founded in the last 3 years.
- The success of spin-outs as a methodology seems to be measured over a relatively short timescales (3-5 years). The key success factor is the growth and survival over this time, and the ability of the venture to attract first and second stage funding. The longer term effectiveness of getting the product or technology to market is not always addressed explicitly or measured by the founding institution, although if a business does survive, the institution is often happy to highlight its `achievements'.

3.3 Regional specifics:

- Most successful mechanisms tend to address local issues rather than national or global ones. For example, the provision of low cost accommodation, or meeting particular skills gaps, might be more of an issue in some locations than in others, and the better mechanisms develop responses to these local needs.
- There is no harmonised European mechanism / system; e.g. Science Parks are different in the UK from Science Parks in the Netherlands or Switzerland.
- There are additional cultural and practical differences (local and regional embeddedness); therefore effective Europeanwide programmes may not be feasible.
- National issues, such as funding gaps, are often better addressed at the local level, where delivery agents are allowed to develop solutions that fit with the prevailing innovation environment and systems.

3.4 Trends:

Given these preliminary learnings the question arises whether they unveil some basic trends.
We see from our case examples a clear tendency to

- Mode-2 Science becoming the more effective player in generating knowledge that is transferable to industry (Gibbons).
- Mode-2 Science becoming the dominant player in taking research outcomes into the next stage of technology commercialisation (Jolly). Mode-1 Science as well as industry itself seem to ignore this central task.
- A large and increasing number of hybrid institutions on the periphery of the classical universities. They fill a gap in speeding up the time-to-market by creating knowledge themselves ('small scale Fraunhofers'). Their existence and vital role have not been acknowledged by research programme initiatives.
- Experiments to enhance the transfer of tacit knowledge (Nonaka's Concept of 'Ba')

The following graph suggests a space which is determined by the

- kind of knowledge the transfer mechanism is focusing on and
- speed to market the transfer mechanism is aiming at.

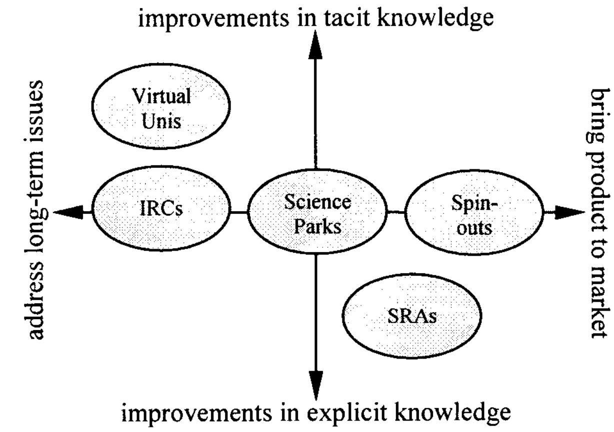


Chart 3: (Self)Positioning of Innovation Transfer Mechanisms

4. Recommendations

It is clear that the space industry can play a role both in capitalising on existing mechanisms and in supporting the commercialisation of technologies through improved university-industry interactions.

Given a preliminary set of recommendations the question might arise why many of them have not already been implemented. We see four main reasons:

1. The number of institutions has grown rapidly. These institutions are filling local / regional

bottlenecks and do not act as active players in a European Research policy.
2. The perceived necessity for shorter time-to-market cycles has hardly entered mission statements or success criteria of the existing institutions
3. Funding and Promoting agencies seem to draw an artificial line between precompetitive / premarket stages of research funding and market stages. These lines have disappeared in bio-sciences and information technologies. Without addressing this new situation the gaps in commercialising technologies will rather increase.
4. Many naturally appearing solutions / institutions have the image of 'grey' and are perceived as acting in a legally unclear space.

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Business incubators

The European approach of European Business & Innovation Centres (BICs) illustrated by EBN (European Business & Innovation Centre Network) and BIC Promotech (Nancy-France)

Main author:

Mr Jacky CHEF,
Manager of BIC Promotech for 20 years
Technopole de Nancy-Brabois
Allée Pelletier Doisy, 6
F - 54603 Villers-les-Nancy
TEL: + 33 3 83 50 44 44
FAX: + 33 3 83 44 04 82
E-mail: promotech@wanadoo.fr

Founder member of the European BIC network, European expert in the field of innovative business creation on the basis of research results and regional innovation systems. Author of a technical guide on academic spin-off, U TRANS.

Partners:

Mr Jacques COCHARD (BIC Promotech):
Expert in charge of European projects in the field of technology transfer. Co-author of the U TRANS guide.

Mr Philippe VANRIE (EBN):
Managing Director of the BIC network gathering 150 BICs throughout Europe. Active for more than 10 years in the field of Business and Innovation Centres at regional and European level and with regard to contacts with the European Commission

Mrs Géraldine FAUCHEUX (EBN):
Project manager in charge of trans-European projects including those relating to the creation of incubators.

The European approach of the Incubation Process through the example of Promotech European Community Business and Innovation Centre in Nancy, France

The concept of business incubation out of Universities and Research Centres appeared in France in 1975-77 and really developed from 1980 on. This new approach is linked to the concept of "technopole" and the initiatives launched by Nice Sophia Antipolis (oriented towards the attraction of external enterprises), Grenoble-Meylan (oriented towards the spin-off of big enterprises) and Nancy-Brabois (oriented towards the creation of enterprises by young graduated and researchers). In these three cases, the concept of "technopole" is the expression of a co-ordination between university potentials, existing enterprises and local public measures to support the emergence of new activities.

During the last 20 years, the process has extended and become more organised, professional and complete:
The concept of "technopoles" and innovation centres has extended throughout Europe and the world. It has also become widespread at institutional level: despite the initial opposition, universities are now open onto the economic world. The major, and sometimes most inaccessible, research centres turn towards business creation (the JRC in Ispra for instance, the Esstec in the future). The institutions also support the creation of

enterprises on the basis of research potential, OECD. UNICE, and more particularly the European Commission.

The method has got itself structured: the operators are members of regional, national, European and sometimes world-wide networks (such as IASP). The concept, which was first isolated, has now become a tool for local, national and international economic development; it is often the symbol of modern economy (net economy, spin off, success story, success of economic development in the 21st century).

The concept, which was first improvised, has become more professional; the valorisation of the research results under the form of new activities has proved to give results when it is implemented seriously and to the full.

The process has become more complete. Besides "technopoles" and technology centres, new concepts appeared, such as incubators, innovation centres, European business and innovation centres; the operators increased and got organised with the emergence of venture capital, business angels and a range of other tools.

My objective will be to illustrate the different points mentioned in this introduction.

1. The approach of the European Commission from 1980 to 2000

In the eighties, the Commission set up a programme to support the feasibility studies of innovation centres and science parks at European level. The feasibility studies of all these projects were financed by the Commission and carried out by at least three experts from 2 countries different from the country concerned.

This programme contributed to the expansion of these centres throughout Europe. All these centres have a main branch devoted to the creation of new activities in connection with and on the basis of university and local research potential. The involvement of foreign experts helped to develop an inter-European partnership for these initiatives, which is now clearly established.

In 1984, the European Commission launched the pilot-project for Business and Innovation Centres. 140 BICs are currently active in the member states, as well as in Central and Eastern Europe. The Parliament wished to create a model to support the endogenous development based on the mobilisation of regional resources. Research and university potential were naturally chosen as new sources of economic activity: despite the initial scepticism, the method has proved efficient. The BIC concept is a permanent tool of the EC Directorate General for Regional Policy and is co-ordinated by EBN (European Business Innovation Centre Network). It is a codified and methodical instrument, which is now recognised all over Europe. Up to now, more than 10.000 new enterprises have been created with a 85% success rate.

In recent actions, the Commission has maintained the programme for the period 2000-2006. The Innovation Plan for Europe is being implemented through the application of programmes encouraging the co-operation between local initiatives. A label is granted to the most competitive regions: those excelling in the creation of enterprises on the basis of research results, but also to dynamic regions, which are not the most competitive: networks of innovative regions in Europe.

2. European Business and Innovation Centres and their European Association, EBN

The European Commission launched the concept in 1984. In 1999, following a decision from the Commission and the European Parliament, the BIC instrument was integrated as an element of the ERDF policy. Up to now, 150 BICs have been granted the EC BIC licence, which is controlled by the EBN (European Business Innovation Centres Network) association, on behalf of the European Commission.

The mission of a BIC is to implement public measures to support SMEs in the creation of innovative enterprises and to encourage existing enterprises to modernise and innovate.

The services offered to enterprises by BICs are the following:
Detection and evaluation of innovative and promising projects, strategic orientation and assistance to business projects through the drawing-up of appropriate and high-quality business plans, assistance to access financing, support to SMEs' internationalisation process, organisation of territorial inter-enterprises co-operation (spin-off for instance), access to premises, entrepreneurial training and follow-up. On behalf of local organisations, BICs can evaluate enterprises' needs in order to set up measures to support SMEs and to launch initiatives to promote entrepreneurship.

In 2000, EBN gathers 200 members including 150 BICs in 20 European countries and 50 associate members throughout Europe. The association aims at promoting the BIC instrument and operates on behalf of the European Commission. The services provided by EBN are: quality assurance of the centres, promotion of BICs, technical assistance to its members and to the European Commission, establishing links between BICs and other EU instruments of SME support, supporting BICs' participation in European Programmes. In a general way, EBN facilitates the communication and the collaboration between BICs and between the enterprises they support.

The network has promoted a closer partnership with the IRCs and EICs networks, which allows a better integration of BICs into their regional environment.

3. The initiative of the JRC ISPRA

The Joint Research Centre of the European Commission includes 4 sites. The main one is located in Ispra (Italy). 1746 researchers work for the centre, 479 of them are non-statutory workers (1996).

Within the context of the Innovation Plan for Europe and in view of the proliferation of innovation centres in Europe, the Commission decided in 1996 to examine the possibility of developing a range of services to support technology transfer and business creation, on the basis of its own research potential. As a result, several initiatives are now being implemented among which are the technological park and the incubator of Ispra.

The role of the incubator is defined as follows: assistance to the commercialisation of technical know-how and expertise through the creation of new technological enterprises and the support of their development.

This incubator will be mainly aimed at staff who, at the end of their contract with the centre, would be offered the possibility to draw-up a business plan for a project of business creation based on the JRC's know-how. 20 enterprises have already been created spontaneously by former employees of the centre; the project would allow regularising, organising and intensifying the process.

The objectives of the system are: to raise awareness of, to detect and to assist people with promising innovative projects by providing training, individual advice and premises including common services. For the last 2 years, training seminars for the elaboration of business plans have been organised for about 10 potential future entrepreneurs.

4. The French example: the law for innovation and the network of "technopoles", BICs and incubators

In France, the law of July 1999 on Innovation and Research contributed to speed-up a process started in 1980: how to encourage teachers to start their own business or how to lead them to raise awareness of their students towards business creation.

The objective of this law is to officialise the role of universities as promoters of business creation by young graduates and to allow universities and their staff to get involved.

In order to materialise this concept, the Ministry of Education and Research finances the creation of incubators in most French universities. Up to date, 26 incubators are being set up. This involved a risk: the destabilisation of existing systems. That is the reason why the main operators got themselves organised: the network "France Technopoles Entreprises Innovation" gathers all "technopoles" and BICs existing for about 15 years, as well as incubators in the process of being created.

5. The network of business creation in Lorraine

The U-trans guide was written in the framework of the innovation programme of the European Commission (Pr Müller-Merbach, J. Chef, EBN 1999). It deals with business creation out of Universities. The guide stresses the importance of having a regional network of operators, a range of procedures and administrative and financial support in order to start a competitive process.

In concrete terms, the State and the Region of Lorraine have signed a planning contract for the period 2000-2006. One of the objectives is to optimise the competitiveness of the economic system in the Region of Lorraine through the stimulation of creativity, innovation and entrepreneurship.

The region of Lorraine has 2 "technopoles", 2 BICs and 8 incubators for 2,7 inhabitants, 60.000 students and 2000 enterprises.

Nine years ago, the BIC and its incubators formed into a regional network. The network has a contractual agreement with regional authorities and commits itself to encourage business creation and business re-launching, to reinforce the process of selection of projects, as well as the assistance in the setting-up and the follow-up of new activities.

This method has proved successful. Indeed, out of the 800 projects supported by the network every year, about 400 lead up to new activities. In the past, the Region of Lorraine had a basic industry: iron and steel, heavy chemical industry, textile and wood. Now it has a varied industry: electronics and many information and communication companies.

6. Promotech, European Business and Innovation Centre

Promotech started in 1980 with the aim of promoting technology transfer from university to industry through the creation of new enterprises or through the diversification of regional SMEs.

In 1985, Promotech was granted the BIC licence (Business and Innovation Centre) delivered by the European Commission (DG Regio), which is the guarantee that the activities of Promotech conform to the criteria laid down by DG Regio. The renewal of this licence is determined by the evaluation of the centre, which is carried out periodically.

Promotech is a member of the network gathering 150 BICs throughout Europe and is supported by the BICs association (E.B.N.).

Since 1988, Promotech has been established at the "Technopole" in Nancy-Brabois. Its role is to encourage and support technology transfer.

Since 1999, Promotech is certified ISO 9001 for all its activities.

The activities of Promotech are oriented towards potential entrepreneurs, universities and enterprises. The BIC provides the following support services:

- **Raising awareness to** enterprise creation, innovation, technology transfer and Europe.
- **Detection, selection and evaluation** of potential entrepreneurs and of projects from universities and from enterprises.
- **Search for partners and assistance**, either to transfer to SMEs, or to business creation within Promotech's incubator (premises, training and individual follow-up).
- **Follow-up of supported enterprises**, if necessary, within the incubator (premises and common services, animation, follow-up).

Promotech is also involved in regional development: it carries out studies and economic animation actions, some of these at European level.

From the administrative point of view, Promotech is an association governed by the Law of 1901 and entirely subject to taxation (VAT, ...).

Promotech employs 12 people; the annual budget amounts to 8.000.000,- FF:

10% allocated to studies and economic animation, 11% allocated to business creation, 13% allocated to business start-up, 24% allocated to existing enterprises, 41% allocated to universities.

Since 1980, Promotech has contributed to the creation of 308 new activities (statistics as at 31/08/99), including 216 new enterprises and 92 cases of diversification of regional SMEs.

The above-mentioned figures are the results of all the activities carried out every year by Promotech.. These include:

- contact with about 100 potential entrepreneurs
- visiting about 100 research teams
- visiting about 100 regional SMEs
- assisting about 30 potential entrepreneurs in the drawing-up of business plans
- project engineering and search for partners for about 15 projects from universities
- about 15 missions within SMEs
- providing premises to about 30 enterprises, including common services and office supplies
- carrying out 10 to 15 economic studies or expertise missions at regional or European level.

List of Authors

European Space Agency
Agence spatiale européenne

Contact: ESA Publications Division

c/o ESTEC, PO Box 299, 2200 AG Noordwijk, The Netherlands