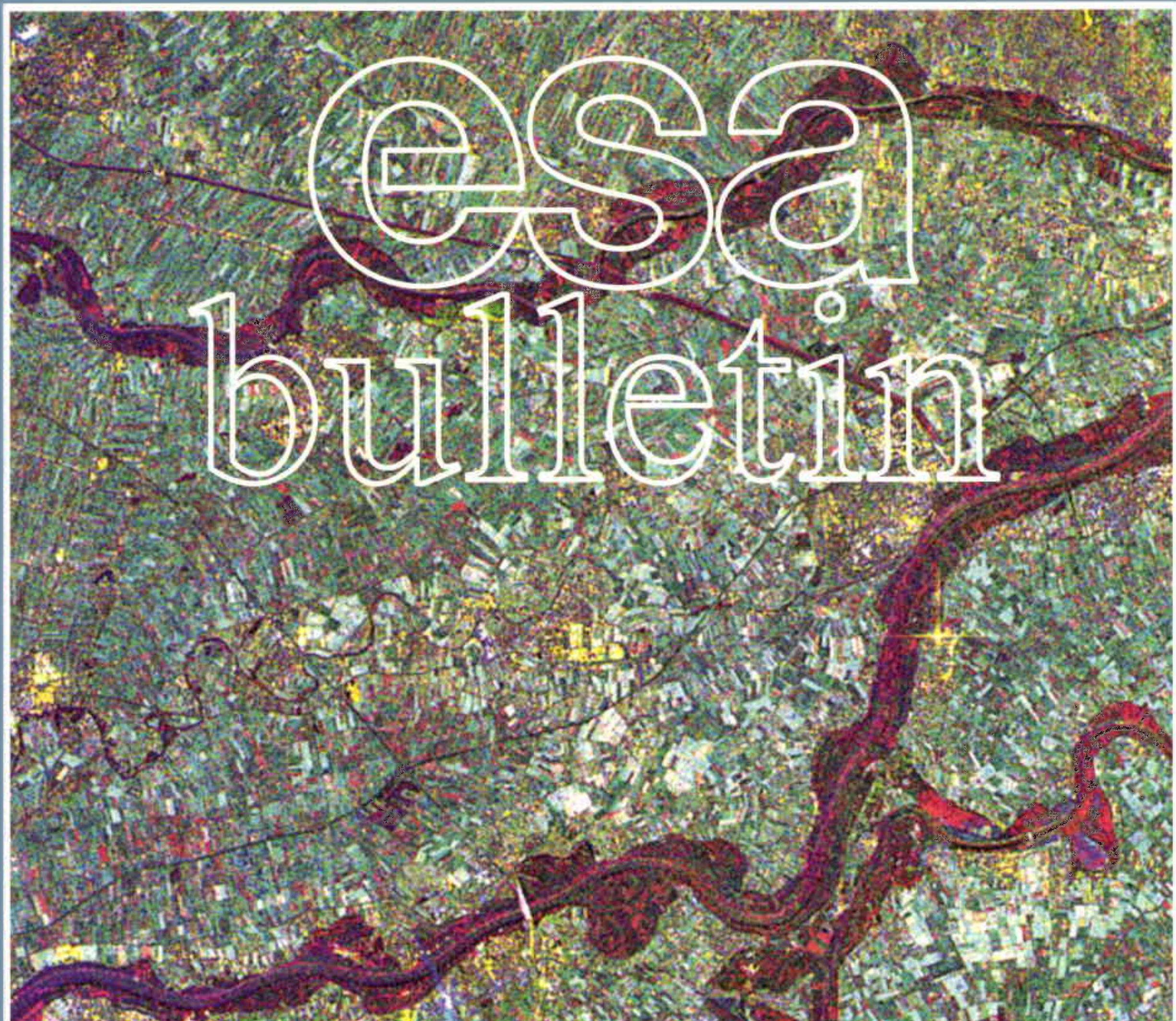

esa

european space agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European Space Organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. Canada is a Cooperating State.

In the words of the Convention: The purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems.

(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

The Agency is directed by a Council composed of representatives of Member States. The Director General is the chief executive of the Agency and its legal representative.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

THE EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE (ESTEC), Noordwijk, Netherlands.

THE EUROPEAN SPACE OPERATIONS CENTRE (ESOC), Darmstadt, Germany

ESRIN, Frascati, Italy.

Chairman of the Council: P.G. Winters

Director General: J.-M. Luton.

agence spatiale européenne

L'Agence Spatiale Européenne est issue des deux Organisations spatiales européennes qui l'ont précédée — l'Organisation européenne de recherches spatiales (CERS) et l'Organisation européenne pour la mise au point et la construction de lanceurs d'engins spatiaux (CECLES) — dont elle a repris les droits et obligations. Les Etats membres en sont: l'Allemagne, l'Autriche, la Belgique, le Danemark, l'Espagne, la Finlande, la France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. Le Canada bénéficie d'un statut d'Etat coopérant.

Selon les termes de la Convention: l'Agence a pour mission d'assurer et de développer, à des fins exclusivement pacifiques, la coopération entre Etats européens dans les domaines de la recherche et de la technologie spatiales et de leurs applications spatiales, en vue de leur utilisation à des fins scientifiques et pour des systèmes spatiaux opérationnels d'applications:

(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;
(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;
(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;
(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

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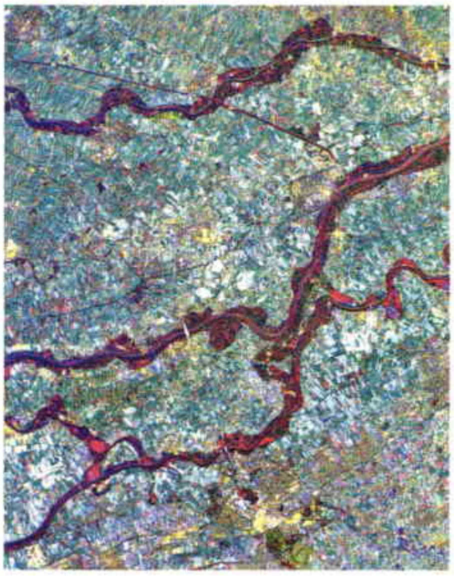

Cover: Multitemporal ERS-1 satellite image of the recent flooding in the Netherlands (see page 94)

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european space agency

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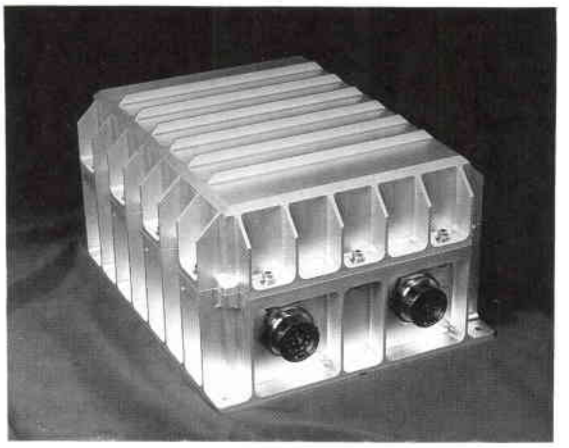

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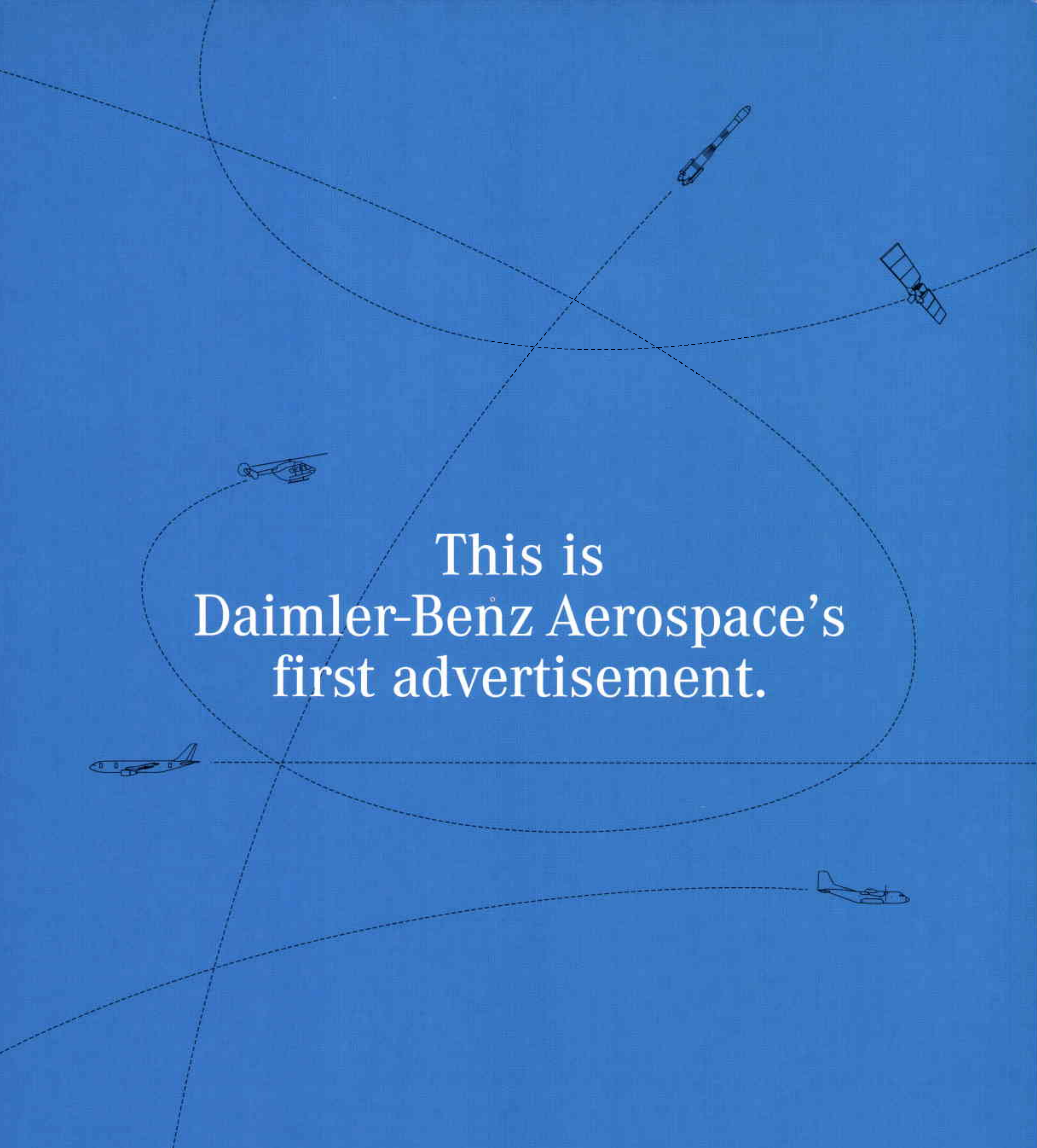

This is
Daimler-Benz Aerospace's
first advertisement.

European Space Science – In Retrospect and in Prospect*

R.M. Bonnet
Director of Scientific Programme, ESA, Paris

Looking back, one can broadly identify four phases in the development of space science in Europe, characterised by:

(i) the publication of the so-called 'Blue Book' in 1961 in the pre-ESRO era
(ii) the first attempt, by ESRO, to define a policy in space science, in February 1970
(iii) the ISPM/Ulysses crisis in 1980 – 1981
(iv) the establishment of the 'Horizon 2000' programme in 1983 – 1984, and its successor 'Horizon 2000 Plus'.

These four phases will be reviewed here, paying more attention to the first two because they contain all the ingredients which, filtered over time and with increasing experience, formed the basis for ESA's success today.

At a time when all space programmes have to redefine their goals following the end of the Cold War, and when some Member States are questioning whether the (modest) pace that marked the first 35 years of European space science should not be slower and the budget allocated to that activity reduced, it is useful to look back and assess whether ESA, and before it ESRO, have been good for science and have played the roles as outlined in their Conventions. It is also useful and enlightening to assess whether ESA has conducted its programme efficiently.

The learning phase (1959 – 1968)

The first phase, which John Krige, one of the ESA historians, has called 'The Auger Years' (ESA publication HSR-8, May 1993) – covering the pre-ESRO and ESA era – was marked by a strong determination to create a European Space Science Programme and by the simultaneous development of national programmes in the future ESA Member States, the creation of CNES in France as early as 1963 being one such example.

The key element in this phase was the famous Blue Book prepared by the Scientific and Technical Working Group (STWG) of COPERS, under the Chairmanship of L. Hulthen, from the Royal Institute of Technology in Stockholm, with R. Lüst as Coordinating Secretary.

The outline of this programme is shown in Table 1, which somewhat reflects the community's lack of realism and maturity at that time. Nevertheless, it was endorsed as such by the Plenipotentiaries who signed the ESRO Convention in June 1962. Already at that time, a dichotomy could be detected between the smaller Member States, which favoured the rocket programme in order to gain experience, and the larger ones which, not having to rest on this element, favoured the inclusion of the bigger elements, i.e. the spacecraft and the space probes. In fact, the Blue Book was more

Table 1. Number and type of launches during ESRO's first eight years, as proposed by the Interim STWG to the Third Session of COPERS, in Munich on 24/25 October 1961. It assumed that two launches would be required for each successful satellite or space probe placed in orbit

Device	Year 1	2	3	4	5	6	7	8
Sounding rockets	< 10	40	65	65	65	65	65	65
Small satellites in near-Earth orbits				4	6	4	4	4
Space probes						2	3	3
Stabilised astronomical satellites and lunar satellites						2	1	1

*This article is based in large part on a paper presented at a Colloquium organised in Kiruna on 7—8 September 1994, on the occasion of the retirement of Prof. Bengt Hultqvist as Director of the Swedish Institute of Space Physics.

a declaration of intent than a definitive programme.

It would be the task of the new organisation's Launching Programme Advisory Committee (LPAC), the ancestor of ESA's present Space Science Advisory Committee (SSAC) and, as such, a body composed of a small number of scientific experts, and of its Science and Technical Committee (STC), a delegate body and the ancestor of ESA's SPC, to transform the content of the Blue Book by Spring 1965 into a programme which, it was assumed, would be achieved within pre-set financial limits.

Three main areas of controversy confronted the LPAC, chaired at that time by Reimar Lüst. The first issue was to maintain a fair distribution between the various fields of science (which did not automatically translate into a balance between the resources allocated to each field, astronomy missions generally being more expensive).

The second issue concerned the concept of a common bus for astronomy satellites of the TD series, with the aim of saving cost. This concept never materialised: only one TD spacecraft was built. Today, ESA is seriously trying to develop one common bus for its astronomy missions XMM, Integral and possibly STARS, a project yet to be approved.

Finally, there was the issue of the large satellites, which were supposed to be the main justification for establishing a European Space Research Organisation to develop missions larger than those that could be carried out by a single nation. Neither of the two large projects, the Large Astronomical Satellite (LAS) and the comet mission, ever materialised. Major descoping and numerous iterations had to be undertaken before they could eventually reach a stage where they could both be built within realistic financial limits and fulfil the interests of the scientific community, through the IUE and Giotto missions.

This first phase ended in 1968 with the successful launches of ESRO-2, ESRO-1A and Heos-1. In the interim, 56 sounding rockets were sent aloft between 1964 and 1967, almost half of them dedicated to ionospheric and auroral studies. The most active countries in this programme were the UK (35% of the proposals received by 1967), Germany (22%), France and Sweden (12%), the latter probably because of the existence of Esrange, in Kiruna.

These numbers, impressive as they are, in fact compare very badly with the original plan established by the STWG. They show how difficult it was to achieve a balanced scientific programme over a short period which would satisfy the diverse interests of the scientific community. It slowly became apparent that the desired balance might be better achieved over a longer term, within the framework of a financially more realistic programme. Nearly 16 years passed before ESA was able to formulate such a plan.

The second phase: the 'Bondi years' (1969 – 1973)

This second phase saw the transition from ESRO to ESA, and the disappearance of ELDO, the European Launcher Development Organisation. By the end of 1968 only one new project, TD-1, had been approved and the time was ripe for taking new decisions in order to avoid a severe lack of continuity in the scientific institutes as well as in industry. In the first half of 1969, three small satellites were approved: ESRO-1B (Boreas), a follow-up to ESRO-1, launched in October 1969, Heos-A2, launched at the beginning of 1972, and ESRO-IV launched in November 1972. In early July 1969, Cos-B and Geos were approved to be part of the second phase of the ESRO programme. These were in fact the last projects to be approved within the ESRO framework.

Hermann Bondi, who took up his duties as ESRO's Director General in November 1967, requested that the LPAC define the Organisation's long-term scientific policy through a careful selection of new feasibility studies. To fulfil this mandate, the LPAC set up a Geophysics and an Astrophysics Panel, the reports of which were presented to the LPAC in January 1970. They contained decisive and surprising – as well as courageous – recommendations.

It took two days of lively discussions in the LPAC, chaired by Reimar Lüst, to establish ESRO's future scientific policy based on these recommendations. Four research fields were given priority:

(i) fundamental physics, with some priority assigned to the testing of gravitational theories
(ii) plasma-physics investigations in the magnetosphere, heliosphere and polar ionosphere
(iii) high-energy x-ray and gamma-ray astrophysics
(iv) special cosmic-ray studies to determine elemental/isotopic abundances, and measurements of solar neutrons and charged particles.

Planetary exploration, ultraviolet astronomy and solar physics were excluded from these recommendations. Nevertheless, still envisaged, optimistically, was the launch between 1975 and 1980 of three medium-sized and three to five small satellites (compared with the three actually launched, namely Geos, ISEE-2 and IUE).

Following this exercise, between June 1970 and April 1971, the LPAC started to discuss which satellites would follow Cos-B and Geos. They gave first priority to Helos, an X-ray positioning mission, later to be renamed Exosat. They also tried to safeguard and rescue the interests of the ultra-violet-astronomy community by recommending that ESRO should participate in NASA's SAS-D project, a recommendation that was taken up and approved by the ESRO Council in July 1971. Hence IUE – still with us today – was born, ironically an ultraviolet mission corresponding to one of the fields excluded from the LPAC's list of priorities.

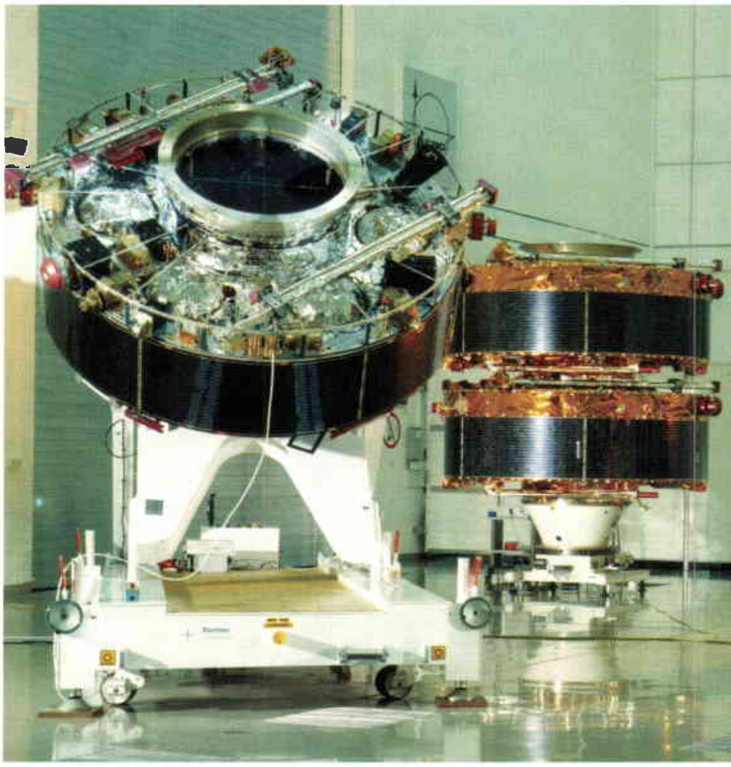
In the meantime, ESRO was entering the crisis that was to give birth to ESA. The science budget was kept to a minimum annual level of 27 MAU, in practice a ceiling that could only be raised in 1985 with the approval of Horizon 2000*. Under the chairmanship of G. Puppi, the ESRO Council accepted the famous 'first package deal', which opened the door to applications missions. The sounding-rocket programme was eliminated and Esrange was given back to Sweden under an appropriate protocol.

Also of fundamental importance was the decision to give Europe independent access to space through the development of the Ariane launcher.

In 1973, the Council had to decide which projects should be undertaken between 1975 and 1980 in the framework of the new organisation, ESA. After a two-day symposium at ESRIN (I) on 26–27 February 1973, attended by some 100 European scientists, the LPAC reconfirmed its earlier choice of Helos. Other potential candidates for selection were participation in the IMP – Mother/Daughter mission, or in a Venus orbiter, both NASA missions. The LPAC chose the 'Daughter' rather than the 'Mother' spacecraft, and thus ISEE-2 was born.

With ISEE-2, IUE and Spacelab (ESA's participation in the NASA Space Transportation System), ESA was tying its own programmes more and more to those of NASA. This cooperation was to be further extended with the participation in the Large Space Telescope (Hubble) and the Out-of-Ecliptic mission, later renamed the International Solar Probe Mission (ISPM), and known finally as Ulysses.

At the end of these first two phases, ESRO was forced to be more realistic in its objectives. It



CLUSTER

was recognised that, instead of launching a large scientific satellite each year plus several small ones, only one medium-size satellite could be launched every two or three years. At the same time, however, the scientists had learnt to establish priorities. They had admitted that only those ideas for which they could achieve a consensus among themselves were destined to succeed. This situation opened the way to the more mature phases in which, in addition, the scientists suddenly realised not only the possibilities offered on the worldwide scene by international cooperation, but also what the limits were.

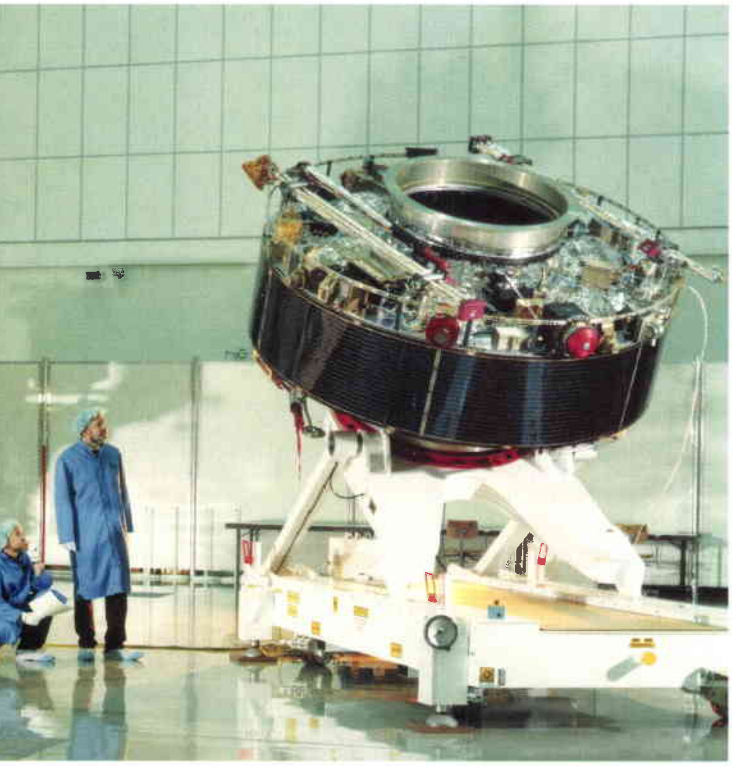
The ESA phase and the ISPM crisis (1975 – 1983)

In January 1974, the AWG and SSWG identified eleven missions from which the Agency's next scientific project(s) should be selected in 1976. Continuing with the practice started by the choice of Cos-B and Geos, and then of Helos and ISEE-2, in an attempt to maintain a balance (or due perhaps to an

* In fact, the LPAC considered the correct level to be somewhere between 43 and 47 MAU.

impossibility to choose between astronomy and magnetospheric missions), they decided to participate with NASA in the Large Space Telescope and the Out-of-Ecliptic mission.

This, in a sense, was the natural consequence of the earlier ESRO – LPAC recommendations which constrained European missions to small or medium-sized projects, while the USA and the Soviet Union were already planning very ambitious and challenging missions. If it did not want to stagnate, Europe had no choice other than to cooperate. Furthermore, cooperation with NASA was developing at a high rate, with Spacelab representing an important part of the US Space Transportation System. A strong wind of optimism was blowing as a result of the possibilities offered by international cooperation.



However, clouds started to form. The Europeans learnt that doing business with NASA was just that, something brought home on a daily basis to the engineers involved in the development of Spacelab and the scientists involved in the selection of instruments for the Large Space Telescope. The ISPM crisis then opened their eyes as they realised for the first time the fragility of agreements signed by their trans-Atlantic counterparts. The Memorandum of Understanding, the official document establishing the basis for the cooperation, which had a binding significance on the European side, had a different interpretation for the Americans, with NASA's budget submitted to yearly discussion at the White House and in Congress. The crisis came in the same period as the arrival of Ariane, which was successfully launched for the first time on Christmas Eve 1979, giving Europe full autonomy in accessing space. These two events together explain the series of decisions taken between 1980 and 1983. Giotto and Hipparcos were selected by the SPC in 1980 (again with great difficulties in deciding between astronomy and solar-system missions) and ISO in March 1983. All three missions were to use the Ariane launcher and were originally European-only missions.

This marked a turning point in ESA's science policy. First a planetary mission, namely Giotto, was selected. It was the first science mission to be launched by ESRO/ESA with its own means, and the first scientific spacecraft carried by Ariane. Hipparcos, an optical astrometry mission, had no equivalent in any other programme. With these two highly-original medium-size missions launched by Ariane, Europe finally achieved space maturity and independence, even taking over the world lead in the areas of comet science and space astrometry. This trend was confirmed by the selection of ISO, which opened the door for European astronomers (already involved in IRAS) to the highly competitive field of infrared astronomy, entering into direct competition with NASA's SIRTF*

The positive effects of the ISPM crisis for Europe should not be overlooked. Firstly, Europe realised that it could master its own destiny and assume a position of leadership in several areas. Secondly, Ulysses was ultimately launched successfully by NASA in October 1990, and on 13 September accomplished its first high-latitude pass over the Sun's south pole. Thirdly, with Giotto and the series of comet missions launched by the Soviets and the Japanese, international cooperation took on a new dimension, with the world's main space agencies/institutes involved in the Inter-Agency Consultative Group (IACG), in which for everyone involved cooperation was the only 'leader'!

It is against this background that ESA could enter the fourth phase of its space-science policy with the advent of Horizon 2000 and Horizon 2000 Plus.

* More than eleven years later, NASA's SIRTF mission is still not decided upon, and ISO remains the only infrared telescope to be launched before the end of the millenium.

The Horizon 2000 and Horizon 2000 Plus Phase (1984 – 1994)

In 1983, it became clear that ESA could no longer continue with its existing method of selecting project after project, without a long-term perspective and some kind of commitment that would allow the scientific community to prepare itself better for the future. ESA too needed a long-term programme in space science. On the other hand, there was some opposition to such an approach on the basis that it would discourage too early those scientists whose area of science would not be covered, leading to a possible loss of support for the ESA Science Programme. The way out was to draw up a programme whose perspectives were sufficiently balanced, following in a sense the first ideas set out by the LPAC in 1970, without ruling out the possibility of introducing new ideas at regular intervals. In addition, the level of the Agency's science budget, unchanged since 1971, confronted the scientific community with the risk of asphyxiation. The only possibility for Council changing that level rested on the assessment of a substantive plan and a reference framework for future space-science activities. It was this set of circumstances that made it possible to initiate the 'Horizon 2000 exercise'.

Table 2. Comparison of responses to 'Calls for Mission Concepts'

	Horizon 2000 2/11 – 31/12/1983	Horizon 2000 Plus 29/6 – 15/10/1993
Astronomy	30	32
Solar physics	34	41
Fundamental physics	–	29
Interdisciplinary	–	4
Miscellaneous proposals	4	2
Total no. of proposals	68	108

Following a Call for Mission Concepts issued in Autumn 1983, to which the European scientific community responded with some 68 proposals (Table 2), a Survey Committee and several Topical Teams were formed to set priorities, assess technical maturity in the various fields, and formulate recommendations to ESA's then Director General Erik Quistgaard, for him to present to the Council of Ministers in January 1985 in Rome. The whole exercise was conducted by the scientific community for the scientific community.

In June 1984 in Venice, when the Survey Committee held its last meeting, priorities had been courageously established (though not an easy task) – so-called 'Cornerstones' were approved in four domains: solar-terrestrial physics (STSP), comet science (CNSR, now called Rosetta), X-ray (XMM) and submillimetre astronomy (FIRST). In addition, the plan also included both small and medium-size projects, as in previous ESRO/ESA recommendations, but with no a priori exclusion of disciplines, so that a community not 'served' directly by the Cornerstones could still find its place in responding to the regularly released 'Calls for Ideas'. In this way, the programme had an element of flexibility, and its content could be adapted to the evolution of science (STEP), as well as to the opportunities offered by international cooperation (Cassini/Huygens).

Furthermore, the philosophy underlying Horizon 2000 was to contain the costs of missions within a fixed envelope, forcing the scientific community to limit its ultimate ambitions and ESA's management to adopt an even more efficient approach.

The existence of Horizon 2000 had an immediate and very important effect – the ESA science budget was granted an annual increase of 5% above inflation (not an easy decision to take!), an increment that was to be implemented over ten years. For the first time also, closer coordination with national programmes could be established, thereby avoiding inefficient competition between national and ESA's resources. Coordination with other international programmes also became easier.

Interestingly, the concept of international cooperation also evolved. In order for ESA to be master of its own future and not be dependent upon decisions taken outside its own control, it became clear with time that the Cornerstones ought to be placed under ESA leadership and be consistent with ESA's own technical and financial means, with cooperation bringing new, added capabilities to these purely European missions. On the other hand, greater risks could be taken at the level of small- or medium-sized projects which, as in the case of Huygens, could represent a small or even medium share of bigger missions being undertaken by other agencies.

With the Cornerstones forming fixed, pre-identified elements in the programme, the scientists – but also industry – knew ahead of time (20 years for the last Cornerstone) in which direction they ought to invest their efforts and pursue the long-lead-time technological developments necessary to bring projects into existence. The Cornerstones also achieved the long-sought-after balance between the community's main scientific fields of interest.

A similar approach is now being followed in the preparation of 'Horizon 2000 Plus' which covers the period 2005 – 2016 and contains three Cornerstones:

- a mission to Mercury
- an interferometer observatory for either astrometry or infrared astronomy
- a gravitational-wave observatory

and four medium-size missions, several of which can be missions on the Space Station or small satellites. This programme is described in detail in ESA Special Publication SP-1180: 'Horizon 2000 Plus – European Space Science in the 21st Century'.

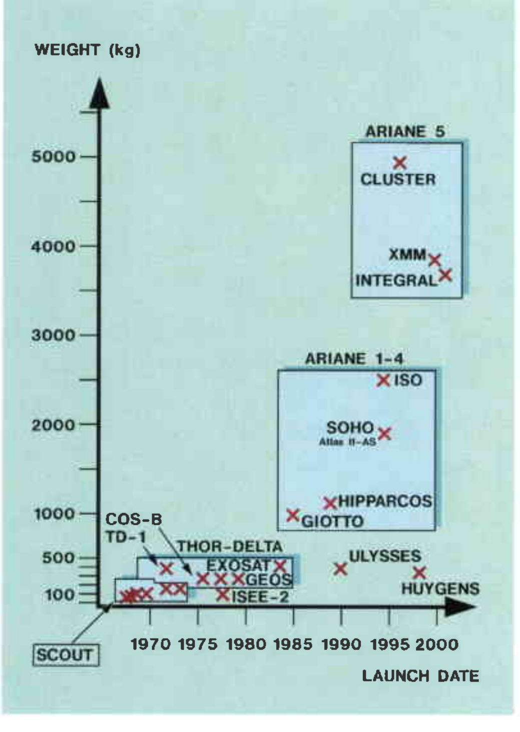


Figure 1. Weight of ESA science spacecraft as a function of their launch date. The rectangles indicate roughly the weight capabilities of the various launchers. Ulysses was launched by the US Space Shuttle and the weight shown corresponds to the dry mass of the satellite. Huygens is also a special case, being carried aboard the US Cassini satellite to Saturn and Titan. The Hubble Space Telescope would be off-scale in this illustration

A look at the evolution of the ESRO/ESA science missions

Figures 1 – 3 show the evolution in the capabilities of the ESRO and ESA science missions since 1968 in terms of weight in orbit, power, and bit rate. There has clearly been a steady increase in mission capabilities since early ESRO times, which is reflected most dramatically in Figure 1 with satellite weights closely mirroring both the evolution in launcher capabilities and the growth in scientific ambitions. Since it is unlikely that launchers more powerful than Ariane-5 (or the Ariane-5 class) will be available in the near or even more distant future, scientists must face a situation in which the weight of their spacecraft will probably be capped at no more than 3 to 4 tons, with no room for expansion.

Table 3 shows the payload weights on ESRO and ESA scientific satellites; although there are substantial fluctuations, the tendency has clearly been towards flying bigger payloads. The number of scientists involved per mission also varies greatly, from just a few to more than one hundred for ISO and Ulysses, to a maximum of 195 on Soho and 180 on Cluster.

Table 4 lists the groups with major experiment hardware involvement. Given that there are approximately 60 hardware groups in Europe, this shows that 20 to 40% of them can be involved at some stage in any of the ESA missions, a proportion that tends to increase with time.

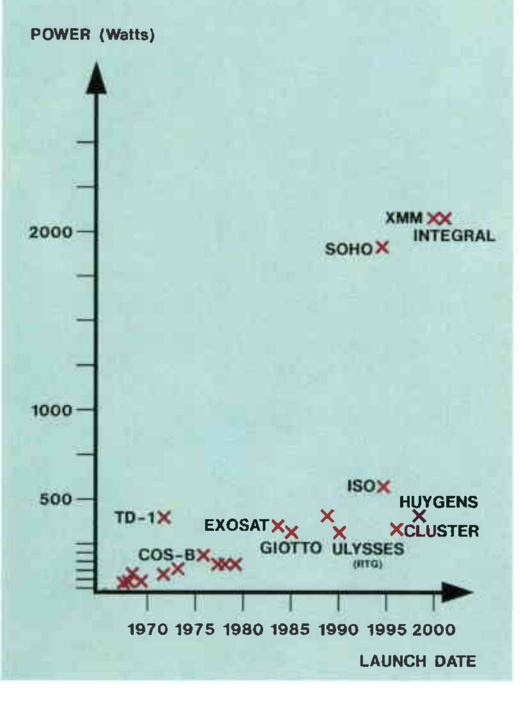


Figure 2. Average power consumptions (in Watts) of ESA science spacecraft as a function of launch date

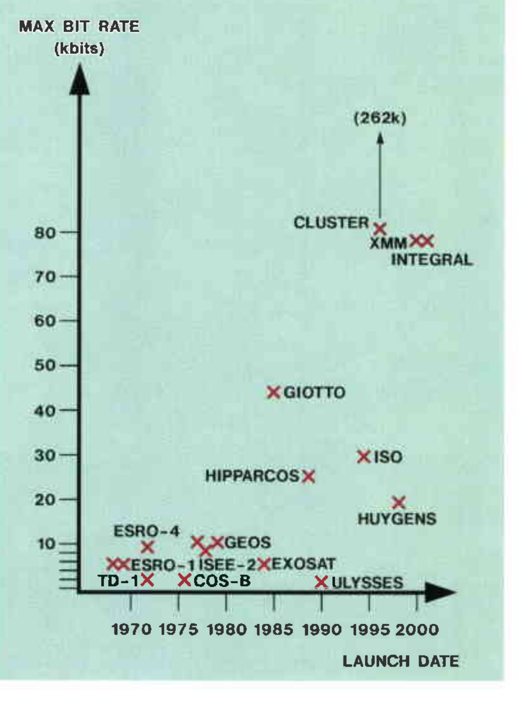


Figure 3. Maximum bit rates (in kbits) of ESA science spacecraft expressed as a function of launch date

Table 3. Evolution in payload weights of ESRO and ESA scientific satellites

Spacecraft	Launch date	Spacecraft mass (kg)	Payload mass (kg)	(%)	Launcher
ESRO-2 (Iris)	17 May 1968	75	21	28	Scout
ESRO-1A (Aurora)	3 October 1968	86	21	24	Scout
Heos-1	5 December 1968	107	27	25	Scout
ESRO-1B (Boreas)	1 October 1969	86	21	24	Scout
Heos-2	31 January 1972	116	30.5	26	Thor Delta
TD-1A	12 March 1972	478	144	30	Thor Delta
ESRO-4	21 November 1972	115	32	28	Scout
Cos-B	9 August 1975	271	118	42	Thor Delta
Geos-1, 2	20 April 1977	305	35	11	Thor Delta
	14 July 1977	(273)		(13)	
ISEE-2	22 October 1977	157	27	17	Thor Delta
Exosat	20 May 1983	500	87	17	Delta
Giotto	2 July 1985	960*	59	6	Ariane-1
		(584)		(10)	
Hipparcos	8 August 1989	1140*	210**	18	Ariane-3
		(677)		(31)	
Ulysses	6 October 1990	370	55	15	Shuttle
Soho	31 October 1995	1830	640	35	Atlas II-AS
ISO	19 September 1995	2496	90	4	Ariane-4
			1433**	57	
Cluster	29 November 1995	4800*	288	6	Ariane-5/Apex
		(2200)		(13)	
Huygens	October 1997	354	48	14	Titan IV (Cassini)
XMM	December 1999	3800	610***	16	Ariane-5

* Including apogee boost motor (dry spacecraft mass is in brackets)
** With telescope
*** Excluding telescope

Table 4. Number of groups with major experiment hardware involvement

Mission	A	B	CH	D	DK	E	F	GB	I	IRL	N	NL	S	SF	SSD	Others	Total Europe	Total
ESRO-2							1	6				1					8	8
ESRO-1A + 1B					2			4					1		1	3	8	11
Heos-1		1		1			2	3	3								10	10
Heos-2				2	1		1	1	2						1		8	8
TD-1A		1		1			3	3	2			2					12	12
ESRO-4				2				1				1	1				5	5
Cos-B				1			1		2			1			1		6	6
Geos-1 & 2			1	3	1		2	1	1				1		1	1	11	12
ISEE-1 & 2			1	6			3	1	1				1		2		15	15
Exosat				2				2	2			2			1		9	9
Giotto			2	5			2	2	1	1						3	13	16
Ulysses			1	7			4	3	2			1			1	10	19	29
ISO				4	1	1	5	3	2			2	1				19	19
Soho		2	3	5		2	4	3	3	1	1			2	1	7	27	34
Cluster	2			4			4	4	1		3		3	1	1	5	23	28
Huygens	2			2		1	2	2	2					1	1	2	13	15
Cassini Orbiter	1			4			5	4	2		1		1	1		20?	19	39
XMM		1	1	2			3	3	3			2				2	15	17
Total	5	5	9	51	5	4	42	46	29	2	5	12	9	5	11	53	240	293
% share of European expts.	2	2	4	21	2	2	18	19	12	1	2	5	4	2	5		100	

In addition, the observatory-type missions involve a large number of astronomers in the community:

- For IUE, some 80 proposals were implemented in 1994 (given the over-subscription ratio of 3, there are about 240 scientists involved annually in IUE). In addition, 686 use the IUE archive data at Vilspa.
- With Hipparcos, about 150 scientists have been involved in some level of activity at some stage over the last 10 years. Currently, some 30 scientists are working on the mission.
- On Hubble Space Telescope, 262 scientists are involved either as guest observers (243) or as guaranteed-time observers (19) in 'cycle 4'.

Figure 4 shows the evolution in mission costs. It indicates that, despite the rapid increase in the technical capabilities of the missions, ESA has been able to keep relatively tight control over its costs and has managed to offer regular, and a reasonably constant number of flight opportunities per decade, as shown also in Table 5. According to Figure 4, the missions can be grouped into two families:

(i) Those whose cost-to-completion is about equal to the annual scientific budget. Giotto, Ulysses, Huygens and Integral (assuming a Proton launch) fall into this category, which is the so-called 'medium-size' mission category of Horizon 2000.

(ii) Missions that cost twice the yearly budget, including missions like Exosat, Hipparcos, ISO, the ESA contribution to the Hubble Space Telescope, and the Cornerstones of Horizon 2000.

Amazingly, the evolution in the cost-to-completion tends to follow the overall trend in the yearly budget for both families of missions.

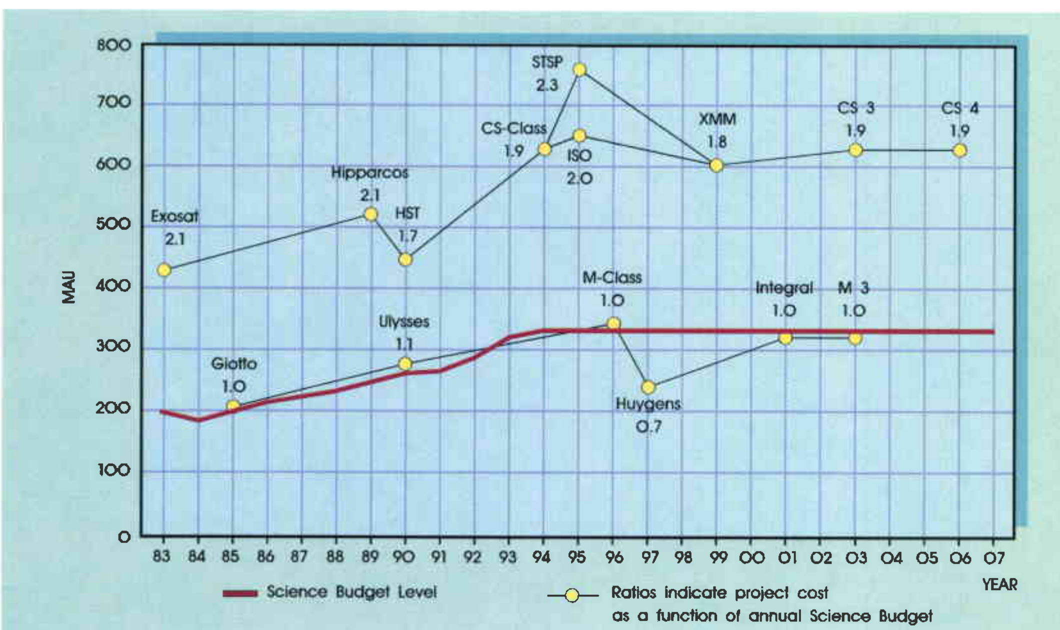


Figure 4. Evolution in the cost-to-completion (in MAU, 1993 economic conditions) of ESA science satellites launched after 1983 as a function of launch date. The solid curve shows the variation in the science programme's annual budget (also expressed in 1993 economic conditions). The numbers indicate the ratio between the cost-to-completion and the level of the science budget in the year of the launch. For missions to be launched beyond 1995, the cost-to-completion figures are today's estimates

Table 5. Number of ESRO/ESA projects launched/to be launched per decade

1965 – 1975		1976 – 1985		1986 – 1995		1996 – 2005	
8		6		6		6	
ESRO-2	(1968)	Geos-1	(1977)	Hipparcos	(1979)	Huygens*	(1997)
ESRO-1A	(1968)	ISEE-2*	(1977)	HST*	(1990)	XMM	(1999)
Heos-1	(1968)	IUE*	(1978)	Ulysses*	(1990)	Integral	(2001)
ESRO-1B	(1969)	Geos-2	(a)	ISO	(1995)	Rosetta	(2003)
Heos-2	(1972)	Exosat	(1983)	Soho*	(1995)	M3	(2003)
TD-1	(1972)	Giotto	(1985)	Cluster*	(1995) (b)	FIRST	(2005)
ESRO-4	(1972)						
Cos-B	(1975)						

* ESA – NASA cooperation

Notes:

(a) Geos-2 was an exact copy of Geos-1 (not placed in correct geostationary orbit by Delta launcher).

(b) Total really 9 due to the 4 Cluster spacecraft.

These curves prompt the following remarks. The two medium-size missions, M1 (Huygens) and M2 (Integral), are presently maintained at the level of one year of the science budget, even though Integral is a Cornerstone-class mission, and as such might be expected to be found on the upper curve of Figure 4. This is the result of international cooperation and the reuse – for the first time in the history of the ESRO/ESA science programme – of an existing spacecraft bus design, namely that from XMM. On the other hand, missions like Exosat, Hipparcos (a 'small' survey satellite at the outset and a 'blue mission' in Horizon 2000) and ISO (also a blue mission), are of the Cornerstone class.

HUYGENS PROBE

Table 6 shows the costs (1994 economic conditions) for missions launched after Geos and shows that the cost to launch 1 kg of mission or 1 kg of payload (excluding the payload cost itself) tends to decrease with time. Hence, Cluster is probably the most efficient satellite ever developed by ESA, an effect of the recurrent approach made possible by a mission based on four identical satellites.

These data permit one to derive a typical cost distribution for a given spacecraft and to assess how these costs are shared between ESA (12.5%) and external contracts (87.5%). This data is displayed in Figure 5.

Figure 6 clearly shows that for the missions after Geos, the duration of Phases B and C/D is nearly constant, independent of the size of the mission (virtually identical for Cluster and Exosat), being of the order of 6 years, with two notable exceptions, Ulysses and ISO. The Ulysses case illustrates the effect of the 'redefinition' of the mission by NASA in 1981 and the later effect of the Space Shuttle 'Challenger' accident. In ISO's case, the cryogenic-valve problem has been the main reason for the abnormally long industrial phase.

Not shown in Figure 6 is the time spent prior to the start of Phase A. This varies from mission to mission and is in fact difficult to define properly. It is usually very long, however, sometimes reaching more than ten years. This was the case for IUE and Giotto derived, respectively, from the concept for the

Table 6. Scientific spacecraft mass and costs to ESA (excluding cost of payloads, except for Exosat and Hipparcos) updated to 1994 economic conditions

Spacecraft	Launch date	Cost to completion (CTC) (MAU)	Mission cost (CTC) vs spacecraft mass (MAU/kg)	Mission cost (CTC) vs payload mass (MAU/kg)	Spacecraft development cost (MAU)
Geos-1	20 April 1977	307.2	1.005	8.727	141.9
ISEE-2	22 October 1977	105.1	0.67	3.864	63.6
Exosat	20 May 1983	444.1	0.888	5.105	200
Giotto	2 July 1985	218.9	0.375	3.716	103.5
Hipparcos	8 August 1989	538.8	0.796	2.566*	291.5
Ulysses	6 October 1990	287.4	0.777	5.225	132.7
ISO	September 1995	670.0	0.268	7.444 (0.467)*	364.9
Soho	September 1995	325.0	0.177	0.508	237.3
Cluster	November 1995	428.8	0.089	1.489	296.3
Huygens	October 1997	251.6	0.711	5.242	147.8
XMM	December 1999	626.1	0.165	1.026	317.2

* Payload includes the Telescope

Note: Cost figures have been updated to 1994 economic conditions using the combined Science Annual Exchange Rates. Consequently, they are only *indicative* and should not be taken as absolute values.

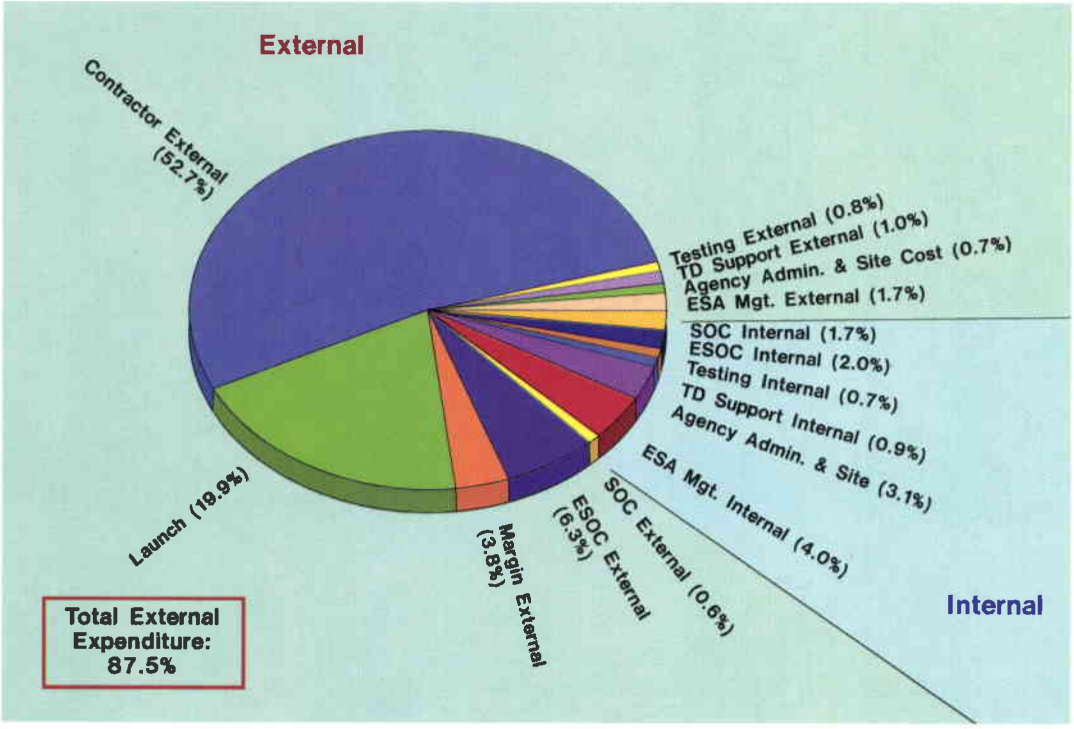


Figure 5. Typical spacecraft costs (excluding the payload) and the distribution between external (87.5%) and internal expenditures (12.5%)

LAS and from the second Large Project of the Blue Book. This was also the case for Ulysses, a mission whose concept was first proposed in the late fifties, and for the Hubble Space Telescope. Both were under discussion by ESRO/ESA and NASA back in the early seventies, but were only launched in 1990.

The Horizon 2000 and 2000 Plus Cornerstones have been or are being decided some 20 years before the missions actually fly. This is the time needed to properly define and prepare these missions technologically, before they can be fitted into a realistic budget, which should in principle not exceed two years of the scientific budget. This is characteristic of the way in which Europe (i.e. ESA) operates and is probably the inevitable consequence of the inescapable necessity of tailoring the scope of missions to a realistic budget. It is also a consequence of the relatively slow progress in technological preparation, itself an effect of the rather low financial effort by ESA in the area of technological research compared to the American approach.

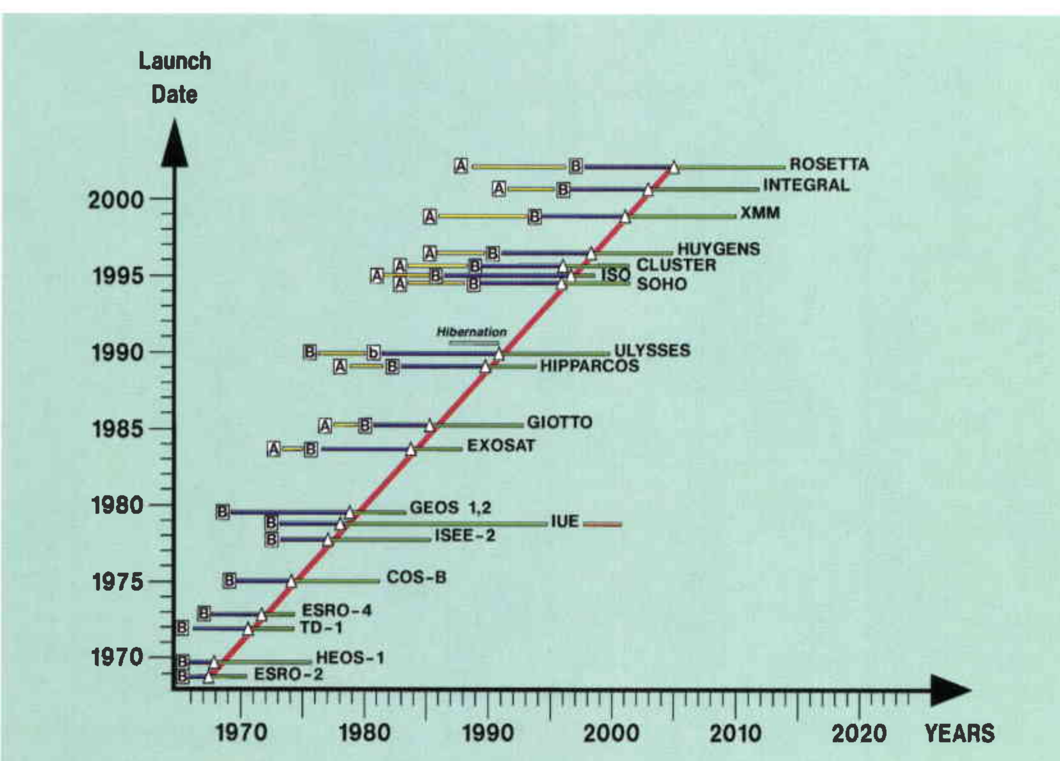


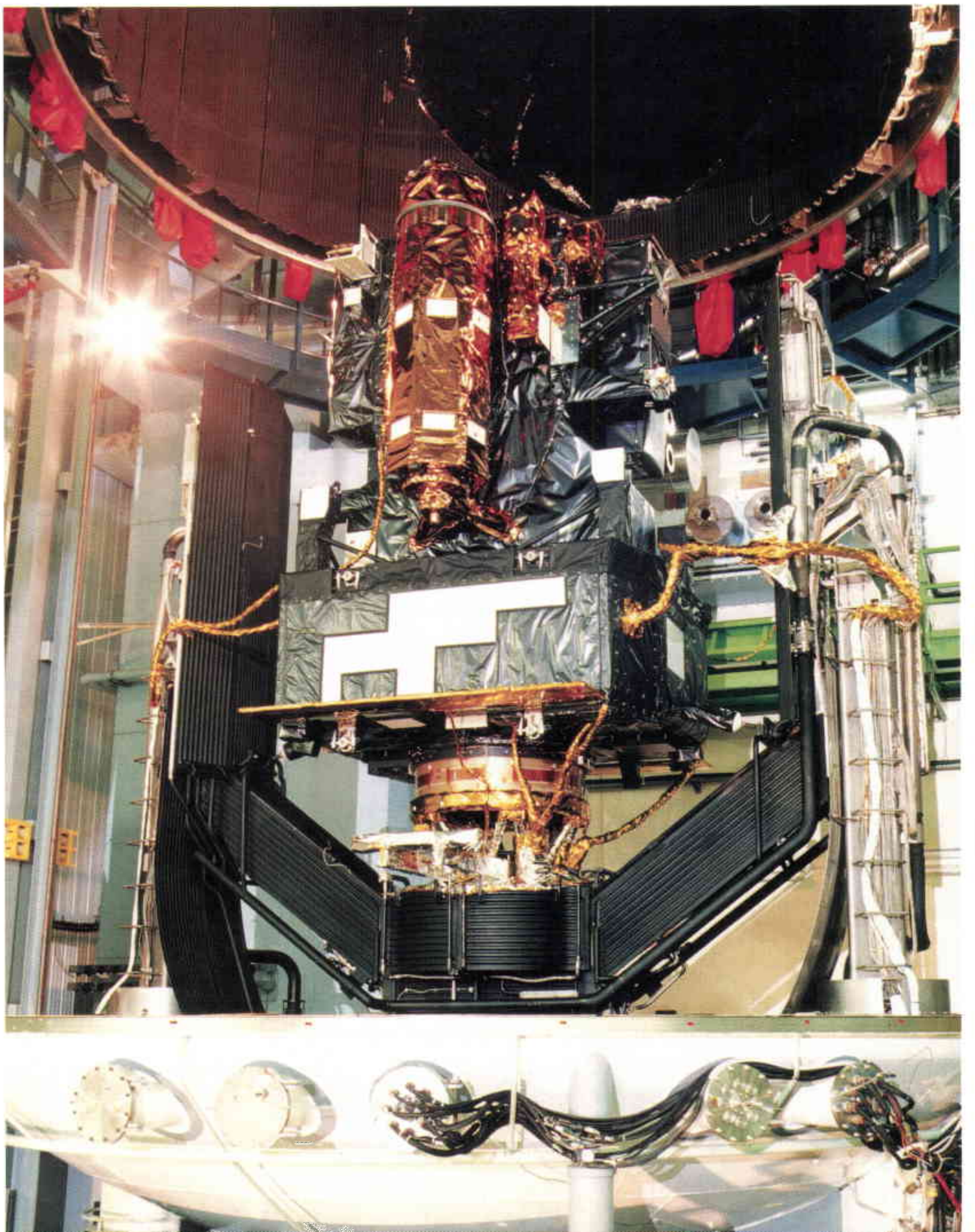
Figure 6. The durations of the various phases of ESA science projects, indicated by the horizontal bars. The A's and white bars indicate the Phase-A starts and durations, respectively. The B's represent the start of Phase B in industry and the grey bars represent the duration of Phase B and C/D. The launches are represented by white triangles, while the black bars indicate the durations (actual or foreseen) of in-orbit operations. Note the difference in the durations of Phases B/C/D for the Delta and Ariane families (see also Fig. 1), and the near constancy of these Phases for each individual family

Despite this, ESA is currently playing a pioneering and leading role in the field of solar physics with Ulysses and Soho, is leading – and will continue to do so in the next century – in cometary science with Rosetta, and with Huygens will accomplish the first landing ever at a distance beyond the orbit of Mars. ESA is also the world leader in space astrometry with Hipparcos, and it will be ahead in infrared, submillimetre and gamma-ray astronomy with ISO, FIRST and Integral, respectively, while XMM is the most sensitive X-ray satellite planned at this moment in the world. Moreover, Horizon 2000 Plus offers potential new leadership positions in plasma, planetary and solar science, as well as in interferometry and the newly emerging field of gravitational physics.

Conclusion

Despite the rapid increase of more than one order of magnitude in the technical capabilities of its missions, ESA has managed to maintain relatively tight control over its costs, enabling it to provide a regular and nearly constant number of flight opportunities per decade. The small (100 kg) satellites launched in ESRO times have been succeeded by missions such as ISO, Soho and Cluster, each weighing several tons.

This dramatic evolution in technical capabilities has not been mirrored in the evolution of the annual science budget. Today's budget, after the annual 5% increase since 1985, is still no higher, in terms of purchasing power, than the ESRO budget of 1964. It takes the same time today for the industrial development of missions weighing several tons, such as Cluster, as it did 15 years ago to develop missions 10 times smaller, such as Exosat. The ESA team managing Cluster is composed of 20 engineers, compared to the 35 who worked on Exosat. It is this strict design-to-cost approach



SOHO

that is allowing spacecraft like Integral, which because of their size and scope would normally qualify as Cornerstone missions, to be envisaged as medium-class missions.

In addition, more scientific opportunities are being offered to the science community: today's missions involve more and more Principal Investigators and an increasing number of Co-Investigators. Moreover, many of ESA's scientific missions are systematically extended beyond their nominal lifetimes and the vastly greater volumes of data being acquired are being systematically archived and made widely available to much larger numbers of users.

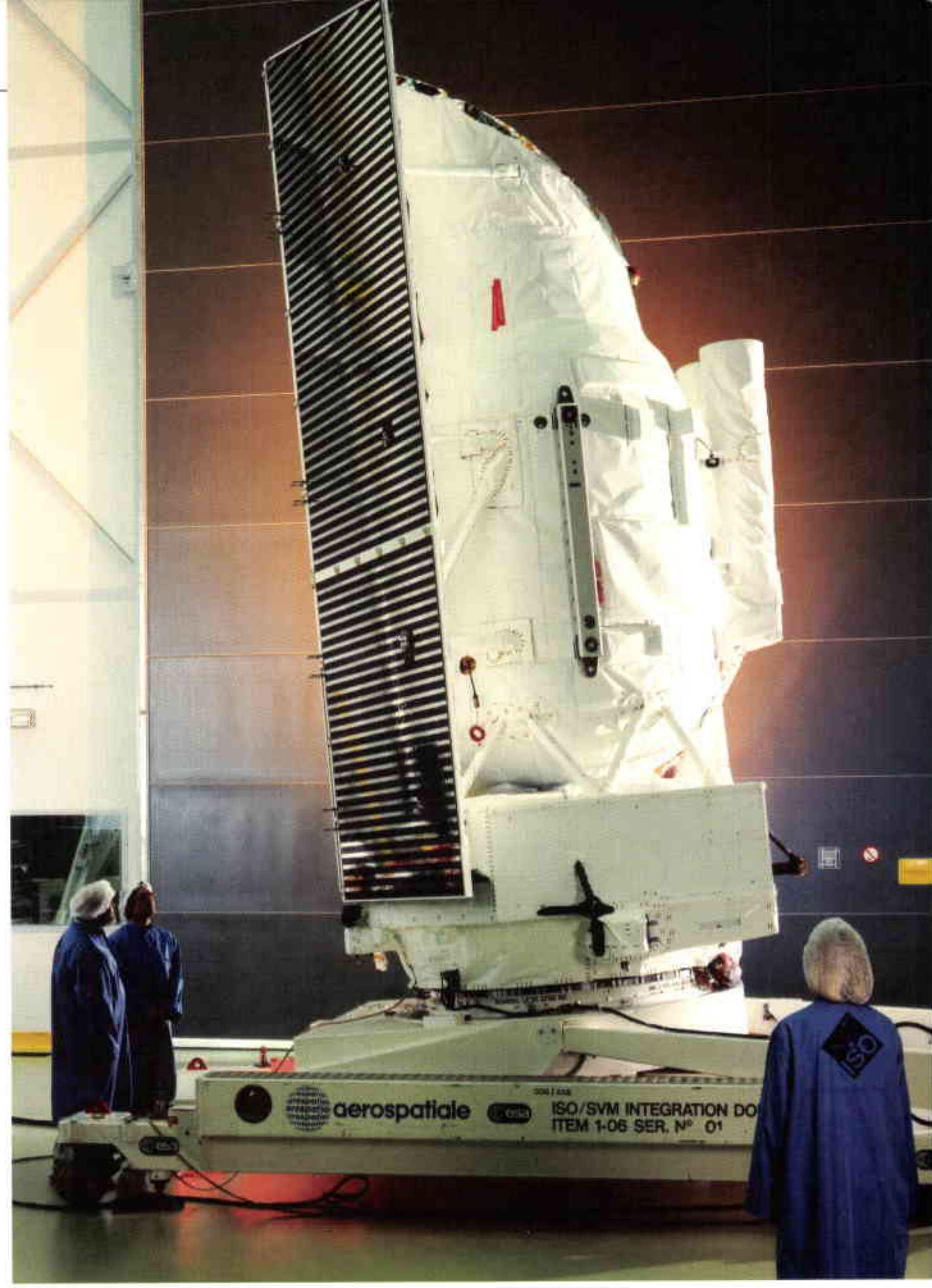
These and many similar examples prove that ESA is becoming more efficient with time, for which there are several reasons. Firstly, the evolution in technology is allowing us to design larger missions with a lower price per kilogramme. Secondly, both ESA and industry have acquired substantial experience and have thereby improved in efficiency with the passage of time. Thirdly, the existence of a long-term programme for science – first Horizon 2000 and now Horizon 2000 Plus – is allowing the necessary technology development to be pursued sufficiently early and the use of common subsystems on a variety of missions.

After some 35 years of endeavour, European space science has finally reached maturity as a result of ESRO's and ESA's efforts. Order has been brought into the management area and a large amount of technical expertise has been acquired. International cooperation can now be seen in a more rational context, based on a more equal partnership, and with new partners involved. In addition, coordination with national programmes is constantly being improved.

Through its mandatory character and the fixing of its budget for five-year periods (so-called 'level of resources'), ESA's Science Programme offers space scientists, primarily in Europe but also around the world, one of the most stable programming elements with missions second to none in their fields, missions that are powerful drivers of technological innovation.

When discussing the future of space science in Europe, one should constantly bear in mind the reasons why the ESA Science Programme has been a success: namely by its
- relying at all stages on the science community, from the submission of mission ideas to their selection and exploitation
- maintaining a science budget at a level sufficient to ensure a balanced programme over a time frame no longer than two decades
- ensuring medium- and, if possible, long-term financial stability for its activities through pluri-annual commitments
- maintaining a high level of technical management in ESA and in national institutes
- taking its own decisions, without reliance on decisions taken by external agencies
- maintaining tight coordination between a common European programme and the national programmes
- maintaining political, technical and financial synergy with the more global elements of the space programme (Space Station, planetary exploration, etc.).

Several of these ingredients were discussed by the early ESRO and later ESA Committees and have been successfully carried through into the ESA science programme. They should by all means be preserved in the future.



ISO

United Nations/European Space Agency Workshops on Basic Space Science

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In 1958, the United Nations (UN) formally recognised a new potential for international cooperation by establishing an ad hoc Committee on the Peaceful Uses of Outer Space (COPUOS). A year later the Committee became a permanent body, and by 1983 membership had expanded to 53 states, with more than half of the members coming from the developing world. In 1970, COPUOS established the UN Progamme on Space Applications in order to strengthen cooperation in space science and technology between non-industrialised and industrialised countries. In the last few years, the UN and its COPUOS have paid increasing attention to education and research in space science and technology, including basic space science.

In 1991 the UN, in cooperation with ESA, initiated the organisation of annual Workshops in Basic Space Science for developing countries. These Workshops are designed to be held in one of the following major regions: Asia and the Pacific, Latin America and the Caribbean, Africa, Western Asia, and Europe. Accordingly, Basic Space Science Workshops have already been held in India (1991), Costa Rica and Colombia (1992), and Nigeria (1993). The fourth Workshop was held from 27 June to 1 July 1994 at the Cairo University, in Egypt, for Western Asia[1].

The title of the Workshops intentionally includes the term 'Basic Space Science' to reflect the fact that in many non-industrialised countries astronomical, planetological and astrophysical research is precarious, while more application-oriented fields of space science and technology are fairly well developed and provide opportunities to accommodate astronomical research projects.

The four Workshops were attended by 300 invited participants from 50 countries and 15 national and international organisations. The scientific programme included 160 presentations addressing topics in international cooperation in basic space science, space-science education, space-science policy, solar-terrestrial interaction, cosmology, planetary science, ground-based and space-based observatories, and space astronomy, astrophysics and cosmology. The scientific programme of the Workshops is developed by the UN Office for Outer Space Affairs, ESA, TPS, and the host institution. The selection of topics depends on the interests of the local organisers, with a strategic combination of the above-mentioned topics.

The UN/ESA Workshops provide an excellent opportunity for scientists from non-industrialised countries to both present the results of their research work to the international scientific community and familiarise themselves with the most recent results in their fields. Proceedings containing scientific papers, papers addressing the status of current and future basic space-science projects, as well as recommendations and observations emanating from the Workshops are published.

The traditional problems of basic science (including isolation, brain drain, lack of

[1] The 1991 Workshop in India was organised in cooperation with the Government of India, hosted by the Indian Space Research Organization (ISRO), and sponsored by ISRO, ESA and the UN. The 1992 Workshop in Costa Rica and Colombia was organised in cooperation with the Governments of Costa Rica and Colombia, and hosted by the University of Costa Rica in San Jose and the International Center for Physics (CIF) and the University of los Andes in Bogota. That Workshop was sponsored by ESA, the National Aeronautics and Space Administration (NASA), The Planetary Society (TPS) and the UN. The 1993 Workshop in Nigeria was organised in cooperation with the National Agency for Scientific and Engineering Infrastructure (NASENI) of the Government of Nigeria, and was hosted by the University of Nigeria, Nsukka, and the Obafemi Awolowo University, Ile-Ile. It was sponsored by ESA, the German Space Agency (DARA), the International Center for Theoretical Physics, the National Aeronautics and Space Administration, the Nigerian Telecommunications PLC (NITEL), TPS and the UN.

financial resources, ever-increasing gap with respect to industrialised countries, lack of scientific tradition, and weak infrastructure) in non-industrialised countries remain a major cause of concern. Interestingly, there are new developments that may change the situation, and these developments deserve serious consideration. The most important facts that have brought some hope for the improvement of the situation of science in non-industrialised countries are: first, local governments are understanding the need to recognise the intrinsic value of basic space science and its importance as an essential component without which the economy cannot grow; secondly, there is a new trend in the scientific community to develop large international facilities, which may make use of the climatological and geographic attributes of non-industrialised countries; thirdly, the revolution in electronic communications allows close contact between scientists and permits access to remote databases and computer power from any part of the world. This technology helps ameliorate the isolation factor in unprecedented ways. Lastly, global problems (i.e. environment) and the consciousness that their solution must be global in nature has led to the inclusion of non-industrialised countries in the science policies of the industrialised countries.

The loss of researchers from non-industrialised countries via a 'brain drain' is a serious problem that must be addressed. To reverse this process, efforts must be made to promote awareness in non-industrialised countries of the importance of space science and to ensure that space scientists have the basic resources necessary for their work. International efforts to ensure that scientists in non-industrialised countries have adequate communication links to the international scientific community, adequate access to the technical literature, more opportunities to participate in international meetings, access to data and data-processing facilities, and opportunities to participate in the planning, design and use of space observatories, research programs and space missions, all help reduce the feeling that scientists in non-industrialised countries have to move abroad in order to produce good scientific work. The UN/ESA Workshops have been organised to address these problems and to help identify solutions.

The objective of these Workshops is to strengthen basic space science in non-industrialised countries by addressing ways and means by which the following goals can be accomplished: to make scientists aware of current and future scientific and technical aspects of basic space science, to enhance scientific cooperation between developing countries, to explore avenues of education, training and research in space-science subjects for the benefit of developing countries, to create an international core group of scientists that will pursue the objectives of the Workshop, to provide access to the most recent advances for scientists from non-industrialised countries, to identify avenues that will facilitate scientific cooperation, to create a forum for the discussion of problems and the formulation of policies and recommendations.

The development of basic science in non-industrialised countries is a key factor for the

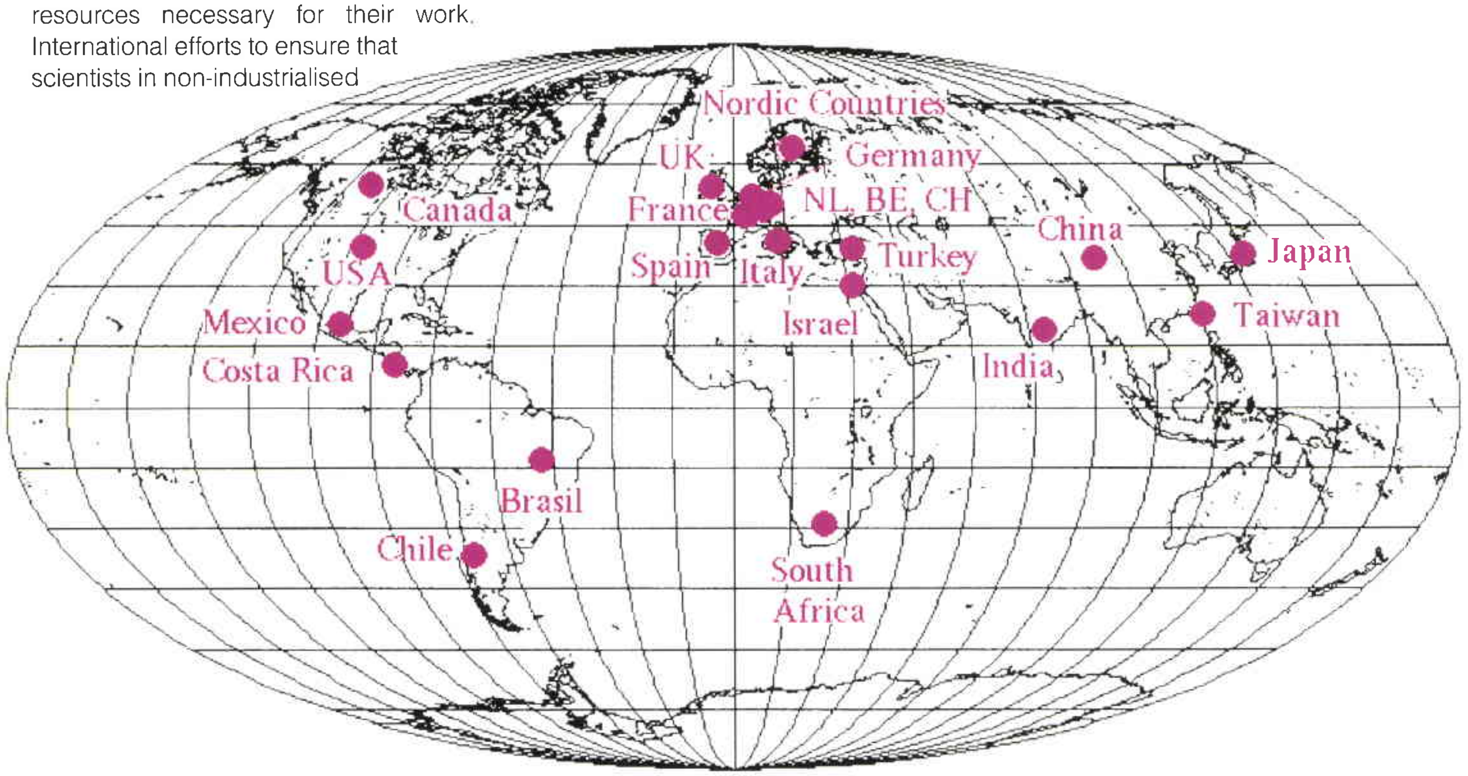

Figure 1. World network of national hosts of the IUE Data Archival System (ULDA/USSP). This ESA-developed system has given many Developing Countries, including those still with limited communications infrastructures, direct access to data from the Agency's International Ultraviolet Explorer (IUE) satellite

economic prosperity of those countries. Scientific research is now being recognised by the governments of non-industrialised countries as an essential ingredient to guarantee economic growth through the establishment of a strong infrastructure for the assimilation and use of high technologies. In the context of these Workshops, 'Basic Space Sciences' have been defined as:

(a) Astromony and astrophysics
(b) Solar-terrestrial interaction and its influence on terrestrial climate
(c) Planetary and atmospheric studies
(d) The origin of life and exobiology.

Figure 2. A United Nations computer engineer, Mr Abraham Edathanal, surrounded in his Vienna office by 30 surplus PCs donated by ESA/ESOC. After a thorough checkout in Vienna, the PCs were shipped by the UN to needy research institutes in Cuba, Ghana, Honduras, Nigeria, Peru and Sri Lanka

Basic space science is closely associated with the economic development of a country. Examples of space-technology applications for the benefit of non-industrialised countries are already very well known – remote sensing, telecommunications, monitoring of natural resources, environment and weather conditions, etc. All of these applications have a direct influence on the economy. The importance of developing basic space science has certainly been recognised in those countries that have sponsored the UN/ESA Workshops, i.e. India, Costa Rica, Colombia, Nigeria, and Egypt.

Many non-industrialised countries have developed some infrastructure for the management of remote-sensing and tele-communications services. However, these are just two of many end products offered by space technology. It is important to develop basic space science in order to take full advantage of space technologies. Without indigenous capabilities, the rapid growth of these technologies rapidly renders the acquired infrastructure obsolete and prolongs the dependence on the industrialised countries. This fact has traditionally been ignored by policy makers and local governments.

A trickle-down effect is produced when highly qualified scientists are present to construct the required infrastructure by training other scientists, engineers, technicians, and students. The buying of packaged ready-to-use technology has failed as a model for technology transfer, with the expected increase in knowledge not materialising. On the contrary, an increase in dependence on the industrialised countries has been noted, and the accumulation of costly and often obsolete equipment has been the end result.

A vital part of the Workshops are the Working Group Sessions, which provide participants with a forum in which observations and recommendations for developing basic space science in all its aspects, through regional and international cooperation, are made. Scientists from different non-industrialised countries have a surprisingly large number of in common. Discussions between them have stimulated an exchange of ideas which, when combined with the diversity of experiences, provides a rich and favorable environment for the creation of new collaborative initiatives. By opening the floor to the scientists, these meetings become an ideal forum where key issues that are impeding progress can be identified and proposals formulated. The content of these discussions and the proposals that may come out will be collected in a set of Recommendations that will form part of UN General Assembly document that will be used to lobby governments and funding agencies.

In addition to the direct benefits of an international scientific conference, the UN/ESA Workshops have generated a number of other supplementary activities such as: the donation of 30 personal computers by ESA to non-industrialised countries, the donation of professional astronomical telescopes by the Japanese government (under Japan's Cultural Grant Aid scheme), as well as the donation of educational space-science material by TPS and NASA/JPL. An important aspect of the recent Workshop in Cairo was the agreement to upgrade the Kotamia Observatory facilities and the intention to make this instrument available as a regional facility to the scientists from the Western Asian region.

Recommendations common to all three Workshops are as follows. It is recommended to build first-rate educational and research capabilities for internationally recognised scientific research, by ensuring availability at national level of existing basic space-science data archives. The participants recognised that the continual progress in basic space science and technology makes the free and efficient flow of ideas and concepts a necessity, and therefore urged Member States to plan and implement local electronic communications at least at, or preferably above, the basic e-mail network level. Access to remote computing power and databases immediately opens up a whole new world of research opportunities to scientists in any region of the world.

Another important recommendation that has come out of the UN/ESA meetings is the need to explore the great scientific potential of some non-industrialised countries due to their special attributes (i.e. climate, geography, bio-diversity, etc.), which put them in a privileged position for the development of certain fields of scientific research: geomagnetism studies, electrojet currents, galactic mapping, solar photometry, astrometry and environmental projects such as ozone mapping.

The recognition of the particular scientific potential of specific regions is not new. The Chacaltaya cosmic-ray station in Bolivia and the European Southern Observatory in Chile are well-known examples of those types of activities that can act as catalyst in the scientific development of non-industrialised countries. However, the development of such international facilities needs coordination, and discussions about future facilities of this type have taken place in the UN/ESA Workshops. Colombia, for example, has started the establishment of a radio-observatory in collaboration with the Lawrence Berkeley Laboratory that will take advantage of its equatorial location, in combination with the presence of high-altitude peaks, in order to construct maps of diffuse galactic radio emission. A proposal for an inter-African astronomical observatory and science park on Gamsberg mountain in Namibia, which offers a high proportion of cloudless nights, a dark sky, excellent atmospheric transparency, and low humidity, has also been discussed. In March 1992, site-selection feasibility studies were initiated in Nsukka, Nigeria, for a computerised optical telescope for detailed solar seismology studies. This project is a collaborative effort by the University of Nigeria, Nsukka, and the Zetetic Institute, Arizona, USA. Another project that originated in the Workshops is the installation of an Internet node in Nigeria, with TPS support.

One of the most important messages to come out of these Workshops is that we can all share the excitement of the new discoveries. Theories of the cosmos and the position of humanity and the Earth within the Universe have always been central to our cultural beliefs and values. However, the concept of economic development has generally focussed on technology and applications, rather than on science and research. As a result, development programmes have not paid sufficient attention to promoting scientific research and international cooperation in science. In the long term, scientific research is essential to the intellectual, spiritual, social and economic vitality of society. We must not only find technical solutions to the problems we understand, but we must also find new ways of understanding our world. Knowledge about nature and the cosmos is a cultural heritage that belongs to humanity as a whole and should enrich all cultures regardless of their geographical location, race, politics or economic standing. In this respect, space is a common link that can unite us all!

Figure 3. The Kotamia Observatory in the Egyptian desert south of Cairo. The Egyptian Ministry of Education's plans for upgrading its 74-inch Cassegrain telescope and opening it as a regional facility represent an important step for the development of the Basic Space Sciences – in this case astronomy – for the western Asian countries

ESA's Participation in the International Microgravity Laboratory (IML-2) Mission

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The Space Shuttle Columbia with the second International Microgravity Laboratory (IML-2) with Spacelab on board was launched on 8 July 1994 at 12:43 a.m. Eastern Daylight Time. Columbia returned safely on 23 July at 6:38 a.m. after a very successful mission. With a flight duration of nearly 15 days, it was the longest Shuttle mission thus far and was also a milestone for microgravity research and international cooperation.

The second International Microgravity Laboratory (IML-2) mission was a truly international event, paving the way for cooperation in the scientific utilisation of the forthcoming International Space Station. ESA provided several major facilities for conducting research in microgravity, as did France and Germany. The facilities were used jointly with scientists from the US; in exchange, NASA provided the mission itself. Several experiments measured and characterised the microgravity environment and the astronauts' response to spaceflight conditions. Others were in the fields of biology, biotechnology, fluid dynamics, crystal growth and alloy solidification, and near-critical-point investigations.

Another important objective of the mission was to demonstrate remote payload operations or 'telescience'. Using that method, principal investigators monitored and controlled their flight experiments from various user centres and laboratories across Europe. This approach is proving to be a very efficient and cost-effective way to conduct and optimise scientific research, and it will become increasingly important as long-duration access to space becomes available.

NASA had invited its international partners to participate in this mission under very favourable conditions, namely the joint utilisation of flight experiment facilities delivered by the partners and of the mission itself provided by NASA, as was the case with the IML-1 mission which took place in January 1992.

The crew of seven astronauts (Fig. 1A), with Robert D. Cabana as commander, James D. Halsell as pilot and Richard J. Hieb as payload commander, faced a very complex mission. The mission specialists, Carl E. Walz, Leroy Chiao, Donald A. Thomas and the Japanese Chiaki Naito-Mukai, a medical doctor, had an extremely tight schedule. They worked in teams in shifts around the clock to accomplish the large number of diverse experiments. The flight crew was supported from the ground by the alternate payload specialist, J.J. Favier (Fig. 1B) from the Centre d'Etudes Nucléaires (CEA) in Grenoble.

Some 82 experiments from 15 different countries and involving about 200 scientists were conducted. The experiments covered a wide range of scientific domains such as human physiology, biology, biotechnology, crystal growth and alloy solidification, fluid dynamics, near-critical-point phenomena and technology.

Microgravity, the key parameter of these experiments was well characterised. Different sensors measuring residual accelerations and vibrations (g-jitter) were attached to the payload at various locations. By orbiting the Earth at an altitude of almost 300 km and with operational conditions optimised with regard to g-level perturbations, low residual accelerations were obtained. Data measured with the German accelerometer QSAM is shown in Figure 2. The overall 'noise level' between 0 and 50 Hz was of the order of one milli-g (1 milli-g = $10^{-3} g_o$, g_o being the gravitational acceleration experienced on the surface of the Earth) (Fig. 2A). Between 0 and 20 Hz, which is the most critical frequency range for experiments, the perturbations did not exceed a few micro-g (1 micro-g = $10^{-6} g_o$) (Fig. 2B). These were almost perfect conditions for investigations in life sciences and physical sciences under near-weightlessness, the primary objective of this mission.

The facilities used in the IML-2 mission are listed in Table 1. Europe's contribution to this mission was very important. ESA provided the Bubble, Drop and Particle Unit (BDPU), the Critical Point Facility (CPF), the Automated Protein Crystallisation Facility (APCF) and the Biorack. France provided RAMSES for free-flow electrophoresis, and Germany contributed TEMPUS for electromagnetic levitation processing, NIZEMI for microscopic observation of biological samples in a slow-rotating centrifuge, Biostack for investigating the response of biological samples exposed to the radiation environment, and QSAM for measuring residual accelerations.

Figure 1A. The flight crew. Top (left to right): R. Hieb, C. Mukai, R. Cabana, L. Chiao, J. Halsell. Bottom: C. Walz, D. Thomas

Figure 1B. J.J. Favier, the payload specialist who assured the link between the flight crew and the investigators on the ground

A first review of the preliminary results of the experiments, which was organised by NASA's Mission Scientist R.S. Snyder, took place at the European Space Operations Centre (ESOC) in Darmstadt, Germany, on 1 and 2 November. The feedback from the principal investigators was very positive, and it seems that most of the science objectives were accomplished. However, a thorough evaluation of the data and samples obtained will require at least 8 to 12 months and, after the final results are known, a full assessment of the scientific accomplishments can be made.

ESA experiment facilities and related scientific investigations

Life Sciences

The primary emphasis in the Life Sciences was on Space Biology. Of the 33 experiments using biological specimens, 19 were performed in ESA's Biorack, a multi-purpose facility designed to investigate the response of cells, tissues and plants to weightlessness and cosmic radiation (Table 2). The Biorack has three incubators for experimentation, a glove-box for handling samples, and a cooler-freezer for preserving samples for analysis in the laboratory after the mission for comparison with reference samples produced on Earth.

Both the Biorack and the coolers, which flew for the first time, performed very well. There were only two problems. One was in the control electronics of a centrifuge in one of the incubators; it was solved by activating the back-up operations mode. The other was a

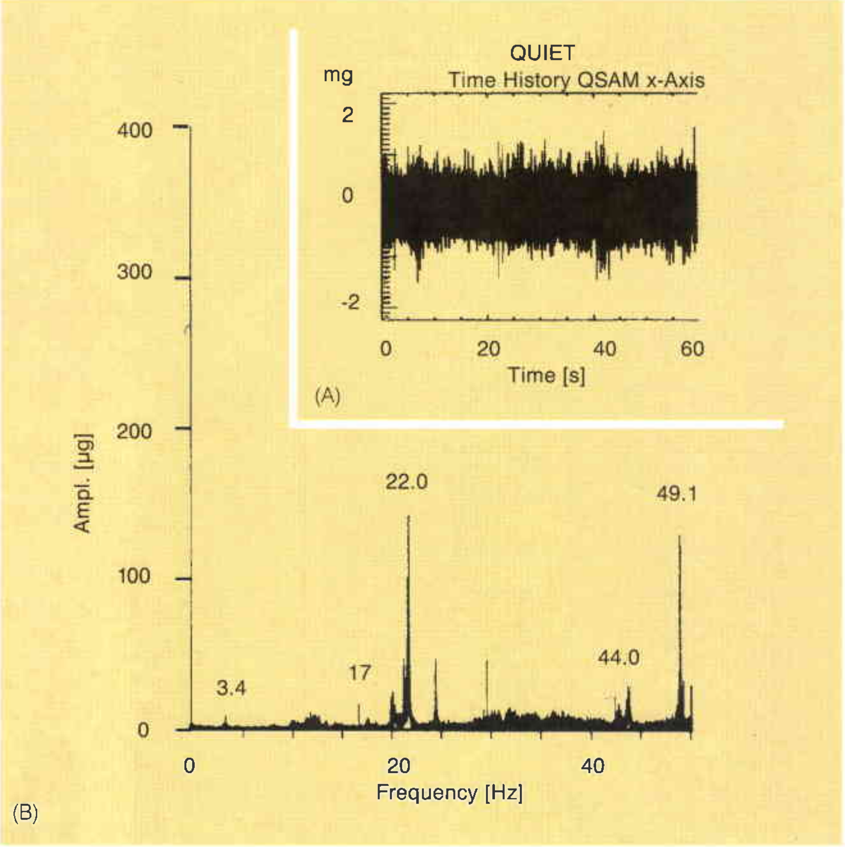


Figure 2. Residual accelerations and g-jitter measured with the German accelerometer QSAM

A. The overall amplitude in milli-g (10^{-3}g) between 0 Hz and 50 Hz as a function of time

B. Perturbations as a function of frequency. The peak at 22 Hz corresponds to the eigenfrequency of the experiment rack, while the peak at 49.1 Hz is due to an as yet unknown source, such as a mechanical pump
(Courtesy of H. Hamacher, DLR, Cologne, Germany)

Table 1. The facilities dedicated to the various IML-2 experiments

Area Investigated	Facility	Name of Facility
Radiation Biology	Biostack	(DLR, Germany)
	RRMD	Real-Time Radiation Monitoring Device (NASDA, Japan)
Biotechnology	APCF	Advanced Protein Crystallisation Facility (ESA)
	FFEU	Free-Flow Electrophoresis Unit (NASDA, Japan)
	RAMSES	Applied Research on Electrophoretic Separation (CNES, France)
Biology	AAEU	Aquatic Animal Experiment Unit (NASDA, Japan)
	Biorack	Facility for biological investigations (ESA)
	NIZEMI	Slow rotating centrifuge with optical microscope (DARA, Germany)
	TEI-CCK	Thermoelectric incubator/Cell Culture Kits (NASDA, Japan)
Human Physiology	EDOMP	Extended Duration Orbiter Medical Project (NASA)
	SCM	Spinal Changes in Microgravity (CSA, Canada)
Fluid Sciences	BDPU	Bubble, Drop and Particle Unit (ESA)
	CPF	Critical Point Facility (ESA)
Material Sciences	LIF	Large Isothermal Furnace (NASDA)
	TEMPUS	Electromagnetic Levitator Facility (DARA, Germany)
Space Environment	SAMS	Space Acceleration Measurement System (NASA)
	QSAM	Quasi-Steady Acceleration Measurement (DLR, Germany)
Vibration Control	VIBES	Vibration Isolation Box Experiment System (NASDA, Japan)

Table 2. Biorack experiments

Investigator	Institute	Experiment Title
A. Cogoli	University of Sassari, Italy	Lymphocyte activation, differentiation, and adhesion dependence of activation Antigen presentation and T-cell proliferation Lymphocyte movements and interactions
D. Schmitt	University of Toulouse, France	Effect of microgravity on cellular action: the role of cytokines
A. Cogoli	ETH-Z, Weltraumbiologie Zürich, Switzerland	Effect of stirring and mixing in a bioreactor experiment
G. Horneck	DLR, Cologne, Germany	Efficiency of radiation repair in eukaryotes Radiation repair kinetics in eukaryotes
R. Marco	Independent University of Madrid, Spain	Investigation of the mechanism involved in the effects of space microgravity on Drosophila development, behaviour and aging
G. Reitz	DLR, Cologne, Germany	Dosimetric mapping inside Biorack
P. Bouloc	University of Paris 7, France	Cell micro-environment and membrane signal transduction
U. Heinlein	University of Düsseldorf, Germany	Molecular biological investigations of animal multi-cell aggregates
S. De Laat	Hubrecht Laboratorium Utrecht, Netherlands	Regulation of cell growth and differentiation: retinoic acid-induced cell differentiation
A. Johnsson	University of Trondheim, Norway	Plant growth and random walk
G. Perbal	University of Paris 6, France	Effect of microgravity on lentil morphogenesis
T.H. Iversen	University of Trondheim, Norway	Root orientation, growth regulation, adaptation and agravitropic behaviour of genetically transformed roots
G. Ubbels	Hubrecht Laboratorium, Utrecht, Netherlands	The role of gravity in the establishment of embryonic axes in the amphibian embryo
H.J. Marthy	Laboratoire Arago, Banyuls-sur-Mer, France	The sea urchin larva, a potential model for studying biomineralisation processes in space
P. Veldhuizen	Free University of Amsterdam, Netherlands	The effects of microgravity on varying 1-g exposure periods on bone resorption: an in vitro experiment

malfunction of the Biorack videocamera; that videocamera was replaced by one of the Spacelab videocameras.

The crew devoted a total of 42 hours to the operation of the Biorack. They transferred experiment containers between incubators, cooler-freezer, glovebox and stowage about 1100 times.

Of the remaining 17 biological experiments, seven were carried out in DARA's NIZEMI, a slow-rotating centrifuge equipped with a microscope; four were performed in NASDA's Aquatic Animal Experiment Unit and three others were carried out in NASDA's Cell Culture Kits. Investigations on human spinal changes in microgravity and radiation studies were also undertaken, using NASDA's real-time radiation monitoring device and DLR's Biostack.

Fluid Sciences

Investigations concerned with fluid dynamics and capillarity made use of ESA's Bubble, Drop and Particle Unit (BDPU). This instrument, which flew for the first time on IML-2, is dedicated to the study of the behaviour of bubbles, drops and particles in transparent liquids. The core unit is equipped with sophisticated optical diagnostics. In addition, there are modular containers with specific diagnostics and stimuli tailored to the needs of the individual experiments. These slide-in units are interchangeable in orbit.

Seven experiments were performed using the BDPU (Table 3). They investigated:

- Thermo-capillary convection
- Bubble and drop behaviour in a thermal gradient
- Heterogeneous bubble nucleation, boiling and condensation
- Wetting dynamics and stability of liquid/gas interfaces
- Interactions between a solidification/melting front and inclusions.

There were problems in executing two of the seven experiments. The problems, however, were related to the experiments themselves; the BDPU performed flawlessly.

The BDPU ground team, with engineers and scientists at NASA's Marshall Space Flight Center, was responsible for the BDPU operations. The team was in contact with the investigators in their laboratories in Europe who were evaluating data and video images in real time in order to assess the performance of an experiment and to define further procedures to optimise an experiment run. This 'telescience' operation adds great flexibility to experimentation, and enhances considerably the scientific return since the investigators, who are the real experts, are actively involved in the experiment. Initially, 104 hours of operation of the BDPU were foreseen. That number was later extended to 146 hours.

The evaluation of the experiments conducted with the BDPU is complex and the principal investigators have not yet received all the data and images. However, some preliminary conclusions can be drawn:

- Quantitative measurements of the migration of bubble inclusions and drops in a liquid matrix subject to a temperature gradient, were obtained. This migration is due to the flow generated by gradients of the interfacial tension (Marangoni flow or thermocapillary convection). Various systems were investigated to test and advance existing theoretical models.
- Thermocapillary instabilities in symmetrical three-fluid layer systems were investigated.

Table 3. BDPU experiments

Investigator	Institute	Experiment Title
J. Koster	University of Colorado Boulder, CO, USA	Interfacial phenomena in a multilayered fluid system
R.S. Subramanian	Clarkson University, Potsdam, NY, USA	Thermocapillary migration and interactions of bubbles and drops
J. Straub	Technical University, Munich, Germany	Nucleation, bubble growth, interfacial micro-layer, evaporation and condensation kinetics
D. Langbein	ZARM, Bremen, Germany	Static and dynamic behaviour of liquid in corners, edges and containers
A. Viviani	Second University of Naples, Italy	Bubble and drop behaviour under low gravity
J.C. Legros	Free University, Brussels, Belgium	Thermocapillary instability in a three-layer system
R. Monti	University of Naples, Italy	Bubble migration, coalescence and interaction with a melting and solidification front

Table 4. CPF experiments

Investigator	Institute	Experiment Title
A.C. Michels	vd Waals Laboratories, Amsterdam, Netherlands	Heat transport and density fluctuations in critical fluids
D. Beysens	Condensed matter laboratories, CEA, Saclay, France	The piston effect in super-critical SF6
H. Klein	Institute for Space Simulation DLR, Cologne, Germany	Density equilibration time scale
R. Ferrell	Dept. of Physics and Astronomy, University of Maryland, USA	Thermal equilibration in a one-component fluid A) Adiabatic fast equilibration B) Thermal equilibration in a one-component fluid

A new mechanism of oscillatory thermo-capillary convection in a system heated perpendicular to the interface was identified.

— Evaporation and condensation mechanisms were studied, including the heat and mass transfer mechanisms taking place at the liquid/gas interfaces. Besides the fundamental aspects, these studies are relevant in the nucleate boiling/cooling of electrical power devices for space applications.

In summary, these highly specialised experiments were very successful. The full results are expected to be presented at the IXth European Symposium on 'Gravity-dependent Phenomena in Physical Sciences' in May 1995 in Berlin.

Near-critical-point phenomena in fluids

ESA's Critical Point Facility (CPF) consists of a very precisely controlled thermostat with interchangeable fluid cells, cameras for observation and light-scattering diagnostics. It was first flown on the IML-1 mission in January 1992. The experiment results obtained during that mission encouraged NASA to include the CPF in the IML-2 payload as well.

A critical fluid is in a physical state that is distinctly different from a gas or a liquid. It is very interesting scientifically since its physical behaviour is unique. A critical fluid is highly compressible. Consequently, on Earth, one can achieve the critical state at a precise critical pressure and temperature in a very thin layer of the fluid only. The weight of the liquid itself prohibits establishing constant pressure conditions vertically. This problem is eliminated in microgravity and bulk samples of critical fluids can be investigated.

As is the case with the BDPU, the CPF has modular slide-in units, which are tailored to provide the optimum conditions for each individual experiment. Five of the units accommodated experiments from American and European investigators (Table 4). The facility performed flawlessly. It was operated for 312 hours and the objectives of the experiments were fully accomplished. The information obtained was greatly enhanced by the facility being operated in a telescience mode. The ground team at NASA's MSFC transmitted about 1200 commands to the payload crew and the principal investigators had access in real time to the important data including video images.

The evaluation of the data is underway and substantial new insight into the physical behaviour of fluids near their critical point is expected.

One example of a new physical phenomenon that was discovered through experimentation in microgravity is concerned with the heat transfer in a supercritical fluid (SF_6). Following a heat pulse from a point source, the temperature rise in the bulk fluid is monitored at various locations with thermistors, as a function of time (Fig. 3). The classical conduction of heat by thermal diffusion occurs and, in addition, a much faster heat transfer mechanism, the 'piston effect', is observed. The latter is due to the expansion of a thermal boundary layer acting as a piston, which pressurises and heats adiabatically a confined fluid.

Protein crystallisation

Crystals of biological macromolecules, such as proteins and enzymes, are required to

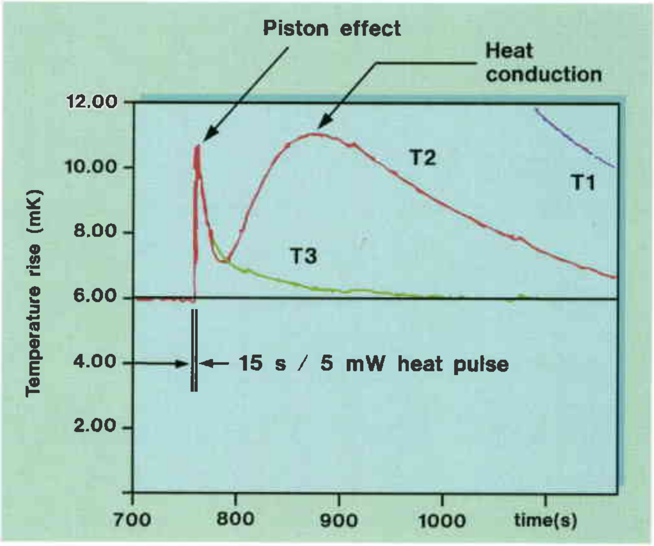


Figure 3. Thermalisation in microgravity of a supercritical fluid (SF_6) after a heat pulse. T1, T2 and T3 are measuring thermistors. The thermalisation by the piston effect is fast and complete, whereas the peak temperature due to heat conduction is reached much later. (Courtesy of D. Beysens, CEA, Saclay, France)

determine a substance's precise molecular structure and atomic arrangement using X-ray diffraction. That information is necessary to understanding the biochemical reactions and mechanisms, including diseases, in living organisms. The obstacle in determining the structure is the preparation of single crystals of sufficient size (0.1 to 0.5 mm) and sufficient quality. Although the underlying mechanisms are not yet understood, there are strong indications that crystallisation is enhanced in microgravity. Since protein crystallisation is an extremely important issue both scientifically and for medical applications, scientists around the world have endeavoured to evaluate and exploit microgravity.

ESA's Advanced Protein Crystallisation Facility (APCF), which had already flown on Spacehab-1 in June 1993, fits into the Shuttle middeck lockers. Two units were flown on IML-2, each held 48 crystallisation reactors contained in a thermostat at 20°C. Video-cameras were used to observe the crystallisation process in selected reactors (12 per unit) and a simple light-scattering device was used to detect nucleation. Both APCF units performed nominally and some 7000 video images were recorded. The units were active for 12 days. After landing, the reactors were returned to the investigators and the first crystals were harvested. Although the diffraction analysis is just beginning, photographs of crystals are already available (Fig. 4 and 5). Based on a preliminary evaluation, the crystals collected appear to be very promising. Numerous crystals were obtained and some appear to be of excellent quality.

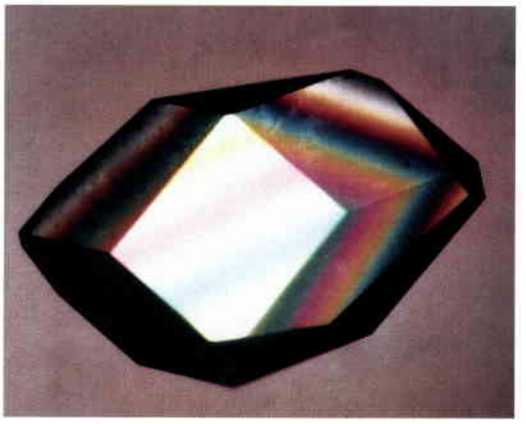
Remote operations support for European experiments

Building on experience gained in Europe with the remote operation of experiments on sounding rockets, Eureca, Spacelab D-1 and D-2, as well as Atlas 1 and 2, an important element of the IML-2 mission was the

Table 5. APCF experiments

Investigator	Institute	Experiment Title
N. Chayen/P. Zagalsky	Imperial College, London, Great Britain	Alpha crustacyanine
A. Ducruix/M. Riès	Institut de Chimie des Substances Naturelles, CNRS, Gif-sur-Yvette, France	Collagenase, Rhodabacter spheroids
V. Erdmann/S. Lorenz	Institut für Biochemie, Freie Universität Berlin, Germany	Ribosomal 5S RNAs
R. Giegé/A. Théobald	Laboratoire de Biochemie IBMC-CNRS, Strasbourg, France	Aspartyl-tRNA synthetase
W. De Grip/J. v. Oostrum	Department of Biochemistry, University of Nijmegen, Netherlands	Rhodopsin
J. Helliwell/E. Snell	Department of Chemistry, Universty of Manchester, Great Britain	Lysozyme (collaboration with Sjölin)
J. Martial/L. Wyns/K. Goraj	University of Liège, Belgium	Octarellin/Copperoxalate
A. McPherson/S. Koszelak	University of California, Riverside, USA	Sat. Tobacco Mosic Virus/Canavalin/Turnip Yellow Mosaic Virus
F. Jurnak*	University of California, Riverside, USA	Pectase lyase
M. Garavito*	University of Chicago, USA	OmpF proin
H. Einspahr*	Bristol-Meyers-Squibb, USA	Cytochrome c (tuna)
L. Sjölin	Department of Inorganic Chemistry Chalmers University of Technology, Gothenburg, Sweden	Ribonuclease S (collaboration with Helliwell)
G. Wagner	Membran- und Bewegungsphysiologie Justus Liebig University, Gießen, Germany	Point-mut. Bacteriorhodopsin
A. Yonath/H. Hansen	MPI für Struct. Molecular Biologie / DESY, Hamburg, Germany	Haloarcula marismortui 50 S

* Co-investigators with A. McPherson, University of Riverside, CA, USA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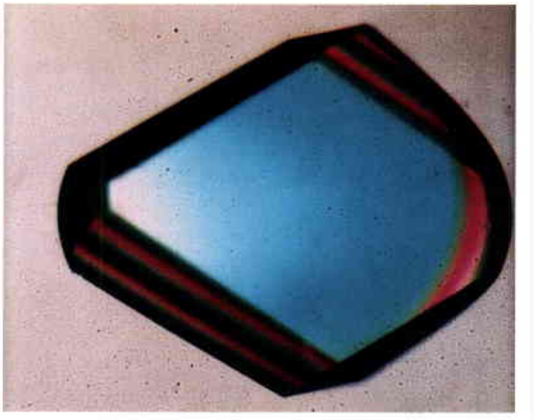
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Figure 4. A flawless single crystal of lysozyme, grown in the APCF on IML-2. This model substance is investigated to quantify improvements in protein crystal growth in microgravity. Approx. 1.8 mm in length. (Courtesy of J.R. Helliwell, University of Manchester, UK)

Figure 5. A single crystal of ribonuclease S grown in the APCF on IML-2. The first, qualitative assessment made was it is 'one of the best crystals ever seen'. (Courtesy of L. Sjölin, Chalmers Technical University, Sweden)

demonstration of telescience or remote operations. ESA is keen to develop these operational techniques and procedures for science. They will take on great significance when the International Space Station becomes operational. A dedicated article on 'Implementation of a Communications Infrastructure for Remote Operations' is included in this issue. Only a brief summary is therefore presented here. It emphasises the experimenter's point of view.

The telescience operations on IML-2 were not just another series of experiments or technology demonstrations, but rather a service to scientists — the role of remote operations is to support scientific experiments. Remote operations give scientists and engineers in Europe the opportunity to participate actively in payload operations during the performance of their experiments. Such direct participation, where commands can be issued from User Centres, means that modifications and changes in schedules can be made in real time, while the experiment is underway. Another significant advantage is that experimental data can be received directly at the laboratory or institute, giving the scientists immediate access to the data for evaluation and reaction.

Communications — including video, voice, low-rate and high-rate — were based on the Interconnection Ground Subnetwork (IGS) for telescience or remote operations, set up by ESA's Space Operations Centre (ESOC) at Darmstadt, Germany. The IGS network connects the NASA Operations Support Center (HOSC) in Huntsville, Alabama, with the IGS Control Centre at ESOC. For scientists, the HOSC represents the access point for real-time experiment data and command.

At ESOC, an integrated Network Management Facility represented the European centre for monitoring and controlling the services for all user sites. It was the communications hub, linking the NASA Payload Operations Control Center (POCC) at the MSFC in Huntsville to the European User Centres. Those User Centres are:
— MUSC, in Cologne, which controlled three facilities: the Critical Point Facility and the TEMPUS and NIZEMI facilities
— MARS, in Naples, Italy, which controlled and carried out an experiment with the BDPU
— DUC, in Amsterdam, which monitored an experiment on the CPF
— SROC/ULB, in Brussels, which controlled an experiment on the BDPU
— Cadmos, in Toulouse, which was responsible for the CNES (France) RAMSES facility.

All staff in Europe and the US were connected via a direct voice link and there were also video links, allowing those in Huntsville to view those working in the User Centres in Europe. Immediate access to data gave co-investigators in Remote Centres the opportunity to make evaluations and modifications during the course of an experiment. There was also the possibility of repeating an experiment.

For future space station missions, where a series of experiments could run over many months, telescience will bring many advantages. It will mean that scientists can monitor and control their experiments from their own laboratory, which is a much more efficient and cost-effective way to conduct scientific research during long-duration space missions.

The IML-2 mission was thus a major and successful step forward in the undertaking of decentralised science and payload operations. From low-rate monitoring to full data-receiving and commanding capabilities, the concept has matured and its usefulness has been demonstrated. The scientific users were extremely satisfied with this service. The possibility of their active participation in the experimentation in an orbiting facility is a great asset that considerably improves the scientific return.

Land-Surface Analysis Using ERS-1 SAR Interferometry

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The European Remote Sensing Satellite ERS-1, launched by ESA in 1991, carries an Active Microwave Instrument (AMI). During several phases of its operations, ERS-1 has been operated in almost exact repeat orbits with periods of 3 and 35 days. The data acquired during these repeat orbits can be used to perform repeat-pass SAR interferometry, as illustrated in Figure 1. The excellence of ERS-1's orbit and attitude control system and the high reliability of its SAR system result in excellent interferograms.

Introduction

Radar remote sensing has made significant advances in recent years, exemplified by the revolutionary new applications developed using Synthetic Aperture Radar (SAR) interferometry. Interferometric processing of SAR data combines images from two spacecraft passes to derive precise measurements of the difference in path lengths to the two sensor positions.

Thanks mainly to the high quality and extensive coverage of the ERS-1 SAR data, the development and application of repeat-pass SAR interferometry has become a prime research activity within the radar remote-sensing community. Two of the major applications, the derivation of height maps and of differential displacement maps, are based on the geometric information contained in the so-called 'interferometric phase' (see below). Much research is being performed to further refine the image-processing steps required for the estimation of this interferometric phase in order to optimise these two types of maps.

The quality of the products is characterised by the 'interferometric correlation', which is a measure of the variance of the interferometric phase estimate. It decreases with increasing system noise, volume scattering, and temporal changes. Consequently, the interferometric correlation itself contains significant thematic information that can be useful for several other applications, which are also discussed below.

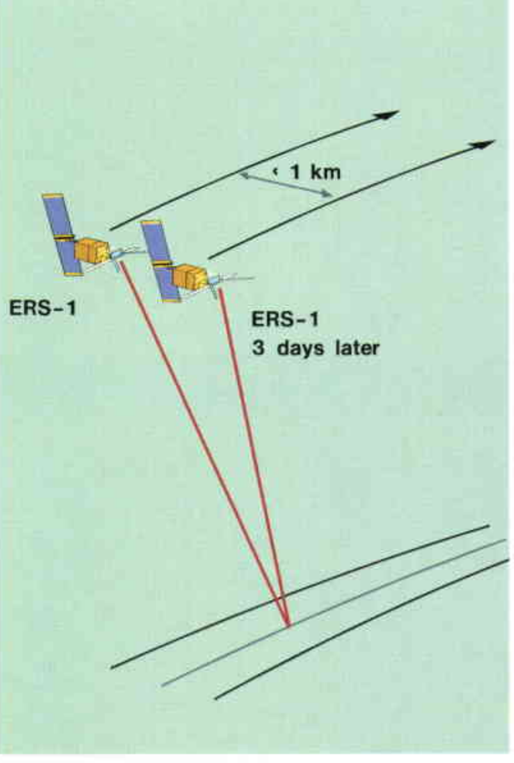


Figure 1. During repeat orbits, ERS-1 returns to provide almost identical sensor positions after intervals of 3 or 35 days, thereby acquiring SAR images that can be analysed interferometrically

SAR interferometry

In SAR imaging, the backscattering signal from a particular area or object – known as a 'resolution cell' – is the coherent superposition of the backscattering from the many individual scatterers within that cell, resulting in a random phase and the typical image phenomenon known as 'speckle'. Until recently, only the magnitude of the SAR signal, but not the phase, was interpreted. Now, with the advent of SAR interferometry, the phase data is proving to be a valuable additional source of information. For two SAR images acquired with almost identical antenna positions, the scatter geometries are almost identical and therefore the speckle patterns of the two images are not independent. The 'interferometric phase' – i.e. the phase difference between the two images – is a measure of the difference in path lengths to the sensor, permitting derivation of the three-dimensional position of the scattering element.

In the case of ERS-1, such data has been acquired during repeat orbits at times differing by multiples of either 3 or 35 days. The interferometric phase derived from these data can therefore be used to produce height maps for the regions with repeat ERS coverage, as illustrated in Figure 2.

Figure 2 shows an example of an interferogram centred on Bern, Switzerland, produced from data collected by ERS-1 on 24 and 27 November 1991 (3-day repeat cycle). The interferometric phase is displayed using the colour scale (cyclical) indicated below the image. The interferometric baseline component perpendicular to the line of sight is 58 m for this image pair, and therefore one phase cycle corresponds to an elevation difference of approximately 160 m. The brightness of the image is a measure of the interferometric correlation.

The interferometric correlation depends on the radar-system parameters of wavelength, signal-to-noise ratio, range resolution, and number of independent observations, and on the geometric parameters of interferometric baseline and incidence angle. As long as we restrict our investigation to data from one instrument, identical instrument parameters can be used. Common spectral band filtering of the SAR image pair before computation of the interferogram ensures that most of the interferometric decorrelation introduced by the baseline geometry is eliminated. The remaining sources for the observed decorrelation are volume scattering and temporal change, i.e. changes occurring between the two ERS-1 data acquisitions. In practice, therefore, repeat-pass SAR interferometry is very sensitive to temporal change.

Forest mapping

In these times of increasing environmental problems, reflected by for example increasing deforestation, possible climatic changes, and

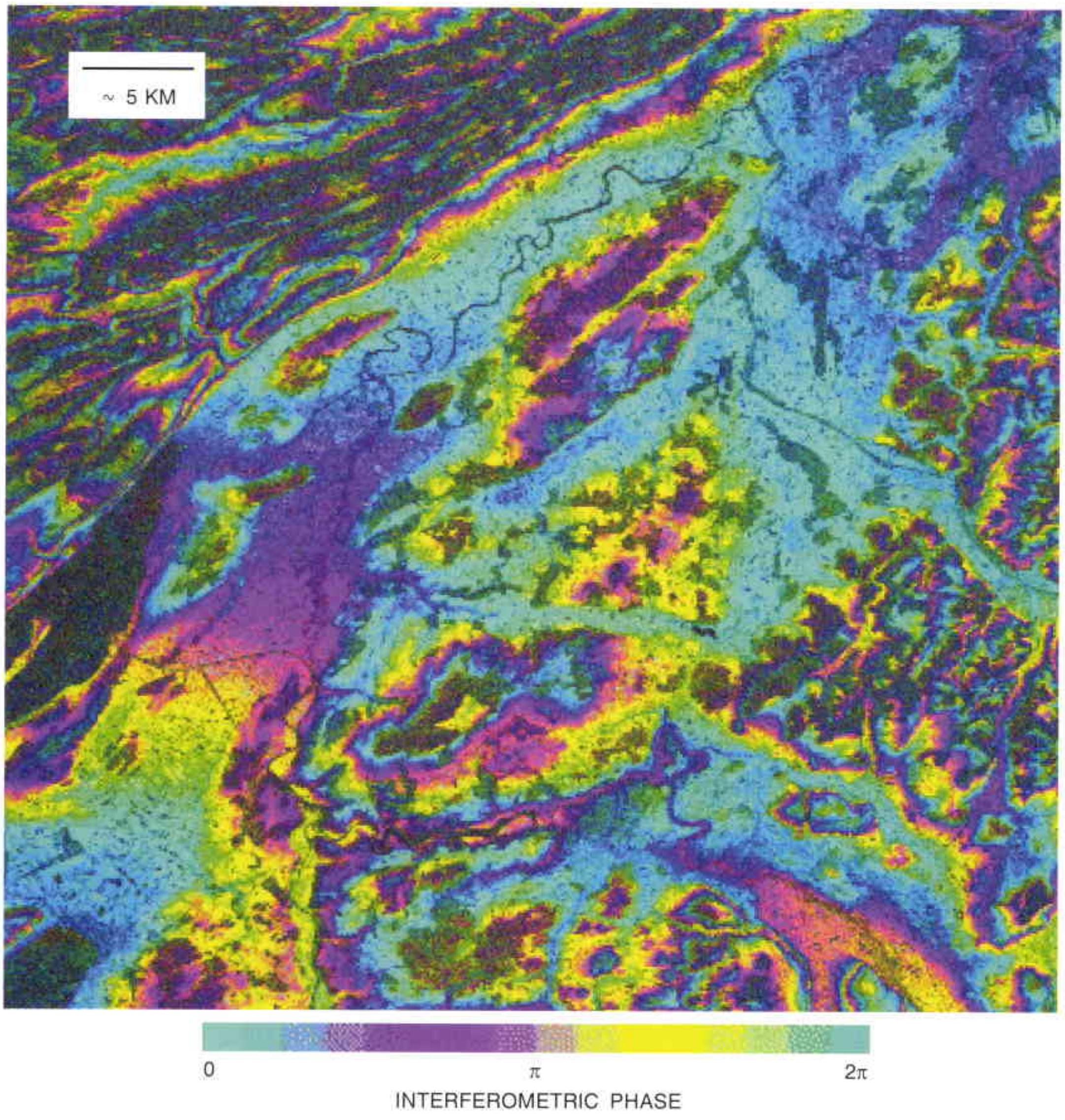


Figure 2. Repeat-pass SAR interferogram computed from ERS-1 SAR data acquired on 24 and 27 November 1991 over Bern, Switzerland. The interferometric phase is colour-coded as indicated below the image. One 2π phase cycle corresponds to an elevation difference of 160 m. The image brightness is proportional to the interferometric correlation

intense use of forests as a source of both energy and construction material, there is a great need for forest mapping and monitoring for both ecological and economic reasons. Satellite remote sensing provides a means of gathering such information regularly on a regional/global scale, even for remote areas that are difficult to access by any other means. Interferometric forest mapping and monitoring from space can therefore play an important role.

Intensive research efforts have been conducted mainly with optical and microwave remote-sensing instruments. The main disadvantage of optical sensors is that cloud-free conditions are required, compared to the all-weather capability of microwave sensors. This turns out to be very limiting for many regions, especially in the tropical, sub-polar and polar zones. Change monitoring is even more problematic, because the data must be acquired at regular time intervals in order to be meaningful.

Thanks to ESA's ERS-1 mission and planned followup programmes ERS-2 and Envisat, Japan's JERS-1, and Canada's planned Radarsat, SAR data will be available to us for at least the next fifteen years. However, the interpretation of individual SAR images is not as straightforward as with optical images because of the complex interaction between the radiated electromagnetic field and the target. Forest mapping is very difficult because of the image noise ('speckle') noted above, because the signatures of the various land categories differ by only small amounts and sometimes overlap, and also because of topographic effects. However, SAR interferometry makes forest mapping with ERS-1 virtually straightforward.

The region shown in Figure 2 covers agricultural, urban and forested areas, as well as a number of lakes. In late November, most agricultural fields are bare or only sparsely vegetated and the deciduous trees (mainly beech, oak and maple) are without leaves. A number of test areas were selected within this ERS-1 scene and in-situ data were collected via site visits and land-use inventories. Forest composition and structure, tree heights, and the local topography were measured. Differences were observed between the deciduous (more than 80% of the trees deciduous), coniferous (more than 80% of the trees coniferous), and mixed forest stands. For selected areas, corresponding to forest stands, agricultural fields, residential areas, and open water (lakes and rivers), the interferometric correlation and average backscatter intensities were extracted.

Figure 3 shows the backscatter intensity measured on 24 November as a function of the interferometric correlation. Only backscatter intensity changes larger than 0.5 dB between 24 and 27 November are indicated by vertical lines. Water surfaces, forest and areas that changed between these two dates show low interferometric correlations. High

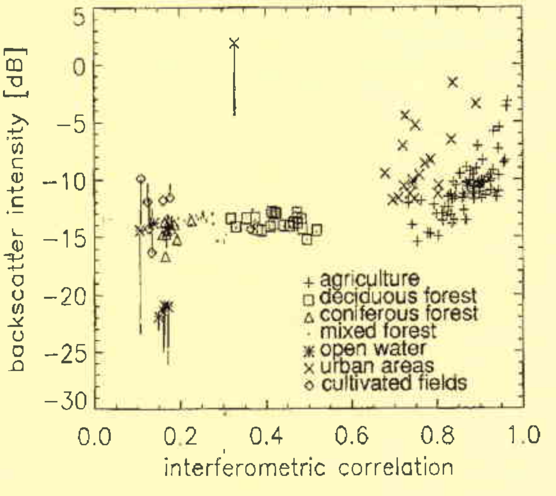


Figure 3. Average backscatter intensities plotted as a function of the interferometric correlation for selected test areas within the ERS-1 SAR scene over Bern. Vertical bars indicate backscatter intensity changes of more than 0.5 dB between 24 and 27 November 1991

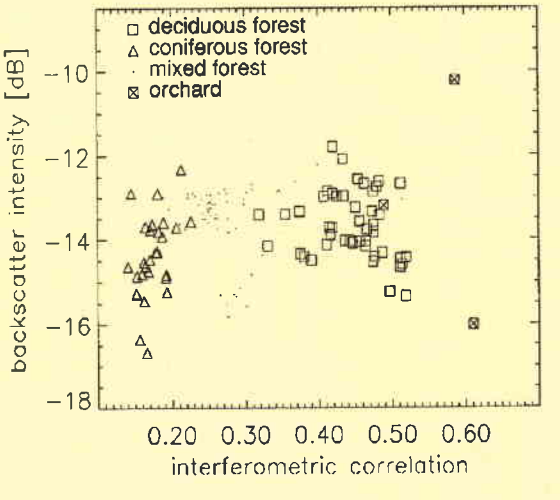


Figure 4. Average backscatter intensities plotted as a function of the interferometric correlation for selected forest stands within the ERS-1 SAR scene over Bern

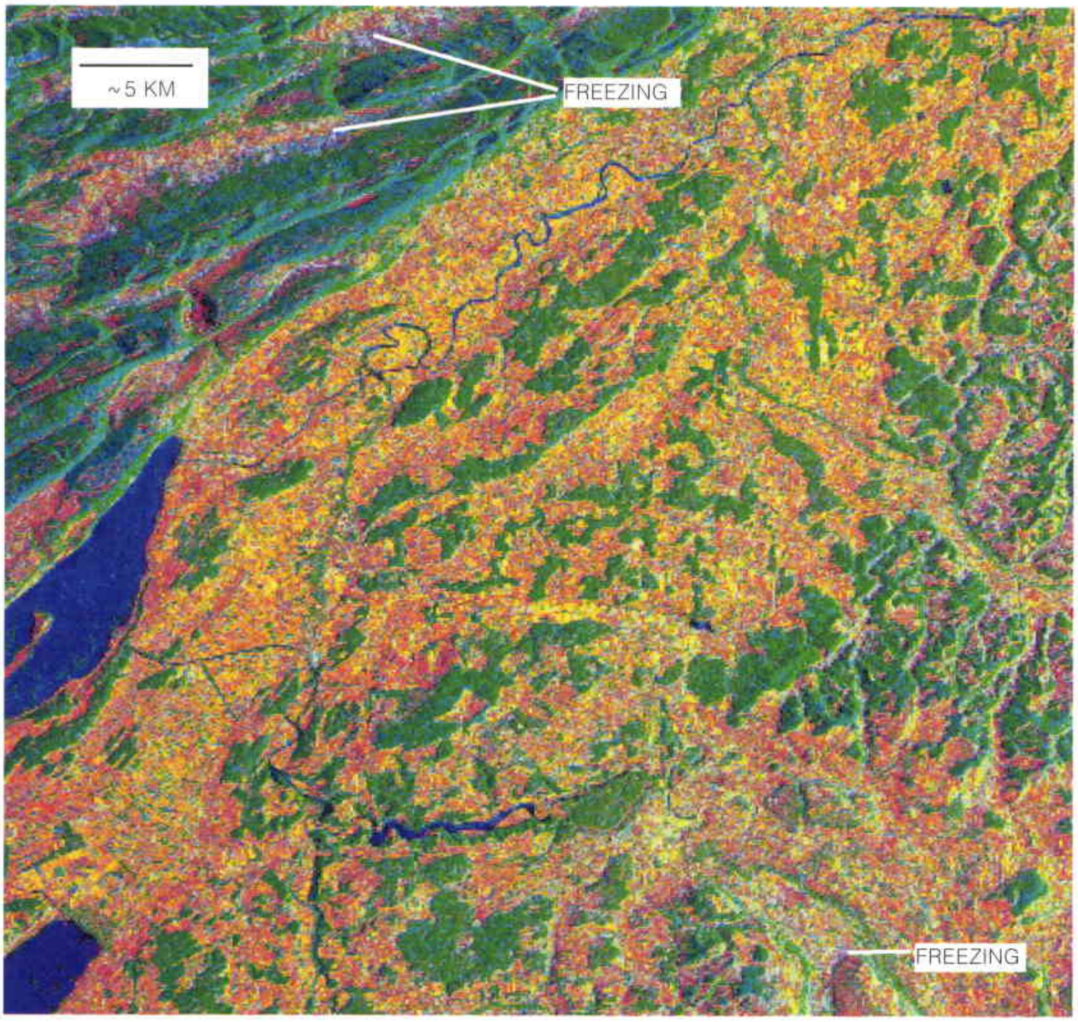


Figure 5. Interferometric signatures – red = interferometric correlation; green = backscatter intensity on 24 November; blue = backscatter intensity change between 24 and 27 November – derived from an ERS-1 SAR image pair over Bern, Switzerland. Water (blue), forest (green), sparse vegetation (orange/yellow), and urban areas (yellow/green), as well as certain farming activities (green/blue) and frost (magenta), can be clearly identified (see also Table 1)

correlation is observed over agricultural and urban areas. The highest backscatter intensities, together with a high spatial variability, are observed over urban areas.

The ranges of backscatter intensities observed over forests and agricultural fields overlap strongly. This explains the difficulty encountered in distinguishing between these two classes based exclusively on the backscattering intensity at C-band. Except during windy conditions, the backscatter intensity over water is very low. Due to the sensitivity to wind speed and direction, a high temporal variability in backscatter intensity is observed. Temporal change introduced by mechanical cultivation (ploughing, harvesting, etc.) causes almost complete interferometric decorrelation. Such change occurs at a specific moment in time, and the same fields may show high interferometric correlation in interferogram pairs preceding or following that event. The signatures for the different land-use categories cluster well. The interferometric correlation, together with the backscatter intensity and the backscatter intensity change, is therefore a very promising tool for the classification of the land-surface classes indicated. It becomes obvious from the extracted signatures that the backscatter intensity and the interferometric correlation are relatively independent quantities containing complementary thematic information.

Figure 4 shows forest signatures in greater detail. The interferometric correlation is higher for deciduous than for coniferous forest stands. Despite the winter season, the backscatter intensity of the leafless deciduous trees does not serve as a reliable forest type discriminator. As one would expect, the values for the mixed forest stands lie between those for deciduous and coniferous stands. Detailed studies of the interferometric correlation over mixed forest stands show that areas of low correlation usually coincide with regions with a high density of coniferous trees. Fruit orchards and open forest stands have higher interferometric correlation values.

To improve accessibility to the information content of the interferometric signatures, the interferometric correlation, the backscatter intensity from one of the passes, and the backscatter intensity change can be displayed using the three channels of an RGB-image, as shown in Figure 5. The red-value is proportional to the interferometric correlation, the green-value to the square root of the backscatter intensity, and the blue-value to the backscatter intensity change in decibels (dB).

Figure 5 again shows the Bern test site, covering an area approximately 45 km by 45 km. With the colour coding chosen, forests appear dark green and open water surfaces dark blue, which simplifies the identification of those important categories. Urban areas appear bright green or yellow. There are often strong individual scatterers within these urban areas. Bare and sparsely vegetated areas appear orange or yellow. Owing to change occurring between the two data acquisitions, a number of agricultural fields appear green-blue in the red-yellow of the surrounding unchanged plots. The colours for the different land categories are listed and explained in Table 1.

Table 1. Interferometric signatures and corresponding colours for various land categories

	Interferometric correlation (red value)	Backscatter intensity (green-value)	Backscatter intensity change (blue-value)	Resulting colour
Water	low	low	often high	blue
Forest	low to medium	medium	low	green
Sparse vegetation	high	medium	low	orange/yellow
Urban area	medium to high	high	low	yellow/green
Farming activity	low	medium	low to high	green/blue
Freezing/thawing	high	medium	high	magenta

Frost monitoring

The Bern test-site data just discussed were acquired in late November 1991. During the night of 26/27 November, parts of the surface within the test site froze. When the SAR image was acquired at 11.20 on the morning of 27 November, certain areas were still frozen while other parts in direct sunshine had already thawed. The frozen areas are on the shady northwest-facing slopes of hills. Such freeze/thaw cycles are common in this area during cloud-free periods in winter.

Freezing causes a reduction in the backscatter intensity of approximately 3 dB. On 24 November, the entire scene was unfrozen and so the areas frozen on 27 November can be clearly identified via a strong backscatter intensity change. Freezing changes the permittivity without significantly changing the surface geometry and so the interferometric correlation remains high despite the strong backscatter intensity change.

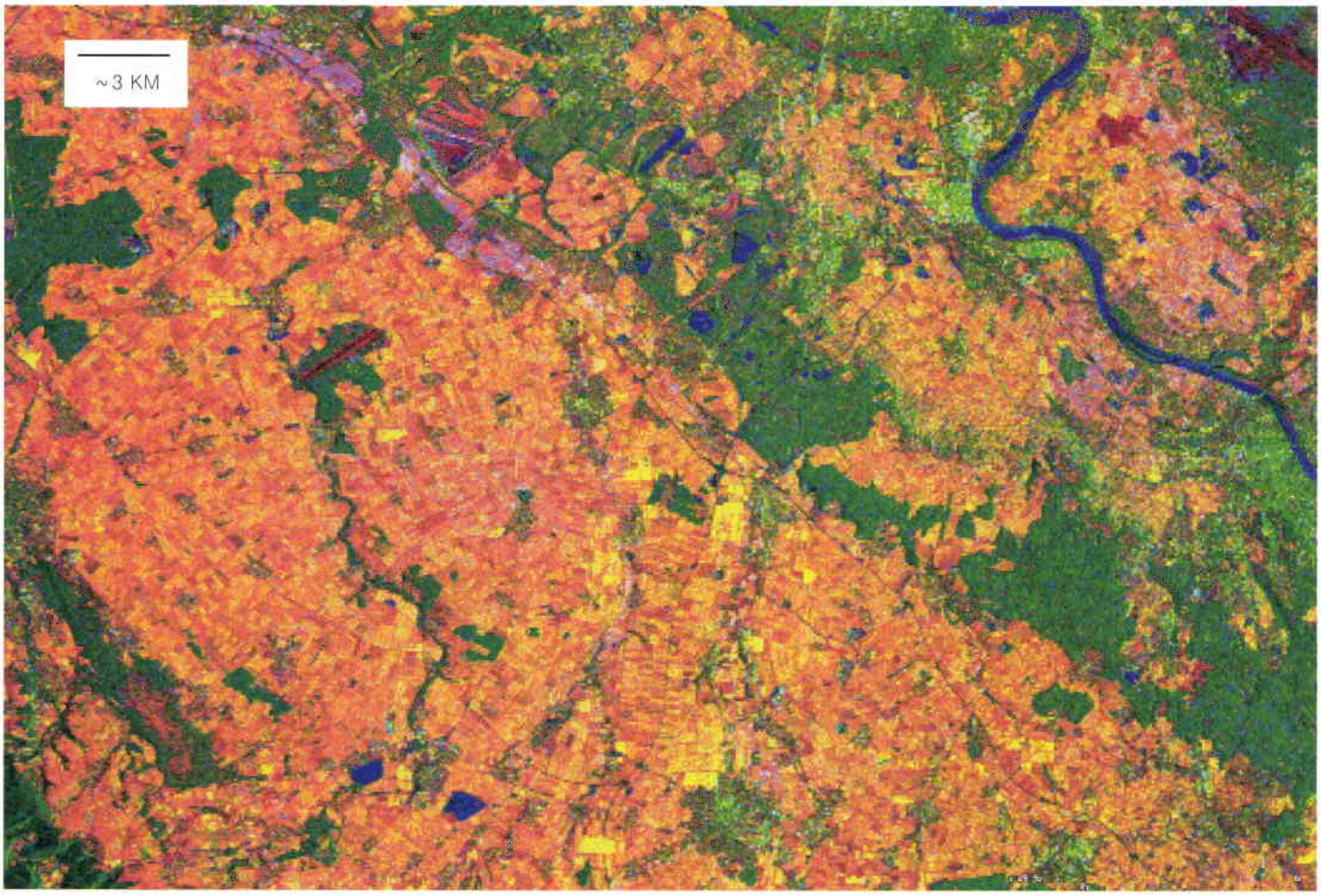
Consequently, areas frozen during the ERS-1 data acquisition on 27 November appear in magenta in Figure 5, i.e. areas northwest of the Belpberg hill (south of the city of Bern), as well as in the hilly parts of the Emmental (right of image centre) and the Jura mountains (upper left corner of image). The entire interpretation was first done based exclusively on the SAR interferometric signatures; only later were these hypotheses validated with meteorological data. ERS-1 data acquired on the same dates at night over the northeastern part of the Bern test site, i.e. the Emmental, further confirms the freeze/thaw hypothesis and allows the extent of the nocturnal freezing to be mapped.

Farmland monitoring

As we have already seen, ERS-1 repeat-pass SAR interferometry can be used to detect and map various types of change occurring between the acquisitions of an image pair. Series of SAR images can therefore be used, for instance, to monitor farming activities.

To demonstrate the feasibility of SAR interferometric farmland monitoring, ERS-1 data acquired on 14, 17, 20 and 29 March over an agricultural test site west of Bonn, in Germany, were selected. It includes the rural area of the Zülpicher Boerde, the mainly forested Ville region, the cities of Bonn, Euskirchen, Düren, Kerpen, Hürth, Brühl and Wesseling, a section of the river Rhine, a number of small lakes, and the open-pit lignite mines of Frechen and Ville.

In March, most agricultural fields are bare or only sparsely covered with grass or crops such as winter cereals. Only in the middle of that month do the farmers start cultivating their fields. The deciduous trees are still leafless. Figure 6 shows interferometric signatures derived from the 14 and 17 March image pair, which allow recognition of the different land-use categories and highlight changes that have occurred during the intervening three days. By applying the same approach to all possible image-pair combinations, relatively detailed monitoring of change throughout the second half of March 1992 becomes possible.



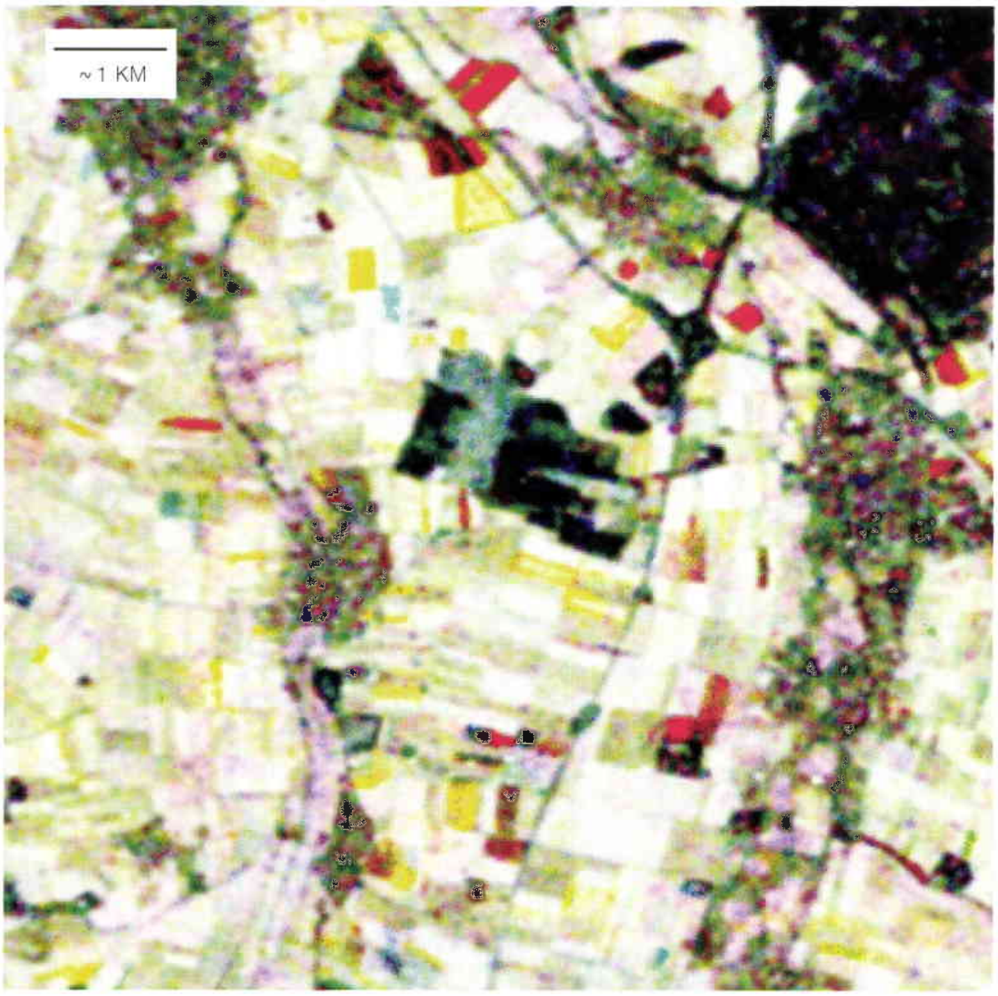


Figure 6. Interferometric signatures – red = interferometric correlation; green = backscatter intensity on 17 March; blue = backscatter intensity change between 14 and 17 March – derived from an ERS-1 SAR image pair acquired west of Bonn, Germany. Water (blue), forest (green), sparse vegetation (orange/yellow), and urban areas (yellow/green), as well as certain farming activities (green/blue) and changing soil moisture (magenta), can easily be identified (see also Table 1)

Figure 7. Multi-temporal image of the interferometric correlation, computed from four ERS-1 SAR images acquired on 14, 17, 20 and 29 March. The interferometric correlations of the 14 and 17 March (red), 17 and 20 March (green), and 17 and 29 March (blue) pairs are combined in this colour composite. Change occurring between the two data acquisitions of an image pair reduces the corresponding interferometric correlation. This colour composite therefore allows farming activities and crop growth during the second half of March 1992 to be monitored easily and reliably (see also Table 2)

Figure 7 is a multi-temporal image of the interferometric correlations of the 14 and 17 March (red colour), 17 and 20 March (green), and 17 and 29 March (blue) image pairs. The corresponding baseline components perpendicular to the line of sight are 420 m, 507 m and 551 m, respectively. The scene is an agricultural area west of Bonn and it highlights changes in individual fields during this period with different colours, indicating the time interval when the change occurred. Individual fields that were mechanically cultivated between 14 and 17 March, for instance, appear turquoise due to the low correlation for that image pair and the high correlations for the other two pairs. Change between 17 and 20 March appears in red due to the low correlation between the 17 and 20 March, and 17 and 29 March pairs, and so on. Help with the interpretation of the different colours is provided by Table 2.

It is worth noting that only a few fields lost correlation between 14 and 17 March. More fields lost correlation between 17 and 20 March, probably as a result of mechanical cultivation. A second, partial decorrelation observed in the data set is thought to be due to small geometric changes, perhaps caused by erosion and vegetation growth. The partial decorrelation resulting from vegetational growth and a relatively small decorrelation in the 17 and 20 March pair due to the lower soil moisture on 20 March can be identified by their brown and magenta colours, respectively, in Figure 7.

For comparison purposes, Figure 8 shows a multi-temporal image of the backscatter intensity. Clearly, the information content of repeat-pass SAR interferometric signatures is significantly higher than that of the identical multi-temporal SAR data if only the backscatter intensity is interpreted. On the other hand, the multi-temporal image of the backscatter intensity adds information to the interferometric correlation. The overall bluish-magenta tone over agricultural areas shows that the soil moisture decreased from 14 March (green colour) to 17 March (red) and then increased again from 17 March to 29 March (blue). The green colour of open-water surfaces indicates that the backscattering over water was highest on 14 March, probably due to the rougher water surface caused by wind or rain. Owing to the almost identical image geometry for the three data sets, temporal changes can be easily detected, even without prior normalisation of the backscattering intensity.

Conclusion

The high potential of ERS-1 repeat-pass SAR interferometry for land applications has been demonstrated, focussing on the interpretation of the interferometric correlation in combination with the backscatter intensity and

Table 2. Repeat-pass SAR interferometric change monitoring of agricultural fields – see Figure 7

Land-use class	Change	Interf. corr. 14 & 17 March (red)	Interf. corr. 17 & 20 March (green)	Interf. corr. 17 & 29 March (blue)	Resulting colour
Sparse vegetation	farming activity (14 – 17 March)	low	high	high	turquoise
	farming activity (17 – 20 March)	high	low	low	red
	farming activity (20 – 29 March)	high	high	low	yellow
	farming activity (14 – 17 and 20 – 29 March)	low	high	low	green
	reduced moisture (on 20 March)	high	slightly lower	high	magenta
	no change	high	high	high	white
	canopy growth (17 – 29 March)	high	slightly lower	medium	brown
Forest		low	low	low	dark
Open water		low	low	low	dark

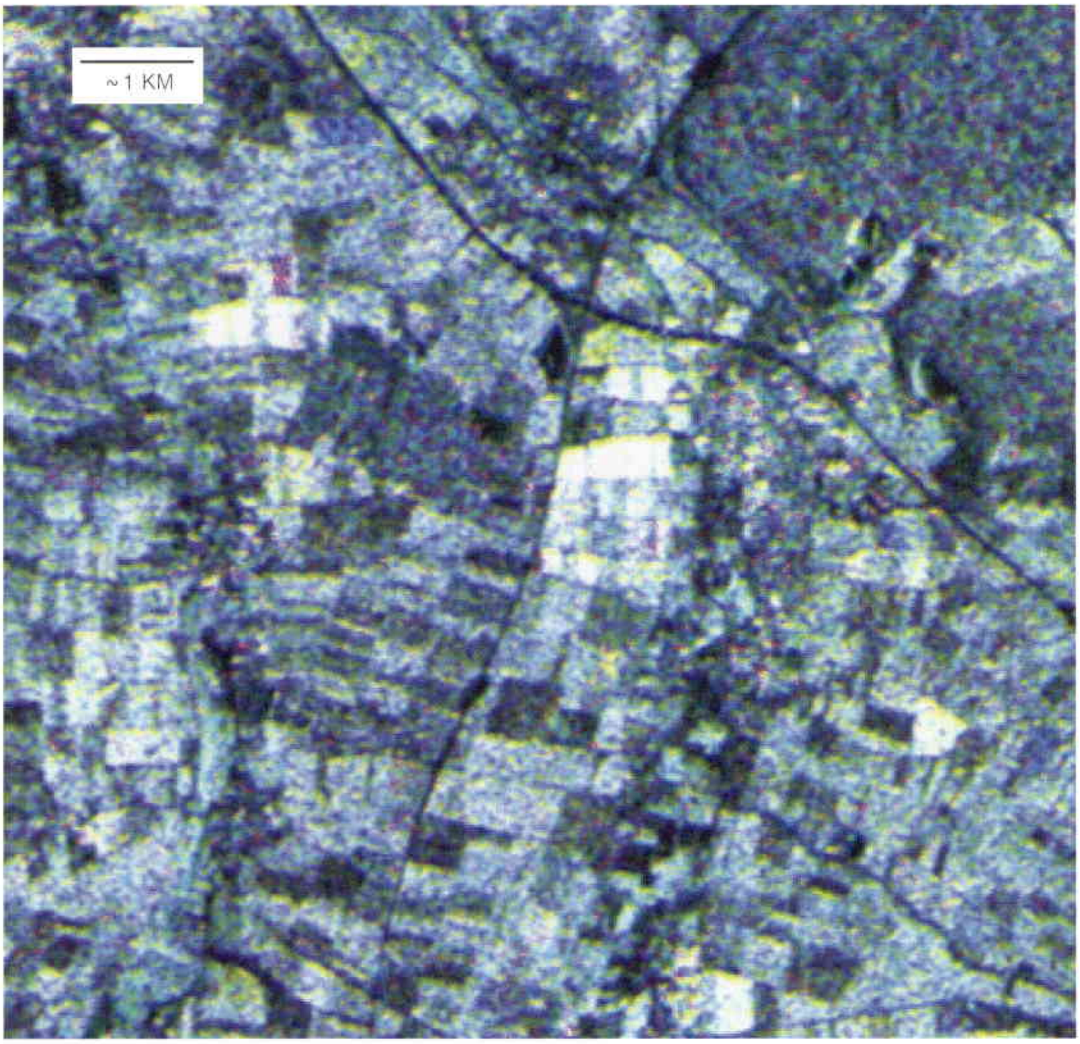


Figure 8. Multi-temporal image of the ERS-1 SAR backscatter intensity on 14 (green), 17 (red), and 29 (blue) March. Interferometric processing was used to precisely co-register the three SAR images. With the exception of the open-water surfaces, the colour composite appears quite grey. Over agricultural fields, the values on 14 and 29 March are higher than on 17 March due to higher soil moisture. The relatively small backscatter intensity differences do not correlate with the individual field boundaries. The green colour of the river Rhine and a number of small lakes results from the low backscattering on 17 March caused by the low wind speed

the backscatter intensity change between the two passes used for the interferogram. The interferometric correlation depends on the amount of volume scattering and temporal change, and therefore provides excellent information for land-use classification applications.

Given the weather-independence of the SAR system and the repetitive global coverage provided by ERS-type spacecraft, the approach described here constitutes a very powerful tool for land-use mapping and monitoring. With the continued availability of appropriate data from ERS-1 and its follow-up satellites ERS-2 and Envisat throughout the next decade, SAR interferometry is expected to contribute significantly to forestry and land-use applications and related global-change studies. The proposed ERS-1/ERS-2 tandem mission scenario with the two satellites operated in the same orbit 1 or 8 days apart would be of special interest for scientific research and applications purposes, since it would permit global coverage with interferometric image pairs at a high repetition rate.

Acknowledgment
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A New Approach to European Space Standards

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The European Cooperation for Space Standardization (ECSS) is an initiative established to develop a coherent, single set of user-friendly standards for use in all European space activities. In the autumn of 1993, several national space agencies in Europe, ESA and the European space industry joined forces to start developing the space standards.

The ECSS standards must improve industrial efficiency and competitiveness, and satisfy European and international clients. The standards will apply as needed to any party participating in the definition, development, manufacturing, verification or operation of any assembly, equipment, subsystem, system or service used for any space mission.

Introduction

The European Cooperation for Space Standardization (ECSS) is an initiative designed to develop a coherent, single set of user-friendly standards for the European space community, which means ESA, its member states and their space industry.

The European space business suffers because of the multiplicity of standards and requirements that the different space agencies in Europe are currently using. Although the agencies' requirements are essentially similar, the impact of the differences in standards is serious and has led in particular to higher costs, lower effectiveness, a less competitive industry and potential errors. The situation is expected to remain unchanged until ECSS produces its standards at the end of 1995.

In 1988, in an attempt to improve the situation, Eurospace, an association representing the European space industry, asked the directors-general of ESA and CNES to standardise their organisations' product assurance requirements. Several efforts were made to define the means of meeting this objective.

By 1993, the European space community was in a position to address the standardisation of space activities as a whole rather than just the product assurance aspects. Several national space agencies and industrial organisations joined forces to build a more comprehensive and coherent system of standards, based on a commercially oriented strategy. In the autumn of 1993, the partners signed the ECSS terms of reference which defines the framework and the basic rules of the system. The European space industry has therefore been fully involved with ECSS from the outset.

The move toward standardisation places Europe in phase with the United States where, in June 1994, the Secretary of Defense advised the Department of Defense to increase access to commercial, state-of-the-art technology and decrease, to the maximum extent practicable, reliance on military specifications and standards.

Importance of standards

Today, standards are no longer considered to be just stacks of dusty papers containing unjustified requirements and constraints. Standardisation is generally viewed as a process that drives commercial viability and success. Successful companies recognise that developing and using standards is the path to remaining competitive and producing quality products.

ESA's Director General, J.-M. Luton, summarised well the importance of standards for the space business, in a meeting between ECSS and industry in October 1993. He stated that the time had come to harmonise existing space standards and to implement a system of common standards to enable the European space industry to become more efficient, more capable and more competitive in general. He stressed several points:

— These standards must satisfy all European and international clients.
— Existing standards that satisfy the requirements should be retained, and new ones should be developed on the basis of solid reasoning and experience.
— European space industry must be a full partner in the preparation, writing and validation of these standards.

Globally accepted European and international standards can promote the development, manufacture and sale of high-quality space products, which are not only demanded by the domestic clients, but also meet the needs of international customers.

By abolishing the multiplicity of project requirements of the various partners in ECSS, and concentrating on a single set of standards — from which all generic requirements of future space projects would be derived — this initiative should drive an increase in industrial efficiency. This policy will generate more recurring products or services, at reduced cost with consistently high quality.

Standardisation is an important tool during all programme phases to both reduce costs and enhance quality and communication. The goal of the ECSS standardisation system is to minimise lifecycle costs while continually improving the quality, functional integrity and compatibility of all elements of a project. This will be achieved by applying common standards for hardware, software, information and all activities within a given project, and between different projects.

Scope of ECSS standards

ECSS is now drafting standards for space projects and applications within the following categories:

— project management requirements
— requirements for design, development, manufacturing, verification and operational space systems and their constituent parts
— technical requirements for assemblies, equipment, subsystems and systems used for space missions
— interface requirements for information relating to space systems and activities and transmitted between organisations.

The ECSS standards will apply as needed to any party participating in the definition, development, manufacturing, verification or operation of any assembly, equipment, subsystem, system or service used for the European element of any space mission.

All ECSS standards will be drafted, approved and published in English. Any ECSS participant wishing to translate, at its own expense, an ECSS standard into another language may do so provided that such intent is made known to the ECSS Secretariat. Such translated documents, however, are not part of the ECSS system. The ECSS Steering Board may, at its discretion, authorise translations of ECSS standards to be part of the ECSS system if a Participating Member commits to translate the relevant documents and to provide updated translations whenever the original document is revised.

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Organisation

Members of ECSS

The members of ECSS include Participating Member Agencies, industry and Associates. At present, the Participating Member Agencies are:

— Agenzia Spaziale Italiana (ASI), Rome, Italy
— Belgian Office for Scientific, Technical and Cultural Affairs (OSTC), Brussels, Belgium
— British National Space Centre (BNSC), London, England
— Centre National d'Etudes Spatiales (CNES), Paris, France
— Canadian Space Agency (CSA), Saint-Hubert, Quebec, Canada
— Deutsche Agentur für Raumfahrt (DARA), Bonn, Germany
— European Space Agency (ESA), Paris, France
— Norwegian Space Centre, Oslo, Norway.

Although not all ESA member agencies are represented in ECSS, all Member States supported the initiative through an ESA Council Resolution (ESA/C/XCIII/Res. 1 final, 23 June 1994). The resolution confirms that ECSS shall be the central structure in Europe for space standardisation to be used by ESA, the national space agencies and industry.

The industrial partners are:
- Eurospace, Paris, France, which represents European Industry
- Association Européenne des Constructeurs de Matériel Aérospatial (AECMA), Issy-les-Moulineaux, France (agreement currently under discussion).

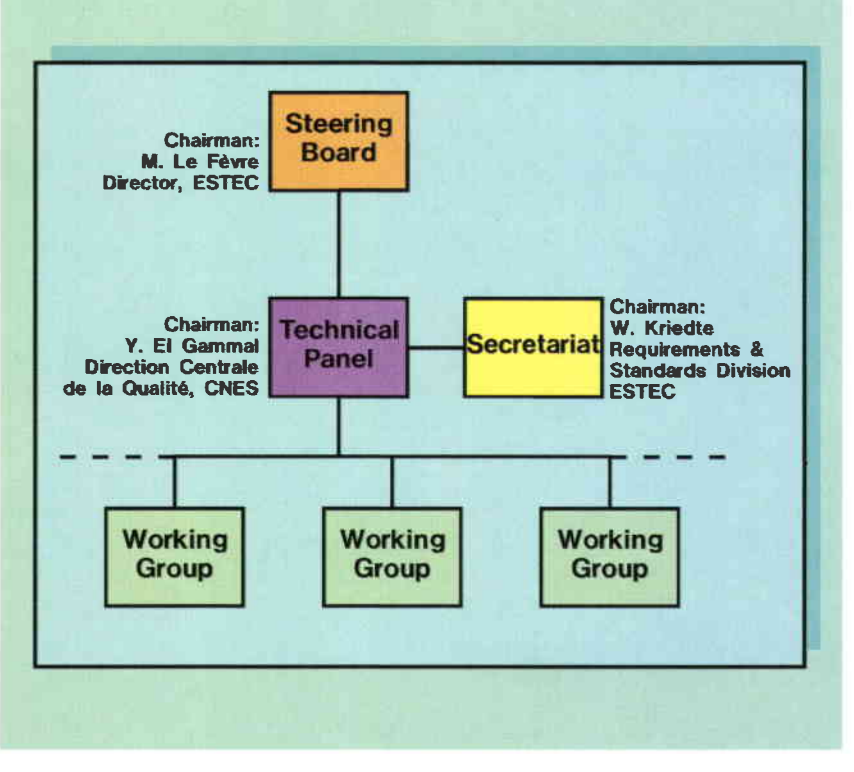
The European space industry, through Eurospace, has made a sustained effort to be an effective partner in ECSS. Eurospace has created its own ECSS panel, modified its bylaws to allow non-member companies to contribute to the ECSS initiative, and played an active role in ECSS meetings at all levels.

Associates are governmental and scientific organisations desiring a formal tie with the ECSS, through which they can observe the development process of technical documentation and contribute to the ECSS system. Associates are encouraged to participate actively and directly in the document development process.

Structure of ECSS
ECSS consists of four organisational entities (Fig. 1):

- a Steering Board, which primarily sets policy
- a Technical Panel, which provides the overall management of all processes
- a Secretariat, which manages the traditional administrative tasks
- Working Groups, which develop draft standards for specific areas.

Figure 1. The structure of ECSS



Steering Board
The ultimate responsibility for ECSS resides with the Steering Board. The Steering Board is responsible for:
- drawing up the main objectives and defining the overall strategy of the European standardisation process
- formally approving all ECSS standards
- ensuring the application of the standards by ECSS members.

Technical Panel
The Technical Panel is composed of one delegate from each Member Agency, as well as representatives of the European space industry and other associated groups as agreed by the Steering Board. The Steering Board may invite a representative of a standardisation organisation to become an associate.

The Technical Panel is responsible for:
- creating Working Groups as necessary and agreeing on the terms of reference
- deploying and integrating the resources provided for the formation of a Working Group in accordance with the rules for Working Groups
- settling technical disputes raised by Working Groups
- commenting, reviewing and discussing draft Working Group documents
- issuing a finalised Working Group draft document for approval by the Steering Board.

Working Group
When the Technical Panel determines that the formation of a Working Group is required to address a specific set of standards, the Panel nominates a provisional convenor and calls for the first meeting of the Working Group. The ECSS Secretariat informs all Participating Agencies, industry and Associates that the Working Group has been established and asks for nominations for active membership. The participation of industry and Associates is an essential element of the standardisation process.

The Working Group is responsible for:

- drafting documents
- writing its final draft document in English and submitting it to the Technical Panel for review
- deciding on the need to create a special sub-group for more in-depth discussions of problem areas
- when new documents are proposed, checking to ensure that no suitable international standard exists.

Secretariat
The ECSS Secretariat, provided by the European Space Agency, carries out all general secretarial and administrative duties needed for the operation of the ECSS System.

Interfaces with standardisation organisations
The Technical Panel has links to two different standardisation bodies, one international one and one European one (Fig. 2).

It maintains a liaison with the International Organization for Standardization (ISO) and its Technical Committee (TC) 20, Subcommittee (SC) 14 — Space Systems, for harmonisation and complementary actions. This liaison is also supported by ESA Member States, who are taking part in developing ISO standards. Most standards developed by ISO TC20/SC14 are standards for interfaces or requirements for international cooperation, such as for docking or space debris.

A European Standard (EN), awarded by the European standardisation organisation, the Comité Européen de Normalisation (CEN), would give the ECSS standards better international credibility and recognition. The Technical Panel is therefore also in close contact with AECMA, which develops aeronautical and space standards for CEN. CEN is composed of 18 member European countries and has more than 200 technical committees although there is not one dedicated to space activities. AECMA is an associated standardisation body of CEN and can issue 'pr EN' (projet de norme européenne) documents, which CEN can then review and formally establish as an EN.

Different levels of standardisation
Standardisation can take place at several levels:

— the company level
— the national level
— the regional level, i.e. Europe
— the international level.

Figure 3 illustrates the relationship between time and scope at the different levels. While company standards have a very broad scope and require a relatively short creation time, international standards are at the other extreme. Much time is needed before international standards are ready for implementation. While company standards involve very quick decision-making, the development of international standards is a very lengthy process because international consensus has to be sought.

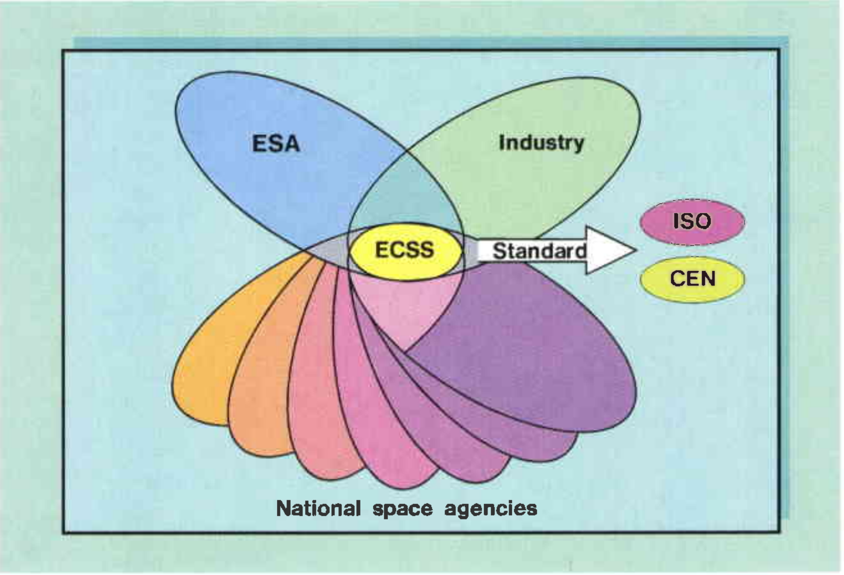


Figure 2. The relationship between the ECSS partners and other standardisation organisations

In a perfect world, the nature and scope of the different levels would be fully complementary. Although the reality is somewhat different, ECSS is still striving to attain that goal.

Funding
The activities undertaken within ECSS are carried out without any exchange of funds among the members. Expenses incurred as a result of participation in ECSS are borne by the party concerned.

ECSS policies
Approval of a standard
ECSS will only function efficiently if consensus is achieved at all levels of the organisation. Consensus has been defined in ISO's ISO/IEC Guide 2:1991 as: *'General agreement, characterised by the absence of sustained opposition to substantial issues by any important part of the concerned interests and*

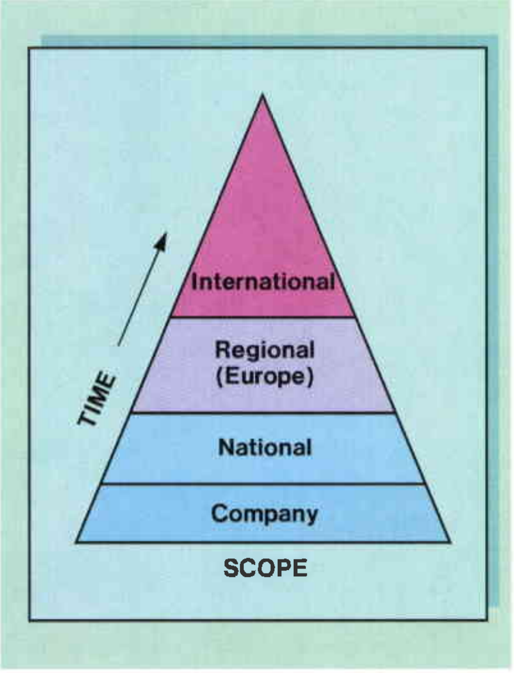


Figure 3. The time/scope relationship for the different levels of standardisation. At the company level, for example, the standards have a broad scope but can be drafted relatively quickly. On the other hand, international standards have a more limited scope but require a longer time to approve.

by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments'.

Consensus need not imply unanimity. All participants have the right to vote on draft documents. The presence of a majority of members is required to constitute a quorum. Each member who casts a negative vote, must identify all the changes which, if made, would allow the member to vote in a positive manner.

ECSS policies

ECSS shall promote the continuous improvement of methods and techniques, and the avoidance of unnecessary work. Experience from past projects and other appropriate sources shall be systematically incorporated into the ECSS system.

ECSS standards should incorporate, where possible, standards already applied by the participating member agencies, and, where standards are missing, utilise already existing international and national standards. Prior to drawing up a standard, the benefits resulting from its use shall be evaluated.

ECSS standards must satisfy all European and international clients, and shall encourage industrial efficiency and competitiveness by limiting the variety of products and processes. Each individual requirement should concern the need to be fulfilled, rather than the means to be used to fulfil it.

ECSS standards shall be harmonised with international standards or working practices where these have been or are in the course of being generally adopted by the European space industry.

The preparation of ECSS standards should take into account valid sources of information and the opinions of all interested parties. These methods will ensure rapid availability of standards at a reasonable cost when they are needed.

All members shall promote the application of the standards by encouraging organisations that develop, manufacture or use items related to space missions to use the ECSS standards.

For Working Groups, it is recommended not to use the voting process in its normal work unless it is impossible to progress without a vote. In the document decision process, the Working Groups must achieve substantial agreement. However, previous dissenting views and objections will have been considered and a concentrated effort made towards their resolution.

Publication of standards

ECSS standards will be publicly available documents agreed as a result of consultation with space agencies in Europe and with industry, designed to secure acceptance by users. However, the publication of a standard by ECSS does not automatically ensure its use. Application of the standard depends on the voluntary action of interested parties. It becomes binding if a party is contracted to work under these conditions.

The European Space Agency, on behalf of the participating members, holds the copyright for all ECSS documents. No ECSS document may be reproduced in any form without the express consent of ESA. However, this consent has been granted to organisations participating in ECSS for their own use and for their contractors or subcontractors.

Monitoring of implementation

The ECSS standards will only be made applicable to a project by contract or other legal document. A specific ECSS standard, or part thereof, will be referenced by the complete document identification.

The party imposing the use of a standard is responsible for monitoring and assuring the correct use and application of that standard.

All users of ECSS standards are invited to inform the ECSS Secretariat about experience gained from application of ECSS standards, so that inadequacies in the standards may be corrected.

Responsibility of the user

It is the responsibility of the party imposing a particular standard to ensure that it meets the intended need. All parties using a standard are advised to acquaint themselves with the intended scope and applicability of the standard to prevent inappropriate usage.

Current status of the standards

ECSS's first task was to draw up a policy document. A dedicated working group, set up in late 1993, has prepared a document entitled Standardization Policy (ECSS-P-00), which has been approved by the Steering Board.

This document addresses the different aspects of the standards system, including its scope, objectives, implementation, authority, organisation and documentation. It also defines the documentation architecture which will facilitate the organisation and retrieval of information within the ECSS standards system. The architecture (Fig. 4) identifies the different levels of detail required to differentiate the major functions, disciplines and activities for which standards will be developed. The documentation is basically organised in three main branches: Management, Product Assurance and Engineering.

The scope, purpose and location of every ECSS standard must conform to this architecture. Any subordinate standards falling

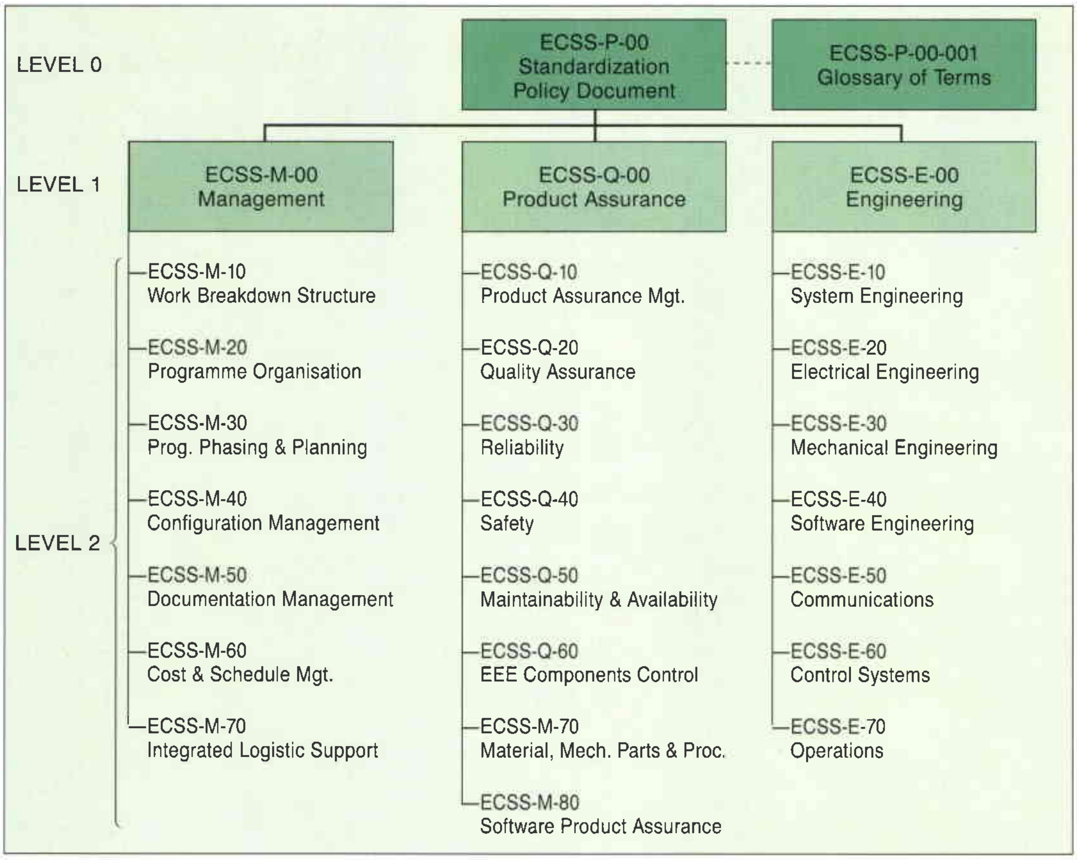


Figure 4. ECSS documentation architecture. The final draft of the documents is expected to be available at the end of June 1995.

below those shown in Figure 4 will be organised in a manner approved by the Technical Panel.

Active Working Groups

The ECSS Secretariat had proposed a work schedule for 1994/95 based on the ESA Council Resolution to enable a transition from the present ESA series of standards, named Procedures, Standards and Specifications (PSS), to ECSS by the end of June 1995. The Technical Panel has therefore authorised three Working Groups to start their work according to established terms of references. The three Working Groups reflect the three main branches of the documentation architecture. They are:

— Management Standards Working Group
— Product Assurance Standards Working Group
— Engineering Standards Working Group.

All groups must prepare the Level 1 and Level 2 standards in draft form as well as a list of proposed Level 3 standards documents by 31 March 1995. These Level 1 and 2 standards have been identified in the documentation architecture of the ECSS Standardization Policy document (ECSS-P-00) (Fig. 4).

Conclusion

The European Cooperation for Space Standardisation (ECSS) initiative is a challenge for the European space community. The initiative is not intended to be revolutionary but rather evolutionary. It aims, insofar as possible, to make maximum use of existing standards, adopt commonly used international standards, and ensure coordination and liaison with organisations dedicated to standardisation.

ECSS is designed to increase the efficiency of the European space industry and to strengthen its international competitiveness. It was set up in a spirit of true cooperation between agencies and industry — achievement of consensus is the major goal and as a consequence participation of agencies and industry in Europe is essential.

It is vital that all customers are convinced that ECSS standards are of high quality, and that they will apply these standards.

Success will depend on a relatively fast implementation. To meet the stated policy of ECSS application within the time limit set by the ESA Council requires a concentrated effort by all parties. The three Working Groups already enjoy extensive, competent and active participation by all participating member countries and the European space industry. This is a very encouraging sign and gives confidence that the basic framework of ECSS standards will become available for new space activities by the end of the summer of 1995.

Implementation of a Communications Infrastructure for Remote Operations

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The communications scenario for support of the Columbus Orbital Facility (COF) operations led to the definition of an Interconnection Ground Subnetwork (IGS) to serve as the baseline communications infrastructure for flight operations for all manned spaceflight elements. This IGS communications support concept has been re-examined in the light of new requirements associated with the Automated Transfer Vehicle (ATV) and the optimisation possibilities have been re-investigated. The implementation as now planned will combine existing common network resources, services and management functions with requirements to minimise hardware investments, the cost of the links, and the number of staff needed for communications operations.

The concept for this revised communications network supporting remote decentralised payload operations has already been successfully demonstrated during the Atlas-2, IML-2 and Atlas-3 Spacelab missions. This article describes the infrastructure itself and reports on the results achieved during those Spacelab missions as a step towards the efficient operation of experiments aboard International Space Station Alpha (ISSA).

COF communications for operations

In defining the communications support needed for operations purposes when the Columbus Orbital Facility (COF) is attached to International Space Station Alpha, a number of distinct communications scenarios need to be considered (Fig. 1):

- When there is coverage by the Data Relay System Satellite (DRSS), which will be true for approximately two-thirds of each Space Station orbit, the data are to be transmitted to ground to the Central Earth Terminal (CET) in Europe.
- At other times, the COF data are to be presented to the Space Station as a single Virtual Channel (VC) for inclusion in the downlink via the NASA Tracking and Data Relay Satellite System (TDRSS).

Further scenarios relate to the cases of:

- S-band cross-support for ISSA
- back-up support in the event of TDRSS Ku-band outages

both of which are to be provided via ESA's Data Relay System.

In the nominal end-to-end communications scenario shown in Figure 1, all data from experiments accommodated in the Columbus laboratory module are to be relayed via the DRSS inter-orbit link to the Central Earth Terminal. The CET represents one of the entry points for space-to-ground data into the IGS, which then provides direct dissemination to remote sites according to the individual service requirements of each site (data, command, voice, video, etc.).

Data from those European experiments that may be accommodated in the US part of the Station are routed to the COF multiplexer. The ESA Relay at Marshall Space Flight Center (MSFC) selects, configures and multiplexes the various services and transmits them via a trans-Atlantic trunk (TAT) to the IGS central node at ESOC in Darmstadt (D), from where they are disseminated to the remote sites as required. Forward inputs from Europe to the Station are transmitted via the ESA Data Relay System for uplinking by NASA facilities.

In addition to the space-to-ground audio, video and data services, the IGS will provide resources and services for operational ground-to-ground communications, including voice, video and data.

In Europe, the IGS will be based on a core network consisting of leased lines where a continuous and stable bandwidth is required, and additional on-demand resources and services. The latter will be accomplished by employing such technologies as multiplexing a number of 64 kbps Integrated Services Digital Network (ISDN) channels and/or B-ISDN (Broadband-ISDN) services where available. In addition, high-bandwidth multipoint video conferencing and broadcasting will be

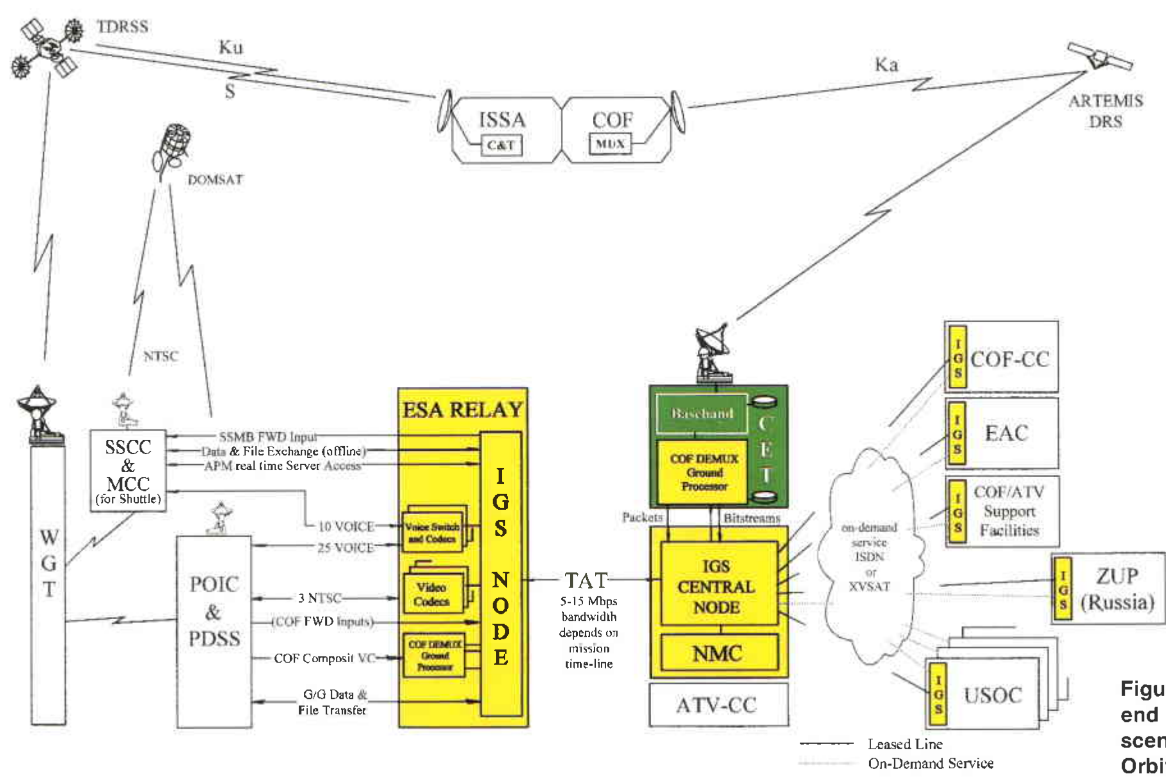


Figure 1. Nominal end-to-end communications scenario for the Columbus Orbital Facility (COF)

supported by Switched Very Small Aperture Terminals (XVSAT) offering dynamic bandwidth allocation. The choice of technology for each individual link and service is primarily driven by the need to minimise carrier cost for the operational phases.

One of the achievements of the NASA/NASDA/ESA Space Network Interoperability Panel has been to ensure compatibility of the DRSS and TDRSS S-band inter-orbit links, which provides the ability for cross-support should one or other satellite system service fail. This agreement presently covers only the inter-orbit S-band links; additional agreements are necessary to complete the on-ground cross-support scenario, the needs of which may differ from project to project.

In the event of a TDRSS S-band failure, this cross-support capability could become highly important within the operations scenario. On the basis of the compatibility agreements that have been achieved, the inter-orbit S-band link can then be relayed via DRS to the CET. In this case, the IGS will provide a transparent service between the CET and the ESA Relay at MSFC, where it constitutes the interface for NASA to the forward and return links to the Station.

In the event of a TDRSS Ku-band failure, the CET ground service processor will have the ability to extract an ISSA Virtual Channel (VC) from the COF return link data and forward it to the co-located IGS node for transmission to the USA.

In the case of a DRS failure, all laboratory data can be multiplexed onboard the Station and transmitted in Ku-band via TDRSS to the ground. The ESA Relay will then receive the COF composite Virtual Channel via the same interfaces as in the nominal communications scenario.

ATV communications for operations

The ATV Control Centre (ATV-CC) will be responsible for the vehicle's navigation, orbital manoeuvres, and attitude control. During the vehicle's free-flying phases, the connectivity between the ATV and its Control Centre will be provided primarily by ESA's Artemis/DRS spacecraft, with a backup possibility via space-to-ground links to suitably located S-band ground stations and onward links via ESA's operations support network OPSNET. Inside the control zone of the Space Station, and also in the ATV attached mode, the space-to-ground link will be routed nominally to the Space Station Control Center (SSCC) and from there via the IGS to the ATV Control Centre.

The OPSNET communications infrastructure for the backup S-band stations already exists and is also being used by other ESA projects.

The ground communications connectivity for the ATV docking/attached phase is comparable to the COF scenario. In this case, the IGS Relay will provide the interface to link the data between the Space Station Control Center and the ATV Control Centre. Since the associated data rates are rather low, this service can be accommodated within the resources and services provided for COF operations.

Common resources, services and network management

Figure 2 provides a summary of all of the communications elements required to support operations. It shows existing ESA resources which it is proposed to reuse (S-band stations for backup, OPSNET, communication control, and the spacecraft control facilities of ESA/ESOC) and the resources that need to be added in terms of augmentations of existing IGS implementations, new IGS elements, and the Artemis/DRS ground terminals.

The OPSNET nodes within the ESA ground stations and the IGS share the same state-of-the-art technology, which both prior studies and Spacelab mission-support experience (Atlas-2, IML-2 and Atlas-3) have demonstrated to be the most appropriate as well as providing adequate migration possibilities to future communications technologies.

Like OPSNET, the core network of the IGS will be based on leased lines, providing permanent connectivity with fixed data rates. The major data volumes will be handled by the IGS in essence using on-demand (dial-up) resources like narrow- or broad-band ISDN or switched satellite links.

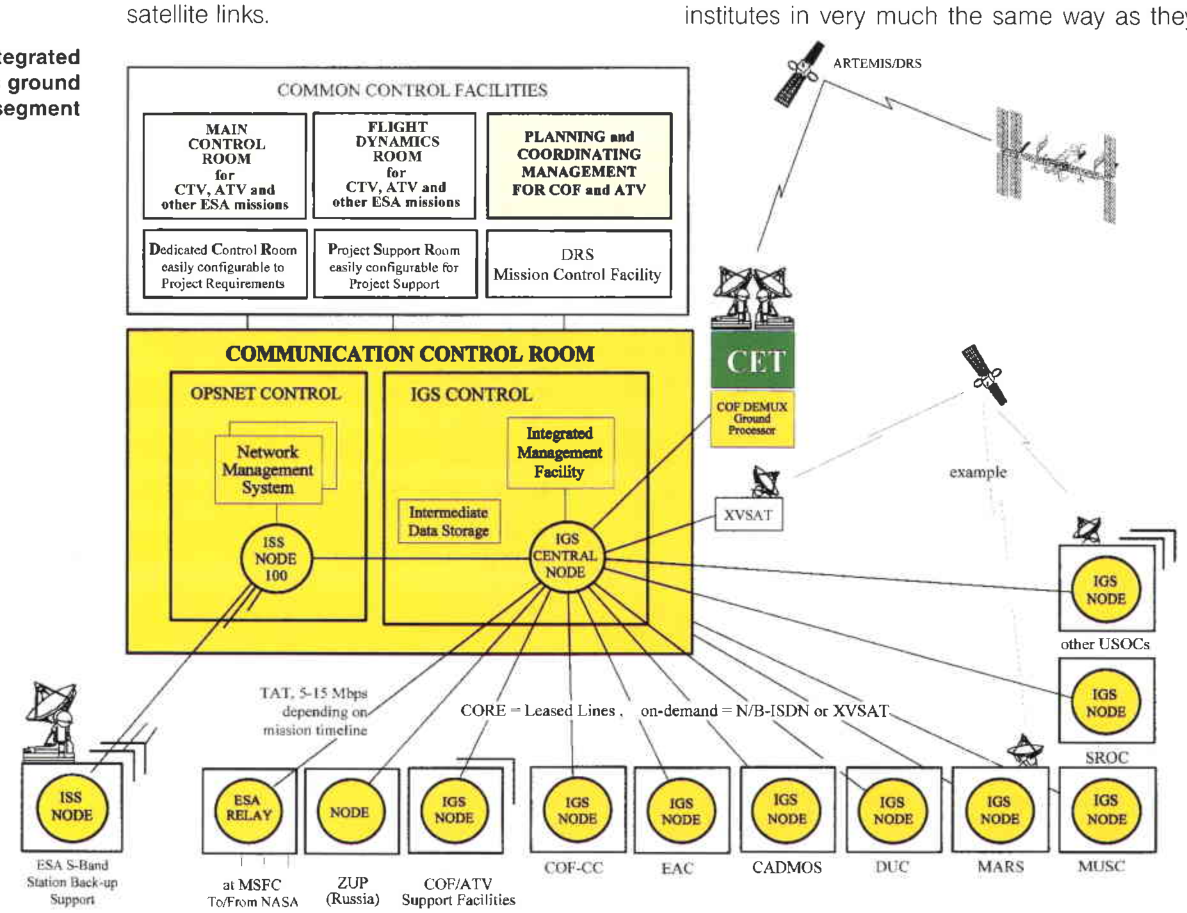
OPSNET communications control functions include management of the communications network to all ESA stations. The IGS communications control functions include the management of the total network and higher level services for element control facilities and remote user sites.

One justification for the proposed communications architecture is commonality of the network management implementations for IGS and OPSNET. Although the IGS management has a higher functional complexity (with respect to dynamic changes in resources and services and the support of new services), key elements of the network management systems appear identical to the communications operator. A common communications management system could therefore be established after completion of the IGS network's build-up.

Recent Spacelab mission experience

During the Atlas-2, IML-2 and Atlas-3 missions, the IGS provided data, voice conferencing, video distribution/conferencing and high-rate data services for remote user centres in Europe. During the IML-2 mission, for example, five such centres were supported simultaneously. The combination of services provided allowed the experimenters to operate and interact with their experiments from their home institutes in very much the same way as they

Figure 2. The integrated communications ground segment



had from the Payload Operations Control Center (POCC) at Marshall Space Flight Center (MSFC) during earlier Spacelab missions.

In addition to achieving enhanced returns from their scientific experiments, experimenters were now also able to make use of reference facilities, computing resources and resident expertise at their home laboratories, which typically are not available at the POCC.

Particular features of the IML-2 communications implementation were its adaptation to the different user needs based on the modular service capabilities of the IGS, and the minimisation of connectivity costs. This was achieved by using a combination of classical leased lines, satellite links and bundled multiples of narrow-band ISDN channels, according to the simulation and mission schedule requirements for each remote site. The IGS's central management system allowed both the staffing and the involvement of communications personnel at the remote sites to be kept to a minimum.

The success of this communications approach for the very demanding IML-2 scenario proved the validity of the concept for COF communications.

As Figure 2 shows, the emerging IGS co-exists with OPSNET, the network dedicated to spacecraft operations support, and ESANET, a large multipurpose ESA network handling all other communications tasks (e.g. administrative support, access to public and research networks, LAN interconnects, mission planning and non-real-time payload data transport). ESANET includes two high-speed trans-Atlantic links to Goddard Space Flight Center (GSFC), where it has a gateway into NASA's multi-purpose Program Support Communications Network (PSCN). The ESANET Control Center is located at ESOC, and the PSCN Management Center at MSFC. Since the trunk capacity required for the IGS was less than the bandwidth of the existing high-speed links, it was an obvious choice to use PSCN/ESANET resources as the trunk between MSFC and ESOC. Availability and mean-time-to-repair levels were made commensurate with the mission requirements by adopting 24-hour operator staffing during simulations and the missions themselves.

In April 1993, the Atlas-2 Spacelab mission was launched, for which the IGS and ESANET provided the communications support needed to operate the two European payloads remotely from the Principal Investigator (PI) site in Brussels. These services included data exchange, voice and video conferencing. This was the first time an experimenter conveniently sited at home base had exercised full control over an experiment aboard Spacelab.

Following this successful demonstration, in July 1994 five European remote user centres participated in a remote experiment operations scenario on the IML-2 mission with Spacelab. They were able to monitor and adjust their experiments by sending commands directly from their home institutes, again relying on the IGS and ESANET. The five remote sites were: CADMOS in Toulouse (F), DUC in Amsterdam (NL), MARS in Naples (I), MUSC in Cologne (D), and SROC in Brussels (B) (see Fig. 3, where the acronyms are also explained).

Communication from Spacelab to MSFC was via NASA's TDRSS and NASCOM systems. ESA established the IGS Relay, the communications and mission operations link to Europe, at the Huntsville Operations Support Center (HOSC), one of the MSFC facilities.

In Europe, the complementary IGS central node terminated the PSCN/ESANET trunk at ESOC and provided the connectivity for voice, video and data services to the remote sites in Europe. IGS nodes were installed at all remote sites, providing the end-to-end network management capabilities needed for the reliable operation of networks of this complexity.

As a low-cost approach was a pre-requisite for the IML-2 remote operations support, no back-up systems or redundant communications links were foreseen except for the Microgravity User Support Centre (MUSC) in Germany, where an ISDN back-up capability was implemented.

Phased IML-2 network implementation

During the test phases that preceded the IML-2 mission, the communications network capabilities were built up in phases in terms of bandwidth, services, etc., leading up to the last tests that resulted in the freezing of the configuration to be used for the mission.

Three different technologies were chosen for the individual sites based on the particular cost and performance requirements:

- leased lines initially with low and later full bandwidth, as required for the various missions
- satellite-based connectivity with mobile ground stations that provided on-demand links with fixed data rates

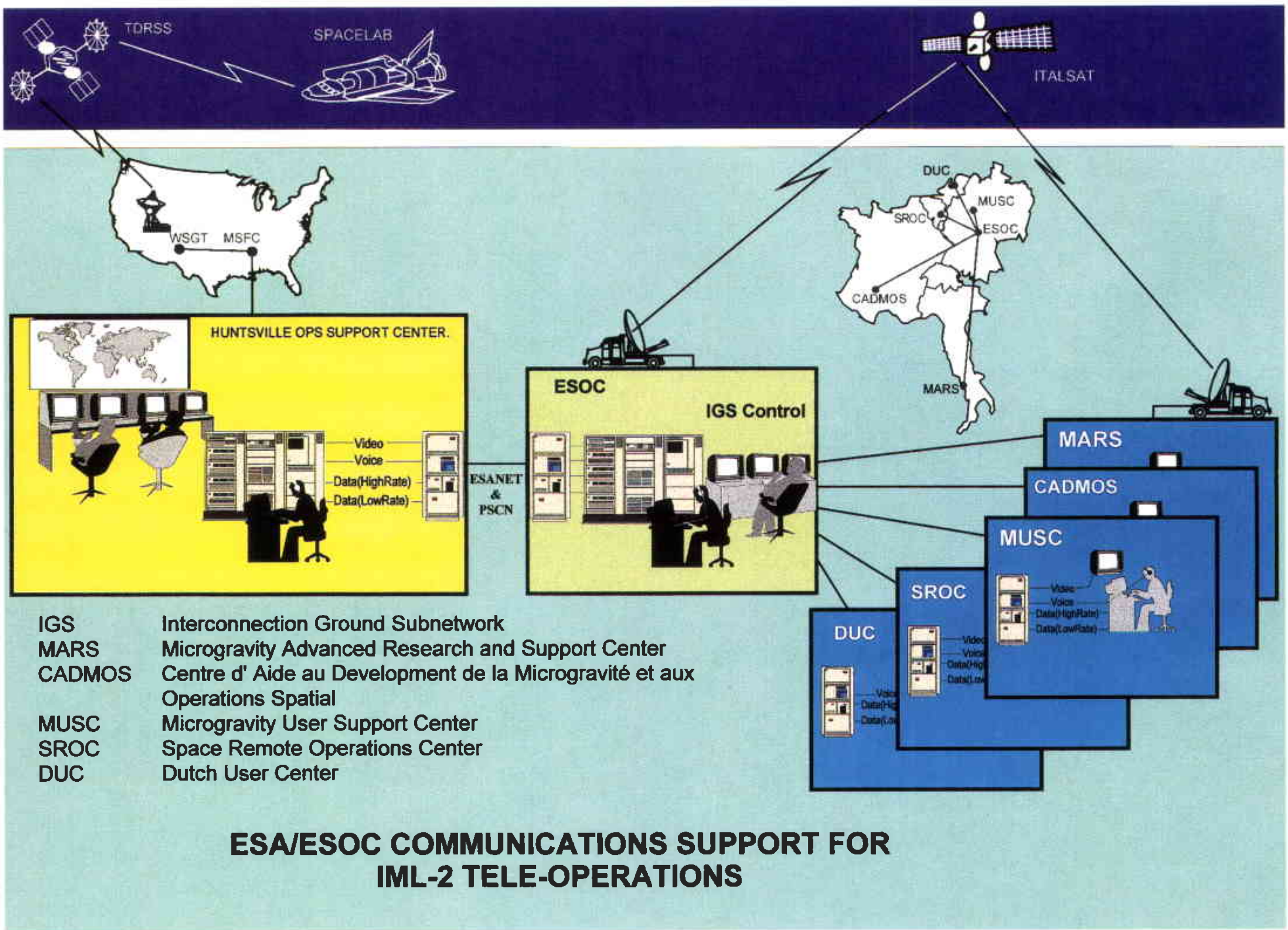


Figure 3. The IGS communications scenario for the IML-2 Spacelab mission

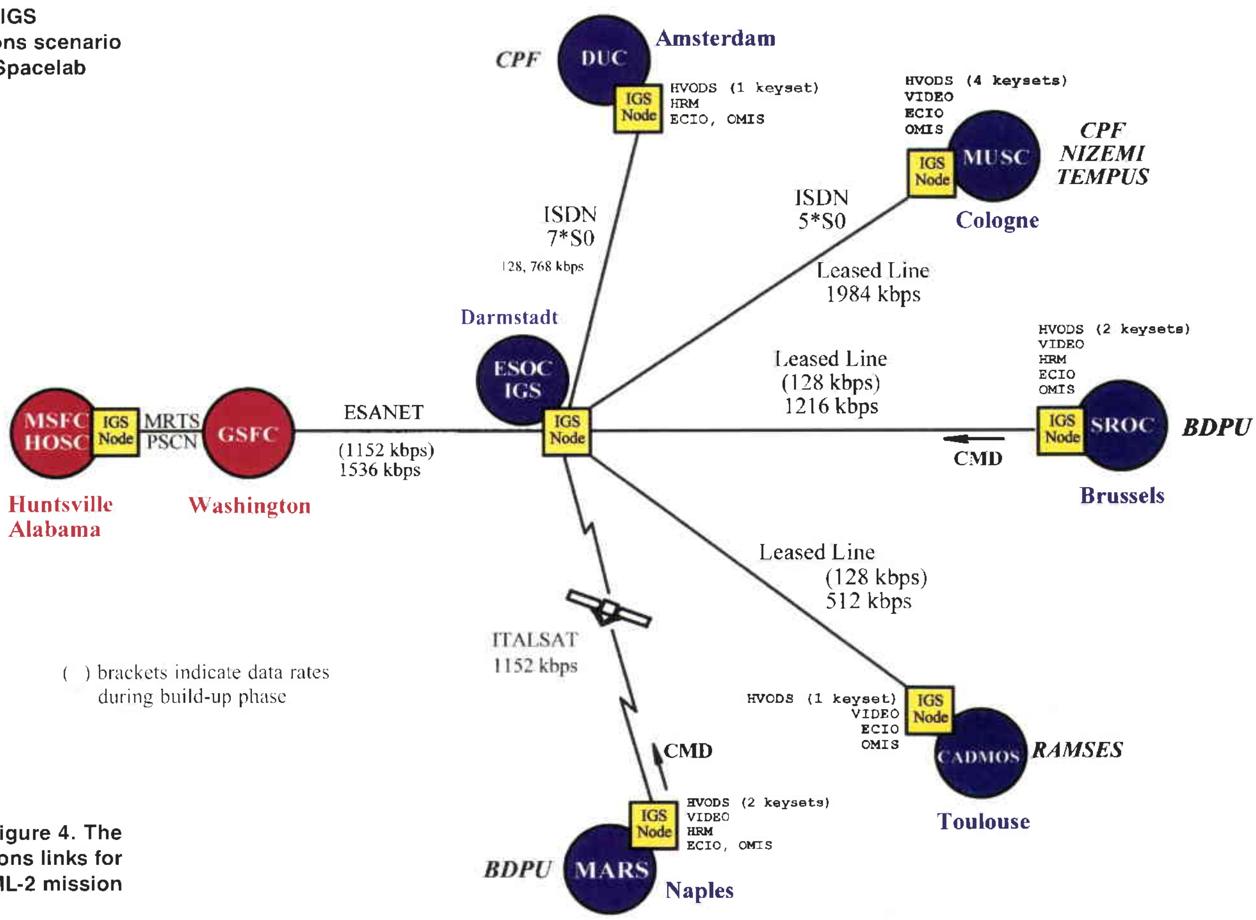


Figure 4. The communications links for the IML-2 mission

- on-demand N-ISDN connectivity using bundling techniques to combine multiple channels into higher aggregates as a substitute for leased lines.

Figure 4 provides an overview of the communications links that were established for IML-2.

IGS communications services supporting Spacelab missions

The communications services provided by the IGS were derived from the remote operations requirements at each site, which included:
- low-rate housekeeping telemetry reception
- low-rate experiment telemetry reception
- high-rate telemetry reception from experiments with different data rates (HRM)
- fixed telecommand sending
- variable telecommand sending
- access to the Operations and Management Information System (OMIS)
- voice conferencing (multiple loops)
- science video reception from the onboard experiments
- video reception of the NASA Select television feed to follow launch and other activities
- video conferencing for Science Operations Planning Group (SOPG) meetings.

The voice conferencing system was based on an extension of the NASA Huntsville Voice Distribution System (HVoDS), with its proprietary formats and signalling. The remote sites could access up to 32 voice loops at the same time.

For the video services, the analogue video signals were digitised and compressed to 384 kbps. Besides simultaneous distribution of onboard video to multiple sites, a digital video multipoint control unit (MCU) at ESOC allowed any video conferencing configuration between the remote sites, ESOC and NASA to be supported.

A data-exchange capability was provided by a LAN interconnect service, linking the LANs at the different sites and the HOSC LAN, from where databases and planning data could be accessed. As the latter was also interconnected via several other networks, including TDRSS, with the LAN onboard Spacelab, the European remote user centres were able to communicate directly with their experiments in space, sending commands and receiving their scientific data.

At the network-management level, all of the communications services and the systems that provide them are managed by the same centralised management platforms: the Network Management System (NMS), and the IGS Integrated Management Facility (IMF). The NMS is the proprietary management system of the core switching nodes on which the network is based. The IGS IMF is based on an expert system, which was customised for IML-2 to integrate the management of the additional subsystems (codecs, routers, etc.) under a single management. This centralisation of the network operations, both for routine operations and trouble-shooting, is a key aspect of the management architecture.

Trouble shooting and out-of-service network management operations can also be conducted centrally from ESOC. Support at the remote sites is required in principle only for hardware replacement.

Operational aspects

The overall timeline defining the activation and duration of the experiments aboard Spacelab was scheduled well in advance of the IML-2 mission. The remote-operations timeline derived from it gave the schedule of communications service requirements for IGS operation.

The planned operational activities were:
- switching of different high-rate science data feeds to either the DUC, SROC or MARS sites
- configuring of the ISDN link to the DUC into low- or high-data-rate mode
- distribution of video to the remote user sites
- configuring of video conferences on request.

Figure 5 shows the nominal communications operation scenario for IML-2. The IGS operations team (IGS Control) monitored and configured the network by means of the integrated Network Management System (NMS). IGS Control was in permanent contact with the Remote Operations Coordinator, who resided at the science operations area in MSFC throughout the mission.

The Remote Operations Coordinator issued requests to IGS Control to perform service changes and received reports on the service status. Some service changes required the support of the HOSC Communications Control, e.g. provision of Spacelab high-rate data flow to the IGS Relay at MSFC. For this and similar reasons, IGS Control remained in permanent contact with its MSFC counterpart. IGS Control permanently monitored the performance of all IGS resources and services and informed the Remote Operations Coordinator of any identified or potential problem.

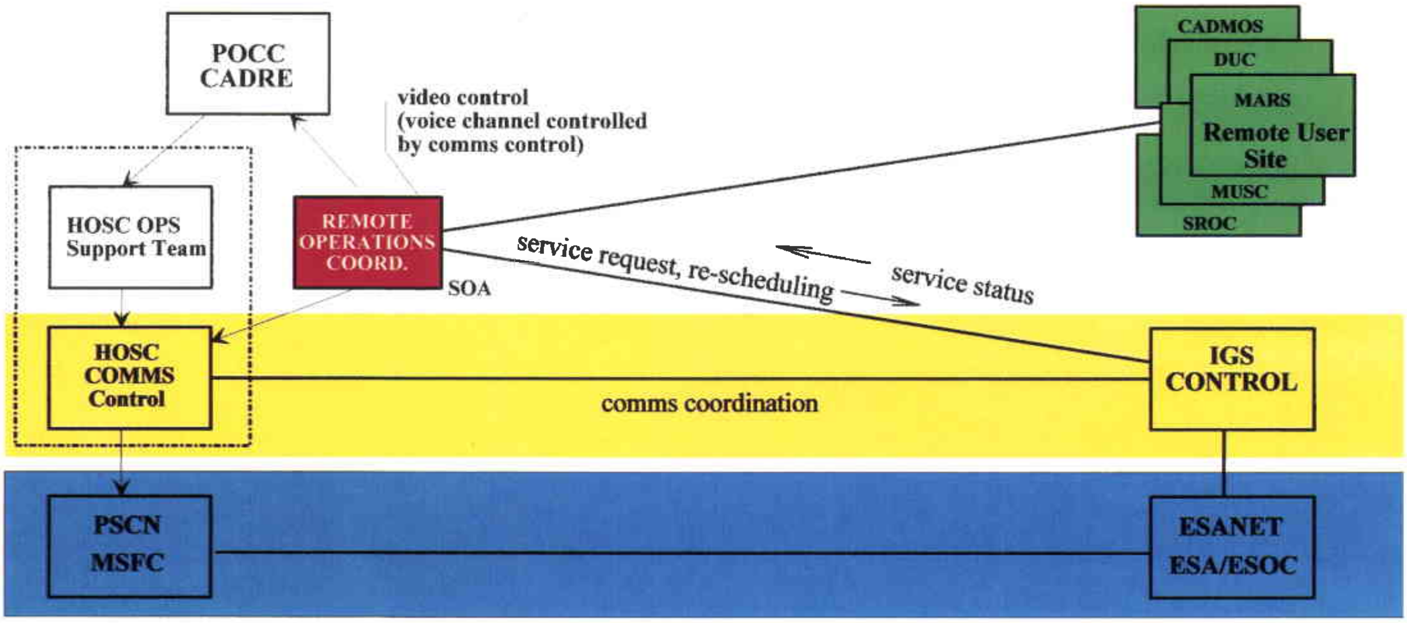


Figure 5. Nominal communications operation

Conclusions and lessons learned

The IGS's successful operation for IML-2 has demonstrated that decentralised remote telescience can be performed both reliably and cost-effectively. The modular service capability of the network allows easy adaptation to different user needs. The connectivity charges, which are the major cost driver for remote telescience, were minimised by employing phased implementation of only the most suitable connectivity techniques, including the exploitation of existing multi-purpose communication networks. The centralised network management approach proved to be a big advantage, allowing the staffing/communications expertise required at the remote sites to be kept to a minimum. It was also shown that multi-purpose network resources can indeed be used successfully for operational support, as yet another example of a growing trend to merge traditionally distinct network domains.

The Interconnection Ground Subnetwork, known as IGS, is based on today's state-of-the-art technologies and the strategy being applied in its development will allow its successful migration to exploit future connectivity techniques such as B-ISDN as when these new services can be demonstrated to be still more cost-effective than the current arrangement.

The scientific return of the subsequent Altas-3 in November 1994 was also considerably enhanced by reusing the already proven capabilities outlined above.

Acknowledgments

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The work reported relied heavily on the support of the Columbus Programme, which also funded some of the IGS testbed activities. The contribution of ESTEC, and J. Degavre in particular, in helping the user centres to set up their infrastructures to handle the remote science operations is also gratefully acknowledged.

Using Satellites for Worldwide Tele-health and Education — The GATES Proposal

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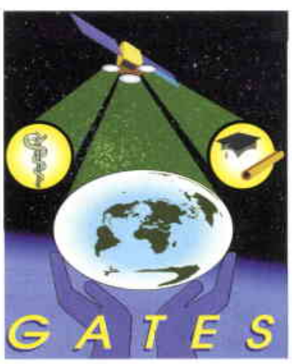


The world is currently witnessing a revolution in communication and information technologies. Concepts like global personal communications via satellite and the 'information superhighway' are becoming common terms in a growing information society. At the same time, basic education and health care are major problems for billions of world citizens. Expected increases in population in the most affected regions will worsen the situation.

In an effort to address those critical problems, participants in the International Space University's 1994 summer session have produced a proposal for GATES, a Global Access Tele-health and Education System. By using the advanced communications and information technologies in tele-health and tele-education applications, GATES aims to improve basic education and medical care on a global scale.

Introduction

We are currently witnessing a rapid evolution in communication and information technologies. In many parts of the world, the uses of computers, mobile telephony and satellite communications are already key elements in an expanding information society. In the near-future, Low Earth Orbit (LEO) satellite constellations will offer mobile personal communications, at any time and place, using pocket-size terminals. Interactive high bandwidth services will be available at home, through satellite or fibre optics technologies. Multimedia computers are becoming standard, allowing the combination, manipulation and exchange of text, sound and images easily and at low cost. The arrival of these technologies will undoubtedly and considerably influence our lives within only a few years' time.

It is very likely that the dominating applications of these new technologies will be found in high-profit domains like business and entertainment. Major companies and international organisations are currently investing billions of dollars to secure their share of a huge commercial market. Primary areas of interest include business communications, paging, video-conferences, home shopping, video on demand, and virtual reality.

Other applications that are perhaps less profitable in traditional terms, but extremely valuable in a long-term global view, may also benefit from this evolution. Outstanding examples are distance education and health care in remote areas or in emergencies. Such applications have proven to have a significant positive effect on the affected areas by compensating for a lack of resources and infrastructure. The users' needs and the requirements of these types of applications must, therefore, be considered in the development of new communication infrastructures.

Meeting the distance education and health care needs of remote areas was the focus of intense activity during the 1994 summer session of the International Space University, held in Barcelona. A group of 46 participants from 19 countries was challenged to propose efficient ways of using existing and future communication and information technologies in education and health care. The project was sponsored by ESA, NASA and several other major space organisations. After analysing the technical, political, legal, cultural and financial aspects of the problem, the international project team recommended an outline for a Global Access Tele-health and Education System (GATES). The aim of the system is to improve education and health care services, particularly in remote areas and developing countries. The proposed solution is based on the use of existing and future telecommunication and information systems on a global scale.

International Space University

The International Space University (ISU) was founded in 1987 as a non-profit, non-governmental institution for the education and training of tomorrow's space professionals. ISU brings together international space experts from academia, industry and government to educate students in multidisciplinary and advanced issues in space development. With a permanent campus in Strasbourg and affiliated campuses in 25 locations around the world, ISU offers educational programmes that range from an intensive summer session to a full Master of Space Studies (MSS) programme.

One of ISU's annual objectives is to conduct design projects, such as GATES, that are of interest to industry and the space community and provide the students with a challenging problem. The material in this article is based on the final report and the experience of those participating in the GATES design project as part of the ISU'94 summer session held in Barcelona, Spain.

ISU summer sessions have previously been held in Cambridge, USA; Strasbourg, France; Toronto, Canada; Toulouse, France; Kitakyushu, Japan; and Huntsville, USA. In 1995, the session will take place at the Royal Institute of Technology in Stockholm, Sweden.

A world in need

Despite global recognition that health and education are the essential building blocks of a sustainable society, serious shortcomings and 'maldistribution' in education and health care services remain. A United Nations study estimates that two billion people have either minimal access to basic education or health care, or are completely lacking access to these services. Predicted increases in population, particularly in the areas most affected, will put even more strain on education and health care efforts in the future.

Limited access to educational and health care services is generally driven by complex economic, political, social and cultural factors. One technological project alone cannot hope to resolve such vast and complex shortcomings. It has, however, been demonstrated that technology can improve the situation. Modern telecommunications technology has the potential to play an important role in this situation, in particular given its ability to reach many people at a reasonable cost.

Technology in response to the needs

Tele-health and tele-education involve the use of telecommunication techniques to provide respectively medical or educational services over a distance. Common examples are a doctor in a remote area transmitting an X-ray image to a specialist thousands of kilometres away for consultation, or the use of satellite television to teach students in remote areas. These and many other applications have already proven to be feasible and effective through many local and regional projects.

In Europe, ESA has been active in distance education using the Agency's now-retired Olympus satellite. Its involvement in the Eurostep activities has been previously described (ESA Bulletin No. 56, 60 and 66). The European Union is carrying out other related projects, including the DELTA project for distance learning and the AIM project for telematic systems in health care. Many other projects undertaken around the world have shown that distance education can provide results of the same quality as classical classroom education.

Similarly, it has been shown that tele-medicine can be adapted to many situations, particularly in the case of emergencies, lack of qualified personnel or in remote areas. Examples of major projects already undertaken are:

- Project SHARE (Satellites in Health And Rural Education), which provided video transmission capacity via Intelsat satellites to 20 projects and 43 countries, for humanitarian purposes
- Tele-Medicine Spacebridge, an audio-video-fax link via satellite that connected American medical centres to Russian and Armenian medical centres to enable physicians to remotely provide medical assistance after the Armenian earthquake in 1988 and after a gas explosion in Ufa, Russia, in 1989
- Remote Clinical Communications System, a portable tele-medicine system used by the US Army during its operations in Croatia and Somalia
- SISDIKSat (Indonesian Distance Education Satellite System), one of the first audio-

conferencing networks to be created in a developing country to fulfil educational needs. The system addresses the lack of well-trained faculty in Eastern Indonesia. It has been in operation since 1982.

Mission and goals of GATES

The scope of the ISU design project was defined as 'reducing inequalities in health and education within countries and between countries by providing global access to health care and educational services using telecommunications technology'. The unique aspects of the resulting GATES system are that it takes a global approach and it has the dual objective of combining education and health care.

In addition to the broad definition of the mission, the project group identified the high-level goals that were used as major guidelines for the study:

- Priority should be given to services related to basic health care, literacy and skills for sustainable development.
- Priority should be given to remote and under-served areas.
- The system must be responsive to social and cultural realities.
- The system must be modular and flexible.
- The system must meet specified requirements at minimum cost to the customers (those providing the funds for development) and ultimately at minimum cost to the users (those receiving the services).
- The system must provide global coverage within the next ten years.

A global strategy was justified by the worldwide distribution of the shortcomings to be addressed. Financially, a global system can be funded by combining available resources from many sources. This allows shared use of the system with regions less able to support high investment costs. Satellite telecommunications using existing systems in Geosynchronous Orbit (GEO) and future proposals in Low Earth Orbit (LEO) ensure technical feasibility and offer coverage of a global nature.

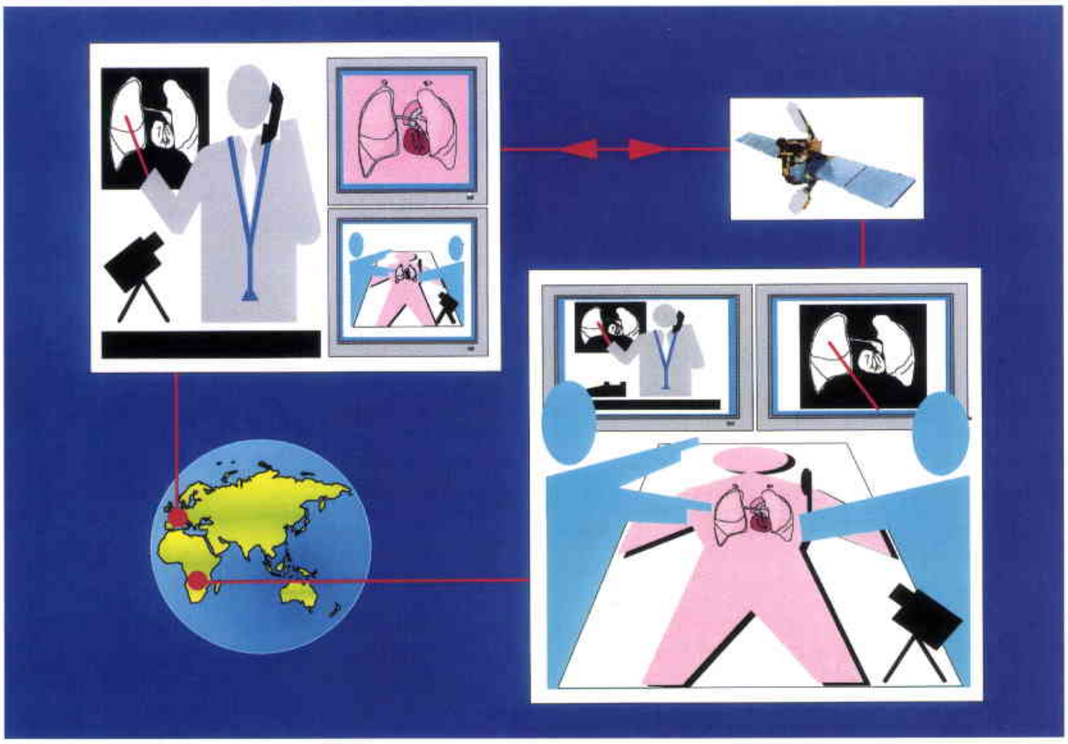
The dual approach, combining education and health care, is justified by the fact that the highest educational and medical needs generally appear in the same areas. Furthermore, the basic communications requirements for educational and health care services are very similar. The validity of this approach was demonstrated for example by Project SHARE, which provided both tele-health and tele-education.

Potential GATES users

The potential users of GATES can be divided into three categories: specialists, non-specialists and beneficiaries. A specialist is typically a medical doctor with expertise in a specific field of medicine, or a specialised teacher. The non-specialist is generally a doctor, a nurse or a teacher who is working in a remote area. The beneficiary is the patient or the student who receives the medical or educational service.

In a typical medical situation, a general practitioner (the non-specialist) working in a remote area seeks the advice of a specialist in a distant location to establish or confirm a diagnosis (Fig. 1). This method results in improved quality of the diagnosis, and allows the diagnostic time and the need for patient transportation to the specialist to be drastically reduced. Similarly, a teacher working in a remote area may call upon a more highly trained teacher, access stored information or make use of advanced audiovisual media to improve the quality or level of education offered where alternatives do not exist.

Figure 1. Interaction between tele-medicine users



Non-specialists using the system to improve their own skills and knowledge by learning from more highly trained individuals is an example of the 'teaching teachers' and 'teaching doctors' concepts. These concepts are particularly important in regions such as developing countries where the qualification level and number of non-specialists like primary school teachers and nurses are often insufficient to provide all required services.

The patient or student, as beneficiary, has only indirect contact with the specialist. This keeps the number of user terminals required and the volume of communication to a minimum. Furthermore, an intermediate person (the non-specialist) will often be necessary since many patients or students do not yet have the skills to use the system.

System requirements

The message

For the user to accept a global system, it is important that the actual information or content of the transmitted message is not defined centrally. It must be managed regionally or even locally to fit the culture and priorities of the region.

The message will generally circulate between the specialist and the non-specialist. For medical applications, it will typically consist of information about the patient that is needed to establish a diagnosis or treatment. It may include images, voice, and digital data created by instruments such as an electrocardiograph, electroencephalograph, electronic stethoscope, ecograph, image scanner, or alphanumeric keyboard. For education applications, the message will typically consist of voice, images and digital data produced by a telewriter, image scanner, telefax or keyboard.

User terminals

The user terminal provides the interface between the user and the telecommunication link. Based on the experience of previous tele-education and tele-medicine projects, general requirements rather than detailed technical solutions were determined. The essential characteristics are flexibility, interactivity, modularity and low cost. Furthermore, power autonomy, ruggedness and ease of installation are vital for remote areas, disasters and emergencies.

A dedicated terminal that could be used for combined basic tele-medicine and tele-education in remote areas was studied. Based on existing computer and Very Small Aperture Terminal (VSAT) technology, this concept was considered to be feasible.

Telecommunication links

The telecommunication links must reach the user even in remote areas and regions lacking a communication infrastructure. Furthermore, it must allow a sufficient flow of information to fit the application. This is generally limited by the bandwidth of the link. The required data rate varies drastically with the level of service to be provided but it appears that many basic services can be provided via narrowband links. The evolution of data compression techniques, reducing the required data for a service without major loss of quality, further increases the capabilities of limited bandwidth applications. A reasonable minimum service offering two-way voice communication, data transmission (e-mail, fax) and still-image transmission capability is feasible with less than 64 kbit/s per channel. More advanced applications such as video conferencing or compressed video require minimum data rates in the range of 384 kbit/s to 6.3 Mbit/s respectively.

The proposed solution

A technology review was carried out to identify the most adequate technical solution for GATES. Communication standards, analog and digital networks, wire and microwave ground systems, and existing and planned satellite systems were examined. It was found that although terrestrial telecommunication systems offer high capacity at decreasing cost in densely populated areas, they are not cost effective in remote areas where the population density is lower. In the absence of existing terrestrial networks, satellite systems were found to be the most effective way of providing the necessary communication links.

Proposed system architecture

To meet the requirements of both education and health care services, a system architecture based on three levels of centres is proposed (Fig. 2).

Several High Level Centres are spread globally with at least one centre per continent. Each centre is to be located in a city or a region with a large hospital and a university. The High Level Centre is formed by electronically connecting the hospital and the university to form an integrated unit. This acts as a joint regional information source and focal point for both tele-education and tele-medicine. The High Level Centres are interconnected by high bandwidth satellite links or terrestrial connections to form the top level of the global network.

Each High Level Centre is connected by high bandwidth links to several Medium Level Centres. Each Medium Level Centre is also located in a city with health care and educational institutions interconnected to form joint local focal points. Due to legal issues, special needs and adaptability to cultural environments, at least one Medium Level Centre should exist in each country.

The Medium Level Centres are connected to several Low Level Centres, located where the medical or educational need exists. Since these locations may often include villages, remote areas and disaster sites, narrow-band or even mobile links may be required. The large number of links needed and their geographical distribution drive the requirements of the communication system.

on existing geostationary satellites. An investigation of 20 existing satellite systems showed that global coverage with identical ground terminals could most easily be achieved using C-band frequencies. Existing Intelsat V, VI and VII systems would provide sufficient capacity and compatibility with regional systems. The geostationary C-band solution is a low-risk choice based on proven technology that provides acceptable performance for part of the required applications. There are, however, drawbacks concerning power requirements, bandwidth, portability, transmission delays and the cost of the ground terminal. The cost of the existing systems solution greatly depends on the

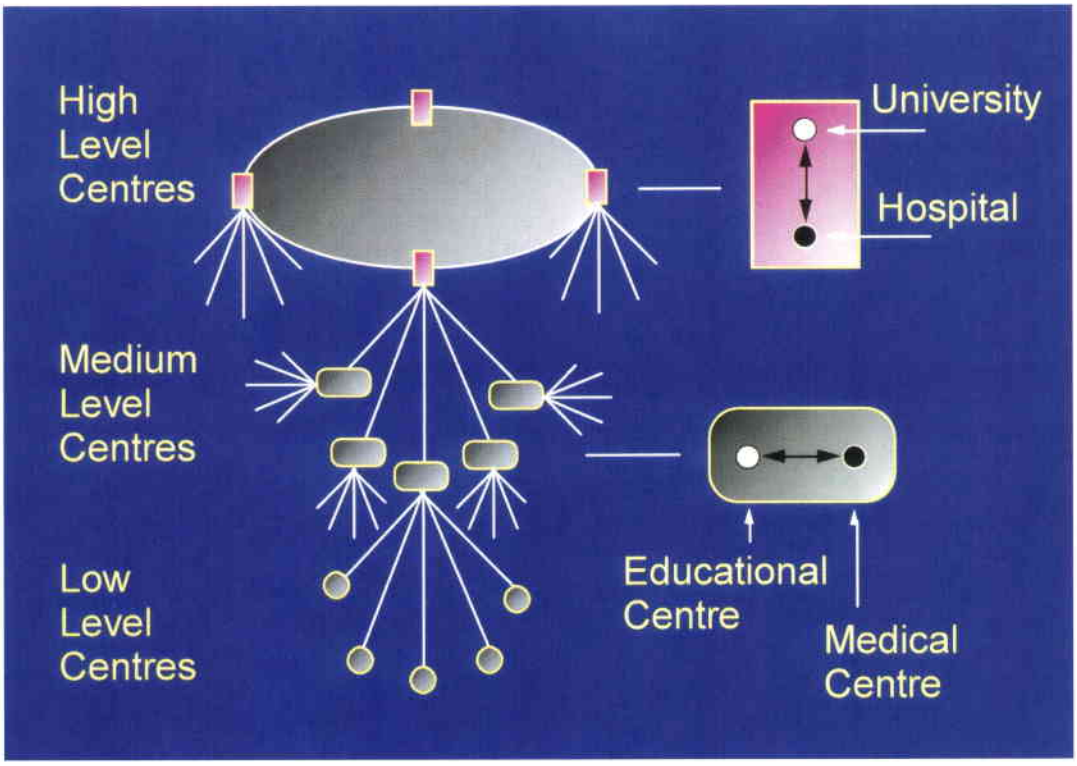


Figure 2. Proposed GATES system architecture. There will be a least one High Level Centre per continent. Each one will be connected to several Medium Level Centres. There will be at least one Medium Level Centre per participating country, and it will be connected to several Low Level Centres located where there is a medical or educational need.

Three technical solutions
Three different technology scenarios were defined for the implementation of the necessary satellite links. These options include the use of existing systems, planned new systems or a dedicated new constellation. The general approach is to initially start providing services using existing systems. Once the system is working well, a move to one of the various planned systems or a dedicated constellation could then be considered. The choice would depend on the potential improvement in service versus the cost, which would be determined at that time.

Use of existing systems
The initial solution, which would allow the global system to be demonstrated with minimum investment cost and service delay, is based on the leasing of transponder capacity

negotiation of the service charges. It is hoped that non-commercial rates would be applied, considering the international and humanitarian characteristics of the application.

Use of planned new systems
The foreseen technology evolution in new satellite constellations may offer attractive potential for GATES. Through technology evolution, smaller and cheaper user terminals or higher bandwidth services are becoming feasible. Many proposed systems are based on large constellations in orbits relatively close to the Earth such as LEO. This offers the advantages of shorter distance to the satellite, lower power requirements and cheaper, smaller terminals. The disadvantages are the large number of satellites required for continuous coverage and the complex technology requirements for coordination. This

implies large investment costs, an uncertain technical and financial feasibility, and unknown costs of services. Other proposals involve more traditional use of GEO orbits, with potentially lower service costs. The proposals differ greatly in the bandwidth offered, which determines the complexity of the possible application. Services range from inexpensive, low-rate data transmission to high bandwidth links with interactive multimedia capacity.

An examination of several leading proposals for new systems was made based on the available information on costs and performance. Depending on eventual realisation, the preferred options are (in order of priority): Teledesic and Hughes Spaceway for broadband services, and Globalstar, Odyssey and Constellation for narrowband services. There is however considerable uncertainty regarding service charges and the actual implementation of the proposed systems, making the options difficult to evaluate at this time.

Use of a dedicated constellation

To study the potential of a solution tailored exclusively to the needs of the chosen application, a third option was defined. This design is based on the implementation of a dedicated, relatively small constellation of satellites. The ambitious solution is optimised to meet global coverage and the priority of serving developing countries, both of which are fundamental GATES requirements. The proposed configuration of the dedicated constellation is shown in Figure 3 and its ground coverage in Figure 4.

The design is based on eight 600-kg satellites equally distributed in a circular equatorial orbit (0° inclination) at an altitude of 8000 km. In addition, four smaller satellites are placed in a polar orbit at the same altitude. The equatorial segment provides continuous service to the area between the 55° North and 55° South latitudes, which is where the majority of the world's population lives. The polar segment provides an extension to

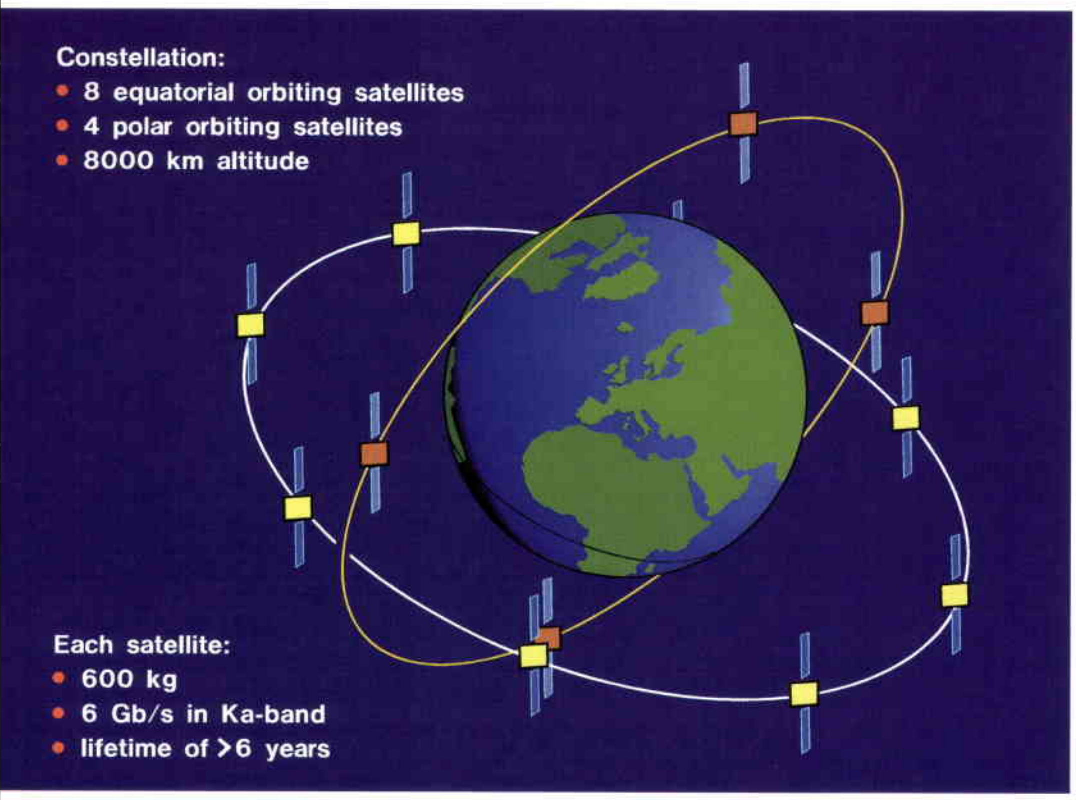


Figure 3. Configuration of the proposed GATES dedicated constellation

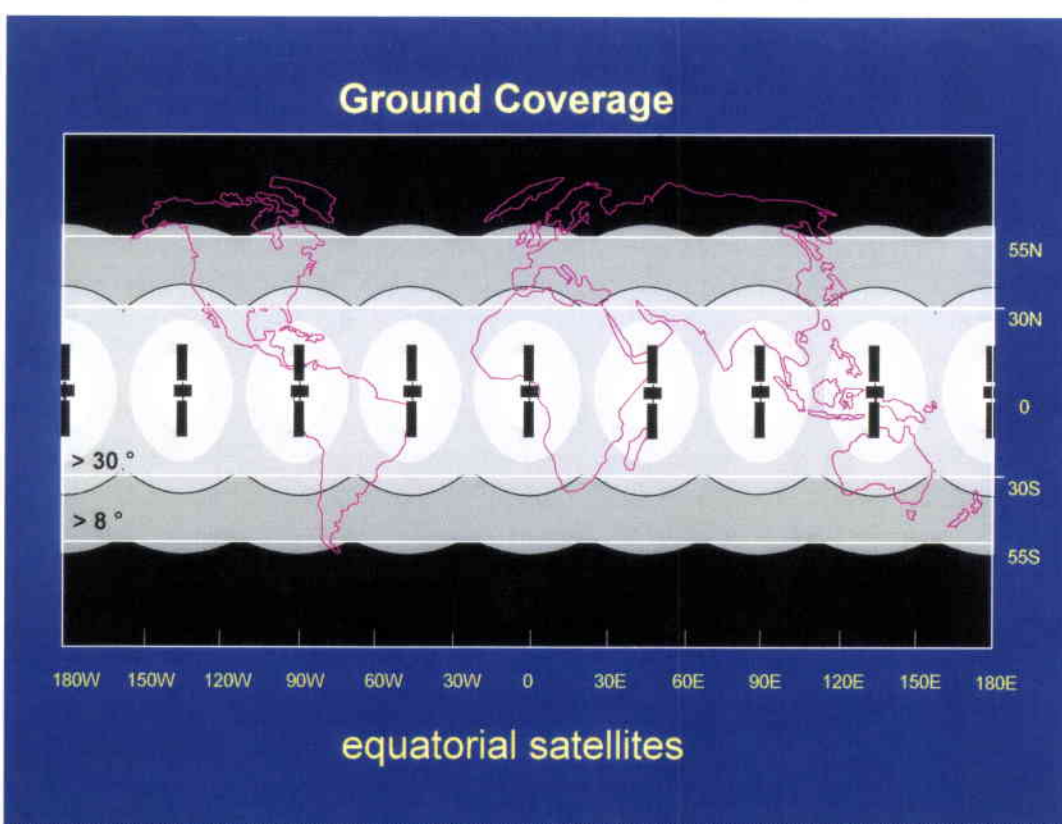


Figure 4. Ground coverage of the proposed constellation

a. Coverage by the equatorial-orbiting satellites continuous global coverage. High elevation angles, enabling more compact and cheaper ground terminals, are offered in the area between the 30° North and 30° South latitudes, where most developing countries are found.

A wide range of launch options is feasible and a single Ariane-5 launch would be sufficient in terms of mass to launch the eight equatorial satellites. The radiation threat, however, is great at the chosen altitude, particularly for the equatorial satellites. Careful consideration was given to the necessary protective measures and it is estimated that a design lifetime of more than six years can be achieved.

With state-of-the-art technology, the total communication capacity of the payload can reach up to 6 Gbit/s per satellite in Ka-band. This results in a total system capacity that is potentially larger than the current Intelsat global satellite system capacity, at a relatively small fraction of its cost. GATES would require only 10% of this huge capacity, which creates a window of opportunity for cooperation with a commercial operator or an international consortium.

Implementing GATES

Organisational structure

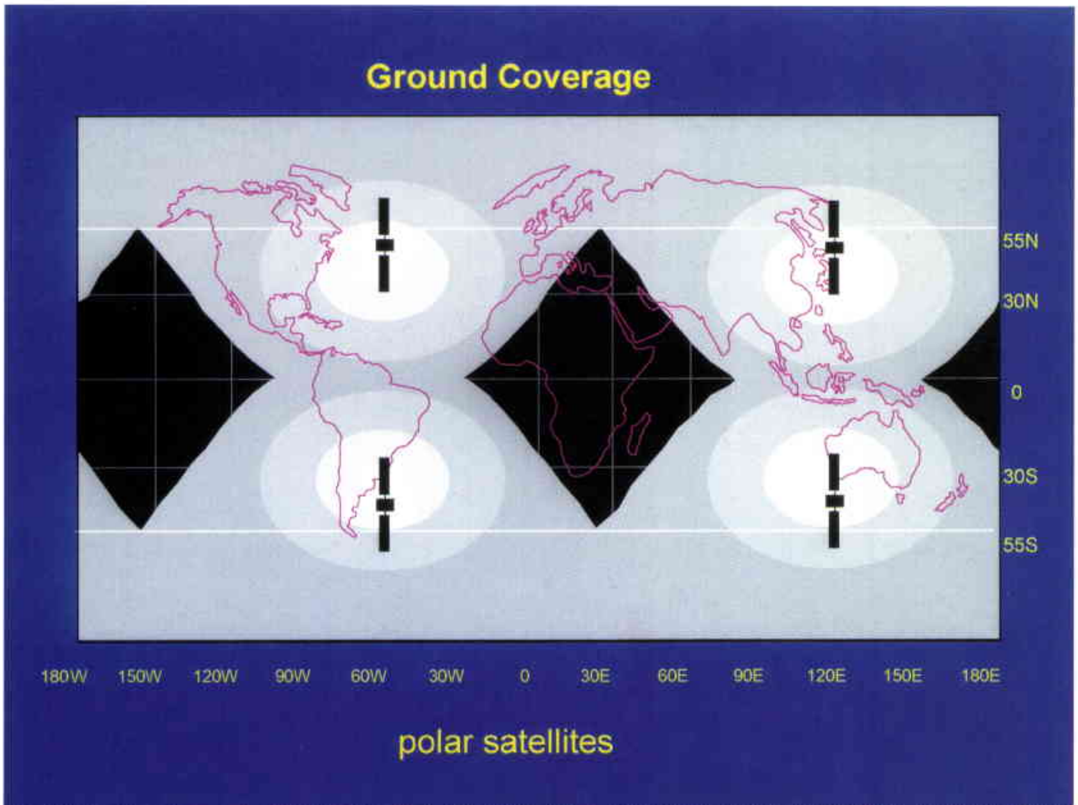
The challenge of implementing GATES can be considered to be more political and financial than purely technical. For its realisation, a dedicated organisation driven by a humanitarian spirit while employing effective commercial methods is proposed. Membership in GATES would be open to any state but all nations and areas may have access to GATES services regardless of membership. Services will be provided to commercial users at a charge while non-profit use will be subsidised.

A hybrid structure, resembling that of organisations such as Intelsat and Inmarsat, is the preferred option for combining both profit and non-profit motivations. The desired characteristics of the organisation are tight management and low operational costs achieved by using minimum staff, competitive awarding of contracts, and volunteer workers. One coordinating office would be in charge of establishing the political and legal framework, managing the organisation, and dealing with frequency regulations and contractual relationships with the various partners. A sound use of the system will be assured by the creation of the GATES Code of Conduct, a set of rules to be followed by all users.

Implementation strategy

An implementation in three phases is proposed, starting with an initial preparatory phase expected to last two to three years. The main tasks in that phase include the formation of an organisational structure and the drafting of preliminary agreements between political, legal, financial and industrial partners in preparation for the next phase.

In the second phase, the initial deployment phase, the first tele-education and telemedicine services are demonstrated. Only a few sites are initially covered, using leased transponders on existing geostationary satellites. Early parallel introduction is suggested in Kenya and remote areas of Canada, expanding to regional coverage in these areas. Growth towards global coverage is



b. Coverage by the polar-orbiting satellites

Participants in the GATES design project

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prepared. The fundamental decision on the final technology option for the next phase, i.e. to use planned systems or a dedicated constellation, is made.

The third phase, the operational phase, features service growth towards full global coverage. The system is implemented in regions of Mexico/South America and South East Asia, followed by interconnection of regions globally, leading to full coverage. It is also expected that, in parallel with the geographical growth, the level of the services offered will increase due to technological evolutions and increases in link capacity.

Financial aspects

An exploration of potential financial sources identified the World Bank and other UN Organisations (e.g. UNESCO), National Development Finance Corporations, organisations dealing with development issues and space agencies as major potential contributors to GATES. In addition, commercial funding may be attracted in the early phases by the perspective of large future markets for providers of user terminals. Considering the yearly global budgets for education and health care, and the potential of GATES to effectively contribute in these domains, it is believed that donations and low-interest loans could cover most of the financial needs for the first years. The total expenditures for the first five years of service, using leased existing capacity, are shown in Figure 5.

The estimated investment cost for the entire dedicated satellite constellation system is $1.2 billion US, which includes the space segment, ground segment and launch. Both this cost and the offered capacity are, however, too high for GATES. To obtain low utilisation costs, the solution may be to offer the excess capacity to a commercial operator or an international consortium, reserving only a portion (e.g. 10%) of the system capacity for GATES use.

Additional applications

In addition to global education and health care services, the establishment of a system such as GATES has the potential to contribute significantly to other applications. There can be direct benefits for disaster and emergency applications as well as in addressing environmental issues. In the domain of environmental protection, GATES can be a unique tool to foster environmental education and collect environmental data. Collaboration with other projects such as GLOBE (Global Learning and Observation to Benefit the Environment) would be directly applicable.

The tele-medicine aspect of GATES is an ideal contribution to the relief phase of disasters and emergencies. Experience shows that the time required to organise basic medical care and make an initial diagnosis is essential in reducing fatalities and aggravation of injuries. The combination of a disaster management system such as GEOWARN, Global Emergency and Warning (an ISU'93 project, Bulletin No. 77), and GATES forms an ideal solution for rapid and efficient relief. The two systems could share the communications infrastructure to reduce costs. Furthermore, the tele-education aspect of GATES would be directly valuable in disaster preparedness. Fatalities in under-served areas could be decreased simply through education on basic measures to take in case of disasters such as earthquakes, hurricanes or floods.

Conclusions

The current revolution in communication technologies will allow many new commercial applications in the near future. We must assure that their potential is also applied to improve the quality of life of billions of people, especially in the developing world, who need it the most.

GATES, the Global Access Tele-health and Education System, constitutes a practical way of using space systems to address some of the most dramatic human problems on Earth. This is an application that offers obvious benefit to humankind in a time when investments in space are being questioned by the public.

The idealism and enthusiasm of the team of students and young professionals who developed this project have not ended with the closing ceremony of the ISU'94 summer session. The team is now working hard to find support for the realisation of the project.

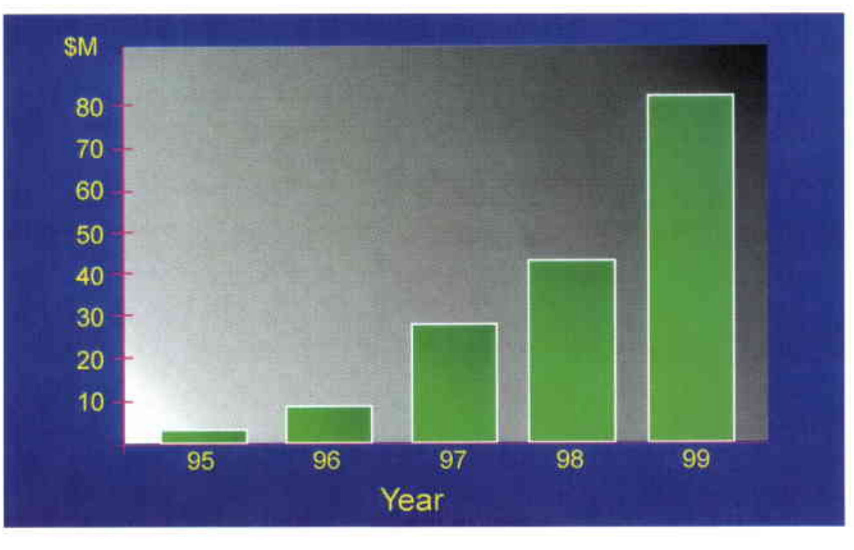

Figure 5. Total expenditures for the first five years of implementation using leased, existing capacity

The ECSL Summer Course on Space Law and Policy — An Example of ESA's Role in Space Law Teaching

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Space law is often thought to be a discipline for dreamers and lawyers whose heads are full of stars and comets and who are sometimes far from reality. This may have been true in the beginning of the space era but, with the advances of space technology and the development of commercial space activities, lawyers are very rapidly being faced with more and more practical issues. In the past, lawyers could follow these developments and study space law as a complement to their daily activities. This is not true anymore: young lawyers have to be trained adequately in order to be able to adapt to the growing needs of space activities, and to foresee the legal challenges of the future. The European Centre for Space Law has developed a specific training programme on space law, which has become far more successful than its founders could have expected.

From space law to the law of space activities

As happens with many human activities, space activities have provoked the gradual emergence of a body of legal rules designed to govern the relations of those involved in these activities. At the beginning of the space age, space law was essentially part of public international law since only individual states were performing space activities and, at that time, the activities were exploratory in nature.

The main legal principles of space law were elaborated within the framework of the United Nations, and more specifically its Committee on the Peaceful Uses of Outer Space (UNCOPUOS). The committee adopted a series of fundamental treaties that still constitute the core of space law:
- the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (1967)
- the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (1968)
- the Convention on International Liability for Damage Caused by Space Objects (1972)
- the Convention on Registration of Objects Launched into Outer Space (1975)
- the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (1979).

In recent years, with the profound changes that have occurred in the international environment and the entry of new members (mostly developing countries) into the COPUOS, the Committee's adoption of texts has slowed and the legal nature of the texts that have been adopted has changed considerably. No treaties have been adopted after those mentioned above, but a series of principles was agreed upon and embodied in United Nations Resolutions, with therefore less legal constraint. The following have been adopted:
- the Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting (1982)
- the Principles Relating to Remote Sensing of the Earth from Space (1986)
- the Principles Relevant to the Use of Nuclear Power Sources in Outer Space (1992).

The traditional view of space law as part of public international law has also changed because of the weakened role of the United Nations as well as because of pressure from the new type of operator entering the space arena, one with different views on how to use space. At the beginning of the 1980s, there was a strong move toward the commercialisation of space activities, especially those being performed by private operators. Telecommunications already had a commercial component but state involvement was also very strong. The greatest change occurred in the field of launch services where private operators wanted to take part in the launch of space objects. The lawyers' creativity was then welcomed: rules governing the activities of private firms in this field had to be drafted, incorporating all the basic principles of space law while also paying particular attention to liability and insurance issues.

A range of activities that are more or less closely related to space operations and space business has also emerged. Those activities include drafting industrial contracts, processing of remote-sensing data, performance of telecommunications services, and financing. Because of the specificity of space activities from the administrative, financial, legal and practical points of view, the traditional fields of law governing those areas have faced new difficulties and a new environment. Once again, lawyers have had to adapt the rules to the changing needs of space activities. Such adaptations, together with creative thinking, will be needed even more in the future as the field of telecommunications evolves, the International Space Station allows humans to live in space for longer periods, and aerospace planes start carrying passengers through space as well as air space.

Establishment of ECSL

In the mid-1980s, there was a growing need for European reflection on space law issues in order to stimulate thinking and gather ideas, and to contribute to the building of a European capability to deal with these issues, in particular in view of the ever-increasing cooperation on large projects such as the International Space Station. A number of lawyers and professors active in the field, led by G. Lafferranderie, ESA's Legal Advisor, decided to set up the European Centre for Space Law (ECSL). It was founded in 1989. ECSL is operated under the auspices of and with the support of ESA, and aims mainly at promoting the knowledge of and interest in space law in Europe, coordinating European efforts in the field, stimulating exchange among interested parties, and playing a leading role in research that contributes to the development of regulations or norms at the European level. ECSL currently has 170 members and a mailing list of about 1500 people, which constitutes the core of the space law community in Europe and around the world.

The Centre's activities have developed exponentially. Although interest in space law already existed in Europe, the creation of ECSL has led to an unprecedented development of activities and thinking in this field. The Centre has gradually helped its members to gather nationally around National Points of Contact (NPOCs), intermediaries between ECSL and its members. Together with the NPOCs, ECSL has organised a number of workshops and conferences on space law topics and has published proceedings of most of these events.

NPOCs are also very active, often with the support of ECSL, in organising their own events and stimulating interest in their own countries. ECSL also maintains, together with ESA Legal Affairs, a database called ESALEX which contains ESA legal documents as well as bibliographic references and legal documents relating to space law from other sources.

The Centre has undertaken two research projects, both on its own and with the help of experts. The first study dealt with legal protection of remote-sensing data and led to an ESA proposal to the European Commission to amend parts of a directive on databases in order to take into account specific needs related to remote-sensing activities. The second project, which is currently in its final phase, addresses intellectual property rights relating to space activities. The World Intellectual Property Organisation (WIPO) has shown strong interest in this study and efforts will be made to achieve, with WIPO, harmonisation of laws in this field on the basis of the ECSL study and suggestions.

Since many of the ECSL members are practitioners, either from law firms, national space agencies or industry, ECSL has set up a Practitioners' Forum, designed to meet the members' specific needs. The Practitioners' Forum is a yearly conference, attended by those active in the practice of space business and space law. Presentations on recent developments in the field are given, and participants are able to exchange views, in an informal way, on legal problems they encounter in their practice. ECSL also regularly publishes a newsletter, ECSL News, informing its members of past, current and future activities and focusing, in almost every issue, on a specific space-law problem. Many articles on ECSL activities are also published in other space law journals, thanks to the active cooperation between ECSL and editors of space law publications in Europe and around the world.

The ECSL Summer Course on Space Law and Policy

ECSL's major success, however, is undoubtedly in the field of teaching. The community of space law teachers and professors that ECSL has assembled is exceptional in Europe, as well as around the world (see coloured box). Also, because the Centre is a repository for information, students have been very interested in it. Their motivation has often been determined or stimulated by their contacts with the Centre. ECSL has published a booklet entitled Space Law Teaching in Europe, which provides information on the universities in Europe where space law is taught either as a free-standing course or as part of a more general course, and on professors giving such courses. A yearly Moot Court Competition is also organised in cooperation with the International Institute of Space Law, where teams of students from European universities defend a case before the International Court of Justice. The Moot Court experience is very enriching for students and professors; it allows them to move from abstract course work to the exercise of solving and defending a practical case and addressing the International Court of Justice.

The Centre's major effort in the field of teaching is geared to the ECSL Summer Course on Space Law and Policy. This course is designed to be an introduction to legal and political issues arising out of space exploration and space applications. It is organised with the support of the European Communities' Erasmus Programme, a host university and ECSL. It has also received the support of several other sponsors: the British National Space Council, Arianespace, Matra Marconi Space, Spot Image, the Centre National d'Etudes Spatiales, Gras-Savoye, SENER, CASA, INTA, the Canadian Space Agency and Martinus Nijhoff Publishers. The two-week course has been held for the past three years, at a different university each year: in Messina, Italy in 1992, Toulouse, France in 1993 and Granada, Spain in 1994. The 1995 Summer Course will take place in Aberdeen, Scotland. About 35 professors will be involved and about 50 students — from 25 universities in Austria, Belgium, Canada, Finland, France, Germany, Italy, Netherlands, Portugal, Spain, and the United Kingdom — are expected to attend.

In those three years, ECSL has gained much experience, thanks to the quality of the teaching staff assembled for the course. The course is constantly being updated to take into account the most recent developments in space activities and the related legal issues.

ECSL has published two volumes of materials to be used by students as support material for the course. It will also publish the proceedings of the Summer Course held in Granada last summer, which will become a complement to the basic materials.

Course content

Before the course begins, the students are given a demonstration of how to use the ESALEX database and the IRS databases relating to law. They are encouraged to use the systems throughout the session.

Teaching staff of the 1994 Summer Course

Prof Andem (University of Lapland, Finland)
Prof Back-Impallomeni (University of Padua, Italy)
Mr Jeanne (ESRIN, Italy)
Ms Onorato (ESRIN, Italy)
Dr Jasentuliyana (United Nations Office for Outer Space Affairs)
Dr Hobe (University of Kiel, Germany)
Prof Courteix (University of Paris I, France)
Prof Martin (University of Toulouse, France)
Prof Reijnen (University of Utrecht/University of Delft, The Netherlands)
Prof Kerrest de Rozavel (University of Brest, France)
Prof Verhoeven (University of Louvain, Belgium)
Prof Lyall (University of Aberdeen, United Kingdom)
Prof Zanghi (Scuola Superiore, Rome)
Prof Kessedjian (University of Dijon, France)
Dr Bourély (Former ESA Legal Advisor, France)
Prof Krige (ESA History Team, Firenze, Italy)
Dr Lafferranderie (ESA Legal Advisor, Paris)
Mr Doblas (ESA Contracts, Paris)
Mr Tuinder (Consultant, Paris, France)
Mr Thiebaut (ESA Legal Affairs, Paris)
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Mr Von der Dunk (University of Leiden, The Netherlands)
Ms Baudin (ESA Legal Affairs, Paris)
Ms Balsano (ESA Legal Affairs, Paris)
Dr de San Pio (Garrigues Abogados, Madrid, Spain)
Prof Malanczuk (University of Amsterdam, The Netherlands)
Ms Masson-Zwaan (International Institute of Space Law, Paris)
Prof Milde (McGill Institute of Air and Space Law, Montreal, Canada)
Mr Masson (Gras-Savoye, Paris)
Mr Fea (ESRIN, Italy)
Prof de Faraminan (University of Jaen, Spain)
Prof Linan (University of Granada, Spain)
Dr Catalano-Sgrosso (University of Rome, Italy)
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Prof Panella (University of Messina, Italy)
Mr Farand (ESA Legal Affairs, Paris)
Prof Ockels (ESTEC, The Netherlands)
Mr Esterle (Centre National d'Etudes Spatiales, France)
Mr Dordain (Directorate of Strategy, Planning and International Policy, ESA, Paris)
Prof Pocar (University of Rome)
Prof Spatafora (University of Rome).

The course itself is composed of two parts. In the first part, the basic principles of space law and the main treaties are introduced. The students acquire a solid knowledge of the core of space law, which contains the rules governing the use of the space environment. The institutional organisation of space activities is presented, with particular emphasis on ESA. A full day is devoted to ESA with presentations on the history of European space endeavours, a description of ESA and its industrial policy and relations with other organisations such as the EC, Eutelsat and Eumetsat.

In the second part of the course, students become familiar with issues encountered in space applications (e.g. satellite telecommunications, remote sensing and launch services). Specific lectures on liability, insurance, and intellectual property are given. Guest lecturers, who are usually practitioners, often speak to the students. They give the students an idea of the questions they are dealing with in their daily practice. Their presentations are very important as they demonstrate what the theory may be and what the practice is. They also help students to understand the practical side of what they are learning in the course.

To teach the students to manage a practical case, group work was introduced this year. The students were given a practical and somewhat futuristic case dealing with a mission to the Moon, in which many surprises were encountered creating a legal nightmare. Students were split into groups, each group representing a state or an organisation, and constituting a delegation that would participate in an international conference convened to agree on a settlement of all legal issues arising from the mission to the Moon. Under the direction of tutors and with the help of the professors, the students prepared their arguments and exchanged correspondence among delegations in preparation for the conference. The conference itself lasted two days, at the end of which concessions and compromises led to a reasonable settlement of the disputes. The minutes of the conference were taken and a final act was agreed upon and signed by the heads of the delegations.

Many benefits are gained from such role playing, and the exercise has proven to be a tremendous success. Students are very often not prepared enough by universities to face practical problems. The teaching in Europe is mostly theoretical and practical cases are often dealt with on an individual basis. Such an international conference proved to meet the needs of students, who need to put their theoretical knowledge at stake and enjoy the reality of the exchange of legal arguments in somewhat official surroundings. Thanks to the exceptional chairmanship of Professor Pocar, who is an expert on space law, a UNCOPUOS delegate, and an outstanding teacher, students learned not only about the principles they were arguing about, but about all procedural aspects of such a conference, including formulation of addresses to the Chair and other delegations, protocol, and drafting of legal texts and arguments. Such an exercise was rendered more interesting by the interplay between the various nationalities, legal backgrounds and educations that were involved.

A bright future for the Summer Course

The success of the ECSL Summer Course on Space Law and Policy goes far beyond the expectations of those who launched the idea. A solid programme has now been developed and the new group-work method has undoubtedly passed the 'qualification test'. Still, many improvements have yet to be made, but the foundations are strong and the viability of the course and the interest in it have been recognised by all those active in the field in Europe. A number of practitioners have expressed interest in attending the course and some have even attended sessions. However, it is not designed to provide space law education to practitioners and advanced students, although there is a need for it which is not always met in Europe. Eventually, the idea of setting up a specific session offering advanced courses, in parallel with the basic course, will be considered, but the consolidation of the achievements made in the latter are at present the priority.

The success of such a course is certainly a subject for reflection on the role of ESA in the field of space law. Through its daily activities, ECSL promotes ESA in Europe and around the world, and the success of the Centre's achievements undoubtedly help to consolidate the reputation of the Agency in academic and legal circles. The Summer Course plays an even more important role for ESA: it trains lawyers to be able to deal with the challenges of future space programmes. In the development and implementation of any kind of activity, legal issues that may arise from these activities should not be overlooked. In addition, when deciding upon major space programmes, ESA will have to pay increasing attention in the future to their legal framework and consequences because, not only space-law issues will be at stake, but also issues that will relate to other fields of law such as air law. For instance, besides the legal framework to be established for the Space Station, the resolution of issues relating to future air navigation systems will require important legal work and specific expertise.

With ESA's support, ECSL is making all efforts, especially in the framework of its Summer Course, to develop a training and education tailored to meet those specific needs, and to ensure that the space community will continue to benefit, in the future, from the contribution of young talented lawyers, able to support technological development and think for the future.

For more information on ECSL, its activities and the ECSL Summer Course on Space Law and Policy, contact:

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Engineering Costing Techniques in ESA

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It has always been important for organisations to be able to estimate and control their costs properly, but it is particularly so today. In the commercial domain there has been a marked tendency towards increased competition with international trade restrictions being reduced or removed and the question of competitiveness having to be considered on a global rather than simply on a local, national or regional scale. In the public domain also, consideration of cost is also assuming much greater importance with the tightening of budgets and changing budget priorities, together with the general expectation that there should be better value for money from public expenditure.

The importance of the cost-estimating function

In a competitive situation, if a company's estimate of its costs is unrealistically low then it may obtain an order but risks making a financial loss. On the other hand, if its cost estimates are too high, it is likely to be uncompetitive on price and to lose the order. Of course, strategic considerations also play a role and a company may quote a market price based on the knowledge of its estimated costs and its assessment of the highest price at which it can secure an order, which could be significantly higher or lower than its estimated costs.

Where customers can award contracts on the basis of real competition, they may feel reasonably comfortable about accepting contractor prices as quoted, with minimal negotiation, subject to other key parameters such as technical performance, delivery schedule and contract conditions being satisfactory. Nevertheless, in a developmental environment and in the case of technically sophisticated items, it is still important to have a good understanding of the make-up of the price, not least to be able to assess effectively the cost of technical and programmatic changes that may subsequently have to be introduced.

It would be unrealistic to assume that companies will necessarily have the same pricing policy irrespective of whether they are quoting in a highly competitive commercial market or to a national or international space agency on a direct-negotiation basis. In the latter situation, therefore, it is essential that customers have the ability to make their own independent assessment of what is a fair price for a given product and there also has to be some general notion of a basis on which to determine whether the price is reasonable and acceptable or not in the particular circumstances, apart from whether it can be accommodated within a particular budget.

In Annex I of the ESA General Clauses and Conditions of Contract, in the general context of cost accounting matters and specifically concerning the allowability of costs, it is stated that in order to be deemed allowable, costs must be: 'reasonable, and expedient in nature and not exceeding that expended by a prudent organisation in the conduct of competitive business'. For ESA, which places a significant number of contracts on a direct-negotiation basis, the above serves as a working guideline against which to assess the acceptability of the prices it is quoted.

In practice, the situation is often more complicated, there being the need for some calibration of the reference price to reflect the particular circumstances, such as the nomination of a relatively inexperienced contractor for a particular task (e.g. on the basis of geographical return).

Basic approaches to cost estimation

Stated simply, all estimating depends to a greater or lesser degree on past experience or knowledge. We can therefore repeat the adage of the Chinese philosopher, Confucius, who advised that you should 'study the past if you wish to predict the future'.

Broadly speaking, there are four main approaches to the process of cost estimation:

– The first is the **bottom-up or detailed estimate**, which is widely used by organisations to build up an estimate from task or work-package level. The number of hours needed for each category of labour, with its appropriate hourly rate, is assessed and a detailed assessment made of the non-labour resources required. This is the most time-consuming and costly approach, requiring a very detailed knowledge of the organisation. However, it is usually necessary for internal planning purposes and, not least, to enable the organisation to comply with customer requirements to present detailed cost estimates down to work-package level. Finally, this level of detail is also usually necessary for cost-control purposes after contract award. Such estimates are usually made by the engineers nominated to perform the work, often overseen by professional estimating services to check for consistency.

- The second method, which can be described as a 'rule of thumb' approach, also relies on the **expert judgement** of engineers familiar with the tasks being estimated. The experience accumulated by an engineer can constitute a large but 'unstructured' knowledge base from which to assess the resources needed for a specific task. This experience is then often translated into 'rules of thumb' which are applied by the engineer for a rough 'sizing' of costs. The creation of these 'rules of thumb' does not always follow a systematic process, but the technique is extensively used.

- The third estimating approach uses the principle of **analogy**. This process is similar to the sort of 'expert judgement' described above, but it relies extensively on the degree of similarity of the task to some existing or past task. It requires the collection of source information by the estimator for these analogous elements (usually stored in a computer database) and then comparison with the new task or item to be estimated. The effectiveness of this method depends heavily on an ability to identify correctly differences between the case in hand and those deemed to be comparable.

- The fourth general approach is a **statistical and parametrical method**. It involves not only the collection of historical cost and technical information, but also its analysis using mathematical techniques. The statistical method correlates costs and manpower information with 'parameters' describing the system to be costed. It results in sets of formulae, called 'cost-estimation relationships', which are obtained as a result of regression analysis and which can be applied to produce cost outputs for the different elements of an estimate. Such methods can involve considerable effort because of the systematic collection and revision process required to keep the cost-estimation formulae updated, but once this data is available estimates can be produced fairly rapidly. In addition, 'parametric models' that have been developed to facilitate this process are now available commercially.

The above approaches are applied in estimating the costs of engineering activities – including design, management, assembly, integration and verification, and product assurance – and the production of hardware. However, software development represents an increasing portion of the space-project effort, and often more than 50% of the total cost of new ground-segment development.

Estimation of the software development effort has always been among the most difficult of processes. Firstly, the abstract nature of software makes it a difficult product to characterise, and design changes are often introduced into software before, during and after its pure code-production phase. Secondly, there are often too few projects in process within a particular organisation to provide a good basis for estimating the cost of new developments. Lastly, software production has evolved in recent years from being more of a black art into an engineering discipline in which there is a very rapid evolution of techniques. This makes the process of basing new estimates on anything but fairly recent developments somewhat precarious. Consequently, the collection of software metrics is now viewed as the best basis for increasing software production efficiency by providing rational ways of measuring and estimating development costs. It also allows the application of statistical estimation.

The changing role of the cost estimator

In Europe, estimating practices differ widely, ranging from relying totally on the traditional bottom-up approach implemented by project personnel, to supplementing this in some cases by a wide range of other approaches applied by professional cost engineers/estimators.

Differences in the approaches adopted by different organisations are likely to increase in future because the process of cost estimating is developing so rapidly. This is partly through necessity as programmes become more complex, but also because the dramatic advances in computer technology and software are greatly facilitating both the gathering and analysis of data. A further factor is the changing circumstances of many organisations, which is tending to focus attention on cost cutting in general, and thereby on the cost-estimating process also.

Traditionally, the estimating of costs has been one of the last tasks in the process of proposal or programme budget preparation, with the estimates being based on detailed designs or plans. This is all very well, but if the final product of this approach is an unacceptably high cost estimate, time constraints may mean there is no possibility of repeating the exercise with an alternative, less costly design solution or programme approach. At this point, the organisation's only course is to impose an arbitrary percentage cut in the estimated costs, leaving the problem of any financial shortfall to be addressed later. Moreover, for large complex programmes leaving the estimating task to the end, when time is often pressing, invites errors and omissions, particularly in respect of technical and contractual interfaces.

It is therefore desirable to have the ability to estimate costs with a reasonable degree of confidence at an early stage in the process, based on preliminary/summary-type information. The cost implications of a particular design can then be considered and assessed at the outset, as well as progressively through the detailed design process. The design and estimating processes therefore become interactive, with the cost estimate being a vital input to the design solution adopted. This changes the nature of the cost-estimating function from being a purely passive activity to an active one that has a positive impact both on final cost and productivity.

Many organisations are now striving to increase quality/performance at the same time as reducing costs. Consequently, costs are being reduced not only as a result of rationalisation, but also as a result of looking critically at work practices and processes, as a result of encouraging closer teamwork, and from generally trying to create a culture of innovation and continuous improvement.

Activity-based costing is one way of trying to make a more accurate determination of the true time, cost and value of specific activities, and thereby evaluate their real contribution to meeting the overall objective. Some organisations are therefore starting to use this approach in formulating their cost estimates, rather than simply relying on the traditional cost-accounting elements. Through early involvement, the cost estimator can not only influence the final design by feeding in the relevant cost information, but can also actively contribute to cost reduction by identifying cost drivers and to highlight how, for instance, a relatively small increase in system performance can have a disproportionately heavy impact on final cost.

Cost estimation in ESA

There are a number of unique features of ESA and its multi-national operations which have a considerable bearing on its approach to the preparation of estimates and its analysis of costs:

- ESA has over 900 contractors in its 14 Member States and elsewhere, with whom it cooperates.
- In principle, there may be as many as 16 currencies involved for a particular programme.
- The Agency's Industrial Policy requirements can lead to: a high degree of fragmentation of the work; sometimes to non-optimal work allocation and interfaces; somewhat restricted competition; some duplication of developments; awarding of contracts to relatively inexperienced contractors for certain items and under certain circumstances; and political and technical uncertainties can give rise to a high degree of change in the formative stages of programmes when a lot of estimating activity is required.

There are then more general requirements or features which are likely to be common to the estimating functions in most organisations:

- It is desirable that the cost estimator be involved at the earliest possible stage in a programme in order to be well-informed of developments and receive information as soon as it becomes available.
- Estimates are often required quickly and sometimes with minimal inputs.
- There are limited available estimating resources to deal with conflicting priorities.
- Cost drivers and possible cost-reducing features should be identified.
- Risks need to be identified and assessed.
- Iterations of estimates may be required as the design evolves and more information becomes progressively available, thus facilitating the use of a wider range of available estimating tools.

- A comprehensive and well-documented estimating report will be required, including: estimates, explanation of methodology applied, details of technical and programmatic baseline, assumptions, qualifications, risk assessment, and 'pearls of wisdom' (additional comments and judgements).

Generally speaking, it is not practicable for ESA to apply the detailed bottom-up estimating method to programme estimates due both to the large numbers of contractors involved and to the many different possible permutations of sources of supply, each using different cost accounting systems, etc. However, as in other similar organisations, most engineers in ESA are involved to some degree in the cost-estimating and analysis process, through their participation in comparing competitive bids, with reference to earlier similar bids and based on a bottom-up-type approach using prior engineering experience. The latter is particularly useful when considering the cost impact of modifications, as the estimate will depend on a close knowledge of the circumstances and timing of the introduction of the change (including any abortive work already performed), the re-planning that may be necessary, as well as awareness of potential impacts on other parties in the contractual chain.

In addition, ESA has at its disposal the skills of the Cost Engineering Section within its Cost Analysis Division at ESTEC. Its principal functions are to:

- produce independent cost estimates for potential new programmes and in anticipation of industrial proposals to be submitted
- evaluate and analyse industrial cost proposals submitted
- provide support services to contracts officers and project-control services for the negotiation of prices.

The centralising of this function offers advantages in terms of the development and availability of 'estimating tools', in making available for the benefit of the whole organisation the data gathering from and analysis of projects from all Directorates, and by providing an experienced, expert task force to support project teams on cost-related matters in all the stages leading up to contract signature.

Furthermore, the Cost Engineering Section has the benefit of direct access to the cost-accounting expertise and records that reside in the Industrial Cost Auditing Section of the Cost Analysis Division.

The tools and methods used

The Cost Engineering Section at ESTEC makes use of the following tools and methods:

ECOS

ECOS – the ESA COsting Software – is a standardised software package developed for the Agency, which permits the submission of cost proposals to ESA on diskettes or via telecommunications links. Its use necessitates a homogeneity of approach at different contractual levels of a proposal for a particular programme and between different programmes. This has led to the adoption of a strictly product-oriented breakdown ('product tree') in conjunction with the traditional Work Breakdown Structure, which tends to be discipline- and organisation-oriented.

ECOS facilitates the preparation and presentation of major proposals, permitting computerised tender integration at each contractual level. It allows analysis of those proposals by higher-level contractors and by the Agency, there being the capability to sort the information in various ways and to generate special reports and graphical presentations. Last but not least, ECOS facilitates the establishment of a cost database containing details of all of these electronically submitted proposals for future reference.

In estimating terms, ECOS's contribution is to automate repetitive processes, to introduce a standardised approach to task breakdown, and to permit the collection of technical and programmatic details to complement the cost details provided. This latter point is important because cost estimates should also be well-documented and, in particular, related to specific technical and programmatic baselines. This point may seem self-evident but, in an environment in which time pressures are a permanent feature, this approach is sometimes not pursued.

A further feature of the ESA procurement process for major programmes, particularly those on a direct negotiation basis, is the need, for various reasons, for a number of iterations in the proposals, often against a changed technical/programmatic baseline. In these circumstances, without well-documented estimates it may be difficult by say the third iteration of the estimate to recall the exact basis used for the first one and to follow the overall evolution of the estimate.

The ECOS package itself was more fully described in an earlier Bulletin article, in May 1993.

Analogy

The analogy method relies on the availability of a database as a reference for future estimates. The implementation of ECOS, and as a result of previous estimating exercises, the Cost Engineering Section has at its disposal an extensive, well-classified and well-documented database covering projects from all ESA Directorates. Its main value lies in the fact that, even for the apparently most innovative programmes, there is usually considerable utilisation of existing designs and technology. At equipment level in particular, items are frequently re-used for projects in different ESA Directorates.

Thus, whilst the Agency does not generally use a bottom-up approach from the work-package level, it does use it at unit and equipment level. Considerable efforts are therefore made to identify such items of equipment and to relate them back to experience acquired with previous proposals, with due regard for present development status and the degree of modification necessary, which implies an element of new development.

Parametric models

For many years, the Agency has used a commercial parametric cost model, called PCM. It has the advantage of being able to run with relatively few inputs. More recently, the Agency has also started to use another commercial model called PRICE (H), following the introduction of a new PC-based version.

Together with the analogy approach, parametric modelling is one of the most commonly used estimating methods within the Cost Engineering Section at ESTEC.

Software projects history database

In 1988, the Cost Engineering Section initiated a continuous cycle of gathering completed software-project development information from many European software producers and promulgating it to all participating companies. This process is now carried out in collaboration with the INSEAD international business school in Fontainebleau, (F)*.

ESA has also participated in a four-year development effort on a software cost-estimation system known as 'Mermaid', funded by the European Commission. It has resulted in a commercial estimating tool based on the application of algorithms to the metrics of past projects stored in a dedicated database. The Cost Engineering Section is making use of this database when preparing cost estimates for new ESA projects. The database is also regularly distributed to companies actively participating in the data collection.

ECOM: an integrated cost-estimating tool

Each cost-estimating approach has its own particular advantages or limitations in a specific situation. For instance, the development status and previous prices for frequently used items of equipment from qualified suppliers will be well-known. However, the cost of singular, atypical spacecraft elements can only be assessed in an approximate way by comparison with other comparable systems. The Cost Engineering Section therefore started to look for a more efficient means of building up a programme estimate using a mixture of cost-estimating techniques for the various elements of a space system and a system was conceived to optimise the use of the basic historical information held by the Agency and of the individual estimating tools available. This system is the ESA Costing Model, or ECOM.

ECOM, which is modular in structure, consists of (Fig. 1):

- An ECOS-derived database, drawn from previous proposals and costs incurred, and a database of previous estimates.
- A knowledge base of Cost-Estimating Relationships (CERS) derived from analysis by the Agency of previous proposals and of parametric input precalculations for each type of spacecraft equipment and sub-system costs.
- A database interrogation module.
- An escalation module to automatically convert different cost elements to the same economic conditions (exchange rates and inflation).
- A risk-analysis module, based on ESA statistical analyses and also using commercially available software.
- Proprietary parametric models.

ECOM therefore allows the combination in a single estimating calculation of any of the cost-prediction methods appropriate for particular elements of the space system being evaluated. Different design options can therefore be rapidly costed and documented in an unambiguous form, thereby allowing good reproducibility and traceability of results.

The system also records the technical and programmatic baseline details, as well as the

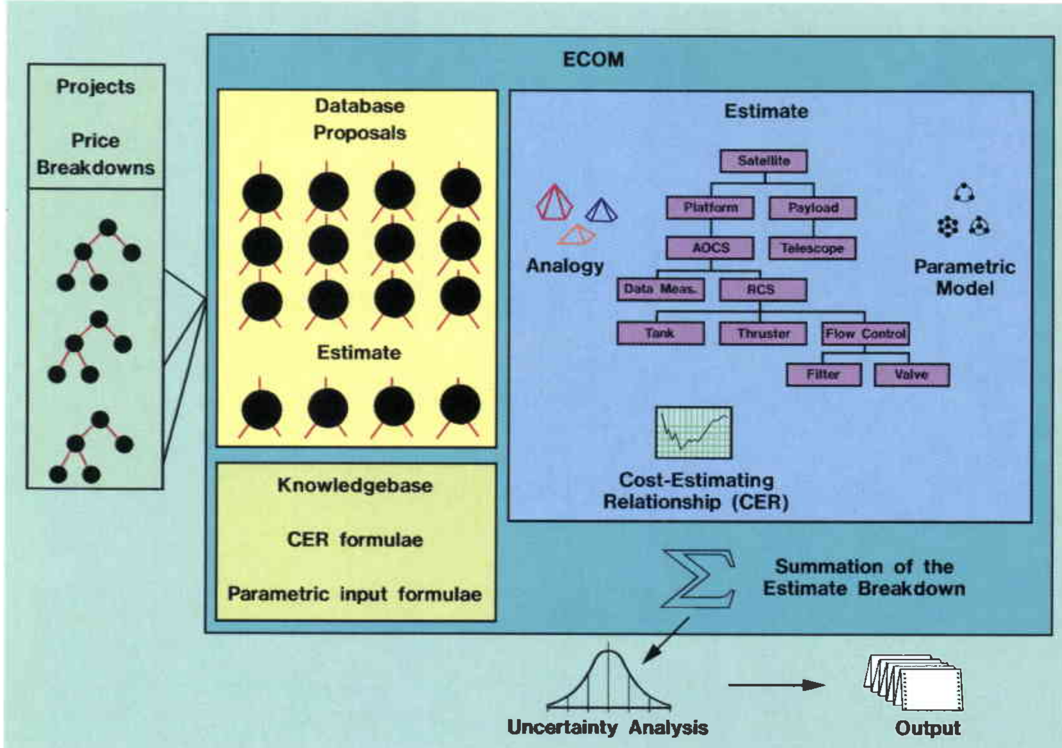
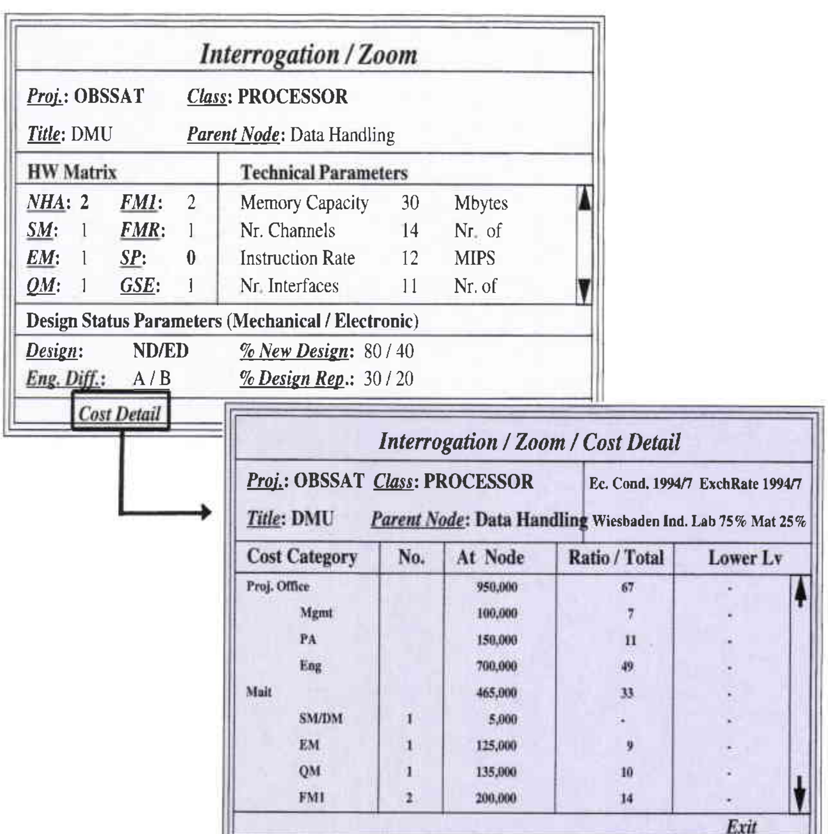


Figure 1. The modular structured ESA Costing Model (ECOM)

method by which the inputs for the estimating techniques have been deduced. The price indices issued independently by the Wiesbaden Institute for the Agency's budgetary updating are also incorporated. There is also an extensive satellite-component price/technical performance database included, which can display prices for any economic conditions, using the appropriate currency exchange rates to compare prices from different sources/countries.

The present ECOM development programme will be completed this year and, inkeeping with the Agency's general objectives of promoting Europe's space technology and industrial capabilities, the Agency will then consider making ECOM available to other companies and organisations that could benefit from its application.

Figure 2. Sample interrogation of the ECOM database



Interrogation / Zoom

Proj.: OBSSAT Class: PROCESSOR
Title: DMU Parent Node: Data Handling

HW Matrix				Technical Parameters		
NHA:	2	FMI:	2	Memory Capacity	30	Mbytes
SM:	1	FMR:	1	Nr. Channels	14	Nr. of
EM:	1	SP:	0	Instruction Rate	12	MIPS
QM:	1	GSE:	1	Nr. Interfaces	11	Nr. of

Design Status Parameters (Mechanical / Electronic)
Design: ND/ED % New Design: 80 / 40
Eng. Diff.: A / B % Design Rep.: 30 / 20

Cost Detail

Interrogation / Zoom / Cost Detail

Proj.: OBSSAT Class: PROCESSOR Ec. Cond. 1994/7 ExchRate 1994/7
Title: DMU Parent Node: Data Handling Wiesbaden Ind. Lab 75% Mat 25%

Cost Category	No.	At Node	Ratio / Total	Lower Lv
Proj. Office		950,000	67	-
Mgmt		100,000	7	-
PA		150,000	11	-
Eng		700,000	49	-
Mait		465,000	33	-
SM/DM	1	5,000	-	-
EM	1	125,000	9	-
QM	1	135,000	10	-
FM1	2	200,000	14	-

Exit

The way ahead

As noted at the outset, the space/aerospace cost-estimating process is evolving extremely rapidly. The international nature of ESA and its programmes means that there are particular challenges in estimating the costs of its projects, the largest of which involve many contractors and subcontractors widely scattered geographically throughout the Agency's Member States. ECOM constitutes a significant advance in terms of ESA's cost-estimating, and therefore cost-constraining capabilities. In addition, its modular structure will facilitate future enhancements to take full advantage of new ideas and emerging technologies.

A Photogrammetry System for Use in Thermal Vacuum Testing

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The study of shape deformations in large spacecraft structures such as the antennas of communication satellites and large space reflectors, is essential in the design of any space system. Thus, there is a great interest in accurately characterising the performance of the structures under operational conditions. A photogrammetry system can accurately monitor the structural deformation of these large objects under sun-induced thermal stress in space conditions. To do this, a large number of targets are affixed to the object under study and their motion is followed with a number of very high-precision optical photogrammetry cameras. An important feature of photogrammetry is that the measurements can be made remotely, i.e. without any physical contact with the specimen. The design and performance characteristics of a photogrammetry camera system, accommodated in canisters, to be used under space environmental conditions, are described here.

Introduction
The ESA Test Centre, located at ESTEC in The Netherlands, is equipped with a series of environmental test facilities that allow a complete test campaign to be executed on the ESTEC site. Mechanical, electrical and thermal tests can be performed in sequence. A key element of the ESA Test Centre is the Large Space Simulator (LSS) which enables the performance of a variety of tests under vacuum, such as solar simulation, temperature cycling tests and deformation measurements.

The main features of the LSS test facility are:
- The dimensions of the main chamber enable it to house spacecraft of the full Ariane-4 class.
- The high-vacuum system maintains an operating pressure in the 10^{-7} mbar range.
- The inner surfaces of the chamber are covered with shrouds, cooled by liquid nitrogen to simulate the cold background in space, or operated with gaseous nitrogen for thermal cycling.
- The sun simulator provides a parallel horizontal beam with a diameter of 6 m.
- The motion and attitude of the spacecraft relative to the sun can be simulated by means of a two-axis motion simulator.

Feasibility study undertaken
Close-range photogrammetry is being used more and more in various applications such as aircraft manufacturing and surveying of telescopes, but it is being done in the open air. ESA has carried out a feasibility study to evaluate the use of a photogrammetry system in a vacuum, in the LSS. Such a system can provide a powerful tool for monitoring the structural deformations of large objects under sun-induced thermal stress and simulated space environmental conditions.

Photogrammetry can also be used to measure dimensions to verify compliance with design specifications (e.g. for deployable or inflatable objects). The selection of an adequate camera system is determined by the high accuracy requirement of one part in 10^5 of the diameter of the object to be tested. This demanding accuracy stems from the surface accuracy requirements for antenna reflectors..

The conclusions of the feasibility study are:
- It is possible to perform measurements with an accuracy of better than 50 µm with a configuration of four cameras.
- Simulation results show that medium-size cameras with an image frame of 94 x 126 mm² and high-precision mono-comparators will meet the requirements.

The essential advantages of a photogrammetric measurement, compared for instance with a theodolite measurement system, are:
- Large numbers of object points can be recorded simultaneously, resulting in rapid data acquisition.

— The use of two or more cameras allows dynamic changes to be acquired.

Installing and operating cameras inside the LSS vacuum chamber, however, leads to basic requirements such as:

— The cameras must be housed in thermally controlled, vacuum-proof canisters.
— All functions must be controlled remotely.
— The cameras must be accessible for film recovery or exchange after the test.
— The cameras must in no way interfere with the LSS's performance.

Development of a prototype camera/canister

Based on the results of the feasibility study, ESTEC decided to procure and evaluate a photogrammetry camera and to develop a vacuum-proof canister to enclose the camera as a protection against the harsh environmental conditions present in the LSS during a testing operation. The camera model chosen is the Rollei R-Metrika.

Basics of photogrammetry

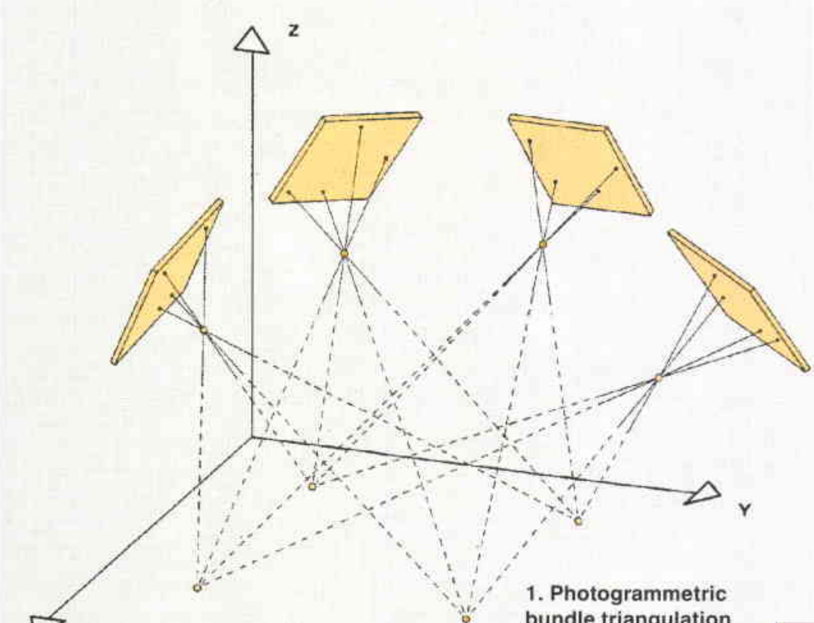
The photogrammetric measuring process involves three essential phases:

— Data acquisition, i.e. photography of the object
— Image coordinate measurement
— Image processing.

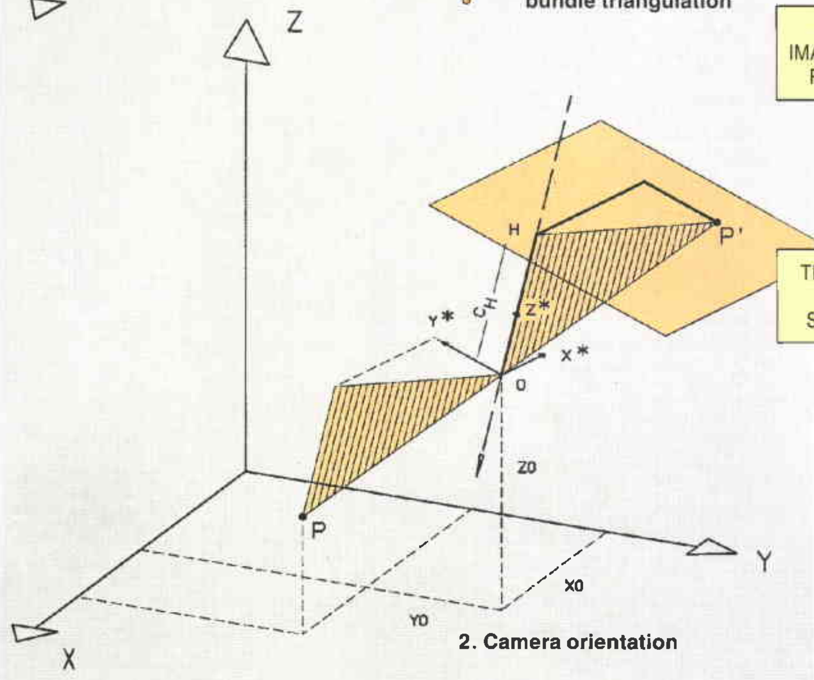
Photographs of a targeted object are taken with one or more cameras from several directions. The photographic images of the object target array represent perspective projections of the three-dimensional scene onto a two-dimensional plane. The image coordinates (xy) of the targets in turn are used to reconstruct the coordinates of the marked points in object space (XYZ). The photogrammetric bundle triangulation is illustrated in Figure 1.

As shown in Figure 2, object point P is projected via the perspective centre O (camera lens) onto the image plane (P'). The position of the perspective centre O is defined in image space by the perpendicular distance c_k between O and the image plane, the principal distance, and by the principal point H, where

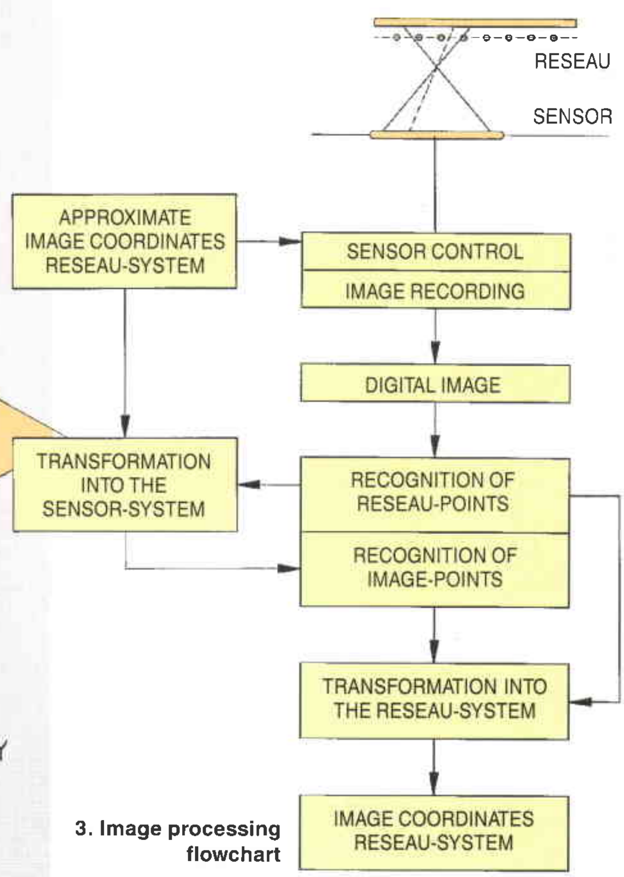
Figures 1, 2 and 3. Basics of photogrammetry



1. Photogrammetric bundle triangulation



2. Camera orientation



3. Image processing flowchart

the camera axis meets the image plane. The position of the perspective centre O in image space, identified by c_k and H, is called the interior orientation of the camera. The location of the perspective centre in object space and the orientation of the axes of image space with respect to those of object space define the exterior orientation of the photogrammetric camera.

The unknown object coordinates as well as the orientation parameters of the images are determined by least square adjustment, so that the bundles built by the object points and the perspective centres intersect with the measured image points in the best possible way. By treating the image space parameters as unknown, the recording cameras can be calibrated simultaneously. The accuracy and reliability of the triangulation process is greatly influenced by the number of photographs on which a target point is imaged. The configuration of camera stations, i.e. the photogrammetric network, is of even greater importance.

After the object has been photographed, the coordinates of the image points on the film are measured by means of an automatic film-reseau scanning process. A CCD-array sensor is used for digital automatic measurement of the image coordinates. The reseau grid is also measured to serve as a reference for the image coordinates (Fig. 3).

The digital image is stored in a real-time image processor board in the microcomputer. Using modern image-processing methods, the accuracy of each measuring point and reseau cross is better than 1 µm.

Design requirements

The design requirements for the photogrammetry system can be summarised as follows:

- The measuring accuracy must be in the range of 20 – 50 µm relative to tests objects with a diameter of up to 6 m.
- The camera/canister system must operate under simulated space environmental conditions, i.e.:
  - high vacuum
  - temperature range of 100 – 373K
  - eclipse or solar simulation.
- The system may not degrade either the LSS performance or its environment.
- The canister and its window must not degrade the performance of the camera.
- The camera system and accessories, such as the flash, view-finder, and drive system, must be remotely controlled.
- The system must comply with the ESA Product Assurance and Safety requirements.
- The camera must be accessible for film recovery or exchange after the test.

The overall concept of the camera system installed in the LSS is shown in Figure 4.

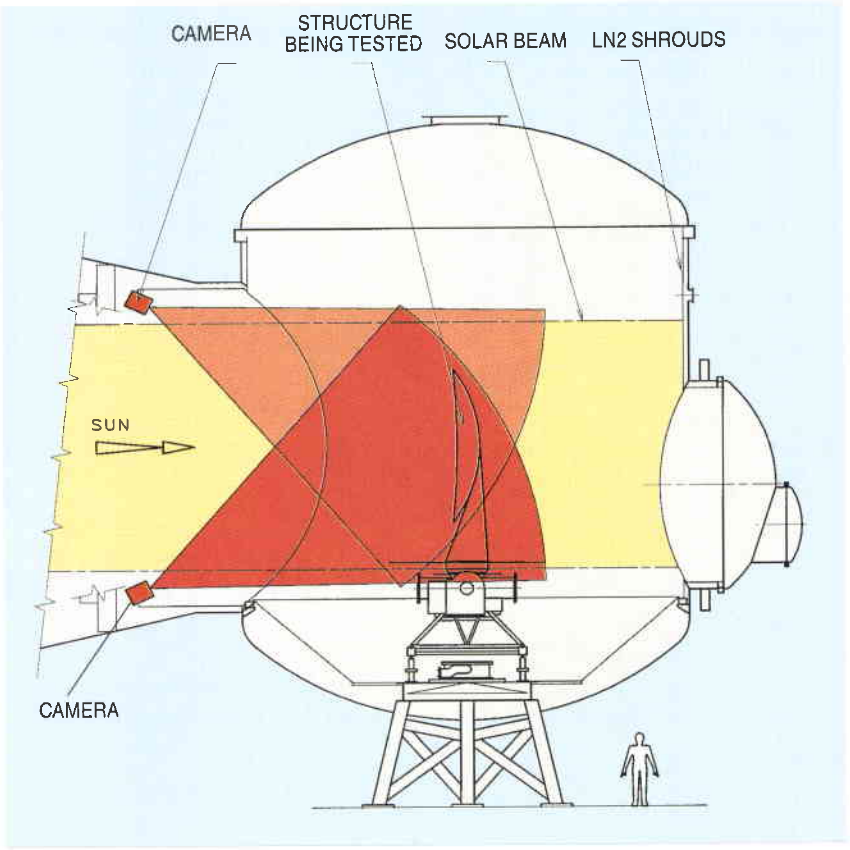


Figure 4. Camera system in the Large Space Simulator (LSS)

Functional system description

An overview of the photogrammetry system is given in Figure 5.

The camera-canister system consists of the following subsystems:

- Camera system
- Canister
- Drive assembly
- Thermal control
- Control console.

Camera system

The camera system is the combination of the camera body, its lens, a CCD viewfinder and the electronic control unit. The camera features a vacuum pull-down system for flattening the film on a high-density cross reseau grid. The reseau grid is imaged on the film and permits the correction of any film 'unflatness' and possible shrinkage (during development), a crucial step for precise measurements.

An annular flash is placed around the free end of the lens. The flash is powered from the outside. Its ignition circuit receives the

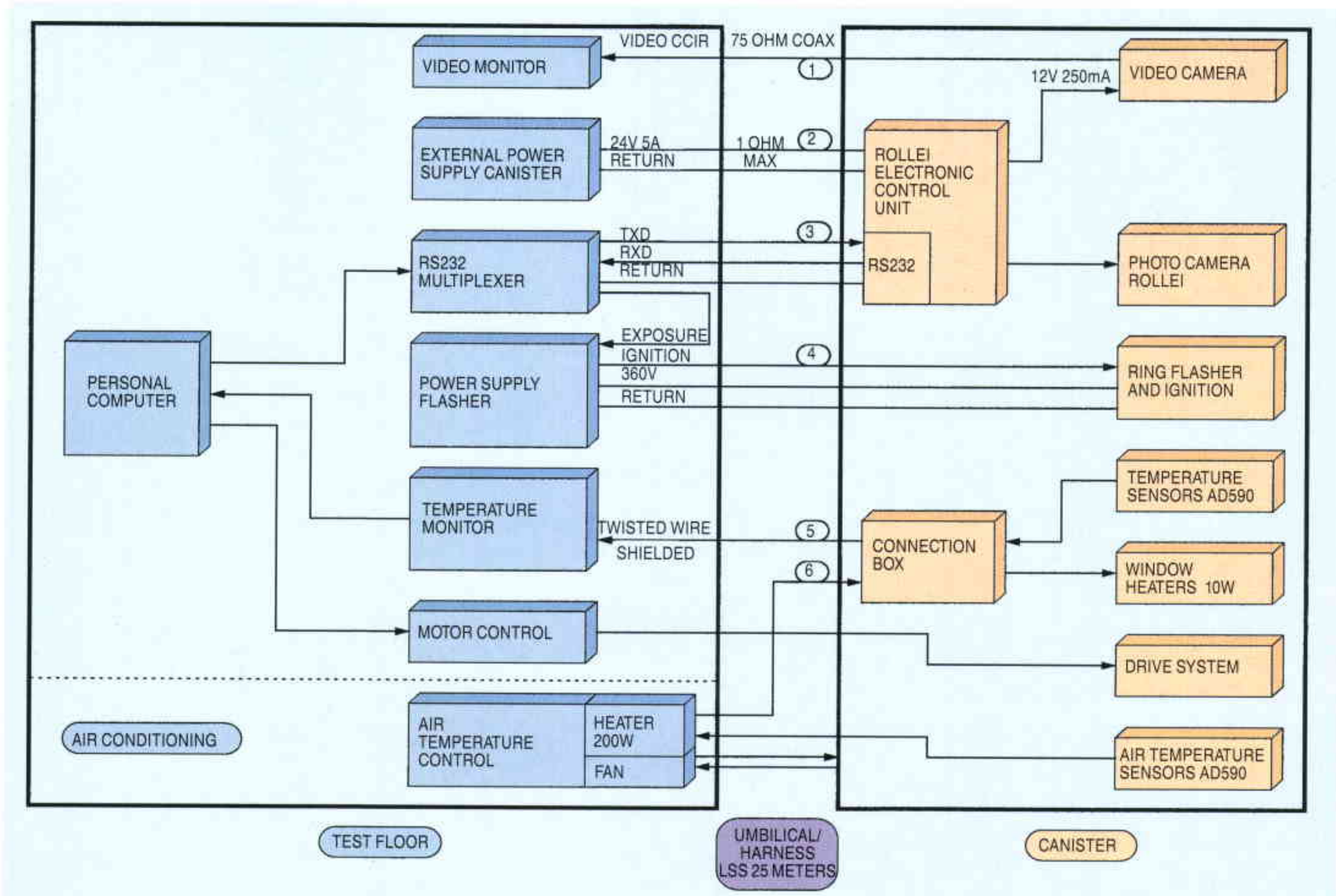


Figure 5. Functional system diagram of the photogrammetry system

command to fire via a dedicated line. The viewfinder, a small CCD television camera, is directly above the camera.

The electronic camera control box is attached to the canister's inner wall. Accessed from the outside via an RS232 link, this box controls the camera, for example, it takes a picture, advances the film, and sets the reseau exposure level. When interrogated, it relays back information on the camera's general status, such as the current shutter speed and the reseau exposure level.

Canister

The canister is a vacuum-proof aluminium cylinder protecting the camera against the harsh environmental conditions present in the LSS during a test (Fig. 6). The main window assembly consists of two different quartz sections joined together using an optically opaque glue, to avoid any light reflections from reaching the lens when the flash is operated. The main window is held in place by two O-ring seals. The seals mechanically detach the window from the canister's front flange, accommodating any differential expansion or contraction between the quartz and the aluminium. The viewfinder window is built using a single quartz element.

All arriving electrical wires and air tubes enter the canister via the rotary feed-through located on the rear flange.

Drive assembly

The canister's roll-drive is governed by a stepper motor, located in its vacuum-proof housing, with warm air arriving through an umbilical tube.

The motor assembly consists of a gear reduction box, a temperature sensor, a brake, two limit switches, two emergency limit switches and two arresting bolts. A drive chain connects mechanically the roll motor to the canister. When the motor is powered up, its brake is disengaged via a solenoid. Once the motor has reached the desired position, its power is cut off with the break re-engaging automatically.

Emergency switches prevent the motor from moving any further when, due to a software failure, either of the final positions is overridden. Arresting bolts provide additional redundancy in case the emergency limit switches fail.

Thermal control

The need for temperature stability of the camera and its film drives the design of the air-conditioning unit: the temperature at the camera body must remain constant, at close to 30°C. Furthermore, the air-conditioning system should ensure that no water condenses on either the lens or the window. An air-conditioning unit, located outside the LSS, monitors the air temperature at the canister's inlet and adjusts accordingly the flux, humidity and temperature of the supplied input airstream. An enclosure surrounds the camera; its purpose is to improve the heat removal properties of the airflow and to ensure the temperature stability of the camera.

In order to avoid further condensation problems, both windows can be warmed using independent annular window heater sets. A dedicated control unit, located in the central control console, can command the window heaters to turn on. Temperature sensors are affixed to key items in the canister. Two are attached to each of the window's borders and one is located at the air inlet to monitor the temperature of the incoming airstream.

Control console

In addition to the air-conditioning unit, the following equipment is located outside the LSS:

- A video monitor for displaying the images obtained by the viewfinder
- The power supply for the camera control unit
- The flash power supply
- An RS232 multiplexer
- A temperature monitor
- A motor controller
- A personal computer.

All these elements are integrated in the control console. Commands can be sent from the computer to the roll-drive motor via the motor controller. The computer calculates the angular positions of the canister by counting the number of steps the motor has moved away from the last end position. The computer has access also to all the temperature sensors through the temperature monitor.

Through the RS232 multiplexer, the computer is able to address the camera's control unit to give commands or request information about the camera. It is also able to assure a correct synchronisation between the exposure and the flash.

Design approach and rationale

In view of the relative complexity of the system and the interfaces with the LSS, it was decided to design a prototype of the canister and use it as a development model. The preliminary design requirements were drafted in close liaison with ESTEC's Test Operations Section,

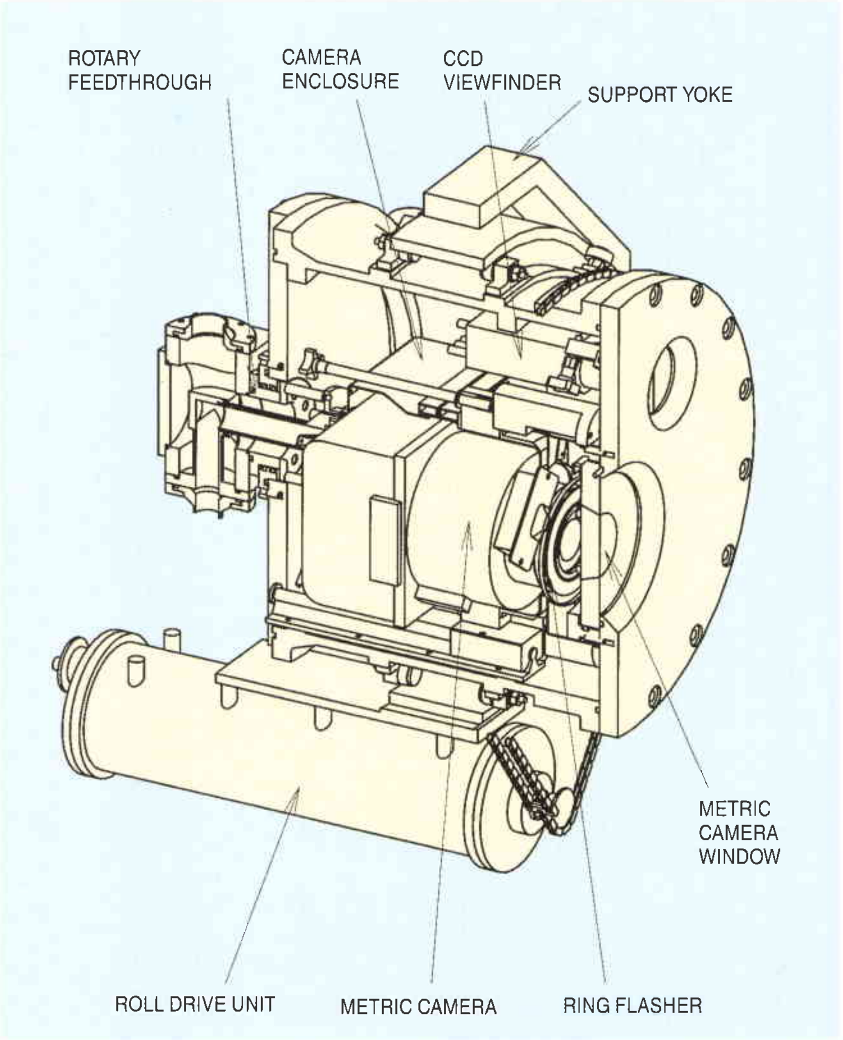
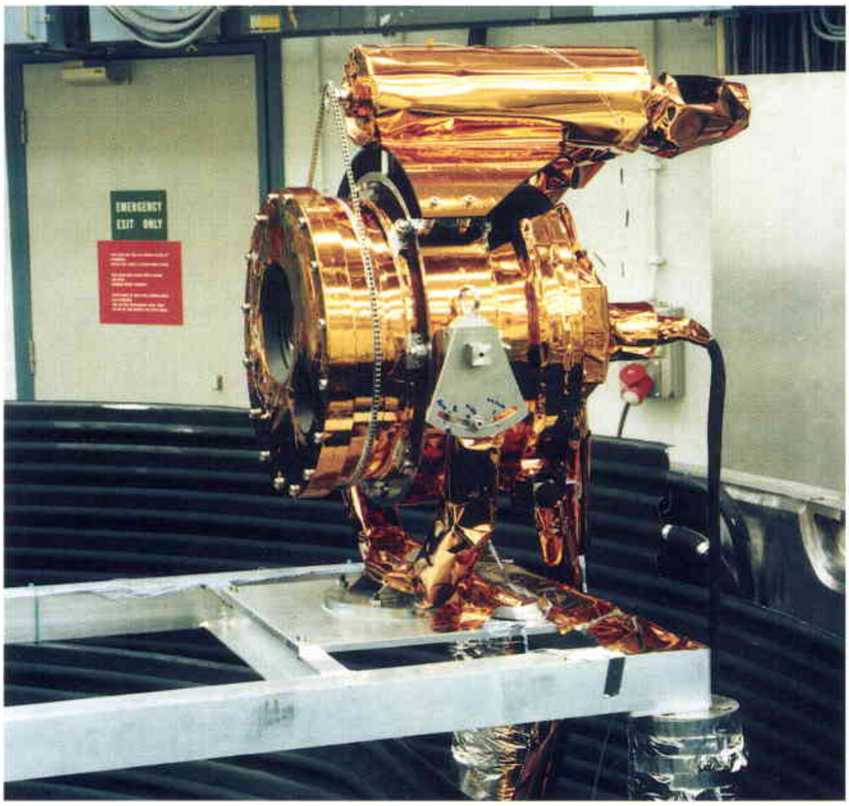


Figure 6a. Camera canister assembly

Figure 6b. Camera canister assembly in HBF3



which is responsible for operating the LSS and the camera.

The camera was developed by the Engineering Section of ESTEC's Testing Division, in close liaison with Rollei and ESTEC experts in various specialised fields, such as optics, thermal control, safety and reliability. During the design process, various aspects had to be analysed. In the following, some significant topics are highlighted.

Camera window
One of the most critical elements of the canister is the camera window. In order to minimise the distortion, quartz glass of the Homosil type was chosen. An overall analysis of the window has shown that the thermal gradients in the window and the pressure gradient of 1 bar has no notable degrading effects on the image quality.

Thermal control system
Because of the stringent requirements with respect to temperature stability and humidity inside the canister, a detailed design analysis of the Thermal Control System (TCS) has been carried out. It has shown that the TCS with an open air-loop will guarantee the required camera environment.

The main features of the TCS are:
— A camera enclosure through which the air coming from the test floor enters the canister volume at a constant temperature ($T = T_{amb}$).
— An ambient temperature, T_{amb}, of 30°C.
— Insulation of the canister with Mylar insulation constructed to assure a good solidity to manual operations.
— Heaters around the window to keep its edge at a stable temperature.
— A parallel air-loop travelling along the windows to minimise the temperature variations during transience.

In this concept, the requirement of the temperature stability will be fulfilled in the camera enclosure only.

Safety and reliability aspects
Failure Mode Effect and Criticality Analysis (FMECA) and hazard analyses are currently being carried out. Some remarks, however, can already be made.

Safety aspects
From a safety point of view, the quartz window is one of the most critical elements. A pressure gradient of 1 bar across the window in the high vacuum conditions of the LSS constitutes a hazardous situation. Failure of the window under these circumstances could have catastrophic results. Therefore, preventive measures have been taken to minimise the hazard:

— The fastening of the window has been properly designed.
— Clear assembly instructions have been prepared to avoid damage to the window during assembly.
— Quality control of the window proper has been carried out.

Secondly, in case of window failure, the consequential damage is minimised by means of an automatic closure of the air supply and outlet. Furthermore, prior to any operation of the canisters in vacuum, a leak test on the canister will be a basic checkpoint in the operation procedures.

Reliability aspects
Wherever possible, 'off the shelf' equipment of proven reliability has been chosen in order to achieve an optimum reliability in a cost effective way. The air-conditioning unit will supply all four canisters and ensure the thermal control of the cameras. From a system point of view, this sub-system constitutes a single point failure, which may result in a failure of the test session. Therefore redundancies in the air-conditioning system will be implemented.

Test programme
In order to ensure the proper functioning of the camera/canister system, a test programme has been implemented, comprising a calibration in ambient, a functional test in thermal vacuum and a test of the overall performance in the LSS.

Calibration
The calibration of the camera/canister in ambient was successfully implemented by means of a calibration reference object, provided by the German National Standards Laboratory (PTB).

Functional test under thermal vacuum conditions
The purpose of this test was to verify the proper functioning of the complete photogrammetry system under thermal vacuum conditions. In particular, the thermal control system had to be tested. The main objective of the thermal control system is to maintain an environment in the canister such that the temperature level of the canister ambient lies between 0°C and 40°C and that the temperature shift is less than 1°C per hour. Moreover, there should be no condensation on any surface inside the canister.

The test has shown that the photogrammetry system meets all its design specifications and is able to work properly under thermal vacuum conditions. Temperature and humidity were monitored in some 17 locations. As an example, Figure 7 shows the temperature fluctuations of four relevant locations on the camera body. In particular, sensors T3 and T10 are located in the area of the reseau plate and T2 on the film container. All temperatures stay within the range of 29 – 33°C. The temperature variations in time comply with the requirement of $\Delta T < 1°C$ per hour.

Verification of measuring performance under thermal vacuum in LSS

The purpose of this test was to verify the measuring performance of the photogrammetry system under thermal vacuum conditions. In particular, the overall measuring accuracy had to be verified.

Since only one camera/canister is available, a photogrammetric network with several cameras had to be simulated by rotation of $\pm 30°$ of the test structure around its vertical axis. The test structure is made of CFRP rods and is a flat, quadratic grid truss measuring 3 m x 3 m. The structure, which has a high specific stiffness and a very small thermal expansion co-efficient ($a < 0.2 \times 10^{-6}$mm °C), was mounted on a turntable inside the LSS (Fig. 8).

The test has shown that no significant distortions occurred in the quartz window, due to the pressure difference of 1 bar, as the effect of the distortions is below the measurement accuracy of the system. The RMS standard deviation of the object coordinates of all measurements is better than 50 µm.

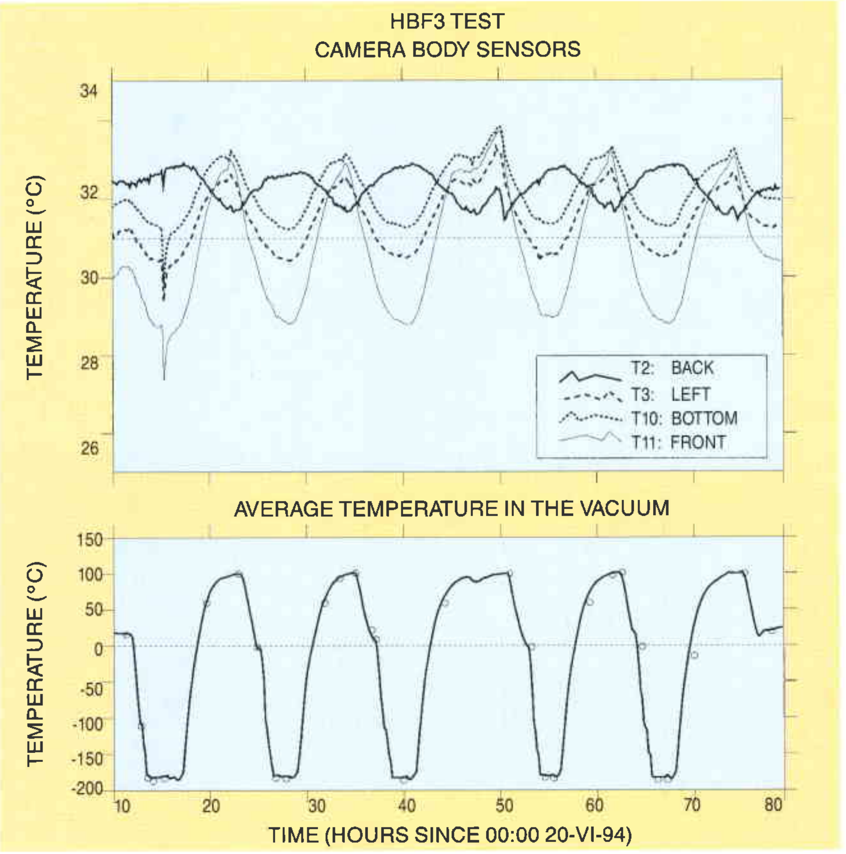


Figure 7. Temperature fluctuations at four locations on the camera body (top) and of the thermal vacuum environment (bottom)

Deformation measurement of Artemis' antenna reflector

After the successful verification measurements in the LSS, a thermal distortion measurement

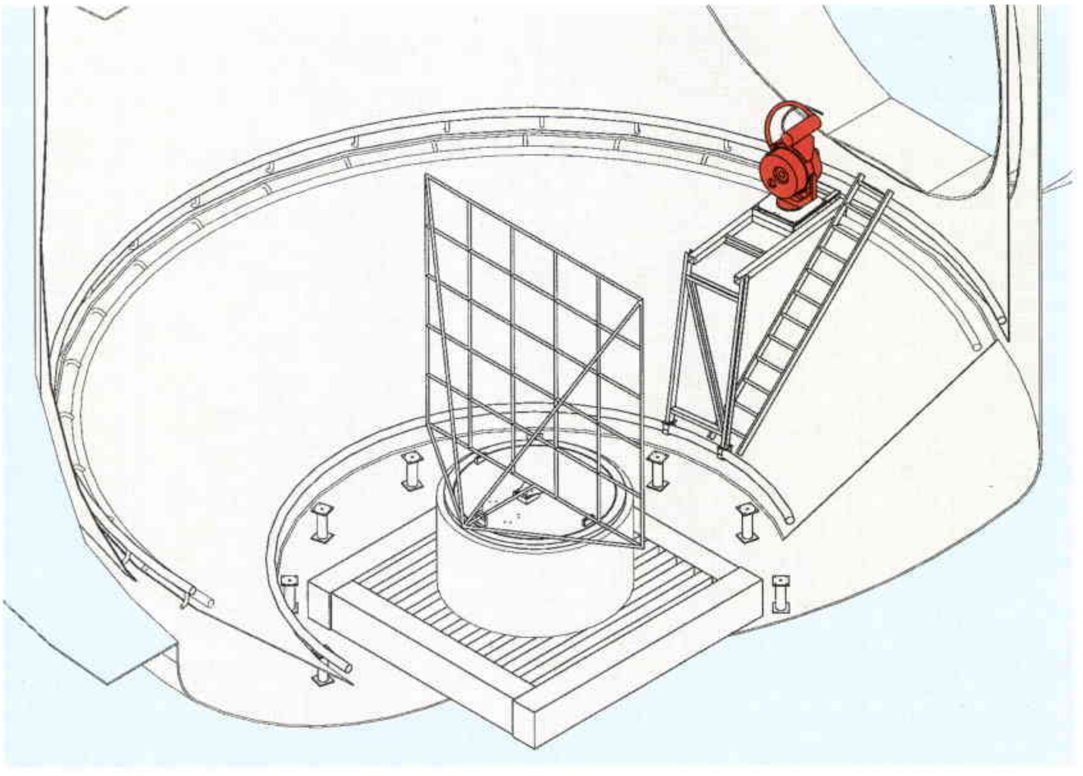


Figure 8. Test set-up to verify the photogrammetry system's measuring performance in a thermal vacuum

under vacuum was carried out for the EM-model of the Artemis Common Large Reflector Dish, designed and manufactured by CASA. Some 300 retro-reflective targets were fixed on the Dish, which has a size of 3.3 x 2.8 m (Fig. 9). During the test, the dish was rotated around its vertical axis ± 30° on the rotary table in the LSS. All planned photos were taken with the dish in three different rotated positions. The measuring accuracies obtained (RMS standard deviation) were 20 μm in the plane of the reflector and 45 μm perpendicular to it.

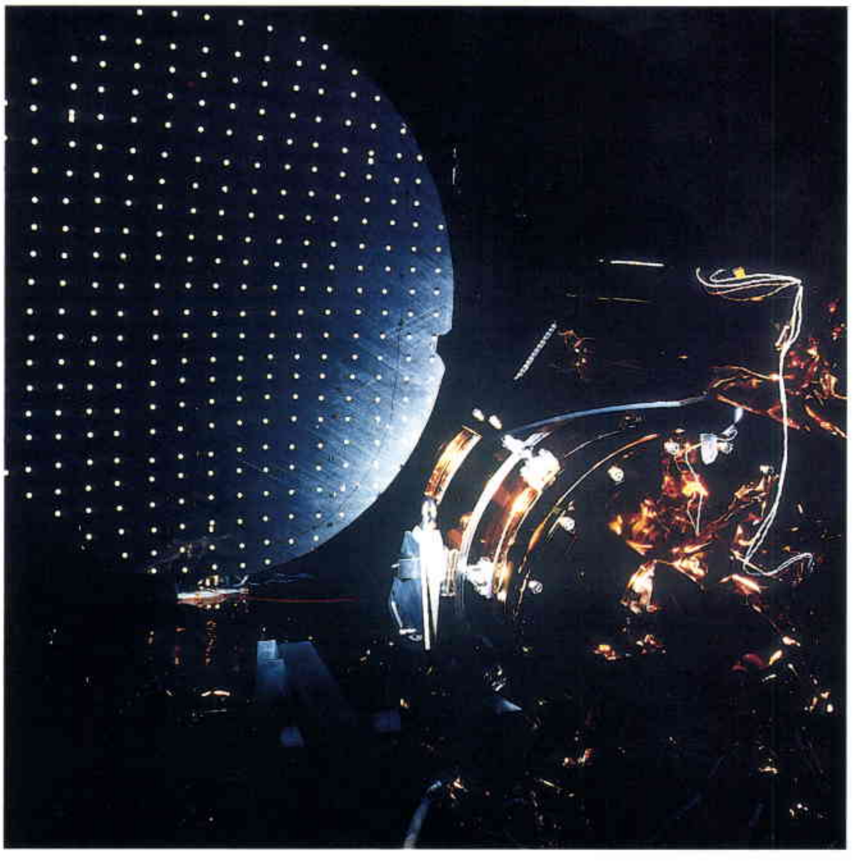


Figure 9. Artemis antenna reflector (left) during testing in the LSS

The performance tests in the LSS have shown that the photogrammetry system meets its design specifications well in thermal vacuum. With RMS standard deviations on average better than 40 μm in the direction of the optical axis and better than 30 μm perpendicular to it, high-precision deformation measurements in a thermal vacuum are possible. By carrying out photogrammetric network simulation for the actual object, even better accuracies can be achieved, which was proven using the Artemis reflector.

Measuring facilities at ESTEC

Single-camera system

At present, with a single-camera configuration, measurements can be performed by rotating the test object around its vertical axis to obtain the different recording directions. The performance tests in the LSS have shown that such a single-camera system achieves sufficiently accurate results, in the order of one part in 10^5, to meet the requirements for the deformation measurements of communication spacecraft antennae.

The single-camera system can be used in the LSS for large objects (Fig. 8) as well as in the smaller vacuum facility, HBF3 (Fig. 6b) to test objects measuring up to 3.5 metres.

The prototype camera/canister is being upgraded to a fully operational system, which will be ready for use in both facilities by the spring of 1995.

Multi-camera system

In order to achieve even greater precision and to be able to perform deformation measurements during solar simulations, it is planned to install a multi-camera system in the LSS. Once such a system is in place, it will also be possible to monitor structural deformations of large spacecraft structures under thermal stress in space conditions.

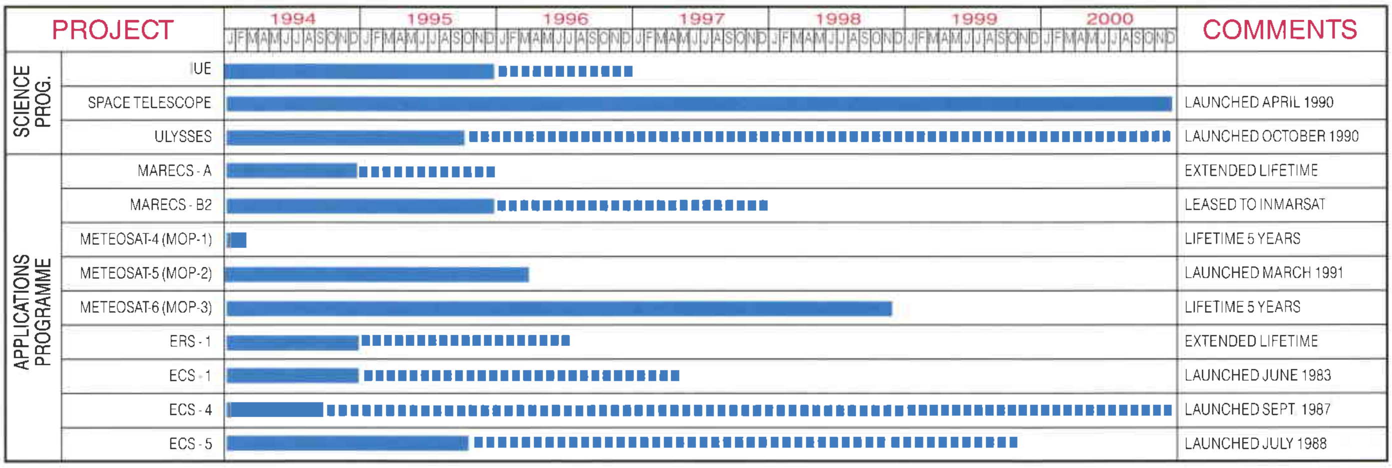
Conclusion

A prototype canister system has been developed and built for a Rollei photogrammetry camera to be used in thermal vacuum. Functional and performance tests of the system have shown that the camera/canister system meets all of its requirements. The tests have shown that accuracies of on average better than 30 μm can be achieved for an object with a diameter of 3 m. By carrying out a simulation of the actual object prior to the test, the photogrammetric network can be optimised and even better accuracies can be achieved, as was proven with the Artemis reflector.

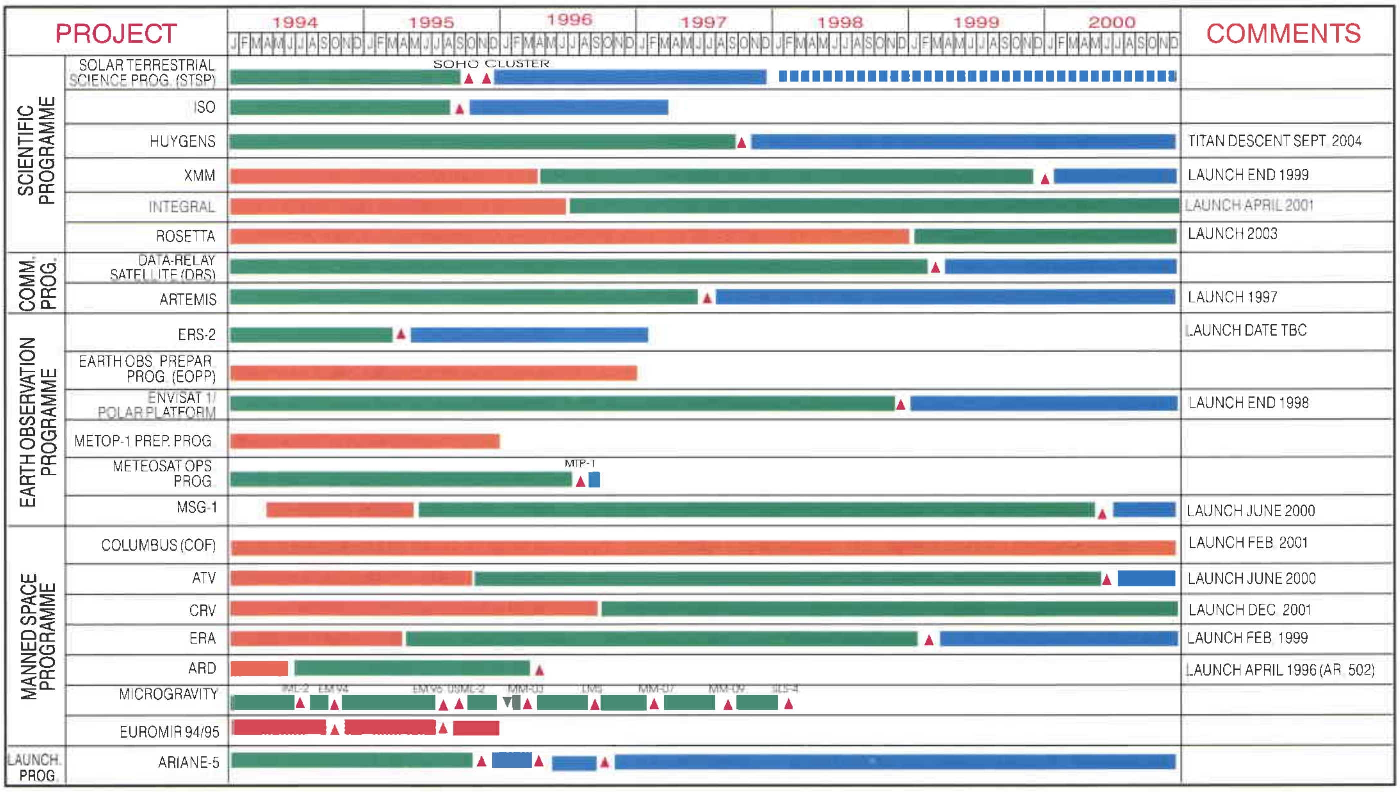
At present, with a single-camera configuration, high-precision distortion measurements in a thermal vacuum can be performed by rotating the object around its vertical axis. The camera system can be used in both ESTEC's Large Space Simulator and in the medium-size HBF3 vacuum facility. Once a multi-camera system has been installed in the LSS, it will be possible to monitor dynamic structural deformations of large spacecraft structures under sun-induced thermal stresses in space conditions.

Programmes under Development and Operations
Programmes en cours de réalisation et d'exploitation

In Orbit / En orbite



Under Development / En cours de réalisation



DEFINITION PHASE
MAIN DEVELOPMENT PHASE
LAUNCH/READY FOR LAUNCH
OPERATIONS
ADDITIONAL LIFE POSSIBLE
RETRIEVAL

IUE

Etat du véhicule spatial

Le véhicule spatial a continué de 'se remettre' de l'anomalie FES (une source de rayonnement solaire parasite à l'intérieur du suiveur d'étoiles qui venait s'ajouter à la lumière diffuse présente depuis février 1991), de sorte que le temps disponible pour l'acquisition de données utiles augmente à nouveau.

Production des archives définitives

La production des archives définitives d'IUE (IUEFA) pour les données en ondes courtes à faible résolution se déroule sans encombre après une phase approfondie d'essais de production et de vérifications scientifiques. Une première série de 6000 images à faible résolution enregistrées dans la station de Villafranca et traitées au moyen du nouveau système de traitement d'images spectrales NEWSIPS est actuellement à la disposition des utilisateurs extérieurs selon des modalités d'accès expérimentales. On définit actuellement un nouveau système de distribution des données, plus efficace, pour remplacer le logiciel de soutien pour archives uniformes à faible dispersion (ULDA/USSP), déjà très apprécié, tout en maintenant la formule de distribution locale par les serveurs nationaux. L'entretien de coût minimal prévu dans les plans permettra d'assurer la mise à disposition et le soutien des données archivées pendant au moins dix ans.

Evénements scientifiques marquants

Un programme spécial d'observation découpé en 56 périodes de huit heures a été exécuté à l'occasion de la collision de la comète Shoemaker-Levy avec Jupiter, en fonction des propositions d'observation présentées. En juin, préalablement à la rencontre, une étude précise avait été réalisée pour dresser un relevé bi-dimensionnel de spectres de référence, selon la latitude et selon l'heure jovienne locale. L'évolution des sites d'impact des fragments A, B, E, G, K, Q, R, S et W a été suivie dans le détail du 13 au 24 juillet, le programme complet d'observation se poursuivant jusqu'au 15 août. Des études poussées des zones d'émission aurorale ont été faites. Parmi les premiers résultats on citera:

(i) la forte atténuation de l'aurore septentrionale observée sur une durée prolongée, et due à la présence de poussières dans la magnétosphère de Jupiter;
(ii) l'observation directe des poussières piégées dans la magnétosphère de Jupiter, faisant penser à une injection massive possible de poussières;
(iii) le renforcement de l'émission Lyman-alpha équatoriale.

La première campagne d'étude d'une galaxie active à forte luminosité par la technique de la réverbération, qui s'appuie sur les variations de l'émission de continuum et l'émission de raie subséquente, se déroule actuellement. La galaxie étudiée (F-9) présente des variations considérables et cette campagne qui durera près d'un an à raison d'une observation tous les 5 jours devrait apporter des éléments qui permettront de donner une réponse ferme à la question de l'existence d'un rapport entre luminosité et taille dans les galaxies actives.

Télescope spatial Hubble (HST)

Opérations

L'observatoire HST poursuit impeccablement son travail, recueillant régulièrement des images d'une qualité et d'une finesse sans précédent. Les améliorations récemment apportées aux procédures et au logiciel de programmation des opérations ont porté à 45% le rendement sur cible du télescope, c'est-à-dire le temps pendant lequel il est pointé sur une cible céleste prédéfinie, avec une augmentation correspondante de 25-30% de son rendement en temps d'exposition, pendant lequel le télescope collecte des photons. Ces chiffres sont à rapprocher des pourcentages respectifs de 33% et 10% obtenus au cours des années 1991 – 1992.

Evénements scientifiques marquants

La qualité restaurée du fonctionnement du HST se traduit par un afflux de données d'un haut intérêt scientifique. L'un des exemples peut-être les plus tangibles des nouvelles capacités du télescope en 1994 a été offert par la campagne d'observation de la rencontre entre la comète Shoemaker-Levy et la planète Jupiter. La mise à disposition des données en temps quasi réel sur le réseau téléinformatique a constitué un important aspect de cette campagne.

Archives

Au cours des derniers mois, le passage aux nouveaux supports sur disque optique et au nouveau système d'archivage DADS, mis en service à l'Institut scientifique du Télescope spatial de Baltimore, a représenté la principale activité du groupe responsable des archives au Centre européen de coordination du Télescope spatial (ST-ECF). Une nouvelle interface d'accès aux archives reposant sur le logiciel Mosaic et WWW dont l'utilisation est largement répandue a été mise en oeuvre et offerte aux utilisateurs comme solution de remplacement possible à l'interface STARCAT existante.

Saturn as seen by the Hubble Space Telescope on 1 December 1994

Saturn vu par le Télescope spatial Hubble le 1er décembre 1994

IUE

Spacecraft status
The 'FES Anomaly' (a source of scattered sunlight in the IUE star tracker, on top of the diffuse light present since February 1991) has continued to 'heal', so that the acquisition overhead is decreasing again.

Final Archive production
The IUE Final Archive (IUEFA) production for short-wavelength low-resolution data has been running smoothly after an extensive production-test and science-verification phase. A first set of 6000 low-resolution images recorded at the Villafranca station and processed with NEWSIPS (NEW Spectral Image Processing System), is currently available to external users via an experimental access. A new, more efficient data-distribution system to replace the highly successful ULDA/USSP (Uniform Low Dispersion Archive Support Software Package), yet continuing the distributed model with National Hosts as local distribution points, is currently being defined. The planning foresees minimum-cost maintenance so that the archived data will be available and supported for at least ten years.

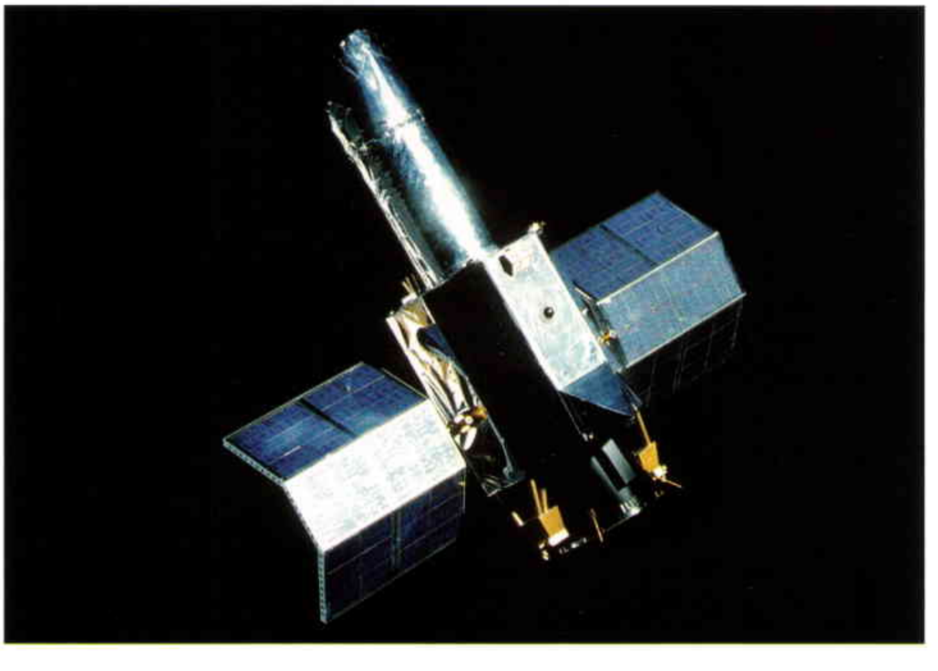
Scientific highlights
With a special allocation on the basis of proposals for observing Jupiter around the time of comet Shoemaker-Levy's impact, a programme of 56 eight-hour observing shifts was carried out. A careful study was made in June, before the impacts, to construct a two-dimensional map of reference spectra in latitude versus local Jovian time. Between 13 July and 24 July, the evolution of the impact sites of fragments A, B, E, G, K, Q, R, S and W were monitored extensively and the full observing programme continued until 15 August. Extensive studies were made of the auroral emission zones. Some of the early results include:

(i) the extensive fading of the northern aurora observed over a long period due to the presence of dust in the Jovian magnetosphere
(ii) direct observation of the dust trapped in the Jovian magnetosphere, suggesting a possible massive dust injection;
(iii) enhanced equatorial Lyman-alpha emission.

The first campaign to study a High Luminosity Active Galaxy through the reverberation technique using the variations in the continuum emission and the subsequent line emission is in progress. The Galaxy (F-9) shows considerable variations and this campaign – lasting almost a full year, with one observation every 5 days – is expected to supply data for a firm answer to the question of the existence of a luminosity/size relation for Active Galaxies.

Le véhicule spatial IUE

The IUE spacecraft



Hubble Space Telescope (HST)

Operations
The HST Observatory continues to operate in a flawless routine mode, acquiring images of unprecedented resolution and quality. Recent improvements in the scheduling software and procedures have brought the 'on-target' efficiency – the time spent by the Telescope pointing to a pre-defined celestial target – up to 45%. Consequently, the 'exposure-time' efficiency – the time spent by the Telescope collecting photons – has increased to 25–30%. These figures have to be compared, respectively, with the 33% and 10% efficiencies during the years 1991/92.

Scientific highlights
The restored quality of the HST performance is producing a wealth of data of great scientific value. Possibly the most visible example of the new capabilities of HST in 1994 was offered by the observing campaign covering the comet Shoemaker-Levy/Jupiter encounter. An important facet of the above campaign was that the data were made available on the computer net almost in real time.

Archive
During the past months, the main activity of the ST-ECF Archive group has been the transition to the new optical disk media and to the new Archive System, DADS, which has become operative at the Space Telescope Science Institute in Baltimore. A new interface to the Archive, based on the widely used Mosaic and World Wide Web (WWW) software, has been implemented and offered to the users as an alternative to the existing STARCAT interface.

Soho

Industry
Activities during September were concentrated mainly on the planned first Soho flight-model system functional test, which lasted about three weeks. At the beginning of October, the Service and Payload Modules (SVM and PLM) were de-mated and entered separate activity cycles.

Soho

Industrie

En septembre, les activités ont essentiellement porté sur les premiers essais fonctionnels au niveau système du modèle de vol de Soho, essais qui ont duré environ trois semaines. Au début d'octobre, les modules de servitude et charge utile (SVM et PLM) ont été dissociés et sont entrés dans des cycles d'activités distincts.

Le SVM a été préparé et instrumenté en vue d'essais de bilan thermique simulant l'orbite de transfert (module en rotation) qui ont été menés à bien chez Intespace à Toulouse du 10 au 14 novembre. Le PLM, d'autre part, a été préparé en vue de la deuxième série d'essais de bilan thermique/sous vide thermique, avec la mise à niveau de certaines expériences et la mise en place des éléments de régulation thermique (MLI).

Le 25 novembre, les deux moitiés du véhicule spatial ayant été à nouveau réunies, un essai fonctionnel de référence au niveau système a permis de vérifier le fonctionnement de l'ensemble des systèmes avant les essais de bilan thermique/sous vide thermique.

D'autres activités telles que la mise à niveau du réseau solaire et la fabrication du modèle de vol de l'enregistreur à état solide se sont poursuivies parallèlement aux activités système relatives au modèle de vol.

NASA

Après en avoir débattu, les hauts responsables de l'ESA et de la NASA sont convenus de fixer au 31 octobre 1995 la nouvelle date visée pour le lancement de Soho.

Martin-Marietta et le Lewis Research Center de la NASA envoient les données de la nouvelle analyse de charge couplée dans les délais voulus pour les essais vibratoires du modèle de vol au niveau système.

Les préparatifs d'un essai de compatibilité du secteur sol de conception nouvelle entre le Goddard Space Flight Center de la NASA et le véhicule spatial situé à Toulouse, début janvier 1995, se sont déroulés conformément au calendrier malgré certaines difficultés rencontrées par la NASA pour la préparation en temps utile du programme de simulation.

Expériences

Le Directeur du programme scientifique de l'ESA a fait le point en septembre sur les expériences UVCS, EIT et CELIAS.

Les travaux relatifs au mécanisme d'occultation des miroirs et à l'ensemble de spectrométrie (SPA) de l'UVCS ont progressé en vue d'une livraison fin 1994, dans les délais pour être intégrés à l'expérience après les essais de bilan thermique/thermique sous vide. Les détecteurs à ligne à retard croisées (XDL) des expériences UVCS et SUMER ont également été livrés en octobre, pour être intégrés depuis lors dans les modèles de vol de leurs ensembles d'appartenance respectifs. Les autres expériences en sont pour la plupart au stade de la configuration de vol finale, à l'exception de quelques éléments dont la mise au point définitive s'effectuera dans le cadre des activités prévues en janvier 1995.

Toutes les équipes scientifiques ont travaillé à la définition des procédures de vol qui leur permettront de piloter leurs instruments du Goddard Space Flight Center où sont préparées les installations de commande des expériences. La première simulation exécutée à la mi-novembre a fait intervenir le système sol de la NASA ainsi que les postes de travail et le logiciel de l'équipe scientifique.

Cluster

Le prototype de vol (PFM) et le satellite F2 ont tous deux franchi avec succès l'étape du programme des essais d'ambiance chez IABG, à Munich. Actuellement, les charges utiles ont été retirées des deux satellites en vue d'être remises en état et étalonnées. Leur réintégration commencera début janvier.

Les satellites F3 et F4 ont subi le programme des essais vibratoires avec de bons résultats. On prépare maintenant F3 aux essais magnétiques, F4 étant de son côté préparé au programme des essais thermiques.

Une fois ces programmes terminés, les charges utiles seront remises en état et les satellites préparés pour livraison à l'Agence.

Les préparatifs sont maintenant bien engagés pour la campagne de lancement qui doit démarrer en août 1995, en vue d'un lancement par Ariane-5 (V501) le 29 novembre.

La recette des modèles de vol des enregistreurs à état solide a été prononcée; les deux premiers ont été montés sur les unités F3 et F4 pour l'exécution des essais d'ambiance. Leur

The four Cluster spacecraft, at IABG (D)

Les quatre satellites Cluster, chez IABG (D)

The SVM was prepared and instrumented for a thermal-balance test simulating transfer orbit (spinning module), which took place successfully at Intespace in Toulouse between 10 and 14 November. The PLM, on the other hand, was prepared for the second thermal-balance /thermal-vacuum test by upgrading some experiments and fitting the thermal-control elements (MLIs).

On 25 November, the two halves of the spacecraft were re-mated and a reference system functional test has been conducted to check the functioning of all systems before the thermal-balance/ thermal-vacuum test.

Other activities, like the upgrading of the solar array and manufacture of the flight model of the solid-state recorder have been pursued in parallel with the flight-model system activities.

NASA

Discussions at senior-management level between ESA and NASA have led to the joint decision to target 31 October 1995 as the new Soho launch date.

Data from the new coupled load analysis are being received from Martin-Marietta/ NASA Lewis Research Center in time for the system flight-model vibration tests.

Preparations for a newly conceived ground-segment compatibility test between NASA Goddard Space Flight Center and the spacecraft in Toulouse in early January 1995 have been proceeding on schedule, although some difficulties have surfaced regarding the readiness of the software simulator being prepared by NASA.

Experiments

The status of the UVCS, EIT and CELIAS experiments was reviewed by the Director of ESA's Scientific Programme in September.

Both the Mirror Occulter Mechanism and the Spectrometer Assembly (SPA) of the UVCS have progressed towards delivery by the end of 1994, in time for integration with the experiment after the thermal-balance/thermal-vacuum test. The Cross Delay Line Detectors (XDLs) for UVCS and SUMER were also delivered in October and have since been integrated in the respective flight assemblies. Most of the other experiments are in final flight configuration, with the exception of a few elements that will be finalised in the planned January 1995 activities.

All scientific teams have been defining their flight procedures, in order to operate instruments from the Experiment Operations Facilities being readied at Goddard Space Flight Center. In mid-November, a first simulation was held involving both the NASA ground system and the scientific team's work stations and software.

Cluster

Both the Protoflight Model (PFM) and F2 spacecraft have successfully completed the environmental test programme at IABG in Munich. Currently the payloads have been removed from both spacecraft for refurbishment and calibration. Re-integration is due to commence in early January.

The F3 and F4 spacecraft have successfully completed the vibration test programme. F3 is now being made ready for DC magnetic testing, while F4 is being prepared for the thermal test programme.

Following completion of the programme the payloads will be refurbished and the spacecraft prepared for delivery to the Agency.

Preparations are now well in hand for the launch campaign, which is due to start in August 1995 for an Ariane-5 launch (V501) on 29 November.

The flight models of the solid-state recorders have been accepted and the first two integrated on F3 and F4 for the environmental test programme. Retrofitting to other spacecraft will take place during the refurbishment periods.

The ground segment continues on schedule with the first interactive end-to-end validation testing being planned with the PFM in March. This represents a crucial test for the ground segment. Construction and upgrading of the Redu and Odenwald ground stations continues on schedule.

The first delivery of the user interface software has been successfully installed at the individual Science Data Centres. The major system-test phase is planned for late spring 1995.

Work on the Joint Science Operations Centre is proceeding on schedule, with the payload command software under development, and the payload monitoring and control software being defined.

A unique event occurred in early October at IABG (Munich) when all four Cluster spacecraft were in the clean room together. The accompanying photograph shows the scientific Principal Investigators in front of the spacecraft.

ISO

Satellite and ground segment

Very good progress has been made with the flight-model satellite. All of the major system-level environmental tests, the electromagnetic-cleanliness, mechanical vibration, acoustic and thermal-vacuum and balance tests, were completed successfully and on schedule. A few anomalies observed during the thermal test are presently being investigated.

The concern mentioned in Bulletin No. 80 that the cryocover had some local warm areas has been resolved. The cover could be made cold enough during the thermal test to properly test the scientific instruments. Overall, the satellite and scientific instruments are being shown to perform very well.

The next step in the satellite test programme is to conduct operational interface tests with the ground segment (spacecraft and science operations) in January/February 1995 and then to perform an extensive integrated system test on the satellite in February/March. The final full satellite ground-segment test will be conducted in April.

Observation programme

Over half of ISO's observing time (so-called 'Open Time') is competitively available to astronomers in the ESA Member States, Japan and the USA; the remaining time ('Guaranteed Time') is reserved for astronomers involved in the construction and operation of the ISO facility.

mise en place sur les autres satellites aura lieu à l'occasion des périodes de remise en état.

Les activités relatives au secteur sol se poursuivent conformément au calendrier; le premier essai de validation interactif de bout en bout qui doit avoir lieu en mars sur le PFM représente un essai crucial pour le secteur sol. La construction et la mise en hauteur des stations sol de Redu et de l'Odenwald se déroulent conformément aux plans.

L'installation de la première livraison du logiciel d'interface d'utilisateur a été menée à bien dans les différents centres de données scientifiques. La phase des essais système est prévue pour la fin du printemps 1995.

Les travaux relatifs au Centre commun d'opérations scientifiques respectent le calendrier: le logiciel de télécommande des charges utiles est en cours d'élaboration et le logiciel de contrôle et de commande des charges utiles est en cours de définition. La présence simultanée des quatre satellites Cluster dans la salle propre de l'IABG (à Munich) a marqué un temps fort début octobre.

ISO

Satellite et secteur sol

Le modèle de vol du satellite a beaucoup avancé. Tous les principaux essais d'ambiance au niveau système, les essais de propreté électromagnétique, les essais mécaniques vibratoires et acoustiques et les essais thermiques sous vide et de bilan thermique ont tous été menés à bien et dans les délais. Quelques anomalies observées au cours des essais thermiques sont en cours d'investigation.

La préoccupation dont faisait état le précédent bulletin au sujet de points chauds localisés sur le couvercle cryogénique n'a plus de raison d'être. On a pu refroidir suffisamment le couvercle durant les essais thermiques pour vérifier les instruments scientifiques dans les conditions voulues. Le fonctionnement général du satellite et des instruments scientifiques apparaît très bon.

La prochaine étape du programme d'essai du satellite portera sur les interfaces opérationnelles avec le secteur sol (opérations du véhicule spatial et opérations scientifiques) en janvier-février 1995 et sera suivie par des essais poussés du satellite, au niveau système intégrés en février-mars. La phase finale des essais complets satellite et secteur sol se déroulera en avril.

Programme d'observation

Plus de la moitié du temps d'observation d'ISO (le temps dit 'disponible') est offert aux astronomes des Etats membres de l'ESA, du Japon et des Etats-Unis sur une base concurrentielle; le temps restant, dit 'garanti', est réservé aux astronomes associés à la construction et à l'exploitation de l'installation ISO.

En décembre, la définition du programme d'observation d'ISO a été marquée par deux principaux événements:

(i) Pour la partie disponible du temps d'observation, l'ESA a reçu 1000 propositions portant sur plus de 30 000 observations, soit quatre fois plus environ que le satellite ne peut en offrir. Après l'évaluation des propositions par les services de l'ESA sur le plan technique et par des scientifiques extérieurs sur le plan de leur intérêt scientifique respectif, une réunion du Comité d'attribution du temps d'observation a conclu le cycle d'examen.

(ii) Un service programmé est prévu pour l'exploitation d'ISO. Il faudra donc disposer d'avance d'informations complètes sur toutes les observations, avec des données détaillées sur le réglage des instruments. Pour rassembler ces données, un centre spécial a été mis sur pied à l'ESTEC (NL). Pouvant recevoir simultanément jusqu'à trente astronomes venus de l'extérieur, ce centre a été ouvert le 5 décembre. On verra ainsi au cours des six à sept prochains mois un flux ininterrompu d'astronomes du monde entier se succéder à l'ESTEC pour mettre au point tous les détails de leurs observations au moyen d'ISO.

Coopération internationale

Le Directeur du programme scientifique de l'ESA et le Directeur général de l'Institut de science spatiale et d'astronautique (ISAS) du Japon ont signé fin septembre le mémorandum d'accord (MOU) entre l'ESA et l'ISAS (voir nos nouvelles brèves dans la section 'In Brief' du présent numéro). Cet accord entérine l'extension du soutien des opérations en vol d'ISO que doit assurer l'ISAS en contrepartie (pour l'essentiel) de 0,5 heure par jour d'utilisation d'ISO par les scientifiques japonais.

La coopération progresse également de façon satisfaisante avec la NASA, qui met à niveau à Goldstone une station d'antennes à utiliser comme deuxième station sol pour ISO. Avec cette deuxième station, les scientifiques disposeront d'environ trois heures supplémentaires de temps d'observation chaque jour. En contrepartie, la NASA disposera pour l'essentiel de 0,5 heure par jour de temps garanti pour les scientifiques américains. Le MOU habilitant entre l'ESA et la NASA en est au stade final des négociations.

Huygens

Les activités industrielles ont atteint aujourd'hui leur point culminant, trois modèles de la sonde se trouvant actuellement au stade de l'intégration ou des essais.

Chez IABG (Munich, D), c'est le modèle structurel/thermique/pyrotechnique (STPM) qui subit à présent les essais vibratoires, après avoir franchi avec succès la phase des essais de qualification pour la pénétration dans l'atmosphère sur centrifugeuse, avec mesure des caractéristiques physiques, sur les deux configurations de lancement et de descente sur Titan.

Chez Fokker (Amsterdam, NL), le modèle spécial numéro 2 (SM2) de la sonde en est à la phase finale de l'intégration et des essais au niveau système, pour un achèvement prévu en février 1995. Ce modèle sera largué d'un ballon, à 40 km d'altitude environ, pour démontrer le bon déroulement de la séquence des opérations et le déploiement adéquat des mécanismes et parachutes dans des conditions dynamiques similaires à celles de l'entrée dans l'atmosphère de Titan. Dans le modèle SM2, aux normes de vol sur le plan mécanique, les sous-systèmes électroniques sont remplacés par des dispositifs spéciaux de mesure et d'enregistrement.

During December, two major events occurred in the definition of the observing programme for ISO:

(i) For the 'Open Time', ESA received 1000 proposals requesting over 30 000 observations, a total of about four times as much observing time as is available. Following a technical assessment by ESA staff and an evaluation of relative scientific merit by external scientists, the review cycle was completed by a meeting of the 'Observing Time Allocation Committee'.

(ii) ISO will be operated in a pre-planned service mode. Thus, full information about all observations including detailed instrument settings must be available in advance. To gather this data, a 'Proposal Data Entry Centre' has been set up at ESTEC, in Noordwijk (NL). This facility, which can accommodate up to 30 visiting astronomers in parallel, was opened on 5 December. Thus, for the next 6 – 7 months, a constant stream of the World's astronomers will be visiting ESTEC to elaborate the full details of their ISO observations.

International cooperation

The Memorandum of Understanding (MOU) between ESA and Japan's Institute of Space and Astronautical Sciences (ISAS) was signed at the end of September by ESA's Director of Science and ISAS's Director General (see item elsewhere in this issue's 'In Brief' section). This agreement concerns the extension of support to ISO's flight operations to be provided by ISAS in return (mainly) for 0.5 hours/day of ISO usage by Japanese scientists.

Good progress is also being made in the cooperation with NASA, which is upgrading an antenna station at Goldstone for use as the ISO second ground station. This second station will increase the science observation time by about 3 hours/day. In return, NASA will receive (mainly) 0.5 hours/day of guaranteed time for US scientists. The enabling MOU between ESA and NASA is in the final stages of negotiation.

Huygens

Industrial activities are now at their peak, with integration or testing being performed for three Probe models.

At IABG (Munich, D) the Structural/Thermal/Pyro Model (STPM) Probe is currently undergoing vibration testing, having already successfully completed entry qualification/centrifugal and physical-properties testing for both launch and Titan-descent configurations.

At Fokker (Amsterdam, NL) the Special Model 2 (SM2) Probe is undergoing final integration and system-level testing with a planned completion in February 1995. This model will be dropped from a balloon at approximately 40 km altitude to demonstrate the correct sequence of operation and deployment of mechanisms and parachutes under conditions dynamically similar to those expected during Titan atmosphere entry. The SM2 is mechanically of flight standard, with electronic subsystems replaced by specific measuring and recording devices.

At DASA (Munich, D), the engineering-model Probe is presently being integrated.

A potentially serious problem arose when a replacement batch of hi-rel gallium-arsenide components for the flight-model Data Relay Subsystem was rejected during lot acceptance testing. A full investigation has been launched to determine the cause of this failure and to find work-around solutions.

Rosetta

Two industrial support study contracts have been started with Matra Marconi Space and Dornier to support the in-house mission definition team. In addition, detailed work is continuing on the Orbiter configuration and mission timeline.

Letters of intent have been received from a wide variety of European Institutes covering the Orbiter payload. The Announcement of Opportunity will be issued in March 1995.

Two consortia have submitted proposals for the Surface Science Packages (SSPs), one led by NASA/CNES and the other by Germany and Finland. These are currently under evaluation for accommodation on the Orbiter. A further workshop with both consortia will take place in February 1995.

The Science Management Plan was approved at the November meeting of ESA's Science Programme Committee. It represents the basis on which potential Principal Investigators and their teams will interface with the Agency.

The plan covers also the selection of the Orbiter's scientific payload and the

Le véhicule spatial Rosetta

The Rosetta spacecraft

A la DASA (Munich, D), c'est le modèle d'identification de la sonde qui est en cours d'intégration.

Le rejet, lors des essais de recette d'un lot de remplacement de composants à haute fiabilité à l'arséniure de gallium destinés au sous-système de relais de données du modèle de vol pourrait poser un problème sérieux. Une enquête approfondie a été lancée en vue de déterminer la cause de cette défectuosité et de trouver des solutions de repli.

Rosetta

Deux contrats d'étude ont été mis en route chez Matra Marconi Space et chez Dornier en soutien de l'équipe intra-muros chargée de la définition de la mission. Des travaux détaillés se poursuivent d'autre part sur la configuration de l'orbiteur et sur la séquence des opérations de la mission.

Des instituts européens très divers ont envoyé des lettres d'intention au sujet de la charge utile de l'orbiteur. L'avis d'offre de participation sera lancé en mars 1995.

Des propositions relatives aux appareillages d'étude scientifique de la surface (SSP) ont été soumises par deux consortiums, l'un conduit par le groupe NASA/CNES et l'autre par l'Allemagne et la Finlande. Leur évaluation est en cours en ce qui concerne leur mise en place sur l'orbiteur. Un atelier complémentaire se déroulera avec les deux consortiums en février 1995.

Le plan de gestion scientifique approuvé par le Comité du programme scientifique de l'Agence lors de sa réunion de novembre définit le cadre des relations avec l'ESA des responsables de recherches potentiels et de leurs équipes.

Le plan couvre également la sélection de la charge utile scientifique de l'orbiteur et l'interaction avec les charges utiles sélectionnées pour les SSP. Il est prévu de confirmer la composition retenue pour la charge utile lors de la réunion que le Comité du programme scientifique doit tenir en février 1996.

Integral

Le plan de gestion scientifique du projet Integral ayant reçu l'approbation du Comité du programme scientifique (SPC) de l'ESA, l'avis d'offre de participation (AO) a été lancé pour les instruments de la charge utile en juillet 1994. Les propositions d'instruments correspondantes, reçues depuis lors, sont actuellement évaluées par l'Agence.

La demande de prix (RFQ) relative à la phase B d'Integral a été présentée à Alenia (I) le 18 octobre; le démarrage de la phase B est prévu pour fin 1995.

Le Conseil de l'ESA a officiellement approuvé l'utilisation du lanceur russe Proton pour Integral, en maintenant toutefois la compatibilité avec Ariane-5 comme lanceur de réserve. L'Agence spatiale russe (RKA) participera au programme Integral en fournissant le lanceur Proton à titre gratuit en échange de temps d'observation pour les scientifiques durant la mission. Un projet d'arrangement entre l'ESA et la RKA a été élaboré conjointement pour Integral, en vue d'être soumis aux procédures d'approbation des deux parties.

ERS-2

La revue de recette pour le vol et la revue d'aptitude correspondante du secteur sol se sont déroulées au dernier trimestre de 1994, confirmant qu'ERS-2 était prêt à être lancé. Le satellite a donc été expédié au mois de novembre en Guyane française et la campagne de lancement a commencé à Kourou. L'échec du lancement Ariane V70 est malheureusement venu retarder le lancement qui était prévu pour fin janvier 1995. Le satellite sera entreposé au Centre spatial guyanais en attendant son lancement et ERS-1 continuera entre temps à remplir le rôle de satellite opérationnel, garantissant la continuité des données.

EOPP

Métop-1

La présentation finale de la phase A industrielle a eu lieu le 22 octobre. Deux options ont été élaborées et chiffrées. Toutes les activités ont maintenant été transférées au programme préparatoire Métop.

Programmes futurs

Le concept de base de missions Earth Explorer, pour l'étude des processus scientifiques, et Earth Watch, davantage tournées vers les applications, a été entériné lors de la réunion de consultation des utilisateurs qui s'est déroulée à l'ESTEC du 25 au 27 septembre. Un ensemble de huit missions Earth Explorer possibles associé à la série d'impératifs connexes des utilisateurs a été approuvé à cette occasion, avec trois missions prioritaires. Une première mission du type Earth Watch a également été définie pour les zones côtières.

Les activités à conduire en 1995 dans le cadre de l'EOPP s'articuleront autour de ces missions potentielles.

Campagnes

La campagne aéroportée EMAC de 1994 s'est terminée, faisant place à la préparation actuellement en cours de la campagne de 1995. La campagne aéroportée Elite conduite en conjonction avec la Navette spatiale a été menée à bien en septembre. Le compte rendu de l'atelier final sur 'MAC Europe 1991' qui s'est déroulé en octobre est en cours de préparation.

Météosat deuxième génération (MSG)

L'industrie a franchi avec succès le deuxième point de passage obligé pour les activités de définition aux niveaux système et sous-système de la phase B au cours de la revue système intermédiaire.

Des appels d'offres ouverts ont été préparés et adressés à l'industrie au cours de ces derniers mois pour les principaux sous-systèmes, en vue de la sélection des sous-traitants qui seront chargés des activités d'ingénierie et de conception détaillées de phase B. De nombreuses soumissions ont déjà été reçues et évaluées. Parmi celles-ci figurait l'offre d'un consortium industriel, bénéficiant du soutien d'un responsable de recherches, concernant la fourniture à l'ESA d'un instrument pour l'étude du bilan radiatif de la Terre sur orbite géostationnaire (GERB), à intégrer dans le MSG en qualité d'équipement fourni en réponse à un avis d'offre de participation (AOP).

interaction with the selected payloads for the SSPs. It is intended to confirm the selected payload complement at the February 1996 meeting of the Science Programme Committee.

Integral

Following approval of the Integral Science Management Plan by the ESA Science Programme Committee (SPC), the Announcement of Opportunity (AO) for Integral payload instruments was released in July 1994. These payload instrument proposals have been received in the meantime and are now being evaluated by the Agency.

The Request for Quotation (RFQ) for the Integral Phase-B was issued to Alenia (I) on 18 October and it is planned to start Phase-B in June 1995.

The ESA Council has formally approved use of the Russian Proton launcher for Integral, but maintaining compatibility with Ariane-5 as back-up launcher. The Russian Space Agency (RSA) will participate in the Integral programme by providing the Proton vehicle free of charge in return for scientific observation time during the mission. A draft document covering the ESA/RSA Integral Arrangement has been jointly prepared for submission to the ESA and Russian approval cycles.

ERS-2

The Flight Acceptance Review and the associated Ground Segment Readiness Review were held in the last quarter of 1994, confirming that ERS-2 was ready for launch. Consequently, the satellite was shipped to Kourou in French Guiana in November and the launch campaign began. The failure of the Ariane V70 launch has, however, resulted in a delay in the planned end-January 1995 launch date. The satellites will be stored at the Guiana Space Centre for the duration of this delay. In the meantime, ERS-1 will continue to be used as the 'operational satellite' in order to ensure data continuity.

EOPP

Metop-1

The final presentation of the industrial Phase-A has taken place on 22 September. Two options have been developed and costed. All activity has now been transferred to the Metop Preparatory Programme.

Future programmes

The user Consultation Meeting held at ESTEC on 25 – 27 September endorsed the basic concept of 'Earth Explorer' and 'Earth Watch' missions. It agreed a set of eight potential Earth Explorer missions and the associated set of user requirements, with three 'priority' missions. It also identified a first Earth Watch mission for coastal zones.

These potential missions will form the backbone of the EOPP activities in the coming year.

Campaigns

The 1994 'EMAC' flight campaign has been concluded and the 1995 campaign is now in preparation. The Shuttle underflight 'Elite' campaign was successfully carried out in September. The final workshop on 'MAC Europe 1991' took place in October and the Proceedings are in preparation.

Meteosat Second Generation (MSG)

The second check point for Phase-B system and subsystem design definition activities has been successfully passed by industry during the Interim Systems Review.

Major subsystem Invitation-to-Tender (ITT) packages have been prepared and issued to industry in the last months, in an open competition to select subcontractors for detailed Phase-B engineering and design activities. Many proposals have already been received and evaluated. One was from an Industrial Consortium, supported by a Prime Investigator, for the supply to ESA of a Geostationary Earth Radiation Budget (GERB) Instrument for integration within MSG as an Announcement of Opportunity Package (AOP).

Further to the approval of MSG-1 the Eumetsat Council, at its November session, accepted in principle that ESA should be their procurement agent for the MSG-2 and MSG-3 spacecraft, subject to the conclusion of a satisfactory cooperation agreement.

Meteosat Transition Programme (MTP)

Metop

A large measure of agreement has been reached with Eumetsat on the Metop satellite configuration and its payload definition. The satellite system Phase-B industrial study is now going through its tender action. The study itself is expected to start n the second quarter of 1995, given confirmation of the presently defined concept by ESA and Eumetsat delegates.

A programme proposal for the Metop-1 implementation phase (Phase-C/D) has been prepared.

The MIMR (Multifrequency Imaging Microwave Radiometer) and ASCAT (Advanced Scatterometer) industrial studies are progressing.

Envisat-1/Polar Platform

Systems

The problems identified during the Envisat Mission and System Preliminary Design Review (EMS-PDR) in July 1994 have been vigorously investigated, in particular the ASAR antenna interface to the Polar Platform. As a result, minor changes have been made to the detailed layout and configurations of some of the instruments and the antenna on the spacecraft's Earth-pointing face.

Polar Platform

Significant effort has been devoted to progressing the final negotiations of the PFF contract at subcontractor and prime contractor level. Most of the subcontracts have been cleared. The merger of the former BAe and Matra Marconi, and the subsequent reorganisation in this new industrial group, have meant that the negotiations on prime-contractor tasks have been somewhat delayed. Signature of the contract is now expected in the first half of 1995. Industrial work is proceeding, however, under cover of an extended Authorisation to Proceed.

Following the integration of structural models of electronics units, the structural model Service Module was subjected to a successful separation shock test with the

Outre l'approbation de MSG-1, le Conseil d'Eumetsat a donné son accord de principe lors de sa session de novembre sur la fourniture des satellites MSG-2 et MSG-3 par le truchement de l'ESA, sous réserve qu'un accord de coopération satisfaisant soit conclu.

Programme de transition Météosat (MTP)

Métop

L'accord s'est fait dans une large mesure sur la configuration du satellite Métop et la définition de sa charge utile. L'étude industrielle de phase B du satellite au niveau système en est actuellement au stade de l'appel d'offres. L'étude elle-même devrait commencer au deuxième trimestre de 1995, après confirmation par les délégués de l'ESA et d'Eumetsat du concept actuellement défini.

Une proposition de programme a été élaborée pour la phase de mise en oeuvre de Métop-1 (phase C/D).

Des études industrielles sont en cours sur les instruments MIMR (radiomètre imageur hyperfréquences multibande) et ASCAT (diffusiomètre de technologie avancée).

Envisat-1/Plate-forme polaire

Systèmes

Les problèmes relevés en juillet 1994 lors de la revue de conception préliminaire d'Envisat sur le double plan de la mission et du système (EMS-PDR) ont donné lieu à une étude approfondie, pour ce qui concerne notamment l'interface de l'antenne de l'instrument ASAR avec la plate-forme polaire. A la suite de ce travail, de légères modifications ont été apportées au détail de l'agencement et de la configuration de certains instruments et de l'antenne située sur la face du satellite tournée vers la Terre.

Plate-forme polaire

Un gros travail a été accompli pour faire avancer les négociations finales du contrat relatif à la plate-forme polaire, aux niveaux sous-traitant et maître d'oeuvre. Le résultat est acquis pour la plupart des sous-contrats. La fusion des anciennes sociétés BAe et Matra Marconi et la réorganisation qui en a résulté au sein de ce nouveau groupe industriel ont entraîné un certain retard dans les négociations relatives aux activités du maître d'oeuvre. La signature du contrat est maintenant attendue pour le premier semestre de 1995. Les travaux se poursuivent toutefois dans l'industrie sous couvert d'une prolongation de l'autorisation d'engagement des travaux.

Après intégration des modèles structurels des unités électroniques, le modèle structurel du module de servitude a été soumis avec succès à des essais de choc à la séparation faisant intervenir le modèle de développement de l'adaptateur lanceur fourni par le programme Ariane-5.

En ce qui concerne le mécanisme d'entraînement du réseau solaire et le mécanisme de pointage de l'antenne DRS qui avaient présenté des défauts de conception, des remaniements partiels ont été étudiés et mis en oeuvre et font maintenant l'objet d'essais de validation sur modèles de développement.

Pour la plupart des sous-systèmes du module de charge utile, le développement du modèle d'identification/qualification entre dans la phase de l'intégration et des essais. On a détecté dans certains cas des anomalies et des non-conformités qui demandent à être analysées dans le détail.

Charge utile Envisat-1

En ce qui concerne le consortium Envisat responsable des instruments à réaliser par l'ESA (EDI), des négociations contractuelles ont eu lieu avec les sous-traitants directs du maître d'oeuvre mission et plusieurs sous-traitants du GOMOS. Les négociations contractuelles relatives à la plupart des autres sous-traitants sont en préparation. Un avenant additionnel à l'autorisation officielle d'engagement des travaux de phase C1 a pourvu à la couverture contractuelle du consortium en 1995.

Tous les instruments, le radiomètre hyperfréquences (MWR) mis à part, ont subi leur revue de conception préliminaire et la fabrication des modèles d'identification a commencé. Les modifications récentes du consortium industriel ont ralenti les travaux menés sur le MWR. Une redistribution des travaux est également devenue nécessaire pour le MIPAS. Un problème de rayonnement parasite interne qui pourrait avoir une incidence sur le fonctionnement d'ensemble de l'instrument MERIS est toujours à l'étude.

Secteur sol

Le concept du secteur sol d'Envisat, recouvrant notamment le segment relatif aux données de charge utile (PDS), a été définitivement arrêté en septembre et approuvé par le Conseil directeur du programme d'observation de la Terre. Les activités relatives au PDS avancent maintenant dans le cadre de deux contrats parallèles de phase de consolidation mettant en concurrence les deux chefs de file Matra et Thomson-CSF. Les revues à mi-parcours de l'architecture du PDS ont été menées à bien avec les deux consortiums. Pendant ce temps, l'ESA prépare l'appel d'offres relatif au contrat industriel de réalisation (phase C/D) du PDS.

Microgravité

Des propositions ont été faites au Conseil directeur du programme au sujet de la poursuite du programme européen de recherche fondamentale en microgravité (EMIR-1), programme en cours et qui doit actuellement se terminer en 1997, ainsi que d'un programme de développement d'installations à utilisateurs multiples destinées à la Station spatiale (le programme MFC). Ces propositions qui ont reçu un accueil favorable seront examinées plus avant et élaborées dans le détail.

Lors d'une première réunion tenue après la mission Spacelab IML-2, qui s'est déroulée avec le plus grand succès du 8 au 24 juillet 1994, les responsables de recherches dont les expériences avaient été embarquées sur ce vol ont passé en revue les résultats préliminaires recueillis, déjà porteurs d'une masse de données prometteuses.

La NASA prévoit d'ores et déjà pour juin 1996 une nouvelle mission Spacelab de 16 jours, la mission MLS (Life and Microgravity Spacelab), qui offrira aux scientifiques de nouvelles occasions de vol en attendant de disposer de la Station spatiale. La NASA a proposé à l'ESA d'embarquer sur cette mission, en coopération, des installations à utilisateurs multiples de l'Agence:

development model of the Launch Vehicle Adaptor provided by the Ariane-5 Programme.

In the case of the solar-array drive mechanism and the DRS antenna pointing mechanism, where design problems have been experienced, partial redesigns have been studied and implemented and are now subject to validation tests on development models.

For most subsystems of the Payload Module, engineering/qualification model development is entering the integration and test phases. In some cases, anomalies and non-conformances have been detected which require detailed analyses.

Envisat-1 payload

As far as the Envisat Consortium responsible for the ESA-Developed Instruments (EDIs) is concerned, contract negotiations have taken place for the direct subcontractors to the mission prime contractor and for several GOMOS subcontractors. Contract negotiations for most other subcontractors are in preparation. Contractual coverage for the Consortium in 1995 has been provided by an additional Rider to the Phase-C1 formal Authorisation to Proceed.

All instruments, with the exception of the Microwave Radiometer (MWR), have gone through their Preliminary Design Reviews, and engineering-model manufacture has started. Late changes in the industrial consortium had slowed down work on the MWR. For MIPAS also, a redistribution of work had become necessary. A MERIS internal straylight problem, which could have an impact on overall instrument performance, is still under investigation.

Ground segment

The Envisat Ground Segment Concept, including in particular the Payload Data Segment (PDS), was finalised in September and approved by the Earth Observation Programme Board. Work on the PDS is now progressing in the framework of the two parallel consolidation phase contracts with the lead contractors Matra and Thomson-CSF in competition. Mid-term reviews of the PDS architecture have been successfully held with both consortia. In the meantime, ESA is preparing the Invitation to Tender for the final ground segment PDS Phase-C/D implementation contract with industry.

Microgravity

Proposals for the continuation of the ongoing European Microgravity Programme (EMIR-1), currently ending in 1997, as well as for a programme for the development of Multi-User Facilities for the Space Station (referred to as the MFC programme) were made to the Microgravity Programme Board. These proposals were well received and will be further discussed and elaborated in detail.

At a first post-flight meeting of Investigators who had experiments on the highly successful IML-2 Spacelab mission (8 – 24 July 1994) initial experiment results, already including a wealth of promising data, have been reviewed.

A new 16-day Spacelab mission known a 'Life and Microgravity Spacelab', or LMS, is being planned by NASA for June 1996 to provide further flight opportunities to scientists before the Space Station becomes available. NASA has proposed to fly the following ESA multi-user facilities on this mission on a cooperative basis: the Bubble, Drop and Particle Unit (BDPU), the Advanced Gradient Heating Facility (AGHF), two Advanced Protein Crystallisation Facility (APCF) units, and the Torque Velocity Dynamometer (TVD). This continued cooperation with NASA reflects both the good performance of the ESA multi-user facilities and the satisfaction of the US investigators who conducted their experiments using these ESA facilities.

The 20th ESA parabolic flight campaign was conducted with the Caravelle aircraft in October 1994, with a total of eleven experiments being performed.

At the end of November, the Texus-33 sounding rocket was successfully launched carrying three ESA-funded experiments in the fluid-physics domain.

The next flight in the EMIR-1 programme will be the launch of 'Biopan', an exposure facility for biological samples, on the Russian retrievable Foton 10 satellite. Launch is foreseen for January/February 1995 and sample integration will be carried out in the ESA laboratory at the Institute for Biomedical Problems in Moscow.

Intérieur de la cabine de la Caravelle au cours d'un vol parabolique

View of the Caravelle aircraft's cabin during a parabolic flight *l'ensemble d'étude des bulles, gouttes et particules (BDPU), le four à gradient de haute technologie (AGHF), deux ensembles de cristallisation de protéine de technologie avancée (APCF) et le dynamomètre pour l'étude du couple force-vitesse (TVD). La coopération qui se poursuit ainsi avec la NASA témoigne à la fois du bon fonctionnement des installations à utilisateurs multiples de l'ESA et de la satisfaction des chercheurs américains qui s'en sont servies pour leurs expériences.*

La 20ème campagne de vols paraboliques de l'ESA s'est déroulée en octobre 1994, inscrivant à son actif un total de 11 expériences conduites à bord de la Caravelle.

Fin novembre a eu lieu le lancement réussi de la fusée-sonde Texus 33, avec à son bord trois expériences de physique des fluides financées par l'ESA.

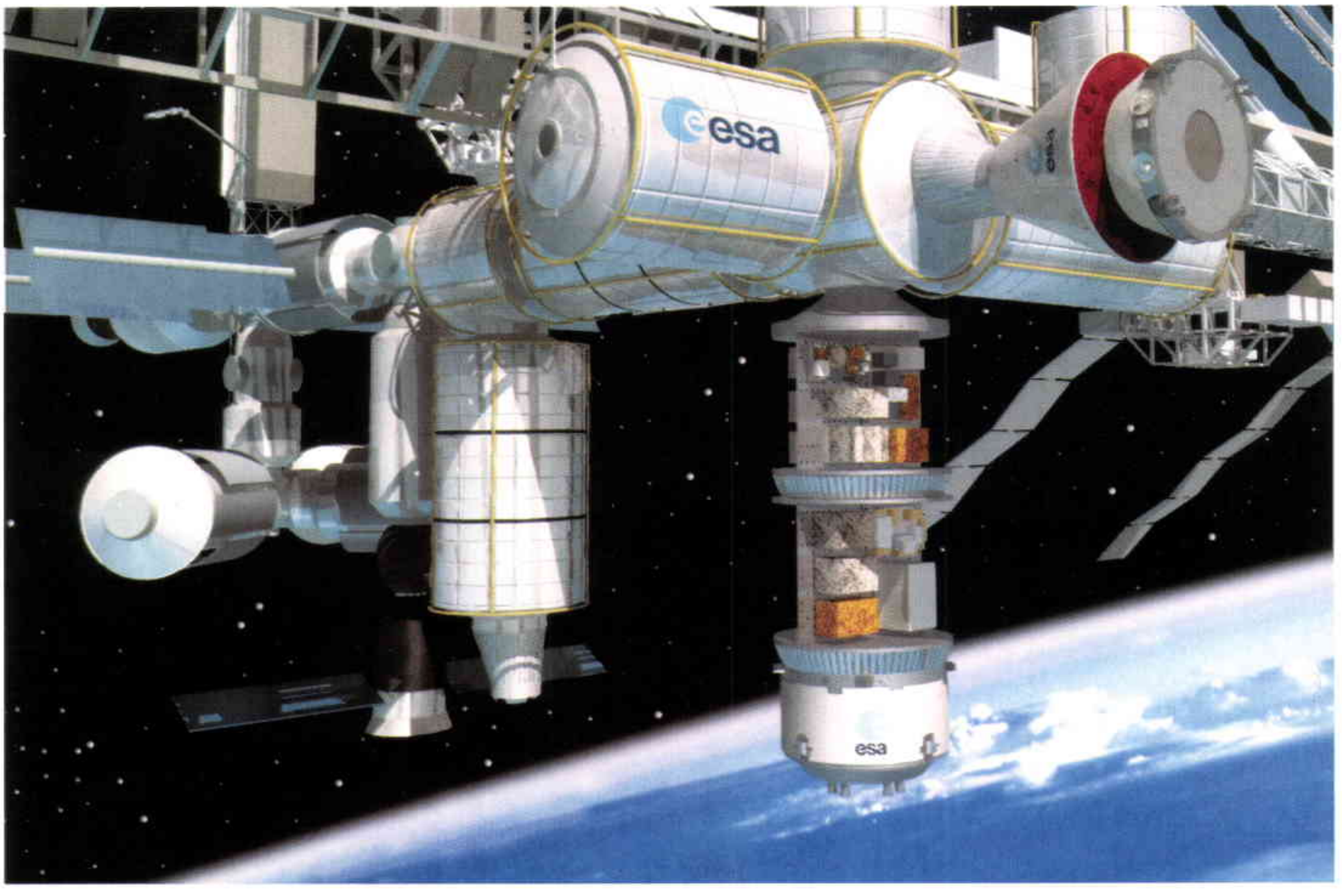
Le prochain vol à exécuter dans le cadre du programme EMIR-1 sera le lancement de Biopan, une installation permettant l'exposition d'échantillons biologiques au milieu spatial, à bord du satellite récupérable russe Photon 10. Ce lancement est prévu pour janvier-février 1995, l'intégration des échantillons ayant lieu dans le laboratoire de l'ESA, à l'Institut de recherche biomédicale de Moscou.

Programme spatial habité

Lors de sa session des 19 et 20 octobre 1994, le Conseil a approuvé la démarche suivie par l'Exécutif en ce qui concerne le choix de la configuration de référence de l'Elément orbital Columbus et a convenu de la nécessité de consolider début 1995 la position de l'Europe sur sa participation à la Station spatiale internationale, compte tenu des déclarations des Directeurs de la NASA et de la RKA au sujet d'un gel des contributions des partenaires lors de la revue d'étape de la conception (IDR) prévue en mars 1995.

Les mesures prises en conséquence par l'Exécutif pour faire face à l'échéance de cette décision imminente ont eu pour effet d'accélérer l'élaboration d'une proposition de programme relative à la participation de l'Europe à la Station spatiale internationale, dont un projet doit être envoyé aux délégations le 20 décembre 1994 pour examen et discussion lors d'une réunion spéciale du Conseil directeur des programmes spatiaux habités prévue pour les 18 et 19 janvier 1995. Des réunions bilatérales et trilatérales ont également été organisées avec la NASA et la RKA en vue de conclure avant la fin de 1994 tous les accords de principe nécessaires sur un scénario logistique reposant sur une flotte mixte et faisant place aux capacités Ariane-5/ATV (véhicule de transfert automatique), notamment pour les missions de ravitaillement en ergol et de rehaussement de la Station, ainsi que sur des formules de coopération possibles avec les Etats-Unis ou avec la Russie portant essentiellement sur un véhicule de sauvetage d'équipages/ véhicule de transport d'équipages (CRV/CTV).

Une progression par étapes a été explorée plus avant pour le CTV, compte tenu



The International Space Station (artist's impression by D. Ducros)

La Station spatiale internationale (vue conceptuelle par D. Ducros)

Manned Space Programme

The Council at its session on 19 and 20 October 1994 approved the Executive's approach for selection of the Columbus Orbital Facility reference configuration and acknowledged the necessity to consolidate the European position with respect to its participation in the International Space Station in early 1995, based on declarations from Heads of NASA and RKA about freezing partners' contributions at an Incremental Design Review (IDR) planned for March 1995.

Subsequent actions undertaken by the Executive to meet such an imminent decision date have accelerated the elaboration of a programme proposal for 'Europe's Participation in the International Space Station', and a draft is to be sent to Delegations by 20 December 1994 for review and discussion at a special Manned Space Programme Board meeting planned for 18 – 19 January 1995. Also, bilateral and trilateral meetings with NASA and RKA have been organised in order to conclude all the necessary principle agreements before the end of 1994 regarding a mixed-fleet logistic scenario, including the Ariane-5/Automated Transfer Vehicle (ATV) capabilities in particular for the propellant resupply and Station reboost missions, and possible cooperation schemes with the US or Russia mainly on a Crew Return Vehicle/Crew Transport Vehicle (CRV/CTV).

A stepped approach has been further investigated for the CTV, taking into account both NASA's requirements for the availability of a new operational rescue vehicle in 2002, and the expected European budgetary limitations in the 1996/2002 period.

Industry has presented an overall cost estimate for the Columbus Orbital Facility (COF), confirming that the target set by ESA should be achievable. A formally committing offer for the main development phase (Phase-C/D) based on subcontractor proposals will be available by end February 1995.

Following approval of development of the Mission Database (MDB) as an 'Early Contribution Item' to NASA, and the Columbus Ground Software Reference Facility (GSRF) as a COF Enhancement Item, the Executive requested industry to update and finalise their detailed proposals in line with the approved Programme Proposals.

Euromir

With the safe landing of the Soyuz TM-19 capsule on 4 November near Arkalyk in Kazakhstan, ESA astronaut Ulf Merbold successfully completed his 31-day 'Euromir-94' mission on board the Russian Mir space station. Merbold returned in good health and began his post-flight medical baseline data collection programme.

The scientific data and samples from Eurmir-94 were recovered safely and are now being evaluated by the scientists involved in the mission.

Work for the Euromir-95 mission is now concentrated on finalisation of, and agreement between experimenters, ESA and RSC-Energia on the basic experiment and equipment specifications, as well as on the final development of the actual experiment facilities and equipment items.

Launch of another European astronaut to the Mir station is foreseen for 18 August 1995.

Space Shuttle Mission STS-66

ESA astronaut Jean-Francois Clervoy participated in this particular mission, which was a coordinated effort to study the Earth's environment. Space Shuttle 'Atlantis' was carrying the Atmospheric Laboratory for Applications and Science (ATLAS), based on the ESA Spacelab system, and the German-built Shuttle Pallet Satellite (SPAS), with two major instruments: the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA), and the Middle-Atmosphere High-Resolution Spectrograph Investigation (MAHRSI).

Atlantis lifted-off on 3 November from the Kennedy Space Center, Florida, and landed on 14 November at Edwards Air Force Base in California. As one of the STS-66 crew of six, ESA astronaut Clervoy was having his first experience of space flight, charged with the tasks of Mision Specialist. He played an important role in the mission, using the Shuttle's robot arm to deploy CRISTA/SPAS on 4 November, and conducting other experiments within the Shuttle cabin. He also tested a special seat that will be used next year when Atlantis docks with the Mir space station. It will allow astronauts and cosmonauts to return to Earth in a reclining position after long-duraton Mir flights.

The CRISTA/SPAS satellite was retrieved by the Shuttle's robot arm as planned on 12 November.

European experiments formed an Important part of the ATLAS mission, The Belgian-led SOLCON and the French-led SOLSPEC experiments both gathered data on the Sun's energy and its variability. These instruments were mainly operated remotely from the Belgian Space Remote Operations Centre (BSROC) in Brussels using a telescience system set up by ESA.

Clervoy is the second ESA astronaut to fly as a Shuttle Mission Specialist, Claude Nicollier being the first. Maurizio Cheli has now also completed training at NASA's Johnson Space Center as a Mission Specialist and is awaiting his first flight.

d'une part des impératifs de la NASA qui a besoin de disposer d'un nouveau véhicule de sauvetage opérationnel en 2002, et de l'autre, des limitations budgétaires à prévoir du côté européen au cours de la période 1996—2002.

L'industrie a présenté une estimation chiffrée d'ensemble pour l'Elément orbital Columbus (COF) confirmant qu'il devrait être possible de respecter l'objectif fixé par l'ESA. On disposera fin février 1995 d'une offre ferme officielle pour la phase principale de réalisation (phase C/D), reposant sur les propositions des sous-traitants.

A la suite de l'approbation de la création de la base de données mission (MDB), au titre des éléments à livrer à court terme à la NASA, et du banc de référence de développement au sol de logiciels (GSRF), au titre des installations complémentaires du COF, l'Exécutif a demandé aux industriels de mettre à jour et d'arrêter définitivement leurs propositions détaillées en accord avec les propositions de programme approuvées.

ESA Astronaut Ulf Merbold undergoing medical tests after the Euromir mission

Examen médical de l'astronaute Ulf Merbold à l'issue de la mission Euromir

Euromir

Le retour à bon port de la capsule Soyouz TM-19, le 4 novembre près d'Arkalyk, dans le Kazakhstan, a clos la mission Euromir 94 de 31 jours menée à bien par Ulf Merbold à bord de la station spatiale russe Mir. Revenu à terre en bonne forme, Merbold a entrepris le programme prévu de recueil de données médicales de référence postérieures au vol.

Les scientifiques associés à la mission procèdent maintenant à l'évaluation des données scientifiques et échantillons d'Euromir 94, récupérés dans les conditions voulues.

Les activités relatives à la mission Euromir 95 se concentrent désormais sur la mise au point définitive des spécifications des expériences et des équipements de base et leur approbation par les expérimentateurs, l'ESA et RSC-Energia, ainsi que sur la réalisation finale des installations expérimentales et des équipements eux-mêmes.

Le départ d'un autre astronaute européen à destination de la station Mir est prévu pour le 18 août 1995.

Mission de la Navette spatiale STS-66

L'astronaute de l'ESA Jean-François Clervoy a participé à cette mission qui portait particulièrement sur l'étude coordonnée de l'environnement terrestre. La Navette Atlantis emportait à son bord le laboratoire de recherche fondamentale et appliquée sur l'atmosphère (ATLAS) reposant sur le système Spacelab de l'ESA, ainsi que le satellite porte-instruments SPAS construit pour la Navette par l'Allemagne et qui était équipé de deux grands instruments: CRISTA, télescope cryogénique à spectromètre infrarouge pour l'étude de l'atmosphère, et MAHRSI, pour l'étude spectro-graphique à haute résolution de la moyenne atmosphère.

Partie du Centre spatial Kennedy, en Floride, le 3 novembre, Atlantis est revenue au sol le 14 novembre sur la base de l'Armée de l'air Edwards, en Californie. Membre de l'équipage de six personnes du vol STS-66, l'astronaute de l'ESA a vécu sa première expérience du vol spatial dans les fonctions de spécialiste 'mission'. Un rôle important lui était dévolu: largage du satellite CRISTA/SPAS le 4 novembre au moyen du bras télémanipulateur de la Navette, conduite d'autres expériences à l'intérieur de la cabine de la Navette. Clervoy a également mis à l'essai un siège spécial qui doit être utilisé l'an prochain lorsqu'Atlantis ira s'amarrer à la station spatiale Mir et qui permettra aux astronautes et cosmonautes de revenir sur Terre en position allongée après des séjours de longue durée à bord de Mir.

Le satellite CRISTA/SPAS a été récupéré au moyen du bras télémanipulateur de la Navette, comme prévu, le 12 novembre.

Les expériences européennes entraient pour une part importante dans la mission ATLAS. Les expériences SOLCON, sous égide belge, et SOLSPEC, sous égide française, ont toutes deux recueilli des données sur l'énergie solaire et sa variabilité, la conduite de ces instruments étant pour l'essentiel télécommandée du Centre belge de téléopérations spatiales, à Bruxelles, au moyen du système de téléscience mis sur pied par l'ESA.

Clervoy est le deuxième astronaute de l'ESA, après Claude Nicollier, à voler en qualité de spécialiste mission. Maurizio Cheli vient également de terminer au Johnson Space Center de la NASA une formation de spécialiste 'mission'; il attend son premier vol.

In Brief

ESA & NASDA to Test Communications Links Between Satellites

ESA and the National Space Development Agency of Japan (NASDA) have agreed to test communications at optical and S-band frequencies between an ESA satellite and a Japanese satellite.

Under a Memorandum of Understanding signed in December, ESA's Artemis satellite, which will be placed in geostationary orbit, will relay experimental data links to and from NASDA's Optical Interorbit Communications Engineering Test Satellite (OICETS), which will be placed in low-Earth orbit. The links will be made using a Semi-Conductor Laser Intersatellite Link Experiment (SILEX) optical communications terminal carried aboard Artemis and a similar terminal aboard OICETS. ESA and NASDA will then jointly evaluate the results of the experimental links.

This agreement constitutes the first major collaboration between ESA and Japan in the field of satellite telecommunications.

The Artemis satellite is currently scheduled to be launched in 1997. It is part of ESA's plan to set up an orbital data relay service to allow satellites to communicate with the ground more quickly and with higher data rates. OICETS is currently scheduled to be launched in 1998.

J.-M. Luton (left), Director General of ESA, and M. Yamano (right), President of NASDA, sign the agreement on the testing of inter-orbit communications links

Finland Becomes Full ESA Member

On 1 January 1995, Finland became a full Member State of ESA. This brings the number of full members to 14.

Finland, which had been an associate Member State since 1987, was already participating in ESA's Earth Observation and Telecommunications programmes as well as in the Science programme.

The accession of a new Member State enables ESA to 'strengthen its position at a time when space programmes are taking on a world dimension', stated ESA's Director General, Jean-Marie Luton, when the Agreement on Finland's Accession to the ESA Convention was signed.

Intellectual Property Rights Addressed

ESA and the European Centre for Space Law (ECSL) recently organised the second workshop on intellectual property rights and space activities, this time with a worldwide perspective. About 90 participants attended the two-day workshop held in Paris in December.

The workshop allowed, for the first time, representatives of many different nations and industries to meet to discuss the legal and policy issues with regard to intellectual property rights and space activities. In addition, representatives of several organisations with an interest in intellectual property rights, such as the World Intellectual Property Organisation (WIPO), the European Patent Office (EPO) and the European Commission, also participated in the discussions. The purpose was to raise the importance of space activities with those organisations. The workshop proceedings are available from ESA's Publications Division.

As a result of the workshop, WIPO will raise the issues during its General Assembly next autumn in order to request approval to undertake further studies on the possibility of elaborating a more harmonised legal environment for space activities.

ESA Astronauts to Fly on Tethered Satellite System Mission

Two ESA astronauts, Claude Nicollier and Maurizio Cheli, have been selected by NASA to fly as mission specialists on board the Space Shuttle 'Columbia' on flight STS-75 in early 1996. During that mission, the Tethered Satellite System (TSS) will be deployed for the second time. It will also be the third flight of scientific investigations using the US Microgravity Payload (USMP) complement. The mission is scheduled to last 13 days.

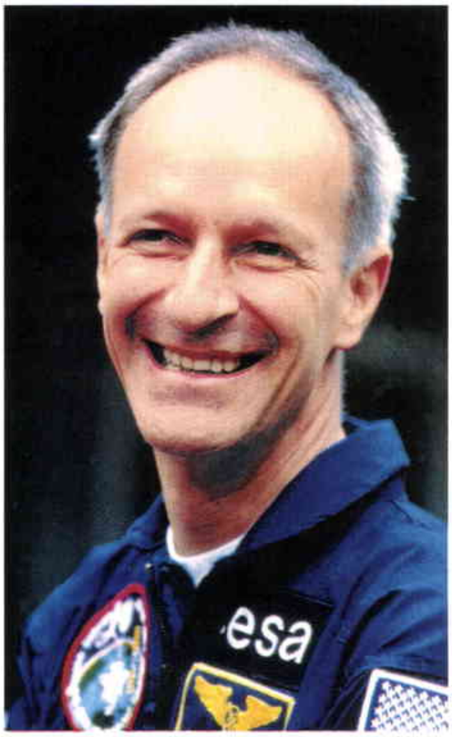
Claude Nicollier, who is Swiss, is one of ESA's 'most travelled' astronauts. His most recent mission was in December 1993 on board STS-61, the Hubble Space Telescope First Servicing mission. During that mission, he fulfilled two roles: he was a mission specialist as well as the main operator of the remote arm that was used in the retrieval and repair of the satellite. He was also a mission specialist on STS-46 in July/August 1992, during which Eureca, ESA's retrievable science platform, was deployed and the first TSS test flight was conducted.

The other ESA astronaut, Maurizio Cheli, an Italian, will be undertaking his first mission. He was selected in 1992, along with five other young candidates, to expand the corps of ESA astronauts. He has been working in Houston since mid-1992 and qualified as a mission specialist in 1993.

During the mission, a satellite measuring 1.6 metres in diameter will be deployed on the end of a 20-km conductive tether to study the electrodynamic effects of moving such a tether through the Earth's magnetic field. The system will host 12 different scientific experiments. ESA will contribute sensors and control electronics for the Italian Research on Electrodynamics Tether Effects (RETE) instrument. Techniques for managing the tethered spacecraft at great distances will also be tested.

The project is a joint effort between NASA and the Italian space agency ASI.

During the first TSS mission in 1992, the satellite could not be fully deployed because of a malfunction in the deployer mechanism. Four of the crew members on



Claude Nicollier

Maurizio Cheli

that mission will also be on the upcoming mission. The crew will include a TSS payload specialist, Umberto Guidoni from ASI.

The mission will also allow scientists to perform microgravity and fundamental science investigations using experiments housed in the Shuttle's payload bay. The USMP is designed to provide the foundation for scientific investigations similar to those planned for on-board the International Space Station.

Ariane Flights to Resume in March

Following the failure of Ariane flight 70 last December, launches are now expected to resume in March. Flight 71, carrying two satellites, Eutelsat's HotBird 1 and Embratel's Brasilsat B2, is planned to be launched on 14 March.

Flight 70, which took place on the night of 1/2 December 1994, ended in failure. The American telecommunications satellite PanAmSat-3, built by Hughes Space & Telecommunications for PanAmSat LP, was not placed into orbit. The launcher performed nominally through the first and second stages. The third-stage engine ignited normally but did not function at full thrust and therefore could not meet the conditions required to place the satellite into orbit. The stage and satellite disintegrated upon re-entering the atmosphere and fell into the ocean off the west coast of Africa.

Arianespace, along with ESA and CNES, immediately set up a technical inquiry board to investigate the cause of the failure. Arianespace/CNES and the industrial partners concerned, namely SEP and Aerospatiale, also conducted their own analyses. The inquiry board found that 'a lack of oxygen into the third-stage gas generator' was the most probable reason for the malfunction. The exact cause could not be identified.

The inquiry board proposed 21 remedial actions to the management of Ariane. All actions were accepted and are now being implemented as Arianespace prepares for the March 14 launch date.

Staying in Bed for Science

To understand the adaptation processes to microgravity conditions that astronauts must undergo, ESA and the French space agency CNES have recently completed an experiment that required subjects to remain in bed for a long duration while the changes in their physiological systems were studied. The reduction in physical activity leads to changes in bones and muscles similar to those experienced by astronauts in microgravity. In addition, lying in a head-down position causes body fluids to shift towards the head and thorax in the same way as is observed in microgravity. The results will enable scientists to better define counter-measures to be developed to minimise the physiological impact of the absence of gravity for long periods and to improve readaptation upon return to Earth.

Eight young and healthy male volunteers participated in the project. They were selected based on stringent medical and psychological tests. For the first two weeks of the experiment, the subjects underwent an ambulatory phase to stabilise their physical and emotional state and allow basic data to be gathered. Although they were mobile, they were confined to the hospital ward, their diet was controlled, they could not partake in strenuous physical exercise nor receive visitors.

They were then confined to their beds for the subsequent six weeks. They lay in a position with their head at a $-6°$ angle to the horizontal. At that angle, the organic fluids flow to the head and thorax in a manner similar to that observed in astronauts under microgravity. Seven of the eight subjects completed the bedrest period; one had to stop after four weeks because of pain in his vertebrae, which disappeared after he became mobile again.

After the bedrest period, the subjects had a two-week ambulatory recovery period during which their return to 'normal' was monitored.

The MEDES Institute of Space Medicine and Physiology carried out the experiment at the Purpan Hospital in Toulouse, France, with full medical back-up provided by the Toulouse health authority. To ensure that the subjects' health was never at risk, the subjects were kept under close medical and psychological monitoring throughout the experiment. They will also be monitored periodically over the next few months to ensure that no longer-term problems develop.

This was one experiment in a series of experiments that ESA has undertaken to study the human psychological and physical responses to life in space. Previous experiments have included the isolation of a crew of four in a pressure chamber and laboratory in a deep-diving facility for 60 days, and the Human Behaviour Study (Hubes) in which a crew lived and worked in a module similar to the Mir complex for 135 days to simulate the EuroMir-95 mission.

A subject measures his energy expenditure while at rest, before the six weeks of bed-rest begin.

ERS Monitors Flooding in The Netherlands

When the lower Rhine area was hit by floods at the end of January, ESA's ERS-1 satellite, with its day-and-night imaging radar, was able to monitor the situation constantly, even through thick cloud. The image on the front cover of this Bulletin shows three rivers – the Lower Rhine (top), the Waal (centre) and the Maas (bottom) – in a region just west of Nijmegen in The Netherlands. It covers an area of approx. 35 km by 45 km, with the town of Den Bosch near the bottom right of the scene.

This multi-temporal image shows the situation between 30 January (green) and 5 February 1995 (red), in comparison with a 'normal' situation last autumn (image from 21 September 1994, displayed in blue). The considerably swollen rivers are well delineated in magenta, while the 'normal' river courses can be identified as dark-blue lines.

The bright-red patches in the flood areas show what had re-emerged from the water on 5 February, whilst some bright-green patches elsewhere in the image indicate where flooding occurred between 30 January and 5 February.

Parts of the urban areas appear in yellow due to a change in radar illumination direction, the ascending orbit on 5 February looking east-northeast having been combined with two descending passes looking west-southwest. This effect is enhanced by the higher soil humidity on the winter dates.

The data was acquired at the ESA/ERS-1 Receiving Station in Fucino, Italy, and processed by the ESRIN and EURIMAGE/Earth Watch Teams.

J. Lichtenegger & G. Calabresi
ERS Data Utilisation Section, ESA/ESRIN, Frascati, Italy

Focus Earth

Northern Territories of Australia

ERS-1's Synthetic Aperture Radar (SAR) instrument here uncovers the beauty of Kakadu National Park in the Northern Territories of Australia. The area imaged covers about 100x100 km^2. It shows the South Alligator River in the centre, the smaller West Alligator river to the left, and the East Alligator River to the top right.

The shape of the estuaries and the meandering river courses suggest a constant tidal influence, and brackish water can indeed be found in the rivers up to 80 km inland. The area is very well known not only as an ideal habitat for several migrating bird species, but also for its alligators!

The image is especially colourful because of the pronounced seasonal changes occurring in the area. It is a composite of three separate images, acquired on: 24 August 1993 (red), 2 November 1992 (green) and 5 July 1993 (blue). One of these dates (November) corresponded with the beginning of the wet season; the other two correspond to the dry season. Areas exhibiting no changes between these dates are displayed in grey and white. The white colour to the right identifies mainly the Arnhem sandstone plateau, where poorly vegetated, deeply cut cliffs are to be found. Grass and shrubland areas, periodically burnt by the aborigines, are displayed in grey. The dark zones near the lower river courses correspond to tidal mudflats. The wide but short affluents, with dendrite delineation, imaged mostly in pink but sometimes also in white, are the so-called 'billabongs'. During the wet season they form huge lakes, but when the soil dries it contains many cracks, making the microwave backscatter very strong. The green colour represents the contribution of the November image, which was probably acquired during or soon after rainfall had occurred over the area to the west (left part of the image). The bright areas along the coastline reveal the presence of dense mangrove forests, whilst the adjacent greenish or bluish hues indicate degraded woodlands and sand dunes.

This is a national-park area and small man-made features can be also observed. Roads are only partially visible, either as dark lines, or as bright north – south lines when the road is cut into the landscape so that the banks facing the microwave illumination result in strong reflections. The airstrips of Jabiru (centre right) and Yellow Water (near the centre of the image) are clearly visible.

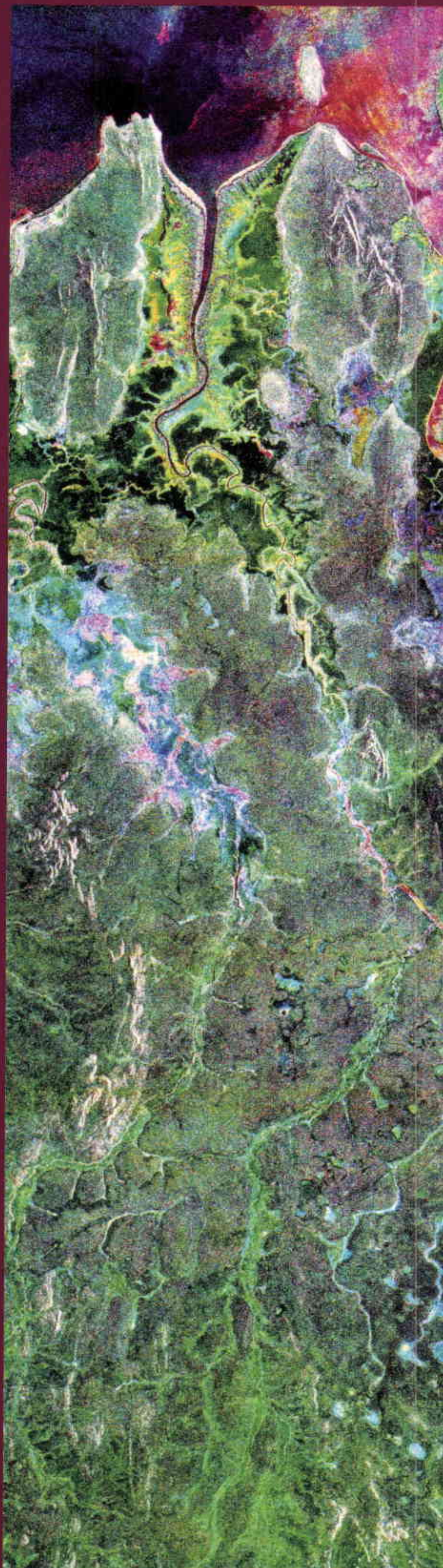
ERS-1 SAR time series of data are particularly suitable for monitoring large ecosystems. They can contribute to more efficient management of the national park by facilitating early detection of any degradation in individual landscape elements.

Acquisition dates and orbit reference:

24 August 1992 (red)	– orbit no. 05787 – frame no. 3861
2 November 1992 (green)	– orbit no. 06789 – frame no. 3861
5 July 1993 (blue)	– orbit no. 10296 – frame no.3861.

Acquisition station: Alice Springs, Australia

Data processing: ESA/ESRIN, Frascati, Italy



Publications

The documents listed here have been issued since the last publications announcement in the ESA Bulletin. Requests for copies should be made in accordance with the Table and Order Form at the back of this issue.

ESA Journal

For cost-saving purposes, ESA will no longer publish the ESA Journal. The final issue was ESA Journal Vol. 18, No. 3, published in September 1994.

ESA Special Publications

ESA SP-363 // 80 DFL
PROCEEDINGS OF THE SECOND EURO-LATIN AMERICAN SPACE DAYS
9 – 13 May 1994, Buenos Aires, Argentina
(ED. J.J. HUNT)

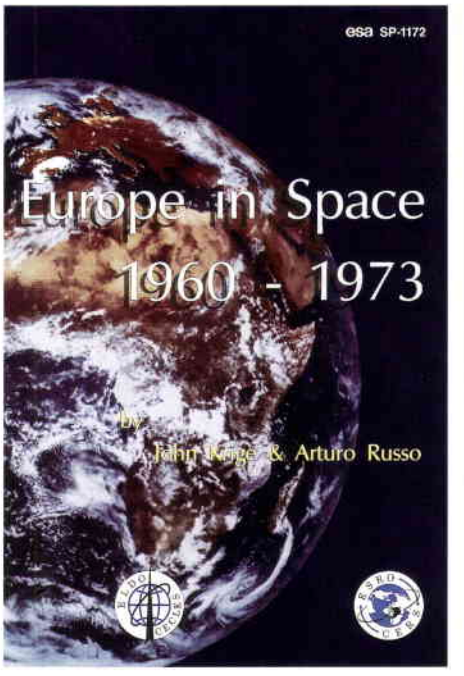
ESA SP-365 // 80 DFL
FIRST WORKSHOP ON ERS-1 PILOT PROJECTS
22 – 24 June 1994, Toledo, Spain
(ED. T.D. GUYENNE)

ESA SP-368 // 80 DFL
SIXTH INTERNATIONAL SYMPOSIUM ON MATERIALS IN A SPACE ENVIRONMENT
19 – 23 September 1994, Noordwijk, The Netherlands
(ED. T.D. GUYENNE)

ESA SP-373 // 100 DFL
SOLAR DYNAMIC PHENOMENA AND SOLAR WIND CONSEQUENCES
Third SOHO Workshop,
26 – 29 September 1994, Colorado, USA
(ED. J.J. HUNT)

ESA SP-1132 (Vol. 4) // 80 DFL
FINAL REPORTS OF SOUNDING ROCKET EXPERIMENTS IN FLUID SCIENCE AND MATERIALS SCIENCES
(EDS. O. MINSTER & B. KALDEICH)

ESA SP-1170 // 70 DFL
INTERNATIONAL LUNAR WORKSHOP
31 May – 3 June 1994,
Beatenberg, Switzerland
(EDS. H. BALSIGER, M.C.E. HUBER, P. LENA & B. BATTRICK)

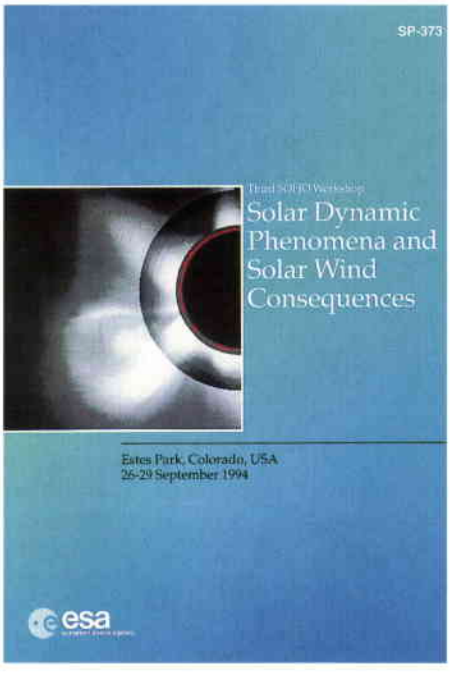


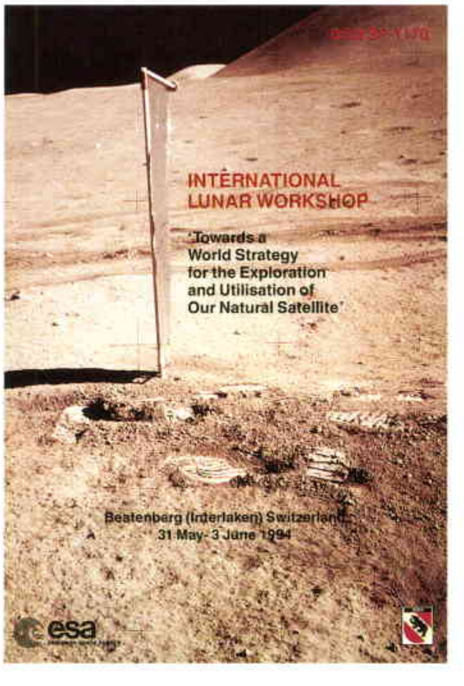
ESA SP-1172 // 70 DFL
EUROPE IN SPACE 1960 – 1973
J. KRIGE & A. RUSSO

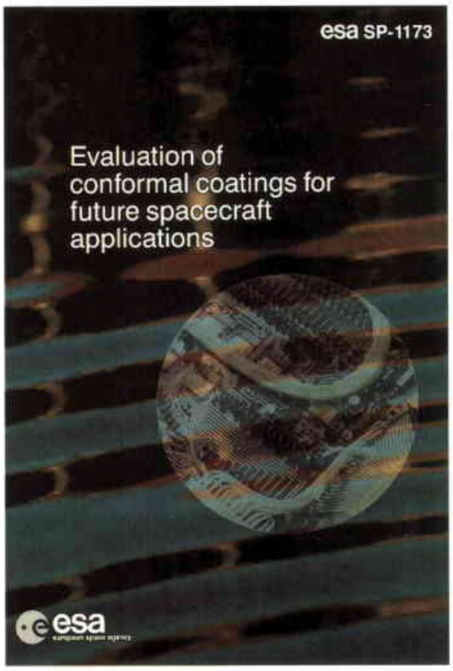
ESA SP-1173 // 50 DFL
EVALUATION OF CONFORMAL COATINGS FOR FUTURE SPACECRAFT APPLICATIONS
B.D. DUNN & P. DESPLAT
(ED. W.R. BURKE)

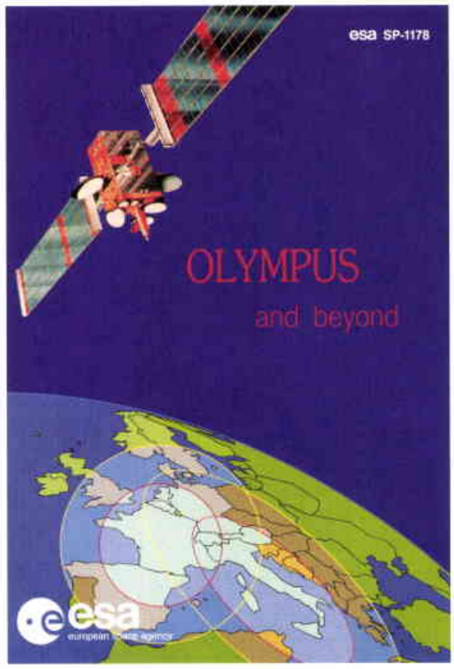
ESA SP-1178 // 35 DFL
OLYMPUS AND BEYOND
C.D. HUGHES ET AL.
(ED. M. PERRY)

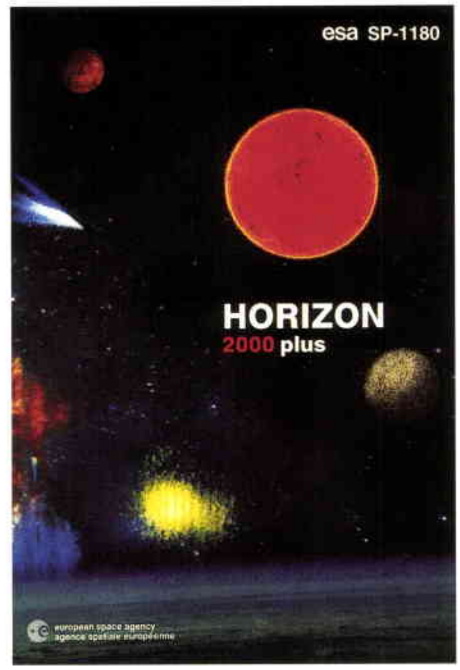
ESA SP-1180 // 35 DFL
HORIZON 2000 PLUS: EUROPEAN SPACE SCIENCE IN THE 21st CENTURY
(ED. B. BATTRICK)











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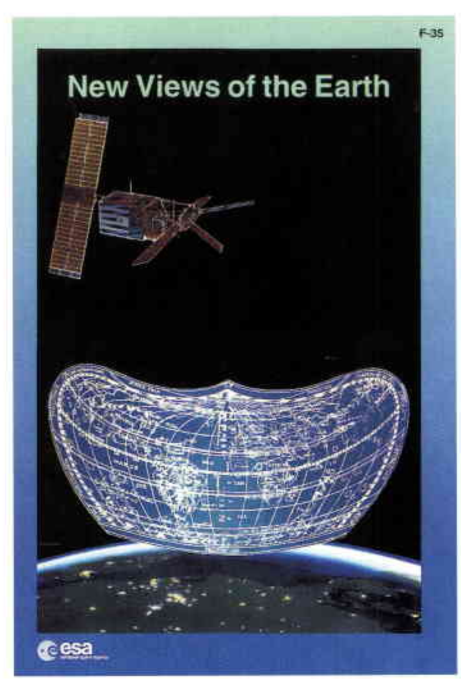

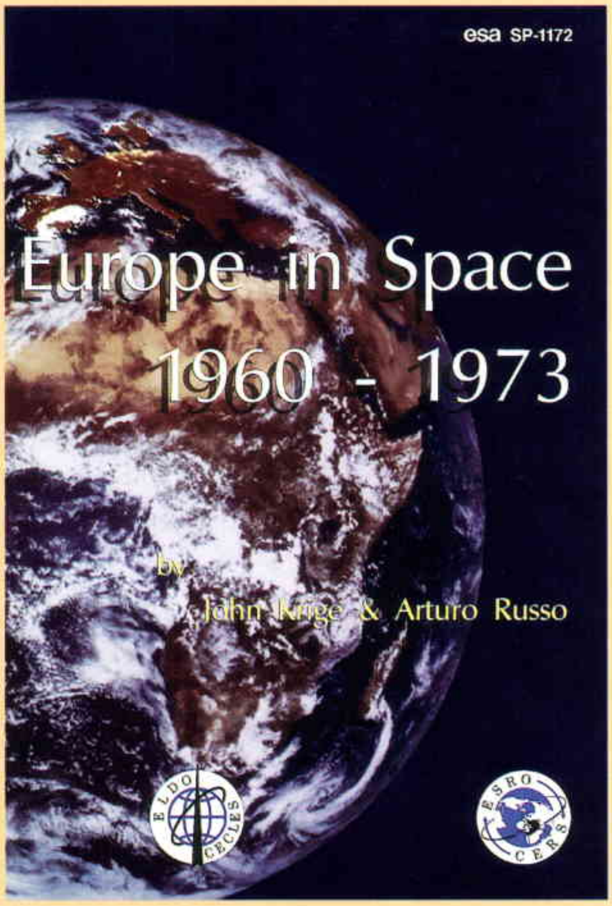

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Reimar Lüst
Chairman of the Advisory Committee to the ESA History Study

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